

Course Notes on Combinatory Categorical Grammar

Jason M. Baldridge & Geert-Jan M. Kruijff

June 30, 2004

Contents

1	Introduction	7
2	Formal foundations	13
2.1	Introduction	13
2.2	The AB Calculus	14
2.2.1	Categories	14
2.2.2	Rules	15
2.2.3	Limitations of the AB Calculus	17
2.3	Combinatory Categorical Grammar	19
2.3.1	Harmonic Composition	20
2.3.2	Type-raising	22
2.3.3	Crossed Composition	24
2.3.4	Substitution	25
2.3.5	Limits on the Space of Possible Rules	26
2.4	Using multisets to lexically specify word order variation	27
2.5	Generative Power	29
2.6	Modalizing control in CCG	32
2.6.1	Restricting Associativity	32
2.6.2	Modes and the Application Rules	34
2.6.3	Type-raising and Harmonic Composition	36
2.6.4	Control Over Permutativity	37
2.6.5	More Non-associative Contexts	38

Acknowledgments

Material from our dissertations Baldrige (2002) and Kruijff (2001) as well as various papers Baldrige and Kruijff (2002, 2003); White and Baldrige (2003); Kruijff and Baldrige (2004a). Thanks to Mark Steedman, Dick Oehrle, and Mike White.

Chapter 1

Introduction

In this course we will explain the motivation and working of Combinatory Categorical Grammar (CCG), with particular emphasis on its predictive power as a formalism for natural language syntax and architectural considerations of interfaces between surface form, linguistic meaning, and discourse interpretation (notably, information structure). The material for this course consists of recent publications which have sought to improve its suitability in both of these areas. Here, we give an overview to tie the threads of these various readings together to allow readers to gradually learn about CCG and guide them through the developments presented in this course.

If we look at contemporary natural grammar frameworks, we find that for most frameworks formalization has a methodological function, namely to make precise what counts as a linguistic analysis. As Chomsky emphasized in his preface to Chomsky (1957), formalization plays an important role in empirical testing and possible falsification:

“... The search for rigorous formulation in linguistics has a much more serious motivation than mere concern for logical niceties or the desire to purify well-established methods of linguistic analysis. Precisely constructed models for linguistic structure can play an important role, both negative and positive, in the role of discovery itself. By pushing a precise but inadequate formulation to an unacceptable conclusion, we can often expose the exact source of this inadequacy and, consequently, gain a deeper understanding of the linguistic data. More positively, a formalized theory may automatically provide solutions for many problems other than those for which it was explicitly designed. Obscure and intuition-bound notions can neither lead to absurd conclusions nor provide new and correct ones, and hence they fail to be useful in two important respects.”

We can see the relation between formalism and theory, then, as follows. A formalism delineates a space of possible linguistic descriptions, within which we can formulate theories that account for phenomena in natural language. From this perspective, the question of *descriptive adequacy* thus ultimately concerns the formalism: Does it enable us to formulate theories that describe every observable phenomenon? On the other hand, *explanatory adequacy* concerns a theory: Is the theory able to account for every observable phenomenon, predicting the occurrence (or absence) of phenomena not only for a singular language but also across languages?

An important methodological point raised in the above quotation is that we ought to be able to put the predictions of a theory to the test. Formalisation enables us to specify precisely how a theory predicts that some phenomena are possible whereas others are not – in other words, what *restrictions* a theory imposes on the structure of natural language.

Frameworks differ, however, in where they see these restrictions to arise from: from theory alone, or from an interaction between theory and the underlying formalism.

We can take Head-driven Phrase Structure Grammar (HPSG, Pollard and Sag (1993)) as an illustration of a framework in which the underlying formalism imposes little or no restrictions on the kinds of structures that an HPSG-theory can talk about – much unlike its predecessor, Generalized Phrase Structure Grammar (GPSG, Gazdar *et al.* (1985)), in which the formalism limits structures to be at most context-free. Although the GPSG formalism thus narrows down the scope of structures a GPSG-theory can avail itself of, it also incorporates a set of linguistic assumptions (“all linguistic structures are context free”) that all GPSG-theories will share.

The impact of such shared assumptions goes beyond merely establishing a certain theoretical coherence. Restrictions which arise from the formalism underlying each theory that adopts it, have the potential to play an important role in linguistic theory as such. Namely, the explanatory adequacy of any theory of grammar will ultimately rest on its ability to provide linguistic universals that are predicted to hold across the grammars of all languages – and these restrictions, making strong predictions about the space of possible human languages, can fill just that niche.

Chomsky (1965) classifies such universals as being of two types: *formal* universals that arise from the abstract properties and conditions of a grammatical system and *substantive* universals that state that objects of a particular kind must be drawn from a fixed class of items. Chomsky gives the proposal that transformational rules must be included in the syntactic component as an example of a formal universal, and the proposal that certain fixed syntactic categories such as noun and verb are utilized in the grammar of any language as an example of a substantive universal.

However, we cannot always definitively declare a given universal as formal or substantive. In fact, Chomsky’s dual classification may be better characterized as a continuum from more to less abstract universals. The more abstract formal universals are generally stronger in their predictive force. They are more likely to dictate the nature of entire classes whereas more substantive universals typically only carve out a select group of objects from a potentially infinite set in a class. That is to say that formal universals set the stage upon which substantive ones are formulated.

One way in which a formalism can provide formal universals is for it to have invariant components which all languages share. A simple example would be restricting all languages to use only binary rules in context-free grammar. This places a constraint which handcuffs the grammars of all languages and may (or may not) produce interesting linguistic predictions. Another way of producing formal predictions is for a formalism to have restricted generative capacity. For example, as we mentioned earlier, GPSG permitted only context-free grammar rules. This means that any linguistic theory based on GPSG would formally predict that the crossing dependencies of Dutch and Swiss German should not be possible constructions in human languages. Since the construction does indeed exist, this prediction is wrong and formalisms with greater generative power were needed.

HPSG, CCG, and Tree-Adjoining Grammar all have greater than context-free power, and all can capture the Dutch crossing dependencies. An interesting characteristic shared by the latter two formalisms is that they have only *slightly* greater power than context-free. Once again, this comes with predictive force – neither formalism permits unbounded scrambling. HPSG, on the other hand, is very powerful, and not only is it possible to provide an analysis for unbounded scrambling, it is also possible to do so in many different ways.

It is on this frontier that CCG sits. Its generative capacity is mildly context-sensitive –

enough for what has been proven necessary for natural language grammars, but no more. In this course, we present an extremely lexicalist form of CCG, called MULTI-MODAL CCG.

MULTI-MODAL CCG implements a form of resource management familiar from CTL, namely using modal decorations on slashes to control the applicability of combinatory rules in derivations. In this way, we can do away with grammar-specific instantiations of the CCG combinatory schemata, and derivational control becomes completely lexicalized. For each grammar we can thus employ exactly the same set of combinatory rules: In MULTI-MODAL CCG the combinatory rules are defined as *formal universals*, which delineate the space of possible linguistic structure (by delineating the space of possible derivations). At the same time, should descriptive adequacy demand we increase the power of the framework, modalization means we can add more powerful rules in a conservative and controlled manner: conservative in that no previously possible derivations become impossible, and controlled in that additional power does not necessarily lead to a permutation closure, (see also Moortgat (1988)).

Consequently, grammars may only differ in the lexica they specify, not in their rules. While this necessarily leads to a more complex lexicon, it provides modularity – a number of competing theories of the lexicon may be entertained while using the same derivational apparatus.

We thus accord the theory of the lexicon a central role in MULTI-MODAL CCG. Combinatory rules specify *how* languages may vary in their structure, but they do not specify in *what* aspects of structure languages may be similar or different. Given that the rules are formal universals, this means that we need to capture this *what* by means of a theory of the lexicon – a theory of how lexical categories are constructed.

Explanatory adequacy demands that the categories, which are construable for a given language, at least describe the observable phenomena of that language, by enabling their derivation using the accessible combinatory rules. A stronger claim to explanatory adequacy is to have the construable categories *predicting* the observable phenomena, by allowing only these phenomena to be derived using the accessible combinatory rules. (Wonderful example: Dutch cross-serial dependencies.)

An even stronger claim to explanatory adequacy would be to let the construction of categories be influenced by typological universals, to phrase typological similarities and differences between languages in terms of the kinds of categories their grammars employ. Recent attempts to include typology in categorial grammar are Kruijff (2001) (using CTL) and, specifically focusing on theory of the lexicon, Bozsahin and Steedman (2003).

There are, at the moment, more open questions than answers here. Clearly, we will have to strike a balance between typological universals that specify purely structural aspects, and more functionally oriented universals. If we would adopt a theory of the lexicon that is based “purely” structural universals, we would end up with a kind of CCG that is rather structuralist – and with that, a far cry from the original (functionalist-oriented) tenet that categories are formed after the meaning they express. Besides CCG and its relation to semantics through combinatory logic, e.g. Moortgat (1988) and Oehrle (1994) express similar views on the relation between category and meaning: “A category is but an artefact, being derived from the meaning it expresses.”

Overview of the course

Below we provide a brief overview of the five lectures that make up this course. We describe for each lecture what its theme is, give “necessary” reading, and suggest further reading for those who would like to know more. All the papers listed as “necessary” reading are

included in this reader.

Lecture 1: The categorial perspective on grammar

Our goal in the first lecture is to present the modalized version of CCG. We begin by discussing the historical developments that provide the background for the framework: Early context-free formulations of categorial grammar; the realization that context-free grammars do not suffice; the consequent search for stronger (but controlled!) versions of categorial, like CCG and CTL; and finally, the combination of the advantages of CTL (mathematically clean resource management) with those of CCG (computational complexity of parsing algorithm), yielding modalized CCG. The result is a framework in which the applicability of combinatory rules is entirely determined by the structure of categories – derivational control is completely lexicalized.

READING: **Baldrige & Kruijff 2003, Baldrige & Kruijff “Formal foundations”**. Baldrige and Kruijff (2003) is a paper published at *EACL’03*. In this paper we provide a brief discussion of the motivations for the modalized version of CCG, and present the basic definitions. We provide a more detailed discussion in a draft chapter on CCG, based on chapters 2 and 5 from Baldrige (2002). The draft provides a brief, but fairly gentle introduction to the CCG formalism in the form it was used throughout the 1980’s and 1990’s, primarily in work by Mark Steedman, and then motivates the inclusion of modalities from CTL in the CCG system.

SUGGESTED SUPPLEMENTARY READING. As supplementary reading we suggest Steedman (2000b), entitled *The Syntactic Process*, and the manuscript by Steedman and Baldrige, “Combinatory Categorial Grammar”. The latter is available from the web as (<http://www.iccs.informatics.ed.ac.uk/~jmb/ccg.pdf>).

Lecture 2: Modeling linguistic meaning using hybrid logic

In the first lecture, we concentrated on the syntactic side of CCG. In this second lecture we show how we can build a representation of the (linguistic) meaning of an expression, in a compositional fashion, following the syntactic analysis. We begin with a brief discussion of traditional way of modeling meaning using the lambda calculus. Then, we introduce *hybrid logic dependency semantics* (HLDS). In HLDS, we model linguistic meaning as a relational structure following the Prague School, capturing the complexity of meaning using a sorting strategy (rich ontology) rather than through higher-order functions (differentiation meaning -indirectly- through compositional behavior). After we have presented the basic ideas behind HLDS, and how HLDS representations can be built compositionally in parallel with the syntactic derivation, we explore various themes in modeling meaning: Sorting and selectional restrictions, spatiotemporal-causal structure, interpretative import of relations (i.e. what does it mean for a dependent to ‘play’ a particular role?), and contextual reference.

READING: **Kruijff 2001 chapter 3, Baldrige & Kruijff 2002, White & Baldrige 2003**. Chapter 3 in Kruijff (2001) provides the original formulation of HLDS. Baldrige and Kruijff (2002) explore how HLDS representations can be built compositionally using CCG, and compare HLDS to (other) computational semantics frameworks. White and Baldrige (2003) improve the syntax/semantics-interface.

SUGGESTED SUPPLEMENTARY READING. Kruijff (2003) discusses how HLDS representations, obtained through grammatical analysis, can be interpreted in the context of a larger

discourse.

Lecture 3: Coordination

Traditionally, we consider coordination from the viewpoint of constituency, distinguishing between *constituent coordination* and *non-constituent coordination*. In the third lecture, we show how CCG can account for both types of coordination, using a rule (standard CCG, Steedman (2000b)) in conjunction with the combinators, or just through lexical categories (modalized CCG). We look at constituent coordinations such as subject and VP-coordination, as well as non-constituent coordinations like argument clustering and gapping. At the end of the lecture, we explore adding *dependency* as an additional dimension of coordination: Some constituent coordinations involve different types of dependents (roles), and not every combination of different roles is grammatical Panevová (1974).

READING: **Baldrige & Kruijff 2003, White & Baldrige 2003**. Baldrige and Kruijff (2003) discuss why in modalized CCG there is no longer a need for a separate rule for coordination. White and Baldrige (2003) discuss lexically specification of coordination, and efficient realization of coordination constructions.

SUGGESTED SUPPLEMENTARY READING. Steedman (2000b) provides an up-to-date account of coordination in CCG. White (2004) deepens out the approach presented in White and Baldrige (2003).

Lecture 4: Extraction and long-distance dependencies

The goal of the fourth lecture is twofold. We discuss how we can model extraction and long-distance dependency phenomena in CCG – phenomena for which we need a formalism that is stronger than context-free grammar to capture them in their full generality. The deeper point we want to discuss is how extraction asymmetries and structural aspects like cross-serial dependencies *arise* in the modalized analysis as a result of the interaction between category assignments and the combinatory rules (formal universals) they make accessible.

READING: Baldrige, “Locality in Unbounded Extraction Asymmetries”

Lecture 5: Information structure and its realization

The information structure of an expression indicates what parts of its meaning are dependent on the preceding context, and which parts contribute “new information” to the context. Languages may realize information structure using a variety of means, such as word order variation, intonation, morphological marking, or marked syntactic constructions. In the fifth lecture we discuss several existing approaches to modeling IS and its realization using categorial grammar. We then present an analysis of information structure in modalized CCG, looking at word order, intonation, and their interaction in realizing informativity.

READING: **Kruijff and Baldrige (2004b)**. In Kruijff and Baldrige (2004b), a paper at *COLING’04*, we discuss how we can model different levels of linguistic information in CCG, and capture their interaction using shared indices rather than by compiling the effect of the interaction into a complex category. To illustrate the idea, we discuss how we can capture different aspects of the realization of information structure.

SUGGESTED SUPPLEMENTARY READING. Steedman (2000a,b) present a detailed discussion of Steedman’s account of how intonation helps realizing information structure, in English. We simplify various aspects of this account in Kruijff and Baldridge (2004b). Hoffman (1995) introduces MULTISSET CCG and shows how it can account for how word order variation is used for realizing information structure in Turkish.

Chapter 2

Formal foundations

2.1 Introduction

The task of any theory of natural language grammar is to provide the means to mediate the relation between the properties of sub-parts of a linguistic expression and the global properties associated with it. How this is achieved of course varies widely between different theories depending on the kinds of mechanisms, data structures, and constraints of which they avail themselves. The approach we present here draws heavily on a number of *compositional* approaches to natural language grammar — formalisms for which the global properties associated with a linguistic expression are entirely determined by the correlative properties of its component parts. In such systems, linguistic expressions are generally considered to be multi-dimensional structured *signs* that contain phonological/orthographic, syntactic and semantic specifications for the expression (Pollard and Sag, 1994; Morrill, 1994; Oehrle, to appear; Steedman, 2000b). Each formalism provides its own way of defining basic signs and makes some set of operations available in order to combine them and thereby create more complex signs which monotonically incorporate the content of their subparts.

Our approach is set in the tradition of one such family of compositional formalisms, namely categorial grammar. In categorial grammar formalisms, grammatical composition takes the form of an inference problem in which the sub-signs of a linguistic expression act as premises in a process which deduces the concluding sign that contains the global properties associated with the expression (Oehrle, to appear). Different categorial approaches take this connection with logical deduction to varying degrees, with some being only partial systems of implicational reasoning and others providing a fully logical system.

Categorial grammar formalisms typically adopt an extremely lexicalist position in which nearly all grammatical information is contained within the entries of the lexicon. Words are assigned categories which may combine with others in a semantically transparent manner through a small set of rules. This lexicalist view on the objects of grammatical inquiry and adherence to semantic transparency is a starting point which leads to a variety of categorial perspectives on natural language grammar.

In this chapter we provide the formal foundations for our approach. Beginning in §2.2 with pure categorial grammar and discussing some of its strengths and weaknesses, we then discuss Combinatory Categorial Grammar (CCG), which addresses some of the limitations of pure categorial grammar by defining rules of combination based on a small set of combinators from combinatory logic, and Multiset Combinatory Categorial Grammar, an extension of CCG designed to allow greater flexibility in word order. Against this backdrop we then define the modalized versions of CCG and multiset-CCG, showing that

we can obtain a completely lexically driven form of control over rule applicability through modal decoration.

2.2 The AB Calculus

Pure categorial grammar is the common starting point of all categorial grammar formalisms. It is the product of the directional adaptation by Bar-Hillel (1953) of Ajdukiewicz's calculus of syntactic connection (Ajdukiewicz, 1935) and is thus generally referred to as the AB calculus. The discussion below is brief, and we refer the reader to Wood (1993) and Steedman (2000b) for more detailed discussions of the material covered here.

2.2.1 Categories

The grammatical objects of the AB system are categories which may be either atomic elements or (curried) functions which specify the canonical linear direction in which they seek their arguments.

Definition 1 (AB categories). *Given $\mathcal{A}$, a finite set of atomic categories, the set of categories $\mathcal{C}$ is the smallest set such that:*

- $\mathcal{A} \subseteq \mathcal{C}$
- $(X \backslash Y), (X / Y) \in \mathcal{C}$ if $X, Y \in \mathcal{C}$

◀

Atomic categories are themselves feature structures which can include major syntactic features like *case* and minor features such as those for *number* and *person* agreement (Steedman, 1996). When it is necessary to display a feature like nominative case on a category, the category is written as $n_{case=nom}$, n_{nom} , or even just n_n when it is clear that nominative case is intended. This convention shortens the length of derivations considerably.

Lexical entries are specified by pairing words with categories via the $\vdash$ operator. Some simplified example entries are given below:

- (1) a. *Brazil* $\vdash np$
- b. *Germany* $\vdash np$
- c. *defeated* $\vdash (s \backslash np) / np$

Notation. We use Steedman's argument rightmost notation for categories. It is common in the Lambek tradition to use an alternative notation in which arguments sought to the left are placed on the left of the functor. Under this notation, the entry for *defeated* becomes $(np \backslash s) / np$. Also, in Steedman's notation the slashes $\backslash$ and $/$ associate to the left, so a functor category like $(s \backslash np) / np$ given for *defeated* is equivalent to $s \backslash np / np$. To save space in derivations, we will generally suppress redundant parentheses. ◀

A flat representation of the lexicon such as that depicted in (1) is of course a simplification. While it is concise and useful when presenting linguistic analyses of particular phenomena, it is inadequate for specifying large grammars such as those used in computational settings. See Baldridge (2002) for a detailed discussion about proposals for using inheritance to efficiently and concisely define the lexicon and reduce redundancy in lexical entries.

2.2.2 Rules

In the AB system, categories may combine through two directionally sensitive rules of functional application, presented below. The application rules are simply two instantiations of basic functional application, particularized to respect the direction in which the functor category expects its argument.

(2) *Functional application*

$$\text{a. } X/Y \quad Y \Rightarrow X \quad (>)$$

$$\text{b. } Y \quad X \backslash Y \Rightarrow X \quad (<)$$

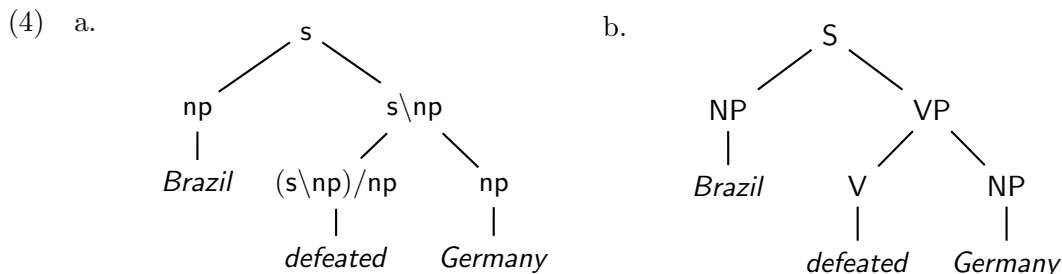
In binary rules such as this, we will refer to the functor category (e.g. X/Y) as the *primary* input to the rule and the other argument as the *secondary* input.

These rules can also be viewed as rules of a context-free grammar written in the accepting, rather than producing, direction (Steedman, 2000b), a relationship which forms the basis for the proof that AB is context-free (Bar-Hillel *et al.*, 1964).

In giving a derivation for a string ω , we line up the lexical items of ω , introduce their associated categories from the lexicon, and proceed by applying the rules to adjacent pairs of categories. Once a pair of categories have been combined, only the category resulting from the combination is visible for further derivational steps. Each step is annotated by underlining the combining categories and labeling the underline with the symbol for the rule used. Unlabeled underlines indicate introduction of a category from the lexicon. An example derivation is given below for the string *Brazil defeated Germany* using the lexical entries given in (1).

$$\begin{array}{c} (3) \quad \begin{array}{ccc} \textit{Brazil} & \textit{defeated} & \textit{Germany} \\ \hline \text{np} & (\text{s}\backslash\text{np})/\text{np} & \text{np} \\ \hline & \text{s}\backslash\text{np} & \\ \hline & \text{s} & \end{array} \end{array}$$

This derivation can be seen as a phrase structure tree turned upside-down, as shown in (4), in which the categorial analysis (4a) is clearly isomorphic to a standard phrase structure analysis (4b).



Despite such a correspondence, the categories labeling the nodes of the tree in (4a) are much more informative than the atomic symbols of a tree produced by a context-free grammar such as (4b). Subcategorization is directly encoded in functor categories rather than through the use of new symbols such as $V_{intrans}$, V_{trans} and $V_{ditrans}$. Furthermore, there is a systematic correspondence between notions such as *intransitive* and *transitive* — after the transitive category $(\text{s}\backslash\text{np})/\text{np}$ consumes its object argument, the resulting category $\text{s}\backslash\text{np}$ is exactly the same as that of an intransitive verb. This comes as a result of the way lexical categories are defined in combination with the universal rules of functional application.

See Oehrle (to appear) for a deductive explanation within the Lambek framework of the relationship between categories and phrase structure labels.

The type-driven nature of categorial grammar provides a natural explanation for basic coordination phenomena. By assuming that the categories for *and* are functions over two categories of the same type into another category of that type, which can be represented schematically as in (5), we immediately predict the distribution in (6).¹

$$(5) \quad \textit{and} \vdash (X \backslash X) / X$$

- (6) a. Brazil played and defeated Germany.
 b. *Brazil played Germany and defeated.
 c. Brazil defeated Germany and won the World Cup.
 d. Brazil defeated Germany and celebrated.
 e. John bought and gave his family tickets to the World Cup.
 f. Brazil defeated Turkey and Germany.

For example, (6a) receives the following derivation:

$$(7) \quad \frac{\frac{\frac{\textit{Brazil}}{\text{np}} \quad \frac{\textit{played}}{(s \backslash \text{np}) / \text{np}} \quad \frac{\textit{and}}{((s \backslash \text{np}) / \text{np}) \backslash ((s \backslash \text{np}) / \text{np}) / ((s \backslash \text{np}) / \text{np})} \quad \frac{\textit{defeated}}{(s \backslash \text{np}) / \text{np}} \quad \frac{\textit{Germany}}{\text{np}}}{((s \backslash \text{np}) / \text{np}) \backslash ((s \backslash \text{np}) / \text{np})} > \\ \frac{}{(s \backslash \text{np}) / \text{np}} < \\ \frac{}{(s \backslash \text{np}) / \text{np}} < \\ \frac{}{s \backslash \text{np}} > \\ \frac{}{s} <$$

On the other hand, (6b) is blocked automatically because *played Germany* has the category of an intransitive verb and thus cannot coordinate with the transitive verb *defeated*:

$$(8) \quad \frac{\frac{\frac{* \textit{Brazil}}{\text{np}} \quad \frac{\textit{played}}{(s \backslash \text{np}) / \text{np}} \quad \frac{\textit{Germany}}{\text{np}}}{s \backslash \text{np}} > \quad \frac{\textit{and}}{((s \backslash \text{np}) / \text{np}) \backslash ((s \backslash \text{np}) / \text{np}) / ((s \backslash \text{np}) / \text{np})} \quad \frac{\textit{defeated}}{(s \backslash \text{np}) / \text{np}}}{((s \backslash \text{np}) / \text{np}) \backslash (s \backslash \text{np} / \text{np})} > *$$

Convention 1 (Abbreviated derivations). *To avoid writing down derivations (such as (8)) in which most of the steps are obvious and only one critical step needs to be highlighted, it is common to use a one line representation that groups relevant words together and shows the categories associated with those substrings. For example, derivation (8) can be equivalently shown as follows:*

$$(9) \quad * \textit{Brazil} [\textit{played Germany}]_{s \backslash \text{np}} \textit{ and } [\textit{defeated}]_{(s \backslash \text{np}) / \text{np}}.$$

As a further abbreviation strategy, some steps in full derivations are omitted when they are either entirely obvious or irrelevant for the purpose of the particular derivation. ◀

¹It is also common to use the following syncategorematic ternary rule for coordination rather than a category such as (5):

a. $X \text{ CONJ } X \Rightarrow_{\Phi} X$ (Coordination(Φ))

Using such a rule avoids certain undesirable combinations available with the category in (5) when categorial systems more powerful than AB are employed. The modalized approach we develop later in this chapter enables coordination to be dealt with on a category rather than rule basis without the undesirable consequences suffered previously.

- b. team that I thought that you said that Brazil defeated.
- c. team that I thought that you said that John knew ... that Brazil defeated.

The category of *that* as a complementizer is generally assumed to be s'/s . With the AB system there is no way of deriving the category s/np (required by the relativizer) for the string *I thought that Brazil defeated*, even if we use the alternative category for *defeated* that was utilized in (15).

$$(17) \quad \text{team that I [thought]_{(s \setminus np)/s'} [\text{that}]_{s'/s} [\text{Brazil defeated}]_{s/np}}$$

To capture such a relative clause, we would need further categories for both *thought* and *that* which explicitly pass up the extracted element, as shown in the following derivation:

$$(18) \quad \begin{array}{ccccccc} \text{team} & & \text{that} & & I & & \text{thought} & & \text{that} & & \text{Brazil defeated} \\ & & \frac{}{(n \setminus n)/(s/np)} & & \frac{}{np} & & \frac{}{((s/np)/(s'/np)) \setminus np} & & \frac{}{(s'/np)/(s/np)} & & \frac{}{s/np} \\ & & & & & & \frac{}{(s/np)/(s'/np)} < & & & & \frac{}{s'/np} > \\ & & & & & & \frac{}{s/np} > & & & & \\ & & & & & & \frac{}{n \setminus n} > & & & & \end{array}$$

Another problematic example comes from so-called *non-peripheral* extractions, such as the following:

$$(19) \quad \text{team}_i \text{ that Brazil defeated } t_i \text{ yesterday}$$

Here, the extraction site is between the verb and the adverb, so we must find some means to combine these two elements. With the standardly assumed categories, no derivation is available:

$$(20) \quad \text{team that Brazil [defeated]_{(s \setminus np)/np} [\text{yesterday}]_{(s \setminus np) \setminus (s \setminus np)}}$$

Categorial ambiguity could of course be used to overcome this deficiency — simply give all adverbs another category that takes the transitive category as input and produces the transitive category as output. However, here we see how the kind of categorial ambiguity suggested above begins to cause greater havoc with the grammar — we need not only the category $((s \setminus np)/np) \setminus ((s \setminus np)/np)$, but also $((s \setminus np) \setminus np) \setminus ((s \setminus np) \setminus np)$, and this would be necessary for other verbal categories as well (e.g. ditransitives). The situation gets even worse if we consider the many categories that would be necessary for pre-verbal adverbs to permit relative clauses like *that Brazil easily defeated yesterday*.

Another problem comes with phrasal verbs, in which a particle can shift with respect to a direct object, as in the following examples:

- (21) a. Marcos picked the ball up.
- b. Marcos picked up the ball.

With AB, it would be necessary to provide two categories to handle this variation. Also, with respect to extraction, yet another category for object extraction is needed.

These are just a few demonstrations of how the inherent limitations of AB induce considerable categorial ambiguity if we are to provide adequate coverage. The essential reason that AB cannot handle object extraction and unbounded dependencies with single category assignments is that it is completely non-associative and non-permutative. It could be argued that throwing a large number of categories at the problem is actually a fine strategy and that we should be content with the utter simplicity of the system itself.

However, the inadequacy of AB is not simply an aesthetic issue. For one thing, due to compiling out combinatory possibilities we lose any systematic relationship that could otherwise be predicated between the multiple categories, despite the fact that they are able to provide alternative derivations for the same strings. This is bound to create problems for a learning theory that uses categories as a data structure. A more damaging point is that AB's generative power is too weak. As shown by Huybregts (1984) and Shieber (1985), systems with only context-free generative power are unable to capture crossing dependencies in languages such as Dutch and Swiss German. As we will see later, these crossing dependencies require a grammar to license a limited degree of permutativity which comes into play for constructions in a wide variety of languages, including English.

The AB calculus has been extended in two primary ways to create systems that can provide the flexibility needed to capture both the associativity and permutativity that natural language apparently demands. The first strategy is to augment the rules of AB with further rule schemas that have greater combinatorial potential, whilst the other recasts AB as a logical system with full implicational reasoning capabilities. The rule-based strategy is exemplified by early work such as Geach (1972) and Ades and Steedman (1982), the main manifestations of which in the present day are CCG and Unification-Based Generalized Categorical Grammar. The logical tradition initiated by Lambek (1958) has evolved in a number of directions which we shall generally refer to as Categorical Type Logic (CTL), following Moortgat (1997).

2.3 Combinatory Categorical Grammar

Just as AB's syntactic rules of functional application can easily be seen to correspond to the semantic operation of functional application, we might consider creating syntactic correlates for other semantic operations. In particular, several of the combinators which Curry and Feys (1958) use to define the λ -calculus and applicative systems in general are of considerable syntactic interest (Steedman, 1988). As the basis for defining new rule schemas to extend the AB base, CCG employs three combinators: composition (**B**), type-raising (**T**), and substitution (**S**). The relationships of these combinators to terms of the λ -calculus are defined by the following equivalences (Steedman, 2000b):

- (22) a. $\mathbf{B}fg \equiv \lambda x.f(gx)$
- b. $\mathbf{T}x \equiv \lambda f.f x$
- c. $\mathbf{S}fg \equiv \lambda x.fx(gx)$

The combinator **B** composes a function f with its argument g before g has applied to its own argument. The result is a new function that applies its argument to the embedded function g . The combinator **T** turns an argument x into a function whose argument f is a function that x applies itself to. Finally, the combinator **S** is quite similar to **B**, except that the function it creates applies its argument x to both f and g – in other words, **S** is a *non-linear* operator, allowing for the multiple use of a single argument, whereas application, **B** and **T** are *linear* operators.

These combinators give rise to new classes of rules, the forms of which are governed by the following principle (Steedman, 2000b):

- (23) *The Principle of Combinatory Type Transparency*
All syntactic combinatory rules are type-transparent versions of one of a small number of simple semantic operations over functions.

Each rule type is comprised of several directionally specific instantiations that allows CCG to systematically provide derivational capabilities that would either require excessive stipulations or be uncapturable under AB. See §2.3.5 for a discussion on the kinds of rules which the principle does not allow.

In following sections, we introduce several rules which are formed from the combinators **B**, **T**, and **S** and the Principle of Combinatory Type Transparency. We begin with the composition combinator **B** and its order-preserving syntactic rule correlates.

2.3.1 Harmonic Composition

There are a number of reasons to believe that the grammar of English is associative at some levels. In particular, evidence from extraction and coordination showed that we must assume that a grammatical system must be capable of deriving constituents for word sequences that do not correspond directly to standard notions of constituency (recall the examples in §2.2.3). A further example that cannot be handled elegantly with the limited apparatus of AB involves the coordination of verbal complexes such as that in (24).

(24) Brazil will meet and should defeat China.

A standard analysis of modal verbs is that they are functions from intransitive verb phrases into intransitive verb phrases. However, for this coordination to proceed, the modal verbs *will* and *should* must combine with *meet* and *defeat* respectively before the latter two may consume their object argument. Because the only rule available in AB is functional application (2), there is no way of performing this combination.

(25) $[\text{will}]_{(s \backslash np)/(s \backslash np)} [\text{meet}]_{(s \backslash np)/np}$

Given these categories, there is a simple rule corresponding to the combinator **B** which allows modals to combine with transitive verbs directly by composing the two functions:

(26) *Forward composition* ($>\mathbf{B}$)
 $X/Y \quad Y/Z \Rightarrow_{\mathbf{B}} X/Z$

Remark. It should be pointed out that *functional* composition should not be confused with the notion of *grammatical* composition employed in much work in the Lambek tradition, such as Oehrle (to appear). In CCG, composition strictly refers to the use of **B**-based combinatory rules, whereas in CTL it can refer to any (logical) way of operating on categories and the structures they yield. ◀

The derivation of (24) then proceeds as in (27), where applications of the composition rule are indexed with $>\mathbf{B}$. For now, we will also use the schematic category $(X \backslash X)/X$ for the coordinator and collapse the two steps for it applying to its arguments into one step indexed by $<\Phi>$.

(27)
$$\begin{array}{ccccccc} \text{Brazil} & \text{will} & \text{meet} & \text{and} & \text{should} & \text{defeat} & \text{China} \\ \text{np} & (s \backslash np)/(s \backslash np) & (s \backslash np)/np & (X \backslash X)/X & (s \backslash np)/(s \backslash np) & (s \backslash np)/np & np \\ & & \xrightarrow{>\mathbf{B}} & & \xrightarrow{>\mathbf{B}} & & \\ & (s \backslash np)/np & & & (s \backslash np)/np & & \\ & \xrightarrow{<\Phi>} & & & \xrightarrow{<\Phi>} & & \\ & & (s \backslash np)/np & & & & \\ & & \xrightarrow{s} & & & & \\ & & & s \backslash np & & & \\ & & & < & & & > \end{array}$$

The rule (26) must be generalized to allow modal verbs to compose with ditransitives:

On the other hand, it seems that the crossed rules can be declared without specifying the directionality of the schematized arguments since they are already non-order preserving. For example, we can generalize forward crossed composition (46) as follows:

$$(33) \quad X/Y \quad (Y \setminus Z) \$_1 \Rightarrow_{\mathbf{B}^n} X \setminus Z \$_1 \quad (>\mathbf{B}^n)$$

It should also be noted that although the form of the generalized rules (29) and (33) indicates that composition is unbounded, it should be viewed as a schema over several bounded instances of the rule (Steedman, 2000b). This is important since allowing unbounded composition increases the generative power of CCG beyond mild context-sensitivity (Weir, 1988). ◀

Because the categories of English generally contain forward slashes, it is difficult to provide a simple example of the use of backward composition. However, the next section shows how this rule is nonetheless an important component in providing the CCG analysis of argument cluster coordination (also known as *non-constituent coordination*). Before considering the permutation-inducing rules based on $\mathbf{B}$, we thus turn next to type-raising rules, which conspire with the harmonic composition rules to generalize CCG's associativity even further and permit the flexible constituency for which CCG is perhaps best known while using exactly the same categories used thus far.

2.3.2 Type-raising

CCG employs a further class of rules that allows a syntactic argument to become a function that seeks a function that seeks the original argument type, mirroring the effect of the combinator $\mathbf{T}$ (22b). For example, the following rule permits a subject noun phrase in English to become a function seeking an intransitive verb phrase:

$$(34) \quad \text{Forward type-raising } (>\mathbf{T}) \\ X \Rightarrow_{\mathbf{T}} Y/(Y \setminus X)$$

In order to reduce the size of derivations and improve their readability, we will use the following conventions for type-raised categories.

Convention 3 (Instantiation of variables in type-raised categories). *When presenting derivations, the relevant instantiation of the variable in the type-raised category necessary for the derivation to succeed will be used in place of the variable. For example, a type-raised subject in English will be written as $s/(s \setminus np)$ instead of $Y/(Y \setminus np)$.* ◀

Convention 4 (Abbreviated type-raised categories). *When a type-raised category is not the focal aspect of a derivation, the shortened representation $np^\uparrow$ will be used in place of the full category.* ◀

An immediate implication for the inclusion of forward type-raising is that it works in concert with the rule of forward composition (26) to induce associativity in English transitive sentences. Thus, we have the following alternative to the derivation (3) provided by AB.

$$(35) \quad \begin{array}{c} \frac{\text{Brazil}}{np} \quad \frac{\text{defeated}}{(s \setminus np)/np} \quad \frac{\text{Germany}}{np} \\ \hline \frac{s/(s \setminus np)}{s/np} \xrightarrow{>\mathbf{T}} \\ \hline \xrightarrow{>\mathbf{B}} \\ \hline s \end{array} \rightarrow$$

By including just the two additional rules of forward harmonic composition and forward type-raising, CCG gains associativity in an entirely type-driven fashion, allowing for a more flexible notion of constituency. The same core linguistic signs now give rise to associativity by interaction with the combinatory rules. AB could only do this by using categorial ambiguity.

The ability of CCG to combine subject noun phrases with a verb before the verb has consumed its object noun phrases allows it to straightforwardly account for phenomena such as right-node raising, object extraction, and topicalization in English. For example, object extraction now proceeds as follows, using the categories assumed for AB:

$$(36) \quad \begin{array}{ccccccc} \text{team} & & \text{that} & & \text{Brazil} & & \text{defeated} \\ \hline n & & (n \backslash n) / (s / np) & & np & & (s \backslash np) / np \\ & & & & \xrightarrow{T} & & \\ & & & & s / (s \backslash np) & & \\ & & & & \xrightarrow{B} & & \\ & & & & s / np & & \\ & & & & \xrightarrow{>} & & \\ & & n \backslash n & & & & \\ & & \xrightarrow{<} & & & & \\ & n & & & & & \end{array}$$

The fact that object extraction is unbounded is immediately captured because forward harmonic composition allows the extracted argument to be successively passed up until it is revealed to the relativizer:

$$(37) \quad \begin{array}{ccccccccccc} \text{team} & & \text{that} & & I & & \text{thought} & & \text{that} & & \text{Brazil} & & \text{defeated} \\ \hline n & & (n \backslash n) / (s / np) & & np & & (s \backslash np) / s & & s / s & & np & & (s \backslash np) / np \\ & & & & \xrightarrow{T} & & & & & & \xrightarrow{T} & & \\ & & & & s / (s \backslash np) & & & & & & s / (s \backslash np) & & \\ & & & & \xrightarrow{B} & & & & & & \xrightarrow{B} & & \\ & & & & s / s & & & & & & s / np & & \\ & & & & & & & & & & \xrightarrow{B} & & \\ & & & & & & & & & & s / np & & \\ & & & & & & & & & & \xrightarrow{>} & & \\ & & & & & & & & & & n \backslash n & & \\ & & & & & & & & & & \xrightarrow{<} & & \\ & n & & & & & & & & & & & \end{array}$$

The composition of the subject and the verb is also implicated in right node raising:

$$(38) \quad \begin{array}{ccccccc} \text{Marcos} & & \text{threw} & & \text{and} & & \text{Ronaldo} & & \text{kicked} & & \text{the ball} \\ \hline np & & (s \backslash np) / np & & (X \backslash X) / X & & np & & (s \backslash np) / np & & np \\ & & \xrightarrow{T} & & & & \xrightarrow{T} & & & & \\ & & s / (s \backslash np) & & & & s / (s \backslash np) & & & & \\ & & \xrightarrow{B} & & & & \xrightarrow{B} & & & & \\ & & s / np & & & & s / np & & & & \\ & & \xrightarrow{>} & & & & \xrightarrow{< \Phi >} & & & & \\ & & & & & & s / np & & & & \\ & & & & & & \xrightarrow{>} & & & & \\ & & & & & & s & & & & \end{array}$$

The rule of forward type-raising of course has a directional converse:

$$(39) \quad \text{Backward type-raising } (<T) \\ X \Rightarrow_T Y \backslash (Y / X)$$

In conjunction with the rule of backward composition, this rule plays a crucial role in the analyses of Steedman (1985) and Dowty (1988) for argument cluster coordinations such as the following:

$$(40) \quad \text{The referee gave Unsal a card and Ronaldo the ball.}$$

This example succinctly shows type-raising, harmonic composition, and crossed composition rules all working in concert to induce the associativity and permutativity required of the grammar. Important to note, though, is that the combination of associativity and permutativity in a single set of rules does *not* lead to a permutation closure (i.e. collapse to the Lambek-Van Benthem calculus LP, Moortgat (1988)). The reason why CCG avoids this collapse is that permutation is applied in a strictly *local* fashion; the rules do not permit the free interaction between associativity and permutativity, cf. also Joshi *et al.* (1999).

As might be expected from the pattern with previous rules, there is of course a forward version of crossed composition.

$$(46) \quad \text{Forward crossed composition } (>\mathbf{B}_\times) \\ X/Y \quad Y \backslash Z \Rightarrow_{\mathbf{B}} X \backslash Z$$

Forward crossed composition is generally considered to be inactive in the grammar of English because it can induce some highly ungrammatical scrambled orders. A detailed discussion of forward crossed composition and its implications for English is provided in Baldridge (2002). Nonetheless, it must be part of the universal grammar because it is crucial for permitting scrambled orders in languages like Turkish which have greater word order freedom than English. Furthermore, the developments in this dissertation will ultimately allow us to pin down and exploit the power of permutative rules such as (43) and (46) even in languages like English without engendering undesirable collapses in word order.

CCG makes available only one further rule class, based on the substitution combinator **S**.

2.3.4 Substitution

The combinator **S** is different from **B** and **T** in that it allows a single resource to be utilized by two different functors. We find the need for such a combinator in parasitic gap constructions (Ross, 1967) such as the following:

- (47) a. John watched without enjoying the game between Germany and Paraguay.
b. game that John watched without enjoying

In both of these strings, a single dependent acts as the argument of both *watched* and *without enjoying*. If we consider the categories of the constituents in (47b), it is clear that the rules defined thus far will not allow the derivation to proceed.

$$(48) \quad \text{game that John [watched]}_{(s \backslash np)/np} \text{ [without enjoying]}_{((s \backslash np) \backslash (s \backslash np))/np}$$

As Steedman (2000b) notes, the fact that sequences like *watched without enjoying* can coordinate with transitive verbs as in *watched without enjoying and disliked* indicates that it must be possible to combine the categories $(s \backslash np)/np$ and $((s \backslash np) \backslash (s \backslash np))/np$ to form a transitive category. The following rule provides exactly this functionality:

$$(49) \quad \text{Backward crossed substitution } (<\mathbf{S}_\times) \\ Y/Z \quad (X \backslash Y)/Z \Rightarrow_{\mathbf{S}} X/Z$$

With this rule available in the system, the derivation of (47b) then proceeds as follows:

$$(57) \quad X \backslash Y \quad Y / Z \Rightarrow X \backslash Z$$

To exclude such rules, Steedman (2000b) employs the following principles:

(58) *The Principle of Consistency*

All syntactic combinatory rules must be consistent with the directionality of the principal function.

(59) *The Principle of Inheritance*

If the category that results from the application of a combinatory rule is a function category, then the slash defining directionality for a given argument in that category will be the same as the one(s) defining directionality for the corresponding argument(s) in the input function(s).

The Principle of Consistency excludes (57) because the principal function $X \backslash Y$ seeks its argument to the left whilst the rule states that its argument is located to its right. The Principle of Inheritance also rules out (57) because the leftward slash on the result category $X \backslash Z$ does not match that of the input category Y / Z .

2.4 Using multisets to lexically specify word order variation

CCG categories specify a rigid order of combination that limits the amount of variability in word order that a given CCG lexicon can express without using a great deal of categorial ambiguity. Motivated by the freedom in word order exhibited by Turkish, Hoffman (1995) proposes Multiset Combinatory Categorical Grammar (MULTISET-CCG), an extension of CCG which allows categories to express greater liberty in the word orders they will accept. This section provides a very brief explanation of the MULTISET-CCG system and shows how its constructs can be utilized even in English.

Consider the two sentences of (60), in which the position of the particle *up* can change with respect to the object of the verb.

- (60) a. Marcos picked up the ball.
b. Marcos picked the ball up.

To handle this variation in standard CCG, we could assume that the order in (60a) is basic and capture it with the category $((s \backslash np) / np) / prt$. The alternative order (60b) would then arise by type-raising the object *the ball* and then using backward crossed composition to combine it with the verb before the verb consumes the particle.

We could however consider an alternative in which the strict order specified by the verbal category is relaxed, permitting the two elements to permute more straightforwardly. This is the strategy adopted by Hoffman in creating MULTISET-CCG. To do so, she first redefines the manner in which categories are constructed so that arguments are placed into multisets which interact with the rules of MULTISET-CCG to allow permutation.

Definition 2 (Multiset-CCG categories). *Given $\mathcal{A}$, a finite set of atomic categories, the set of categories $\mathcal{C}$ is the smallest set such that:*

- $\mathcal{A} \subseteq \mathcal{C}$
- $X_0 \{ |^1 X_1, \dots, |^n X_n \} \in \mathcal{C}$, if $X_0, X_1, \dots, X_n \in \mathcal{C}$, for $n \geq 1$, $|^i \in \{ \backslash, /, | \}$

The non-directional slash $|$ can unify with both $\backslash$ and $/$.

2.5 Generative Power

One of the most salient differences between the various frameworks discussed above is their respective generative strengths. This section briefly addresses the ideological conflict that has arisen between these frameworks on this issue.

The perceived position of natural language on the Chomsky hierarchy (for those who believe it has such a position) has fluctuated during the past five decades. During the the 1960's and 1970's, it was generally accepted by linguists that grammars for natural languages required greater than context-free power. Due to this perception, frameworks like AB categorial grammar was somewhat sidelined after it was proven to be context-free by Bar-Hillel, Gaifman, and Shamir in 1964 – even Bar-Hillel himself gave up on categorial grammar because of this result. Bar-Hillel should not have despaired so easily – the purported proofs that natural language was greater than context-free were shown later to be flawed by Pullum and Gazdar (1982). Ultimately, the belief that context-free power is insufficient for natural language syntax was upheld by the proofs of Huybregts (1984) and Shieber (1985) that the crossing dependencies of Swiss German and Dutch are not context-free. Rambow (1994) and Hoffman (1995) argue that even greater power is needed to cover long distance scrambling in German and Turkish, respectively. However, the apparent supposition that the categorial approach could not somehow be generalized to create systems of greater power was itself incorrect, as evidenced by the flowering of extended categorial grammar formalisms in the late 1970's and the 1980's. See Wood (1993) for elaboration on the various extensions.

The combinatory rules employed by CCG increase the context-free power of AB by a small but linguistically significant amount. With this extra power, CCG falls into the class of formalisms which have mildly context-sensitive generative power, along with Tree-Adjoining Grammar (Joshi, 1988), Linear Indexed Grammar (Gazdar, 1988), and Head Grammar (Pollard, 1984), which were all shown to be weakly equivalent by Vijayashanker and Weir (1994). Mild context-sensitivity is the weakest generative strength that is still powerful enough to handle the crossing dependencies of Dutch and Swiss German.

The categorial climb up the Chomsky hierarchy does not end with CCG. Motivated by scrambling phenomena, MULTiset-CCG modifies the manner in which categories are constructed and defines rules of combination for them which allow greater flexibility, resulting in a formalism with more than mildly context-sensitive power and less than fully context-sensitive power (Hoffman, 1995). CTL permits even more powerful operations, allowing it to attain Turing-complete power in its most general form (Carpenter, 1995). Moot (2002) provides a much finer characterization of the different generative strengths produced by CTL systems which conform to certain constraints, including the result that systems which use non-expanding structural rules are only context-sensitive. This result is particularly interesting since it appears that nearly all linguistic applications of CTL have obeyed this constraint (Moot, 2002).

Figure 2.1 presents a pictorial summary of where each of the formalisms discussed here sits on the Chomsky hierarchy.

The issue of generative capacity has proven itself to be a sticking point between the CCG and CTL traditions, which otherwise share many of the same intuitions and analyses. CTL's Turing-complete expressive power puts it at odds with CCG's conservatism, as is evident in the following comment by Steedman:

Although the (weakly context-free) Lambek calculus provides an interesting starting point..., the addition of any of the non-order-preserving rules to its

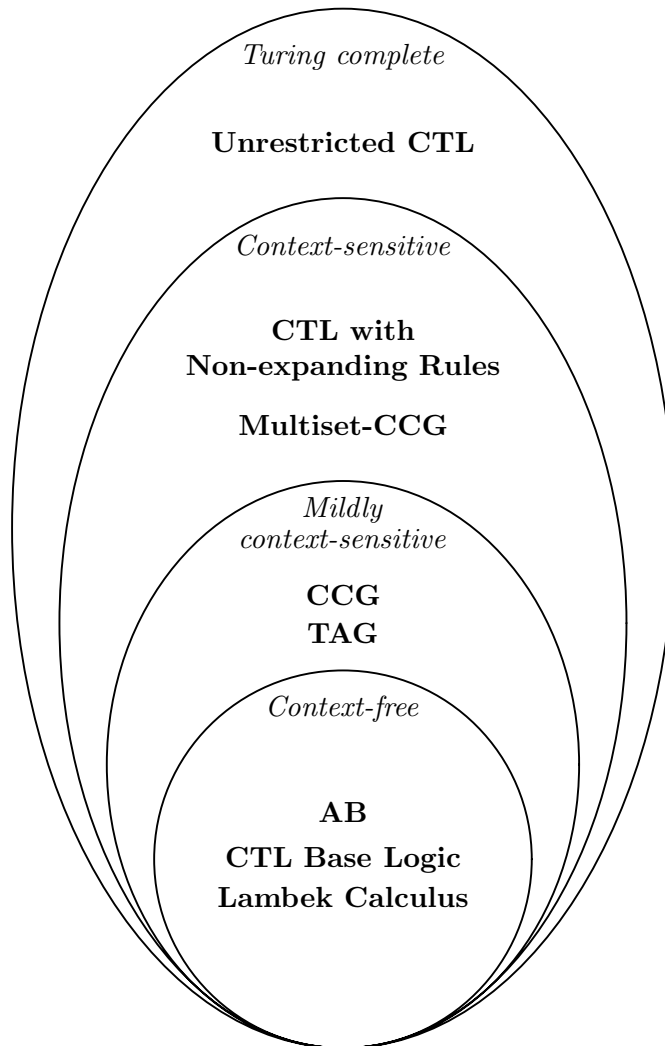


Figure 2.1: The positions of several formalisms on the Chomsky hierarchy.

axioms immediately makes it collapse into permutation closure, as Moortgat (1988) has shown. (Steedman, 1996, p. 44)

Actually, the modern descendants of the Lambek calculus do not fall prey to such a collapse because permutation operations can be introduced in a controlled fashion and specified to induce permutation in only very particular configurations. In fact, Moortgat (1988) used this collapse as the basis for an argument for introducing resource-sensitivity into Lambek-style categorial grammars.

Nonetheless, the fact that CTL is general enough to define rules which induce permutation closure is still problematic for Steedman, who argues that taking a committed stance on restricted generative capacity limits the range of analyses which may be put forth according to the theory and therefore boosts their predictive power:

We should also try to minimize power in the modules of the theory, consistent with the primary goal of building interpretations that capture predicate-argument relations correctly. If we can do so with grammars that are provably low on the Chomsky hierarchy of formal languages and automata-theoretic power, then we are on stronger theoretical ground than if we adopted theories that achieve the same coverage at the expense of greater power, because greater automata-theoretic power increases the variety of alternative constructions and phenomena that we *could* capture beyond the point where there seems to be any motivation from empirical or imaginable semantic dependencies. (Steedman, 2000b, p. 23)

Thus, the basic linguistic claim for mildly context-sensitive formalisms in general is that their restricted formal power provides inherent limitations on theories which are built up around them and thereby enforce a wide-range of formal universals which do not even need to be explicitly stated. Such formalisms sit on the lower bound of natural language complexity without venturing any further – they are expressive enough, but cannot do everything. Theories that employ a low power formalism have fewer degrees of freedom than those which assume higher powered mechanisms as their basis, and they have thus far proven suitable for extensive coverage of empirical linguistic data.

For CTL researchers, issues of generative capacity are generally not considered to be of prime theoretical importance. For example, Morrill states that

there is no absolute measure as to what constitutes a restricted class of languages, so that while observations of generative capacity are perhaps interesting, there seems no sense in which they are important. (Morrill, 1994, p. 257)

Morrill further notes that we might consider generative scales other than the Chomsky hierarchy, such as a categorial hierarchy stratified by structural rules. Though there certainly have been investigations into the abstract complexity of particular CTL systems, such as the important proof in Pentus (1997) of the context-freeness of the Lambek calculus (Lambek, 1958), as well as Carpenter (1995) and Moot (2002), the CTL tradition does not generally place much *linguistic* significance on generative capacity.

One of the contributions of Baldridge (2002) is cross-linguistic support for the position that restricted generative power *is* linguistically relevant, and furthermore that mild context-sensitivity is sufficient. One side of the argument involves demonstrating that mildly context-sensitive power is sufficient for handling a variety of constructions from a

number of languages for which more powerful mechanisms have been proposed. The other side is that the analyses we propose have inherent limitations that lead to interesting linguistic predictions.

It should be noted that generative capacity does not provide an argument for the primacy of CCG *per se*. For example, a CTL grammar which uses only particular kinds of structural rules is every bit as capable of producing such linguistic predictions. In fact, this is part of the true elegance of the type-logical approach – it is able to mix substructural logics in a resource-sensitive manner that permits the creation of systems with power ranging from its context-free base logic all the way to Turing-completeness. Thus, we are able to assume a conservative base for a CTL grammar and introduce more powerful operations of grammatical composition in a *controlled* manner. Indeed, a main contribution of the approach presented here is to show that even a formalism with limited power like CCG must incorporate fine-grained resource-sensitivity to gain similar control over its finite range of operators.

2.6 Modalizing control in CCG

Analogous to the use of modal decorations in CTL to control the applicability of structural rules, we can consider bringing modalities into CCG to obtain the sort of fine-grained *lexical* control over when combinatory rules can be used in a derivation. It is quite common to find in CCG analyses that constraints need to be stipulated on the applicability of several of the combinatory rules for that fragment. By modifying the formal definition of CCG to utilize the idea of modalities from CTL, we can do away with the use of rule restrictions to control the applicability of CCG’s rules in favor of using categories that specify different modes of grammatical composition. Ultimately, this will provide us with a principled and meaningful way of characterizing the manner in which syntactic extraction asymmetries arise in different languages while allowing controlled use of permutative operations.

Before presenting the modalized CCG system, we will motivate the multi-modal approach with a brief look at coordination, demonstrating that not all categories should have full access to the combinatory rules.

2.6.1 Restricting Associativity

CCG’s composition and type-raising rules provide the kind of associativity which is needed to handle many constructions. However, while this associativity is crucial for forming the constituents which are to be coordinated, it causes problems when we consider the categories of coordinating words themselves. For example, we might consider giving *and* the following category:

$$(66) \quad \textit{and} \vdash (s_i \backslash s_i) / s_i$$

Unfortunately, such a category can lead to overgeneration because it is able to consume its first argument and then compose, producing noun phrases such as **player that shoots and he misses*.

$$\begin{array}{c}
 (67) \quad *player \quad \frac{that}{(n \setminus n) / (s_i \setminus np)} \quad \frac{shoots}{s_i \setminus np} \quad \frac{and}{(s_i \setminus s_i) / s_i} \quad \frac{he}{np} \quad \frac{misses}{s_i \setminus np} \\
 \hline
 \frac{\frac{\frac{s_i \setminus s_i}{s_i} \quad \frac{s_i \setminus np}{s_i \setminus np}}{s_i \setminus s_i} \quad \frac{s_i \setminus np}{s_i \setminus np}}{s_i \setminus np} \quad \frac{s_i \setminus np}{n \setminus n} \\
 \hline
 n \setminus n
 \end{array}$$

This problem has led to the use of the ternary syncategorematic coordination rule (68), which forces the consumption of both arguments of the coordinator simultaneously.

$$(68) \quad X \quad CONJ \quad X \Rightarrow_{\Phi} \quad X \quad (Coordination(\Phi))$$

However, this rule is unsatisfactory for two main reasons. First, it does not correspond to one of the combinators **B**, **T**, and **S**, and is therefore a rule created outside the scope of the Principle of Combinatory Type Transparency (23). More importantly, it does not permit fine-grained control over the properties of the various coordinating words. For example, *and* and *but* have different semantic properties, not only between each other, but also between their different uses in sentential and nominal coordinations. Furthermore, lexical control is particularly important in languages which actually have different coordinators for sentential and phrasal coordination. An example of such a language is Malagasy, which uses *ary* to coordinate sentences (69) and *sy* to coordinate phrases (70) (from (Keenan, 1978, pp. 319-320)).

$$\begin{array}{l}
 (69) \quad \text{Misotro taoka} \quad \text{Rabe ary mihinam bary Rabe.} \\
 \text{drink} \quad \text{alcohol Rabe and eat} \quad \text{rice Rabe} \\
 \text{Rabe is drinking alcohol and Rabe is eating rice.}
 \end{array}$$

$$\begin{array}{l}
 (70) \quad \text{Misotro taoka} \quad \text{sy mihinam bary Rabe.} \\
 \text{drink} \quad \text{alcohol and eat} \quad \text{rice Rabe} \\
 \text{Rabe is drinking alcohol and eating rice.}
 \end{array}$$

It thus appears that coordination should be handled in the lexicon, and the multi-modal approach gives us the tools to support this strategy without leading to overgenerations such as (67). Assuming a non-associative mode of grammatical composition is quite standard in work in CTL — in fact, a CTL system which utilizes just one mode of composition that is non-associative is the well-known Non-associative Lambek calculus. In the present setting, we will implement this mode with the $\star$ modality, giving it access to only the forward and backward application rules of CCG, but crucially not to the composition rules. We can then use this mode to create refined categories for coordinating words that ensure that they cannot take part in composition steps. For example, the category for *and* can now be declared as (71) without the danger of overgenerations like (67).

$$(71) \quad and \vdash (s_i \setminus_{\star} s_i) /_{\star} s_i$$

In effect, the ternary coordination (68) amounts to covert use of $\setminus_{\star}$ and $/_{\star}$ confined to the meta-category **CONJ**. Note that for coordination, it would be impossible to use restrictions on the composition rules to block overgenerations like (67) since the restrictions we would need to state would block most of the other desired uses of the composition rules. Though this is not the only reason why the resource-sensitivity of CCG should be enhanced, it already provides a strong indication the need for it.

The next sections show how CCG can be reformulated to incorporate lexically specified derivational control via categories that license different modes of grammatical composition.

2.6.2 Modes and the Application Rules

The definition of CTL declares a general form which can be used to create specific multi-modal systems that use a *particular* finite set of modalities and a *particular* finite set of structural rules that interact with those modalities. Because of this, CTL-based systems can vary greatly with respect to the power of the operations they use and the inventory of modalities which those operations have access to. In bringing a multi-modal perspective to CCG, it is thus necessary to choose the set of modalities and define the rules to respect the different modes of grammatical composition we wish to utilize. In this section, we propose one way of how this may be done.

In the preceding section, we showed that a non-associative mode is necessary for providing a lexical account of coordination. The modality that we used to enforce non-associativity is $\star$. This symbol was chosen simply because it has not, to our knowledge, been used for other purposes in the CTL literature. The full set of modalities which we will employ is the following:

$$(72) \quad \mathcal{M}_{MM-CCG} = \{\star, \diamond, \ltimes, \rtimes, \triangleleft, \triangleright, \cdot\}$$

The effect of each of these modalities will be explicated as we introduce each of the combinatory rules and define their interaction with the modalities. Some of the modes explicitly reflect directionality, represented as $\triangleleft$ and $\triangleright$. Disregarding the directionality, the basic intent behind the modalities is as follows: the $\star$ modality already discussed is the least permissive and permits access only to the application rules; $\diamond$ allows access to the harmonic composition rules; $\times$ licenses the crossed composition rules; and finally, $\cdot$ licenses all of the rules.

To use modally refined slashes in CCG, we have to extend the definition of categories as defined earlier for the AB calculus (Definition 1 on page 14).

Definition 3 (MMCCG categories). *Given $\mathcal{A}$, a finite set of atomic categories, the set of categories $\mathcal{C}$ is the smallest set such that:*

- $\mathcal{A} \subseteq \mathcal{C}$
- $(X \backslash_m Y), (X /_m Y) \in \mathcal{C}$ if $X, Y \in \mathcal{C}, m \in \mathcal{M}_{MM-CCG}$

◀

We will begin by defining a small English lexicon to demonstrate the effects of each of the rules as we proceed through the modalization of the rules. The choice of the particular modalities on the slashes will become clear as more phenomena are discussed.

- $$(73) \quad \begin{array}{ll} \text{a.} & \textit{Rivaldo} \vdash \text{np} \\ \text{b.} & \textit{kicked} \vdash (s_i \backslash_{\triangleleft} \text{np}) /_{\triangleright} \text{np} \\ \text{c.} & \textit{the} \vdash \text{np} /_{\diamond} \text{n} \\ \text{d.} & \textit{ball} \vdash \text{n} \\ \text{e.} & \textit{skillfully} \vdash (s \backslash_{\ltimes} \text{np}) /_{\triangleright} (s \backslash_{\triangleleft} \text{np}) \\ \text{f.} & \textit{that} \vdash (n \backslash_{\star} \text{n}) /_{\star} (s_i / \text{np}) \end{array}$$

The atomic categories and feature abbreviations used here are defined on page Figure 2.2.

Instead of viewing the set of modalities as an unstructured collection of modalities, we can consider it to be an inheritance hierarchy, in which a modality has all the powers

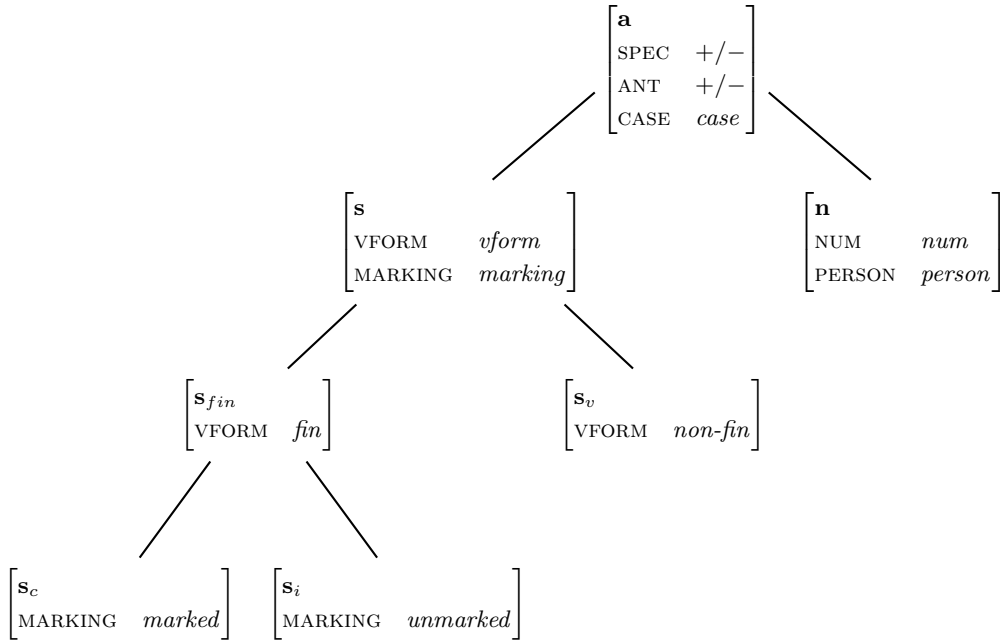


Figure 2.2: Inheritance hierarchy for atomic categories.

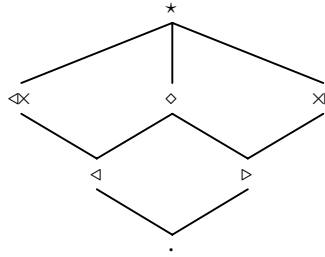


Figure 2.3: Hierarchy of modes.

of its supertypes. We will assume that the hierarchy given in Figure 2.3 is operative for these purposes. The intuition behind a hierarchy such as this is that a category with a particular modality may serve as input not only to all of the structural rules which reference the modality explicitly, but also rules which reference its supertypes.

We must next redefine the CCG rules to be sensitive to the modalities. We start with the application rules, the simplest rule class. They are the equivalent of the slash elimination rules of CTL's base logic, and thus are defined to work with all modes of grammatical composition. Given the hierarchy in Figure 2.3, we can define the application rules so that they are keyed to the root modality $\star$:³

(74) MULTI-MODAL CCG *application rules*

$$\text{a. } X/_\star Y \ Y \Rightarrow X \quad (>)$$

$$\text{b. } Y \ X \backslash_\star Y \Rightarrow X \quad (<)$$

³Without the hierarchy, the definition would look more similar to that of the CTL rules:

$$\text{a. } X/_i Y \ Y \Rightarrow X \quad (>)$$

$$\text{b. } Y \ X \backslash_i Y \Rightarrow X \quad (<)$$

where $i \in \mathcal{M}_{MM-CCG}$

$$\begin{array}{c}
(78) \quad \frac{\frac{\text{the}}{\text{np}/\diamond\text{n}} \quad \frac{\text{ball}}{\text{n}} \quad \frac{\text{that}}{(n \backslash_{\star} n) / \star (s_i / \text{np})} \quad \frac{\text{Rivaldo}}{\text{np}} \quad \frac{\text{kicked}}{(s_i \backslash \text{np}) / \text{np}}}{\frac{s_i / \triangleleft (s_i \backslash \text{np})}{s_i / \text{np}} \xrightarrow{\text{B}}} \\
\frac{\frac{\frac{\text{np}}{\text{n}} \quad \frac{\text{n} \backslash_{\star} \text{n}}{\text{n}}}{\text{np}} \xrightarrow{\text{B}}}
\end{array}$$

With this derivation, the way in which the hierarchy of modalities works can be seen more clearly. For example, since $\triangleleft$ and $\triangleright$ are supertypes of $\diamond$, the application of the forward harmonic composition rule to the category inputs $s_i / \triangleleft (s_i \backslash \text{np})$ and $(s_i \backslash \text{np}) / \text{np}$ succeeds. Had either of the slashes carried the $\star$ modality, $\triangleleft$ modality, or $\triangleright$ modality, the rule could not have applied. This is exactly why the use of the category $(s_i \backslash_{\star} s_i) / \star s_i$ for sentential coordination stops overgenerations such as (67), as discussed in §2.6.1.

Enhanced resource-sensitivity does not cause a loss in the *desired* derivational potential of the original CCG system — the categories of (73) and the rules defined so far permit the same mostly incremental derivation of *Rivaldo skillfully kicked the ball* as standard CCG.

2.6.4 Control Over Permutativity

The multi-modal setting brings further benefits. With standard CCG, we may choose to include or omit any of the combinatory rules for a given grammar. For example, Steedman (1996, 2000b) bans the forward crossed composition rule ($\triangleright \mathbf{B}_{\times}$) from the grammar of English. However, one of the goals of the present enterprise is to eliminate the use of rule restrictions. The desired effect of such restrictions must instead arise due to the modalities found on the categories of the lexicon.

To carry this proposal forward, we need to provide modalized versions of the crossed composition rules. Although it has been argued that the grammar for English cannot include forward crossed composition, its twin backward crossed composition is needed for deriving constructions such as heavy shift, as discussed in §2.3.3 and shown in derivation (44). However, backward crossed composition cannot apply universally in English since it would cause the grammar to accept strings such as **a powerful by Rivaldo shot* with the meaning *a powerful shot by Rivaldo*.

$$(79) \quad \star a \text{ [powerful]}_{n/n} \text{ [by Rivaldo]}_{n \backslash n} \text{ [shot]}_n$$

Steedman (1996) blocks such sequences by permitting backward crossed composition to apply only when both the primary and secondary categories are rooted in s , as shown in (80).

$$\begin{array}{l}
(80) \quad \text{Backward crossed composition } (< \mathbf{B}_{\times}) \\
\frac{Y/Z \quad X \backslash Y}{\text{where } X = Y = s \backslash \$} \Rightarrow_{\mathbf{B}} X/Z
\end{array}$$

See Convention 2 on page 21 for the definition of the $\$$ used in the restriction of the rule.

Rather than allowing certain CCG rules to be active or inactive in a given grammar, we can pass the control of such reflexes into the lexicon, just as we did for application-only constructions such as coordination. It is here that we employ the modalities $\triangleleft$ and $\triangleright$ in defining the crossed composition rules.

$$(81) \quad \text{MULTI-MODAL CCG crossed composition rules}$$

- a. $X/_\times Y \quad Y \backslash_\times Z \Rightarrow_{\mathbf{B}} X \backslash_\times Z \quad (>\mathbf{B}_\times)$
b. $Y/_\times Z \quad X \backslash_\times Y \Rightarrow_{\mathbf{B}} X/_\times Z \quad (<\mathbf{B}_\times)$

An immediate payoff is that we can now use rules like backward crossed composition in a grammar like English without having to place restrictions to limit its applicability. Instead, categories are declared in the lexicon to have slash types that are either compatible or incompatible with crossed composition. This provides a clean solution to the problem noted earlier, in which post-verbal adverbs can come between a verb and its direct object (44), while at the same time avoiding the possibility for a post-nominal modifier to appear between an adjective and its nominal argument. For example, the category of *skillfully* is that in (82), while that of *by* is the one in (83).

$$(82) \quad \textit{skillfully} \vdash (s \backslash_{\text{np}}) \backslash (s \backslash_{\text{np}})$$

$$(83) \quad \textit{by} \vdash (n \backslash_{\star n}) /_{\triangleleft} \text{np}$$

The category defined for English transitive verbs, $(s_i \backslash_{\text{np}}) / \text{np}$, can serve as input to rule (81b), thus allowing a derivation equivalent to (44) in MULTI-MODAL CCG, as shown in (84). However, (85) shows that it is impossible to derive (79) because of the slash type on the category given for *by*.

$$(84) \quad \text{Kahn [blocked]}_{(s_i \backslash_{\text{np}}) / \text{np}} [\textit{skillfully}]_{(s \backslash_{\text{np}}) \backslash (s \backslash_{\text{np}})} \text{ a powerful shot by Rivaldo.}$$

$$(85) \quad \ast_a [\textit{powerful}]_{n \backslash_{\triangleleft} n} [\textit{by Rivaldo}]_{n \backslash_{\star n}} [\textit{shot}]_n$$

Of course, the harmonic slash specified for the adjective *powerful* in (85) also blocks crossed rules from applying, resulting in a double block on the use of backward crossed composition (and forward crossed composition as well, actually).

Note that the analysis of heavy shift suggested here will permit adverbs to come between the verb and non-heavy direct objects, which is often claimed to be ungrammatical for English. Not only is it debatable whether to label them as ungrammatical, it is actually not uncommon to hear such utterances from native speakers of American English. Here is one real-life example:

- (86) We've laid out very carefully the targets.
– *Former United States Defense Secretary William Cohen, quoted in the New York Times, 17th of December 1998*

Nonetheless, if we did desire an analysis which only permitted shifting when the direct object is heavy, the mechanisms developed in the next section provide the means to enforce such behavior.

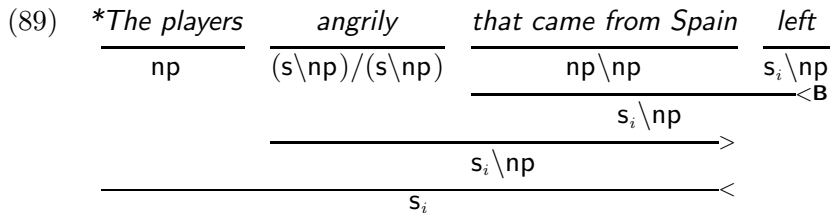
Now that the resource-sensitive system has been introduced for the primary rule classes, we return to more evidence to that given in §2.6.1 that we need control not just over permutativity, but over associativity as well.

2.6.5 More Non-associative Contexts

The application-only modality $\star$ provides a clean solution to a problem noted by Milward (1994) for lexicons which do not rigidly distinguish between bare nouns and noun phrases. There is considerable convenience for CCG lexicons made for computational tasks in allowing underspecification of this distinction (Bierner, 2001), but it can give rise to some undesirable word order consequences. Under this non-standard assumption, relativizers are functions over noun phrases (instead of bare nouns), and a grammar which handles (87) will also produce the disallowed order (88) with the same reading.

- (87) The players that came from Spain angrily left.
 (88) *The players angrily that came from Spain left.

This is derivable because the verb can combine via backward composition with the relative clause before the latter combines with the subject:



Given that *that* has the category $(np \backslash_{\star} np) /_{\star} (s_i \backslash np)$, this derivation is blocked in MULTIMODAL CCG because the category $np \backslash_{\star} np$ of the constituent *that came from Spain* cannot serve as input to the rule of harmonic backward composition (76b).

- (90) *The players angrily [that came from Spain]_{np \star np} [left]_{s_i \ np}

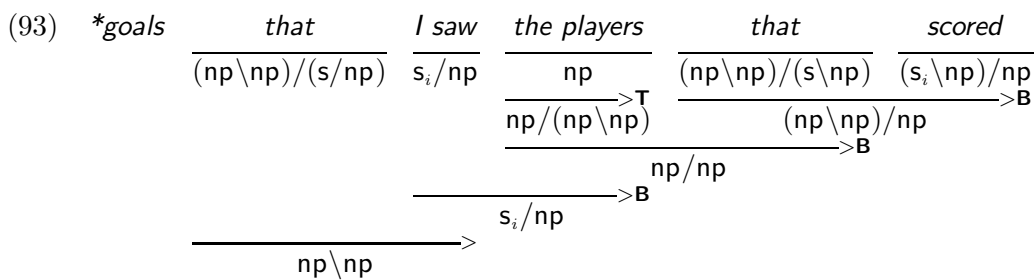
Of course, the derivation for (87) is still permitted since the relative clause can combine with *The players* via backward application.

It should be noted that Milward's example is not actually a problem for non-modalized CCG if relativizers only take bare nouns as arguments instead of full noun phrases. This strategy would of course require lexical ambiguity or a unary rule that turned the category of bare nouns into noun phrases for combination with the verb. Nonetheless, MULTI-MODAL CCG would support an analysis such as that given in Bierner (2001) without the above-mentioned overgeneration.

The category $(\mathbf{np} \backslash_{\star} \mathbf{np}) /_{\star} (\mathbf{s} \backslash \mathbf{np})$ given above for relativizers also blocks illicit double relativizations such as the following:

- (91) *goals_j that I saw the players_i that t_i scored t_j
 (92) *player_i that I saw the card_j that the referee gave t_i t_j

Such relative clauses could otherwise be derived if nouns can type-raise over nominally rooted functions such as relativizers:



With modalized rules, the slashes decorated by the $\star$ modality on the relativizer ensure that not even the first step of the above derivation can go through:

- (94) $*[\text{that}]_{(\text{np} \setminus \star \text{np}) / \star (\text{s}_i \setminus \text{np})} [\text{scored}]_{(\text{s}_i \setminus \text{np}) / \text{np}}$

Note that the categories of relativizers are quite similar to those of coordinating words, which also utilize the non-associative mode.

By making similar assumptions about the modes specified by the categories of prepositional phrases, the following sort of overgeneration is also blocked because the verbs cannot backward compose into the unsaturated prepositional phrases:

(95) *The fan $[\text{in the field}]_{\text{np} \backslash \star \text{np}}$ $[\text{left}]_{\text{s}_i \backslash \text{np}}$ and $[\text{in the stadium}]_{\text{np} \backslash \star \text{np}}$ $[\text{stayed}]_{\text{s}_i \backslash \text{np}}$.

The non-associative slash is of course used in CTL approaches as well to restrict certain categories to the base logic. Also, the use of the non-associative slash is very much like the null adjunction label used in Tree-Adjoining Grammar (TAG) (Joshi, 1988; Abeillé and Rambow, 2000) to lexically block certain adjunctions and permit the rule of adjunction (the TAG correlate of composition) to apply universally.

Bibliography

- Abeillé, Anne and Rambow, Owen, 2000. “Tree Adjoining Grammar: an overview.” In *Tree Adjoining Grammar: formalisms, linguistic analysis, and processing*, Stanford: CSLI Publications. 1–68.
- Ades, Anthony and Steedman, Mark, 1982. “On the order of words.” *Linguistics & Philosophy* 7:639–642.
- Ajdukiewicz, Kazimierz, 1935. “Die syntaktische Konnexität.” In Storrs McCall (ed.), *Polish Logic 1920-1939*, Oxford University Press, 207-231. translated from *Studia Philosophica*, 1, 1-27.
- Baldrige, Jason, 2002. *Lexically Specified Derivational Control in Combinatory Categorical Grammar*. Ph.D. thesis, Division of Informations, University of Edinburgh, Edinburgh, Scotland.
- Baldrige, Jason and Kruijff, Geert-Jan, 2002. “Coupling CCG and Hybrid Logic Dependency Semantics.” In *Proceedings of 40th Annual Meeting of the Association for Computational Linguistics*. Philadelphia, Pennsylvania, 319–326.
- Baldrige, Jason and Kruijff, Geert-Jan, 2003. “Multi-Modal Combinatory Categorical Grammar.” In *Proceedings of 10th Annual Meeting of the European Association for Computational Linguistics*. Budapest, Hungary.
- Bar-Hillel, Yehoshua, 1953. “A Quasi-arithmetical Notation for Syntactic Description.” *Language* 29:47–58.
- Bar-Hillel, Yehoshua, Gaifman, C., and Shamir, E., 1964. “On categorial and phrase structure grammars.” In Yehoshua Bar-Hillel (ed.), *Language and information*, Reading MA: Addison-Wesley. 99–115. 1964.
- Biernier, Gann, 2001. *Alternative Phrases: Theoretical Analysis and Practical Applications*. Ph.D. thesis, Division of Informatics, University of Edinburgh.
- Bozsahin, Cem and Steedman, Mark, 2003. “Control, Grammatical Relations, and Argument Structure: Towards a Parameterized Theory of the Lexicon for CCG.” In *Proceedings of the Fifth Syntax and Semantics Conference in Paris (CSSP’03)*. Paris, France.
- Carpenter, Bob, 1995. “The Turing-Completeness of Multimodal Categorical Grammar.” ms, <http://www.illc.uva.nl/j50/contribs/carpenter/index.html>.
- Chomsky, Noam, 1957. *Syntactic Structures*. The Hague, the Netherlands: Mouton.
- Chomsky, Noam, 1965. *Aspects of the Theory of Syntax*. Cambridge MA: MIT Press.

- Copestake, Ann, Flickinger, Dan, Sag, Ivan, and Pollard, Carl, 1999. “Minimal Recursion Semantics: An Introduction.” unpublished ms, available from <http://www-csli.stanford.edu/~aac/newmrs.ps>.
- Copestake, Ann, Lascarides, Alex, and Flickinger, Dan, 2001. “An Algebra for Semantic Construction in Constraint-based Grammars.” In *Proceedings of the 39th Annual Meeting of the Association of Computational Linguistics*. Toulouse, France, 132–139.
- Curry, Haskell B. and Feys, Robert, 1958. *Combinatory Logic: Vol I*. North Holland, Amsterdam.
- Dowty, David, 1988. “Type-raising, Functional Composition, and Non-constituent Coordination.” In Richard T. Oehrle, Emmon Bach, and Deirdre Wheeler (eds.), *Categorial Grammars and Natural Language Structures*, Dordrecht: Reidel. 153–198. Proceedings of the Conference on Categorial Grammar, Tucson, AR, June 1985.
- Gazdar, Gerald, 1988. “Applicability of Indexed Grammars to Natural Languages.” In Uwe Reyle and Christian Rohrer (eds.), *Natural Language Parsing and Linguistic Theories*, Dordrecht: Reidel. 69–94.
- Gazdar, Gerald, Klein, Ewan, Pollum, Geoffrey K., and Sag, Ivan A., 1985. *Generalized Phrase-Structure Grammar*. Oxford, United Kingdom: Basil Blackwell.
- Geach, Peter, 1972. “A Program for Syntax.” In Donald Davidson and Gilbert Harman (eds.), *Semantics of Natural Language*, Dordrecht: Reidel. 483–497.
- Hoffman, Beryl, 1995. *Computational Analysis of the Syntax and Interpretation of “Free” Word-Order in Turkish*. Ph.d. thesis, ircs report 95-17, University of Pennsylvania.
- Huybregts, Riny, 1984. “The Weak Inadequacy of Context-free Phrase-structure Grammars.” In Ger de Haan, Mieke Trommelen, and Wim Zonneveld (eds.), *Van Periferie naar Kern*, Foris Dordrecht.
- Joshi, Aravind, 1988. “Tree Adjoining Grammars.” In David Dowty, Lauri Karttunen, and Arnold Zwicky (eds.), *Natural Language Parsing*, Cambridge: Cambridge University Press. 206–250.
- Joshi, Aravind K., Kulick, Seth, and Kurtonina, Natasha, 1999. “Cross-Serial Dependencies and Partial Proof Trees.” In Geert-Jan M. Kruijff and Richard T. Oehrle (eds.), *Proceedings of Formal Grammar Conference 1999*. Utrecht, The Netherlands.
- Keenan, Edward, 1978. “The Syntax of Subject-Final Languages.” In Winfred Lehmann (ed.), *Syntactic Typology: Studies in the Phenomenology of Language*, The Harvester Press. 267–328.
- Kruijff, Geert-Jan M., 2001. *A Categorial-Modal Logical Architecture of Informativity: Dependency Grammar Logic & Information Structure*. Ph.D. thesis, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic.
- Kruijff, Geert-Jan M., 2003. “Binding across boundaries.” In Geert-Jan M. Kruijff and Richard T. Oehrle (eds.), *Resource Sensitivity, Binding, and Anaphora*, Dordrecht, Boston, London: Kluwer Academic Publishers.
- Kruijff, Geert-Jan M. and Baldridge, Jason, 2004a. “Generalized Dimensionality in Combinatory Categorial Grammar.” In *Proceedings of COLING 2004*. Geneva, Switzerland.

- Kruijff, Geert-Jan M. and Baldridge, Jason, 2004b. “Generalizin Dimensionality in Combinatory Categorical Grammar.” In *Proceedings COLING’04*. Geneva, Switzerland.
- Lambek, Joachim, 1958. “The mathematics of sentence structure.” *American Mathematical Monthly* 65:154–169.
- Milward, David, 1994. “Dynamic Dependency Grammar.” *Linguistics & Philosophy* 17(6):561–605.
- Moortgat, Michael, 1988. *Categorical Investigations: Logical and Linguistic Aspects of the Lambek Calculus*. Dordrecht, The Netherlands: Foris.
- Moortgat, Michael, 1997. “Categorical Type Logics.” In Johan van Benthem and Alice ter Meulen (eds.), *Handbook of Logic and Language*, Amsterdam New York etc.: Elsevier Science B.V.
- Moot, Richard, 2002. *Proof Nets for Linguistic Analysis*. Ph.D. thesis, University of Utrecht.
- Morrill, Glyn V., 1994. *Type Logical Grammar: Categorical Logic of Signs*. Dordrecht, Boston, London: Kluwer Academic Publishers.
- Oehrle, Richard T., 1994. “Term-Labelled Categorical Type Systems.” *Linguistics & Philosophy* 17(6):633–678.
- Oehrle, Richard T., to appear. “Multi-Modal Type-Logical Grammar.” to appear in Borsley and Börjars *Non-transformational Syntax*, available at <http://www.let.uu.nl/essli/Courses/moortgat/moortgat-oehrle3.ps>.
- Panevová, Jarmila, 1974. “On Verbal Frames in Functional Generative Description I.” *Prague Bulletin of Mathematical Linguistics* 22:3–40.
- Pentus, Mati, 1997. “Product-Free Lambek Calculus and Context-Free Grammars.” *The Journal of Symbolic Logic* 62(2):648–660.
- Pollard, Carl, 1984. *Generalized Phrase Structure Grammars, Head Grammars, and Natural Languages*. Ph.D. thesis, Stanford University, Stanford, CA.
- Pollard, Carl and Sag, Ivan, 1994. *Head Driven Phrase Structure Grammar*. CSLI/Chicago University Press, Chicago.
- Pollard, Carl and Sag, Ivan A., 1993. *Head-Driven Phrase Structure Grammar*. Chicago IL: University of Chicago Press.
- Pullum, Geoffrey K. and Gazdar, Gerald, 1982. “Natural languages and context-free languages.” *Linguistics and Philosophy* 4:471–504.
- Rambow, Owen, 1994. *Formal and Computational Aspects of Natural Language Syntax*. Ph.D. thesis, University of Pennsylvania, Philadelphia PA.
- Ross, John Robert, 1967. *Constraints on Variables in Syntax*. Ph.D. thesis, MIT. Published as “Infinite Syntax!”, Ablex, Norton, NJ. 1986.
- Shieber, Stuart, 1985. “Evidence against the context-freeness of natural language.” *Linguistics and Philosophy* 8:333–343.

- Steedman, Mark, 1985. “Dependency and Coordination in the Grammar of Dutch and English.” *Language* 61:523–568.
- Steedman, Mark, 1988. “Combinators and Grammars.” In Richard T. Oehrle, Emmon Bach, and Deirdre Wheeler (eds.), *Categorial Grammars and Natural Language Structures*, Dordrecht: Reidel. 417–442. Proceedings of the Conference on Categorial Grammar, Tucson, AR, June 1985.
- Steedman, Mark, 1996. *Surface Structure and Interpretation*. Cambridge Mass.: MIT Press. Linguistic Inquiry Monograph, 30.
- Steedman, Mark, 2000a. “Information Structure and the Syntax-Phonology Interface.” *Linguistic Inquiry* 31(4):649–689.
- Steedman, Mark, 2000b. *The Syntactic Process*. Cambridge Massachusetts: The MIT Press.
- Vijayashanker, K. and Weir, David, 1994. “The Equivalence of Four Extensions of Context-free Grammar.” *Mathematical Systems Theory* 27:511–546.
- Weir, David, 1988. *Characterising Mildly Context-sensitive Grammar Formalisms*. Ph.D. thesis, University of Pennsylvania. Tech. Report CIS-88-74.
- White, Michael, 2004. “Efficient Realizations of Coordinate Structures in Combinatory Categorial Grammar.” *Research on Language and Computation* to appear.
- White, Michael and Baldridge, Jason, 2003. “Adapting Chart Realization to CCG.” In *Proceedings of the 9th European Workshop on Natural Language Generation*.
- Wood, Mary McGee, 1993. *Categorial Grammar*. Routledge.
- Zeevat, Henk, 1988. “Combining Categorial Grammar and Unification.” In Uwe Reyle and Christian Rohrer (eds.), *Natural Language Parsing and Linguistic Theories*, Dordrecht: Reidel. 202–229.
- Zeevat, Henk, Klein, Ewan, and Calder, Jo, 1987. “An Introduction to Unification Categorial Grammar.” In N. Haddock et al. (ed.), *Edinburgh Working Papers in Cognitive Science, 1: Categorial Grammar, Unification Grammar, and Parsing*, University of Edinburgh. 195–222.

Multi-Modal Combinatory Categorical Grammar

Jason Baldridge

ICCS
School of Informatics
2 Buccleuch Place
University of Edinburgh
Edinburgh EH8 9LW, UK
jmb@cogsci.ed.ac.uk

Geert-Jan M. Kruijff

Universität des Saarlandes
Computational Linguistics
Lehrstuhl Uszkoreit
Building 17, Postfach 15 11 50
66041 Saarbrücken, Germany
gj@coli.uni-sb.de

Abstract

The paper shows how Combinatory Categorical Grammar (CCG) can be adapted to take advantage of the extra resource-sensitivity provided by the Categorical Type Logic framework. The resulting reformulation, Multi-Modal CCG, supports lexically specified control over the applicability of combinatory rules, permitting a universal rule component and shedding the need for language-specific restrictions on rules. We discuss some of the linguistic motivation for these changes, define the Multi-Modal CCG system and demonstrate how it works on some basic examples. We furthermore outline some possible extensions and address computational aspects of Multi-Modal CCG.

1 Introduction

The family of categorial grammar frameworks contains a diverse set of formalisms committed to many of the same core principles, such as compositionality, a strong degree of lexicalism, and semantic transparency. Nonetheless, each formalism has its own characteristics with respect to the category constructors and rules of combination it employs and the differing kinds of linguistic explanations which arise from its unique assumptions.

A formalism's category constructors and combination rules together define its *resource-sensitivity*: given the resources we have (i.e. ex-

pressions and their associated categories) we can, or can *not*, apply particular rules to form more complex expressions. It is particularly this idea of resource-sensitivity that is realized differently across different formalisms.

In this paper, we explain how two prominent categorial grammar frameworks, namely Combinatory Categorical Grammar (CCG, Steedman (2000)) and Categorical Type Logic (CTL, Morrill (1994); Moortgat (1997); Oehrle (to appear)), can be integrated to create a hybrid categorial framework, Multi-Modal Combinatory Categorical Grammar (Baldridge, 2002), that inherits the attractive properties of both. Specifically, Multi-Modal CCG retains the favorable computational aspects of CCG whilst incorporating the approach to resource-sensitivity taken in CTL. At the theoretical level, we discuss how this form of resource-sensitivity enables us to replace the rather *ad hoc* rule-specific constraints found in CCG with a clean resource-management regime, leading to more parsimonious linguistic analyses. We also discuss some of the benefits of modalized CCG for computational processing.

Although Multi-Modal CCG has the same set of rules as standard CCG, its improved resource-sensitivity enables it to have a *universal* rule component. It places *all* cross-linguistic variation in the lexicon, leading to a typological perspective on grammar that not only describes, but can also make predictions about, syntactic structure: Multi-Modal CCG provides a new view on how a typological perspective can be incorporated in a lexicalized, non-transformational setting.

Overview. We introduce CCG in §2, and then motivate the need for a revised notion of resource-sensitivity in CCG in §3. In §4, we introduce Multi-Modal CCG and present possible extensions in §5. Finally, we discuss the computational advantages of Multi-Modal CCG in §6 and then close with conclusions.

2 Combinatory Categorical Grammar

CCG’s grammatical objects are categories which may be either atomic elements or (curried) functions which specify the canonical linear direction in which they seek their arguments. Lexical entries are specified by pairing words with categories via the $\vdash$ operator. Some simplified example entries are given below:¹

- (1) (a) $Ed \vdash np$, (b) $Ann \vdash np$, (c) $saw \vdash (s \backslash np) / np$

The basic rules for combining categories are forward ($>$) and backward ($<$) application:

$$\begin{aligned} (>) \quad X/Y \quad Y &\Rightarrow X \\ (<) \quad Y \quad X \backslash Y &\Rightarrow X \end{aligned}$$

With these rules and the categories given in (1), we can provide the derivation (2) for a simple sentence such as *Ed saw Ann*. Because of CCG’s semantic transparency, a logical form for the sentence can be built compositionally and in parallel to the syntactic derivation. We will, however, suppress semantics in this paper.

$$(2) \quad \frac{\frac{\frac{Ed}{np} \quad \frac{saw}{(s \backslash np) / np} \quad \frac{Ann}{np}}{s \backslash np} >}{s} <$$

CCG also utilizes further rules based on the composition (**B**), type-raising (**T**), and substitution (**S**) combinators of combinatory logic, each of which gives rise to several directionally-distinct rules. For example, there are forward and backward rules for both composition and type-raising:

$$\begin{aligned} (>\mathbf{B}) \quad X/Y \quad Y/Z &\Rightarrow X/Z \\ (<\mathbf{B}) \quad Y \backslash Z \quad X \backslash Y &\Rightarrow X \backslash Z \\ (>\mathbf{T}) \quad X &\Rightarrow Y / (Y \backslash X) \\ (<\mathbf{T}) \quad X &\Rightarrow Y \backslash (Y / X) \end{aligned}$$

¹We use Steedman’s argument rightmost notation for categories. It is common in some traditions to use an alternative notation in which arguments sought to the left are placed on the left of the functor, e.g. $saw \vdash (np \backslash s) / np$.

These additional rules induce *associativity* in derivations, which is crucial for building the non-standard constituents for which categorial grammars are well-known. For example, we can now provide the following alternative derivation to (2), in which the verb combines with its subject before applying to its object:

$$(3) \quad \frac{\frac{\frac{Ed}{np} \quad \frac{saw}{(s \backslash np) / np}}{s / (s \backslash np)} > \mathbf{T} \quad \frac{Ann}{np}}{s / np} > \mathbf{B} \quad \frac{}{s} >$$

Note that the combinatory rules have an invariant type-driven semantics, so this derivation produces precisely the same logical form as (2).

Arguably, one of CCG’s greatest successes has been in demonstrating that the behavior of unbounded dependencies in syntax can be explained in a purely type-driven fashion in which the same lexical types that are responsible for bounded dependencies interact with CCG’s combinatory rules to generalize to unbounded phenomena. For example, the same category (1c) given for *saw* is implicated in the derivation of not only *Ed saw Ann*, but also in the relative clause object extraction *that I think that Ed saw*.

$$(4) \quad \frac{\frac{that}{(n \backslash n) / (s / np)} \quad \frac{\frac{\frac{I}{np} \quad \frac{think}{(s \backslash np) / s}}{s / (s \backslash np)} > \mathbf{T} \quad \frac{that}{s / s}}{s / s} > \mathbf{B} \quad \frac{\frac{\frac{Ed}{np} \quad \frac{saw}{(s \backslash np) / np}}{s / (s \backslash np)} > \mathbf{T} \quad \frac{}{s / np} > \mathbf{B}}{s / np} > \mathbf{B} \quad \frac{}{n \backslash n} >$$

Other frameworks typically rely on empty elements or extra lexical assignments to handle such relative clauses. Such strategies are often specific to the construction in question, whereas CCG supports a uniform treatment of phenomena as diverse as relativization, coordination, topicalization, intonational phrasing, and incremental processing (Steedman, 2000).

The rules introduced above are all *harmonic*, or *order preserving*. Thus, they are unhelpful when we consider sentences in which certain elements have “moved” with respect to their canonical position, such as in English heavy-NP shift, where an adverb comes between a verb and its object:

- (5) Ed saw briefly his old friend from Skye.

To handle such sentences without relying on categorial ambiguity, rules are needed to combine the adverb with the verb before the latter consumes its object argument. CCG makes available two permutation-inducing composition rules that provide exactly the required functionality:

$$\begin{aligned} (>\mathbf{B}_\times) \quad X/Y \quad Y/Z &\Rightarrow X/Z \\ (<\mathbf{B}_\times) \quad Y/Z \quad X/Y &\Rightarrow X/Z \end{aligned}$$

As can be seen from the form of these rules, the primary functor composes with the secondary one in a manner that puts it between the secondary functor and its argument Z. This is precisely what is needed for (5): $<\mathbf{B}_\times$ permits a derivation using the same categories necessary for capturing the non-shifted version. The non-order-preserving nature of these rules is what boosts CCG's generative strength beyond context-free.

3 Rule restrictions

CCG uses a limited number of rules which work in conjunction with complex lexical categories to provide grammatical analyses, leaving the bulk of cross-linguistic variation in the lexicon. Even so, any given rule can be banned or restricted in any given grammar, so variation can thus arise in the rule component as well. For example, Steedman (2000) argues that the permutation-inducing rule $>\mathbf{B}_\times$ must be banned from the grammar of English to avoid derivations such as (6), where $>\mathbf{B}_\times$ would allow the subject of the embedded verb *saw* to scramble into the higher clause.

$$\begin{array}{ccccccc} (6) & *I & Ed & think & that & saw & Ann \\ & \frac{}{np_1} & \frac{}{np_2} & \frac{}{(s \setminus np_1)/s} & \frac{}{s/s} & \frac{}{s \setminus np_2} & \\ & & & & * * * \rightarrow & \mathbf{B}_\times & * * * \\ & & & & & s \setminus np_2 & \\ & & & & & * * * \rightarrow & \mathbf{B}_\times & * * * \\ & & & & & (s \setminus np_1) \setminus np_2 & \\ & & & & & \frac{}{s \setminus np_1} & \\ & & & & & \frac{}{s} & \end{array}$$

By banning $>\mathbf{B}_\times$ from the grammar of English, Steedman not only ensures that such scrambled orders do not arise, but also correctly *predicts* that embedded subjects cannot be extracted:

$$(7) \quad *man_i \text{ that I think that } t_i \text{ saw Ann}$$

The extraction of an object is performed with only the harmonic rules, as shown in (4). Providing a derivation for (7), however, relies on $>\mathbf{B}_\times$

and thus fails under the assumption that $>\mathbf{B}_\times$ is banned, as shown in (8).

$$(8) \quad \frac{*man}{n} \quad \frac{that}{(n \setminus n)/(s \setminus np)} \quad \frac{I \text{ think} \quad that}{\frac{s/s \quad s/s}{s/s} \rightarrow \mathbf{B}} \quad \frac{saw \text{ Ann}}{s \setminus np}$$

The rules of a given grammar can also be restricted to apply only to particular types. This is necessary in English for $<\mathbf{B}_\times$, which is needed for phenomena such as heavy-NP shift, as in (5), but which also can lead to ungrammatical scrambled orders inside noun phrases. For example, consider (9), in which the category of a post-nominal prepositional phrase composes into that of a pre-nominal adjective.

$$\begin{array}{ccccccc} (9) & *a & nice & in & Edinburgh & pub \\ & \frac{}{np/n} & \frac{}{n/n} & \frac{}{(n \setminus n)/np} & \frac{}{np} & \frac{}{n} & \\ & & & \frac{}{n \setminus n} & & & \\ & & & \frac{}{n/n} & & & \\ & & & \frac{}{np} & & & \end{array}$$

To block such derivations, Steedman (2000) restricts the rule $<\mathbf{B}_\times$ for English as follows:²

$$(<\mathbf{B}_\times) \quad Y/Z \quad X/Y \Rightarrow X/Z$$

where $X = Y = s\$$

Furthermore, multiple versions of a given combinatory rule, each having its own restrictions, can be employed. For example, Steedman's analysis of Dutch utilizes two restricted versions of *each* of the rules $>\mathbf{B}$, $>\mathbf{B}_\times$, and $<\mathbf{B}_\times$.

The use of rule restrictions is unappealing for a number of reasons. First and foremost, the restrictions themselves are often *ad hoc* and can lead to the abuse of grammatical features. For example, Steedman's restricted version of $>\mathbf{B}_\times$ for Dutch can only apply when the secondary functor is a category that will ultimately produce a matrix clause (i.e., $s_{-SUB}\$$), whereas we wish to avoid using such features to enforce combinatory *control*. That is, the formal system should not have to refer to grammar specific properties. Another *ad hoc* use of features with rule restrictions is that some analyses utilize features on categories that have the sole function of controlling the applicability of a single rule, such as $[\pm\text{FORWARD COMPOSITION}]$

²The $\$$ notation used in the restriction schematizes over all functions into the target category s .

(Treichsel, 2000). A further unappealing aspect of rule restrictions is that they are at times not simple declarations of categories with particular features, but can also involve modified forms of the rule schemata, such as one of Steedman’s versions of $>\mathbf{B}$ for Dutch:

$$(>\mathbf{B}) \quad X/Y \quad Y/(Y \backslash Z) \Rightarrow X/(Y \backslash Z) \\ \text{where } Y = s\$$$

None of these ways of restricting rules is cross-linguistically motivated — they are employed to obtain control over very specific aspects of a particular analysis of a particular language. Also, they can be arbitrarily sensitive to particular categories, such that in the most extreme case, we could imagine writing a combinatory rule for every possible combination we want our grammar to handle. This would amount to using the categorial grammar system as a kind of specialized phrase structure grammar — at which point we lose the appeal of the purely type-driven nature of categorial grammar.

These problems can be solved by incorporating the more fine-grained slash types of the Categorial Type Logic (CTL) tradition into CCG to produce a system with just as much control, but which has a rule component that is universal to all grammars. Even though CTL already has a clean resource-management regime that can deal with the problems mentioned in this section, we choose to adapt CCG because of its far more attractive computational properties. No efficient algorithms exist that solve the NP-hard search problem in parsing CTL grammars, whereas realistic CCG grammars can be parsed with much greater efficiency. As we show in the next section, CCG’s resource-sensitivity can be straightforwardly enhanced, and §6 shows that we do not give up CCG’s computational attractiveness in doing so.

4 Improved resource-management

The main reason why CCG has needed rule restrictions is that it has an impoverished notion of the categorial slash. CCG uses a single pair of slashes $\{\backslash, /\}$, which allows it only to distinguish between arguments found to the left or the right, respectively. The rules make reference to these slashes, which in the case of the composition rules

gives rise to a spectrum of four distinct rules.³ There is, however, no way to discriminate between the primary functors $X \backslash Y$ of the backward rules:

$$\begin{aligned} (<) \quad Y \quad X \backslash Y &\Rightarrow X \\ (<\mathbf{B}) \quad Y \backslash Z \quad X \backslash Y &\Rightarrow X \backslash Z \\ (<\mathbf{B}_\times) \quad Y / Z \quad X \backslash Y &\Rightarrow X / Z \end{aligned}$$

This fact means that there is no *lexical* way of specifying that a particular functor can only be used with a particular one of these rules. For example, if we give the category (10) to the coordinator, it can act as the primary functor in the $<\mathbf{B}$ rule (after consuming its first argument), and thereby produce derivations for ungrammatical strings as shown in (11).

$$(10) \quad \text{and} \vdash (s \backslash s) / s$$

$$(11) \quad *man \quad \frac{that}{(n \backslash n) / (s \backslash np)} \quad \frac{sleeps}{s \backslash np} \quad \frac{and}{(s \backslash s) / s} \quad \frac{he}{np} \quad \frac{talks}{s \backslash np}$$

$\xrightarrow{s}$
 $\xrightarrow{s \backslash s}$
 $\xrightarrow{s \backslash np}$
 $\xrightarrow{n \backslash n}$

To avoid such derivations, Steedman (2000) employs a ternary rule of coordination that ensures that coordinating particles cannot behave in this manner. However, this strategy threatens to increase the size of the rule base as the semantics and usage of different coordinators are accommodated. In the context of providing a universal rule base, it would thus be preferable to be able to deal with different kinds of coordination in a lexical manner.

The Categorial Type Logic tradition (CTL, Morrill (1994); Moortgat (1997); Oehrle (to appear)) provides a very clean solution to the lack of discrimination noted above. The fundamental idea is that not all slashes are the same; that is, we should be able to distinguish any number of slash types, each of which exhibits its own particular behavior. Rather than having just $\{\backslash, /\}$ like in CCG, CTL distinguishes multiple modes for combining categories and each mode i is associated with its own leftward and rightward slashes $\{\backslash_i, /_i\}$.⁴ As with CCG, there are basic rules for string-adjacent, non-associative combination which allow a functor category to consume its arguments respecting the directionality of the slash, but unlike CCG,

³The Principles of Consistency and Inheritance filter out other possible rules based on the composition combinator.

⁴We ignore the product $\bullet_i$ and unary modes here.

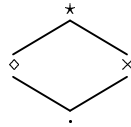
these rules build logical structures that record the modes through which constituents have combined. These structures can then be subsequently reconfigured by more powerful *structural rules* that allow specific ways of rebracketing (associativity), reordering (permutativity), or both.

Unlike CCG's rules, the structural rules of CTL cannot be restricted by imposing extra-logical constraints. Instead, they are sensitive to the modes by which sub-structures have been built and therefore cannot apply in all contexts. The typed slashes of CTL project their modes into structures and thereby limit or enable the application of structural rules to their local context. Thus, contrary to CCG, there are no rule-constraints acting as absolute and global choices; instead, parametric options regarding the way in which expressions can be combined are selectively invoked via the appropriate category assignments in the lexicon.

Despite the overall architectures of CCG and CTL being quite different, the use of modalized slashes to control combinatory behavior can be incorporated in CCG to enable cleaner resource-management and render rule restrictions unnecessary. The basic intuition is that each of the different combinatory rules will be sensitive to particular modes and thus apply only to input categories which have the appropriate slash types. To start, we assume four modes governing different levels of associativity and permutativity, as follows:

	non-permutative	permutative
non-associative	*	×
associative	◇	·

Furthermore, we organize these modes into the type hierarchy shown on the right. The most limited mode * is thus the top of the hierarchy, whereas the most permissive one · inherits the properties of all the others.



With these modes, we can make use of their corresponding slash types, such as $/_*$ and $\backslash_\times$, in the categories of the combinatory rules. For example, we can now state the application rules as follows:

$$\begin{aligned} (>) \quad X/_*Y \ Y \Rightarrow X \\ (<) \quad Y \ X\backslash_\times Y \Rightarrow X \end{aligned}$$

Because the mode * is the root of the hierarchy, these rules are thus available to categories with any

slash type. However, now consider the modalized composition rules:

$$\begin{aligned} (>\mathbf{B}) \quad X/_\diamond Y \ Y/_\diamond Z &\Rightarrow X/_\diamond Z \\ (<\mathbf{B}) \quad Y\backslash_\diamond Z \ X\backslash_\diamond Y &\Rightarrow X\backslash_\diamond Z \\ (>\mathbf{B}_\times) \quad X/_\times Y \ Y\backslash_\times Z &\Rightarrow X\backslash_\times Z \\ (<\mathbf{B}_\times) \quad Y/_\times Z \ X\backslash_\times Y &\Rightarrow X/_\times Z \end{aligned}$$

The first ramification of these formulations is that categories defined with the slashes $\backslash_\times$ and $/_*$ will not be able to serve as input to these rules since the mode * is not a subtype of either $\diamond$ or $\times$. This is precisely what is needed to provide lexical categories for coordinating particles without enabling illicit derivations such as (11). We now can simply assign the category (12) to *and*, with the result that the category $s\backslash_\times s$ of *and he talks* cannot compose with that of *sleeps*, as shown in (13).

$$(12) \quad \text{and} \vdash (s\backslash_\times s)/_*$$

$$(13) \quad \begin{array}{c} \text{sleeps} \quad \text{and} \quad \text{he} \quad \text{talks} \\ s\backslash_{np} \quad \frac{}{(s\backslash_\times s)/_*} \quad \frac{}{np} \quad \frac{}{s\backslash_{np}} \\ \hline \frac{}{s\backslash_\times s} \end{array}$$

Note that the fact that the category of intransitive verbs has the $\backslash_\cdot$ slash allows it to serve as the primary functor in all the backward rules, since the mode $\cdot$ is a subtype of all the other modes.

A second effect of the modalized composition rules is that the modes $\diamond$ and $\times$ can now be used to discriminate between the harmonic and the crossed rules, giving Multi-Modal CCG a lexical handle on permutation. This means that it is no longer necessary to ban $>\mathbf{B}_\times$ in English since we can instead assign the complementizer the category (14). This category can only compose associatively, thereby allowing extraction of embedded objects while blocking that of subjects.

$$(14) \quad \text{that} \vdash s/_\diamond s$$

Similarly, we get lexical control over $<\mathbf{B}_\times$ and the permutation of elements within noun phrases (9). Whereas standard CCG requires a rule restriction to avoid such derivations, the applicability of the $<\mathbf{B}_\times$ rule can be blocked by the use of the modes * and $\diamond$ on the categories of pre-nominal and post-nominal modifiers:

$$(15) \quad \begin{array}{c} \text{*a} \quad \text{nice} \quad \text{in} \quad \text{Edinburgh} \quad \text{pub} \\ np/_\diamond n \quad n/_\diamond n \quad \frac{}{(n\backslash_\times n)/_{np}} \quad \frac{}{np} \quad \frac{}{n} \\ \hline \frac{}{n\backslash_\times n} \end{array}$$

Note that the categories $n/\diamond n$ and $n\backslash_{\star} n$ cannot combine through either $>\mathbf{B}_{\times}$ or $<\mathbf{B}_{\times}$.

Although the mode $\times$ (non-associative & permutative) does not appear necessary for English, it is needed in the grammar of Dutch. The CCG account given by Steedman (2000) for crossing dependencies in Dutch subordinate clauses relies crucially on $>\mathbf{B}_{\times}$. However, Steedman must restrict the harmonic rule $>\mathbf{B}$ in order to block some ungrammatical orders. With the multi-modal setting, Baldridge (2002) shows that such restrictions are unnecessary because the same slash $/_{\times}$ that allows two subordinate verbs to combine through $>\mathbf{B}_{\times}$ also correctly blocks $>\mathbf{B}$ from applying. The encoding of Steedman’s analysis into Multi-Modal CCG thus *predicts* that certain word orders are ungrammatical, whereas this must be stipulated in standard CCG. The encoding also has no need of the restrictions Steedman places on several other rules — instead it uses exactly the same rules that are used for English.

The input to the type-raising rules does not make reference to any slashes, but there are two slashes in the output category. Type-raising is actually provable in the most basic CTL system, and any mode can decorate the output slashes; however, it must be the same mode on both slashes. We use a variable mode i for the modalized versions of the type-raising rules:

$$(>\mathbf{T}) \quad X \Rightarrow Y/i(Y\backslash_i X)$$

$$(<\mathbf{T}) \quad X \Rightarrow Y\backslash_i(Y/i X)$$

There is no modal control over the applicability of type-raising, but the combinatory potential of the output category will be subject to constraints made on the category it applies to.

The core aspect of the multi-modal extension of CCG is thus the simple, but powerful ability to stratify the rules so that lexical items can be declared suitable or unsuitable as inputs to different rules. We have outlined here just a few of the motivating examples that demonstrate the utility of this ability and the manner in which it allows us to cast aside rule restrictions for controlling the grammar. This is a principled move which replaces arbitrary, globally declared restrictions with a small set of cross-linguistically motivated distinctions encoded in terms of the multiple slash types utilized in CTL. Baldridge (2002) sup-

ports this formulation with multi-modal analyses for a wide range of phenomena in English, Dutch, Turkish, Tagalog, and Toba Batak.

5 Extensions

Modes lead not only to a very clean formalization of resource-sensitivity, but also give rise to an interesting linguistic perspective. As e.g. Hople (1995) notes, each pair of decorated slashes $\{\backslash_i, /_i\}$ can correspond to a particular grammatical phenomenon. Rules then model how different phenomena can be combined to form larger grammatical structures.

For example, one way we can use modal decoration is to model *dependency*, the asymmetry between heads and dependents, which has been used in CTL to give accounts of coordination and word order, e.g. (Moortgat and Morrill, 1991; Kruijff, 2001). Observe that we really need modes here: function-argument structure does not correspond to dependency. For example, a sentential adjunct can have the category $s\backslash s$ where the adjunct acts as the function, taking a verb (s) as its argument. However, the adjunct itself is the dependent of the verbal head, and not vice versa.

Adopting notation common in dependency grammar, we use as our basic modes a pair of arrows $\leftarrow, \rightarrow$ that point from head (h) to dependent (d): ($d \leftarrow h$) or ($h \rightarrow d$). Additionally, we use $\sqcap$ to handle headless constructions (e.g. coordination), and $\leftrightarrow$ as analogous to $\cdot$. The issue that now arises is how to integrate these modes with $\{\star, \diamond, \times, \cdot\}$: the latter modes control adjacency, and we would like to keep adjacency and dependency as separate (orthogonal) dimensions.

Therefore, we propose to keep these dimensions as separate decorations on slashes as well, as follows: given dependency mode d , and adjacency mode a , we can form slashes $\backslash_a^d$ versus $/_a^d$. Combinatory rules can operate on either dimension or on both, e.g. consider $(<\mathbf{B}_{\times})$ with dependency:

$$(<\mathbf{B}_{\times}) \quad Y /_{\times}^{\rightarrow} Z \quad X \backslash_{\times}^{\rightarrow} Y \Rightarrow X /_{\times}^{\rightarrow} Z$$

Another modal dimension is one which distinguishes a slash as being suitable or unsuitable as the primary functor in a combinatory rule. This can be used to implement the notion of antecedent government discussed by Steedman (2000) for allowing some arguments to be extractable but not

movable. Encoding this modally avoids the need to require all lexical noun phrases to be declared as not antecedent governed and maintains the separation we desire between features that control combination and features for agreement, tense, etc.

Though we have not made use of CTL’s unary modes in the presentation of Multi-Modal CCG given here, they could prove useful in limiting the applicability of type-raising rules. Following CTL, we introduce $\Diamond_i$ and its residuated counterpart $\Box_i^\downarrow$ such that we have, for an arbitrary category A , $\Box_i^\downarrow \Diamond_i A \Rightarrow A$ and $A \Rightarrow \Diamond_i \Box_i^\downarrow A$. Having unary modes would remove the need under some analyses to make type-raising of all argument categories obligatory. Thus, $>\mathbf{T}$ would appear as follows:

$$(>\mathbf{T}) \quad \Box_{tr}^\downarrow X \Rightarrow Y/_i(Y \backslash_i X)$$

As such, $>\mathbf{T}$ can only apply to $\Box_{tr}^\downarrow$ ’d categories: the categories for determiners and noun phrases would then be $(\Box_{tr}^\downarrow \Diamond_{tr} np)/_o n$ and $\Box_{tr}^\downarrow \Diamond_{tr} np$, respectively. Because of residuation, we can drop $\Box_{tr}^\downarrow \Diamond_{tr}$ if we do not need to type-raise.

Finally, the multi-modal setting also enables us to introduce more powerful combinators into the grammar, possibly taking it beyond mild context-sensitivity. Precisely because of the tight resource-sensitive control over the applicability of combinatory rules, we can avoid a collapse to a situation where “anything goes”.

6 Computational aspects and implementation

CCG has mildly context-sensitive generative power and CCG grammars can be parsed in worst-case polynomial time by using a structure sharing algorithm (Vijay-Shanker and Weir, 1990). This algorithm does incur some computational overhead, and Komagata (1999) shows that the performance of a worst-case exponential CKY parser with a semantic equivalency check is cubic in the average case (tested on Japanese sentences averaging 20 words in length). This a major attraction of CCG over CTL, for which no reasonably efficient parsers have been constructed that can handle realistic grammars.

Multi-Modal CCG inherits CCG’s attractive computational properties and adds the possibility

to take advantage of some new strategies. Most importantly, it remains mildly context-sensitive. We have not added any new rules of combination; instead, we employ the standardly assumed rules and make them sensitive to particular kinds of slashes. A Multi-Modal CCG grammar can be simulated with standard CCG by adding a mode feature to the ultimate targets of (possibly complex) categories and then formulating the rules with restrictions that reference those features. For example, the multi-modal category (16) would be converted into (17).

$$(16) \quad (s \backslash np) /_x (s \backslash np)$$

$$(17) \quad (s \backslash np_{mode=.}) / (s_{mode=\times} \backslash np_{mode=.})$$

The rule $>\mathbf{B}_\times$ would then be formulated as follows, where a and b are variables standing for any atomic category.

$$(<\mathbf{B}_\times) \quad Y/Z \quad X \backslash Y \Rightarrow X/Z$$

$$\text{where } Y = a_{mode=\times} \$1 \text{ and } Z = b_{mode=\times} \$2$$

Using restrictions in this manner in standard CCG would technically provide the same advantages as Multi-Modal CCG, but is a less clean formulation. Furthermore, by using modally decorated slashes to enforce these effects, we have a clear separation between specifications that control category combining operations and more standard features which encode distinctions such as number, gender, verbal voice, tense, etc.

It is straightforward to adapt an existing CCG parser to deal with modally decorated slashes as they are a simple, non-recursive feature added to the slash specification. Though there are no reductions in overall parsing complexity, we nonetheless obtain several advantages by using Multi-Modal CCG. One is that the invariant rule component makes it possible to implement the combinatory rules as hard-coded procedures that are the same for all grammars (Baldrige, 2002). With standard CCG rules, it may be necessary to unify the input categories against several restrictions in order to verify that a rule can even be applied, whereas a multi-modal rule needs only to inspect the simple slash data structures of the input categories to do the same. Also, a standard CCG rule may need to check that the X portion of a combinatory rule satisfies some restriction (e.g., the restricted $<\mathbf{B}_\times$ rule for English). A multi-

modal rule can instead ignore the X and just ensure that the Y portion of both inputs unify. Finally, CCG grammars typically need multiple versions of the same rule, whereas only one version of each is necessary in Multi-Modal CCG. The extra resource-sensitivity of multi-modal rules thus allows us to pack the functionality of several standard CCG rules into a single procedure, again cutting down on the number of unifications which are necessary in applying a grammar's rules.

The fact that slashes are more refined could make it seem that writing grammars would become more difficult since we must make choices about the modes. Our experience, however, is that the task becomes easier since different constructions can be dealt with on their own terms without worrying about complex interactions with rule restrictions that are already in place for other aspects of the grammar. We can further reduce the "burden" of specifying modes by defining the grammar as a lexical inheritance hierarchy along the lines of Villavicencio (2002), thereby exploiting redundancy between different classes of lexical items.

7 Conclusions

We have presented an adaptation of CCG in which the applicability of combinatory rules is controlled directly through lexically assigned categories. Using modally decorated slashes as in CTL, we obtain a fine-grained form of derivational control in a purely lexicalized fashion. Consequently, we can assume all combinatory rule schemas to be active *universally*. Grammars need to differ in the types of lexical categories only, i.e. what types of modalized slashes they use, and thus what rules they make applicable. We motivated the basic theory on data from English and Dutch, and discussed several possible extensions. Further linguistic evidence and more in-depth Multi-Modal CCG analyses for English, Dutch, Turkish, Tagalog, and Toba Batak are provided in Baldridge (2002).

In this paper, we have omitted semantics. See Steedman (2000) or Baldridge and Kruijff (2002) for different ways of constructing logical forms compositionally with CCG.

Acknowledgements. We would like to thank Cem Bozsahin, Mark McConville, Mark Steed-

man and the EACL reviewers for comments. Jason Baldridge's work is supported by Edinburgh-Stanford Link R36763, ROSIE project. Geert-Jan Kruijff's work is supported by the DFG SFB 378 *Resource-Sensitive Cognitive Processes*, Project NEGRA EM6.

References

- Jason Baldridge and Geert-Jan Kruijff. 2002. Coupling CCG and hybrid logic dependency semantics. In *Proceedings of 40th Annual Meeting of the Association for Computational Linguistics*, pages 319–326, Philadelphia, Pennsylvania.
- Jason Baldridge. 2002. *Lexically Specified Derivational Control in Combinatorial Categorical Grammar*. Ph.D. thesis, University of Edinburgh.
- Mark Hepple. 1995. Mixing modes of linguistic description in categorial grammar. In *Proc. EACL-7, Dublin Ireland*.
- Nobo Komagata. 1999. *Information Structure in Texts: A Computational Analysis of Contextual Appropriateness in English and Japanese*. Ph.D. thesis, University of Pennsylvania.
- Geert-Jan M. Kruijff. 2001. *A Categorical Modal Architecture of Informativity: Dependency Grammar Logic & Information Structure*. Ph.D. thesis, Institute of Formal and Applied Linguistics (ÚFAL), Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic.
- Michael Moortgat and Glyn Morrill. 1991. Heads and phrases: Type calculus for dependency and constituent structure. Unpublished manuscript. Available from <http://www-lsi.upc.es/~glyn/>.
- Michael Moortgat. 1997. Categorial type logics. In Johan van Benthem and Alice ter Meulen, editors, *Handbook of Logic and Language*. Elsevier Science B.V.
- Glyn V. Morrill. 1994. *Type Logical Grammar: Categorical Logic of Signs*. Kluwer Academic Publishers, Dordrecht, Boston, London.
- Richard T. Oehrle. to appear. Multi-modal type-logical grammar. In Robert D. Borsley & Kersti Borjars, editor, *Non-transformational Syntax: A Guide to Current Debate*. Basil Blackwell, Oxford, United Kingdom.
- Mark Steedman. 2000. *The Syntactic Process*. The MIT Press, Cambridge Mass.
- Frank Trechsel. 2000. A CCG account of Tzotzil pied piping. *Natural Language and Linguistic Theory*, 18:611–663.
- K. Vijay-Shanker and David Weir. 1990. Polynomial time parsing of combinatory categorial grammars. In *Proceedings of the 28th Annual Meeting of the Association for Computational Linguistics*, Pittsburgh, pages 1–8, June.
- Aline Villavicencio. 2002. *The Acquisition of a Unification-Based Generalised Categorical Grammar*. Ph.D. thesis, University of Cambridge.

CHAPTER 3

FROM WORD MEANING TO LINGUISTIC MEANING

The aim of this chapter is to develop a logical account of three concepts that play an important role in the composition and specification of a sentence's linguistic meaning: predicate-valency structures, dependency relations, and aspectual categories. Predicate-valency frames specify the meaning of a head, and by what dependency relations it has to be modified. A dependency relation determines how the meaning of a dependent contributes to the overall (linguistic) meaning of the head it modifies. For example, causative and temporal dependency relations project entailments that may help determine a content verb's aspectual category (i.e. its causal and temporal structure). Such entailments may also need to be accommodated in the discourse context for the sentence's linguistic meaning to be coherent. The main results of this chapter are a logic of aspectual change and aspectual categories (after (Steedman, 2000b)), and a logical specification of basic aspects of the meaning of most dependency relations discerned in (Sgall et al., 1986).

3.1 INTRODUCTION

The aim of the current chapter is to make a beginning with explaining how the meanings of individual words which occur in a sentence compose into a conceivable linguistic meaning of that sentence. Underlying this aim are two assumptions. First of all, we assume that the purpose of a grammar is to describe the relation between surface forms of sentences to their conceivable linguistically realized meanings (i.e., linguistic meanings). Thus, grammar is not identical to syntax pure - well-formedness is only a waypoint in the effort to establish a sentence's underlying meaning.¹ Secondly, we assume that the behavior of a verb is to a large extent determined by its meaning,

¹Sharper contrasts can be drawn here between -at least- the Praguian viewpoint and other grammar frameworks. Whenever a sentence is well-formed, FGD considers there to be a corresponding linguistic meaning; ill-formed sentences do not express a linguistic meaning. The crucial point here is that even for sentences like "Colorless green ideas sleep furiously" we obtain a linguistic meaning, even though on most discourse models this meaning is probably nonsensical, cf. (Sgall et al., 1986) p.108ff. Thus, we make a distinction between the *absurdity* of meaning, and the *absence* of linguistic meaning.

particularly with respect to the expression and interpretation of its arguments² - cf. for example Panevová (1974; 1975) and Sgall *et al.* (1986) for the Praguian approach, but also Levin (1993) on lexical semantics of verbs, and much of contemporary work on categorial grammar (Moortgat, 1988; Steedman, 1996; Morrill, 1997). It is not difficult to see that the two points above taken together precipitate a close relation between a word's subcategorization ('surface syntax') and its (lexical) meaning, thus rendering surface structure (Chomsky's S-structures) superfluous and putting forward the representation of a sentence's linguistic meaning as the *only* proper (level of) representation.

For this reason I start with having a closer look at how we can specify a sentence's linguistic meaning. Following the intuitions behind Sgall *et al.*'s Functional Generative Description (FGD, cf. (Sgall et al., 1986)), linguistic meaning is conceived of here as a relational structure in which dependents modify heads along named dependency relations, and where each node in such a structure has an indication of its informativity (contextual boundness). Furthermore, following a perspective that goes back to at least Vendler (1967) and Dowty (1979), a specification of the sentence's aspectual category is added. The aspectual category reflects the causal and temporal structure that a sentence's linguistic meaning projects (Steedman, 2000b), determined by the main content verb and -possibly- causative and temporal dependents. Thus, a linguistic meaning's aspectual category and information structure are two important factors bearing upon its coherence with respect to a discourse context.

In this chapter I make extensive use of hybrid logic's sorting strategy and @-operator to give a logical account of aspectual change and aspectual categories (after (Steedman, 2000b)), and a logical specification of basic aspects of the meaning of the dependency relations discerned in (Sgall et al., 1986). Both show how not only information structure may trigger entailments that need to be accommodated in a discourse context, but that also a linguistic meaning's aspectual category and dependency relations may do so - for example, about causal and temporal structure. In §3.2 I discuss predicate-valency structures in more detail, and in §3.3 I develop a logic of aspectual categories and aspectual change on the basis of the model by

²In fact, this relation between meaning and syntactic behavior is assumed to hold for *any* word that takes arguments.

Moens & Steedman, cf. (Steedman, 2000b). Finally, in §3.4 I present a preliminary account of the semantic import of dependency relations, and exemplify their use in various languages.³

3.2 PREDICATE-VALENCY STRUCTURES

A notion of valency is at the heart of most approaches to dependency grammar, and -on one interpretation or another- it specifies how the meaning of a word can be conceived of as a *function* taking the meanings of other words as *arguments*.

The idea of valency is used in dependency grammar to elucidate how a word acts as a function, requiring arguments (or “modifiers”) for completion. As such, the valency of words can be likened to the original use of the term in chemistry, where it defines the bonding requirements of different elements.⁴ Within dependency grammar, the notion of valency was introduced by Tesnière (1959).

3.2.1 PREDICATE-VALENCY STRUCTURES

How does a valency frame define the meaning of a word? One might think that a valency frame of a word is like a predicate, say **read**, and that predicate’s arguments (the valency frame proper):

$$(22) \quad \mathbf{read}(x, y, z), \text{ or with the familiar } \lambda\text{'s: } \lambda x \lambda y. \lambda z \mathbf{read}(x, y, z)$$

This gives rise to an interpretation of a predicate and its arguments whereby the *order* in which the arguments appear (and are bound by the λ ’s) is essentially constitutive of their meaning. Thus, the first argument could be taken to hold what corresponds to the ‘reader’, whereas the second argument would then correspond to what is being read. This type of characterization is of course familiar from mathematical logic, and certainly gained prominence in formal semantics with the advent of Montague Grammar.

³The account is ‘preliminary’ in that it is an attempt at providing between formal grammar, formal semantics, and (formal) lexical semantics, without claiming to be a complete description of all the possible semantic imports that each dependency relation may be understood to have.

⁴From a historical perspective, it might be interesting to note that Peirce, who had a Harvard degree in chemistry, used the concept of valency in his theory of relational algebra - and the application thereof to analyzing natural language sentences. See for example (Peirce, 1992), dating back to 1898. Note that the notion of valency was only introduced into chemistry in the second half of the 19th century.

However, this is not how we should understand a valency frame. In a valency frame, the meaning of an argument is not derived from its position in the predicate. Rather, we explicitly name the argument, and consider that name to be indicative of how that argument should be interpreted - how the argument's meaning contributes to the overall meaning. That 'name' characterizing the kind of argument comes from a small set of roles that is assumed to be cross-linguistically justifiable. For example, assume that we have two argument names, ρ_1, ρ_2 , then we could represent a valency frame in either of the following ways:

$$(23) \quad \{(predicate \textbf{read}), (\rho_1 \ x), (\rho_2 \ y)\}$$

$$(24) \quad \lambda x \lambda y. \textbf{read}(\rho_1 : x, \rho_2 : y)$$

The valency frame in (23) is an example modelled after (Dowty, 1989). The example in (24) looks like the one in (22), though it is important to note that for assigning a meaning to the arguments we are no longer dependent on the order in which they are filled in.

Contemporary dependency grammarians differ though on the exact nature of the argument types we should use to specify valency frames: Should a valency frame specify a word's (syntactic) subcategorization, or its (semantic) argument structure? The former interpretation is adhered to in Hudson's Word Grammar (1984) or Maxwell's Unification Dependency Grammar (1995), among others. On the other hand, theories like Sgall *et al.*'s FGD (1986), Mel'čuk's Meaning-Text Model (1988) or Bröker's model-theoretic dependency grammar (1997) all consider valency frames to be of a more semantic nature, contributing to the specification of a word's meaning. With that, their notion of valency frame closely corresponds to, for example, the ideas behind θ -frames as used in Government & Binding (cf. (Haegeman, 1991)), and Fillmore's case frame's (1968).

Obviously, the conception of a valency frame as specifying a word's semantic argument structure, i.e. leading up to a definition of its *meaning*, brings about at least the following two issues:

1. How does a word's valency frame give rise to a subcategorization specifying the word's proper syntactic use?
2. How can dependency relations be characterized such that their import on contextual interpretation becomes clear (and predictable)?

The first question relates to problems raised by, for example, Dowty, Wechsler, and Davis against theories based on thematic roles (cf. Davis' (1996)) - particularly, the apparently problematic nature of such theories' explanation of linking thematic roles to subcategorization ("linking theory"). After explaining the syntactic apparatus of DGL in the next chapter, I will return to this question and argue how it can be satisfactorily answered in the context of DGL, following ideas advanced in e.g. Kuryłowicz (1964), Panevová (1974), and Sgall *et al.* (1986). The second question will be addressed in this chapter.

3.2.2 ARGUMENT COMBINATORICS

Normally, given a predicate and its argument positions, we consider it to be the case that each argument position should be filled for the predicate to be saturated, and that each argument position is filled by exactly one object. This picture also arises from semantic theories based on thematic roles. Davis (1996) (Ch.2) discusses a set of characteristics that holds for the early theories of thematic roles proposed by Fillmore, Gruber, and the thematic relations hypothesis developed by Gruber and later by Jackendoff. Although Davis points out that few would maintain all characteristics today, it is instructive to consider them:

- (25) a. There is a small set of thematic roles.
- b. Thematic roles are atomic - there is no role that subsumes another.
- c. Each argument position in an argument structure is assigned exactly one thematic role.
- d. Thematic roles are uniquely assigned within an argument structure.
- e. Thematic roles are non-relational - the presence of one role does not imply the presence of another role in an argument structure.

Dowty proposes a smaller set of characteristics in (1989) (pp.78-79):

- (26) a. (*Completeness*) Every argument position in an argument structure is assigned a thematic role.
- b. (*Distinctness*) Every argument position of every argument structure is distinguished from every other argument position in the

same argument structure by the thematic roles they are assigned.

- i. (Variant 1) No two argument positions of the same argument structure are assigned the same thematic role, and every argument position is assigned only one thematic role.
- ii. (Variant 2) No two argument positions of the same argument structure are assigned the same thematic role.
- iii. (Variant 3) No two argument positions of the same verb are assigned exactly the same set of thematic roles.

Dowty and Davis discuss several problems that may be noted for theories based on thematic roles (and see also the lengthy discussion in Chapter 2 of (Sgall et al., 1986)). For the larger part, the problems they note are of a semantic-pragmatic nature.⁵ As Hajičová and Sgall note in (Hajičová et al., 1998), though, such considerations have their proper place in contextual interpretation, not in establishing a sentence's linguistic meaning.⁶

Rather, our interest here is that the characteristics in (25) and (26) make clear that a theory might assume a combinatorics of arguments that is more involved than is ordinarily assumed in logic.

For FGD, an elaborate proposal for characterizing the combinatorics of arguments was advanced by Panevová in (1974). This proposal was adopted in (Sgall et al., 1986) and (Petkevič, 1987; Petkevič, 1995). To allow for an adequate description of how a predicate and its argument relate, Panevová suggests to employ criteria along *two* dimensions:

⁵For example, as Oehrle (p.c.) notes, it can be doubted whether *thematic roles* are always atomic: Physical agency ("The storm destroyed our trees") is different from intentional agency ("John cut himself with the razor."). Similarly, it is not clear whether thematic roles are indeed non-relational. For example, it seems difficult to have an instrumental role without something undergoing the change.

⁶For example, both Davis and Dowty note the apparent problem with verbs denoting commercial transactions, like *buy*. As Jackendoff noted in the early 1970's, the buyer and the seller could both be considered to be "Agent" and "Source" (on Jackendoff's theory), since both make a transaction by handing something over and receiving something in turn. This observation, though interesting, is not a problem applicable to the kind of dependency grammar considered here. The 'fact' that there is a buyer and a seller in a commercial transaction, and that both are giving and getting objects, is an inference involving "world knowledge" and should therefore be relegated to contextual interpretation. It does not appear to have any bearing on determining the well-formedness of a sentence, nor on establishing its linguistic meaning. Similarly, Oehrle's comments regarding agency are not directly applicable to dependency grammar, as in both cases we consider the dependency relation to be an **Actor**. The difference is made elsewhere, namely outside the grammar.

- (27) a. *Occurrence*: Whether a predicate can have only one argument of a given type, or several arguments of one and the same type.
 b. *Obligatoriness*: Whether, for a given predicate, an argument position must be filled or may be left open.

Clearly, (27b) specifies whether an argument position is optional or obligatory. (27a) is best described by example: A verb can have only one argument that is specified as its **Actor**, but it can have more than one argument specifying when the eventuality (referred to by the verb) takes place (**Time:When**):

- (28) [Last Wednesday]_{T:When} [Christopher]_{Actor} came home [in the evening]_{T:When}. (Panevová, 1994)(p.228)

Panevová calls **Actor** an *inner participant*, whereas **Time:When** is an example of a *free modifier*.

In contradistinction to various other theories that may bear resemblance to the approach we consider here (e.g. the semantic theories based on thematic roles, as discussed above), Panevová develops clear linguistic criteria for determining whether an argument (or dependency relation) is an inner participant or a free modifier, whether it is optional or obligatory, and in what sense we should understand such obligatoriness. Behind all these criteria is the idea that any distinction that we make should be linguistically relevant, and connected to surface-syntactic facts.⁷

To determine whether a particular dependency relation should be considered as an inner participant or a free modifier, Panevová proposes the following, fairly straightforward test ((1974), p.11):

- (29) a. Can the given type of dependency relation modify every verb?
 b. Can a verb be modified more than once by the given type of dependency relation?

A dependency relation is classified as an inner participant if it answers both questions in the negative.⁸ To be classified as a free modifier, the

⁷This places FGD clearly apart from for example Fillmore's theory, in which at least at a certain stage 'cases' were distinguished using a "subjective or impressionistic classification" (1974), p.29; see also the discussion in (Sgall et al., 1986), §2.11. The viewpoint that every distinction should be connected to observable (distinct) syntactic behavior also holds in a fundamental way for FGD's set of dependency relations, discussed below.

⁸Panevová actually points out that for the **Actor** the first question is answered positively (p.11). However, when we include impersonal verbs like *rain*, *snow*, etc. then it is

second question necessarily has to be answered positively. However, due to great variation in the semantics of adverbials (most of which are considered to be free modifiers), it is not necessarily the case that the first question is answered positively ((1974), p.12).⁹

Whether an argument is obligatory or optional (in a predicate-valency structure, i.e. at the level of linguistic meaning) can be determined by means of a *dialogue test*.¹⁰ Intuitively, we can describe the dialogue test as follows. Assume we have two people participating in a dialogue, Elijah and Christopher. At one point in the dialogue, Elijah utters a sentence having a particular main verb. If, thereupon, Christopher asks a question pertaining to one of the verbal predicate's arguments, and that argument is an obligatory argument (though Elijah might have used ellipsis), then Elijah must be able to answer Christopher's question for the dialogue to continue naturally. If the (elided) argument is obligatory, Elijah cannot answer with "I don't know" - whereas he can if the argument is only optional.

For example, consider the following sample dialogue:

- (30) a. (Elijah) "The Simpsons arrived."
 b. (Christopher) "Where?"

After (30b), Elijah cannot utter "I don't know" since doing so would have a disturbing effect on the natural flow of the dialogue. In other words, the meaning of *arrive* includes a destination as an obligatory argument - when you say that someone arrived, you are expected to know *where to* that person arrived. At the same time, if Christopher would have asked "Where from?" then Elijah could have perfectly well answered that question by "I don't know where they had been" since knowledge thereof is not implied by

clearly not the case that every verb has an **Actor** since mentioned verbs do not have one. This observation is made later on in (Sgall et al., 1986), cf. p.127.

⁹Regarding ellipsis, Sgall *et al.* (1986)(p.109) remark that "if a unit of the meaning of a sentence is deleted by an optional surface rule, on uttering the sentence, the speaker assumes that the hearer can easily recover the deleted item; if this condition were not met, the speaker would not have chosen the reduced surface variant."

¹⁰The dialogue test differs from the question test. The latter was briefly sketched by Sgall and Hajičová in (1970) as a means to characterize informativity of elements that make up a sentence's information structure. Particularly, as described in (Sgall et al., 1986), "the question test has a certain usefulness not only if we want to draw the boundary between topic and focus (or, between the [contextually bound] and [contextually nonbound] elements of the nucleus of a [tectogrammatical representation]), but also for assigning degrees of [communicative dynamism]" (p.211).

the meaning of the verb. That type of argument (**Direction:From Where**) is not obligatory for *arrive*.

Thus, to quote Panevová:

“If A uses a sentence S and B asks him a *wh*-question concerning the participant P, A’s answer might be “I don’t know” (without disturbing the dialogue) if and only if the participant P is not semantically obligatory in S. (If S contains an embedding, it must be specified which verb is expanded by P in the question, and the answer must not, of course, switch to another verb.)” (1974), p.18

To sum up, let us have a brief look then at how FGD’s characterization contrasts with the characteristics of thematic role-based theories, as noted by Davis and Dowty:

- To begin with, FGD shares the idea of there being a small, fixed set of dependency relations.
- Furthermore, it is also assumed that each argument position (and each argument) is assigned a single dependency relation (cf. also Petkevič’s discussion in §3.1.1, (in prep)).
- However, unlike Dowty’s *Distinctness* characteristic and Davis’ (d) (which still holds for Government & Binding), FGD does allow for a predicate to be expanded by several arguments that are of the same type of dependency relation - namely, if that type of dependency relation is a free modifier.
- Another difference concerns obligatoriness: whereas it is implicit in Davis’ and Dowty’s characterizations that all arguments are obligatory, this is not the case in FGD.

As Panevová points out, the approach taken in FGD permits one to avoid extreme approaches, that arise either by restricting the analysis of verbal arguments to surface structure only, or by confusing linguistic structure and cognitive relations (in that every action always takes place at some time, at some place, in some manner, etc.).

3.2.3 PREDICATE-VALENCY STRUCTURES AND HYBRID LOGIC

In the previous chapter I already briefly illustrated how predicate-valency structures could be represented in hybrid logic - see for example 13 on page 27. Let me briefly repeat what was said there.

Modalities provide an excellent means to represent relations. Given a set of dependency relations $\Delta = \{\delta_1, \dots, \delta_n\}$, we can define modals $\langle \delta_i \rangle$ that model these relations, cf. also (Blackburn and Tzakova, 1998). Furthermore, I already briefly pointed out that the distinction between inner participants and free modifiers can be modeled using pure formulas. (31) expresses that δ is an inner participant. Formally, it does so by imposing the constraint that whenever j and k are both related to i by δ , then j and k refer to the same state. Intuitively, this means that a head, identified by i , can only be modified by a single δ -dependent: j and k refer to the same dependent.

$$(31) \quad @_i \langle \delta \rangle j \wedge @_i \langle \delta \rangle k \rightarrow @_j k$$

Thus, FGD's classification of **Actor**, **Addressee**, **Effect**, **Origin**, and **Patient** as inner participants can be specified axiomatically in our logic, (32).

$$(32) \quad \begin{aligned} \text{a. } & @_i \langle \text{ACTOR} \rangle j \wedge @_i \langle \text{ACTOR} \rangle k \rightarrow @_j k \\ \text{b. } & @_i \langle \text{ADDRESSEE} \rangle j \wedge @_i \langle \text{ADDRESSEE} \rangle k \rightarrow @_j k \\ \text{c. } & @_i \langle \text{EFFECT} \rangle j \wedge @_i \langle \text{EFFECT} \rangle k \rightarrow @_j k \\ \text{d. } & @_i \langle \text{ORIGIN} \rangle j \wedge @_i \langle \text{ORIGIN} \rangle k \rightarrow @_j k \\ \text{e. } & @_i \langle \text{PATIENT} \rangle j \wedge @_i \langle \text{PATIENT} \rangle k \rightarrow @_j k \end{aligned}$$

Without any further constraints like (31), a dependency relation δ acts as a free modifier.

Abstractly, a predicate-valency structure then takes the form as in (33) for a verb with a valency frame consisting of dependency relations $\delta_1, \dots, \delta_i$. E is an *eventuality nucleus* and $\overline{p_1}, \dots, \overline{p_i}$ are *structured objects*. Both terms are described in more detail below.

$$(33) \quad (E \wedge \text{verbal} - \text{predicate} \wedge \langle \delta_1 \rangle (\overline{p_1}) \wedge \dots \wedge \langle \delta_i \rangle (\overline{p_i}))$$

A little reflection on the nature of the arguments (variables) clarifies what I mean by a structured object. In line with the discussion in the previous chapter, these arguments are *discourse objects*, consisting of a discourse

referent and its conditions. A structured object captures exactly that - it is a formula built from a nominal (the discourse referent) conjoined with one or more propositions (the conditions).

Definition 7 (Structured objects). *A structured object $\overline{\varphi}$ is a formula that is a conjunction of a nominal and one or more propositions: $\overline{\varphi} = i \wedge \phi_1 \wedge \dots \wedge \phi_n$. $\circledast$*

The eventuality nucleus I use here is a formalization of Moens and Steedman's discussion of tense, aspect and modality. In the next section, I first present their discussion, based on Steedman's (2000b), and then the formalization.

3.3 VERBAL TENSE AND ASPECT

Verbs, together with their modifiers, convey propositions - propositions that are (usually) about the world around us.

In this section, I briefly discuss Vendler's Aktionsarten, here called aspectual categories, and then continue with Steedman's discussion relating aspectual categories to morphological tense and aspect (2000b) (based on earlier work with Moens, (Moens and Steedman, 1988)). Steedman describes a model that can be conceived of as elaborating particular ideas present in Kuryłowicz's (1964) discussion of tense and aspect. Since the discussion of tense and aspect in (Sgall et al., 1986) appears to be fashioned in a way similar to Kuryłowicz, we would like to advance Steedman's theory as a suitable explication and elaboration of the ideas discussed in (Sgall et al., 1986) (cf. also Hajičová and Panevová's (1969) and Panevová's (1980)).

I should like to start the discussion of tense and aspect by making it clear what we are talking *about*. As Steedman points out in (2000b), there are essentially *three* different types of issues. First of all, there is the issue of *temporal ontology*, which concerns the various kinds of events and states we may want to discern. Secondly, there are issues of *temporal relation*, determining what kinds of relations could be predicated over such events and states. These relations may be purely temporal, signifying temporal order, overlap, or inclusion; or they may point to causal, teleological, or epistemic relationships that hold between events or states, (Steedman, 2000b)(p.1).

Finally, the examples in (34)-(36) illustrate that some temporal relations might induce a dependence on the larger context in which the sentence is uttered. To be able to integrate this point into our discussion, we need to distinguish *temporal reference* from temporal relations and temporal ontology.

(34) **English**

Kathy will read the entire book.

(35) **English**

Kathy will read the entire night.

Whereas in (34) the direct object “the entire book” expresses a **Patient**, “the entire night” in (35) expresses a **Time:How Long**. As Sgall *et al.* note in (1996), inflectional languages often allow for the accusative case to be used in both these ways.

However, the **Time:How Long** dependency relation in (35) triggers a presupposition similar to those found with *when*-clauses, as discussed for example by Steedman in (2000b)(p.18ff).

(36) When Nixon was elected, Chapman breathed a sigh of relief. (Steedman, 2000b)(p.16)

The use of the past tense in (36) demands that there is an identifiable past reference point, either identified in the sentence itself by a temporal adverbial or by the preceding discourse. The **Time:When** dependent provides such a reference point, supposing that the hearer knows when Nixon was elected.

3.3.1 TEMPORAL ONTOLOGY

As the basis for our temporal ontology we use the taxonomy of action-types like Vendler (1967), or Kenny (1963). Vendler (1967) provides us with a classification that perceives of the propositions expressed by verbs and their modifiers, as different action-types or *aspectual categories*. As Dowty discusses in Chapter 2 of his (1979), Vendler’s classification of verbs can be traced back to work as early as Aristotle, and bears similarities to work by for example Ryle. What sets Vendler’s classification apart from the rest is that Vendler’s was the first attempt “to separate four distinct categories of verbs

by their restrictions on time adverbials, tenses, and logical entailments” (Dowty, 1979)(p.54).

The idea to conceive of the aspectual categories as classifying the *propositions* that verbs express rather than the verbs themselves does not originate with Vendler - as Steedman points out in (2000b), this reinterpretation of Vendler’s theory is due to Dowty and to Verkuyl.

Vendler identified four types of aspectual categories, namely *achievement*, *activity*, *accomplishment*, and *state* (see Ch.4 of Vendler’s (1967)). Following Steedman’s discussion in (2000b), we can describe these types as follows.

An achievement is a category of event that is characterized as being instantaneous, and by resulting in a distinct change in the world. Verbal propositions expressing an achievement can be detected by the fact that they can be combined with adverbials that express a (reference to a) specific point of time (**Time:When**), like **English** *in*-prepositional groups (37), but cannot be combined with adverbials that express a duration over a period of time (notably, **Time:For How Long**) like **English** *for*-prepositional groups (38). Furthermore, verbs that realize an achievement do not carry a factive entailment under the progressive (39), and -at least in Germanic languages- they can be combined with the perfect (40):

(37) **English**

Christopher reached the top of the hill [in two hours]_{Time:When}

(38) **English**

Christopher reached the hilltop [for two hours]_{Time:For How Long}¹¹

(39) **English**

Christopher is arriving to the top of the hill (≠ Christopher will have arrived to the top of the hill)

(40) a. **Dutch**

Christopher heeft de top van de heuvel bereikt.

b. **German**

Christopher hat den Gipfel des Hügels erreicht.

c. **English**

Christopher has reached the top of the hill.

¹¹Whereby we do not understand “for two hours” as meaning “two hours ago”.

Vendler points out that achievements should not be confused with the different category of accomplishments. Consider the following examples (41) and (42) which Vendler discusses in (Vendler, 1967)(p.104):

(41) **English**

It took him three hours to reach the summit.

(42) **English**

He wrote a letter in an hour.

Example (42) illustrates an accomplishment. Saying that writing the letter took an hour implies that the writing of that letter went on during that hour. Vendler contrasts this to example (41), which is an achievement. Even though one may say that “reaching the summit” took three hours, it surely isn’t implied that the act of reaching took three hours: The *climbing* towards the summit, eventually culminating in reaching it, took three hours.

Concisely put, what distinguishes an accomplishment from an achievement is that an accomplishment is extended over time. Steedman illustrates the difference on *writing a sonnet* and *finishing a sonnet*. Even though formally both achievements and accomplishments allow for the same modifiers, the entailments thus differ. With an accomplishment, the time span is *part of* the event of writing (42). Similarly, it is part of the event of climbing (43), whereas we do not consider the event of reaching to be taking three hours (41).

(43) **English**

Christopher climbed to the summit in three hours.

The contrast that we find between the entailments of achievements and accomplishments led Verkuyl and Dowty to propose that accomplishments should be regarded as composites of an activity and a culminating achievement (Steedman, 2000b)(p.8).

Whereas both achievements and accomplishments result in a reasonably well-marked culmination point, *activities* do not. Activities are extended in time, but they do not result in a very distinct change in the world. As such, they go well with **English** *for*-prepositional groups (expressing **Time:For How Long**) (44) but not with **English** *in*-prepositional groups (45). Furthermore, the progressive does carry a factive entailment here, unlike the case of achievements and accomplishments (46).

(44) **English**

Christopher climbed [for two hours]_{Time:For How Long}.

(45) **English**

Christopher climbed [in two hours]_{Time:When}.

(46) **English**

Christopher is climbing (= Christopher will have climbed).

Finally, Vendler distinguishes the category of *states*. Steedman describes states as lacking definite bounds, and as being inherently non-dynamic, whereas Dowty characterizes states by drawing a parallel between the contrast between states and activities on the one hand, and Lakoff's distinction between *stative* and *non-stative*. Straightforward examples of verbs that signify a state are given in (47) through (49).

(47) **English**

Kathy is a genius.

(48) **English**

Elijah believes in the existence of UFOs.

(49) **English**

Christopher is tall.

Also considered as states are certain “predications of habitual action” (Steedman, 2000b)(p.8), like (50) and (51):

(50) **English**

Kathy works at the university.

(51) **English**

After Elijah gets up, he makes a cup of coffee.

Now, the question may arise whether the aspectual categories above are intrinsic properties of verbs and their lexical meanings. Dowty (1979) discusses a variety of examples that show that this is clearly not the case (cf. his §2.2.5). See also (Verkuyl, 1973). For example, a verb that prototypically expresses an activity, like **English** *walk*, realizes an accomplishment when it is modified by either a location (**Locative**) or a destination (**Direction:Where To**):

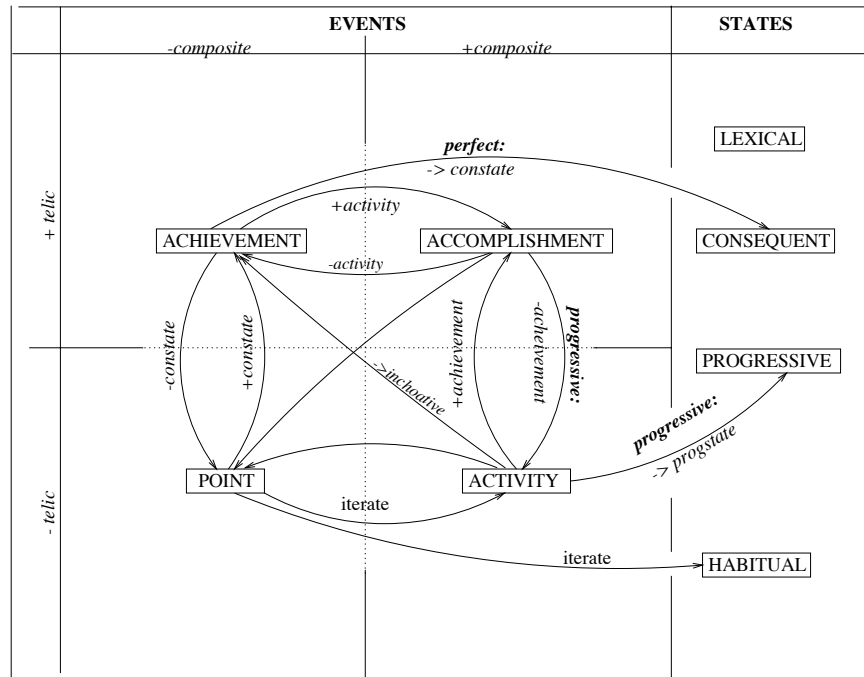


Figure 3.1: A scheme of aspectual coercion, adapted from (Moens and Steedman, 1988)

- (52) John walks $\left\{ \begin{array}{l} \text{a mile.} \\ \text{to the park.} \end{array} \right.$ (Dowty, 1979)(p.60)

The crucial point here is that aspectual *change* arises from the nature of the verb's modifiers - i.e. from the *dependency relations* involved. Both Verkuyl and Dowty pointed this out - to quote (Steedman, 2000b)(p.9), "some similar protean shifts in aspectual category of the event conveyed by a sentence depend[...] upon the semantic type of the nominal categories involved as arguments of the verb."

Before I review the fundamental role that dependency relations appear to play in aspect and aspectual change, I first discuss Moens and Steedman's scheme of aspectual change or aspectual coercion as originating from their (1988).

The scheme in Figure 3.1 reflects how we can conceive of aspectual change or "coercion" as semantically guided transitions between Vendlerian aspectual categories or aspectual categories. The scheme divides the aspectual categories into states and events, with the latter again being divided

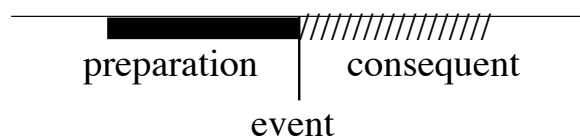


Figure 3.2: The event nucleus

further into the familiar categories *achievement*, *accomplishment*, *activities*, and a forth atomic telic category, *point*. As Steedman explains, the real significance of *point* is that it acts as a way-station “where the internal structure of an event is ‘frozen’ on the way to being iterated or turned into a consequent state by the perfect.” (2000b)(p.11) The division of the events is based on two semantic features - *telicity* and *decomposability*. Steedman describes telicity as the association with a particular change of state, whereas decomposability regards the possibility to decompose into sub-events (rather than having to do with temporal extent or duration).

The possibilities to change from one type of aspectual category to another is depicted by arrows. Each arrow is annotated with an indication of the nature of the semantic change, like *iterate*. Additionally, a change may be conditioned by lexical meaning or form, such as the perfect or the progressive. These conditions are indicated in bold-face.

An interesting feature of aspectual change is that they all seem to reflect an underlying semantics in which events of all kinds are associated with a *preparation*, being the activity that brings the event about, and a *consequent*, which is the ensuing state that the activity results in. To represent this semantics Moens proposed in his dissertation in 1987 to use a tripartite structure called the *event nucleus*, see Figure 3.2.

We consider the event nucleus to be composed of the aspectual categories as given in Figure 3.1. Particularly, the event is associated to a preparation which relates an activity to the event that it that brings about, and a consequent, connecting the event to the ensuing state. The event itself is thus a (possibly complex) achievement. Finally, as Steedman points out (2000b)(p.11), the event nucleus itself is closely related to the category of accomplishments.

To round off this brief discussion of Vendler’s aspectual categories, we would like to have a closer look at the relation between these categories, and different dependency relations (which each are considered to impart a differ-

ent meaning). For example, we already saw above that an achievement, not being extended over time, can take a dependency relation like **Time:When** but not one that inherently expresses an interval, like **Time:For How Long**. Although this is of course most clearly illustrated on dependency relations of a temporal nature, it is also true that achievements do not go with a dependency relation like **Extent**. **Extent** is not a temporal dependency relation, but still embodies an idea of an extended period of time, and can therefore be considered inappropriate (cf. (Dowty, 1979), p.60).

But not only are there interesting connections between the aspectual category a proposition or more precisely, a saturated predicate-valency structure, expresses and the dependency relations occurring in that predicate-valency structure. Also *aspectual change* elucidates such connections.

For example, let us reconsider the example of aspectual change illustrated in (52). There we considered how an activity, which lacks a clear culmination point, can be changed into an accomplishment by basically *adding a dependency relation* that would express (in one way or the other) such a culmination point. In the example we used **Locative** and **Direction:Where To**, after (Dowty, 1979). Surely, these are not the only possible ones. To change from activity to accomplishment, we can also consider **Time:Till When** (53):

(53) **English**

$$\left\{ \begin{array}{l} \textbf{Activity:} \text{ Kathy walked} \\ \textbf{Accomplishment:} \text{ Kathy walked [till dawn]}_{Time:Till \text{ When}} \end{array} \right.$$

Similar connections can also hold (under certain conditions) between other aspectual categories. For example, consider the following example:

(54) **English**

The visitors arrived.

In the absence of any further specification of when, or during what period, the visitors arrived, the sentence in (54) conveys an achievement. However, by adding a modifier expressing a duration, like **Time:How Long**, the plurality of the **Actor** “Visitors” enables a more ‘distributed’ reading in which the visitors are arriving all through the night - which is an activity (after (Steedman, 2000b),p.10):

- (55) **English**
 $\left\{ \begin{array}{l} \textbf{Achievement:} \text{ The visitors arrived.} \\ \textbf{Activity:} \text{ The visitors arrived [through the night]}_{Time:How \ Long.} \end{array} \right.$

The same observation holds for other Indo-European languages as well.
 (Note the change of verbal aspect in (59).)

- (56) **German** $\left\{ \begin{array}{l} \textbf{Achievement:} \text{ Die Besucher kamen an.} \\ \textbf{Activity:} \text{ Die Besucher kamen an [während der Nacht]}_{Time:How \ Long.} \end{array} \right.$
- (57) **Dutch** $\left\{ \begin{array}{l} \textbf{Achievement:} \text{ De bezoekers kwamen aan.} \\ \textbf{Activity:} \text{ De bezoekers kwamen aan [gedurende de nacht]}_{Time:How \ Long.} \end{array} \right.$
- (58) **French** $\left\{ \begin{array}{l} \textbf{Achievement:} \text{ Les visiteurs arrivaient.} \\ \textbf{Activity:} \text{ Les visiteurs arrivaient [pendant la nuit]}_{Time:How \ Long.} \end{array} \right.$
- (59) **Czech** $\left\{ \begin{array}{l} \textbf{Achievement:} \text{ Hosté přišli.} \\ \textbf{Activity:} \text{ Hosté přicházeli [celou noc]}_{Time:How \ Long.} \end{array} \right.$

The examples below illustrate more aspectual changes that can be brought about by adding particular modifiers: **Result** (60)¹², **Purpose** (61), and **Condition (Counterfactual)** (62).

- (60) **English**
 $\left\{ \begin{array}{l} \textbf{Activity:} \text{ Elijah swam.} \\ \textbf{Accomplishment:} \text{ Elijah swam [so that Jaws did not catch him]}_{Result.} \end{array} \right.$
- (61) **English**
 $\left\{ \begin{array}{l} \textbf{Accomplishment:} \text{ Christopher made a chair.} \\ \textbf{Activity:} \text{ Christopher made a chair [so that he had one to sit on]}_{Purpose.} \end{array} \right.$
- (62) **English**
 $\left\{ \begin{array}{l} \textbf{Activity:} \text{ Christopher ran.} \\ \textbf{Achievement:} \text{ Christopher ran [but didn't make it in time]}_{Counterfact.} \end{array} \right.$

Of course not *all* aspectual change is brought about by adding particular dependency relations, nor is it even the case that all aspectual categories are

¹²Cf. also the factives in Dowty's table on accomplishments, (1979)(p.69-71).

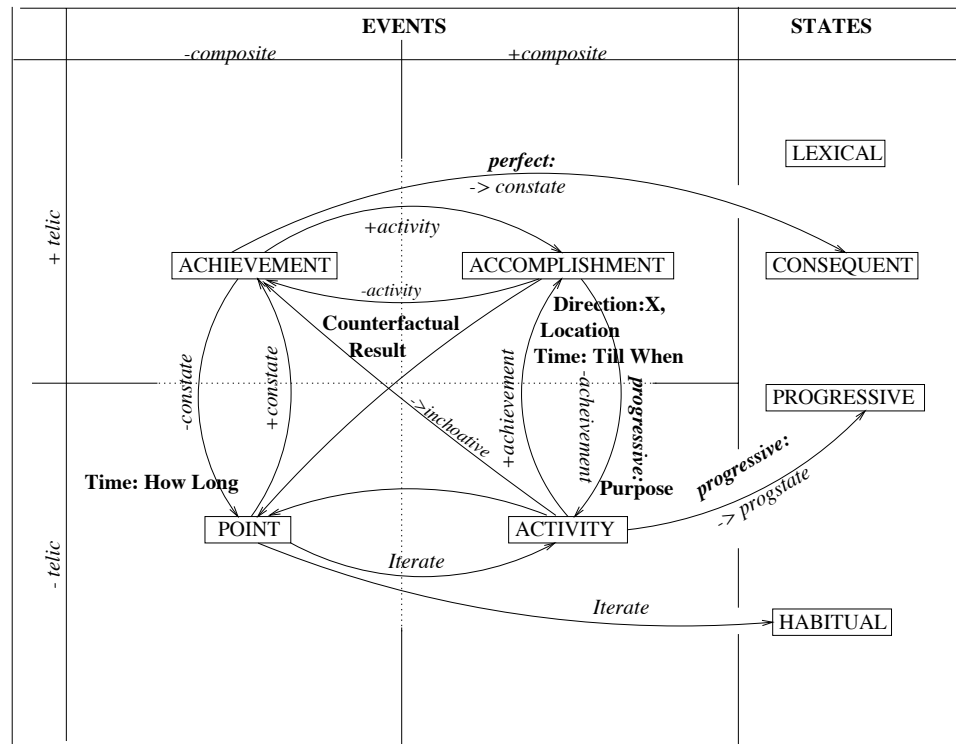


Figure 3.3: Aspectual coercion, including effects of using particular dependency relations

realized by verbs that take (only) particular types of modifiers. For example, languages employ particular verbal *forms* to realize aspect, usually phrased in terms of binary oppositions like *perfective/imperfective*, and possibly the opposition *iterative/resultative*. For example, iterativity is expressed productively in Czech, using the infix *-va-* (3.3.1):

(63) **Czech**

psát (be writing), *psávat* (write, repeatedly)

psát (be writing), *napsat* (write)

dávat (be giving), *dát* (give)

The scheme of Moens and Steedman includes the effects of the above aspectual forms, for example one can bring about a change from an achievement to consequent state by using the perfective. Below I present the scheme again in Figure 3.3, but now including all the aspectual changes as brought about by adding particular dependency relations, as I discussed above.

3.3.2 TEMPORAL RELATIONS

In the above discussion we established an ontology of temporal/action types, called aspectual categories. We now turn to the linguistic system that covers *relations* between these different types. In most languages, these *temporal relations* consist in tense, aspect, and modality.

My interest here is mainly in pointing out a basic perspective on these subsystems, rather than delving too deep into language-specific detail. The purpose is to *clarify* the basic perspective - in the later chapters, I show that the framework accommodates this perspective, thus *enabling* one to model any such system for a given language. There is a very substantial discussion in the literature on systems for tense and aspect - see for example Steedman's (1997; 2000b) for overviews and references, Kuryłowicz's (1964) for a fundamental typological discussion of tense and aspect in indo-european languages.

To describe tense, we adhere to a model based on Reichenbach's work (1947) that is used in general. Reichenbach advanced in (1947) the view that, linguistically speaking, tense does not quantify over *two* times, like a "now" and a "then", but over *three* times: the speech time (*S*), the event time (*E*), and the reference time (*R*).

The speech time *S* is obviously the time at which the sentence is uttered. The event time *E* is the time (or *temporal extension*) of the expressed proposition - the ontology we discussed above is an ontology of *E*. Finally, the reference time *R* is the time (or context) that we are talking *about*, or from which point the event *E* is viewed.

Particularly *when*-clauses are illustrative of such reference-setting:

(64) **English**

When Elijah arrived to the party in his cowboy boots, everybody starting laughing.

The different tenses a language distinguishes can be defined in terms of *R*, *S*, *E*, and their mutual relationship (ordering/equivalence). For example, we have for English the following (cf. (Steedman, 2000b) and (Hajčová and Panevová, 1969)):

- (65) a. Christopher saw Elijah. *Simple Past*, $E = R < S$
 b. Kathy wins! *Present*, $E = R = S$

- c. Elijah goes to Timbuctoo by bike. *Simple Future*, $S < R = E$

Or, for a more diagrammatic representation, see Figure 3.4.

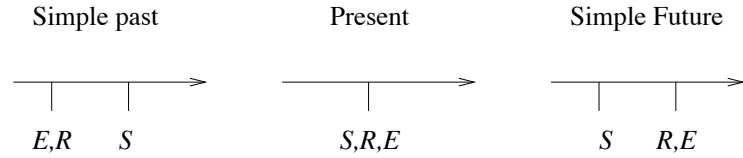


Figure 3.4: Reichenbachian model of basic English tenses

This model has been extended to cover a large variety of different tenses, for example see (Steedman, 2000b). Here, we continue with integrating the aspectual opposition *perfective/imperfective* (or perfective/progressive) into the picture established for tense.

Both perfective and progressive compose with tense. When we combine the perfective with the tenses as in (65), we obtain realizations of the Consequent State, with R in that state, derived from E which in and by itself would have realized an achievement - cf. again the diagram in Figure 3.1.

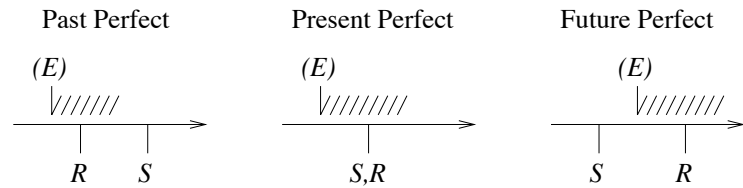


Figure 3.5: The English perfect

In the case of the progressive, R lies in the Progressive State, with E an activity.

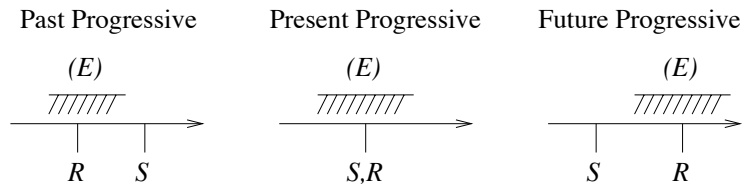


Figure 3.6: The English progressive

Interesting possibilities arise when we consider aspectual change again. Aspectual change may result in the derivation of the core event E from a different category E' . For example, consider the event of *winning the*

race, which is an achievement. This event can be turned into an activity, if it becomes associated to an event that is prototypically an activity, like *running*. According to Steedman, “[t]he progressive can then strip off the original achievement, to leave the bare activity, which is then mapped onto the corresponding state, which is predicated of *R*, the time under discussion.” (2000b)(p.24). Being able to change the aspectual category in this way explains, according to Steedman, the possibility of futurate progressives, like in (66).

- (66) a. I am winning! *Present Futurate Progressive*
 b. I was winning! *Past Futurate Progressive*

The above discussion depicted tense and aspect, quite literally, in terms of a single “time-line”. Modality enables us to consider the flow of time not as a single, deterministic history, but as a road on which we can follow alternative directions. Technically, we usually represent such a model of the flow of time as a transition graph where, at each state, there are several alternative continuations - the *branching time model*, cf. also (Gamut, 1991).

We distinguish two different types of modality, namely *epistemic modality* and *deontic modality*. Epistemic modality has to do with the necessity, possibility, inferability, or predictability of the proposition that is expressed by the main verb (that is being modified by the modal expression). For example,

- (67) a. Elijah must be crazy to have bought those boots. (*Necessity*)
 b. Kathy may want to throw them away. (*Possibility*)
 c. That will infuriate Elijah. (*Inferability*)

Deontic modality regards the feasibility or permissibility of the proposition, or the ability, desirability or obligation on part of the **Actor**. Thus, we have for example

- (68) a. Elijah must buy decent shoes. (*Obligation*)
 b. Christopher can do the bugaloo. (*Ability*)
 c. Kathy may park her car here. (*Permissibility*)
 d. This planning can be fulfilled. (*Feasibility*)
 e. Elijah wants to look like a cowboy. (*Desirability*)

Sgall *et al.* discuss in (1986) a different but comparable approach to modality (p.170ff). The approach employs Benešová(1972)(with minor modifications), and is based on an analysis of modality in Czech.

As Sgall *et al.* point out, it appears appropriate (at least for Czech, and arguably for English as well, as the authors illustrate) to distinguish the following values: For *modal properties*, necessity, possibility, and desirability; and for the *source of modality*, circumstance, a subject other than the **Actor**, or the **Actor** him-/herself. A combination of values for these two factors determines the actual modality of a verb. (Sgall et al., 1986) mentions the following examples for English (p.170-171).

	necessity+{circumstance, subject o.t. Actor }	<i>have to</i>
	necessity+{ Actor }	<i>must</i>
(69)	desirability+{circumstance, subject o.t. Actor }	<i>should, ought to</i>
	desirability+{ Actor }	<i>want</i>
	possibility+{circumstance, Actor }	<i>can</i>
	possibility+{subject o.t. Actor }	<i>may</i> (permissive)

The modalities presented in (Sgall et al., 1986) are comparable to most of the deontic modalities that Steedman (2000b) discusses.

	(Sgall et al., 1986)	(Steedman, 2000b)
	necessity + { Actor }	Obligation
(70)	desirability + { Actor }	Desirability
	possibility+{ Actor }	Ability
	possibility + {subject o.t. Actor }	Permissibility

If we allow for Steedman's Desirability to hold for propositions as well, then that would cover desirability + {subject other than **Actor**}. Further parallels can only be drawn if we include a concrete notion of *circumstance* in (Steedman, 2000b).

To model modality, I presume familiarity with the notion of Kripke models, their role in modal logic, and how a branching time model can be constructed using a modal logic with multiple modalities. For more on basic modal logic and its model theories, see Bull & Segerberg (1984) and Van Benthem (1984), whereas the interaction between tense and modality is discussed in detail in Thomason (1984) and Gamut (1991).

3.3.3 TEMPORAL REFERENCE

Finally, with tense and aspect indicating different ways of putting the Reichenbachian reference point *R* on the time-line, and with modality making that time-line into a more complex, braching structure, the question arises how we can represent and access *R*. In other words, we should turn to our third issue, that of *temporal reference*.

Let us first consider a few examples that can be taken as indicative not only of the use but also of the nature of temporal reference. The examples are after (Steedman, 2000b)(Chapter 4).

- (71) a. [When Elijah took Kathy's pawn]_{Time: When}, she took his queen.
 b. Elijah took Kathy's pawn. Kathy took Elijah's queen.

The **Time:When**-dependent in (71a) establishes a reference point for the main clause to refer to anaphorically, much in the same way as the definite noun like *Kathy* constitutes a referent for the pronoun *she* in the main clause. This provides an interesting difference to the first sentence in (71b). The **Time:When**-dependent in (71a) presupposes that it is *possible* for the hearer to establish the reference point indicated by the dependent. The past tense of the first sentence in (71b), on the other hand, *requires* that this reference point has already been established.

Obviously, the state that the **Time:When**-dependent in (71a) refers to is not the same state that the main clause in (71a) refers to. Rather, the state expressed by the main clause resulted from the state referred to by the **Time:When**-dependent. The situation can also be different, as (72) illustrates. Here, the **Time:When**-dependent establishes the state that the stative main clause is about.

- (72) When Elijah took Kathy's pawn, he did not know it was protected by one of Kathy's knights.

Rather than moving the action on, as in (71a), or using a stative to elaborate on the reference point (72), we can also predicate an event of the original reference point - (73).

- (73) When Elijah took Kathy's pawn, he used a rook.

Finally, as for example (Partee, 1984) points out, a **Time:When**-dependent need not establish a reference point that precedes the main clause's. (74) illustrates this.

- (74) When Elijah won his only game against Kathy, he used the John Wayne opening.

Steedman argues that phenomena like the ones illustrated in (71) through (74) can arise because the temporal referent is not strictly temporal. Instead of being simply a reference to a point or an interval, it is a reference to an event nucleus. To repeat what was said on page 49 (see also Figure 3.2), the event nucleus consists of a preparation (an activity), a consequent (a state), and the core event (an achievement). Or, to use Steedman's words, "The preparation of an event is the activity that led to the state in which that achievement took place." (2000b)(p.55)

Reflecting on the examples above, the **Time:When**-dependent thus identifies an event nucleus, and the main clause is related to an aspect of that event nucleus. For example, the main clause can be related to the core event of the event nucleus as a property of the initial state (72), or as a property of the transition itself (73). The main clause can also be related to the preparation of the event nucleus, as in (74). Finally, if we consider modal frames, then the main clause in (71) is just one of the possible subsequent actions accessible from the consequent state of the event nucleus identified by the **Time:When**-dependent.

The conception of temporal reference as the identification of an event nucleus is important to the definition of the semantic import of -notably-temporal dependency relations. But, before we are able to do so, I first have to establish a logical account of Moens & Steedman's event nucleus and its role in their model of aspectual change and aspectual categories. This is the aim of the next section.

3.3.4 A FORMALIZATION OF MOENS & STEEDMAN'S MODEL

An important aspect of Moens & Steedman's model of aspectual change and aspectual categories is its emphasis on using a *rich temporal ontology*. This raises an interesting issue for its formalization, as most formal accounts

argue for either a point based semantics or an interval based semantics.¹³

From Moens and Steedman (1988) it should be clear that we actually need both. To my knowledge, Blackburn, Gardent and De Rijke present in (1993) the first logical model in which such a combined ontology was worked out, specifically aimed at formalizing the event nucleus. Their proposal is to define a *back-and-forth structure* (BAFs) in which one (quite literally) moves back and forth between an *interval structure* (including minimal, “point-like” intervals) and an *eventuality structure*. In a BAF, the interval structure models temporal extent, providing the temporal structure, whereas the eventuality structure represents eventualities and the possibility of one eventuality giving rise to another. The crucial ingredient of a back-and-forth structure is a set of two relations that link these structures: a relation z , from the eventuality structure to the interval structure, returns the temporal extent of an eventuality, whereas the other relation Z relates an interval to the eventualities that ‘take place’ during that interval. Figure 3.7 represents this diagrammatically, and Definition 8 gives Blackburn *et al.*’s basic definition of BAFs as provided in (1993)(§3).

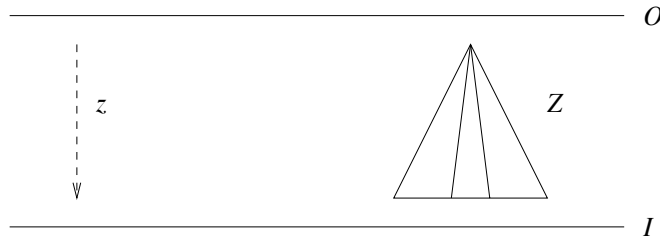


Figure 3.7: Back-and-forth structures

Definition 8 (Simple back-and-forth structures). interval structure $\mathcal{I}$ is a triple $\langle I, <, \sqsubseteq \rangle$ as defined in (Van Benthem, 1991b). $\mathcal{I}$ is a set of (possibly point-like) intervals, $<$ models the temporal precedence relation, and $\sqsubseteq$ is the subinterval relation. For simple BAF, interval structures are linear and atomic. An eventuality structure of signature $\mathcal{E}$ is a triple $\mathcal{O} = \langle O, \text{GRiTo}, \{P_e\}_{e \in \mathcal{E}} \rangle$. O is a non-empty set of eventuality occurrences, GRiTo is a binary relation on O , and $\{P_e\}$ is a set of unary relations on O . It is assumed that $\mathcal{E}$ is not empty. If $e \text{ GRiTo } e'$ then we say that e gives

¹³For an interesting, though perhaps by now slightly outdated, argument against interval based semantics and for a point based one, see Tichý’s (1981; 1985). In (1981), Tichý presents his own model of tense and aspect, using transparent intensional logic.

rise to e' . The unary relations P_e can be thought of as eventualities - for example $\text{running}(e)$ specifies e as an eventuality of running.

A back-and-forth structure of signature $\mathcal{E}$ is a quadruple $\langle \mathcal{O}, z, \mathcal{Z}, \mathcal{I} \rangle$, with $\mathcal{O}, \mathcal{I}$ as defined above. z is a function from O to I preserving the relation **GRiTo**: if e **GRiTo** e' then $z(e) < z(e')$. Thus, z is an order-preserving morphism from O to I - it is this morphism that synchronizes $\mathcal{O}$ and $\mathcal{I}$. $\mathcal{Z}$ is a relation with domain O and range I defined by $e\mathcal{Z}i$ iff $i \subseteq z(e)$. Thus, it is assumed that all eventualities are downward persistent to subintervals.

⊛

Example (A simple model of the English present perfect). To illustrate the basic intuitions behind simple BAFs as defined above, let us consider the English present perfect as exemplified in (75).

(75) **English**

Elijah has spilled his coffee.

First, let us recall the Reichenbachian model of the English present perfect - repeated below.

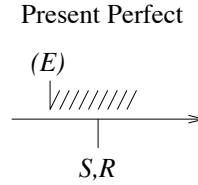


Figure 3.8: Reichenbachian schema of the English Present Perfect

As Moens & Steedman argue (cf. p.24,(2000b)), the reference point R lies within a consequent state, derived from the original event E which is an achievement. Instead of the Reichenbachian diagram as in Figure 3.8 we thus get a diagram as in Figure 3.9, including Moens & Steedman's event nucleus.¹⁴

To model these intuitions in a BAF, we first establish a language. To keep matters simple, we take a vocabulary that consists of all the elements in $\mathcal{E}$, written as $p, q, r, \dots$ called *eventuality symbols*, and a unary operator **PERF**. If ε is an eventuality symbol, then **PERF** ε is a well-formed formula; and nothing else is.

¹⁴Note that the schema in Figure 3.9 has the event E bracketed. This signifies that the perfect does not fully determine the position of E with respect to R, S - see (Steedman, 2000b)(p.24).

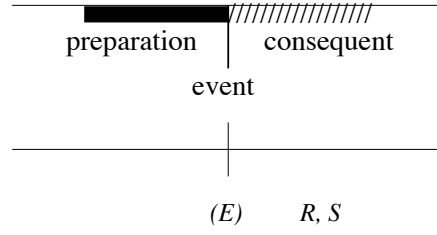


Figure 3.9: Moens & Steedman's schema of the English Present Perfect

Subsequently, let $B = \langle \mathcal{O}, z, \mathcal{Z}, \mathcal{I} \rangle$ be a BAF. For all intervals i , and all eventuality symbols ε , we define:

(76)

$$\begin{aligned}
 B, i \Vdash \text{PERF } \varepsilon \quad \text{iff} \quad & \exists i' \exists e' \exists e (i' < i \ \& \\
 & i' = z(e') \ \& \\
 & e' \in P_\varepsilon \ \& \\
 & e' \text{ GRiTo } e \ \& \\
 & e \mathcal{Z} i)
 \end{aligned}$$

Consider again the sentence in (75). In the simple language defined here, this takes the form as in (77).

(77) $\text{PERF}(\text{Elijah spills his coffee})$

Now let us see what this does, given the semantics (76). If we evaluate (77) on an interval i in B , then we must ‘complete a square’ through the back-and-forth structure leading eventually back to i . Thus, we first move back to an interval i' that precedes i ($i' < i$), and which is the temporal extent of an event e' ($i' = z(e')$). The event e' is of the correct ‘kind’, that is to say that it is an event of spilling coffee ($e' \in P_\varepsilon$). Moreover, e' gives rise to e ($e' \text{ GRiTo } e$), which $\mathcal{Z}$ relates to i ($e \mathcal{Z} i$). Intuitively, we can understand e to be the consequence of the event of spilling coffee, e.g., Elijah’s trousers being dirty.

We can couple this back to Moens and Steedman’s diagram in Figure 3.9 in a straightforward manner: The interval i is the time of speech (S), i'

is the event time (E), and e is the consequent state arising from the event that is being described, namely e' . $\otimes$

Naturally, simple BAFs give only a rather rudimentary picture. Blackburn *et al.* extend their definition of simple BAFs, enriching the eventuality structure by distinguishing different sorts of events. The sortal distinctions they introduce, and the additional relations that can hold among them, are motivated by the Vendlerian aspectual categories that Moens and Steedman capture in their diagram.

Remark 6 (Essential intuitions behind BAFs). Before I continue with describing how one could employ a sorting strategy (familiar from the discussion of hybrid logic in the previous chapter), I will clarify what I see as the essential intuitions behind BAFs and the kind of model they define (as illustrated above).

- (78) a. *Separate time from event structure:* This separation gives rise to the (intuitively correct) perspective that an event *has* a temporal extent, rather than that it *is* a particular stretch of time.
- b. *Complete the square:* If there exists a possibly complex relation between two intervals, then there needs to exist another, again possibly complex relation between the events whose temporal extent is signified the respective intervals.

When elaborating BAFs into richer structures, it is the above intuitions that we need to bear in mind. The second intuition acts as a requirement on establishing a coherent picture. The first intuition enables us to take the sorting strategy to the (logical) extent where we can consider different sorts of time to be defined in parallel to different sorts of events. $\otimes$

As said, Blackburn, Gardent and De Rijke extend the simple BAFs by considering more sorts in the eventuality structure. However, in the light of Blackburn's earlier work on tense logic (1990; 1994; to appear) it is perhaps surprising that they do not make any explicit use of hybrid logic. The advantages, I would argue, would be that couching BAFs on hybrid logic results in a more perspicuous formalization, and that it opens the obvious possibility to include the work done on formalizing tense logics in hybrid logic. Furthermore, using hybrid logic also has a distinct advantage for my purposes here, as it would mean that the model could immediately be

integrated in the overall approach to representing meaning. It is with these thoughts in mind that the formalization below is done using hybrid logic.

To begin with, consider two sets of sorts of nominals, $\mathcal{E}$ and $\mathcal{S}$. In keeping with Moens and Steedman’s proposal, $\mathcal{E}$ consists of the sorts *achievement*, *accomplishment*, *point*, and *activity*, whereas $\mathcal{S}$ contains *consequent*, *progressive*, and *habitual*. A nominal of sort $\mathcal{S}$ is typeset as S .

To relate different nominals, I simply follow Blackburn *et al.* (1993) and Steedman (2000b) in considering the preparation and the consequent of the event nucleus as *relations*. If we understand these relations as two modal operators PREP and CONS, then the (basic) event nucleus can be represented as in (79).

$$(79) \quad @_{activity} \langle \text{PREP} \rangle achievement \\ \wedge achievement \\ \wedge @_{achievement} \langle \text{CONS} \rangle consequent$$

Both PREP and CONS are of course modalities defined on the eventuality structure of a BAF. To abbreviate a representation like in (79), we write *ach* for *achievement*, *act* for *activity*, and *con* for *consequent*.

Now consider again a Priorian tense logic as illustrated earlier, in Example 2.1 on page 20. If we take the Simple Past, then the relations between E, R and S can first of all be specified as in (80): both E and R are in the past of S , and for the Simple Past it holds furthermore that E and R coincide ($@_E R$).

$$(80) \quad S \wedge \langle P \rangle E \wedge \langle P \rangle R \wedge @_E R$$

A temporal perspective like in (80) is interpreted on the interval structure of a back-and-forth structure. The interesting question is of course, how to integrate (79) and (80)?

The answer is *relatively* simple. First of all, note that “[t]he ontology of events [...] should be viewed as an ontology of the Reichenbachian E ” (Steedman, 2000b)(p.21). Furthermore, we can leave S implicit, as we already saw earlier in the representation of the discourse (16), given in (17) (see page 28).¹⁵ Thus, intuitively, we could create a representation as in (81), with *ref* being the temporal nominal corresponding to R , and “finish”

¹⁵Essentially, the model theory takes care of S as the vantage point from which a formula is evaluated.

understood as an achievement. In (81c), $\mathcal{E}$ further abbreviates the nucleus (79), such that the formula only mentions the relevant parts.

- (81) a. Kathy finished a letter.
 b. $\langle P \rangle (@_{act} \langle \text{PREP} \rangle \text{ach} \& @_{ach} \langle \text{CONS} \rangle \text{cons} \& @_{ach} \text{ref} \& @_{ach} \mathbf{finish})$
 $\rightarrow (@_{act} \langle \text{PREP} \rangle \text{ach} \& @_{ach} \langle \text{CONS} \rangle \text{cons} \& @_{ach} \text{ref} \& @_{ach} \mathbf{finish} \& \langle P \rangle \text{ach})$
 c. $(\mathcal{E} \wedge @_{ach} \text{ref} \wedge @_{ach} \mathbf{finish} \wedge \langle P \rangle \text{ach})$

There is one important observation to make about (81), and that is that we have slightly complicated the logical situation. Originally, tense operators like $\langle P \rangle$ or $\langle F \rangle$ operated on elements of the interval structure - whereas now they *seem* to be applied to elements that are interpreted on the *eventuality structure*. Their logical definition should rectify this, and we can do so in a straightforward manner by making use of z . That is, the interpretation of a tense operator $\langle T \rangle \varepsilon$ is defined on $z(\varepsilon)$, i.e. the temporal extent of the event ε .

Definition 9 (Hybrid logical BAFs). *We begin by defining a sorted eventuality structure, O_s . O_s is a tuple $O_s = \langle \mathfrak{E}, \text{GRiTo}, \text{PREP}, \text{CONS}, P \rangle$. $\mathfrak{E}$ is the set of eventuality nominals, composed from two disjoint sets $\mathcal{E}$ and $\mathcal{S}$. $\mathcal{E}$ consists of the sorts *achievement*, *accomplishment*, *point*, and *activity*, whereas $\mathcal{S}$ contains *consequent*, *progressive*, and *habitual*. GRiTo is a function defined analogously to Blackburn et al.'s GRiTo function. PREP and CONS are modal operators for which it holds that $\text{PREP} \subset \text{GRiTo}$ and $\text{CONS} \subset \text{GRiTo}$. PREP is a partial function with domain *activity* and range *achievement*, whereas CONS is a total function with domain *achievement* and range *state* (cf. (Blackburn et al., 1993)). P is simply the set of propositional formulas that can hold at eventuality nominals.*

Furthermore, we define an interval structure I_s . I_s is a tuple $I_s = \langle \mathfrak{I}, P, F, \text{DURING}, <, \sqsubseteq \rangle$. $\mathfrak{I}$ is a (suitably sorted) set of nominals modeling temporal extent, with $<, \sqsubseteq$ to provide the basic temporal structure. The modal operators P, F are the familiar hybrid logical versions of the Priorian past and future operators (Blackburn, 1994; Blackburn, to appear), and DURING is the modal reflection of $\sqsubseteq$. For all modal operators it holds that their (operational) semantics are defined in the context of a hybrid logical BAF: We allow $\langle P \rangle \varepsilon$ with $\varepsilon \in \mathfrak{E}$ as a well-formed formula by defining the operational semantics of the modal operators using z , i.e. the interpretation of $\langle P \rangle \varepsilon$ uses $z(\varepsilon)$. Thus, for example, we have that

$$\mathbf{B}, i \Vdash \langle \mathbf{P} \rangle \varphi \quad \text{iff} \quad \exists j, e (e \in \mathfrak{E} \wedge j < i \wedge e \mathcal{Z} j \wedge @_e \varphi)$$

A hybrid logical BAF is a HL-BAF $\mathbf{HB} = \langle \mathbf{O}_s, z, \mathcal{Z}, \mathbf{I}_s \rangle$. The relations $z, \mathcal{Z}$ are defined as in Definition 8, and we require by definition that $\forall e, i (i \sqsubseteq z(e) \leftrightarrow e \mathcal{Z} i)$. Additionally, we have the following conditions, after (Blackburn et al., 1993). The operator $\sqcap$ connects two intervals.

1. $z(\text{activity})$ is a non atomic bounded interval in $\mathfrak{I}$
2. $z(\text{achievement})$ is a non atomic bounded interval in $\mathfrak{I}$
3. $z(\text{accomplishment})$ is a non atomic bounded interval in $\mathfrak{I}$, which is separable (Blackburn, 1990)(p.167) into two intervals i, i' such that $i = z(\text{activity})$, $i' = z(\text{achievement})$, $i < i'$, $i \sqcap i' = z(\text{accomplishment})$.
4. $z(\text{point})$ is an atomic interval in $\mathfrak{I}$
5. $z(\text{consequent})$ is a non atomic, non bounded interval in $\mathfrak{I}$
6. $z(\text{progressive})$ is a non atomic, non bounded interval in $\mathfrak{I}$
7. $z(\text{habitual})$ is a non atomic, non bounded interval in $\mathfrak{I}$

Finally, to be able to talk explicitly in a hybrid logic about the temporal extent ι of a given eventuality ε , we define the sorted satisfaction operator $@^I$ such that for the equation $@^I_{\varepsilon} \iota$ it holds that $\iota = z(\varepsilon)$. $\circledast$

Remark 7 (Representing English tense and aspect). With the above definitions at hand, it becomes a straightforward exercise to represent the basic English tenses, as we gave them earlier on in Figure 3.4 on page 54. Important to note is that we attach a tense operator to the nominal that is of the proper sort σ given the proposition φ being expressed.

- (82) a. Simple Past, $E = R < S$: $(\mathcal{E} \wedge @_{\sigma} \varphi \wedge @_{\sigma} \text{ref} \wedge \langle \mathbf{P} \rangle \sigma)$
b. Present, $E = R = S$
c. Simple Future, $S < E = R$: $(\mathcal{E} \wedge @_{\sigma} \varphi \wedge @_{\sigma} \text{ref} \wedge \langle \mathbf{F} \rangle \sigma)$

To add aspect, we should make precise the interpretation of PERF and PROG. Blackburn et al. give in (1993) their basic definitions, formulated using hybrid logic in (83) below.

(83) a.

$$\begin{aligned}
\mathbf{B}, i \Vdash \text{PERF } \varepsilon \quad \text{iff} \quad & \exists i' \exists e' \exists e (i' < i \wedge \\
& i' = z(e') \wedge \\
& @_{e'} \varepsilon \wedge \\
& @_{e'} \langle \text{GRITo} \rangle e \wedge \\
& e \mathcal{Z} i)
\end{aligned}$$

b.

$$\begin{aligned}
\mathbf{B}, i \Vdash \text{PROG } q \quad \text{iff} \quad & \exists ach (@_{ach} q \wedge i \sqsubseteq^+ z(ach)) \vee \\
& \exists progressive (@_{progressive} q \wedge i \sqsubseteq^+ z(progressive))
\end{aligned}$$

Here, $i \sqsubseteq^+ j$ holds if the interval i is a proper interval of j with neither i 's start nor end coinciding with that of j . For our present purposes, we consider $@_i \langle \text{DURING} \rangle j$ to be interpreted as $i \sqsubseteq^+ j$. Given (83), it is easy to define for example the past progressive - see (84).

$$(84) \quad \mathbf{B}, i \Vdash \langle \text{PAST} \rangle \langle \text{PROG} \rangle \varphi \quad \text{iff} \quad \exists j (j < i \wedge \mathbf{B}, j \Vdash \langle \text{PROG} \rangle \varphi)$$

To round off these remarks, consider how we could represent the pair of example sentences as in (85), with their representations in (86).

(85) a. Christopher was writing a letter.

b. Christopher wrote a letter.

$$\begin{aligned}
(86) \quad \text{a.} \quad & (\mathcal{E} \wedge @_{act} \mathbf{write} \wedge @_{ref} \langle \text{DURING} \rangle act \wedge \langle \text{PAST} \rangle \langle \text{PROG} \rangle act \\
& \wedge @_{act} \langle \text{ACTOR} \rangle (c \wedge \mathbf{Christopher}) \\
& \wedge @_{act} \langle \text{PATIENT} \rangle (l \wedge \mathbf{letter})) \\
\text{b.} \quad & (\mathcal{E} \wedge @_{act} \mathbf{write} \wedge @_{actref} \wedge \langle \text{P} \rangle act \\
& \wedge @_{act} \langle \text{ACTOR} \rangle (c \wedge \mathbf{Christopher}) \\
& \wedge @_{act} \langle \text{PATIENT} \rangle (l \wedge \mathbf{letter}))
\end{aligned}$$

When explaining how aspectual change can be modeled using hybrid logical BAFs, I will discuss what happens to (86a)'s term " $@_{act} \mathbf{write} \wedge \langle \text{PAST} \rangle \langle \text{PROG} \rangle act$ " in more detail. $\otimes$

Remark 8 (The imperfective paradox can be explained). Next to (85), consider (87).

- (87) a. Elijah was wasting valuable time and money on becoming a John Wayne look-alike.
 b. Elijah wasted valuable time and money on becoming a John Wayne look-alike.

The examples in (85) and (87) can be used to illustrate a phenomenon that Dowty (1979) called the *imperfective paradox* (cf. pp.133-135). The imperfective paradox intuitively comes down to the following problem. How can we account for the meaning of sentences like (85a) and (87a), such that (85a) may be true without (85b) ever necessarily becoming true, whereas (87a) would tautologically imply (87b)? Rephrased in terms of the event nucleus, the question whether $(85a) \Vdash (85b)$ means asking whether a preparation (necessarily) implies its completion in the event. Just as in (Blackburn et al., 1993), there is no contradiction in continuations of preparations to explicitly deny its culmination, (88).

- (88) Christopher was writing a letter, but gave it up to play a game.

In a hybrid logical BAF the failure of a preparation e of sort **act** to culminate in a particular event e' of sort **ach** is represented by the fact that the *partial* function PREP is not defined onto e' .

This explains the relation between (85a) and (85b), but that is one part of the problem. The other part is, How does a hybrid logical BAF guarantee that $(87a) \Vdash (87b)$? The ground for this guarantee is the requirement that $\forall e, i (i \sqsubseteq z(e) \leftrightarrow eZi)$. For any HL-BAF HB, and any interval i in HB, we have -per (83) and (84)- the following:

- (89) $B, i \Vdash \langle \text{PAST} \rangle \langle \text{PROG} \rangle (\text{Christopher's wasting ...})$
 iff $\exists j (j < i \wedge B, j \Vdash \langle \text{PROG} \rangle (\text{Christopher's wasting ...}))$
 iff $\exists j, e (j < i \wedge @_e (\text{Christopher's wasting ...}) \& j \sqsubseteq {}^+ z(e))$

But (89) means that $j \sqsubseteq z(e)$, and hence eZj . From this, we obtain (90).

- (90) $B, i \Vdash \langle \text{PAST} \rangle (\text{Christopher's wasting ...})$

In other words, we arrive at the conclusion that $(87a) \Vdash (87b)$, in a way similar to (Blackburn et al., 1993). $\otimes$

Remark 9 (Capturing aspectual change.). How do we use hybrid logical BAFs to capture aspectual change, as it is explained by Moens & Steedman's

model? Here, I first focus on aspectual change brought about by the progressive (PROG) and the perfective (PERF) which I already discussed above. Then, I look at how we can model the aspectual change effectuated by particular dependency relations.

The aspectual changes that the progressive and the perfective may give rise to are modeled by the implications in (91), analogously to the modal rewriting rules that Oehrle (1999) employs in an account of binding.

- (91) a. $\langle \text{PROG} \rangle (@_{act}\varphi \wedge @_{act}ref)$
 $\rightarrow @_{act}\langle \text{PROG} \rangle progstate \wedge @_{progstate}\varphi \wedge @_{progstate}ref$
 b. $\langle \text{PROG} \rangle (@_{acc}\varphi \wedge @_{acc}ref)$
 $\rightarrow @_{acc}\langle \text{PROG} \rangle act \wedge @_{act}\varphi \wedge @_{act}ref$
 c. $\langle \text{PERF} \rangle (@_{ach}\varphi \wedge @_{ach}ref)$
 $\rightarrow @_{ach}\langle \text{PERF} \rangle constate \wedge @_{constate}\varphi \wedge @_{constate}ref$

Pictorially, what happens in e.g. (91a) is illustrated Figure 3.10. The lefthand side of the picture shows the normal framestructure of the event nucleus at the sorted eventuality structure $\mathcal{O}$, and its reflection at the interval structure $\mathcal{I}$ as bounded intervals [...]. The righthand side displays the resulting structure: We now refer to a *progressive state* *progstate*, which is reflected by a non bounded interval [...].

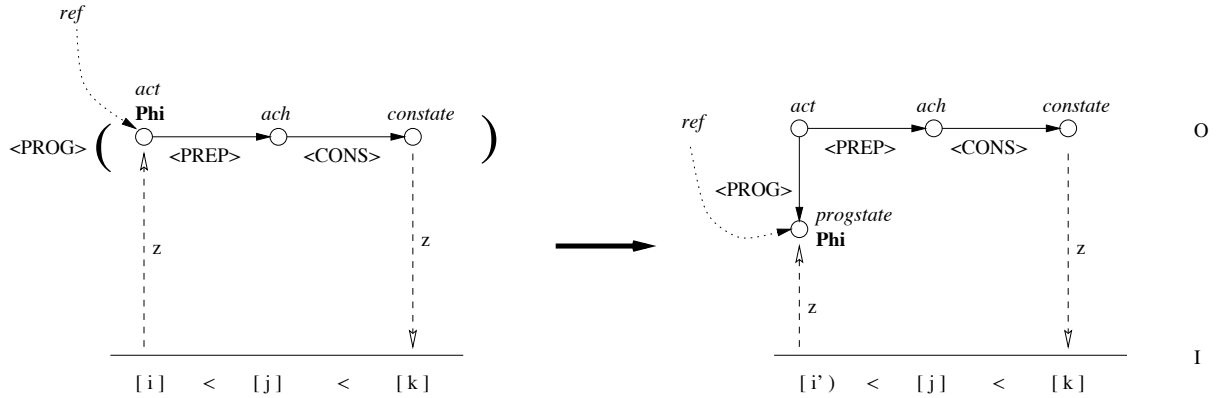


Figure 3.10: BAF visualization of PROG induced aspectual change

The contention here is that similar constructions can be given to represent other coercions - a topic I leave for future work, though. Instead, I would like to illustrate how we represent the effect that particular dependency relations have on aspectual change, as discussed earlier. Consider

again (52), here repeated as (92). Our base case, the representation of “John walks”, is given in (93).

$$(92) \quad \text{John walks} \begin{cases} \text{a mile.} \\ \text{to the park.} \end{cases} \quad (\text{Dowty, 1979})(\text{p.60})$$

$$(93) \quad \mathcal{E} \wedge @_{act}ref \wedge @_{act}\mathbf{walk} \wedge @_{act}\langle\mathbf{ACTOR}\rangle(j \wedge \mathbf{John})$$

As Dowty (1979) points out, the aspectual category of “John walks” from being an activity to being an accomplishment, due to the modification by either a **Time:Till When** or **Direction:Where To** dependent. The resulting representation could then be as given e.g. in (94), with +ACHVMNT a modal relation to model the *+achievement* transition in Moens & Steedman’s model.

$$(94) \quad \begin{aligned} \text{a. John walks [to the park]}_{WhereTo}. \\ \text{b. } \mathcal{E} \wedge @_{act}\langle+\mathbf{ACHVMNT}\rangle acc \wedge @_{acc}ref \wedge @_{acc}\mathbf{walk} \\ \wedge @_{acc}\langle\mathbf{ACTOR}\rangle(j \wedge \mathbf{John}) \wedge @_{acc}\langle\mathbf{WHERETO}\rangle(p \wedge \mathbf{park}) \end{aligned}$$

However, applying any rule of the form as in (91a) would also have to result in reconsidering all bindings with the dependents, as the nominal referring to the state where the head holds, changes. To localize any aspectual change to the event nucleus proper, we can first of all consider the logical equivalent of (94b), given in (95).

$$(95) \quad \begin{aligned} \mathcal{E} \wedge @_{act}\langle+\mathbf{ACHVMNT}\rangle acc \wedge @_{acc}ref \\ \wedge @_w acc \wedge @_w\mathbf{walk} \\ \wedge @_w\langle\mathbf{ACTOR}\rangle(j \wedge \mathbf{John}) \wedge @_w\langle\mathbf{WHERETO}\rangle(p \wedge \mathbf{park}) \end{aligned}$$

A formulation like (95) makes it possible to formulate rules for aspectual change effectuated by dependency relations, analogously to (91).

$$(96) \quad \begin{aligned} \text{a. } @_hact \wedge @_href \wedge @_h\langle\mathbf{WHERETO}\rangle d \\ \rightarrow @_{act}\langle+\mathbf{ACHVMNT}\rangle acc \wedge @_hacc \wedge @_href \wedge @_h\langle\mathbf{WHERETO}\rangle d \\ \text{b. } @_hact \wedge @_href \wedge @_h\langle\mathbf{TILLWHEN}\rangle d \\ \rightarrow @_{act}\langle+\mathbf{ACHVMNT}\rangle acc \wedge @_hacc \wedge @_href \wedge @_h\langle\mathbf{TILLWHEN}\rangle d \\ \text{c. } @_hact \wedge @_href \wedge @_h\langle\mathbf{LOCATIVE}\rangle d \\ \rightarrow @_{act}\langle+\mathbf{ACHVMNT}\rangle acc \wedge @_hacc \wedge @_href \wedge @_h\langle\mathbf{LOCATIVE}\rangle d \\ \text{d. } @_hact \wedge @_href \wedge @_h\langle\mathbf{RESULT}\rangle d \\ \rightarrow @_{act}\langle\mathbf{INCHOATIVE}\rangle acc \wedge @_hach \wedge @_href \wedge @_h\langle\mathbf{RESULT}\rangle d \end{aligned}$$

$$\begin{aligned} \text{e. } @_h act \wedge @_h ref \wedge @_h \langle \text{COUNTERFACTUAL} \rangle d \\ \rightarrow @_{act} \langle \text{INCHOATIVE} \rangle acc \wedge @_h ach \wedge @_h ref \wedge @_h \langle \text{COUNTERFACTUAL} \rangle d \end{aligned}$$

To ensure that the hybrid logical representation of a sentence's linguistic meaning indeed comes to reflect the proper aspectual category, the rules in (91) and (96) are included in our logic as axioms. $\otimes$

3.4 DEPENDENCY RELATIONS

The aim of the current section is to describe the dependency relations that are distinguished in FGD (and which we use in DGL as well)¹⁶. The description relies in part on the discussions in Panevová's (1974; 1975), Sgall *et al.*'s (1986), and Petkevič's (1995; in prep). For each of the 38 dependency relations FGD distinguishes, I provide examples of forms in which the dependency relation can occur (usually, in various languages).¹⁷ Most importantly, for each dependency relation I specify the *semantic import* it can have.¹⁸

By the 'semantic import' of a dependency relation I mean the following. When we interpret word forms, which occur in a sentence's outer form, either as heads or as dependents modifying those heads along specific relations, we are not just building a formal structure (that is, or is not, different from a structure developed on a constituency-based formalism). Particularly, by interpreting a word form as a dependent, we specify *how* the meaning underlying the word form contributes to the meaning of the head - and as such, to the linguistic meaning of the sentence. It is this 'how' that I mean when I speak of the semantic import of a dependency relation.

When I describe the semantic import of a dependency relation in this section, I make explicit use of the event nucleus discussed (and defined) in the preceding section. The event nucleus provides us with the essential information about temporal and causal structure, information that is

¹⁶That is to say, FGD as discussed in Sgall *et al.*'s (1986), and Petkevič's (1995; in prep). Sgall *et al.* do remark that the list is not final. For example, see the longer list employed in tagging the Prague Dependency Treebank, documented in Hajičová *et al.* (2000).

¹⁷Important sources of inspiration for the examples given here are Panevová's (1975), Sgall *et al.*'s (1986), and Petkevič's (1995). If an example is taken straight from either of sources, proper citation is given.

¹⁸I should like to make clear though that the semantics I specify for the dependency relations are not claimed to exhaust all the possible interpretations of the dependency relations that FGD distinguishes.

augmented by the semantic import of dependency relations. The semantic import of a dependency relation is specified using hybrid logic and the hybrid logic-BAFs.

With every dependency relation being individually different, as pointed out earlier, we act here on the hypothesis that each dependency relation differs (among other things) in the characterization of its semantic import. At the same time, making the semantic import of each dependency relation more explicit, as we shall do here, also certain regularities across such characterizations come to light. These regularities give -quite naturally- rise to various *classes* of dependency relations. In particular, the classes of dependency relations I describe below are the following:

- Dependency relations relating eventualities in an “implicative” way.
- Dependency relations reflecting stage (time, direction, location).
- Dependency relations attributing qualities to objects.
- Dependency relations expressing *modus operandi*.
- Inner participants.

These classes are in part inspired by the intuitive grouping of dependency relations that Sgall *et al.* give in (1986) (pp.158-163).

3.4.1 DEPENDENCIES RELATING EVENTUALITIES IN AN IMPLICATIVE WAY

FGD distinguishes several dependency relations that indicate an “implicative” or “causal” relation between the eventuality to which the verbal head is related, and the eventuality to which the dependent can be related. Syntactically, a construction involving one of these dependency relations prototypically has a dependent that is itself a verbal head, or a noun derived from a verb (i.e. in both cases there is a clear reference to an eventuality).

The dependency relations that we consider to belong to this class are **Purpose**, **Cause**, **Result**, **Condition**, and **Concession**. All these dependency relations focus on one or another aspect of the causal structure of the event nucleus, as defined using GRiTO, PREP and CONS.

Purpose

The **Purpose** dependency relation signifies that obtaining the eventuality referred to by the dependent is the aim, or purpose, of the process denoted by the verb that is being modified by the dependent. For example,

(97) **English**

Christopher studies intensively [in order to pass the exam]_{Purpose}.

(98) **Dutch**

Elijah heeft hard gespaard [om op vakantie te
Elijah has been diligently saving in order to on holidays to
kunnen gaan]_{Purpose}.
be able go

“Elijah has been diligently saving in order to be able to go on holidays.”

(99) **Czech**

Kryštof intensivně studuje, aby se dostal na
Christopher intensively studies so that REFL admit to
universitu.
university.

“Christopher studies intensively to be admitted to the university.”

More specifically, I define the semantic import of **Purpose** as follows. The semantic import of **Purpose** assumes that the head is an *activity*.¹⁹ The **Purpose** specifies an event nucleus to which the head’s activity is a *preparation*. If we consider δ to be the event nucleus referred to by the **Purpose** dependent, and h the head (referring to an activity), then the semantic import can be defined as in (100).

(100) **Purpose:**

$$@_h\langle \text{PURPOSE} \rangle \delta \rightarrow @_h\langle \text{PURPOSE} \rangle \delta \wedge @_h\langle \text{F} \rangle \delta,$$

“The process denoted by the verbal head makes it possible for the eventuality referred to by the dependent to obtain later.”

¹⁹Oehrle (p.c.) remarks that it is perhaps better to consider the construction to be an “intentionally maintained state” rather than an activity. For example, it seems odd to express “I am here to further World Peace” with a progressive, in English. It needs to be considered whether (and if so, how) we need to refine Moens & Steedman’s model to capture these more fine-grained distinctions.

Hence, reconsidering for example (97), we could phrase the semantic import of the **Purpose** relation as saying that

- (101) (Chris studies intensively, “now”) makes it possible that (Chris might pass the exam, “later on”)

A point that can be raised against the characterization above is that it involves a dependent having a reference to an eventuality. But what about examples like (102-105)?

- (102) **English**

The poor man begged for a few pennies.

- (103) **Dutch**

De student vroeg om korting.

The student asked for discount

“The student asked for a discount.”

- (104) **Dutch**

Het kind hoopte op een groot kado.

The child hoped for a large present

“The child hoped for a large present.”

In neither of these cases there is an explicitly mentioned verb. However, it seems reasonable to assume that with the meaning of the preposition it is specified that there is an implicit reference to *some relation*, here illustrated as an eventuality of obtaining - if we want to interpret the preposition as realizing the function of **Purpose**:

- (105) **English**

The poor man begged for [obtaining] a few pennies.

- (106) **Dutch**

De student vroeg om korting [te krijgen].

The student asked for discount [to obtain]

“The student asked for [obtaining] a discount.”

- (107) **Dutch**

Het kind hoopte op een groot kado [te krijgen].

The child hoped for a large present [to obtain]

“The child hoped for [obtaining] a large present.”

Result

There exists an interesting contrast between **Purpose** and **Result**. For one, whereas **Purpose** indicates the *possibility* of an eventuality obtaining, a **Result** states the *necessity* of that eventuality obtaining. As Panevová notes (1974), that necessity can either be positive (the eventuality does obtain) or negative (the eventuality ‘definitely’ does not obtain). This can be modeled using negation of the proposition holding at the state referred to by a **Result** dependent.

Another interesting aspect of **Result**, closely related to the mentioned necessity, is that it assumes the head to be of a different aspectual category than **Purpose** does. Namely, a **Result** assumes the head to be an aspectual category that has an identifiable culmination point - thus, either an achievement or an accomplishment. For simplicity, I define the semantic import of **Result** using achievement only.²⁰ Then, because a result lacks any definite temporal bounds, it can be identified with a state - particularly, a **Result** specifies the consequent state of the head’s event nucleus.

(108) **Result:**

$$\mathcal{E} \wedge @_h \langle \text{RESULT} \rangle \delta \rightarrow \mathcal{E} \wedge @_{\text{consequent}} \delta \wedge @_h [\text{F}] \delta \wedge @_h \langle \text{RESULT} \rangle \delta$$

“The process denoted by the verbal head makes it necessary for the eventuality referred to by the dependent to obtain (“as a result of that”).”

(109) **English**

Elijah lowered the fire [so that the meat would not burn]_{Result}.

(110) **English**

Kathy opened the door [in order to let Christopher in]_{Result}.

Cause

Both in the case of **Purpose** and in that of **Result** the eventuality referred to by the dependent is assumed to occur after it. **Cause** presents the opposite case, as it were. Namely, the eventuality referred to by the head is

²⁰There is a deeper reason here than a mere desire for simplicity: It seems to me that if we take an accomplishment, then what we would *actually* take is a composite event consisting of an achievement with an active component (“+activity”), whereby the *composite* is indeed an achievement due to type coercion. Empirical data would hopefully shed more on this.

implied by the one referred to by the dependent - and, from a temporal perspective, necessarily so.²¹ Consider for example the following sentences.

(111) **English**

The road was blocked [because the river had crossed its banks]*Cause*.

(112) **English**

Christopher's salad tasted horrible [because he had forgotten to add olive oil]*Cause*.

(113) **English**

The dinner party was saved [owing to Kathy having prepared a splendid dessert]*Cause*.

However, we can also have sentences of the like of (114-117).

(114) **Dutch**

De berekening leverde een foute uitkomst op [vanwege een
The calculating provided a wrong result due to an
fout in het programma]*Cause*.
error in the program

“The calculation provided a wrong result due to an error in the program.”

(115) **English**

The train halted [because of a sheep on the tracks]*Cause*.

(116) **English**

The road was blocked [due to an accident]*Cause*.

(117) **English**

The road was blocked [because of a flooding]*Cause*.

The situation here is not much different from before, cf. examples (102-105) on page 73. Leaving those nouns aside that are derived from verbs (and thus are assumed to already refer to an eventuality; example 117), we still have constructions like (114-116). Again it seems reasonable to assume, as I did before, that there is an implicit ‘verb’ introducing a reference to an eventuality:

²¹This characterization should be understood as a simplification. I do not have here the possibility to systematically inquire into the often discussed issue of what is the proper meaning of ‘cause’. Therefore, I present here only a characterization of **Cause** as a condition having a necessary consequence, referred to by the governing clause.

(118) **English**

The road was blocked [due to [there being] an accident]_{Cause}.

(119) **English**

The train halted [because of [there being] a sheep on the tracks]_{Cause}.

For illustration we used “there being” but one could also think of “there having occurred”, etc. The point is not what ‘verb’ we should consider to have been ‘deleted’ - the issue here is *not* deletion, the issue is that there is an implicit reference to an eventuality. Like we proposed in the case of the English *for* and the Dutch *om*, if the preposition combines with a noun that is not derived from a verb, and the form (i.e. the prepositional group) is to be interpreted as realizing the function of a **Cause**, then we can assume a reference to an eventuality to be part of its meaning.

This leads us then to the characterization of **Cause**, as in (120). I assume the **Cause** to be an activity, relating on the head’s preparatory activity.

(120) **Cause:**

$$\mathcal{E} \wedge @_h \langle \text{CAUSE} \rangle \delta \rightarrow \mathcal{E} \wedge @_{\delta} act \wedge @_{\delta} [F] h$$

“The eventuality referred to by the verbal head was caused by the process referred to by the dependent, which happened before the eventuality referred to by the verbal head.”

Figure 3.11 visualizes the relations induced by a **Cause**, both at the level of **O** and at **I**. To elucidate how the idea of *causality* is incorporated in a definition like (120), it is instructive to recall Definition 9 at this point. There, I defined hybrid logical BAFs, and -among others- the **GRiTo** (“Gives Rise To”) function. **GRiTo** defines the behavior of the modal operators **PREP** and **CONS**, which provide the causal structure of Moens & Steedman’s event nucleus. Now it is easy to see how a causal relationship between a **Cause** dependent and the head is established: We equate δ with *act*, and thus bring it into a **PREP** relation with the head. (In other words, we make essential use of the causal nature of event nucleus.)

Finally, consider (121), as an illustration of **Cause** as a free modifier allowing for multiple occurrences.

(121) **English**

[Due to poverty]_{Cause} many people died [of TBC]_{Cause}, [since its

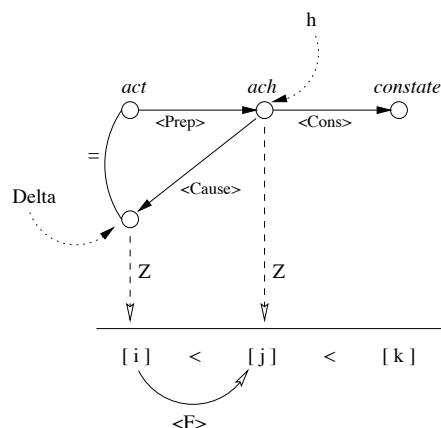


Figure 3.11: BAF visualization of CAUSE's semantic import

treatment was expensive]_{Cause}.
 (Panevová, 1994), p.228

Condition

The dependency relation **Condition** is related to **Cause** in that it assumes a similar implication between the eventuality referred to by the head, and that referred to by the dependent. In the context of this dissertation, I make the simplifying assumption that **Condition** differs from **Cause** in its temporal reference - that is to say, the time frame it concerns. Whereas with **Cause** I understand the eventualities to have occurred (or at least started) before the time the sentence was uttered, a **Condition** is taken here to involve a future reference.²²

The exact form that such 'future reference' takes depends on the type of condition. Various authors have distinguished -at least- two types of conditions. Here, I consider **Factual** and **Counterfactual**, (because of their inclusion in the list of dependency relations presented in (Petkevič, 1995)). With the **Factual**, we might understand the 'future reference' to refer to a point in the future relative to the here and now when the sentence is being uttered:

(122) English

Elijah will not be able to go skiing [if Kathy does not financially

²²Note that *indicative conditionals* form an exception to this: "If Christopher is at the met now, then he arrived in New York last night."

support him]*Factual*.

(123) **English**

[In hot weather]*Condition* the number of patients rises very quickly,
[if medical assistance is not substantially increased]*Condition*.
(Panevová, 1994), p.228

The **Counterfactual** is based at a point in the past relative to the eventuality to whose future the **Counterfactual** refers. That future can possibly be in the past relative to the here and now as (124) illustrates, but this is not necessarily so.

(124) **English**

[If Christopher had known the project would be so time-consuming
]*Counterfactual*, he would never have started working on it.

For **Factual** and **Counterfactual** I propose the following, preliminary characterizations:²³

(125) **Factual:**

$@_h\langle \text{FACTUAL} \rangle \delta \rightarrow @_h\langle \text{FACTUAL} \rangle \delta \wedge @_h[P]\delta$

“For the eventuality referred to by the head to obtain, it is necessary that first of all the eventuality referred to by the dependent obtains.”

(126) **Counterfactual:**

$@_h\langle \text{COUNTERFACTUAL} \rangle \delta \rightarrow @_h\langle \text{COUNTERFACTUAL} \rangle \delta \wedge \neg @_\delta \langle F \rangle h$

“It necessarily follows from the eventuality referred to by the dependent that the eventuality referred to by the head cannot obtain.”

Again, the definitions employ in an essential way the causal aspects of the event nucleus. For example, consider the definition for the **Counterfactual**, (126). There, it is stated that δ has no possible future relating it to h - a relation at the level of intervals, I. By ‘completing the square’, it follows that δ cannot be in either a PREP or a CONS relation to h , at the level of eventuality occurrences O. Thus, h cannot be brought about by the **Counterfactual** δ .

²³ Again, it is important to bear in mind that at this point the aim is to develop an intuitive feel for what the various dependency relations might mean. Characterizations like (125) and in particular (126) are not intended to do full justice to the logical interpretation factual and counterfactual statements might have, as discussed in the literature. Carpenter provides a brief review in (1997).

Concession

The final dependency relation we consider under the heading of dependency relations that reflect an implicative relation between the verbal head and its dependent, is **Concession**. That there is a notion of implication involved is illustrated for example by Halliday's characterization in (1985) of concession as conveying "if P then, contrary to expectation, Q ." The next couple of examples instantiate this view:

(127) **English**

[Although the traffic lights showed red]*Concession*, Kathy recklessly drove on.

(128) **Dutch**

[Alhoewel Elijah anders een goede smaak heeft]*Concession*,
Although Elijah otherwise a good taste has ,
kon Kathy zijn onlangs aangeschafte rood-leren cowboy laarzen
could Kathy his recently acquired red-leather cowboy boots
niet waarderen.
not appreciate

"Although Elijah has otherwise got a good taste, Kathy could not appreciate his recently acquired red-leather cowboy boots."

(129) **English**

Although Christopher carried his dog in the underground, he got a fine.

Implicit in all these examples is that the **Concession**-dependent invokes an expectation, which takes the form of an implication, the consequent of which then gets negated by the clause of the verbal head. Or, to use the causal structure of the event nucleus, the preparation did not lead to the expected event, but rather to the opposite.

(130) **Concession:**

$$\begin{aligned} \mathcal{E}_h \wedge @_h \langle \text{CONCESSION} \rangle \delta \wedge \mathcal{E}_\delta &\rightarrow \\ \mathcal{E}_h \wedge @_h \langle \text{CONCESSION} \rangle \delta \wedge \mathcal{E}_\delta \wedge @_\delta \langle \text{PREP} \rangle \text{ach}_\delta \wedge @_{\text{ach}_\delta} \varphi \\ \wedge @_\delta \langle \text{PREP} \rangle \text{ach}_h \wedge @_{\text{ach}_h} \neg \varphi \end{aligned}$$

"Whereas it was possible ("expected") that φ would obtain given the process denoted by the dependent, the opposite actually occurred."

Constructions realizing a **Concession** mostly involve what Knott (1996) calls “negative polarity causal connectives”, like the English *although*, *however*, *nevertheless*. Kruijff-Korbayová and Webber discuss in their (2000; 2001) how one can give a more detailed account of the semantics of these connectives, making use of Knott’s work and of Lagerwerf’s (1998).

The characterization of **Concession** I give in (130) leaves open a number of issues that Kruijff-Korbayová and Webber do address - notably, the exact status of expectations, when thought of as defeasible rules that are being presupposed by a negative polarity causal connective. The main idea expressed here is that aspect plays an important role also in concessions, as they relate to the causal structure of an event nucleus. Naturally we could try to *accommodate* the more precise causal relation(s) that Kruijff-Korbayová and Webber discuss. One way in which this could conceivably be done would be to refine the model-theoretic semantics of **GRiTo** (and, more specifically, **PREP**), such that the relation would display a model-theoretic behavior mimicking a defeasible implication. Figure 3.12 shows the relations that hold between the event nuclei that the head and the dependent relate to, and illustrates the above point regarding **GRiTo**.

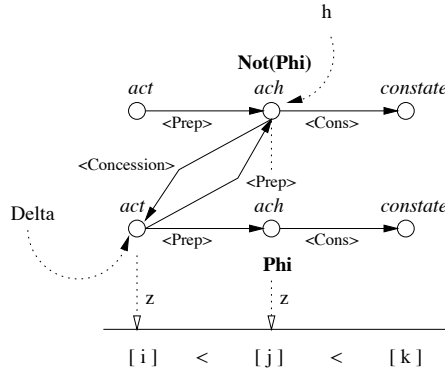


Figure 3.12: BAF visualization of CONCESSION’s semantic import

3.4.2 DEPENDENCIES SIGNIFYING TIME, DIRECTION, OR LOCATION

A fairly large number of dependency relations signify a temporal aspect of the process that the verbal head signifies, or a direction or location. All these dependency relations are gathered here under the common denominator “stage dependencies”, as they can be thought of as ‘setting the stage’.

Time

The **Time:Since When** dependency relation indicates that the head's eventuality covers an interval of time which started at the time of the dependent's eventuality. Making use of the $\langle \text{SINCE} \rangle$ modal operator (cf. (Blackburn, 1990)) we can define **Time:Since When** as in (131).

- (131) **Time:Since When:** for e the eventuality of the head, and τ the temporal nominal expressed by the dependent, $@^I_e \langle \text{SINCE} \rangle \tau$. Or, if the dependent refers to an eventuality, then we have that
- $$@_e \langle \text{SINCE WHEN} \rangle \delta \wedge @^I_\delta \tau \rightarrow$$
- $$@_e \langle \text{SINCE WHEN} \rangle \delta \wedge @^I_\delta \tau \wedge @^I_e \langle \text{SINCE} \rangle \tau$$

In English, constructions involving **Time:Since When** often use prepositional groups formed with *from* or *since*, as illustrated in (132-134) below.

- (132) **English**
Kathy has been working [since last night]_{Since}.
- (133) **English**
Charles University has been in existence [from the 14th century on]_{Since}.
- (134) **English**
Christopher and Elijah know each other [from the time they were at basic school together]_{Since}.

The **Time:Till When** dependency relation is in a sense the opposite of **Time:Since When**. Whereas **Time:Since When** indicates a starting point, the dependent modifying a head by **Time:Till When** marks the ending point of the verbal head's eventuality²⁴. In keeping with that observation, I use $\langle \text{UNTIL} \rangle$ rather than $\langle \text{SINCE} \rangle$ to define **Time:Till When**.

- (135) **Time:Till When:** for e the event of the head, and τ the temporal nominal expressed by the dependent, $@^I_e \langle \text{UNTIL} \rangle \tau$. Or, if the dependent refers to an eventuality, then we have that
- $$@_e \langle \text{UNTIL WHEN} \rangle \delta \wedge @^I_\delta \tau \rightarrow$$
- $$@_e \langle \text{UNTIL WHEN} \rangle \delta \wedge @^I_\delta \tau \wedge @^I_e \langle \text{UNTIL} \rangle \tau$$

²⁴Or, if present tense is used, and it is clear from the context that the speaker means to be talking about the here and now, then the dependent can be taken to indicate that the process signified by the verb has lasted -at least- until the very moment the sentence was uttered - see example (137).

(136) **English**

Christopher was in New York [till yesterday]_{Till When}.

(137) **English**

Kathy has not been able to find a solution [until now]_{Till When}.

A dependent modifying a verbal head along **Time:When** identifies the time of the head's eventuality.

- (138) **Time:When**: for e the event of the head, and τ the temporal nominal expressed by the dependent, $@^I e\tau$. Or, if the dependent refers to an eventuality, then we have that $@_e\langle\text{WHEN}\rangle\delta \wedge @^I_\delta\tau \rightarrow @_e\langle\text{WHEN}\rangle\delta \wedge @^I_\delta\tau \wedge @^I_e\tau$.

Again, as the following examples make clear, we need not be thinking about a concrete time-*point*: the dependent may well indicate an *interval*. The crux is that dependent refers to a more or less identifiable timing (i.e. a time point or an interval, the boundaries of which in the general case are indistinct). Examples (139) and (140) identify intervals, whereas (141) marks a specific time point.

(139) **English**

Christopher visited the *Barnes & Nobles* on Broadway [the day before yesterday]_{When}.

(140) **English**

Kathy finished her book [before going to sleep]_{When}.

(141) **English**

The server crashed exactly at [punctually 6 o'clock in the evening]_{When}.

Aspect and tense naturally can play an important role here, as discussed for example by Steedman (2000b). Similarly, Panevová (p.c.) cites examples as in (142) through (145).

(142) **Czech**

Když maminka vstoupila do místností, tatínek
When entered-PERF mom into room, daddy
rozsvítil.
turn-on-light-PERF

“When mom entered the room, daddy turned on the light.”

(143) **Czech**

Když maminka vstupovala do místností, tatínek
When entered-IMPERF mom into room, daddy
rozsvěcoval.
turn-on-light-IMPERF

“When mom was entering the room, daddy was turning on the light.”

(144) **Czech**

Když maminka vstupovala do místností, tatínek
When entered-IMPERF mom into room, daddy
rozsvítil.
turn-on-light-PERF

“When mom was entering the room, daddy turned on the light.”

(145) **Czech**

Než maminka vstoupila do místností, tatínek
Before mom entered-PERF into room, daddy
rozsvítil.
turned-on-light-PERF.

“Before mom entered the room, daddy turned on the light.”

The understanding is that (142) can be paraphrased using “after”, thus indicating that the temporal extent indicated by the dependent occurs in the future of that of the event of the modified head. (143) on the other hand illustrates a dependent that specifies a temporal extent occurring *during* that of the modified head, with the change in aspect in (143) indicating (only) a partial *overlap*. Panevová’s last example, (145), illustrates strict temporal precedence (i.e. no overlap). All these dependents would be analyzed as **Time:When** dependents in FGD, though, since the quoted differences are expressed by those of the conjunction and by aspect, in Czech, rather than by tense (Sgall & Hajičová, p.c.).

Formally, to cover examples like (142) through (145), we need to couple the definition of e.g. the perfective PERF (83) or an imperfective counterpart IMPERF to the definition of e.g. **Time:When** (138), and consider their interaction. For example, the perfective with the semantic import of **Time:When** identify a past interval. If we combine this with the perfective

of the main clause, as in (145), and an -intuitive- interpretation of “before” as temporal precedence ($<$), then we adequately cover the intended meaning of (145).

Time:How Long identifies a period of duration.

- (146) **Time:How Long:** for e the event of the head, and τ the temporal nominal expressed by the dependent, $@^I e \tau$ (with τ of an interval sort).

- (147) **English**

Elijah stayed in Texas [through the entire winter]_{How Long}.

- (148) **English**

The *Muppet Show* was broadcast on Dutch TV [during the 1970’s and 1980’s]_{How Long}.

Sgall *et al.* briefly point out in (1986), a **Time:For How Long** describes an *intended period* (p. 159), as in (149) below:

- (149) **English**

He will work on this topic [for his whole life.]_{For How Long}

Here, I define the semantic import of **Time:For How Long** as identical to that of **Time:How Long**, leaving the inference of any possible intentions behind **Time:For How Long** to the stage of discourse interpretation.

The **Time:Contemporariness** dependency relation elucidates that the dependent’s eventuality overlaps with the verbal head’s eventuality. Syntactically, the dependent is either a verb (150), or a noun derived from a verb (151). Both are assumed to have meanings with an identifiable temporal extent (at I).

- (150) **English**

Christopher fell asleep while the potatoes were boiling.

- (151) **English**

Christopher slept during his flight from New York.

- (152) **Time:Contemporariness:**

$$@_h \langle \text{CONTEMP} \rangle \delta \wedge @^I_{\delta} \tau \wedge @^I_h \tau' \rightarrow$$

$$@_h \langle \text{CONTEMP} \rangle \delta \wedge @^I_{\delta} \tau \wedge @^I_h \tau' \wedge (@_{\tau} \langle \text{DURING} \rangle \tau' \vee @_{\tau'} \langle \text{DURING} \rangle \tau)$$

Directions and Locative

FGD distinguishes one dependency relation specifying the location of the head (**Locative**), and various types of dependency relations designating direction (**Direction:From Where**, **Direction:Through**, **Direction:Where To**). We can conceive of each of these dependency relations as determining a location relative to the eventuality referred to by the head that is being modified.

To be able to capture this, the hybrid logical BAFs capturing causal and temporal information need to be extended to cover also *locations*. Intuitively, eventualities are not just causally related at O and have a temporal extent reflected at I , but they also have a *spatial* extent. Again, the sorting strategy of hybrid logic provides interesting possibilities. Here, I propose to start with two sorts of spatial extent (“locations”): *points*, and *areas*.²⁵ Definition 10 makes these ideas more precise.

Definition 10 (Adding spatial extent to HyLo-BAFs). *We define a sorted spatial structure, S_s , as a tuple $S_s = \langle \mathfrak{S}, Conn, MOVE, INCL, P_s \rangle$. $\mathfrak{S}$ is a set of spatial nominals, composed from two disjoint sets $\mathcal{P}$ (points) and $\mathcal{A}$ (areas). $Conn$ is a function that defines whether two spatial extents are connected. $MOVE$ and $INCL$ are modal operators for which it holds that $MOVE \subset Conn$ and $MOVE \subset Conn$. $MOVE$ is a partial function on spatial nominals, defining whether one can move from one place to another. $INCL$ is also a partial function on spatial nominals, defining spatial inclusion.*

To relate S_s to I_s and O_s , we define two relations, l and $\mathcal{L}$. l is a function that determines the spatial extent of an eventuality occurrence at a particular time. It is defined as a morphism from $\mathfrak{E} \times \mathfrak{I}$ to S_s . Similar to $\mathcal{Z}$ we define a relation $\mathcal{L}$. $\mathcal{L}$ ensures downward spatial connectedness: If we take a subinterval of a $\mathfrak{E} \times \mathfrak{I}$ tuple, then we obtain a spatial extent that is (reflexively, transitively) connected to a spatial extent of another subinterval of that tuple.²⁶ Finally, an additional “bi-sortal” jump-operator is defined to state that an eventuality e occurs at a particular place π , at a particular time i in I : $@^{i/S}_e \pi$, i.e. $i = z(e) \ \& \ l(i, e) = s \Rightarrow @_s \pi$.

A hybrid logical BAF with spatial extension is defined here as a tuple

²⁵Without further discussion about spatial ontology, I understand them as the spatial analogues of temporal points and intervals.

²⁶Essentially, this means that if an eventuality involves a movement through time, that movement goes along connected places.

$HB = \langle O_s, z, Z, l_s, S_s, l, \mathcal{L} \rangle$, with O_s, z, Z, l_s as defined in Definition 9.⊗

A **Direction:Where To** dependent identifies the location to which we are able to make a move from the head's eventuality's current location:

(153) **English**

Christopher intends to go [to Amarillo, Texas]_{Where-To}.

(154) **English**

Elijah rather wanted to go [to Big Springs, Texas]_{Where-To}.

Direction:From Where similarly identifies a location relative to the head's eventuality, from where the process signified by the head has its origin:

(155) **English**

Christopher arrived [to Dallas]_{Where-To} [from New York]_{Where-From}.

(156) **English**

Kathy will leave [from Prague]_{Where-From} to go [to Rio]_{Where-To}.

Whereas **Direction:Where To** identifies an 'end point' and **Direction:From Where** a 'starting point', **Direction:Through** specifies a location that is neither the starting point nor the end point. Depending on the tense of the verbal head, the dependent either determines a location that was visited in the past before reaching the current location (157), or a location that will be visited in the future (158):

(157) **English**

Christopher drove [through Big Springs]_{Through} on his way to Amarillo.

(158) **English**

Kathy will fly [via Schiphol]_{Through} when going to Rio.

Finally, **Locative** specifies the location of the head's eventuality:

(159) **English**

[In Amarillo]_{Locative}, Christopher and Elijah met [at the local *Starbucks* coffee shop]_{Locative}.

To formulate the semantic import of these dependency relations, I employ the extended hybrid logical BAFs provided in Definition 10.

(160) **Locative:**

$$@_h\langle\text{LOCATIVE}\rangle\delta \rightarrow @_h\langle\text{LOCATIVE}\rangle\delta \wedge @^I_h\tau \wedge @^{\tau/S}_h\delta$$

(161) **Direction:Where To:**

$$\begin{aligned} @_h\langle\text{WHERETO}\rangle\delta &\rightarrow \\ @_h\langle\text{WHERETO}\rangle\delta &\wedge @^I_h\tau \wedge @^{\tau/S}_h\delta' \wedge @_{\delta'}\langle\text{MOVE}\rangle\delta \end{aligned}$$

(162) **Direction:From Where:**

$$\begin{aligned} @_h\langle\text{WHEREFROM}\rangle\delta &\rightarrow \\ @_h\langle\text{WHEREFROM}\rangle\delta &\wedge @^I_h\tau \wedge @^{\tau/S}_h\delta' \wedge @_{\delta}\langle\text{MOVE}\rangle\delta' \end{aligned}$$

(163) **Direction:Through:**

$$\begin{aligned} @_h\langle\text{THROUGH}\rangle\delta &\rightarrow \\ @_h\langle\text{THROUGH}\rangle\delta &\wedge @^I_h\tau \wedge @_{\tau'}\langle\text{DURING}\rangle\tau \wedge @^{\tau'/S}_h\delta \wedge @^{\tau/S}_h\delta' \wedge @_{\delta'}\langle\text{INCL}\rangle\delta \end{aligned}$$

3.4.3 ATTRIBUTIVE DEPENDENCY RELATIONS

Attributive dependency relations are those dependency relations that can modify nouns, attributing particular characteristics to the head noun. The fact that these dependency relations modify nouns, and not verbs (or adjectives) makes them different from the manner-like dependency relations we will discuss below.

Modifications of nouns, and the idea of valency frames for nouns, has been explored in Praguian linguistics for example by Piťha (1980; 1981) - see also (Sgall et al., 1986) p.161ff and (Panevová, 1994). Piťha describes how some of the dependency relations distinguished primarily for modifying verbal heads can also occur in valency frames for nouns. On the other hand, the following dependency relations typically modify nominal heads only: **Partitive**, **Appurtenance**, **Identity**, **General Relationship**, and **Descriptive Property**.

The **Partitive** dependency relation expresses measured units (164) or a measured abstract notion (165):²⁷

(164) **English**

Christopher brought Kathy a bunch [of flowers]_{Partitive} for her valiant behavior.

²⁷One does find the **Partitive** defined in terms of “measured *material*”, cf. e.g. (Petkevič, 1995) - which seems a bit of an awkward way to talk about, for example, ‘a group of children’.

(165) **English**

Elijah was full [of hope]_{Partitive} that people would like his red-leather cowboy boots.

An **Appurtenance** dependent describes an integral part of the meaning of the nominal head that it modifies. There are nouns that are considered to have a valency frame in which **Appurtenance** occurs as obligatory. Sgall *et al.* mention in (1986) nouns like “brother”, “beginning”, and “surface” - since, for example, a brother is always referred to as a brother *of someone*, and similarly for the beginning or surface *of something*, etcetera:²⁸

(166) **English**

Christopher is [Elijah’s]_{Appurtenance} brother.

(167) **English**

Kathy inadvertently hit the leg [of the table]_{Appurtenance}.

The other three dependency relations, namely **General Relationship**, **Identity**, and **Descriptive Property**, attribute characteristics to the meaning of the nominal head that are either *restrictive* (**General Relationship**) or *unrestrictive* (**Identity**, **Descriptive Property**). A **General Relationship** is restrictive in the sense that it narrows what Petkevič calls the “semantic extent” of the nominal head (cf. also (Sgall *et al.*, 1986), pp 161-162 and the reference therein to work by Koktová):

(168) **English**

Elijah really treasures a [half-eaten]_{GenRel} [*BIC*]_{GenRel} pen.

(169) **English**

Fortunately, Elijah only bought [one]_{GenRel} pair of red-leather cowboy boots.

On the other hand, neither **Identity** nor **Descriptive Property** are understood to be restrictive, like in (170) and (171) respectively:

(170) **English**

Both Christopher and Elijah have visited the city
[of New York]_{identity}.

²⁸Observe how we can again apply the dialogue test to find out whether a complement is obligatory or not - it seems hard to conceive that one could call a person to be a brother (i.e. a member of a family) without knowing whose brother that person would be.

(171) **English**

However, they prefer [Golden]_{Descr.Prop} Prague or [sweet]_{Descr.Prop} France over the Big Apple. (After (Petkevič, 1995))

The differentiation of **General Relationship** and **Descriptive Property** can be related to the distinction *restrictive* and *attributive* readings, respectively.

In formal semantics, an attributive reading is understood as specifying an additional property of a referent which is already sufficiently identified by the head noun. A restrictive reading, on the other hand, specifies a property which further restricts the (set of) possible referent(s). The extent to which we can understand the differentiation of **General Relationship** and **Descriptive Property** as similar to this semantic distinction is as follows. As Sgall *et al.* (1986)(§2.42) point out, **General Relationship** and **Descriptive Property** can have different surface realizations. Thus, a speaker can choose to *present* an adjective as either attributive or restrictive, (just as a speaker can choose to *present* something as contextually bound or nonbound). It is then left to the later stage of discourse interpretation to see whether an attributive or restrictive reading indeed leads to a possible coherent linguistic meaning, on the basis of accessible referents. At the level of linguistic meaning we do not resolve that issue, leaving it -in a sense- underspecified.²⁹

With the above in mind, we could give the following, preliminary specification of the semantic import of **Descriptive Property** (172).

(172) **Descriptive Property:**

$$\begin{aligned} @_h\langle\rho\rangle\delta \wedge @_\delta\langle\text{DESCRPROP}\rangle\pi &\rightarrow \\ @_h\langle\rho\rangle\delta \wedge @_\delta\langle\text{DESCRPROP}\rangle\pi @_h\langle\text{XS}\rangle\delta \wedge @_h[\text{XS}]\delta \end{aligned}$$

²⁹The orthogonal issue of intersective/non-intersective readings is left entirely to the stage of discourse interpretation. Because we do not use a predicate logic here but a modal logic, we always have a relational structure: both *ball(x) ∧ red(x)* and *skillful(writer(x))* are presented in the form *head ∧ (RELATION)dependent*. Instead of imposing different logical structures to reflect (non-)intersectivity, the “responsibility” is moved to the lexicon: It is with the meaning of e.g. the adjective that we would have to specify whether it leads to an intersective reading, or a nonintersective one. For the sake of illustration, assume that the lexical meaning of a nonintersective adjective would lead -in a concrete case- to the following specification of a **Descriptive Property** modification: $@_h\langle\text{DESCRPROP}\rangle(\delta \wedge @_\delta\langle\text{NONINTERSECT}\rangle h)$. Then, the following axiom could provide a preliminary formulation of the intuition that the same property δ is not attributed to some other head h' as well: $@_h\langle\text{DESCRPROP}\rangle(\delta \wedge @_\delta\langle\text{NONINTERSECT}\rangle h) \rightarrow @_h\langle\text{DESCRPROP}\rangle(\delta \wedge @_\delta\langle\text{NONINTERSECT}\rangle h) \wedge \neg(@_{h'}\langle\text{DESCRPROP}\rangle\delta \wedge \neg@_{h'}h)$, “for a suitable h' .”

3.4.4 DEPENDENCY RELATIONS OF MANNER - MODUS OPERANDI

In (1986), Sgall *et al.* discuss various classes of dependency relations, among which they distinguish a class of dependency relations regarding manner, and a class of dependency relations closely related to manner (p.160):

1. “modifications of **Manner** and a few other, similar ones, such as **Regard**, **Extent** [...], **Norm** [...], **Criterion** [...], **Substitution** [...], and **Accompaniment**”
2. “other free modifications that are close to **Manner** [...]. These modifications comprise **Means** [...], **Difference**, [**Beneficiary**], and **Comparison**”

Here, we consider a slightly different division. Abstractly, we will group most of the above relations into a general class of *modus operandi* dependency relations (except for **Beneficiary**). Within that class, a further distinction is made between dependency relations that express *modus operandi* relatively, like a **Norm** describes the manner in which the process denoted by the verbal head happens relative to an (external) standard, or dependency relations that describe the manner more “intrinsically”, like **Manner** or **Extent**.

Relational *modus operandi*

By “relational *modus operandi*” we understand those dependency relations that describe the way in which the process denoted by the verbal head happens, by relating it to an external event or object. Prototypical examples are **Norm** and **Criterion**, or Koktová’s **Attitude** that we understand here to give a qualification of a process by relating it to the speaker’s attitude towards it. The other dependency relations we consider in this class are **Restriction**, **Accompaniment**, **Substitution**, **Regard**, and **Difference**.

The **Norm** dependency relation expresses that the process denoted by the verbal head happens in accordance with an established standard (173) or expectation (174):

(173) **English**

Kathy drives [in accordance with the traffic rules.]_{Norm}

(174) **English**

The experiment went [as we had expected it to go]_{Norm}.

A dependency relation that is similar to **Norm** is **Criterion**: Whereas **Norm** expresses that something happens *in accordance with*, a **Criterion** describes that something happens or should happen according to the information of someone. Thus, whereas **Norm** is *descriptive*, we understand **Criterion** to be *prescriptive* - which obviously has a different semantic import. For example, compare (175) to (173) above:

(175) **English**

[According to traffic law]_{Criterion}, you are not allowed to drive when under influence of alcohol.

Example (173) expresses that Kathy drives in accordance with the traffic rules, and that that is so (at least for the period covered) - there is no exception to be derived from that. Example (175) establishes a more *defeasible* connection - even though one is not allowed to drive when drunk, that still does not mean it does not happen that people do drive shortly after having consumed alcohol.

Among the other dependency relations in this class are **Substitution** (176), **Means** (177-178), **Accompaniment** (179,180). For **Accompaniment** we can distinguish a positive and negative version.

(176) **English**

Kathy was appointed chair of the party committee [instead of Elijah]_{Subst.}.

(177) **English**

Elijah prefers to write [with a half-eaten *BIC* pen]_{Means+}.

(178) **English**

Christopher arrived [by bike]_{Means+}.

(179) **English**

In the park, Christopher likes to walk [with his dog]_{Accomp+} and whistle.

(180) **English**

Despite the freezing wind, Christopher went out [without a coat]_{Accomp-}.

Also in the case of the **Regard** dependency relation, positive and negative versions can be distinguished:

- (181) **English**
[As for his figure]*Regard+*, Elijah is a tall guy.
- (182) **English**
Christopher is very sensitive [with regard to his sun tan]*Regard+*.
- (183) **English**
Kathy crossed the busy street [regardless of the possibility of causing a serious accident]*Regard-*.

In FGD a distinction is also made between dependency relations **Comparison** and **Difference** (Sgall et al., 1986). **Comparison** is the complementation in examples such as “faster than X” or “as fast as X” (Sgall et al., 1986)(p.160,199) whereas a **Difference** is “a complementation of verbs and adjectives with the comparative degree of comparison” (Petkevič, 1995).

- (184) **English**
Christopher is [two inches]*Differ.* taller than Elijah. (Sgall et al., 1986)
- (185) **English**
Elijah’s cowboy boots are [as red as]*Compar.* herrings.
- (186) **English**
Elijah is [faster than Christopher]*Compar.*. (Sgall et al., 1986)

Finally, we consider **Attitude** to be a member of this class of dependency relations. The **Attitude** dependency relation expresses the attitude, either of the *speaker* (187) or of a person explicitly mentioned (188):

- (187) **English**
Elijah is [probably]*Attitude* small.
- (188) **English**
Christopher thinks that Elijah is [probably]*Attitude* small.

“Intrinsic” *modus operandi*

Under the heading of “intrinsic” *modus operandi* we consider the **Manner** and **Extent** dependency relations. These dependency relations might be understood to express a characteristic of a process that regards the way in which it is performed.

(189) **English**

Kathy is doing [well]*Manner*. (Sgall et al., 1986)

(190) **English**

In composing music, Kathy takes [after her father]*Manner*. (Petkevič, 1995)

(191) **English**

Elijah spent his money [to the last penny]*Extent* on red leather cowboy boots. (Petkevič, 1995)

(192) **English**

Christopher studies [intensively]*Extent*. (Petkevič, 1995)

At the same time, depending on (further) interpretation, we can also have (193), besides (192). The difference is that (193) is understood as expressing that “Christopher is studying in such a way that he does it very intensively.”

(193) **English**

Christopher studies [intensively]*Manner*.

3.4.5 INNER PARTICIPANTS

Separately from the above dependency relations, which are mostly free modifiers (except for **Partitive** and **Identity**), we describe here the so-called (basic) inner participants - **Actor**, **Patient**, **Addressee**, **Origin**, and **Effect**. Included with the discussion of **Addressee** is a discussion of **Beneficiary**.

Actor

The **Actor** dependency relation can modify either a verb, or a noun. We consider the **Actor** as that participant which the meaning of the verb specifies as doing or directly causing something. That act can possibly be intentional (194,195), though it need not necessarily be so (196) (cf. (Sgall et al., 1986), p.114):

(194) **English**

[Elijah]*Actor* sleeps.

(195) **English**[Kathy]_{Actor} reads a book.(196) **English**[Christopher]_{Actor} fell off a cliff. (Sgall et al., 1986)

Syntactically, the **Actor** is prototypically realized as the surface subject - or, in terms of the relation between form and function in FGD, the **Actor** is “the primary function of the surface subject” (Sgall et al., 1986)(p.111).³⁰

Of course, it need not necessarily be the case that every surface subject realizes an **Actor**. The subject of a passive sentence like (197a) does not express the **Actor** of the verbal head (which is *bake*), but its **Objective** (see also 96 below). In (197a) the **Actor** is simply not expressed, whereas in (197b) it is expressed using a *by*-phrase.

(197) a. **English**[The bread]_{Object} was baked.b. **English**[The bread]_{Object} was baked [by Kathy]_{Actor}.

As Panevová discusses in (1974), and Sgall *et al.* in (1986)(§2.11), there are also constructions like in (198,199) which, despite of the verb having an “active voice” flavor, are still considered to be passive:

(198) **English**

The bread bakes in the oven.

(199) **English**

The door opens with a key.

Neither the bread in (198) nor the door in (199) is considered in FGD to express an **Actor**. Both times, the sentences can be understood “as synonymous with a passive construction containing a deleted *by*-phrase” (Sgall et al., 1986) (pp.116-117). For English, this perspective may be less straightforward. However, it comes out more naturally when considering constructions labelled *medio-passive* as for example in Slavonic, Romance, or Germanic languages. Medio-passives are constructed using a reflexive particle, like *se* in Czech (200), *zich* in Dutch (201), or *se* in French (202):

³⁰Thus, the **Actor** is comparable to Tesnière’s *premier actant* (1959).

(200) **Czech**

Dveře se otevírají klíčem.
 Doors REFL-PART open by key-INSTR
 “The doors open by a key.”

(201) **Dutch**

De deur opent zich met een sleutel.
 The door opens REFL-PART with a key.
 “The door opens with a key.”

(202) **French**

Cette porte s’ ouvre à clèf.
 The door REFL-PART opens with key.
 “The door opens with a key.”

In English, “The door opens with this key” could be considered as a medio-passive construction (Sgall & Hajičová, p.c.), or the rather exotic (203), (Steedman, p.c.).

(203) This wine lends itself to drinking cold.

(204) The following theory suggests itself. (Oehrle, p.c.)

Also nouns can be modified by an **Actor**. Mostly, this occurs with nouns that are derived from actions - like *ing*-forms in English, or verbal nouns in Japanese (Tsujimura, 1996). Syntactically, an **Actor** modifying another noun usually does so in the form of a genitive,³¹ indicated in the English (205) by the *'s* and in the Japanese (206) by the morpheme *-no*:

(205) **English**

Kathy has a copy of [[Lichtenstein’s]_{Actor} *Cloud and Sea*].

³¹More specifically, using that genitival form that expresses this type of relationship, semantically. In Dutch, it seems that a noun in *'s*-genitive case (i) does not lend itself very well to be interpreted as an **Actor** - whereas a *van*-genitive noun easily could (ii).

- i. **Dutch** Rembrandt’s schilderij
 of-Rembrandt painting
 “[a] painting of (belonging to) Rembrandt”
- ii. **Dutch** een schilderij van Rembrandt
 a painting of Rembrandt
 “a painting by Rembrandt”

(206) **Japanese**

[[Rooma-gun-no]_{Actor} sinnyuu-izen], soko-wa sizukana
 Romans-GEN invasion-before , there-TOP tranquil
 mura dat-ta
 village be-PAST

“Before the Roman invasion, that was a tranquil village.”

(Tsujimura, 1996), p.140

In other words, the **Actor** noun modifies the head noun “by virtue of” the verb that can be conceived of as bringing about the meaning of the head noun (Sgall et al., 1986) (§4.21).

Patient

The **Patient**, sometimes also called **Objective** (deep Object) or **Goal**, corresponds to the object that is affected by the action denoted by the verbal head it modifies (Sgall et al., 1986)(p.233).³² Prototypically, the verb’s **Patient** is realized as its direct complement:

(207) **English**

Because he fell asleep, Christopher overcooked [the potatoes]_{Patient}.

(208) **English**

He had been talking [about his holidays]_{Patient} for hours.

(209) **English**

Consequently, Kathy had to help [to prepare dinner]_{Patient}.

Petkevič describes two subdistinctions of **Patient** that can be made in case the verb is a copula: **Temporal Property** and **Permanent Property**. A **Temporal Property** expresses a property that holds for the **Actor** for only a limited time:

(210) Kathy is [the chairperson of the party committee]_{Temp.Prop.}.

On the other hand, **Permanent Property** describes a *permanent* property:

(211) Kájík is a [cat]_{Perm.Prop.}.

³²For the effected object, see §3.4.5 below.

As Petkevič remarks, it is interesting to consider the form of Czech sentences like (210) and (211) - whereas the **Temporal Property** is realized using instrumental case (212), a **Permanent Property** is realized as a nominative (213):

(212) **Czech**

Kathy je [předsedkyní]_{Term.Prop.}.
Kathy is chairperson-INSTR

“Kathy is a chairperson.”

(213) **Czech**

Kájík je kocour.
Kájík is cat-NOM

“Kájík is a cat.”

Below I provide a possible specification of the semantic import of **Temporal Property** (214) and **Permanent Property** (215).

(214) **Temporal Property:**

$$\begin{aligned} @_h \langle \text{TEMPPROP} \rangle \delta \wedge @^I_h \tau &\rightarrow \\ @_h \langle \text{TEMPPROP} \rangle \delta \wedge @^I_h \tau \wedge @_\tau \langle F \rangle \tau' \wedge \neg (@^I_h \tau' \wedge @_h \langle \text{TEMPPROP} \rangle \delta) \\ \text{“A temporal property is a property for which it holds that at some} \\ \text{future time the property no longer holds for the object referred to by} \\ \text{head.”} \end{aligned}$$

(215) $@_h \langle \text{PERMPROP} \rangle \delta \wedge @^I_h \tau \rightarrow$

$$@_h \langle \text{PERMPROP} \rangle \delta \wedge @^I_h \tau \wedge @_\tau \langle F \rangle \tau' \wedge \neg (@^I_h \tau' \wedge \neg @_h \langle \text{PERMPROP} \rangle \delta)$$

“A permanent property is a property for which it holds that at any future time the property holds for the object referred to by head.”

A more elaborate discussion about the nature of the **Patient** dependency relation can be found in (Panevová, 1974), on pages 20-29.

Addressee

The **Addressee** expresses the recipient of an action (Sgall et al., 1986)(p.132). Syntactically, if a verb takes both a **Patient** and a **Addressee**, the **Addressee** is prototypically realized as the “indirect object” or dative:

(216) **English**

Kathy gave a book [to Christopher]_{Addr.}.

(217) **Dutch**

Christopher had [aan Elijah]_{Addr.} om een Stetson gevraagd.
 Christopher had to Elijah for a Stetson asked

“Christopher had asked Elijah for a Stetson.”

(218) **Japanese**

Ziroo-ga [Yosio-ni]_{Addr.} ringo-o age-ta.
 Ziroo-NOM Yosio-DAT apple-ACC give-past

“Ziroo gave an apple to Yosio.”

(219) **Czech**

Elijah přinesl [Katce]_{Addr.} kočku.
 Elijah brought Kathy-DAT kitten-ACC

“Elijah brought Kathy a kitten.”

A more complex case arises if the valency frame of a verb contains a complementation *C* that refers to a cognitive role prototypically patterned as **Addressee**, but not one patterned as **Patient**. Then, a certain shift occurs, and *C* is assigned the valency slot **Patient**. Prototypically, the morphemic expression of this slot is using accusative case. Panevová describes this in more detail in (1974)(pp.30-31), see also (Sgall et al., 1986) (pp.125-127) and (Panevová, 1994). Examples of such shifts are the following:

(220) **English**

As its official chairperson, Kathy addressed [the committee]_{Addr.}.

(221) **Dutch**

Elijah wilde wel [op Kájík]_{Addr.} passen.
 Elijah wanted alright on Kájík take-care-of.

“Elijah didn’t mind taking care of Kájík.”

(222) **Czech**

Christopher [kočce]_{Addr.} nerozumí .
 Christopher kitten-ACC not-understand

“Christopher does not understand the kitten.”

Closely related to the **Addressee** dependency relation is the **Beneficiary** dependency relation, the latter being a free modifier. The intended meaning of **Beneficiary** is “to the benefit of someone” (*for whom*). For example, consider (223), (Sgall et al., 1986)(p.199).

(223) **English**

[She]_{Act} sent [Jane]_{Addr} [a sweater]_{Pat} [for her colleague]_{Benef}
[to a small town in Wales.]_{WhereTo}

Effect

The **Effect** describes the effected object of the action denoted by the verbal head that is being modified. Examples that Panevová gives in (1974) are -among others- predicative complements of verbs like *elect*, *nominate*, or *promote*

(224) **English**

Kathy was elected [chairperson of the committee]_{Effect}.

(225) **English**

Nobody else had been nominated [for that job]_{Effect}.

(226) **English**

Elijah had already been promoted [to Head Honcho of the cowboy gang]_{Effect}.

An interesting pairs of examples is the following, illustrating the difference between **Patient** expressing the *affected* object (227, 229), and **Effect** expressing the *effected* object (228,230):

(227) **English**

Christopher swept [the carpet]_{Patient}

(228) **English**

Elijah dug [a hole]_{Effect} with a hoe.

(229) **English**

Christopher told Kathy [about his secret]_{Patient}.

(230) **English**

Christopher told Kathy [his secret]_{Effect}

Panevová remarks that **Effect** should not be confused with **Result**, since for the latter “such means of realizations as *so that* are typical” (see also (Sgall et al., 1986), p. 134). Moreover, **Result** is a free modifier, allowing for a verbal head to be modified more than once along a **Result** dependency relation, (whereas **Effect** shows no such behavior).

(231) **English**

Chris overcooked the potatoes [so that they burned]_{Result}, [resulting in there being no proper dinner]_{Result}.

Origin

Finally, the **Origin** is a dependency relation that expresses either the source of the verbal action (232), or -socially- the commonalty of the **Actor** (233):

(232) **English**

Elijah cut a horse [out of wood]_{Origin}.

(233) **English**

Christopher comes [from a noble family]_{Origin}.

Naturally, an origin does not need to be strictly material:

(234) **English**

Elijah’s theory sprung forth [from a simple yet elegant idea]_{Origin}.

Origin is not to be confused with **Direction:From Where** or **Cause** as described above in §3.4.2 and §3.4.1, respectively:

(235) **English**

Christopher returned [from the conference]_{Dir:From} all exhausted.

(236) **English**

The blast originated [from a gas leak]_{Cause}.

Based on empirical research, both (Panevová, 1974) and (Sgall et al., 1986) posit that **Origin** never occurs as an *obligatory* complement of a verb. It is a specific type of inner participant, which can occur in combinations with various other inner participants (Sgall et al., 1986)(p.134):

(237) **Actor + Patient + Origin + Addressee:**

to hand something over from someone to someone (else)

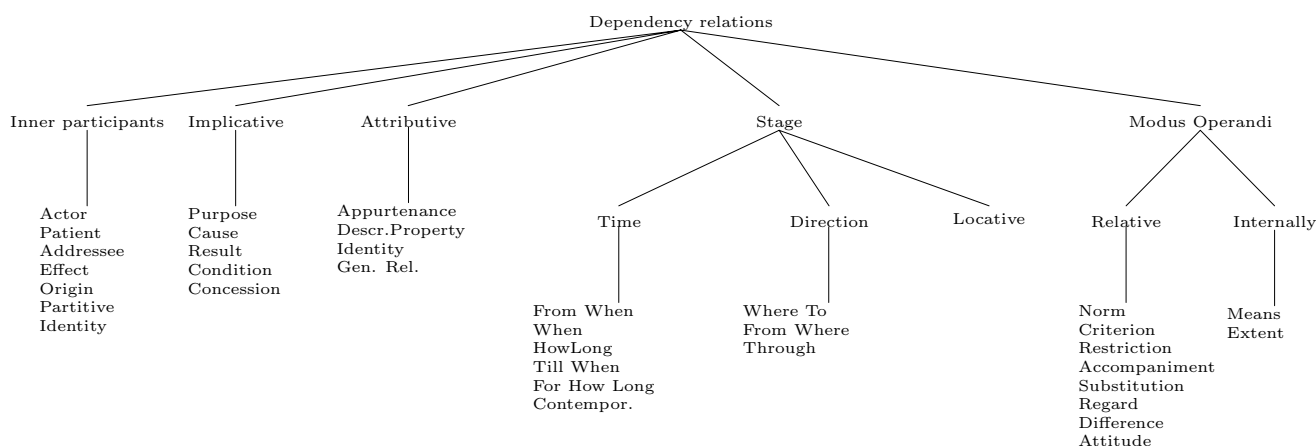


Figure 3.13: A classification of dependency relations

- (238) **Actor + Patient + Origin + Effect:**
to change something from something into something (else)
- (239) **Actor + Origin:**
something grew out of something (else)

3.5 SUMMARY

I focused in this chapter on three important ingredients of (lexical and) linguistic meaning: predicate-valency structures, dependency relations, and aspectual categories. (These are not all the ingredients: information structure is still to be added, and I will do so in Chapter 5.) In brief, predicate-valency frames specify the meaning of a head, and by what dependency relations it has to be modified. A dependency relation determines how the meaning of a dependent contributes to the overall (linguistic) meaning of the head it modifies. Finally, a sentence's underlying aspectual category signifies the discursive causal and temporal structure it reflects.

For many of the dependency relations I discussed in this chapter, I presented a hybrid logical specification of their semantic import. By a dependency relation's semantic import I mean the extra relations (or entailments) that can be projected: Thus, what do they assert, about the meaning of the dependent itself, and in relation to the meaning of the head that is being modified? This is important. A dependency relation's semantic import may help determine a content verb's aspectual category, as I showed for cases involving causal or temporal dependency relations, or may have to be accommodated in the discourse context for the sentence's linguistic meaning to be coherent, as for example in the case of an attributive reading.

The logical descriptions are couched in a many-sorted hybrid logic, formalizing (and elaborating on) Moens & Steedman’s event nucleus (Steedman, 2000b). Combined with the ideas formulated in Chapter 2, and the discussion of predicate-valency structures in this chapter, a more precise picture of linguistic meaning and its representation arises. Representing dependency relations as modal operators makes a formula of the form $head \wedge \langle \rho_1 \rangle \delta_1 \wedge \cdots \wedge \langle \rho_n \rangle \delta_n$ a *relational* structure -which, in DGL, is a tree- rather than a function/argument-structure as we find it in more traditional approaches employing predicate logic. More specifically, the relational structure is a statement about nominals referring to identifiable states in some frame, the relations that are supposed to hold between these states, and what is said to hold at these states. The relational structure is understood to reflect a linguistic patterning found in the surface form - and it is to this extent that it can express meaning.

Now, it is important to observe that its actual *interpretation* is left for the stage of discourse interpretation. That is, only at the level of discourse we tie the nominals into the frame that covers the already established discourse. Moreover, only at this stage we resolve contextual reference, and -if we follow FGD- the scopes of quantifiers, which are left underspecified at the level of linguistic meaning. (Scope resolution arguably relies on the (resolved) information structure, cf. (Sgall et al., 1986)(§3.52) and (Hajičová et al., 1998).) Hence, a sentence’s linguistic meaning may be understood to include a certain degree of underspecification, which would make it improper to equate linguistic meaning with e.g. the traditional notion of “truth condition”.

To recapitulate, a sentence’s linguistic meaning elucidates meaning to the extent that it follows a patterning found in the surface form. The patterning is interpreted as a tree-structure in which dependents modify heads along named dependency relations, and where information structure indicates the perceived relation between the (meanings of the) dependents and the preceding context. Information structure, semantic imports of dependency relations, and the sentence’s aspectual category all may project entailments that need to be accommodated in the context for the linguistic meaning to be coherent. In the next Chapter I describe how the dependency-based relational structure of linguistic meaning can be built as a reflection of an analysis of a sentence’s surface form. Chapter 5 then continues with a discussion of how to represent information structure in these relational structures, and Chapters 6 through 8 provide a proposal for how an analysis of structural indications of informativity leads to a reflection of information structure in a sentence’s linguistic meaning. Finally, in Chapter 9 I address the interpretation of linguistic meaning in a larger discourse context.

Coupling CCG and Hybrid Logic Dependency Semantics

Jason Baldridge

ICCS

Division of Informatics

2 Buccleuch Place

University of Edinburgh

Edinburgh, UK, EH8 9LW

jmb@cogsci.ed.ac.uk

Geert-Jan M. Kruijff

Universität des Saarlandes

Computational Linguistics

Lehrstuhl Uszkoreit

Building 17, Postfach 15 11 50

66041 Saarbrücken, Germany

gj@CoLi.Uni-SB.DE

Abstract

Categorial grammar has traditionally used the λ -calculus to represent meaning. We present an alternative, dependency-based perspective on linguistic meaning and situate it in the computational setting. This perspective is formalized in terms of hybrid logic and has a rich yet perspicuous propositional ontology that enables a wide variety of semantic phenomena to be represented in a single meaning formalism. Finally, we show how we can couple this formalization to Combinatory Categorial Grammar to produce interpretations compositionally.

1 Introduction

The λ -calculus has enjoyed many years as the standard semantic encoding for categorial grammars and other grammatical frameworks, but recent work has highlighted its inadequacies for both linguistic and computational concerns of representing natural language semantics (Copestake et al., 1999; Kruijff, 2001). The latter couples a resource-sensitive categorial proof theory (Moortgat, 1997) to hybrid logic (Blackburn, 2000) to formalize a dependency-based perspective on meaning, which we call here Hybrid Logic Dependency Semantics (HLDS). In this paper, we situate HLDS in the computational context by explicating its properties as a framework for computational semantics and linking it to Combinatory Categorial Grammar (CCG).

The structure of the paper is as follows. In §2, we briefly introduce CCG and how it links syntax

and semantics, and then discuss semantic representations that use indexes to identify subparts of logical forms. §3 introduces HLDS and evaluates it with respect to the criteria of other computational semantics frameworks. §4 shows how we can build HLDS terms using CCG with unification and §5 shows how intonation and information structure can be incorporated into the approach.

2 Indexed semantic representations

Traditionally, categorial grammar has captured meaning using a (simply typed) λ -calculus, building semantic structure in parallel to the categorial inference (Morrill, 1994; Moortgat, 1997; Steedman, 2000b). For example, a (simplified) CCG lexical entry for a verb such as *wrote* is given in (1).

$$(1) \quad \textit{wrote} \vdash (s \backslash n) / n : \lambda x. \lambda y. \mathbf{write}(y, x)$$

Rules of combination are defined to operate on both categories and λ -terms simultaneously. For example, the rules allow the following derivation for *Ed wrote books*.

$$(2) \quad \frac{\frac{\textit{Ed}}{n : \mathbf{Ed}} \quad \frac{\textit{wrote}}{(s \backslash n) / n : \lambda x. \lambda y. \mathbf{write}(y, x)} \quad \frac{\textit{books}}{n : \mathbf{books}}}{s \backslash n : \lambda y. \mathbf{write}(y, \mathbf{books})} > \\ \frac{}{s : \mathbf{write}(\mathbf{Ed}, \mathbf{books})} <$$

Derivations like (2) give rise to the usual sort of predicate-argument structure whereby the *order* in which the arguments appear (and are bound by the λ 's) is essentially constitutive of their meaning. Thus, the first argument could be taken to correspond to the writer, whereas the second argument corresponds to what is being written.

One deficiency of λ -calculus meaning representations is that they usually have to be type-raised to the worst case to fully model quantification, and this can reverberate and increase the complexity of syntactic categories since a verb like *wrote* will need to be able to take arguments with the types of generalized quantifiers. The approach we advocate in this paper does not suffer from this problem.

For CCG, the use of the λ -terms is simply a convenient device to bind arguments when presenting derivations (Steedman, 2000b). In implementations, a more common strategy is to compute semantic representations via unification, a tactic explicitly employed in Unification Categorical Grammar (UCG) (Zeevat, 1988). Using a unification paradigm in which atomic categories are bundles of syntactic and semantic information, we can use an entry such as (3) for *wrote* in place of (1). In the unification setting, (3) permits a derivation analogous to (2).

$$(3) \text{ wrote} \vdash (s : \mathbf{write}(y, x) \backslash n : y) / n : x$$

For creating predicate-argument structures of this kind, strategies using either λ -terms or unification to bind arguments are essentially notational variants. However, UCG goes beyond simple predicate-argument structures to instead use a semantic representation language called Indexed Language (InL). The idea of using indexes stems from Davidson (event variables), and are a commonly used mechanism in unification-based frameworks and theories for discourse representation. InL attaches one to every formula representing its discourse referent. This results in a representation such as (4) for the sentence *Ed came to the party*.

$$(4) [e][\mathbf{party}(x), \mathbf{past}(e), \mathbf{to}(e, x), \mathbf{come}(e, \mathbf{Ed})]$$

InL thus flattens logical forms to some extent, using the indexes to spread a given entity or event through multiple predications. The use of indexes is crucial for UCG's account of modifiers, and as we will see later, we exploit such referents to achieve similar ends when coupling HLDS and CCG.

Minimal Recursion Semantics (MRS) (Copestake et al., 1999; Copestake et al., 2001) is a framework for computational semantics that is designed to simplify the work of algorithms which produce or use semantic representations. MRS provides the

means to represent interpretations with a flat, underspecified semantics using terms of the predicate calculus and generalized quantifiers. Flattening is achieved by using an indexation scheme involving *labels* that tag particular groups of elementary predications (EPs) and *handles* (here, $h_1, h_2, \dots$) that reference those EPs. Underspecification is achieved by using unresolved handles as the arguments for scope-bearing elements and declaring constraints (with the $\equiv_q$ operator) on how those handles can be resolved. Different scopes can be reconstructed by equating unresolved handles with the labels of the other EPs obeying the $\equiv_q$ constraints. For example, (5) would be given as the representation for *every dog chases some white cat*.

$$(5) \langle h_0, \{h_1 : \mathbf{every}(x, h_2, h_3), h_4 : \mathbf{dog}(x), \\ h_{11} : \mathbf{cat}(y), h_8 : \mathbf{some}(y, h_9, h_{10}), \\ h_{11} : \mathbf{white}(y), h_7 : \mathbf{chase}(x, y)\}, \\ \{h_0 \equiv_q h_7, h_2 \equiv_q h_4, h_9 \equiv_q h_{11}\} \rangle$$

Copestake et al. argue that these flat representations facilitate a number of computational tasks, including machine translation and generation, without sacrificing linguistic expressivity. Also, flatness permits semantic equivalences to be checked more easily than in structures with deeper embedding, and underspecification simplifies the work of the parser since it does not have to compute every possible reading for scope-bearing elements.

3 Hybrid Logic Dependency Semantics

Kruijff (2001) proposes an alternative way to representing linguistically realized meaning: namely, as terms of *hybrid modal logic* (Blackburn, 2000) explicitly encoding the dependency relations between heads and dependents, spatio-temporal structure, contextual reference, and information structure. We call this unified perspective combining many levels of meaning Hybrid Logic Dependency Semantics (HLDS). We begin by discussing how hybrid logic extends modal logic, then look at the representation of linguistic meaning via hybrid logic terms.

3.1 Hybrid Logic

Though modal logic provides a powerful tool for encoding relational structures and their properties,

it contains a surprising inherent asymmetry: states (“worlds”) are at the heart of the model theory for modal logic, but there are no means to directly *reference* specific states using the object language. This inability to state where exactly a proposition holds makes modal logic an inadequate representation framework for practical applications like knowledge representation (Areces, 2000) or temporal reasoning (Blackburn, 1994). Because of this, computational work in knowledge representation has usually involved re-engineering first-order logic to suit the task, e.g., the use of metapredicates such as **Hold** of Kowalski and Allen. Unfortunately, such logics are often undecidable.

Hybrid logic extends standard modal logic while retaining decidability and favorable complexity (Areces, 2000) (cf. (Areces et al., 1999) for a complexity roadmap). The strategy is to add *nominals*, a new sort of basic formula with which we can explicitly name states in the object language. Next to propositions, nominals are first-class citizens of the object language: formulas can be formed using both sorts, standard boolean operators, and the *satisfaction operator* “@”. A formula $@_i p$ states that the formula p holds at the state named by i .¹ (There are more powerful quantifiers ranging over nominals, such as $\downarrow$, but we do not consider them here.)

With nominals we obtain the possibility to explicitly refer to the state at which a proposition holds. As Blackburn (1994) argues, this is essential for capturing our intuitions about temporal reference. A standard modal temporal logic with the modalities F and P (future and past, respectively) cannot correctly represent an utterance such as *Ed finished the book* because it is unable to refer to the *specific* time at which the event occurred. The addition of nominals makes this possible, as shown in (6), where the nominal i represents the Reichenbachian event time.

$$(6) \quad \langle P \rangle (i \wedge \text{Ed-finish-book})$$

Furthermore, many temporal properties can be defined in terms of *pure formulas* which use nominals and contain no propositional variables. For example, the following term defines the fact that the relations for F and P are mutually converse:

¹A few notes on our conventions: p, q, r are variables over any hybrid logic formula; i, j, k are variables over nominals; d_i and h_i denote nominals (for dependent and head, respectively).

$$(7) \quad @_i[F]\langle P \rangle i \wedge @_i[P]\langle F \rangle i$$

It is also possible to encode a variety of other representations in terms of hybrid logics. For example, nominals correspond to tags in attribute-value matrices (AVMs), so the hybrid logic formula in (8) corresponds to the AVM in (9).

$$(8) \quad \langle \text{SUBJ} \rangle (i \wedge \langle \text{AGR} \rangle \text{singular} \wedge \langle \text{PRED} \rangle \text{dog}) \wedge \langle \text{COMP} \rangle \langle \text{SUBJ} \rangle i$$

$$(9) \quad \left[\begin{array}{cc} \text{SUBJ} & \boxed{\begin{array}{c} \text{AGR singular} \\ \text{PRED dog} \end{array}} \\ \text{COMP} & \boxed{\text{SUBJ } \boxed{}} \end{array} \right]$$

A crucial aspect of hybrid logic is that nominals are at the heart of a *sorting strategy*. Different sorts of nominals can be introduced to build up a rich sortal ontology without losing the perspicuity of a propositional setting. Additionally, we can *reason* about sorts because nominals are part and parcel of the object language. We can extend the language of hybrid logic with $\{\text{Sort:Nominal}\}$ to facilitate the explicit statement of what sort a nominal is in the language and carry this modification into one of the existing tableaux methods for hybrid logic to reason effectively with this information. This makes it possible to capture the rich ontologies of lexical databases like WordNet in a clear and concise fashion which would be onerous to represent in first-order logic.

3.2 Encoding linguistic meaning

Hybrid logic enables us to logically capture two essential aspects of meaning in a clean and compact way, namely ontological richness and the possibility to refer. Logically, we can represent an expression’s linguistically realized meaning as a conjunction of modalized terms, anchored by the nominal that identifies the head’s proposition:

$$(10) \quad @_h(\text{proposition} \wedge \langle \delta_i \rangle (d_i \wedge \text{dep}_i))$$

Dependency relations are modeled as modal relations $\langle \delta_i \rangle$, and with each dependent we associate a nominal d_i , representing its *discourse referent*. Technically, (10) states that each nominal d_i names the state where a dependent expressed as a proposition **dep** _{i} should be evaluated and is a δ_i successor of h , the nominal identifying the head. As an example, the sentence *Ed wrote a long book in London* receives the representation in (11).

$$(11) \quad @_{h_1}(\mathbf{write} \wedge \langle \text{ACT} \rangle (d_0 \wedge \mathbf{Ed}) \\ \wedge \langle \text{PAT} \rangle (d_5 \wedge \mathbf{book} \wedge \langle \text{GR} \rangle (d_7 \wedge \mathbf{long})) \\ \wedge \langle \text{LOC} \rangle (d_9 \wedge \mathbf{London}))$$

The modal relations ACT, PAT, LOC, and GR stand for the dependency relations **Actor**, **Patient**, **Locative**, and **General Relationship**, respectively. See Kruijff (2001) for the model-theoretic interpretation of expressions such as (11).

Contextual reference can be modeled as a statement that from the current state (anaphor) there should be an accessible antecedent state at which particular conditions hold. Thus, assuming an accessibility relation XS , we can model the meaning of the pronoun *he* as in (12).

$$(12) \quad @_i \langle XS \rangle (j \wedge \mathbf{male})$$

During discourse interpretation, this statement is *evaluated* against the discourse model. The pronoun is resolvable only if a state where **male** holds is XS -accessible in the discourse model. Different accessibility relations can be modeled, e.g. to distinguish a local context (for resolving reflexive anaphors like *himself*) from a global context (Kruijff, 2001).

Finally, the rich temporal ontology underlying models of tense and aspect such as Moens and Steedman (1988) can be captured using the sorting strategy. Earlier work like Blackburn and Lascarides (1992) already explored such ideas. HLDS employs hybrid logic to integrate Moens and Steedman's notion of the *event nucleus* directly into meaning representations. The event nucleus is a tripartite structure reflecting the underlying semantics of a type of event. The event is related to a *preparation* (an activity bringing the event about) and a *consequent* (a state ensuing to the event), which we encode as the modal relations PREP and CONS, respectively. Different kinds of states and events are modeled as different *sorts of nominals*, shown in (13) using the notation introduced above.

$$(13) \quad @_{\{Activity:e1\}} \langle \text{PREP} \rangle \{Achievement:e2\} \\ \wedge @_{\{Achievement:e2\}} \langle \text{CONS} \rangle \{State:e3\}$$

To tie (13) in with a representation like (11), we equate the nominal of the head with one of the nominals in the event nucleus (E) and state its temporal relation (e.g. $\langle P \rangle$). Given the event nucleus in (13), the representation in (11) becomes (14), where the event is thus located at a *specific* time in the past.

$$(14) \quad @_{h_1} (E_{(13)} \wedge \mathbf{write} \wedge \langle \text{ACT} \rangle (d_0 \wedge \mathbf{Ed}) \\ \wedge \langle \text{PAT} \rangle (d_5 \wedge \mathbf{book} \wedge \langle \text{GR} \rangle (d_7 \wedge \mathbf{long})) \\ \wedge \langle \text{LOC} \rangle (d_9 \wedge \mathbf{London})) \\ \wedge @_{h_1} \{Achievement:e2\} \wedge \langle P \rangle \{Achievement:e2\}$$

Hybrid logic's flexibility makes it amenable to representing a wide variety of semantic phenomena in a propositional setting, and it can furthermore be used to formulate a discourse theory (Kruijff and Kruijff-Korbyová, 2001).

3.3 Comparison to MRS

Here we consider the properties of HLDS with respect to the four main criteria laid out by Copestake et al. (1999) which a computational semantics framework must meet: expressive adequacy, grammatical compatibility, computational tractability, and underspecifiability.

Expressive adequacy refers to a framework's ability to correctly express linguistic meaning. HLDS was designed not only with this in mind, but as its central tenet. In addition to providing the means to represent the usual predicate-valency relations, it explicitly marks the named dependency relations between predicates and their arguments and modifiers. These different dependency relations are not just labels: they all have unique semantic imports which project new relations in the context of different heads. HLDS also tackles the representation of tense and aspect, contextual reference, and information structure, as well as their interaction with discourse.

The criterion of grammatical compatibility requires that a framework be linkable to other kinds of grammatical information. Kruijff (2001) shows that HLDS can be coupled to a rich grammatical framework, and in §4 we demonstrate that it can be tied to CCG, a much lower power formalism than that assumed by Kruijff. It should furthermore be straightforward to use our approach to hook HLDS up to other unification-based frameworks.

The definition of computational tractability states that it must be possible to check semantic equivalence of different formulas straightforwardly. Like MRS, HLDS provides the means to view linguistic meaning in a flattened format and thereby ease the checking of equivalence. For example, (15) describes the same relational structure as (11).

$$(15) \quad @_{h_1}(\mathbf{write} \wedge \langle \text{ACT} \rangle d_0 \wedge \langle \text{PAT} \rangle d_5 \wedge \langle \text{LOC} \rangle d_9) \\ \wedge @_{d_0} \mathbf{Ed} \wedge @_{d_5} \mathbf{book} \wedge @_{d_9} \mathbf{London} \\ \wedge @_{d_7} \mathbf{long} \wedge @_{d_5} \langle \text{GR} \rangle d_7$$

This example clarifies how the use of nominals is related to the indexes of UCG's InL and the labels of MRS. However, there is an important difference: nominals are full citizens of the object language with semantic import and are not simply a device for spreading meaning across several elementary predications. They simultaneously represent tags on subparts of a logical form and discourse referents on which relations are predicated. Because it is possible to view an HLDS term as a flat conjunction of the heads and dependents inside it, the benefits described by Copestake et al. with respect to MRS's flatness thus hold for HLDS as well.

Computational tractability also requires that it is straightforward to express relationships between representations. This can be done in the object language of HLDS as hybrid logic implicational statements which can be used with proof methods to discover deeper relationships. Kruijff's model connecting linguistic meaning to a discourse context is one example of this.

Underspecifiability means that semantic representations should provide means to leave some semantic distinctions unresolved whilst allowing partial terms to be flexibly and monotonically resolved. (5) shows how MRS leaves quantifier scope underspecified, and such formulas can be transparently encoded in HLDS. Consider (16), where the relations *RESTR* and *BODY* represent the *restriction* and *body* arguments of the generalized quantifiers, respectively.

$$(16) \quad @_{h_7}(\mathbf{chase} \wedge \langle \text{ACT} \rangle h_4 \wedge \langle \text{PAT} \rangle h_{11}) \\ \wedge @_{h_1}(\mathbf{every} \wedge \langle \text{RESTR} \rangle i \wedge \langle \text{BODY} \rangle j) \\ \wedge @_{h_8}(\mathbf{some} \wedge \langle \text{RESTR} \rangle k \wedge \langle \text{BODY} \rangle l) \\ \wedge @_{h_4} \mathbf{dog} \wedge @_{h_{11}} \mathbf{cat} \wedge @_{h_{11}} \langle \text{GR} \rangle (h_{12} \wedge \mathbf{white}) \\ \wedge @_i \langle \text{QEQ} \rangle h_4 \wedge @_k \langle \text{QEQ} \rangle h_{11}$$

MRS-style underspecification is thus replicated by declaring new nominals and modeling $\models_q$ as a modal relation between nominals. When constructing the fully-scoped structures generated by an underspecified one, the $\models_q$ constraints must be obeyed according to the **qeq** condition of Copestake et al. Because HLDS is couched directly in terms of hybrid logic, we can concisely declare the **qeq** condition as the following implication:

$$(17) \quad @_i \langle \text{QEQ} \rangle j \rightarrow @_i j \vee (@_i \langle \text{BODY} \rangle k \wedge @_k \langle \text{QEQ} \rangle j)$$

Alternatively, it would in principle be possible to adopt a truly modal solution to the representation of quantifiers. Following Alechina (1995), (generalized) quantification can be modeled as *modal operators*. The complexity of generalized quantification is then pushed into the model theory instead of forcing the representation to carry the burden.

4 CCG Coupled to HLDS

In Dependency Grammar Logic (DGL), Kruijff (2001) couples HLDS to a resource-sensitive categorial proof theory (CTL) (Moortgat, 1997). Though DGL demonstrates a procedure for building HLDS terms from linguistic expressions, there are several problems we can overcome by switching to CCG. First, parsing with CCG grammars for substantial fragments is generally more efficient than with CTL grammars with similar coverage. Also, a wide-coverage statistical parser which produces syntactic dependency structures for English is available for CCG (Clark et al., 2002). Second, syntactic features (modeled by unary modalities) in CTL have no intuitive semantic reflection, whereas CCG can relate syntactic and semantic features perspicuously using unification. Finally, CCG has a detailed syntactic account of the realization of information structure in English.

To link syntax and semantics in derivations, every logical form in DGL expresses a nominal identifying its head in the format $@_p$. This handles dependents in a linguistically motivated way through a *linking theory*: given the form of a dependent, its (possible) role is established, after which its meaning states that it seeks a head that can take such a role. However, to subsequently bind that dependent into the verb's argument slot requires logical axioms about the nature of various dependents. This not only requires extra reduction steps to arrive at the desired logical form, but could also lead to problems depending on the underlying theory of roles.

We present an alternative approach to binding dependents, which overcomes these problems without abandoning the linguistic motivation. Because we work in a lexicalist setting, we can compile the effects of the *linguistic* linking theory directly into category assignments.

The first difference in our proposal is that arguments express only their own nominal, not the nominal of a head as well. For example, proper nouns receive categories such as (18).

$$(18) \quad Ed \vdash n : @_{d_1} \mathbf{Ed}$$

This entry highlights our relaxation of the strict connection between syntactic and semantic types traditionally assumed in categorial grammars, a move in line with the MRS approach.

In contrast with DGL, the semantic portion of a syntactic argument in our system does not declare the role it is to take and does not identify the head it is to be part of. Instead it identifies only its own referent. Without using additional inference steps, this is transmuted via unification into a form similar to DGL's in the result category. (19) is an example of the kind of head category needed.

$$(19) \quad sleeps \vdash s : @_{h_2}(\mathbf{sleep} \wedge \langle \mathbf{ACT} \rangle (i \wedge p)) \setminus n : @_i p$$

To derive *Ed sleeps*, (18) and (19) combine via backward application to produce (20), the same term as that built in DGL using one step instead of several.

$$(20) \quad @_{h_2}(\mathbf{sleep} \wedge \langle \mathbf{ACT} \rangle (d_1 \wedge \mathbf{Ed}))$$

To produce HLDS terms that are fully compatible with the way that Kruijff and Kruijff-Korbyová (2001) model discourse, we need to mark the informativity of dependents as *contextually bound* (CB) and *contextually nonbound* (NB). In DGL, these appear as modalities in logical forms that are used to create a topic-focus articulation that is merged with the discourse context. For example, the sentence *he wrote a book* would receive the following (simplified) interpretation:

$$(21) \quad @_{h_1}([NB] \mathbf{write} \wedge [NB] \langle \mathbf{PAT} \rangle (d_5 \wedge \mathbf{book}) \wedge [CB] \langle \mathbf{ACT} \rangle (d_6 \wedge \langle \mathbf{XS} \rangle (d_3 \wedge \mathbf{male})))$$

DGL uses feature-resolving unary modalities (Moortgat, 1997) to instantiate the values of informativity. In unification-based approaches such as CCG, the transferal of feature information into semantic representations is standard practice. We thus employ the feature *inf* and mark informativity in logical forms with values resolved syntactically.

$$(22) \quad Ed \vdash n_{inf=CB} : @_{d_1} \mathbf{Ed}$$

$$(23) \quad sleeps \vdash s : @_{h_2}([NB] \mathbf{sleep} \wedge [q] \langle \mathbf{ACT} \rangle (i \wedge p)) \setminus n_{inf=q} : @_i p$$

Combining these entries using backward application gives the following result for *Ed sleeps*:

$$(24) \quad s : @_{h_2}([NB] \mathbf{sleep} \wedge [CB] \langle \mathbf{ACT} \rangle (d_1 \wedge \mathbf{Ed}))$$

A major benefit of having nominals in our representations comes with adjuncts. With HLDS, we consider the prepositional verbal modifier in the sentence *Ed sleeps in the bed* as an optional **Locative** dependent of *sleeps*. To implement this, we follow DGL in identifying the discourse referent of the head with that of the adjunct. However, unlike DGL, this is compiled into the category for the adjunct.

$$(25) \quad in \vdash (s : @_i(p \wedge [r] \langle \mathbf{LOC} \rangle (j \wedge q)) \setminus s : @_i p) / n_{inf=r} : @_j q$$

To derive the sentence *Ed sleeps in the bed* (see Figure 1), we then need the following further entries:

$$(26) \quad the \vdash n_{inf=CB} : p / n_{inf=NB} : p$$

$$(27) \quad bed \vdash n_{inf=NB} : @_{d_3} \mathbf{bed}$$

This approach thus allows adjuncts to insert their semantic import into the meaning of the head, making use of nominals in a manner similar to the use of indexes in Unification Categorial Grammar.

5 Intonation and Information Structure

Information Structure (IS) in English is in part determined by intonation. For example, given the question in (28), an appropriate response would be (29).²

$$(28) \quad \text{I know what Ed READ. But what did Ed WRITE?}$$

$$(29) \quad (\text{Ed } \overset{\text{L+H*}}{\text{WROTE}}) \quad (\text{A } \overset{\text{H*}}{\text{BOOK}}).$$

Steedman (2000a) incorporates intonation into CCG syntactic analyses to determine the contribution of different constituents to IS. Steedman calls segments such as *Ed wrote* of (29) the **theme** of the sentence, and *a book* the **rheme**. The former indicates the part of the utterance that connects it with the preceding discourse, whereas the latter provides information that moves the discourse forward.

In the context of Discourse Representation Theory, Kruijff-Korbyová (1998) represents IS by splitting DRT structures into a topic/focus articulation of the form $\boxed{\mathbf{TOPIC}} \bowtie \boxed{\mathbf{FOCUS}}$. We represent

²Following Pierrehumbert's notation, the intonational contour L+H* indicates a low-rising pitch accent, H* a sharply-rising pitch accent, and both LH% and LL% are boundary tones.

$$\begin{array}{c}
\text{Ed sleeps } (= (24)) \\
\hline
s : @_{h_2}([NB]\text{sleep} \wedge [CB]\langle ACT \rangle(d_1 \wedge \text{Ed}))
\end{array}
\quad
\begin{array}{c}
\text{in} \\
\hline
s : @_i(p \wedge [r]\langle LOC \rangle(j \wedge q)) \setminus s : @_i p / n_{inf=r} : @_j q
\end{array}
\quad
\begin{array}{c}
\text{the} \\
\hline
n_{inf=CB} : s / n_{inf=NB} : s
\end{array}
\quad
\begin{array}{c}
\text{bed} \\
\hline
n_{inf=NB} : @_{d_3} \text{bed}
\end{array}
\quad
\begin{array}{c}
\hline
n_{inf=CB} : @_{d_3} \text{bed}
\end{array}
\quad
\begin{array}{c}
\hline
s : @_i(p \wedge [CB]\langle LOC \rangle(d_3 \wedge \text{bed})) \setminus s : @_i p
\end{array}
\quad
\begin{array}{c}
\hline
s : @_{h_2}([NB]\text{sleep} \wedge [CB]\langle ACT \rangle(d_1 \wedge \text{Ed}) \wedge [CB]\langle LOC \rangle(d_3 \wedge \text{bed}))
\end{array}$$

Figure 1: Derivation of *Ed sleeps in the bed*.

this in HLDS as a term incorporating the $\bowtie$ operator. Equating topic and focus with Steedman’s theme and rheme, we encode the interpretation of (29) as:

$$(30) \quad @_{h_7}([CB]\text{write} \wedge [CB]\langle ACT \rangle(d_1 \wedge \text{Ed}) \bowtie [NB]\langle PAT \rangle(d_4 \wedge \text{book}))$$

DGL builds such structures by using a rewriting system to produce terms with topic/focus articulation from the terms produced by the syntax.

Steedman uses the pitch accents to produce lexical entries with values for the *INFORMATION* feature, which we call here *sinf*. L+H* and H* set the value of this feature as θ (for theme) or ρ (for rheme), respectively. He also employs categories for the boundary tones that carry blocking values for *sinf* which stop incomplete intonational phrases from combining with others, thereby avoiding derivations for utterances with nonsensical intonation contours.

Our approach is to incorporate the syntactic aspects of Steedman’s analysis with DGL’s rewriting system for using informativity to partition sentential meaning. In addition to using the syntactic feature *sinf*, we allow intonation marking to instantiate the values of the semantic informativity feature *inf*. Thus, we have the following sort of entry:

$$(31) \quad \text{WROTE } (L+H^*) \vdash \\
s_{sinf=\theta} : \phi \setminus n_{inf=w, sinf=\theta} : @_i p / n_{inf=x, sinf=\theta} : @_j q \\
\phi = @_{h_2}([CB]\text{write} \wedge [w]\langle ACT \rangle(i \wedge p) \wedge [x]\langle PAT \rangle(j \wedge q))$$

We therefore straightforwardly reap the syntactic benefits of Steedman’s intonation analysis, while IS itself is determined via DGL’s logical form rewriting system operating on the modal indications of informativity produced during the derivation. The articulation of IS can thus be performed uniformly across languages, which use a variety of strategies including intonation, morphology, and word order variation to mark the informativity of different elements. The resulting logical form plugs directly

into DGL’s architecture for incorporating sentence meaning with the discourse.

6 Conclusions and Future Work

Since it is couched in hybrid logic, HLDS is ideally suited to be *logically engineered* to the task at hand. Hybrid logic can be made to do exactly what we want, answering to the linguistic intuitions we want to formalize *without* yielding its core assets – a rich propositional ontology, decidability, and favorable computational complexity.

Various aspects of meaning, like dependency relations, contextual reference, tense and aspect, and information structure can be perspicuously encoded with HLDS, and the resulting representations can be built *compositionally* using CCG. CCG has close affinities with dependency grammar, and it provides a competitive and explanatorily adequate basis for a variety of phenomena ranging from coordination and unbounded dependencies to information structure. Nonetheless, the approach we describe could in principle be fit into other unification-based frameworks like Head-Driven Phrase Structure Grammar.

Hybrid logic’s utility does not stop with sentential meaning. It can also be used to model discourse interpretation and is closely related to logics for knowledge representation. This way we can cover the track from grammar to discourse with a *single* meaning formalism. We do not need to translate or make simplifying assumptions for different processing modules to communicate, and we can freely include and use information across different levels of meaning.

We have implemented a (preliminary) Java package for creating and manipulating hybrid logic terms and connected it to Grok, a CCG parsing system.³ The use of HLDS has made it possible to improve

³The software is available at <http://openllp.sf.net> and <http://grok.sf.net> under an open source license.

the representation of the lexicon. Hybrid logic nominals provide a convenient and intuitive manner of localizing parts of a semantic structure, which has made it possible to greatly simplify the use of inheritance in the lexicon. Logical forms are created as an accumulation of different levels in the hierarchy including morphological information. This is particularly important since the system does not otherwise support typed feature structures with inheritance.

Hybrid logics provide a perspicuous logical language for representing structures in temporal logic, description logic, AVMs, and indeed any relational structure. Terms of HLDS can thus be marshalled into terms of these other representations with the potential of taking advantage of tools developed for them or providing input to modules expecting them.

In future work, we intend to combine techniques for building wide-coverage statistical parsers for CCG (Hockenmaier and Steedman, 2002; Clark et al., 2002) with corpora that have explicitly marked semantic dependency relations (such as the Prague Dependency Treebank and NEGRA) to produce HLDS terms as the parse output.

Acknowledgements

We would like to thank Patrick Blackburn, Johan Bos, Nissim Francez, Alex Lascarides, Mark Steedman, Bonnie Webber and the ACL reviewers for helpful comments on earlier versions of this paper. All errors are, of course, our own. Jason Baldridge's work is supported in part by Overseas Research Student Award ORS/98014014. Geert-Jan Kruijff's work is supported by the DFG Sonderforschungsbereich 378 *Resource-Sensitive Cognitive Processes*, Project NEGRA EM6.

References

- Natasha Alechina. 1995. *Modal Quantifiers*. Ph.D. thesis, University of Amsterdam, Amsterdam, The Netherlands.
- Carlos Areces, Patrick Blackburn, and Maarten Marx. 1999. A road-map on complexity for hybrid logics. In J. Flum and M. Rodríguez-Artalejo, editors, *Computer Science Logic*, number 1683 in Lecture Notes in Computer Science, pages 307–321. Springer-Verlag.
- Carlos Areces. 2000. *Logic Engineering. The Case of Description and Hybrid Logics*. Ph.D. thesis, University of Amsterdam, Amsterdam, The Netherlands.
- Patrick Blackburn and Alex Lascarides. 1992. Sorts and operators for temporal semantics. In *Proc. of the Fourth Symposium on Logic and Language*, Budapest, Hungary.
- Patrick Blackburn. 1994. Tense, temporal reference and tense logic. *Journal of Semantics*, 11:83–101.

- Patrick Blackburn. 2000. Representation, reasoning, and relational structures: a hybrid logic manifesto. *Logic Journal of the IGPL*, 8(3):339–625.
- Stephen Clark, Julia Hockenmaier, and Mark Steedman. 2002. Building deep dependency structures using a wide-coverage CCG parser. In *Proc. of the 40th Annual Meeting of the Association of Computational Linguistics*, Philadelphia, PA.
- Ann Copestake, Dan Flickinger, Ivan Sag, and Carl Pollard. 1999. Minimal recursion semantics: An introduction. ms, www-csli.stanford.edu/~aac/newmrs.ps.
- Ann Copestake, Alex Lascarides, and Dan Flickinger. 2001. An algebra for semantic construction in constraint-based grammars. In *Proc. of the 39th Annual Meeting of the Association of Computational Linguistics*, pages 132–139, Toulouse, France.
- Julia Hockenmaier and Mark Steedman. 2002. Generative models for statistical parsing with combinatory categorial grammar. In *Proc. of the 40th Annual Meeting of the Association of Computational Linguistics*, Philadelphia, PA.
- Geert-Jan M. Kruijff and Ivana Kruijff-Korbyová. 2001. A hybrid logic formalization of information structure sensitive discourse interpretation. In *Proc. of the Fourth Workshop on Text, Speech and Dialogue*, volume 2166 of LNCS/LNAI, pages 31–38. Springer-Verlag.
- Ivana Kruijff-Korbyová. 1998. *The Dynamic Potential of Topic and Focus: A Praguian Approach to Discourse Representation Theory*. Ph.D. thesis, Charles University, Prague, Czech Republic.
- Geert-Jan M. Kruijff. 2001. *A Categorical Modal Architecture of Informativity: Dependency Grammar Logic & Information Structure*. Ph.D. thesis, Charles University, Prague, Czech Republic.
- Marc Moens and Mark Steedman. 1988. Temporal ontology and temporal reference. *Computational Linguistics*, 14:15–28.
- Michael Moortgat. 1997. Categorical type logics. In Johan van Benthem and Alice ter Meulen, editors, *Handbook of Logic and Language*. Elsevier Science B.V.
- Glyn V. Morrill. 1994. *Type Logical Grammar: Categorical Logic of Signs*. Kluwer Academic Publishers, Dordrecht, Boston, London.
- Mark Steedman. 2000a. Information structure and the syntax-phonology interface. *Linguistic Inquiry*, 34:649–689.
- Mark Steedman. 2000b. *The Syntactic Process*. The MIT Press, Cambridge Mass.
- Henk Zeevat. 1988. Combining categorial grammar and unification. In Uwe Reyle and Christian Rohrer, editors, *Natural Language Parsing and Linguistic Theories*, pages 202–229. Reidel, Dordrecht.

Adapting Chart Realization to CCG

Michael White and Jason Baldridge

School of Informatics

University of Edinburgh

{mwhite,jmb}@inf.ed.ac.uk

Abstract

We describe a bottom-up chart realization algorithm adapted for use with Combinatory Categorical Grammar (CCG), and show how it can be used to efficiently realize a wide range of coordination phenomena, including argument cluster coordination and gapping. The algorithm has been implemented as an extension to the OpenNLP open source CCG parser. As an avenue for future exploration, we also suggest how the realizer could be used to simplify the treatment of aggregation in conjunction with higher level content planning components.

1 Introduction

In this paper, we describe our initial efforts to develop a practical, open source realizer for Combinatory Categorical Grammar (CCG, Steedman (2000b)). While CCG provides theoretically attractive accounts of numerous linguistic phenomena — including unique accounts of coordination and intonation, which is of particular interest to builders of dialog systems¹ — its adoption by the NLG community has been hindered by the lack of a practical realizer. As a first step towards making such a realizer available, we have implemented a

¹We are primarily targeting the realizer for use in dialog systems, and intend to use it in the IST project COMIC (CONversational Multimodal Interaction with Computers), <http://www.mpi.nl/comic/>.

bottom-up chart realization algorithm (Carroll et al., 1999) adapted for use with CCG. The implementation builds upon the Java-based OpenNLP CCG parser² described in Baldridge (2002).

The paper is organized as follows. We provide the rationale for our algorithm choice in §2. In §3 and §4, we provide background for the realization algorithm and the algorithm itself. In §5, we show how the realizer handles a wide range of coordination phenomena. In §6, we provide initial evidence that the realizer can be reasonably efficient in practice. In §7, we discuss related work and conclude with a discussion of future directions.

2 Rationale

Since our chart realization algorithm may not be the most efficient algorithm one might consider implementing, we provide the following rationale for our choice:

Completeness The simple nature of our algorithm makes it relatively straightforward to achieve completeness,³ in contrast, it would be more difficult to do so for all combinatory rules with Hoffman’s (1995) adaptation of semantic head driven realization for CCG.

Parser reuse Since the algorithm is entirely bottom-up, it can directly reuse the parsing-oriented optimizations of the CCG rules described in Baldridge (2002).

²<http://opennlp.sourceforge.net/>

³That is, to ensure that all derivations licensed by the grammar can be reversed.

LF order independence The algorithm does not rely on the order of conjuncts in the input logical form, and thus handles this oft-discussed aspect of the logical form equivalence problem (Shieber, 1993).

Anytime search The use of an agenda makes it easy to control the search for possible realizations, and thus to run the algorithm in anytime mode.⁴

3 Background

3.1 Combinatory Categorial Grammar

We provide here a brief overview of CCG; see Steedman (2000b) for an extensive introduction.

A given CCG grammar is defined almost entirely in terms of the entries of the lexicon, which are (possibly complex) categories bearing standard feature information (such as tense, agreement, etc.) and subcategorization information. Some (simplified) lexical entries are given below:

- (1) a. $man \vdash n$
- b. $that \vdash (n \backslash n) / (s_{vform=fin} / np)$
- c. $Bob \vdash np$
- d. $saw \vdash (s_{tense=past, vform=fin} \backslash np) / np$

CCG has a small set of rules which can be used to combine categories in derivations. The two most basic rules are forward ($>$) and backward ($<$) function application:

- $$\begin{aligned} (>) \quad X/Y \quad Y &\Rightarrow X \\ (<) \quad Y \quad X \backslash Y &\Rightarrow X \end{aligned}$$

CCG also employs further rules based on the composition (**B**), type-raising (**T**), and substitution (**S**) combinators of combinatory logic. Each combinator gives rise to several directionally-distinct rules; for example, there are forward and backward rules for both composition and type-raising:

- $$\begin{aligned} (>\mathbf{B}) \quad X/Y \quad Y/Z &\Rightarrow X/Z \\ (<\mathbf{B}) \quad Y \backslash Z \quad X \backslash Y &\Rightarrow X \backslash Z \\ (>\mathbf{T}) \quad X &\Rightarrow Y/(Y \backslash X) \\ (<\mathbf{T}) \quad X &\Rightarrow Y \backslash (Y/X) \end{aligned}$$

These rules are crucial for building the “non-standard” constituents for which CCG is well-known, and which are essential for CCG’s handling of coordination, extraction, intonation, and

other phenomena. For example, CCG’s rules and the categories given in (1) lead to the following derivation of the relative clause *man that Bob saw*:

$$\begin{array}{c} (2) \quad \frac{\frac{\frac{man}{n} \quad \frac{that}{(n \backslash n) / (s / np)}}{s / (s \backslash np)} \xrightarrow{>\mathbf{T}} \frac{s / np}{n \backslash n} \xrightarrow{>\mathbf{B}} \frac{n \backslash n}{n} \end{array}$$

The OpenNLP CCG system uses a multi-modal version of CCG (Baldrige, 2002; Baldrige and Kruijff, 2003), which has a fully universal rule component that makes it possible to write more efficient unification schemes for rule application than for the original CCG framework.

3.2 Hybrid Logic Dependency Semantics

Like other compositional grammatical frameworks, CCG allows logical forms to be built in parallel with the derivational process. Traditionally, the λ -calculus has been used to express semantic interpretations, but work in other frameworks has moved to using more flexible representations in computational implementations, such as the MRS framework (Copestake et al., 2001) used for HPSG. In the context of categorial grammar, Kruijff (2001) proposes a framework that utilizes hybrid logic (Blackburn, 2000) to realize a dependency-based perspective on meaning. Baldrige and Kruijff (2002) show how this framework, Hybrid Logic Dependency Semantics (HLDS), relates closely to MRS, and show how terms of HLDS can be built compositionally with CCG via unification. In the next section, we show how HLDS’s flexibility enables an approach to semantic construction that ensures semantic monotonicity, simplifies equality tests, and avoids copying in coordinate constructions.

Hybrid logic provides a language for representing relational structures that overcomes standard modal logic’s inability to directly reference states in a model. It does so by using *nominals*, a new sort of basic formula with which we can explicitly name states. In addition to propositions, nominals are first-class citizens of the object language: formulas can be formed using propositions, nominals, standard boolean operators, and the *satisfaction operator* “@”. A formula $@_i(p \wedge \langle F \rangle(j \wedge q))$

⁴That is, to allow the client program to request the best solution found so far at any time. We are currently exploring strategies for ranking partial solutions based on n-gram measures (Varges, 2001).

indicates that the formulas p and $\langle F \rangle(j \wedge q)$ hold at the state named by i and that the state j is reachable via the modal relation F .

In HLDS, hybrid logic is used as a language for describing discourse representation structures — which have their own underlying semantics — as follows. Each semantic head is associated with a nominal that identifies its *discourse referent*, and heads are connected to their dependents via dependency relations, which are modeled as modal relations. As an example, the sentence *Bob saw Gil* receives the representation in (3).

$$(3) \quad @_e(\mathbf{see} \wedge \langle \text{TENSE} \rangle \mathbf{past} \wedge \langle \text{ACT} \rangle (b \wedge \mathbf{Bob}) \wedge \langle \text{PAT} \rangle (g \wedge \mathbf{Gil}))$$

In this example, e is a nominal that labels the predication and relations for the head **see**, and b and g label those for the the **Bob** and **Gil**, respectively. The relations ACT and PAT represent the dependency roles **Actor** and **Patient**, respectively.⁵

By using the $@$ operator, hierarchical terms such as (3) can be flattened to an equivalent conjunction of fixed-size *elementary predications* (EPs), closely related to MRS terms:

$$(4) \quad @_e \mathbf{see} \wedge @_e \langle \text{TENSE} \rangle \mathbf{past} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle g \wedge @_b \mathbf{Bob} \wedge @_g \mathbf{Gil}$$

As (4) shows, EPs come in three varieties: lexical predications, (e.g. $@_e \mathbf{see}$); semantic features (e.g. $@_e \langle \text{TENSE} \rangle \mathbf{past}$); and relations, (e.g. $@_e \langle \text{ACT} \rangle b$).

3.3 Semantic Construction

To facilitate realization from HLDS terms, we have slightly changed Baldridge and Kruijff’s (2002) approach to semantic construction to one which uses maximally flat representations such as (4). In our revised approach, EPs are paired with syntactic categories in the lexicon to form signs, as shown in (5)–(7) below. Each atomic category has an index feature which makes a nominal available for capturing syntactically induced dependencies; these indices are shown as subscripts on the category labels.

$$\begin{aligned} (5) \quad & \text{*saw*} \vdash (s_e \backslash np_x) / np_y : \\ & \quad @_e \mathbf{see} \wedge @_e \langle \text{TENSE} \rangle \mathbf{past} \wedge @_e \langle \text{ACT} \rangle x \wedge @_e \langle \text{PAT} \rangle y \\ (6) \quad & \text{*Bob*} \vdash np_b : @_b \mathbf{Bob} \\ (7) \quad & \text{*Gil*} \vdash np_g : @_g \mathbf{Gil} \end{aligned}$$

⁵To refrain from committing to a particular set of dependency roles, relations such as ARG1, ARG2, etc. can be used.

In derivations, applications of the combinatory rules coindex the appropriate nominals via unification on the categories, and the EPs are then conjoined to form the resulting interpretation. For example, (6) can type-raise and compose with (5) to yield (8), where x has been coindexed with b , and where the EPs have been conjoined; (8) can then apply to (7) to yield (9), which has the same conjunction of predications as (4).⁶

$$\begin{aligned} (8) \quad & \text{*Bob saw*} \vdash s_e / np_y : \\ & \quad @_e \mathbf{see} \wedge @_e \langle \text{TENSE} \rangle \mathbf{past} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle y \\ & \quad \wedge @_b \mathbf{Bob} \\ (9) \quad & \text{*Bob saw Gil*} \vdash s_e : \\ & \quad @_e \mathbf{see} \wedge @_e \langle \text{TENSE} \rangle \mathbf{past} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle g \\ & \quad \wedge @_b \mathbf{Bob} \wedge @_g \mathbf{Gil} \end{aligned}$$

Since the EPs are always conjoined by the combinatory rules, semantic construction is guaranteed to be *monotonic* — in the sense that no semantic information can be dropped during the course of a derivation — which is an essential property for ensuring that the realization algorithm is complete (Copestake et al., 2001).

Another benefit of this approach to semantic construction is that it becomes easier to perform equality tests on signs, since the flat conjunctions of EPs can be sorted into a canonical order and compared in turn. Such equality tests can be used to avoid adding duplicate entries into the chart when there are multiple equivalent derivations for a given sign, thereby alleviating the problem of so-called “spurious” ambiguity (Steedman, 2000b).

A final benefit of simply conjoining EPs in derivations is that it avoids any copying of predications in coordinate constructions. In contrast, the approach implicit in Baldridge and Kruijff (2002) yields duplicate predications in examples such as *Bob heard and Ted saw Gil*, where the proposition **Gil** appears twice (ignoring tense):

$$(10) \quad @_{e_1} (\mathbf{hear} \wedge \langle \text{ACT} \rangle (b \wedge \mathbf{Bob}) \wedge \langle \text{PAT} \rangle (g \wedge \mathbf{Gil}) \wedge \langle \text{COORD} \rangle (e_2 \wedge \mathbf{see} \wedge \langle \text{ACT} \rangle (t \wedge \mathbf{Ted}) \wedge \langle \text{PAT} \rangle (g \wedge \mathbf{Gil})))$$

As we will show in §5, by avoiding such duplicate predications, the present approach to semantic construction keeps the output of the parser in line with the expected input of the realizer.

⁶There is another more traditional (but less incremental) derivation for *Bob saw Gil*, where *saw* combines first with the object *Gil* before combining with the subject *Bob*.

4 The Algorithm

4.1 Data Structures

The input to the algorithm is a logical form encoded as an HLDS term. The input term is flattened to a list of EPs, so that the extent to which partial realizations cover the input LF can be tracked positionally. For example, to realize *man that Bob saw*, the hierarchically structured input in (11) is flattened to (12):

$$(11) \quad @_x(\mathbf{man} \wedge \langle \text{GENREL} \rangle(e \wedge \mathbf{see} \wedge \langle \text{TENSE} \rangle \mathbf{past} \wedge \langle \text{ACT} \rangle(b \wedge \mathbf{Bob}) \wedge \langle \text{PAT} \rangle x))$$

$$(12) \quad \begin{array}{l} 0 : @_x \mathbf{man}, 1 : @_x \langle \text{GENREL} \rangle e, 2 : @_e \mathbf{see} \\ 3 : @_e \langle \text{TENSE} \rangle \mathbf{past}, 4 : @_e \langle \text{ACT} \rangle b \\ 5 : @_e \langle \text{PAT} \rangle x, 6 : @_b \mathbf{Bob} \end{array}$$

The algorithm makes use of three principal data structures: edges, an agenda and a chart. An *edge* is just a CCG sign plus a couple of bit vectors which record the sign's coverage of the input LF and the sign's indices (nominals) that are syntactically available. These bit vectors make it possible to instantly check whether two edges cover disjoint parts of the input LF and whether they have any indices in common. For example, the edges for the finite past and non-finite forms of *see* are given below, with the bit vectors for the EPs and indices shown in braces:

$$(13) \quad \begin{array}{l} \{2, 3, 4, 5\} \{e, b, x\} \\ \mathbf{saw} \vdash (s_{e,fin} \setminus np_b) / np_x : \\ @_e \mathbf{see} \wedge @_e \langle \text{TENSE} \rangle \mathbf{past} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle x \end{array}$$

$$(14) \quad \begin{array}{l} \{2, 4, 5\} \{e, b, x\} \\ \mathbf{see} \vdash (s_{e,nonfin} \setminus np_b) / np_x : \\ @_e \mathbf{see} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle x \end{array}$$

The *agenda* is a priority queue of edges which manages the edges that have yet to be added to the chart. Using the agenda makes it easy to vary the search order by changing the edge sorting strategy.

The *chart* is a collection of edges that enables a dynamic programming search for realizations. Whereas a chart for parsing uses string positions to track partial parses, one for realization uses an edge's coverage vector to track partial realizations.

4.2 Lexical Lookup

In the first phase of the algorithm, for each EP in the flattened input LF, relevant lexical entries are accessed according to the following indexing scheme. Most lexical items are indexed by the

principal lexical predicate which they introduce. However, if a lexical item (e.g. a relative pronoun) only introduces a dependency relation or a semantic feature, it is indexed by the relation or feature. Semantically null lexical items, i.e. ones which introduce no EPs (e.g. infinitival *to*), are not indexed at all; instead, they receive special handling in the combinatory rule phase (see step 4 in figure 1). Case marking prepositions and particles are only considered when there is a matching feature on one of the indexed lexical items indicating that they may be needed.

Once a lexical entry indexed by the current EP has been accessed, instantiation is attempted. During instantiation, the current EP is unified first, and then unification of the remaining EPs in the lexical entry is attempted against the remaining EPs in the input LF. The lexical entry is allowed to introduce extra semantic features, enabling some limited underspecification in the input LF.

For example, the predication EP $@_e \mathbf{see}$ triggers the lookup of the edges shown in (13) and (14). Note that the present tense form *sees* is accessed as well, but instantiation fails due to its incompatible $\langle \text{TENSE} \rangle$ value (whereas the non-finite form *see* has no $\langle \text{TENSE} \rangle$ value). The relational EP $@_x \langle \text{GENREL} \rangle e$ triggers the lookup and instantiation of the two edges for the relative pronoun shown in (15) and (16) below. Similarly, the featural EP $@_e \langle \text{TENSE} \rangle \mathbf{past}$ triggers the introduction of the auxiliary *did*.

$$(15) \quad \begin{array}{l} \{1\} \{e, x\} \\ \mathbf{that} \vdash (n_x \setminus n_x) / (s_{e,fin} \setminus np_x) : @_x \langle \text{GENREL} \rangle e \end{array}$$

$$(16) \quad \begin{array}{l} \{1\} \{e, x\} \\ \mathbf{that} \vdash (n_x \setminus n_x) / (s_{e,fin} / np_x) : @_x \langle \text{GENREL} \rangle e \end{array}$$

4.3 Combinatory Rules

In the second, main phase of the algorithm — at a high level — edges are successively moved from the agenda to the chart and combined with the edges already on the chart, with any resulting new edges added to the agenda, until no more combinations are possible and the agenda becomes empty. Figure 1 describes the main loop in more detail.

Continuing our example, some of the edges generated during the combinatory rule phase are shown in (17)–(21) below, without the bit vectors. The edge for *Bob* is type-raised, yielding (17), and

Until the agenda is empty:

1. Remove the first edge from the agenda and set it to be the current edge. If the chart contains an already derived equivalent edge, skip the rest of the loop.
2. Combine the current edge with the edges already on the chart. More specifically, for each chart edge:
 - (a) Check the coverage bit vectors for the current edge and the chart edge for intersection. If they overlap, skip the chart edge.
 - (b) Check the index bit vectors for intersection. If they do not overlap, only combine the current edge with the chart edge if the input LF contains an appropriate $\langle \text{PAIREDWITH} \rangle$ relation (cf. §5 for discussion).
 - (c) Combine the current edge with the chart edge using all available binary combinatory rules, and add any resulting new edges to the agenda.
3. Apply all unary combinatory rules to the current edge, adding any resulting new edges to the agenda.
4. Combine the current edge with edges for all semantically null lexical items, as if these were chart edges.
5. Add the current edge to the chart.

Figure 1: Main loop

the edge for *see* (14) combines with the semantically null infinitival *to*, yielding (18); (17) then forward composes with both *saw* (13) and *to see* (18), yielding (19) and (20). Since *Bob to see* (20) is marked syntactically as infinitival rather than finite, the relative pronoun edge (16) will only combine (via forward application) with *Bob saw* (19), before combining (via backward application) with *man* to yield the complete edge in (21).

- $$\begin{aligned}
 (17) \quad & \text{Bob} \vdash s_i / (s_i \setminus np_b) : @_b \text{Bob} \\
 (18) \quad & \text{to see} \vdash (s_{e,inf} \setminus np_x) / np_x : \\
 & \quad @_e \text{see} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle x \\
 (19) \quad & \text{Bob saw} \vdash s_{e,fin} / np_x : \\
 & \quad @_e \text{see} \wedge @_e \langle \text{TENSE} \rangle \text{past} \\
 & \quad \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle x \wedge @_b \text{Bob} \\
 (20) \quad & \text{Bob to see} \vdash s_{e,inf} / np_x : \\
 & \quad @_e \text{see} \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle x \wedge @_b \text{Bob} \\
 (21) \quad & \text{man that Bob saw} \vdash n_x : \\
 & \quad @_x \text{man} \wedge @_x \langle \text{GENREL} \rangle e \\
 & \quad \wedge @_e \text{see} \wedge @_e \langle \text{TENSE} \rangle \text{past} \\
 & \quad \wedge @_e \langle \text{ACT} \rangle b \wedge @_e \langle \text{PAT} \rangle x \wedge @_b \text{Bob}
 \end{aligned}$$

5 Coordination

5.1 Sentential Coordination

CCG’s flexible approach to constituency delivers derivations for a wide variety of coordinate structures, often involving the coordination of such “non-standard” constituents as *s/np*, as in the following right node raising example:

- $$(22) \quad [\text{Bob saw}]_{s/np} \text{ and } [\text{Ted heard}]_{s/np} \text{ Gil.}$$

Examples like (22) can be handled using the category for *and* given in (23), where *s*\$ schematizes over functions into *s*:⁷

- $$(23) \quad \text{and} \vdash (s_e \$1 \setminus s_{e_i} \$1) / s_{e_g} \$1 : \\ @_e \text{and} \wedge @_e \langle \text{LIST} \rangle e_1 \wedge @_{e_1} \langle \text{COORD} \rangle e_2$$

Category (23) enables *Bob saw* and *Ted heard* to coordinate as follows:

- $$\begin{aligned}
 (24) \quad & \text{Bob saw and Ted heard} \vdash \\
 & \quad s_e / np_x : \\
 & \quad @_e \text{and} \wedge @_e \langle \text{LIST} \rangle e_1 \wedge @_{e_1} \langle \text{COORD} \rangle e_2 \\
 & \quad \wedge @_{e_1} \text{see} \wedge \dots \wedge @_{e_1} \langle \text{PAT} \rangle x \\
 & \quad \wedge @_{e_2} \text{hear} \wedge \dots \wedge @_{e_2} \langle \text{PAT} \rangle x
 \end{aligned}$$

Category (24) can then be combined with *Gil* to yield a flat conjunction of HLDS terms equivalent to the one below (ignoring tense), which has been collapsed into hierarchical form for readability:

- $$\begin{aligned}
 (25) \quad & @_e (\text{and} \\
 & \quad \wedge \langle \text{LIST} \rangle (e_1 \wedge \text{see} \wedge \langle \text{ACT} \rangle (m \wedge \text{Bob}) \wedge \langle \text{PAT} \rangle g \\
 & \quad \wedge \langle \text{COORD} \rangle (e_2 \wedge \text{hear} \\
 & \quad \wedge \langle \text{ACT} \rangle (t \wedge \text{Ted}) \wedge \langle \text{PAT} \rangle g))) \\
 & \wedge @_g \text{Gil}
 \end{aligned}$$

Since the present approach to semantic construction does not produce duplicate EPs for *Gil*, the output of the CCG parser for (22) shown in (25) can be directly reversed by the realizer. In contrast, the duplicate EPs seen in (10) (cf. §3.3) would cause problems for the realizer’s tracking of input LF coverage. Indeed, the LF in (10) is perhaps more similar to the one for the clause-level coordination in (26) below than it is to (25).⁸

- $$\begin{aligned}
 (26) \quad & \text{Bob heard Gil and Ted saw Gil} \vdash \\
 & \quad s : @_e (\text{and} \wedge \langle \text{LIST} \rangle (e_1 \wedge \text{heard} \wedge \langle \text{ACT} \rangle (b \wedge \text{Bob}) \\
 & \quad \wedge \langle \text{PAT} \rangle (g_1 \wedge \text{Gil}) \wedge \langle \text{COORD} \rangle (e_2 \wedge \text{see} \\
 & \quad \wedge \langle \text{ACT} \rangle (t \wedge \text{Ted}) \wedge \langle \text{PAT} \rangle (g_2 \wedge \text{Gil})))
 \end{aligned}$$

⁷The relations $\langle \text{LIST} \rangle$ and $\langle \text{COORD} \rangle$ encode a linked list; $\langle \text{LIST} \rangle$ points to the first item in the list, and $\langle \text{COORD} \rangle$ points from one item to the next.

⁸Note that each use of a lexical item gives rise to a distinct index nominal, similarly to DRT.

The HLDS terms in (25) and (26) show how differences in the realizer’s input logical form — which are reminiscent of the differences between reduced and unreduced λ -terms — can be used to control the choice of coordination options made available by the grammar.⁹

5.2 NP Coordination

Of the multiple possible readings involving NP coordination, we will only focus on the distributive reading here. As Moore (1989) points out, NPs such as *Ted and Gil* in (27) below pose a challenge for first-order unification-based approaches to semantic construction, since the index x cannot be unified with the referents for both *Ted* and *Gil*.¹⁰

(27) [Bob saw] _{s_e/np_x} Ted and Gil.

Following (Moore, 1989), we tackle this problem by introducing a λ -binder into the semantic representation for (27), while still eschewing the use of λ ’s in variable binding:

(28) $@_s(\mathbf{and} \wedge \langle \mathbf{LIST} \rangle (t \wedge \mathbf{Ted} \wedge \langle \mathbf{COORD} \rangle (g \wedge \mathbf{Gil}))$
 $\wedge \langle \mathbf{PRED} \rangle (l \wedge \mathbf{lambd} \wedge \langle \mathbf{BOUNDVAR} \rangle x$
 $\wedge \langle \mathbf{BODY} \rangle (e \wedge \mathbf{see} \wedge \langle \mathbf{ACT} \rangle (b \wedge \mathbf{Bob}) \wedge \langle \mathbf{PAT} \rangle x))$

The HLDS term in (28) is intended to be equivalent to the conjunction of the terms formed by distributing the λ -term across each member of the list. (27) can be parsed and realized with the semantics in (28) using the category (29), which takes the two NPs and forms a type-raised NP:

(29) $\mathbf{and} \vdash ((s_s \backslash (s_e \backslash np_x)) \backslash np_{x_1}) / np_{x_2} :$
 $@_s \mathbf{and} \wedge @_s \langle \mathbf{LIST} \rangle x_1 \wedge @_s \langle \mathbf{COORD} \rangle x_2$
 $\wedge @_s \langle \mathbf{PRED} \rangle l \wedge @_i \mathbf{lambd} \wedge$
 $\wedge @_i \langle \mathbf{BOUNDVAR} \rangle x \wedge @_i \langle \mathbf{BODY} \rangle e$

5.3 Argument Clusters and Gapping

The above approach to distributive NP coordination can be extended to handle argument clusters — as in (30) below — without the need to invoke otherwise unnecessary deletion operations.

(30) [Bob gave] _{$(s_e/np_y)/np_x$}
 [Ted _{t} a dog _{d}] _{$s \backslash (s/np_d/np_t)$} and
 [Gil _{g} a cat _{c}] _{$s \backslash (s/np_c/np_g)$}

⁹Cf. (Prevost, 1995) for a related use of unreduced λ -terms in the context of representing information structural units.

¹⁰In the collective reading, also plausible in (27), x can simply be unified with a set-valued referent for *Ted and Gil*; with *Ted or Gil*, in contrast, only the distributive reading is possible.

To handle (30), we introduce a $\langle \mathbf{PAIREDWITH} \rangle$ relation to connect pairs of NP referents and bound variables, in the following category for *and*:

(31) $\mathbf{and} \vdash ((s_s \backslash ((s_e \backslash np_y) / np_x))$
 $\backslash (s_s \backslash ((s_s \backslash np_{y_1}) / np_{x_1})))$
 $/ (s_s \backslash ((s_s \backslash np_{y_2}) / np_{x_2}))) :$
 $@_s \mathbf{and} \wedge @_s \langle \mathbf{LIST} \rangle x_1 \wedge @_s \langle \mathbf{PAIREDWITH} \rangle y_1$
 $\wedge @_s \langle \mathbf{COORD} \rangle x_2 \wedge @_s \langle \mathbf{PAIREDWITH} \rangle y_2$
 $\wedge @_s \langle \mathbf{PRED} \rangle l \wedge @_i \mathbf{lambd} \wedge @_i \langle \mathbf{BODY} \rangle e$
 $\wedge @_i \langle \mathbf{BOUNDVAR} \rangle x \wedge @_i \langle \mathbf{PAIREDWITH} \rangle y$

Category (31) enables (30) to be parsed into a semantic representation analogous to (28). The derivation of (30) requires the base NPs *Ted_t* and *a dog_d* to type raise and compose together into the category $s \backslash (s/np_d/np_t)$, as indicated (and similarly for *Gil_g* and *a cat_c*). Reversing this derivation during realization thus requires *Ted_t* and *a dog_d* to combine, even though they have no indices in common. Since removing the index intersection filter from the realization algorithm entirely would let all NPs combine via type-raising and composition in all possible orders, we instead require the indices to be in a $\langle \mathbf{PAIREDWITH} \rangle$ relation in the input LF in order for the NPs to combine.

To handle gapping examples like (32), a similar category can be supplied for *and*, as shown in (33) without the semantics, which remains unchanged:

(32) Ted _{t} received _{$(s_e \backslash np_x)/np_y$} a dog _{$d$} and
 [Gil _{g} a cat _{c}] _{$s \backslash ((s \backslash np_g)/np_c)$}

(33) $\mathbf{and} \vdash (((s_s \backslash np_{x_1}) \backslash ((s_e \backslash np_x) / np_y)) \backslash np_{y_1})$
 $/ (s \backslash ((s \backslash np_{x_2}) / np_{y_2}))$

Category (33) combines first with the pair of NPs *Gil a cat* on the right, then successively with the NP *a dog*, the transitive verb *received* and the NP *Ted* on the left. As such, it handles gapping without appealing to reanalysis, as in Steedman (2000b), though at the expense of requiring *and* to coordinate unlike categories, suggesting that (33) should be viewed as a compiled-out version of Steedman’s (2000b) approach to gapping.

6 Efficiency

As Moore (2002) notes, it appears that the realization problem is inherently exponential in worst case complexity unless one is willing to rely on

	First	All
Avg	0.19	1.32
Max	0.98	13.0

Table 1: Realizer Timing (in seconds)

	First	All
Avg	0.50	13.3
Max	3.84	349

Table 2: Realizer Timing Without Index Filter

the potentially arbitrary order of LF conjuncts. In practice, as Carroll et al. (1999) explain, the main complexity issue is the factorial number of possible word orders that can arise when the grammar leaves modifier order relatively unconstrained. Our current strategy to address this issue is to concentrate on reliably finding good realizations in a reasonably short time span when running the algorithm in anytime mode, rather than worrying about the amount of time it might take on occasion to find all possible realizations. We suggest that this anytime focus is appropriate for practical use in dialog systems.

To test whether our realizer’s speed is in the right ballpark for dialog applications, we have measured its performance on a pre-existing set of test phrases — namely all those discussed in Baldridge (2002) — using a small but linguistically rich grammar covering heavy NP shift, non-peripheral extraction, parasitic gaps, particle shift, relativization, right node raising, topicalization, and argument cluster coordination. On this test suite, the performance is reasonably promising, averaging under 200 ms. until the first realization is found, on a Linux PC. Table 1 shows the average and maximum times until the first realization is found and until all realizations are found.

Even with this small test suite, it is clear that the index filter is essential for efficient realization. Table 2 shows the comparable realization times with the index filter turned off. As the table shows, the average time until the first realization more than doubles, and the maximum time until the first realization is nearly four times worse. The expected exponential increase in realization times (cf. §5) can be seen in the times to find all realizations.

To increase performance, there is ample room to make improvements to the unification algorithm. While the index filter reduces the number of unification operations attempted, unification still dominates the realization time. The implementations of the combinatory rules have been optimized as described in Baldridge (2002), but unification is otherwise naive and performs more copying than necessary.

Employing packing and pruning strategies could also improve performance. Currently, there is no structure sharing among edges, and no means to prune low ranked edges from the chart.

7 Conclusions and Future Work

Our approach to chart realization with CCG is most closely related to Carroll et al. (1999), which in turn builds upon much earlier work cited therein, such as Kay (1996). Moore (2002) presents a related algorithm for a broad class of context free grammars.

Compared to Carroll et al. (1999), we have employed a similar but more straightforward approach to semantic construction than described in Copestake et al. (2001), since we do not allow underspecification of the logical scope of quantifiers,¹¹ and since there is no need for special treatment of external arguments to handle control phenomena in CCG. We also have not tried delaying the insertion of intersective modifiers (Carroll et al., 1999), in part because doing so would complicate the use of n-gram ranking strategies.

The primary novel contribution of our approach is showing how to efficiently realize a wide range of coordination phenomena with CCG. In particular, we have shown how to use an index filter sensitive to paired entities in the input LF in order to handle argument cluster coordination and gapping.

In future work, we plan to take several steps to make the realizer more practical. As already mentioned, we are currently exploring strategies for ranking partial solutions based on n-gram measures, and we plan to improve efficiency via enhancements to our unification algorithm. We are also currently investigating techniques for handling Steedman’s (2000a) approach to information

¹¹Cf. Steedman (1999) for discussion.

structure and intonation. In addition, we plan to bootstrap a wide coverage grammar for English from the CCG Bank (Hockenmaier and Steedman, 2002), and to develop improved XML grammar management tools.

Beyond these practically-oriented steps, we also plan to investigate new techniques for coupling CCG realization with higher level planning components. A particularly appealing direction is to see whether the present approach to coordination can simplify the treatment of aggregation in higher level planning components used in conjunction with the realizer. Since current bottom-up approaches to aggregation such as Dalianis (1996) and Shaw (1998) combine simple syntactic phrases into more complex ones by looking for patterns of related semantic material, they do not fit naturally into applications where it makes sense to group semantic material during content planning, based on intentions or information structural considerations. In contrast, working with our realizer, content planning components could specify their aggregation decisions via distinctions made at the level of logical form, taking advantage of the realizer's ability to use differences in the input LF to control the choice of coordination options made available by the grammar.

Acknowledgements

We would like to thank Mark Steedman, Geert-Jan Kruijff, Johanna Moore, Jon Oberlander and Mary Ellen Foster for helpful discussions. This work was supported in part by the COMIC (IST-2001-32311) and ROSIE (Edinburgh-Stanford Link R36763) projects.

References

- Jason Baldridge and Geert-Jan Kruijff. 2002. Coupling CCG and Hybrid Logic Dependency Semantics. In *Proc. of 40th Annual Meeting of the Association for Computational Linguistics*, pages 319–326.
- Jason Baldridge and Geert-Jan Kruijff. 2003. Multi-Modal Combinatory Categorical Grammar. In *Proc. of 10th Annual Meeting of the European Association for Computational Linguistics*.
- Jason Baldridge. 2002. *Lexically Specified Derivational Control in Combinatory Categorical Grammar*. Ph.D. thesis, School of Informatics, University of Edinburgh.
- Patrick Blackburn. 2000. Representation, reasoning, and relational structures: a hybrid logic manifesto. *Logic Journal of the IGPL*, 8(3):339–625.
- John Carroll, Ann Copestake, Dan Flickinger, and Victor Poznański. 1999. An efficient chart generator for (semi-) lexicalist grammars. In *Proc. of the 7th European Workshop on Natural Language Generation*, pages 86–95.
- Ann Copestake, Alex Lascarides, and Dan Flickinger. 2001. An algebra for semantic construction in constraint-based grammars. In *Proc. of the 39th Annual Meeting of the Association of Computational Linguistics*, pages 132–139.
- Hercules Dalianis. 1996. *Concise Natural Language Generation from Formal Specifications*. Ph.D. thesis, Royal Institute of Technology, Stockholm.
- Julia Hockenmaier and Mark Steedman. 2002. Acquiring compact lexicalized grammars from a cleaner treebank. In *Proc. of the Third International Conference on Language Resources and Evaluation*.
- Beryl Hoffman. 1995. *Computational Analysis of the Syntax and Interpretation of 'Free' Word-order in Turkish*. Ph.D. thesis, University of Pennsylvania. IRCS Report 95-17.
- Martin Kay. 1996. Chart generation. In *Proc. of the 34th Annual Meeting of the Association for Computational Linguistics*, pages 200–204.
- Geert-Jan M. Kruijff. 2001. *A Categorical Modal Architecture of Informativity: Dependency Grammar Logic & Information Structure*. Ph.D. thesis, Charles University.
- Robert C. Moore. 1989. Unification-based semantic interpretation. In *Proc. of the 27th Annual Meeting of the Association for Computational Linguistics*, pages 33–41.
- Robert C. Moore. 2002. A complete, efficient sentence-realization algorithm for unification grammar. In *Proc. of the 2nd International Natural Language Generation Conference*.
- Scott Prevost. 1995. *A Semantics of Contrast and Information Structure for Specifying Intonation in Spoken Language Generation*. Ph.D. thesis, University of Pennsylvania. IRCS TR 96-01.
- James Shaw. 1998. Clause aggregation using linguistic knowledge. In *Proc. of the Ninth International Workshop on Natural Language Generation*, pages 138–148.
- Stuart Shieber. 1993. The problem of logical-form equivalence. *Computational Linguistics*, 19(1):179–190.
- Mark Steedman. 1999. Quantifier Scopep Alternation in CCG. In *Proc. of the 37th Annual Meeting of the Association for Computational Linguistics*, pages 301–308.
- Mark Steedman. 2000a. Information structure and the syntax-phonology interface. *Linguistic Inquiry*, 31(4):649–689.
- Mark Steedman. 2000b. *The Syntactic Process*. MIT Press.
- Sebastian Varges. 2001. Instance-based natural language generation. In *Proc. of the 2nd Meeting of the North American Chapter of the Association for Computational Linguistics*, pages 1–8.

Combinatory Categorical Grammar and Syntactic Extraction Asymmetries

Version 3.1

Jason Baldridge
University of Edinburgh

30 June 2004

1. Introduction

Syntactic extraction asymmetries are characterized by situations in which particular arguments in a sentence are unsuitable targets for extraction in certain contexts. That is, these arguments can not be used when forming questions, relative clauses, topicalized sentences and the like. For example, the well-known subject/object asymmetry of English appears in embedded clauses such as the following:

- (1) a. *boy_i that I think that *t_i* read the book
- b. book_i that I think that Calvin read *t_i*

The attempt in (1a) to extract of the subject of the embedded clause is ungrammatical, whereas the object is accessible, as shown in (1b).¹

There is nothing semantically incoherent about a relative clause such as that in (1a) – the grammar apparently disallows it for entirely syntactic reasons. Chomsky’s 1981 Empty Category Principle (ECP) and its various refinements were formulated to capture this asymmetry within Government-Binding theory. The essence of ECP accounts is that the trace in (1a) cannot be properly governed. As a result, the ECP predicts that objects should generally be easier to extract than subjects. However, Nakamura 1998 points out that the ECP runs into problems with languages like Tagalog, which exhibits cases where the subject is more easily extracted than the object. Nakamura argues that global economy conditions – which amount to transderivational constraints – are needed to account for Tagalog’s asymmetries.

Definitions of the ECP depend on grammars having fixed constituency. For example, subjects are generally assumed to be base generated as

¹ It should be noted that I use the term *extraction* metaphorically, and that the traces shown in (1) are only used descriptively to highlight the canonical position of the extracted element.



sisters of VP while objects are sisters of V. These distinct configurations lead to different possibilities for defining how traces appearing in those base positions are governed. However, not all formalisms assume fixed constituency of this nature. For example, Combinatory Categorical Grammar (CCG) (Steedman, 1987; Steedman, 1996; Steedman, 2000b) allows a verb to form a constituent with its subject before it combines with its object. The usual kind of definitions for government given in GB theory therefore collapse in CCG derivations. This means that CCG accounts of asymmetries cannot depend on the ECP or other government-based principles.

CCG employs a small set of universal rules that combine constituents and thereby allow categories to satisfy their subcategorization requirements. These combinatory rules are stratified: the most basic rules enforce fixed constituency, while more powerful rules gradually permit greater flexibility. Categories lexically project their own derivational limits on this stratified rule system via simple specifications of how they combine with each of their arguments. These limits are enforced as *modalities* which key into the various rules.

In this article, I consider the asymmetries of English, Tagalog, and Toba Batak from the CCG perspective. Derivational flexibility is crucial for how extraction is analyzed in CCG. At least one of the more powerful rules is typically needed to form the necessary constituent for extraction. The core claim is that asymmetries arise when one or more categories in the derivation place limits that bar the applicability of one of these more powerful rules. As a result, some constituencies are blocked, leaving no syntactic means to extract certain arguments. These limits are shown to be independently motivated by other constraints on the grammar. The asymmetries are thus accounted for cross-linguistically without reference to principles like the ECP or powerful transderivational constraints.

I begin by outlining examples of asymmetries found in Tagalog and Toba Batak and discussing previous analyses of Tagalog. Together with English, these languages provide an interesting triangulation for examining extraction asymmetries. Both Tagalog and Toba Batak have an intricate voice system that has made it difficult for researchers to conclusively agree on how to identify their subjects and objects – a crucial distinction for accounts of extraction in many frameworks. On the other hand, Toba Batak shares with English a more constrained clausal word order than Tagalog. In Section 3, I provide a brief but self-contained introduction to the multi-modal version of CCG used here (Baldrige and Kruijff, 2003), giving motivation for how it extends basic categorial grammar. This section also shows how basic extraction for English is handled in CCG and motivates a small set of universal

distinctions for controlling rules lexically. Section 4 shows that the English subject/object asymmetry is due to limits on permutation-inducing rules, evolving from Steedman’s 1996 analysis. Next, I provide an account of basic Tagalog syntax, showing how a number of basic Tagalog constructions receive a suprisingly straightforward analysis by assuming that nouns, adjectives, and intransitive verbs are syntactically unary predicates. This treatment provides a natural means of capturing matrix level extraction asymmetries. This in turn generalizes to long-distance asymmetries, which arise because of limits on order-preserving flexibility in derivations. Finally, section 6 shows that Toba Batak’s asymmetries are, like English, a result of limits on permutation-inducing rules. Together, these analyses provide a cross-linguistic viewpoint on the appearance of extraction asymmetries, using all the degrees of freedom allowed by the multi-modal stratification of CCG’s combinatory rules – a stratification which is independently motivated by the need for control in other basic constructions in English, Dutch, and Turkish (Baldrige, 2002; Baldrige and Kruijff, 2003).

2. Tagalog and Toba Batak: data and previous approaches

The Austronesian languages Tagalog and Toba Batak exhibit even more striking extraction asymmetries than the subject/object asymmetry of English. Their verbs appear in a variety of voices, each of which marks a single argument as special either through position or marking. For example, in the Active Voice form *bumili* of the Tagalog verb *bili* ‘buy’, the Actor² argument is marked by the lexical item *ang*:³

- (2) Bumili ng libro ang titser.
 AV-buy NG book ANG teacher
The teacher bought a book.

Interestingly, although it is possible to form a question regarding the Actor for a verb in Active Voice, as shown in (3), forming a question about Patient *ng libro* is ungrammatical (3b).

- (3) a. Sino ang bumili ng libro?
 who ANG AV-buy NG book
Who bought a book?

² I will use the dependency relations of Functional Generative Description (Sgall et al., 1986) as a non-syntactic, purely descriptive means of referring to verbal arguments.

³ Abbreviations used in glosses: AV = Active Voice; DV = Dative Voice; IV = Instrumental Voice; OV = Objective voice; LNK = linker

- b. *Ano ang bumili ang titser?
 what ANG AV-buy ANG teacher
 (for: *What did the teacher buy?*)

Toba Batak, a language spoken in northern Sumatra, exhibits very similar asymmetrical behavior, though its word order is more fixed than that of Tagalog.

- (4) Mangida si John si Bill
 AV-see PNM-John PNM-Bill
Bill saw John.

Like Tagalog, only the Actor argument may be questioned for a verb in Active Voice form.

- (5) a. Ise mangida si John
 who see PNM-John
Who saw John?
 b. *Aha mangida si Bill
 what see PNM-Bill
 (for: *What did Bill see?*)

It would be rather limiting if it were not possible to ask about the Patient argument through some other means. To accomodate such queries, the extensive voice systems of Tagalog and Toba Batak permit a verb to single out any one of its dependents as special. For example, as an alternative to *bumili*, which is the Active Voice form of the root *bili* ‘buy’, Tagalog also has the Objective Voice form *binili*.

- (6) Binili ng titser ang libro.
 OV-buy NG-teacher ANG-book
A teacher bought the book.

This process has been called topicalization and focussing in the literature on Tagalog, but I will instead use the term *distinguishing* to avoid the baggage that those terms come with, especially since it is not clear that the distinguished argument necessarily corresponds to any generally understood sense of *topic* or *focus*.

As can be seen, the marking on the two nominal arguments is the opposite of that in (2). Here, the Patient *libro* is preceded by the marker *ang* and the Actor *titser* by *ng*. What is particularly interesting at present about this voice alternation is that the extractability of the arguments is reversed. Contrast (3) with the following:

- (7) a. Ano ang binili ng titser?
 what ANG OV-buy NG-teacher
 What did a teacher buy?
- b. *Sino ang binili ang libro?
 who ANG OV-buy ANG-book
 (for: *Who bought the book?*)

A very similar pattern arises in Toba Batak; however, instead of any change in the marking on the arguments, the distinguished argument is moved to the end of the sentence when the verb is in Objective Voice.

- (8) Di-ida si Bill si John
 OV-see PNM-Bill PNM-John
 Bill saw John.

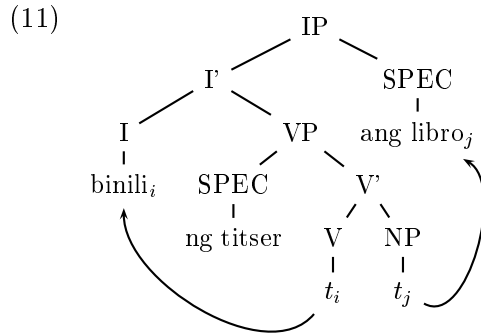
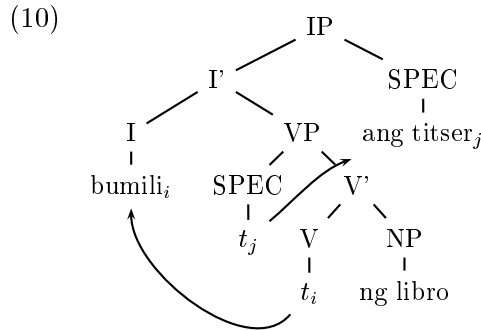
The order of the dependents thus changes, and now only the Patient argument can be extracted:

- (9) a. *Ise diida si John
 who OV-see PNM-John
 (for: *Who saw John?*)
- b. Aha diida si Bill
 what OV-see PNM-Bill
 What did Bill see?

In addition to *wh*-extraction, asymmetries in Tagalog also arise in relativization, floated quantifiers, and a fronting process called *ay*-inversion. The asymmetries have played a central role in the debate on whether or not Tagalog has an identifiable subject. According to the accessibility hierarchy of Keenan and Comrie 1977, the greater syntactic potential of *ang*-marked arguments implies that they are the subjects of Tagalog (Schachter, 1976). However, as Schachter pointed out, the Actor argument appears to retain certain other properties normally associated with subjects even when it is not *ang*-marked. The most important of these are the ability to bind reflexives and the fact that they are the most common targets of Equi-NP deletion.

Kroeger 1993 argues that the case for the Actor argument as subject is diminished in light of the fact that neither of the above properties is unique to Actor arguments. Kroeger amasses a great deal of other data which supports the view that the *ang*-marked argument is the subject. Having done this, Kroeger is able to give a concise analysis of Tagalog asymmetries in terms of grammatical relations with the Functional Uncertainty formalism of (Kaplan and Zaenen, 1989).

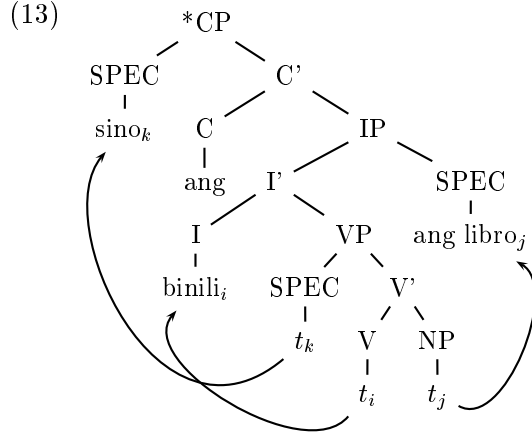
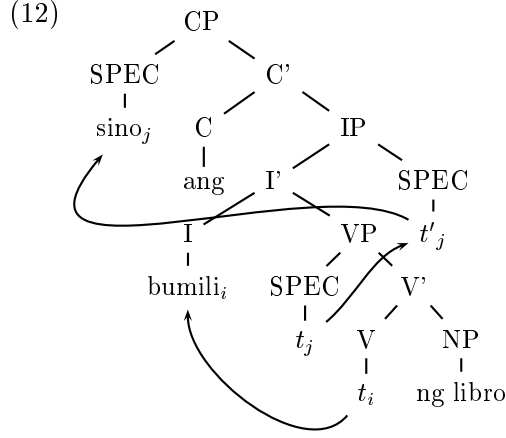
Guilfoyle et al. 1992 are concerned less with identifying the subject than with providing a configurational account of the apparent split in subject properties. They discuss four phenomena—extraction, quantifier float, reflexivization, and control—and discuss how they might be captured by assuming that Actor arguments occupy SPEC of VP and that *ang*-marked noun phrases move to SPEC of IP. The tree configurations which Guilfoyle et al. 1992 assign to (2) and (6) are given in (10) and (11), respectively.



Regardless of verbal morphology, the Actor noun phrase is base generated in SPEC of VP and is thus always external to the V' projection. This fact in conjunction with standard binding theory assumptions explains why it is always a potential antecedent for reflexives and is always a potential target of Equi-NP deletion. On the other hand, the fact that the *ang*-marked argument may always raise to SPEC of IP is said to be responsible for its unique ability to be extracted and to launch floating quantifiers.

Guilfoyle et al. thus identify SPEC of IP as a pivotal configurational position for extractability, suggesting that “extraction obviously requires some type of locality to prevent movement out of the VP across a filled SPEC of IP” (p. 393). Nakamura 1994, 1998 adopts Guilfoyle et al.’s analysis of Tagalog phrase structure and provides a detailed

syntactic account of Tagalog's asymmetries in terms of representational economy. He argues that the licit extraction (3a) competes with and subsequently blocks the illicit (7b). According to Nakamura, the fundamental reason for this is that the derivation of (3a), shown in (12), involves shorter links in the movement chain for the *wh*-word *sino* than the links in the derivation of (7b), shown in (13).



Nakamura defines the length of a chain link as the number of maximal projections that dominate the tail but not the head. In (12), the *wh*-chain (t'_j, t_j) has length 1, whereas the comparable chain $(sino_k, t_k)$ in (13) has length 2. Derivation (13) is thus blocked by (12), in obedience with Nakamura's formulation of the *Minimal Link Condition* (Chomsky and Lasnik, 1993): one derivation blocks another if they have comparable chain links and the link from the former is shorter than the latter.

Nakamura's 1998 analysis provides extensive coverage of Tagalog's extraction facts. Kroeger's 1993 analysis cannot handle extractions out

of certain voiceless constructions in Tagalog, whereas these come as a prediction of Nakamura's analysis. However, Nakamura uses an interpretation of the Minimal Link Condition which amounts to a powerful transderivational constraint. He argues that his Tagalog analysis counters Chomsky's 1994 claim that the Minimal Link Condition should be applied strictly locally. In this paper, I demonstrate that Tagalog's asymmetries can in fact be explained using much less powerful means, thereby undermining Nakamura's claim that transderivational constraints are *necessary*.

3. Combinatory Categorical Grammar

In this section, I introduce Combinatory Categorical Grammar (CCG) by defining the base categorial system and then gradually motivating the addition of further rules with examples from English. The discussion is intended to be self-contained; nonetheless, see Steedman 1996, 2000b for extensive linguistic, computational, and psychological motivation for CCG.

3.1. A HISTORICAL NOTE ON CATEGORIAL GRAMMAR

Categorial grammar (CG) has a long history starting with Ajdukiewicz's calculus of syntactic connection (Ajdukiewicz, 1935) and its subsequent directional adaptation (Bar-Hillel, 1953). The fundamental idea of the approach is that syntactic potential is defined as a property of lexical items in terms of syntactic types, or *categories*, that specify subcategorization and the canonical linear direction in which they find their arguments. The potential of categories is realized via abstract syntactic rules of combination.

The earliest variety of CG used only two basic rules of function application. This system was shown to be weakly equivalent to context-free phrase structure grammar (Bar-Hillel et al., 1964) – at a time when linguists widely believed that grammars for natural languages required greater than context-free power. Partly due to this fact, CG was sidelined by mainstream linguistics during the 1960's for not being sufficiently expressive. Despite this setback, syntacticians' interest in CG began to revive in the late 1970's and early 1980's. One reason for renewed interest came from contemporary developments in formalizing a type-driven semantics for natural language (Montague, 1974; Partee, 1976), for which the syntactic/semantic type-transparency of categorial grammar was particularly attractive. Another reason was the realization that transformational generative grammar was overly expressive

(Peters and Ritchie, 1973). This led to a search for more minimal extensions of context-free core grammars of various kinds (cf. Gazdar 1981), including CG.

The apparent supposition that the categorial approach could not be generalized to create systems of greater power was itself unfounded, as evidenced by the subsequent flowering of extended categorial grammar formalisms (see Wood 1993 for an extensive discussion of these). The first extensions to CG were “combinatory” in nature, extending the core CG with functional operations on adjacent categories, such as “wrap” (Bach, 1979; Dowty, 1979) and functional composition (Ades and Steedman, 1982). These developments in turn led to a revived interest in the type-logical alternative initiated by Lambek 1958.

While the combinatory and type-logical approaches shared a common basis, they gave rise to several different perspectives within the categorial approach. The combinatory branch evolved on more computational grounds and shares much in common with unification-based approaches such as Head-driven Phrase Structure Grammar (HPSG) (Pollard and Sag, 1994). The strongest exponent of this tradition today is CCG, which extends basic CG with defining rules of combination based on a small set of combinators from combinatory logic (Curry and Feys, 1958). The logical branch became what is today known as Categorical Type Logic (CTL) (Morrill, 1994; Moortgat, 1997; Oehrle, ms). CTL departs from pure categorial grammar’s rule-based approach by providing a powerful system of grammatical inference.

The separation between combinatory and type-logical approaches has remained fairly sharp since these early developments. On the one hand, CCG has retained an active concern with keeping expressive power to the “mildly context sensitive” level (Joshi et al., 1991)), and has been actively involved with issues of linguistic explanation and practical computational linguistics, including wide-coverage parsing using statistical models. On the other hand, work in CTL has been more concerned with theoretical issues and relations to logic, theorem proving, and complexity.

The CCG and CTL branches of CG have produced distinct developments that provide different formal devices. These in turn lead to different possibilities for stating linguistic theories couched in those formalisms. In this article, I use a formulation of CCG that goes some way toward reconciling their differences. While the system used here retains CCG’s combinatory apparatus and low expressive power, it also incorporates the multi-modal approach developed for type-logical grammar as the sole means of constraining derivations in CCG. This move allows the rules of the system to be stratified and selectively used in lexically specified contexts, thereby removing the need for the category-based

restrictions on combinatory rules used for this purpose in previous formulations of CCG. This modification leads to a completely universal rule component and thereby a completely lexicalist account of syntax. The system used here also incorporates sets into categories, based on the Multiset-CCG (Hoffman, 1995) extension of CCG. This allows flexible word-order to be encoded without categorial ambiguity.

3.2. CATEGORIES AND APPLICATION RULES

I will start with English to introduce and motivate the multi-modal CCG system used in this article. The basic categories needed to derive the sentence *John read the book* are the following:

- (14) a. Calvin := np
 b. the := np{ $\diamond$ n}
 c. book := n
 d. up := prt
 e. picked := (s{\np}){/np, $\diamond$ prt}

Categories come in two varieties: atomic ones such as np (noun phrase) and prt (particle) and curried functions such as (s{\np}){/np, $\diamond$ prt}. There are two main differences between the categories shown above and those familiar from previous work in CCG: (1) the addition of *modalities*, such as $\star$ and $\cdot$ on the slashes of the function categories, and (2) the use of argument sets which support flexible word-order more directly than previously in CCG. How these devices work will be explicated as the combinatory rules are introduced.

The inclusion of modalities signifies a departure from CCG as described in Steedman 2000b. In CTL, such modalities are logical operators that permit stratification in structural reasoning. In CCG, they provide the means for distinguishing different types of slashes for use with different combinatory rules. The effect on grammar architecture is largely the same in both systems, although the potential power of modalities is much more limited in the CCG context.

Using modalities, function categories may be restricted as to the rules that allow them to combine with other categories, via slashes typed with four basic modalities: $\star$, $\times$, $\diamond$, and $\cdot$. The effect of each of these modalities will be explicated as I introduce each of the combinatory rules and define their interaction with the modalities. The basic intent behind the modalities is as follows: the $\star$ modality is the most restricted and allows only the most basic applicative rules; $\diamond$ permits order-preserving associativity in derivations; $\times$ allows limited permutation; and $\cdot$ is the most permissive, allowing all rules to apply. The

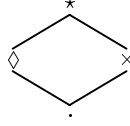


Figure 1. CCG type hierarchy for slash modalities.

relation of these modalities to each other can be compactly represented via the simple hierarchy given in Figure 1. The structure of the hierarchy indicates that, for example, the slash type $/\diamond$ is compatible with $/\star$ but not with $/\times$.⁴

The essential effect of these modalities is to permit lexical control over CCG's combinatory rules by defining the ability of functional categories to serve as input to only a subset of the available rules. Without modally typed slashes, language-specific restrictions or even bans on some combinatory rules are necessary in order to block certain ungrammatical word orders. With them, the combinatory rules are truly universal: the grammar of every language utilizes exactly the same set of rules, without modification, thereby leaving all cross-linguistic variation in the lexicon. As such, CCG is a *fully* lexicalized grammar formalism.

Though I formally introduce the modalities in the system in this section, it is only in the following section that their linguistic effect is brought more fully into play.

The argument sets are also a departure from standard CCG. They hail from the Multiset-CCG extension of CCG (Hoffman, 1995), but here they will be used much more conservatively to ensure that the system retains the same generative capacity as standard CCG. In order to allow functors such as (14d) to combine with their arguments, we need combinatory rules. The two simplest are the following functional application rules:⁵

(15) *Functional application*

- a. $X(\alpha \uplus \{/\star Y\}) \ Y \Rightarrow X\alpha$ ($>$)
- b. $Y \ X(\alpha \uplus \{/\star Y\}) \Rightarrow X\alpha$ ($<$)

In binary rules such as this, I will refer to the functor category (e.g. X/Y) as the *primary* input to the rule and the other argument as the

⁴ The use of a hierarchy such as this as a formal device is optional, and instead could be replaced by multiple declarations of the combinatory rules.

⁵ I use multiset union ' $\uplus$ ' in the rule definitions instead of regular set union ' $\cup$ ' to ensure that, for example, $Y \notin \alpha$, which would lead to the possibility of α containing unboundedly many copies of Y

secondary input. X and Y are variables standing for any category and can be either atomic or curried. The set α can be empty, and, following Hoffman 1995, I assume a general cleanup rule that removes empty set arguments, so that the result category $X\emptyset$ reduces to just X . Because $\star$ is the supertype of all other modalities, the $/_{\star}$ and $\backslash_{\star}$ slashes on these rules mean that *all* categories can combine by these rules.

Defined in this manner, the application rules for derivations in which functors to consume their arguments and thereby satisfy their subcategorization requirements. In giving a derivation, we line up the words of a sentence, introduce their associated categories from the lexicon, and proceed by applying the rules to adjacent pairs of categories. Once a pair of categories have been combined, only the category resulting from the combination is visible for further derivational steps. Each step is annotated by underlining the combining categories and labeling the underline with the symbol for the rule used. Unlabeled underlines indicate introduction of a category from the lexicon. An example derivation is given below for the sentence *Calvin picked up the book* using the lexical entries given in (14).

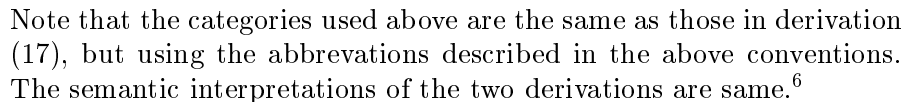
$$\begin{array}{ccccccc}
 (16) & \text{Calvin} & & \text{picked} & & \text{up} & & \text{the} & & \text{book} \\
 & \text{np} & & \text{(s}\{\backslash\text{np}\}\text{)}\{/. \text{np}, /_{\diamond}\text{prt}\} & & \text{prt} & & \text{np}\{/\diamond\text{n}\} & & \text{n} \\
 & & & \text{(s}\{\backslash\text{np}\}\text{)}\{/. \text{np}\} & & & & \text{np} & & \\
 & & & \text{s}\{\backslash\text{np}\} & & & & & & \\
 & & & \text{s} & & & & & &
 \end{array}$$

In order to reduce notational clutter in categories, the following conventions will be used for the rest of this article:

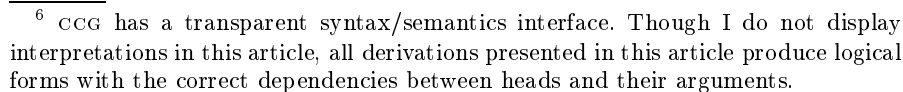
Convention 1 (Singleton set abbreviation). *Singleton sets containing only a single category are written without brackets; for example, $(\text{s}\{\backslash\text{np}\})\{/. \text{np}\}$ is abbreviated as $(\text{s}\backslash\text{np})/. \text{np}$ and $\text{s}\{./(\text{s}\{\backslash\text{np}\})\}$ as $\text{s}/.(\text{s}\backslash\text{np})$.*

Convention 2 (Most permissive slash abbreviation). *The most freely-combining types of slash, $/.$ and $\backslash.$, allow a category to combine by any combinatory rule. They are the most typical kind of slash, so it will be convenient to abbreviate this type as a plain forward $/$ or backward slash $\backslash$, continuing to write such categories as they were in earlier forms of CCG.*

The use of the argument set in the category for *picked* allows the particle to shift past the direct object:



CCG derivations can be viewed as a phrase structure tree turned upside-down. For example, the categorial derivation (16) is shown in tree form in (18). This is clearly isomorphic to a phrase structure analysis such as that in (19).



Despite the correspondence of derivations and PS trees, the categories labeling the nodes of the tree in (18) are much more informative than the atomic symbols of a tree produced by a context-free grammar such as (19). Subcategorization is directly encoded in functor categories rather than through the use of new symbols such as $V_{intrans}$, V_{trans} and $V_{ditrans}$. Furthermore, there is a systematic correspondence between notions such as *intransitive* and *transitive* — after the transitive category $(s \backslash np)/np$ consumes its object argument, the resulting category $s \backslash np$ is exactly the same as that of an intransitive verb. This comes as a result of the way lexical categories are defined in combination with the universal rules of functional application.⁷

The fact that categories explicitly encode subcategorization provides a very direct means to account for extraction of subjects in English. For example, by assuming the category (20) for the relativizer *that*, we can provide the derivation (21) for *boy that picked up the book*.

$$(20) \quad \text{that} := (n \backslash_{\star} n) /_{\star} (s_{ip} \backslash np)$$

$$(21) \quad \begin{array}{c} \text{boy} \quad \text{that} \quad \text{picked} \quad \text{up} \quad \text{the book} \\ \hline n \quad (n \backslash_{\star} n) /_{\star} (s_{ip} \backslash np) \quad (s \backslash np) \{ /np, /_{\diamond} prt \} \quad prt \quad np \\ \hline \quad \quad \quad (s \backslash np) / np \quad > \\ \hline \quad \quad \quad \quad \quad s \backslash np \quad > \\ \hline \quad \quad \quad \quad \quad \quad n \backslash_{\star} n \quad > \\ \hline \quad \quad \quad \quad \quad \quad \quad n \quad < \end{array}$$

Note that the combination of *the book* is not shown in this derivation. This is a simple abbreviation to reduce the size of derivations for obvious steps that are not focal to the point being made by the derivation.

The first argument of category (20) has the type of an intransitive verb category, i.e. a sentence missing its subject noun phrase. This demonstrates another way in which categorial grammar is different from phrase structure. In phrase structure grammar, more involved strategies are needed. For example:

1. Define new non-terminals such as S-NO_SUBJ that indicate a sentence that is missing its subject, and then provide the requisite phrase structure rules that ensure the meaning of such non-terminals is obeyed.

⁷ See (Oehrle, ms) for a deductive explanation within the Lambek framework of the relationship between categories and phrase structure labels.

2. Introduce gap-threading mechanisms on feature structures of non-terminals, eg Generalized Phrase-Structure Grammar (Gazdar et al., 1985).
3. Add new mechanisms such as transformations, i.e. tree-rewriting mechanisms, to the computational system. The movement operations of GB/Minimalism are a common example of this strategy.

All of these approaches require either *ad hoc* specifications or extra mechanisms or power which are unnecessary in the categorial approach. This is not to say that such mechanisms cannot be motivated on independent grounds; it is to highlight the fact that categories are *not* non-terminals. They are structured objects that interact in a *logical* manner with the rules of the system.

Categories are also semantically transparent. The interpretation associated with the category (20) is $\lambda P.\lambda x.(x \wedge Px)$. This binds the interpretation of the extracted subject to that of the noun argument, ultimately producing the logical form *boy* $\wedge$ *picked_up*(*boy*, *book*).⁸

3.4. COMPOSITION AND TYPE-RAISING

Although categories provide an explicit grip on subcategorization and directionality of arguments, the system presented thus far is formally equivalent to a context-free phrase structure grammar – and thus is quite limited. Subject extraction can be dealt with quite straightforwardly, as described above, but object extraction in English shows a weakness of the system as it has been thus far defined. Just as the subject extracting category (20) seeks a sentence missing its leftward argument, the category (22) appropriately encodes what is necessary for extracting the object of a transitive verb:

$$(22) \quad \text{that} := (n \backslash_{\star} n) /_{\star} (s_{ip} / np)$$

However, with only this category, the others defined in (14), and the two rules of function application (15), a relative clause such as *book that Calvin picked up* cannot be derived. The structure of the category of a verb like *picked* keeps the subject argument locked in until the object has been consumed, so there is no way to produce the required category s_{ip}/np for the string *Calvin picked up*:

⁸ This is obviously a simplification of the meaning of such relative clauses. What is important at present is that the correct dependencies are produced from the derivation.

$$\begin{array}{ccccccc}
 (23) & \text{book} & & \text{that} & & \text{Calvin} & & \text{picked} & & \text{up} \\
 & \underline{n} & & \underline{(n \backslash_{\star} n) /_{\star} (s_{ip} \backslash np)} & & \underline{np} & & \underline{(s \backslash np) \{ /_{np}, /_{\diamond} prt \}} & & \underline{prt} \\
 & & & & & & & \underline{(s \backslash np) / np} & & \underline{>} \\
 & & & & & & & \underline{\hspace{1.5cm}} & & \underline{\hspace{1.5cm}}^*
 \end{array}$$

One solution would be to provide *picked* with the second category $(s \{ /_{np}, /_{\diamond} prt \}) \backslash np$. This would allow the verb to first consume its subject and then the particle, leaving the category s_{ip} / np desired by the relativizer (22). While this strategy permits an analysis for this case, it requires categorial ambiguity of a kind that is generally avoided because it relies on stipulations rather than formal universals provided by the system. Also, the strategy quickly breaks down when we consider unbounded relativization, creating an even further proliferation of categories.

The need for categorial ambiguity here arises from the fact that the system defined thus far completely non-associative and non-permutative. It could be argued that throwing a large number of categories at the problem is actually a fine strategy, and that we should be content with the utter simplicity of the system itself. However, CCG takes a different strategy: adding further rules that allow greater flexibility in derivations. Specifically, CCG makes use of three further classes of rules in addition to functional application. These correspond to the combinators composition (**B**), type-raising (**T**), and substitution (**S**) of combinatory logic (Curry and Feys, 1958).

In this article, I use only composition and type-raising. Together, they provide CCG with the means of accounting for unbounded dependencies without increasing categorial ambiguity. I will first introduce both types of rules and then give examples of their use in derivations.

The application rules (15) allow a functor to consume an argument and thereby reduce its arity. Composition rules, on the other hand, allow two functors to combine to create a new functor. The definitions for the *harmonic*, or order-preserving, composition rules are given in (24). Their permutation-inducing counterparts are given in section 3.5.

(24) *Harmonic composition*

- a. $X(\alpha \uplus \{ /_{\diamond} Y \}) \ Y /_{\diamond} \beta \Rightarrow_{\mathbf{B}} X\alpha /_{\diamond} \beta \quad (>\mathbf{B})$
- b. $Y \backslash_{\diamond} \beta \ X(\alpha \uplus \{ /_{\diamond} Y \}) \Rightarrow_{\mathbf{B}} X\alpha \backslash_{\diamond} \beta \quad (<\mathbf{B})$

The notation $/_{\diamond} \beta$ constrains all of the members of the set β have the harmonic slash type. Categories with this slash type are able to combine by these rules and the application rules, but will not be compatible with a permutation-inducing form of composition introduced later. This fact will prove crucial in the account of extraction asymmetries developed in this article.

With the inclusion of sets, the rules in (24) might appear somewhat complex, but the intuition is actually quite straightforward. They are a resource-sensitive, directional encoding of the hypothetical syllogism from propositional logic: given $p \rightarrow q$ and $q \rightarrow r$, we can deduce $p \rightarrow r$.

Type-raising is a less familiar operation, but it also has a simple motivation: it turns an argument into a function that seeks a function which seeks that argument. Here are the rules:⁹

- (25) *Type-raising*
- a. $X \Rightarrow_{\mathbf{T}} Y /_i (Y \backslash_i X)$ ($>\mathbf{T}$)
 - b. $X \Rightarrow_{\mathbf{T}} Y \backslash_i (Y /_i X)$ ($<\mathbf{T}$)
- where $i \in *, \diamond, \times, \cdot$

To illustrate the effect of adding these rules to the system, the following derivation shows how we can now derive object extraction in English using only the categories introduced thus far:

$$\begin{array}{c}
 (26) \quad \text{book} \quad \text{that} \quad \text{Calvin} \quad \text{picked up} \\
 \hline
 \text{n} \quad (n \backslash_* n) /_* (s_{ip} \backslash np) \quad \text{np} \quad (s \backslash np) / np \\
 \hline
 \text{np} \xrightarrow{>\mathbf{T}} Y /_i (Y \backslash_i np) \\
 \hline
 s / np \xrightarrow{>\mathbf{B}} \\
 \hline
 n \backslash_* n \xrightarrow{>} \\
 \hline
 n \xrightarrow{<}
 \end{array}$$

For those less familiar with CCG derivations, a few explanatory notes should help understand the notation used in this derivation. First, note that the use of the forward type-raising rule is indicated by the label $>\mathbf{T}$ and the use of forward composition by $>\mathbf{B}$. Second, the variable Y is resolved to be s during the application of $>\mathbf{B}$, and this resolution is carried to the result s / np .

The addition of composition and type-raising causes the system to produce the following alternative derivation to (16) for the sentence *Calvin picked up the book*:

$$\begin{array}{c}
 (27) \quad \text{Calvin} \quad \text{picked} \quad \text{up} \quad \text{the book} \\
 \hline
 \text{np} \quad (s \backslash np) \{ / np, /_{\diamond} \text{prt} \} \quad \text{prt} \quad \text{np} \\
 \hline
 \text{np} \xrightarrow{>\mathbf{T}} Y /_i (Y \backslash_i np) \\
 \hline
 s \{ / np, /_{\diamond} \text{prt} \} \xrightarrow{>\mathbf{B}} \\
 \hline
 s / np \xrightarrow{>} \\
 \hline
 s \xrightarrow{>}
 \end{array}$$

⁹ The variable mode i is used since the type-raised argument cannot know before combination what function is seeking it.

Although this derivation does not follow standard assumptions about constituency from the phrase structure perspective, it is semantically equivalent to derivation (16). This highlights the fact that derivations are just an artifact in CCG and do not constitute a level of representation as such. Relations such as binding and control cannot be predicated on them; instead, such constraints are usually defined on (structured) logical forms (Steedman 1996, 2000b).

The alternative constituencies made available by the rules introduced above come into play in many other constructions. They are central in providing CCG’s elegant account of various coordination constructions. Of special note are right-node raising (Steedman, 1996), as in *Calvin picked up and read the book that Hobbes gave him*, and argument cluster coordination (Steedman, 1985; Dowty, 1988), as in *Susy gave Hobbes a book and Calvin a letter*.¹⁰ In frameworks based on phrase structure, analyses of these types of coordination typically require new mechanisms and sometimes even radical changes to the derivational machinery.

Alternative constituency is also fundamental in CCG accounts of intonation structure and incremental processing. For the former, no new grammatical levels of representation are needed to represent intonational constituency since the required constituents are already made available by the grammar (Steedman, 2000a). For the latter, the flexible constituency of the competence grammar provides the ability to perform near incremental analysis without the need of a covering grammar (Steedman, 2000b).

3.5. CROSSED COMPOSITION

The composition and type-raising rules allow new derivational potential in the form of alternative constituencies, but they do not make it possible to derive new word orders. This means, for example, that non-peripheral extractions threaten to require increase in categorial ambiguity in a manner similar to the situation described for object extraction in the absence of harmonic composition.

If the category (28) – the categorial equivalent of a VP-adjunct – is assumed for post-verbal adverbs like *yesterday*, then we are able to derive *boy that read the book yesterday*.

$$(28) \text{ yesterday} := (s \backslash np) \backslash (s \backslash np)$$

¹⁰ This is also known as “non-constituent” coordination. This term is a misnomer from the CCG perspective, as it just another case of constituent coordination.

$$\begin{array}{c}
 (29) \quad \text{boy} \quad \text{that} \quad \text{read} \quad \text{the book} \quad \text{yesterday} \\
 \hline
 \text{n} \quad (\text{n} \backslash_{\star} \text{n}) /_{\star} (\text{s}_{ip} \backslash \text{np}) \quad (\text{s} \backslash \text{np}) / \text{np} \quad \text{np} \quad (\text{s} \backslash \text{np}) \backslash (\text{s} \backslash \text{np}) \\
 \hline
 \text{s} \backslash \text{np} \quad \text{>} \\
 \hline
 \text{s} \backslash \text{np} \quad \text{<} \\
 \hline
 \text{n} \backslash_{\star} \text{n} \quad \text{>} \\
 \hline
 \text{n} \quad \text{<}
 \end{array}$$

However, for non-peripheral extraction in a relative clause *book that Calvin read yesterday*, there is no way to combine the category of *read* with that of *yesterday* before *read* has consumed its direct object.

CCG includes two further rules of composition which allow permutation of the kind needed here:

$$\begin{array}{ll}
 (30) \quad \textit{Crossed composition} & \\
 \text{a. } X(\alpha \uplus \{/_\times Y\}) \ Y \backslash_{\times} \beta \Rightarrow X\alpha \backslash_{\times} \beta & (>\mathbf{B}_{\times}) \\
 \text{b. } Y /_{\times} \beta \ X(\alpha \uplus \{\backslash_{\times} Y\}) \Rightarrow X\alpha /_{\times} \beta & (<\mathbf{B}_{\times})
 \end{array}$$

These rules are called *crossed* composition because the slash on the primary input category does not have the same directionality as that of the secondary input.

To see how these rules permit new word orders, the following partial derivation shows $<\mathbf{B}_{\times}$ allowing an adverb to come between the verb and its direct object:

$$\begin{array}{c}
 (31) \quad \text{Calvin} \quad \text{read} \quad \text{yesterday} \quad \text{his brand-new comic book} \\
 \hline
 \text{np} \quad (\text{s} \backslash \text{np}) / \text{np} \quad (\text{s} \backslash \text{np}) \backslash (\text{s} \backslash \text{np}) \quad \text{np} \\
 \hline
 \text{(s} \backslash \text{np)} / \text{np} \quad \text{<B}_{\times} \\
 \hline
 \text{s} \backslash \text{np} \quad \text{>}
 \end{array}$$

Recall that the slash types $\backslash$ and $/$ are abbreviations for $\backslash_{\cdot}$ and $/_{\cdot}$, and that $\cdot$ is a sub-type of $\times$. Hence, the slash types on the categories of *read* and *yesterday* are compatible with the slash types $\backslash_{\times}$ and $/_{\times}$ of the $<\mathbf{B}_{\times}$ rule.

This sort of permutation is also what is needed for non-peripheral extraction of objects:

$$\begin{array}{c}
 (32) \quad \text{book} \quad \text{that} \quad \text{Calvin} \quad \text{read} \quad \text{yesterday} \\
 \hline
 \text{n} \quad (\text{n} \backslash_{\star} \text{n}) /_{\star} (\text{s}_{ip} / \text{np}) \quad \text{np} \quad (\text{s} \backslash \text{np}) / \text{np} \quad (\text{s} \backslash \text{np}) \backslash (\text{s} \backslash \text{np}) \\
 \hline
 \text{Y} /_i (\text{Y} \backslash_i \text{np}) \quad \text{>T} \quad \text{(s} \backslash \text{np)} / \text{np} \quad \text{<B}_{\times} \\
 \hline
 \text{s} / \text{np} \quad \text{>B} \\
 \hline
 \text{n} \backslash_{\star} \text{n} \quad \text{>} \\
 \hline
 \text{n} \quad \text{<}
 \end{array}$$

Note that all of the rule types are utilized in this derivation.

In previous work in CCG, it was common to place restrictions on combinatory rules. With the modified form of CCG presented here, these are rendered unnecessary. Using slashes typed with different modalities allows *lexical* restrictions on derivations since each modality is compatible with only certain rules. A very basic example of how this enables principled control over the rules can be seen by comparing combination at the nominal level versus that at the verbal level in English. We saw in (31) and (32) that the permutation-inducing rule $<\mathbf{B}_\times$ was necessary to allow adverbs to come between the object of a transitive verb and its object. However, this rule cannot be permitted to apply at the nominal level since the grammar would then assign the string **a nice from Hobbes book* the same interpretation as *a nice book from Hobbes*. The categories for the modifiers are the following:

$$(33) \quad \text{nice} := n/\diamond n$$

$$(34) \quad \text{from} := (n \backslash \diamond n)/\diamond np$$

With the $\diamond$ modality on the slashes of these categories, the derivation stops since the crossed composition rules cannot apply:

$$(35) \quad \begin{array}{ccccccc} \text{a} & \text{nice} & \text{from} & \text{Hobbes} & \text{book} & & \\ \hline np/\diamond n & n/\diamond n & (n \backslash \diamond n)/\diamond np & np & n & & \\ \hline & & \xrightarrow{\quad n \backslash \diamond n \quad} & & & & \\ & & \xrightarrow{\quad * \quad} & & & & \end{array}$$

If the slashes on the categories had the $\cdot$ modality instead, the $<\mathbf{B}_\times$ rule could apply to produce the category n/n for *nice from Hobbes*, thereby allowing the derivation to proceed. This is in fact the only kind of slash previously available in CCG. To block such sequences while still permitting (31) and (32), Steedman 1996 restricts $<\mathbf{B}_\times$ (for the grammar of English) to apply only to categories that both produce an s result. In contrast, the combinatory rules are truly universal under the present modal setting. They are active and unchanged in the grammar of every language.

I now turn to analyses of extraction asymmetries. These show that asymmetries arise either due to limits on permutation (English and Toba Batak) or limits on order-preserving associativity (Tagalog). These limits are enforced through modal control that simultaneously constrains both word order variation and unbounded extraction. This demonstrates that the very simple, universal distinctions defined above are sufficient and necessary to provide a cross-linguistic explanation of extraction asymmetries in the derivational system.

4. English subject/object asymmetry

The previous section provided CCG analyses of simple subject and object relative clauses. The subject/object asymmetry, or Fixed Subject Constraint (Bresnan, 1977), of English arises in embedded contexts. This was shown in (1) and is repeated here:

- (36) a. *boy_i that I think that *t_i* read the book
 b. book_i that I think that Calvin read *t_i*

The existence of this asymmetry is actually predicted by independent constraints on word order in English. Steedman (Steedman, 1996) shows that if we were to design a CCG grammar that renders the extraction in (36a) grammatical, then it would also accept the following scrambled word order:

- (37) I Calvin_i think that *t_i* read the book

To see why this is the case, we first need the following categories for the sentential complement verb *think* and the complementizer *that*:

- (38) a. think := ($s_{ip} \backslash np$) / $\diamond s_{cp}$
 b. that := $s_{cp} / \diamond s_{ip}$

The use of the $/\diamond$ slash type on these categories is crucial. Because they bear the $\diamond$ modality, they can be used with the harmonic composition rules (24) but not the crossed composition rules (30). This blocks the scrambled order in (37), as shown in (39).¹¹ (The numerical subscripts on the noun phrase categories perform no grammatical function. They are present only to clarify which np is the subject of which verb under the intended reading.)

- (39) *I Calvin think that read the book

$$\frac{\overline{np_1} \quad np_2 \quad \frac{(s_{ip} \backslash np_1) / \diamond s_{cp} \quad s_{cp} / \diamond s_{ip}}{(\overline{s_{ip} \backslash np_1}) / \diamond s_{ip}} \quad s_{ip} \backslash np_2}{(\overline{s_{ip} \backslash np_1}) / \diamond s_{ip}} > \mathbf{B}$$

*

The category $(s_{ip} \backslash np_1) / \diamond s_{ip}$ is not an acceptable input to the rule $> \mathbf{B}_\times$ given in (30a). Had the slash been either $/_\times$ or $/$ rather than $/\diamond$, the rule could apply to the two inputs to produce the category $(s_{ip} \backslash np_1) \backslash np_2$. This category could then apply via backward application to the two noun phrases to produce the scrambled order.

¹¹ In Steedman's original account, this effect was achieved by banning the rule $> \mathbf{B}_\times$ from the grammar of English. Here, we retain the essence of Steedman's analysis, but maintain a universal rule component.

$$(40) \quad \begin{array}{c} \text{*boy} \quad \text{that} \\ \hline (\text{n} \setminus \text{*n}) / \text{*} (\text{s}_{ip} \setminus \text{np}) \end{array} \quad \begin{array}{c} \text{I think} \quad \text{that} \quad \text{read the book} \\ \hline \frac{\text{s}_{ip} / \diamond \text{s}_{cp} \quad \text{s}_{cp} / \diamond \text{s}_{ip}}{\text{s}_{ip} / \diamond \text{s}_{ip}} \text{B} \quad \text{s}_{ip} \setminus \text{np} \\ \hline \text{*} \end{array}$$

(41) book that I think that Calvin read

$$\begin{array}{c}
 \frac{(n \setminus \star n) / \star (s_{ip} / np)}{s_{ip} / \diamond s_{cp} \quad \frac{s_{cp} / \diamond s_{ip} \quad s_{ip} / np}{s_{cp} / np} \rightarrow B} \\
 \frac{\phantom{\frac{(n \setminus \star n) / \star (s_{ip} / np)}{s_{ip} / \diamond s_{cp} \quad \frac{s_{cp} / \diamond s_{ip} \quad s_{ip} / np}{s_{cp} / np} \rightarrow B}}}{s_{ip} / np} \rightarrow B \\
 \frac{\phantom{\frac{\phantom{\frac{(n \setminus \star n) / \star (s_{ip} / np)}{s_{ip} / \diamond s_{cp} \quad \frac{s_{cp} / \diamond s_{ip} \quad s_{ip} / np}{s_{cp} / np} \rightarrow B}}{s_{ip} / np} \rightarrow B}}}{n \setminus n} \rightarrow
 \end{array}$$

(42) boy_{*i*} that I think *t_i* read the book

$$(43) \quad \text{think} := ((s_{ip} \setminus np) / np_{+ANT}) / \diamond (s_{ip} \setminus np)$$

main.tex; 30/06/2004; 13:45; p.22

$$\begin{array}{c}
 (44) \quad \text{boy} \quad \text{that} \quad \text{I} \quad \text{think} \quad \text{read the book} \\
 \hline
 \frac{(n \setminus n) / (s_{ip} / np_{+ANT}) \quad \frac{np_{-ANT} \xrightarrow{>T} ((s_{ip} \setminus np) / np_{+ANT}) / \diamond (s_{fin} \setminus np) \quad s_{ip} \setminus np}{np \xrightarrow{>B} (s_{ip} \setminus np) / np_{+ANT}}}{\frac{np \xrightarrow{>T} ((s_{ip} \setminus np) / np_{+ANT}) / \diamond (s_{fin} \setminus np) \quad s_{ip} \setminus np}{s_{ip} / np_{+ANT}}} \xrightarrow{>B} \\
 \hline
 n \setminus n
 \end{array}$$

Because of the use of the feature $\pm ANT$, the extra category (43) for *knew* does not overgenerate the ungrammatical sentence (45) since *Calvin* in a lexical noun phrase and is thus specified as $-ANT$.

$$(45) \quad *I [\text{think read the book}]_{(s_{ip} \setminus np) / np_{+ANT}} [\text{Calvin}]_{np_{-ANT}}.$$

The use of the category (43) is a stipulation. Nonetheless, such cases are treated as exceptions which require extra work out of the language learner. As Steedman (2000b, p. 61) notes, this stipulation is confined to a small number of subjects that *do* extract, in contrast to a strategy which places a negative constraint on the majority of subjects that do not extract.¹²

Some SVO languages do allow embedded subject extractions parallel to (36a). However, a confounding factor for such languages is that they exhibit VOS order in addition to SVO (Rizzi, 1982; Steedman, 1996). This is the case in Italian, as the following data from (Rizzi, 1982) shows:

- (46) Credo che verrà qualcuno.
 (I) believe that will-come someone.
I believe that someone will come.
- (47) Chi credi che verrà?
 Who think (you) that will-come
Who do you think will come?

Sentence (46) shows that Italian subjects can be extraposed and that the verb *verrà* has the category s_{ip} / np . Crossed composition is therefore not implicated in the derivation of (47) since *che* and *verrà* may combine through forward harmonic composition.

$$(48) \quad \text{Chi credi} [\text{che}]_{s_{cp} / s_{ip}} [\text{verrà}]_{s_{ip} / np}.$$

Embedded subject extraction is thus possible without forward crossed composition and its associated scrambling effects in a configurational language with a lexicon in which subjects are sought to the right. SVO word order can be obtained by assigning the subject a category that

¹² See Steedman 1996, pp. 57-62, for further discussion of extractable subjects in English.

fronts the subject: $s_{ip}/(s_{ip}/np)$. This category reflects a GB analysis in which the subject has raised to a left-branching SPEC of IP.

$$(49) \quad [Qualcuno]_{s_{ip}/(s_{ip}/np)} [verrà]_{s_{ip}/np}.$$

This section has shown the subject/object asymmetry in English arises because of lexically specifications that block crucial categories from combining via the $>\mathbf{B}_\times$ rule. This was a forced move to limit the rule's potential for inducing scrambled word orders. Given that restricting a permutation-inducing rule produces the English asymmetry, we next consider the Austronesian languages Tagalog and Toba Batak in order to provide a cross-linguistic account of the manner in which asymmetries appear. Typologically, Tagalog and Toba Batak are more similar to each other than English; however, I will show in the next two sections that Tagalog's asymmetries arise because of limitations on forward harmonic composition, whereas Toba Batak's come about due to limitations of a crossed composition rule, like English.

5. Tagalog asymmetries

The specific asymmetries of Tagalog which this section explores are those found in headless relative clause (HRC) formation, relativization, *wh*-extraction, and *ay*-inversion. Before launching directly into these asymmetries, I first define the categories necessary to account for basic word order in Tagalog.

5.1. MARKING AND CASE

Tagalog has a case-marking system that interacts with an intricate voice system. There is disagreement as to whether Tagalog is a nominative/accusative (Guilfoyle et al., 1992; Kroeger, 1993) or ergative/absolutive (de Guzman, 1988; MacLachlan and Nakamura, 1997; Aldridge, 2002). On these accounts, *ang*-marking signifies nominative or absolutive case, respectively, and the thematic role of the *ang*-marked argument is identified by verbal morphology (e.g., the *-um-* is assumed to assign the Agent/Actor thematic role to the *ang*-marked argument). While Kroeger does not provide specific argumentation for using one case-marking system or another, the distinction is important for Guilfoyle et al., MacLachlan and Nakamura, and Aldridge as it affects the possible structural analyses that can be provided for Tagalog syntax. Richards 2000, on the other hand, argues that *ang*-marking indicates a topic based on parallels between Tagalog and Icelandic. He suggests that the connection between *ang*-marking and case must therefore be rethought;

this thread is picked up by Rackowski 2003. She argues that while Tagalog is a nominative/accusative language, verbal morphology does not assign thematic roles. Operations such as checking the case of arguments and assigning their theta-roles are carried out in specific structural positions, but verbal morphology also introduces a case feature which must agree with a particular argument. For example, the *-in-* morphology indicates that accusative case must be checked by verbal projections (TP), while *-um-* has a nominative case feature.

I account for Tagalog's asymmetries without reference to specific structural positions and assumptions about which positions are potential sites for extraction. Although one of the above accounts could be incorporated into the categories assumed here for Tagalog (in line with the discussion of section 3.3), such concerns about the case system are not crucial for the present analysis. Instead, I show that the lexically specified combinatory potential of different arguments leads to differences in extractability – most crucially in the unbounded cases.¹³

With respect to case-marking, what matters for the present analysis is that the different arguments of a verb receive some marking at all. Thus, I will simply refer to arguments as being *ang*-marked, *ng*-marked, and *sa*-marked. In the case of personal name markers, *si* indicates *ang*-marking, *ni* *ng*-marking, and *kay* *sa*-marking.

5.2. BASIC VERBAL CATEGORIES

Tagalog is a verb-initial language, as we can see in simple intransitive (50a), transitive (50b), and ditransitive (50c) sentences. The Actor arguments of Active Voice verbs such as those in (50) are *ang*-marked.

- (50) a. Tumakbo ang lalaki.
 ran-AV ANG-man
 The man ran.
- b. Bumili ang titser ng libro.
 buy-AV ANG-teacher NG-book
 The teacher bought a book.
- c. Nagbigay ang lalaki ng libro sa babae.
 give-AV ANG-man NG-book SA-woman

¹³ Unifying the account presented here with the kind of explanation provided in GB/Minimalism is an interesting possibility. From the CCG perspective, doing so would provide an underlying cross-linguistic justified theory of lexical categories. From the GB/Minimalist perspective, the CCG system would provide a linguistically motivated account of derivational control in a lexicalist system with restricted generative capacity and attractive computational properties. There are likely to be fruitful outcomes of such a unification which would inform developments in both approaches, but it is beyond the scope of this paper.

The man gave a book to the woman.

As mentioned in section 2, arguments may scramble within the clause, as evidenced by the alternative order of (50b) given in (51) and the five alternative orders of (50c) given in (52).

- (51) Bumili ng libro ang titser.
 (52) a. Nagbigay ang lalaki sa babae ng libro.
 b. Nagbigay ng libro ang lalaki sa babae.
 c. Nagbigay sa babae ang lalaki ng libro.
 d. Nagbigay ng libro sa babae ang lalaki.
 e. Nagbigay sa babae ng libro ang lalaki.

Kroeger 1993 claims that these are stylistic permutations that do not change the meaning of the sentence in any obvious manner. Nonetheless, he also notes that word order is not arbitrary in that it tends to follow certain strong preferences. In particular, Actor arguments tend to precede all others and *ang*-marked arguments tend to follow all others. I will assume that the syntactic system allows all alternations; these sort of graded preferences are better left to “fuzzy” characterizations such as Optimality Theory or statistical methods (e.g. a statistical parser trained on a corpus of annotated Tagalog utterances).

This variability plus the case marking suggests the following categories for these verbs:

- (53) a. $\text{tumakbo} := s_{ip} / \text{np}_{ang}$
 b. $\text{bumili} := s_{ip} \{ / \times \text{np}_{ng}, / \text{np}_{ang} \}$
 c. $\text{nagbigay} := s_{ip} \{ / \times \text{np}_{sa}, / \times \text{np}_{ng}, / \text{np}_{ang} \}$

The use of sets in the categories allows the transitive and ditransitive categories allow their arguments to be consumed in any order to the right. For now, I ignore the internal structure of noun phrases and assume that strings such as *ang titser* have the category np_{ang} (short for $\text{np}_{\text{marking}=ang}$).

Note that the *ang*-marked arguments in the categories in (53) have the more powerful / slash than the $\times$ slash of the other arguments. This simple differentiation is forced by data revealed later in this chapter and is the major factor in modeling the asymmetries of Tagalog.

Verbal morphology leads to different arguments being *ang*-marked. This process is often called *focussing* or *topicalization* in the Austronesian literature, but due to the ambiguity inherent in both of these terms with other linguistic processes, I will refer to this as *distinguishing*. The

data in (50) shows verbs in the Active Voice, which distinguish the syntactic argument corresponding to the Actor argument of the verbal predicate. In (54), we find the root verb *bili* ‘buy’ in its Objective Voice form *binili*, which distinguishes the syntactic argument corresponding to the Patient argument.

- (54) Binili ng titser ang libro.
 buy-OV NG-teacher ANG-book
A teacher bought the book.

Again, the order of the arguments may be permuted, which leads us to assign the following category to *binili*.

- (55) $\text{binili} := s_{ip} \{ / \text{np}_{ang}, / \times \text{np}_{ng} \}$

It is possible to use an underspecified category for root verbs which then marks the syntactic category of the distinguished dependent as *ang*-marked and with the more powerful slash / when the morphological operation of voice affixation occurs. However, this issue is orthogonal to the present analysis, so I do not discuss the details of this process here.

The categories of (53b) and (55) may appear to be the same; however, when the dependents are made explicit as in (56), the difference is clear — the *ang*-marked argument of (53b)/(56a) is the Actor whereas that of (55)/(56b) is the Patient.

- (56) a. $\text{bumili} := s_{ip} \{ / \times \text{np}_{ng}^{\text{Pat}}, / \text{np}_{ang}^{\text{Act}} \}$
 b. $\text{binili} := s_{ip} \{ / \text{np}_{ang}^{\text{Pat}}, / \times \text{np}_{ng}^{\text{Act}} \}$

Given these verbal categories, it is now necessary to consider how nominal arguments such as *ang titser* and *ng libro* come to have the categories np_{ang} and np_{ng} , respectively. This will prove crucial in the account of asymmetries developed here.

If bare nouns have the category *n* usually assumed for English and many other languages, then the markers must be functions with a syntactic type of the form np/n . However, Gil 1993 argues that one of the major typological differences between Tagalog and languages like English is that it makes no syntactic or semantic distinction between nouns, verbs, and adjectives. His evidence for this comes from the interchangeability of words which are typically classified as nouns, verbs, and adjectives in English in simple predicate argument constructions. He provides three pairs of words (57) corresponding to the three English classes. These words have the nine combinations shown in (58).

- | | X | <i>ang</i> | Y | |
|------|----------------|------------|-----------------|-------------------------------------|
| (57) | <i>pulubi</i> | | <i>bangkero</i> | (English nouns) |
| | <i>pinatay</i> | | <i>bumalik</i> | (English verbs) |
| | <i>mapayat</i> | | <i>mabait</i> | (English adjectives) |
| (58) | | | | |
| a. | Pulubi | ang | bangkero. | ‘The boatman is a beggar.’ |
| b. | Pulubi | ang | bumalik. | ‘The one who returned is a beggar.’ |
| c. | Pulubi | ang | mabait. | ‘The kind one is a beggar.’ |
| d. | Pinatay | ang | bangkero. | ‘The boatman was killed.’ |
| e. | Pinatay | ang | bumalik. | ‘The one who returned was killed.’ |
| f. | Pinatay | ang | mabait. | ‘The kind one was killed.’ |
| g. | Mapayat | ang | bangkero. | ‘The boatman is thin.’ |
| h. | Mapayat | ang | bumalik. | ‘The one who returned is thin.’ |
| i. | Mapayat | ang | mabait. | ‘The kind one is thin.’ |

Based on this distribution, Gil argues that all of these words belong to the same syntactic category in Tagalog. He assumes a non-standard and fairly primitive categorial grammar system, but I carry the essence of his claim into CCG by assuming that intransitive verbs and so-called nouns and adjectives in Tagalog all have the syntactic category s/np_{ang} . The only difference I assume is that verbs produce finite sentences, i.e. s_{ip} , by virtue of their voice affixes, whereas nouns and adjectives produce non-finite ones, i.e. s_{vp} . This approach treats bare nouns as properties. They are thus syntactically transparent to the semantic type $\langle e, t \rangle$ which Montague 1973 assumes for bare nouns in English.

Having made this assumption, the derivations for (58a,d,g) all proceed similarly:

- (59)
- | | |
|----|--|
| a. | $\frac{\frac{\text{pulubi}}{s_{vp}/np_{ang}} \quad \frac{\text{ang bangkero}}{np_{ang}}}{s_{vp}} >$ |
| b. | $\frac{\frac{\text{pinatay}}{s_{ip}/np_{ang}} \quad \frac{\text{ang bangkero}}{np_{ang}}}{s_{ip}} >$ |
| c. | $\frac{\frac{\text{mapayat}}{s_{vp}/np_{ang}} \quad \frac{\text{ang bangkero}}{np_{ang}}}{s_{vp}} >$ |

We might consider at this point the possibility that nouns have the category n in addition to s_{vp}/np_{ang} . The former would pertain to bare

nouns and the latter to use in predicative sentences such as those given above. However, we may also opt to omit the category n entirely for bare nouns and use just s_{vp}/np_{ang} for all occurrences. A consequence of this move is that the marker categories must be functions from unary predicates to nominal arguments, leading to the following categories:

- (60) a. $ang := np_{ang}/\star(s/\diamond np)$
 b. $ng := np_{ng}/\star(s/\diamond np)$
 c. $sa := np_{sa}/\star(s/\diamond np)$

With these categories in hand, we can give the following derivation for sentence (2).

$$(61) \quad \frac{\frac{\text{bumili}}{s_{ip}\{/\times np_{ng}, /np_{ang}\}} \quad \frac{\frac{\text{ang}}{np_{ang}/\star(s/\diamond np)} \quad \frac{\text{titser}}{s_{vp}/np_{ang}}}{np_{ang}} > \quad \frac{\frac{\text{ng}}{np_{ng}/\star(s/\diamond np)} \quad \frac{\text{libro}}{s_{vp}/np_{ang}}}{np_{ng}} >}{s_{ip}/\times np_{ng}} > \quad s_{ip} >$$

Note that the modality $\cdot$ is a subtype of $\diamond$, so the slashes $/$ and $/\diamond$ are therefore compatible.

These categories look more complicated than the more standard $np/\diamond n$ and n , but an immediate payoff is that with no further assumptions they provide an analysis of headless relative clauses in Tagalog, which we turn to next.

5.3. HEADLESS RELATIVE CLAUSES

Based on the sentences (50b) and (54), the possibilities for using them as headless relative clauses (HRCs) in psuedo-clefts are those in (62).

- (62) a. Titser ang bumili ng libro.
 teacher ANG buy-AV NG-book
The one who bought a book is a teacher.
 b. *Libro ang bumili ang titser.
 book ANG buy-AV ANG-teacher
 (for: *The thing the teacher bought is a book.*)
 c. Libro ang binili ng titser.
 book ANG buy-OV NG-teacher
The thing a teacher bought is a book.
 d. *Titser ang binili ang libro.
 teacher ANG buy-OV ANG-book
 (for: *The one who bought the book is a teacher.*)

As can be seen from the impossibility of (62b,d), psuedo-clefts pattern with the *wh*-questions given in (3) and (7). Only the *ang*-marked arguments of the sentences on which they are based may be absent in HRCs.

The category assignments made thus far already permit an analysis of psuedo-clefts without further stipulation. The derivation of (62a) is given below.

$$\begin{array}{c}
 (63) \quad \begin{array}{cccc}
 \text{titser} & \text{ang} & \text{bumili} & \text{ng libro} \\
 \hline
 s_{vp}/np_{ang} & np_{ang}/\star(s/\diamond np) & s_{ip}\{\times np_{ng}, /np_{ang}\} & np_{ng} \\
 \hline
 & & s_{ip}/np_{ang} & \rightarrow \\
 & & \hline
 & & np_{ang} & \rightarrow \\
 & & \hline
 s_{vp} & & & \rightarrow
 \end{array}
 \end{array}$$

Sentences like (62a,c) are thus syntactically similar to more simple nominal predicative sentence like (58a-c), and their analysis follows immediately from the proposed categories for nouns and markers. Furthermore, only the *ang*-marked argument can be the missing argument in an HRC since it is the only one which is decorated with the $\triangleright$ mode compatible with *ang*'s argument. We see this clearly in the following blocked derivation of (62d).

$$\begin{array}{c}
 (64) \quad \begin{array}{cccc}
 \text{titser} & \text{ang} & \text{binili} & \text{ang libro} \\
 \hline
 s_{vp}/np_{ang} & np_{ang}/\star(s/\diamond np) & s_{ip}\{/np_{ang}, / \times np_{ng}\} & np_{ang} \\
 \hline
 & & s_{ip}/ \times np_{ng} & \rightarrow \\
 & & \hline
 & & & *
 \end{array}
 \end{array}$$

The lexicon developed so far thus produces the asymmetry of (62) by *modeling* in the verbal categories the fact that distinguished arguments in Tagalog are extractable because they have an associative-enabled slash that is compatible with the slash required by the extracting type category of *ang*, $np_{ang}/\star(s/\diamond np)$. Ultimately, the facts of long distance *wh*-extraction considered in 5.5 will show that these assumptions about the Tagalog lexicon are forced and therefore *explain*, as well as model, such asymmetries.

Another advantage of the analysis is that *ang* is treated uniformly in both psuedo-clefts and prenominal positions. Its role in the former (and similar constructions) is often considered to be that of a complementizer (Guilfoyle et al., 1992; Nakamura, 1994; Richards, 2000). In line with the present analysis, however, Kroeger 1993 and Aldridge 2002 also treat *ang* uniformly. For example, the structure Aldridge proposes for psuedo-clefts like (62a) is the following:

$$(65) \quad [\text{PredP} [\text{titser}_i [\text{DP ang} [\text{CP Op}_i [\text{TP bumili ng libro } t_i]]]]]$$

Aldridge thus treats *ang* as the head of a determiner phrase which takes a complementizer phrase with a gap. This is precisely what the category $\text{np}_{ang}/\star(\text{s}/\diamond\text{np})$ given in (60a) does in a categorial manner (though it is not assumed that the argument must result in a CP-level sentence – any *s* will do).¹⁴ The fact that Aldridge uses DP and not NP is inconsequential; on both accounts, *ang* in such sentences is treated no differently than it is in pre-nominal positions. The difference between the present account and Kroeger or Aldridge’s is that nouns are treated *syntactically* as predicates.

Given the proposed category for *ang*, an intransitive verb preceded by a marker will be able to act as an argument in a sentence. This correctly captures Gil’s examples (58b,e,h) without further stipulation. If we furthermore assume that (so-called) adjectives have the same category as nouns, (58c,f,i) are also covered.

Transitive and ditransitive verbs which have consumed all but their *ang*-marked argument may be marked as well. For example, in derivation (63), the string *bumili ng libro* is *ang*-marked and used as an argument. The use of an *ang*-marked argument such as *ang bumili ng libro* is not restricted to just psuedo-clefts — it may be used in a sentence such as (66), which has the derivation in (67).

- (66) Nagbigay ang bumili ng libro ng isda sa babae.
 gave-AV ANG buy-AV NG-book NG-fish SA-woman
 The one who bought a book gave some fish to the woman.

$$\begin{array}{ccccccc}
 (67) & \text{nagbigay} & \text{ang} & \text{bumili ng libro} & \text{ng isda} & \text{sa babae} & \\
 & \text{s}_{ip}\{\text{/}\times\text{np}_{sa}, \text{/}\times\text{np}_{ng}, \text{/}\text{np}_{ang}\} & \text{np}_{ang}/\star(\text{s}/\diamond\text{np}) & \text{s}_{ip}/\text{np}_{ang} & \text{np}_{ng} & \text{np}_{sa} & \\
 & & \text{np}_{ang} & & & & \\
 & \text{s}_{ip}\{\text{/}\times\text{np}_{sa}, \text{/}\times\text{np}_{ng}\} & & & & & \\
 & & \text{s}_{ip}/\times\text{np}_{sa} & & & & \\
 & & \text{s}_{ip} & & & &
 \end{array}$$

By assuming that nouns have only the predication category $\text{s}_{vp}/\text{np}_{ang}$, the markers are forced to have categories that can consume adjectives and verbs as well, in accord with Gil’s 1993 observations about the distribution of these supposed classes in Tagalog. The use of a more powerful slash on *ang*-marked arguments of verbal categories (e.g., “ $\text{/}\text{np}_{ang}$ ” in $\text{s}_{ip}\{\text{/}\times\text{np}_{ng}, \text{/}\text{np}_{ang}\}$) in combination with the harmonic slash on the predication arguments of markers (e.g., “ $\text{/}\diamond\text{np}$ ” in $\text{np}_{ang}/\star(\text{s}/\diamond\text{np})$) gives rise to the restriction that HRCs can only be formed when the *ang*-marked argument is extracted.

¹⁴ The similarity of Aldridge’s treatment with the present account is particularly striking since they were developed independently of each other.

I now turn to further evidence, based on the similarity of adjectival modification and relativization, in favor of the semantically transparent category s_{vp}/np_{ang} for nouns and adjectives.

5.4. MODIFICATION

As with the “predicate-argument” constructions in (58), a similar blurring occurs with modification: (supposed) nouns, adjectives and intransitive verbs are able to modify each other interchangeably (Gil, 1993). This is done with the linker *na/ng* as shown in the following examples (from (9) in Gil 1993), using the same items as the template (57):¹⁵

- (68) a. pulubi-ng bumalik (noun-link-verb)
 beggar-LNK AV-return
 a beggar who returned
- b. pinatay na mabait (verb-link-adjective)
 OV-kill LNK kind
 a kind one who was killed
- c. mapayat na bangkero (adjective-link-noun)
 thin LNK boatman
 a thin boatman

The other six combinations are also grammatical.

Given the analysis in the previous section, the straightforward strategy is to assign the linker a category that takes a predicate on each side to produce a new combined predicate:

$$(69) \quad na, ng := (s/np_{ang})\{/_\star(s/_\diamond np), \backslash_\star(s/_\diamond np)\}$$

This category may appear somewhat complex at first glance, but it is actually not very different from the more simple looking category for noun coordination in English, $n\{\backslash_\star n, /_\star n\}$. Because it is a coordinating type of category, the application-only mode ($\star$) is used on its slashes to limit its combinatory potential.¹⁶ The np_{ang} on the result s/np_{ang} ensures that it can only take an *ang*-marked argument after consuming the two predicate arguments.

¹⁵ Whether *na* or *ng* is the form of the linker used depends on the phonological properties of the last segment of the word preceding it (e.g. a consonant as in ...*Manuel na*... and or a vowel as in ...*libro-ng*...). It should be also noted that the marker *ng* and the linker *ng* are separate, phonetically distinct lexical items which share the same orthography.

¹⁶ In English, this strategy blocks illicit coordinations like that in **boy that [[kicks] and [he misses]]* which is otherwise possible if composition with coordinators is allowed.

With this category, all orderings of nouns, adjectives, and verbs are possible. The derivation of (68a) is given in (70).

$$(70) \quad \frac{\frac{\text{pulabi}}{s_{vp}/np_{ang}} \quad \frac{-ng}{(s/np_{ang})\{/\star(s/\diamond np), \backslash\star(s/\diamond np)\}} \quad \frac{\text{bumalik}}{s_{ip}/np_{ang}}}{\frac{(s/np_{ang})/\star(s/\diamond np)}{s/np_{ang}}} < \rightarrow$$

When preceded by *ang*, *ng*, or *sa*, the derivation is just like that with the bare noun.

$$(71) \quad \frac{\frac{ng}{np_{ng}/\star(s/\diamond np)} \quad \frac{\text{bagong libro}}{s_{vp}/np_{ang}}}{np_{ng}} \rightarrow$$

Unsurprisingly, relativized sentences also involve the linker *na/ng*. The subject/object asymmetry is operative again — only the *ang*-marked argument can be relativized.

- (72) a. lalaki-ng nagbigay ng libro sa babae
 man-LNK give-AV NG-book SA-woman
man that gave a book to the woman
- b. *lalaki-ng ibinigay ang libro sa babae
 man-LNK give-IV ANG-book SA-woman
(for: man that gave the book to the woman)
- c. *libro-ng nagbigay ang lalaki sa babae
 book-LNK give-AV ANG-man SA-woman
(for: book that the man gave to the woman)
- d. libro-ng ibinigay ng lalaki sa babae
 book-LNK give-IV NG-man SA-woman
book that a man gave to the woman

Relativization involves abstracting one argument of a verb. In categorial terms, an intransitive verb can come from the lexicon, or it can be derived by consuming the arguments of a transitive or ditransitive verb. There is thus little difference, syntactically, between an example like (72a) and (68a). The derivation of (72a) thus falls out of the categories already assumed, as follows:

$$(73) \quad \frac{\frac{\text{lalaki}}{s_{vp}/np_{ang}} \quad \frac{-ng}{(s/np_{ang})\{/\star(s/\diamond np), \backslash\star(s/\diamond np)\}} \quad \frac{\frac{\text{nagbigay}}{s_{ip}\{/\times np_{sa}, /\times np_{ng}, /np_{ang}\}} \quad \frac{\text{ng libro}}{np_{ng}} \quad \frac{\text{sa babae}}{np_{sa}}}{\frac{(s/np_{ang})/\star(s/\diamond np)}{s/np_{ang}}} < \frac{\frac{s_{ip}\{/\times np_{sa}, /\times np_{ng}, /np_{ang}\}}{s_{ip}/np_{ang}}}{s/np_{ang}} \rightarrow$$

The category for *ng/na* places the same restriction on its arguments that the markers *ang*, *ng*, and *sa* do: their arguments are functions that have a slash that is compatible with the harmonic modality. Thus, functions with the $/_{\times}$ slash are not suitable, and the ungrammatical attempts at relativization (72b) and (72d) are blocked:

- (74) a. *[libro-ng]_{(s/np_{ang})/*(s/◇np)} [nagbigay ang lalaki sa babae]_{s_{ip}/× np_{ng}}
 b. *[lalaki-ng]_{(s/np_{ang})/*(s/◇np)} [ibinigay ang libro sa babae]_{s_{ip}/× np_{ng}}

Another asymmetry thus manifests itself, due to the consistency of markers and linkers in seeking arguments that have harmonic-compatible slashes. I turn next to *wh*-extraction of arguments, yet another syntactic phenomenon which manifests the subject/object asymmetry.

5.5. LOCAL ARGUMENT *Wh*-EXTRACTION

The primary data for argument *wh*-extraction appears quite similar to that for psuedo-clefts (62). In most clause types, the extraction site must correspond to the *ang*-marked noun, as seen in (75).

- (75) a. Sino ang bumili ng libro?
 who ANG buy-AV NG-book
 Who bought a book?
 b. *Ano ang bumili ang titser?
 what ANG buy-AV ANG-teacher
 (for: *What did the teacher buy?*)
 c. Ano ang binili ng titser?
 what ANG buy-OV NG-teacher
 What did a teacher buy?
 d. *Sino ang binili ang libro?
 who ANG buy-OV ANG-book
 (for: *Who bought the book?*)

From 5.3, we know that the category np_{ang} is derived from strings like *ang bumili ng libro*. Therefore, if we assume that *wh*-words are predicates with the category s_{cp}/np_{ang} , the above asymmetry immediately falls out, in the same manner as was shown for psuedo-clefts.

This category for *wh*-elements accords with their use as modifiers also. Schachter and Otnes 1972 give (76) as an example of this.

- (76) Sino -ng babae ang pinakamaganda?
 who LNK woman ANG-prettiest
 Which woman is the prettiest?

The derivation is straightforward, proceeding along similar lines to those seen before with the assumption of an additional category for the linker. The linker combines the *wh*-predicate with *babae* and then applies to the nominal argument.

$$(77) \quad \frac{\frac{\text{sino}}{s_{cp}/np_{ang}} \quad \frac{-ng}{(s/np_{ang})\{\swarrow(s/\diamond np), \searrow(s/\diamond np)\}} \quad \frac{\text{babae}}{s_{vp}/np_{ang}} \quad \frac{\text{ang pinakamaganda}}{np_{ang}}}{\frac{(s/np_{ang})/\swarrow(s/\diamond np)}{s/np_{ang}} < \quad \quad \quad >} >$$

5.6. LONG DISTANCE *Wh*-EXTRACTION

In the preceding analysis, the modalities have been mainly used as constraints on categories which are arguments. They have not played a role in controlling derivational steps through their interaction with the rule system. As the analysis of the subject/object asymmetry demonstrated, this latter role is the main reason for including modalities in the system. However, all derivations for Tagalog thus far have used only the application rules, for which all slash types are compatible. It is with long distance *wh*-extraction that the modalities exert an effect at the derivational level – leading to asymmetries just as they do for English.

Alternating the voice of the matrix verb and the subordinate verb produces a pattern such as that in (78) (from (Nakamura, 1998)).

- (78) a. Nagsabi si Pedro na bumili si Linda ng kotse.
 say-AV ANG-Pedro COMP buy-AV ANG-Linda NG-car
 Pedro said that Linda bought a car.
- b. Nagsabi si Pedro na binili ni Linda ang kotse.
 say-AV ANG-Pedro COMP buy-OV NG-Linda ANG-car
 Pedro said that Linda bought the car.
- c. Sinabi ni Pedro na bumili si Linda ng kotse.
 say-OV NG-Pedro COMP buy-AV ANG-Linda NG-car
 Pedro said that Linda bought a car.
- d. Sinabi ni Pedro na binili ni Linda ang kotse.
 say-OV NG-Pedro COMP buy-OV NG-Linda ANG-car
 Pedro said that Linda bought the car.

Kroeger 1993 and Nakamura 1998 assume that the matrix subject of sentences such as (78c,d) is in fact the embedded clause. In present terms, this indicates that we should treat the alternation between

nagsabi and *sinabi* in a similar categorial fashion to that given for *bumili* and *binili*: the slash on the noun phrase argument of *nagsabi* is compatible with the harmonic modality and the sentential argument is not, and vice versa for *sinabi*. This leads to the following categories:¹⁷

- (79) a. $nagsabi := s_{ip} \{ /_{\times} s_{cp}, /_{\times} np_{ang} \}$
 b. $sinabi := s_{ip} \{ /_{\times} s_{cp}, /_{\times} np_{ng} \}$

I also assign *na* the category, $s_{cp} /_{\diamond} s_{ip}$ — the same as that given for the English complementizer in (38b).

Local extraction of the matrix noun phrase from the sentences in (78) follows the pattern we have seen for other matrix clauses. It can be extracted when the matrix verb is in Active Voice (80a), but not when the verb is in Objective Voice (80b).

- (80) a. Sino ang nagsabi na binili ni Linda ang kotse?
 who ANG say-AV COMP buy-OV NG-Linda ANG-car
Who said that Linda bought the car?
 b. *Sino ang sinabi na binili ni Linda ang kotse?
 who ANG say-OV COMP buy-OV NG-Linda ANG-car
 (for: *Who said that Linda bought the car?*)

By assuming that the categories for *nagsabi* and *sinabi* have the same form as those for *bumili* and *binili*, the above asymmetry comes for free: it is just another appearance of the same asymmetry noted in (75).

¹⁷ These categories allow the noun phrase and sentential arguments to scramble with respect to each other. The data on this seems questionable – I received the following judgements from a native speaker:

- (1) a. Sinabi na tumakbo si Linda ni Pedro.
 say-OV COMP buy-AV ANG-Linda NG-Pedro
Pedro said that Linda ran.
 b. *Sinabi na bumili si Linda ng kotse ni Pedro.
 say-OV COMP buy-AV ANG-Linda NG-car NG-Pedro
 (for: *Pedro said that Linda bought a car.*)

These sentences are structurally identical. The ungrammaticality of (1b) could thus be due to processing difficulties. Nevertheless, if scrambling of this sort does indeed need to be blocked, the following categories will enforce this:

- (2) a. $nagsabi := (s_{ip} /_{\star} s_{cp}) /_{\diamond} np$
 b. $sinabi := (s_{ip} /_{\diamond} s_{cp}) /_{\star} np$

These categories support the analysis of long-distance extraction provided here equally as well as those in (79). However, I use the categories in (79) as they maintain a greater parallel with the categories (53b) and (55) given for *bumili* and *binili*.

The impact of the modalities is fully felt when we examine long distance extraction in Tagalog. An argument may only be extracted from an embedded clause if the clause itself is the distinguished argument of the matrix clause. The result of attempting to extract the Patient argument of the embedded clauses in (78) is given in (81).

- (81) a. *Ano ang nagsabi si Pedro na bumili si Linda?
 what ANG say-AV ANG-Pedro COMP buy-AV ANG-Linda
 (for: *What is the thing that Pedro said that Linda bought?*)
- b. *Ano ang nagsabi si Pedro na binili ni Linda?
 what ANG say-AV ANG-Pedro COMP buy-OV NG-Linda
 (for: *What is the thing that Pedro said that Linda bought?*)
- c. *Ano ang sinabi ni Pedro na bumili si Linda?
 what ANG say-OV NG-Pedro COMP buy-AV ANG-Linda
 (for: *What is the thing that Pedro said that Linda bought?*)
- d. Ano ang sinabi ni Pedro na binili ni Linda?
 what ANG say-OV NG-Pedro COMP buy-OV NG-Linda
 What is the thing that Pedro said that Linda bought?

The status of each of the sentences (81) follows immediately from what has been said already. The derivation of (81d) is given in (82).

$$\begin{array}{c}
 (82) \quad \frac{\frac{\text{ano}}{s_{cp}/np_{ang}} \quad \frac{\text{ang}}{np_{ang}/\star(s/\diamond np)}}{\frac{s_{cp}/np_{ang}}{s_{ip}/\star(s/\diamond np)}} \quad \frac{\frac{\text{sinabi}}{s_{ip}\{s_{cp}, / \times np_{ng}\}} \quad \frac{\text{ni Pedro}}{np_{ng}}}{\frac{s_{ip}/s_{cp}}{s_{ip}/s_{cp}}} \quad \frac{\frac{\text{na}}{s_{cp}/\diamond s_{ip}} \quad \frac{\text{binili ni Linda}}{s_{ip}/np_{ang}}}{\frac{s_{cp}/\diamond s_{ip}}{s_{cp}/np_{ang}}} > \mathbf{B} \\
 \hline
 \frac{\frac{s_{ip}/s_{cp}}{s_{ip}/s_{cp}} \quad \frac{s_{cp}/\diamond s_{ip}}{s_{cp}/np_{ang}}}{s_{ip}/np_{ang}} > \mathbf{B} \\
 \hline
 \frac{\frac{s_{ip}/np_{ang}}{np_{ang}}}{s_{cp}} >
 \end{array}$$

The slash type is / for both the sentential complement of *sinabi* and the Patient argument of *binili*. Since the $\cdot$ modality¹⁸ is compatible with the harmonic modality $\diamond$, the categories s_{ip}/s_{cp} and s_{cp}/np_{ang} can combine through forward composition ($>\mathbf{B}$).

In contrast, the other three sentences of (81) are blocked because of the failure of one of the verbs to license $>\mathbf{B}$.

- (83) a. *Ano ang [nagsabi si Pedro] _{$s_{ip}/\times s_{cp}$} [na binili ni Linda] _{s_{cp}/np_{ang}} ?
 b. *Ano ang nagsabi si Pedro [na] _{$s_{cp}/\diamond s_{ip}$} [bumili si Linda] _{$s_{ip}/\times np_{ng}$} ?
 c. *Ano ang sinabi ni Pedro [na] _{$s_{cp}/\diamond s_{ip}$} [bumili si Linda] _{$s_{ip}/\times np_{ng}$} ?

¹⁸ Recall that the / slash is short-hand for the / slash.

The long distance extraction asymmetry thus arises because the lower clause, with category $s_{ip}/\times np_{ng}$, constrains its unconsumed argument from escaping (83b,c) or because the matrix verb refuses to allow its subordinate clause or any arguments of its subordinate clause to escape (83a). In this manner, the local configurations responsible for modeling the bounded asymmetries conspire to create a global pattern.

5.7. *Wh*-EXTRACTION FROM VOICELESS VERBS

The categories assigned to Tagalog verbs in (53) have played a large role in producing the asymmetric behavior discussed thus far. Most importantly, they single out one of their arguments to receive *ang*-marking and the $\cdot$ modality. Nonetheless, the system leaves open the possibility of a verb providing all of its arguments with the $\cdot$ modality. This proves to be a necessary degree of freedom, as data regarding verbs that lack voice morphology demonstrates.

Verbs in the recent past lack voice morphology, and none of the arguments are *ang*-marked, as in (84). Reduplication and the morpheme *ka* put the verb *bili* in the recent past form.

- (84) Kabibili lang ni Juan ng tela.
 buy-REC_{PAST} just NG-Juan NG-cloth
Juan has just bought some cloth.

Here we see that there are no *ang*-marked arguments, and we discover that all of the arguments may be *wh*-extracted. In (85a), the Actor has been extracted, while in (85b) it is the Patient.

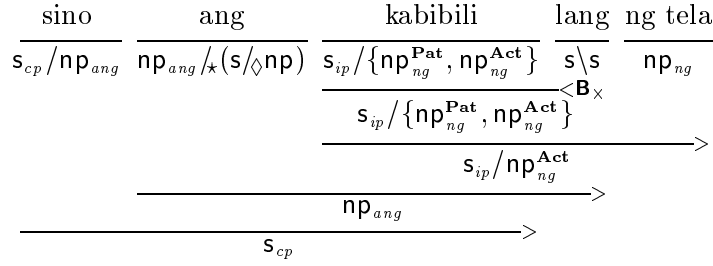
- (85) a. Sino ang kabibili lang ng tela?
 who ANG buy-REC_{PAST} just NG-cloth
Who has just bought some cloth?
 b. Ano ang kabibili lang ni Juan?
 what ANG buy-REC_{PAST} just NG-Juan
What has Juan just bought?

Both arguments may also be relativized. The most straightforward category assignment to assume for *kabibili* is the following:

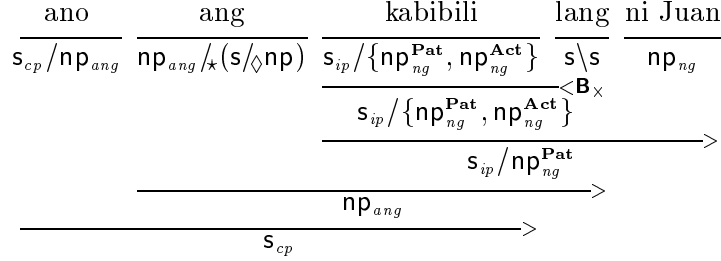
- (86) kabibili := $s_{ip}\{/np_{ng}, /np_{ng}\}$

With this category, the extractions in (85) are derived as in (87). The arguments of *kabibili* are labeled as Actor and Patient to aid readability and to emphasize that the logical form built is different for the two derivations.

(87) a. Actor extraction (85a):



b. Patient extraction (85b):



There is of course an inherent ambiguity induced by the category assigned to *kabibili* since its two arguments are in the same set but have the same case. It will thus permit ambiguous readings (for example, (84) would receive the interpretation corresponding to *Some cloth has just bought Juan* in addition to the gloss of (84)). I take the resolution of this ambiguity to be mediated by reasoning about the plausibility of different arguments filling different roles or statistical dependencies between words, e.g. *tela* ‘cloth’ is more probable as a Patient and *Juan* is the more likely Actor.

Kroeger 1993 accounts for Tagalog’s asymmetries in Lexical Functional Grammar (Kaplan and Bresnan, 1982) by arguing that *ang*-marked arguments are subjects and then formulating a functional structure pathway that is sensitive to the grammatical relation SUBJ. On his own admission, his account fails to permit the non-Actor arguments of verbs like *kabibili* to extract since they can in no way be construed to be subjects.

Also relevant to extraction of arguments which are not *ang*-marked are the comitative and comparative constructions. The following examples are from Cena 1979 (cited in Nakamura 1998):

(88) a. Kasama ni Juan ang tao.

with NG-Juan ANG-man

Juan is with the man.

b. Kasingtaas ni Juan ang tao.

as-tall-as NG-Juan ANG-man

Juan is as tall as the man.

The *ng*-marked one can be extracted in addition the *ang*-marked NP:

- (89) a. Sino ang kasama ang tao?
 who _{ANG} with _{ANG}-man
 Who is with the man?
- b. Sino ang kasingtaas ang tao?
 who _{ANG} as-tall-as _{ANG}-man
 Who is as tall as the man?

Like the recent past, these verbs lack voice morphology. We thus assume the categories in (90) and the extractions follow in the same manner as those in (87) without further specification.

- (90) kasama, kasingtaas := $s_{ip} / \{np_{ang}, np_{ng}\}$

On Nakamura's account, the ability to extract both arguments of voiceless verbs is due to the lack of topic morphology. Topic morphemes are held responsible for attracting some argument to the structural subject position. This leads to a shorter chain link that blocks extractions directly from base positions. In the case of voiceless verbs, the structural subject position cannot be filled, and there are thus no such competing derivations with those for (85) which would have shorter chain links and thereby block either of them.

I have so far avoided discussing the relationship between categories since the primary focus of the paper is on the manner in which assumed categories project different behaviors due to the interaction of their slash types with the CCG rules. While the theory of the lexicon is perhaps one of the least developed aspects of CCG, it is worth pointing out that CCG lexicons are not assumed to be a disconnected set of word-category pairs. For example, we can consider a base entry for the root *bili* to be the category $s_{ip} \{ /_{\times} np_{ng}, /_{\times} np_{ang} \}$. This is then modified in small ways by different verbal affixes to produce the categories for *bumili*, *binili*, *kabibili*, and so on. The affix *-um-*, for example, upgrades the slash of the Actor argument from $/_{\times}$ to $/$.

How this is implemented is not important here – there are many options, including inheritance hierarchies and lexical rules. The point is that such a process can be seen in a similar light to the claim that topic morphology assigns case to a particular argument by attracting it to a structural subject position. In both cases, the topic morphology is what gives one of the arguments special status – for the present analysis this comes in the form of a more powerful slash type and for Nakamura it provides a free-ride to the structural subject position and results in a shorter chain link.

The real difference in these perspectives is that CCG provides greater modularity between these lexical processes (e.g. topic morphology) and the derivational system. This leaves room for different theories of the lexicon and the specific form of categories while providing universal and restricted formal machinery. Such theories could be based on an inductive learning process and inheritance hierarchies. The form of the categories I have used here have been loosely informed by distinctions such as CP and IP from GB/Minimalism (see 3.3), and this tactic could be taken much further to take greater advantage of the extensive cross-linguistic analyses which have taken place under that rubric.

5.8. *Ay*-INVERSION

With the data covered so far, the analysis keeps pace with the coverage of Nakamura 1998 and surpasses that of Kroeger 1993. In this section, I go beyond Nakamura and consider the asymmetry present in *ay*-inversion. Crucially, the restrictions on long distance *ay*-inversion follow for the same grammatical reasons as they did for pseudo-clefts, relativization and *wh*-extraction.

In *ay*-inversion, the *ang*-marked argument of the clause is fronted and the word *ay* comes between the argument and the verb, as demonstrated in the following *ay*-inverted sentences.

- (91) a. Ang lalaki ay tumakbo.
ANG-man AY ran-AV
The man ran.
- b. Ang titser ay bumili ng libro.
ANG-teacher AY buy-AV NG-book
The teacher bought a book.
- c. Ang lalaki ay nagbigay ng libro sa babae.
ANG-man AY gave-AV NG-book SA-woman
The man gave a book to the woman.

Non-*ang*-marked arguments, however, may not be inverted:

- (92) *Ng titser ay bumili ang titser.
NG-book AY buy-AV ANG-teacher
The teacher bought a book.

Also, even though both arguments of the recent past construction (84) may be *wh*-extracted and relativized, neither may be *ay*-inverted, as shown in (93).

- (93) a. *Ni Juan ay kabibili lang ng tela?
 NG-Juan AY buy-RECPAST just NG-cloth
 (for: *Juan just bought cloth.*)
- b. *Ng tela ay kabibili lang ni Juan?
 NG-cloth AY buy-RECPAST just NG-Juan
 (for: *Juan just bought cloth.*)

The behavior of *ay*-inversion has other dimensions not presented here—adjuncts such as adverbials, gerunds, time adverbs, and subordinate clauses may also be inverted (Schachter and Otnes, 1972). Kroeger 1993 suggests that inverted *ang*-marked arguments function as topics, while all other inverted elements are focused. This indicates that these cases can be dealt with differently, and I will hence these other forms of *ay*-inversion.

The straightforward solution is to give *ay* a category which reverses the direction in which the verb seeks its *ang*-marked argument:

$$(94) \quad \text{ay} := (s \backslash_{\star} \text{np}_{ang}) /_{\star} (s / \diamond \text{np}_{ang})$$

The *level* feature of the result *s* of the overall category and that of the result *s* of the first argument are co-indexed so that the former receives the feature value of the latter after rule application, as seen in the derivation (95) below.

The argument which *ay* seeks is thus essentially the same as the one which the markers *ang*, *ng*, and *sa* and the linker *na/ng* seek. The only difference is that it specifies that the extracted argument must be *ang*-marked, thereby blocking *ay*-inversion with the recent past (93). The derivation of (91a) is given in (95).

$$(95) \quad \begin{array}{c} \text{ang} \quad \text{lalaki} \quad \text{ay} \quad \text{tumakbo} \\ \hline \text{np}_{ang} /_{\star} (s / \diamond \text{np}) \quad s_{vp} / \text{np}_{ang} \quad (s \backslash_{\star} \text{np}_{ang}) /_{\star} (s / \diamond \text{np}_{ang}) \quad s_{ip} / \text{np}_{ang} \\ \hline \text{np}_{ang} \quad \quad \quad s_{ip} \backslash_{\star} \text{np}_{ang} \\ \hline s_{ip} \end{array}$$

The category given for *ay* predicts that *ay*-inversion can occur in embedded clauses since the inverted derivation produces a category for the clause that is indistinguishable from that in the non-inverted derivation. More importantly, it permits long distance *ay*-inversion in a manner similar to long distance extraction. Both of these are correct predictions, as the following examples from Kroeger 1993 demonstrate.

- (96) a. Sinabi ni Pedro na ninakaw ni Josie ang kotse.
 say-OV NG-Pedro COMP steal-OV NG-Josie ANG-car
Pedro said that Josie stole the car.

- b. Sinabi ni Pedro na ang kotse ay ninakaw ni Josie.
 say-OV NG-Pedro COMP ANG-car AY steal-OV NG-Josie
Pedro said that the car, Josie stole.
- c. ang kotse ay sinabi ni Pedro na ninakaw ni Josie.
 ANG-car AY say-OV NG-Pedro COMP steal-OV NG-Josie
The car, Pedro said that Josie stole.

Given (95), the derivation for (96b) is obvious. The derivation for (96c), given in (97), demonstrates the syntactic similarity to long distance *wh*-extraction, in which the matrix verb composes with the unsaturated subordinate verb.

$$\begin{array}{c}
 (97) \quad \text{ang kotse} \quad \text{ay} \quad \text{sinabi} \quad \text{ni Pedro} \quad \text{na ninakaw ni Josie} \\
 \hline
 \text{np}_{ang} \quad \frac{(s \backslash \text{np}_{ang}) / \star (s / \diamond \text{np}_{ang})}{\text{np}_{ang}} \quad \frac{\text{sinabi} \quad \text{ni Pedro} \quad \text{na ninakaw ni Josie}}{\text{np}_{ng}} \\
 \hline
 \frac{s_{ip} \{ / s_{cp}, / \times \text{np}_{ng} \}}{s_{ip} / s_{cp}} \quad \text{np}_{ng} \quad \text{na ninakaw ni Josie} \\
 \hline
 \frac{s_{ip} / s_{cp}}{s_{ip} / \text{np}_{ang}} \quad \text{na ninakaw ni Josie} \\
 \hline
 \frac{s_{ip} / \text{np}_{ang}}{s_{ip} \backslash \star \text{np}_{ang}} \quad \text{na ninakaw ni Josie} \\
 \hline
 \frac{s_{ip} \backslash \star \text{np}_{ang}}{s_{ip}} \quad \text{na ninakaw ni Josie}
 \end{array}$$

In fact, the same constraint which holds for long distance *wh*-extraction holds for long distance *ay*-inversion. The matrix verb must be in a voice which distinguishes the sentential complement. Thus, as long as *ay*-inversion takes place within the embedded clause, the matrix verb may vary its voice marking (98), but whenever long distance *ay*-inversion takes place the verb is restricted to a single voice, as demonstrated by the impossibility of (99).

- (98) a. Nagsabi si Pedro na ang kotse ay ninakaw ni Josie.
 say-AV ANG-Pedro COMP ANG-car AY steal-OV NG-Josie
Pedro said that the car, Josie stole.
- b. Sinabihan ako ni Pedro na ang kotse ay ninakaw
 say-DV ANG-I NG-Pedro COMP ANG-car AY steal-OV
 ni Josie.
 NG-Josie
I was told by Pedro that the car, Josie stole.
- (99) a. *Ang kotse ay nagsabi si Pedro na ninakaw ni Josie.
 ANG-car AY say-AV ANG-Pedro COMP steal-OV NG-Josie
 (for: *The car, Pedro said that Josie stole.*)
- b. *Ang kotse ay sinabihan ako ni Pedro na ninakaw
 ANG-car AY say-DV ANG-I NG-Pedro COMP steal-OV
 ni Josie.
 NG-Josie
 (for: *The car, I was told by Pedro that Josie stole.*)

These inversions are blocked for precisely the same reason as the ungrammatical long distance extractions shown in (83).

Though *ay*-inversion and extraction display very similar patterns, they cannot be mixed. The following example from Kroeger 1993 (p.64) shows that *ay*-inverted elements cannot be *wh*-extracted:

- (100) *Sino ay gumawa ng sapatos na iyon.
 who AV make-AV NG-shoe LNK that
 (for: *Who made those shoes?*)

Such examples are predicted to be syntactically impossible by the assumption that *wh*-items are predicates which take noun phrase arguments:

- (101) *[Sino]_{s_{cp}/np_{ang}} [ay gumawa ng sapatos na iyon]_{s_{ip}*np_{ang}}

Attempting to first convert the *ay*-inverted phrase into a noun phrase by marking it with *ang* is still ungrammatical. This is also blocked for free – this time due to the fact that the category for *ang* requires a function that seeks its argument to the right, but *ay*-inversion offers a leftward seeking function:

- (102) *Sino [ang]_{np_{ang}/*(s/\<np)} [ay gumawa ng sapatos na iyon]_{s_{ip}*np_{ang}}

Note also that these categories cannot combine through backward crossed composition because neither category licenses crossed composition. Otherwise, it would be possible to derive the string like *ang ay bumili ng libro lalaki* with the category s_{cp}.

The constraints on long-distance *ay*-inversion thus follow directly from the analysis of extraction, and the fact that inversion and extraction cannot be mixed is predicted as a syntactic reflex of the categories that have been assumed.

6. Toba Batak Asymmetries

Toba Batak is another language which exhibits robust extraction asymmetries. It is like Tagalog in many ways—most importantly, both languages are verb-initial and both have a rich voice system which allow verbs to distinguish one of their arguments. However, Toba Batak shares with English a much more fixed order of clausal arguments than Tagalog. In this section, I show that this leads Toba Batak to exhibit asymmetries for the same reason as English – namely, its places lexical limitations on crossed composition rules. This contrasts with Tagalog,

for which asymmetries arise because of lexical limitations on harmonic composition.

While Toba Batak has a voice system like Tagalog, it uses word order to distinguish a particular argument rather than marking.¹⁹

- (103) a. Mangida si John si Bill
 AV-see PNM-John PNM-Bill
 Bill saw John.
- b. Diida si Bill si John
 OV-see PNM-Bill PNM-John
 Bill saw John.

In (103), it is the clause-final noun phrase that is distinguished. Changing the order of the noun phrases would result in a reversed interpretation for both sentences. The following categories for the two voices of *ida* ‘see’ capture these facts, as shown in derivations (105) and (106).

- (104) a. $\text{mangida} := (\text{s}_{ip}/\diamond \text{np}^{\text{Act}})/\diamond \text{np}^{\text{Pat}}$
 b. $\text{diida} := (\text{s}_{ip}/\diamond \text{np}^{\text{Pat}})/\diamond \text{np}^{\text{Act}}$

$$(105) \quad \frac{\frac{\text{mangida}}{(\text{s}_{ip}/\diamond \text{np}^{\text{Act}})/\diamond \text{np}^{\text{Pat}}} \quad \frac{\text{si John} \quad \text{si Bill}}{\text{np}^{\text{Pat}} \quad \text{np}^{\text{Act}}}}{\frac{\text{s}_{ip}/\diamond \text{np}^{\text{Act}}}{\text{s}_{ip}}} >$$

$$(106) \quad \frac{\frac{\text{diida}}{(\text{s}_{ip}/\diamond \text{np}^{\text{Pat}})/\diamond \text{np}^{\text{Act}}} \quad \frac{\text{si Bill} \quad \text{si John}}{\text{np}^{\text{Act}} \quad \text{np}^{\text{Pat}}}}{\frac{\text{s}_{ip}/\diamond \text{np}^{\text{Pat}}}{\text{s}_{ip}}} >$$

As before, the labeling of categories with dependency roles performs no grammatical function whatsoever. It is meant only to aid the readability of the derivations and stress that the categories are indeed capturing the correct dependencies in the undisplayed logical forms.

The $\diamond$ modality placed on the arguments of the categories for *mangida* and *diida* makes it impossible for the arguments to permute via type-raising and backward crossed composition, as the following blocked derivation demonstrates.

¹⁹ All of my Toba Batak examples are adapted from (Clark, 1991).

$$\begin{array}{c}
 (107) \quad \frac{\frac{*mangida}{(s_{ip}/\diamond np^{Act})/\diamond np^{Pat}} \quad \frac{si \text{ Bill}}{np^{Act}} \quad \frac{si \text{ John}}{np^{Pat}}}{\frac{s_{ip} \setminus (s_{ip}/\diamond np^{Act})}{* * * \xrightarrow{<B_{\times}} * * *} \quad s_{ip}/\diamond np^{Pat}}} \xrightarrow{s_{ip}} >
 \end{array}$$

Thus, *Mangida si Bill si John* cannot be interpreted as *Bill saw John*. This forced use of the non-permuting $\diamond$ modality is the crux of explaining Toba Batak's extraction asymmetries.

6.1. *Wh*-EXTRACTION

Just as Tagalog's asymmetries centered around the bifurcation between the distinguished argument and other arguments, the same is true in Batak. The Actor can only be *wh*-extracted from a verb in active voice:

- (108) a. Ise mangida si John?
 who AV-see PNM-John
 Who saw John?
 b. *Ise diida si John?
 who OV-see PNM-John
 (for: *Who saw John?*)

In similar fashion, the Patient can only be extracted from a verb in objective voice:

- (109) a. *Aha mangida si Bill?
 what AV-see PNM-Bill
 (for: *What did Bill see?*)
 b. Aha diida si Bill?
 what OV-see PNM-Bill
 What did Bill see?

This asymmetry follows from the use of the $\diamond$ modality on verbal categories — a move which was forced by fixed word order requirements. *Wh*-words have the category $s_{cp}/\diamond(s_{ip}/\diamond np)$, which is nearly identical to that for object-extracting *wh*-words in English. This immediately gives leads to derivations for (108a) and (109b), shown in (110) and (111), respectively.

$$\begin{array}{c}
 (110) \quad \frac{\frac{ise}{s_{cp}/\diamond(s_{ip}/\diamond np)} \quad \frac{mangida}{(s_{ip}/\diamond np^{Act})/\diamond np^{Pat}} \quad \frac{si \text{ John}}{np^{Pat}}}{\frac{s_{ip}/\diamond np^{Act}}{s_{cp}}} >
 \end{array}$$

$$\begin{array}{c}
 (111) \quad \begin{array}{ccc} \text{aha} & \text{diida} & \text{si Bill} \\ \hline s_{cp}/\diamond(s_{ip}/\diamond np) & (s_{ip}/\diamond np^{\text{Pat}})/\diamond np^{\text{Act}} & np^{\text{Act}} \\ \hline & s_{ip}/\diamond np^{\text{Pat}} & \\ \hline & s_{cp} & \end{array} \rightarrow
 \end{array}$$

The most deeply nested syntactic argument of either verb can thus be easily extracted.

On the other hand, the non-permuting modalities block the ungrammatical examples (108b) and (109a). Extracting the Patient argument of *mangida* as in (109a) requires deriving the category $s_{ip}/\diamond np^{\text{Pat}}$ for the string *mangida si Bill* — and this can only be done with the backward type-raising and backward crossed composition rules. However, this has already been shown to be impossible in (107) because of the $\diamond$ modality. A similar case holds for the attempt to extract the Actor argument of *diida*. The categories already assumed for Toba Batak verbs in conjunction with the standard category for *wh*-items thus predict this extraction asymmetry.

6.2. ADVERB PLACEMENT

This result receives further support from adverb placement. Adverbs such as *nantoari* ‘yesterday’ cannot appear between the verb and its first argument.

- (112) a. *Mangida nantoari si John si Bill
 AV-see yesterday PNM-John PNM-Bill
 (for: *Bill saw John yesterday.*)
- b. Mangida si John nantoari si Bill
 AV-see PNM-John yesterday PNM-Bill
Bill saw John yesterday.
- c. *Diida nantoari si Bill si John
 OV-see yesterday PNM-Bill PNM-John
 (for: *Bill saw John yesterday.*)
- d. Diida si Bill nantoari si John
 OV-see PNM-Bill yesterday PNM-John
Bill saw John yesterday.

The adverb placement data follows immediately if *nantoari* ‘yesterday’ has the category $(s/\diamond np) \backslash (s/\diamond np)$. This category is very much like a VP-modifier in English. The failure of (112a) and success of (112b) are given in (113) and (114), respectively.

(113)
$$\frac{\text{*mangida}}{(\text{s}_{ip}/\diamond \text{np}^{\text{Act}})/\diamond \text{np}^{\text{Pat}}}}{\frac{\text{nantoari}}{(\text{s}/\diamond \text{np}) \setminus (\text{s}/\diamond \text{np})}} \frac{\text{si John}}{\text{np}^{\text{Pat}}} \frac{\text{si Bill}}{\text{np}^{\text{Act}}}}{\text{B}_x}$$

(114)
$$\frac{\text{mangida}}{(\text{s}_{ip}/\diamond \text{np}^{\text{Act}})/\diamond \text{np}^{\text{Pat}}} \frac{\text{si John}}{\text{np}^{\text{Pat}}} \frac{\text{nantoari}}{(\text{s}/\diamond \text{np}) \setminus (\text{s}/\diamond \text{np})} \frac{\text{si Bill}}{\text{np}^{\text{Act}}}}{\text{s}_{ip}/\diamond \text{np}^{\text{Act}}} \frac{\text{si John}}{\text{np}^{\text{Pat}}} \frac{\text{nantoari}}{(\text{s}/\diamond \text{np}) \setminus (\text{s}/\diamond \text{np})} \frac{\text{si Bill}}{\text{np}^{\text{Act}}}}{\text{s}_{ip}/\diamond \text{np}^{\text{Act}}} \frac{\text{si John}}{\text{np}^{\text{Pat}}} \frac{\text{nantoari}}{(\text{s}/\diamond \text{np}) \setminus (\text{s}/\diamond \text{np})} \frac{\text{si Bill}}{\text{np}^{\text{Act}}}}{\text{s}_{ip}}$$

In (113), the adverb and the verb cannot combine due to the the fact that *mangida*'s category does not license backward crossed composition. Thus, no constituents can be inserted between the verb and its Patient argument. However, once the verb has taken its first argument as in (114), it produces a result which the adverbial category may take via simple backward application.

Tagalog, on the other hand, allows adverbs to immediately follow the verb since the slash types assumed for Tagalog verbs license backward crossed composition.

(115) **Tagalog:** Sumulat kahapon ng liham kay Maria si Juan
 AV-write yesterday NG-letter SA-Maria ANG-Juan
Juan wrote a letter to Maria yesterday.

Assuming the following categories for *sumulat* and *kahapon* allows the derivation of (115) to go through.

(116) $\text{sumulat} := s_{ip} \{ /np_{ang}^{\text{Actor}}, / \times np_{sa}^{\text{Addressee}}, / \times np_{ng}^{\text{Patient}} \}$

(117) kahapon := s\s

6.3. EXTRACTION FROM DITRANSITIVE VERBS

Further support for this analysis of Toba Batak comes from ditransitive verbs. Clark 1985 shows that the Addressee and the distinguished argument may scramble with respect to each other, leading to the following two possibilities for an active voice ditransitive verb:

(118) a. Mangalean missel i tu soridadu jeneral i.
AV-give missile-the to soldier general-the
The general gave the missile to the soldier.

b. Mangalean missel i jeneral i tu soridadu.
AV-give missile-the general-the to soldier
The general gave the missile to the soldier.

The Addressee is preceded by *tu*, which I will assume marks a noun with dative case. The optionality in (118) can be captured straightforwardly with the following category:

$$(119) \quad \text{mangalean} := (s_{ip} \{ /_{\diamond} np^{\text{Act}}, /_{\diamond} np_{\text{dat}}^{\text{Addr}} \}) /_{\diamond} np^{\text{Pat}}$$

An interesting consequence of this category assignment is that it correctly predicts that both the Addressee and the distinguished argument may be extracted. The following data shows these possibilities.

- (120) a. Ise mangalean missel i tu soridadu?
 who AV-give missile-the to soldier
 Who gave the missile to the soldier?
- b. Tu ise mangalean missel i jeneral i?
 to whom AV-give missile-the general the
 To whom did the general give the missile?

These questions have the following derivations, which show how the assumptions forced on the category of *mangalean* by (118) make both extractions of (120) possible.

$$(121) \quad \frac{\frac{\text{ise}}{s_{cp} /_{\diamond} (s_{ip} /_{\diamond} np)}}{\quad} \frac{\frac{\text{mangalean}}{(s_{ip} \{ /_{\diamond} np^{\text{Act}}, /_{\diamond} np_{\text{dat}}^{\text{Addr}} \}) /_{\diamond} np^{\text{Pat}}}}{\quad} \frac{\frac{\text{missel } i \text{ tu soridadu}}{np^{\text{Pat}}}}{np_{\text{dat}}^{\text{Addr}}} \xrightarrow{s_{ip} \{ /_{\diamond} np^{\text{Act}}, /_{\diamond} np_{\text{dat}}^{\text{Addr}} \}} \xrightarrow{s_{ip} /_{\diamond} np^{\text{Act}}} \xrightarrow{s_{cp}} >$$

$$(122) \quad \frac{\frac{\text{tu ise}}{s_{cp} /_{\diamond} (s_{ip} /_{\diamond} np_{\text{dat}})}}{\quad} \frac{\frac{\text{mangalean}}{(s_{ip} /_{\diamond} \{ np^{\text{Act}}, np_{\text{dat}}^{\text{Addr}} \}) /_{\diamond} np^{\text{Pat}}}}{\quad} \frac{\frac{\text{missel } i \text{ jeneral } i}{np^{\text{Pat}}}}{np^{\text{Act}}} \xrightarrow{s_{ip} \{ /_{\diamond} np^{\text{Act}}, /_{\diamond} np_{\text{dat}}^{\text{Addr}} \}} \xrightarrow{s_{ip} /_{\diamond} np_{\text{dat}}^{\text{Addr}}} \xrightarrow{s_{cp}} >$$

Of course, the Patient argument *missel i* cannot be extracted, for the same reasons as those discussed for transitive verbs. Similar effects can be seen for the objective voice form *dilean* ‘give’, except with *dilean*, it is the Actor argument which cannot be extracted.

7. Conclusion

To be written... see Baldrige 2002, chapter 7 (section 7.3 especially) and chapter 9) for the time being.

References

- Ades, A. and M. Steedman: 1982, 'On the order of words'. *Linguistics & Philosophy* **7**, 639–642.
- Ajdukiewicz, K.: 1935, 'Die syntaktische Konnexität'. In: S. McCall (ed.): *Polish Logic 1920-1939*. Oxford University Press, 207-231. translated from *Studia Philosophica*, 1, 1-27.
- Aldridge, E.: 2002, 'Wh-movement in Seediq and Tagalog'. In: *Proceedings of AFLA 8*. Cambridge, MA, MIT Press.
- Bach, E.: 1979, 'Control in Montague Grammar'. *Linguistic Inquiry* **10**, 513–531.
- Baldrige, J.: 2002, 'Lexically Specified Derivational Control in Combinatory Categorial Grammar'. Ph.D. thesis, University of Edinburgh.
- Baldrige, J. and G.-J. Kruijff: 2003, 'Multi-Modal Combinatory Categorial Grammar'. In: *Proc. of 10th Annual Meeting of the EACL*. Budapest.
- Bar-Hillel, Y.: 1953, 'A Quasi-arithmetical Notation for Syntactic Description'. *Language* **29**, 47–58.
- Bar-Hillel, Y., C. Gaifman, and E. Shamir: 1964, 'On categorial and phrase structure grammars'. In: Y. Bar-Hillel (ed.): *Language and information*. Reading MA: Addison-Wesley, pp. 99–115. 1964.
- Bresnan, J.: 1977, 'Variables in Transformations'. In: P. Culicover, T. Wasow, and A. Akmajian (eds.): *Formal Syntax*. New York: Academic Press, pp. 157–196.
- Cena, R.: 1979, 'Tagalog Counterexamples to the Accessibility Hierarchy'. *Studies in Philippine Linguistics* **31**, 119–24.
- Chomsky, N.: 1981, *Lectures on Government and Binding*. Dordrecht: Foris.
- Chomsky, N.: 1994, 'Bare Phrase Structure'. In: *MIT Occasional Papers in Linguistics*. Cambridge, MA.
- Chomsky, N. and H. Lasnik: 1993, 'The Theory of Principles and Parameters'. In: J. Jacobs, A. von Stechow, W. Sternefeld, and T. Vennemann (eds.): *Syntax: An International Handbook of Contemporary Research*. Berlin: Walter de Gruyter.
- Clark, R.: 1985, 'The Syntactic Nature of Logical Form: Evidence from Toba Batak'. *Linguistic Inquiry* **16**, 663–669.
- Clark, R.: 1991, 'Towards a Modular Theory of Coreference'. In: J. Huang and R. May (eds.): *Logical Structure and Linguistic Structure: Cross-Linguistic Perspectives*. Dordrecht: Kluwer, pp. 49–78.
- Curry, H. B. and R. Feys: 1958, *Combinatory Logic: Vol I*. North Holland, Amsterdam.
- de Guzman, V.: 1988, 'Ergative analysis for Philippine languages: An analysis'. In: R. McGinn (ed.): *Studies in Austronesian Linguistics*. Athens, OH: Ohio University Center for International Studies, pp. 323–345.
- Dowty, D.: 1979, 'Dative Movement and Thomason's Extensions of Montague Grammar'. In: S. Davis and M. Mithun (eds.): *Linguistics, Philosophy, and Montague Grammar*. Austin, TX: University of Texas Press, pp. 153–222.
- Dowty, D.: 1988, 'Type-raising, Functional Composition, and Non-constituent Coordination'. In: R. T. Oehrle, E. Bach, and D. Wheeler (eds.): *Categorial Grammars*

- and *Natural Language Structures*. Dordrecht: Reidel, pp. 153–198. Proceedings of the Conference on Categorical Grammar, Tucson, AR, June 1985.
- Gazdar, G.: 1981, ‘Unbounded Dependencies and Coordinate Structure’. *Linguistic Inquiry* **12**, 155–184.
- Gazdar, G., E. Klein, G. K. Pullum, and I. A. Sag: 1985, *Generalised Phrase Structure Grammar*. Oxford: Blackwell.
- Gil, D.: 1993, ‘Tagalog Semantics’. In: *Proceedings of the 19th Berkeley Linguistics Society*, pp. 390–403.
- Guilfoyle, E., H. Hung, and L. Travis: 1992, ‘Spec of IP and Spec of VP: two subjects in Austronesian Languages’. *Natural Language and Linguistic Theory* **10**, 375–414.
- Hoffman, B.: 1995, ‘Computational Analysis of the Syntax and Interpretation of ‘Free’ Word-order in Turkish’. Ph.D. thesis, University of Pennsylvania. IRCS Report 95-17.
- Joshi, A., K. Vijay-Shanker, and D. Weir: 1991, ‘The Convergence of Mildly Context-Sensitive Formalisms’. In: P. Sells, S. Shieber, and T. Wasow (eds.): *Processing of Linguistic Structure*. Cambridge, MA: MIT Press, pp. 31–81.
- Kaplan, R. and J. Bresnan: 1982, ‘Lexical-Functional Grammar: A formal system for grammatical representation’. In: *The Mental Representation of Grammatical Relations*. Cambridge, MA: MIT Press, pp. 173–281.
- Kaplan, R. and A. Zaenen: 1989, ‘Long-distance Dependencies, Constituent Structure, and Functional Uncertainty’. In: M. Baltin and A. Kroch (eds.): *Alternative Conceptions of Phrase Structure*. Chicago University Press, Chicago.
- Keenan, E. and B. Comrie: 1977, ‘Noun Phrase Accessibility and Universal Grammar’. *Linguistic Inquiry* **8**, 63–99.
- Kroeger, P.: 1993, *Phrase Structure and Grammatical Relations in Tagalog*. Stanford: CSLI Publications.
- Lambek, J.: 1958, ‘The mathematics of sentence structure’. *American Mathematical Monthly* **65**, 154–169.
- MacLachlan, A. and M. Nakamura: 1997, ‘Case-checking and specificity in Tagalog’. *The Linguistic Review* **14**, 307–333.
- Montague, R.: 1973, ‘The proper treatment of quantification in ordinary English’. In: J. Hintikka, J. Moravcsik, and P. Suppes (eds.): *Approaches to natural language: proceedings of the 1970 Stanford workshop on grammar and semantics*. Dordrecht: Riedel, pp. 221–242. Reprinted in Montague 1974, 247–279.
- Montague, R.: 1974, *Formal Philosophy: Papers of Richard Montague*. New Haven, CT: Yale University Press. Richmond H. Thomason, ed.
- Moortgat, M.: 1997, ‘Categorical Type Logics’. In: J. van Benthem and A. ter Meulen (eds.): *Handbook of Logic and Language*. Elsevier Science B.V.
- Morrill, G. V.: 1994, *Type Logical Grammar: Categorical Logic of Signs*. Dordrecht, Boston, London: Kluwer Academic Publishers.
- Nakamura, M.: 1994, ‘An Economy Account of Wh-extraction in Tagalog’. In: *Proceedings of WCCFL XII*. Stanford, CSLI Publications.
- Nakamura, M.: 1998, ‘Reference Set, Minimal Link Condition, and Parameterization’. In: P. Barbosa, P. Fox, M. McGinnis, and D. Pesetsky (eds.): *Is the Best Good Enough?* Cambridge, MA: MIT Press, pp. 291–313.
- Oehrle, R. T.: ms, ‘Multi-Modal Type-Logical Grammar’. to appear in Borsley and Börjars *Non-transformational Syntax*, available at <http://www.let.uu.nl/essli/Courses/moortgat/moortgat-oehrle3.ps>.
- Partee, B. (ed.): 1976, *Montague Grammar*. New York: Academic Press.

- Peters, S. and R. Ritchie: 1973, 'On the Generative Power of Transformational Grammars'. *Information Science* **6**, 49–83.
- Pollard, C. and I. Sag: 1994, *Head Driven Phrase Structure Grammar*. CSLI/Chicago University Press, Chicago.
- Rackowski, A.: 2003, 'The Case of Voice in Tagalog'. In: *Proceedings of AFLA 9*. Ithaca, NY, Cornell University.
- Richards, N.: 2000, 'Another Look at Tagalog Subjects'. In: *Formal Issues in Austronesian Linguistics*. Dordrecht: Kluwer.
- Rizzi, L.: 1982, *Issues in Italian Syntax*. Foris, Dordrecht.
- Schachter, P.: 1976, 'The Subject in Philippine Languages: Topic, Actor-Topic, or None of the Above'. In: C. Li (ed.): *Subject and Topic*. New York: Academic Press, pp. 491–518.
- Schachter, P. and F. Otanes: 1972, *Tagalog Reference Grammar*. Berkeley: University of California Press.
- Sgall, P., E. Hajičová, and J. Panevová: 1986, *The Meaning of the Sentence in Its Semantic and Pragmatic Aspects*. Dordrecht, Boston, London: D. Reidel Publishing Company.
- Steedman, M.: 1985, 'Dependency and Coordination in the Grammar of Dutch and English'. *Language* **61**, 523–568.
- Steedman, M.: 1987, 'Combinatory Grammars and Parasitic Gaps'. *Natural Language and Linguistic Theory* **5**, 403–439.
- Steedman, M.: 1996, *Surface Structure and Interpretation*. Cambridge Mass.: MIT Press. Linguistic Inquiry Monograph, 30.
- Steedman, M.: 2000a, 'Information Structure and the Syntax-Phonology Interface'. *Linguistic Inquiry* **34**, 649–689.
- Steedman, M.: 2000b, *The Syntactic Process*. Cambridge Mass.: The MIT Press.
- Wood, M. M.: 1993, *Categorial Grammar*. Routledge.

Generalizing Dimensionality in Combinatory Categorical Grammar

Geert-Jan M. Kruijff

Computational Linguistics
Saarland University
Saarbrücken, Germany
gj@coli.uni-sb.de

Jason Baldridge

ICCS, Division of Informatics
University of Edinburgh
Edinburgh, Scotland
jballdrid@inf.ed.ac.uk

Abstract

We extend Combinatory Categorical Grammar (CCG) with a generalized notion of multi-dimensional sign, inspired by the types of representations found in constraint-based frameworks like HPSG or LFG. The generalized sign allows multiple levels to share information, but only in a resource-bounded way through a very restricted indexation mechanism. This improves representational perspicuity without increasing parsing complexity, in contrast to full-blown unification used in HPSG and LFG. Well-formedness of a linguistic expressions remains entirely determined by the CCG derivation. We show how the multidimensionality and perspicuity of the generalized signs lead to a simplification of previous CCG accounts of how word order and prosody can realize information structure.

1 Introduction

The information conveyed by linguistic utterances is diverse, detailed, and complex. To properly analyze what is communicated by an utterance, this information must be encoded and interpreted at many levels. The literature contains various proposals for dealing with many of these levels in the description of natural language grammar.

Since information flows between different levels of analysis, it is common for linguistic formalisms to bundle them together and provide some means for communication between them. Categorical grammars, for example, normally employ a Saussurian sign that relates a surface string with its syntactic category and the meaning it expresses. Syntactic analysis is entirely driven by the categories, and when information from other levels is used to affect the derivational possibilities, it is typically loaded as extra information on the categories.

Head-driven Phrase Structure Grammar (HPSG) (Pollard and Sag, 1993) and Lexical Functional Grammar (LFG) (Kaplan and Bresnan, 1982) also use complex signs. However, these signs are monolithic structures which permit information to be

freely shared across all dimensions: any given dimension can place restrictions on another. For example, variables resolved during the construction of the logical form can block a syntactic analysis. This provides a clean, unified formal system for dealing with the different levels, but it also can adversely affect the complexity of parsing grammars written in these frameworks (Maxwell and Kaplan, 1993).

We thus find two competing perspectives on communication between levels in a sign. In this paper, we propose a generalization of linguistic signs for Combinatory Categorical Grammar (CCG) (Steedman, 2000b). This generalization enables different levels of linguistic information to be represented but limits their interaction in a resource-bounded manner, following White (2004). This provides a clean separation of the levels and allows them to be designed and utilized in a more modular fashion. Most importantly, it allows us to retain the parsing complexity of CCG while gaining the representational advantages of the HPSG and LFG paradigms.

To illustrate the approach, we use it to model various aspects of the realization of information structure, an inherent aspect of the (linguistic) meaning of an utterance. Speakers use information structure to present some parts of that meaning as depending on the preceding discourse context and others as affecting the context by adding new content. Languages may realize information structure using different, often interacting means, such as word order, prosody, (marked) syntactic constructions, or morphological marking (Vallduví and Engdahl, 1996; Kruijff, 2002). The literature presents various proposals for how information structure can be captured in categorical grammar (Steedman, 2000a; Hoffman, 1995; Kruijff, 2001). Here, we model the essential aspects of these accounts in a more perspicuous manner by using our generalized signs.

The main outcomes of the proposal are threefold: (1) CCG gains a more flexible and general kind of sign; (2) these signs contain multiple levels that interact in a modular fashion and are built via CCG derivations without increasing parsing com-

plexity; and (3) we use these signs to simplify previous CCG’s accounts of the effects of word order and prosody on information structure.

2 Combinatory Categorical Grammar

In this section, we give an overview of syntactic combination and semantic construction in CCG. We use CCG’s multi-modal extension (Baldrige and Kruijff, 2003), which enriches the inventory of slash types. This formalization renders constraints on rules unnecessary and supports a universal set of rules for all grammars.

2.1 Categories and combination

Nearly all syntactic behavior in CCG is encoded in categories. They may be atoms, like np , or functions which specify the direction in which they seek their arguments, like $(s \backslash np)/np$. The latter is the category for English transitive verbs; it first seeks its object to its right and then its subject to its left.

Categories combine through a small set of universal combinatory rules. The simplest are application rules which allow a function category to consume its argument either on its right ($>$) or on its left ($<$):

$$\begin{aligned} (>) \quad X/_*Y \quad Y &\Rightarrow X \\ (<) \quad Y \quad X \backslash_*Y &\Rightarrow X \end{aligned}$$

Four further rules allow functions to *compose* with other functions:

$$\begin{aligned} (>\mathbf{B}) \quad X/_\diamond Y \quad Y/_\diamond Z &\Rightarrow X/_\diamond Z \\ (<\mathbf{B}) \quad Y \backslash_\diamond Z \quad X \backslash_\diamond Y &\Rightarrow X \backslash_\diamond Z \\ (>\mathbf{B}_\times) \quad X/_\times Y \quad Y \backslash_\times Z &\Rightarrow X \backslash_\times Z \\ (<\mathbf{B}_\times) \quad Y \backslash_\times Z \quad X \backslash_\times Y &\Rightarrow X \backslash_\times Z \end{aligned}$$

The modalities $*$, $\diamond$ and $\times$ on the slashes enforce different kinds of combinatorial potential on categories. For a category to serve as input to a rule, it must contain a slash which is compatible with that specified by the rule. The modalities work as follows. $*$ is the most restricted modality, allowing combination only by the application rules ($>$ and $<$). $\diamond$ allows combination with the application rules and the order-preserving composition rules ($>\mathbf{B}$ and $<\mathbf{B}$). $\times$ allows limited permutation via the crossed composition rules ($>\mathbf{B}_\times$ and $<\mathbf{B}_\times$) as well as the application rules. Additionally, a permissive modality $\cdot$ allows combination by all rules in the system. However, we suppress the $\cdot$ modality on slashes to avoid clutter. An undecorated slash may thus combine by all rules.

There are two further rules of *type-raising* that turn an argument category into a function over functions that seek that argument:

$$\begin{aligned} (>\mathbf{T}) \quad X &\Rightarrow Y/_i(Y \backslash_i X) \\ (<\mathbf{T}) \quad X &\Rightarrow Y \backslash_i(Y/_i X) \end{aligned}$$

The variable modality i on the output categories constrains both slashes to have the same modality.

These rules support the following incremental derivation for *Marcel proved completeness*:

$$\begin{array}{c} (1) \quad \frac{\frac{\frac{Marcel}{np} \quad \frac{proved}{(s \backslash np)/np} \quad \frac{completeness}{np}}{s/(s \backslash np)} \quad \frac{}{s/np} \quad \frac{}{s}}{s} \end{array}$$

This derivation does not display the effect of using modalities in CCG; see Baldrige (2002) and Baldrige and Kruijff (2003) for detailed linguistic justification for this modalized formulation of CCG.

2.2 Hybrid Logic Dependency Semantics

Many different kinds of semantic representations and ways of building them with CCG exist. We use Hybrid Logic Dependency Semantics (HLDS) (Kruijff, 2001), a framework that utilizes hybrid logic (Blackburn, 2000) to realize a dependency-based perspective on meaning.

Hybrid logic provides a language for representing relational structures that overcomes standard modal logic’s inability to directly reference states in a model. This is achieved via *nominals*, a kind of basic formula which explicitly names states. Like propositions, nominals are first-class citizens of the object language, so formulas can be formed using propositions, nominals, standard boolean operators, and the *satisfaction operator* “@”. A formula $@_i(p \wedge \langle F \rangle(j \wedge q))$ indicates that the formulas p and $\langle F \rangle(j \wedge q)$ hold at the state named by i and that the state j is reachable via the modal relation F .

In HLDS, hybrid logic is used as a language for describing semantic interpretations as follows. Each semantic head is associated with a nominal that identifies its *discourse referent* and heads are connected to their dependents via dependency relations, which are modeled as modal relations. As an example, the sentence *Marcel proved completeness* receives the representation in (2).

$$(2) \quad @_e(\text{prove} \wedge \langle \text{TENSE} \rangle \text{past} \wedge \langle \text{ACT} \rangle(m \wedge \text{Marcel}) \wedge \langle \text{PAT} \rangle(c \wedge \text{comp.}))$$

In this example, e is a nominal that labels the predication and relations for the head **prove**, and m and c label those for **Marcel** and **completeness**, respectively. The relations ACT and PAT represent the dependency roles **Actor** and **Patient**, respectively.

By using the @ operator, hierarchical terms such as (2) can be flattened to an equivalent conjunction of fixed-size *elementary predication*s (EPs):

$$(3) \quad @_e \text{prove} \wedge @_e \langle \text{TENSE} \rangle \text{past} \wedge @_e \langle \text{ACT} \rangle m \\ \wedge @_e \langle \text{PAT} \rangle c \wedge @_m \text{Marcel} \wedge @_c \text{comp.}$$

2.3 Semantic Construction

Baldrige and Kruijff (2002) show how HLDS representations can be built via CCG derivations. White (2004) improves HLDS construction by operating on flattened representations such as (3) and using a simple semantic index feature in the syntax. We adopt this latter approach, described below.

EPs are paired with syntactic categories in the lexicon as shown in (4)–(6) below. Each atomic category has an index feature, shown as a subscript, which makes a nominal available for capturing syntactically induced dependencies.

- $$(4) \quad \text{prove} \vdash (s_e \backslash np_x) / np_y : \\ @_e \text{prove} \wedge @_e \langle \text{TENSE} \rangle \text{past} \\ \wedge @_e \langle \text{ACT} \rangle x \wedge @_e \langle \text{PAT} \rangle y$$
- $$(5) \quad \text{Marcel} \vdash np_m : @_m \text{Marcel}$$
- $$(6) \quad \text{completeness} \vdash np_c : @_c \text{completeness}$$

Applications of the combinatory rules co-index the appropriate nominals via unification on the categories. EPs are then conjoined to form the resulting interpretation. For example, in derivation (1), (5) type-raises and composes with (4) to yield (7). The index x is syntactically unified with m , and this resolution is reflected in the new conjoined logical form. (7) can then apply to (6) to yield (8), which has the same conjunction of predications as (3).

- $$(7) \quad \text{Marcel proved} \vdash s_e / np_y : \\ @_e \text{prove} \wedge @_e \langle \text{TENSE} \rangle \text{past} \\ \wedge @_e \langle \text{ACT} \rangle m \wedge @_e \langle \text{PAT} \rangle y \wedge @_m \text{Marcel}$$
- $$(8) \quad \text{Marcel proved completeness} \vdash s_e : \\ @_e \text{prove} \wedge @_e \langle \text{TENSE} \rangle \text{past} \wedge @_e \langle \text{ACT} \rangle m \\ \wedge @_e \langle \text{PAT} \rangle c \wedge @_m \text{Marcel} \wedge @_c \text{completeness}$$

Since the EPs are always conjoined by the combinatory rules, semantic construction is guaranteed to be *monotonic*. No semantic information can be dropped during the course of a derivation. This provides a clean way of establishing semantic dependencies as informed by the syntactic derivation. In the next section, we extend this paradigm for use with any number of representational levels.

3 Generalized dimensionality

To support a more modular and perspicuous encoding of multiple levels of analysis, we generalize the notion of sign commonly used in CCG. The approach is inspired on the one hand by earlier work by Steedman (2000a) and Hoffman (1995), and on

the other by the signs found in constraint-based approaches to grammar. The principle idea is to extend White’s (2004) approach to semantic construction (see §2.3). There, categories and the meaning they help express are connected through co-indexation. Here, we allow for information in any (finite) number of levels to be related in this way.

A sign is an n -tuple of terms that represent information at n distinct dimensions. Each dimension represents a level of linguistic information such as prosody, meaning, or syntactic category. As a representation, we assume that we have for each dimension a language that defines *well-formed representations*, and a set of *operations* which can create new representations from a set of given representations.¹

For example, we have by definition a dimension for syntactic categories. The language for this dimension is defined by the rules for category construction: given a set of atomic categories $\mathcal{A}$, C is a category iff (i) $C \in \mathcal{A}$ or (ii) C is of the form $A \backslash_m B$ or $A /_m B$ with A, B categories and $m \in \{*, \diamond, \times, \cdot\}$. The set of combinatory rules defines the possible operations on categories.

This syntactic category dimension drives the grammatical analysis, thus guiding the composition of signs. When two categories are combined via a rule, the appropriate indices are unified. It is through this unification of indices that information can be passed between signs. At a given dimension, the co-indexed information coming from the two signs we combine must be unifiable.

With these signs, dimensions interact in a more limited way than in HPSG or LFG. Constraints (resolved through unification) may only be applied if they are invoked through co-indexation on categories. This provides a bound on the number of indices and the number of unifications to be made. As such, full recursion and complex unification as in attribute-value matrices with re-entrancy is avoided.

The approach incorporates various ideas from constraint-based approaches, but remains based on a derivational perspective on grammatical analysis and derivational control, unlike e.g. Categorical Unification Grammar. Furthermore, the ability for dimensions to interact through shared indices brings several advantages: (1) “parallel derivations” (Hoffman, 1995) are unnecessary; (2) non-isomorphic, functional structures across different dimensions can be employed; and (3) there is no longer a need to load all the necessary information into syntactic categories (as with Kruijff (2001)).

¹In the context of this paper we assume operations are multiplicative. Also, note that dimensions may differ in what languages and operations they use.

4 Examples

In this section, we illustrate our approach on several examples involving information structure. We use signs that include the following dimensions.

Phonemic representation: word sequences, composition of sequences is through concatenation

Prosody: sequences of tunes from the inventory of (Pierrehumbert and Hirschberg, 1990), composition through concatenation

Syntactic category: well-formed categories, combinatory rules (see §2)

Information structure: hybrid logic formulas of the form $@_d[in]r$, with r a discourse referent that has informativity in (theme θ , or rheme ρ) relative to the current point in the discourse d (Kruijff, 2003).

Predicate-argument structure: hybrid logic formulas of the form as discussed in §2.3.

Example (9) illustrates a sign with these dimensions. The word-form *Marcel* bears an H^* accent, and acts as a type-raised category that seeks a verb missing its subject. The H^* accent indicates that the discourse referent m introduces new information at the current point in the discourse d : i.e. the meaning $@_m \text{marcel}$ should end up as part of the rheme (ρ) of the utterance, $@_d[\rho]m$.

$$(9) \quad \begin{array}{c} \text{Marcel} \\ H^* \\ \hline s_h / (s_h \setminus np_m) \\ @_d[\rho]m \\ @_m \text{marcel} \end{array}$$

If a sign does not specify any information at a particular dimension, this is indicated by $\top$ (or an empty line if no confusion can arise).

4.1 Topicalization

We start with a simple example of topicalization in English. In topicalized constructions, a thematic object is fronted before the subject. Given the question *Did Marcel prove soundness and completeness?*, (10) is a possible response using topicalization:

- (10) Completeness, Marcel proved, and soundness, he conjectured.

We can capture the syntactic and information structure effects of such sentences by assigning the following kind of sign to (topicalized) noun phrases:

$$(11) \quad \begin{array}{c} \text{completeness} \\ \top \\ \hline s_i / (s_i / np_c) \\ @_d[\theta]c \\ @_c \text{completeness} \end{array}$$

This category enables the derivation in Figure 1. The type-raised subject composes with the verb, and the result is consumed by the topicalizing category. The information structure specification stated in the sign in (11) is passed through to the final sign.

The topicalization of the object in (10) only indicates the informativity of the discourse referent realized by the object. It does not yield any indications about the informativity of other constituents; hence the informativity for the predicate and the Actor is left unspecified. In English, the informativity of these discourse referents can be indicated directly with the use of prosody, to which we now turn.

4.2 Prosody & information structure

Steedman (2000a) presents a detailed, CCG-based account of how prosody is used in English as a means to realize information structure. In the model, pitch accents and boundary tones have an effect on both the syntactic category of the expression they mark, and the meaning of that expression.

Steedman distinguishes pitch accents as markers of either the *theme* (θ) or of the *rheme* (ρ): $L+H^*$ and L^*+H are θ -markers; H^* , L^* , H^*+L and $H+L^*$ are ρ -markers. Since pitch accents mark individual words, not (necessarily) larger phrases, Steedman uses the θ/ρ -marking to spread informativity over the domain and the range of function categories. Identical markings on different parts of a function category not only act as features, but also as occurrences of a singular variable. The value of the marking on the domain can thus get passed down (“projected”) to markings on categories in the range.

Constituents bearing no tune have an η -marking, which can be unified with either η , θ or ρ . Phrases with such markings are “incomplete” until they combine with a boundary tone. Boundary tones have the effect of mapping phrasal tones into intonational phrase boundaries. To make these boundaries explicit and enforce such “complete” prosodic phrases to only combine with other complete prosodic phrases, Steedman introduces two further types of marking – ι and ϕ – on categories. The ϕ markings only unify with other ϕ or ι markings on categories, not with η , θ or ρ . These markings are only introduced to provide derivational control and are not reflected in the underlying meaning (which only reflects η , θ or ρ).

Figure 2 recasts the above as an abstract specification of which different types of prosodic constituents can, or cannot, be combined.² Steedman’s

²There is one exception we should note: two intermediate phrases *can* combine if a second one has a downstepped accent. We deal with this exception at the end of the section.

$$\begin{array}{c}
\begin{array}{ccc}
\text{completeness} & \text{Marcel} & \text{proved} \\
\hline
s_i / (s_i / np_c) & s_j / (s_j \setminus np_m) & (s_p \setminus np_x) / np_y \\
@_d[\theta]c & & \\
@_c \text{completeness} & @_m \text{Marcel} & @_p \text{prove} \wedge @_p \langle \text{ACT} \rangle x \wedge @_p \langle \text{PAT} \rangle y \\
\hline
& s_p / np_y & \\
& @_p \text{prove} \wedge @_p \langle \text{ACT} \rangle m \wedge @_p \langle \text{PAT} \rangle y \wedge @_m \text{Marcel} & \\
\hline
& s_p & \\
& @_d[\theta]c & \\
@_p \text{prove} \wedge @_p \langle \text{ACT} \rangle m \wedge @_p \langle \text{PAT} \rangle c \wedge @_m \text{Marcel} \wedge @_c \text{completeness} & &
\end{array}
\end{array}$$

Figure 1: Derivation for topicalization.

system can be implemented using just one feature *pros* which takes the values *ip* for intermediate phrases, *cp* for complete phrases, and *up* for unmarked phrases. We write $s_{pros=ip}$, or simply s_{ip} if no confusion can arise.

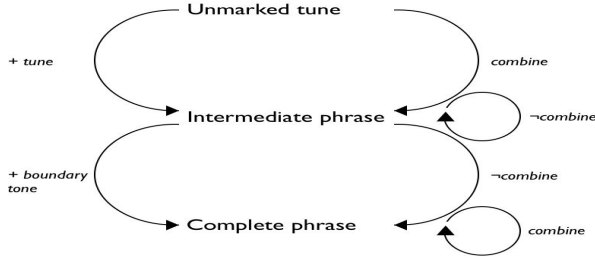


Figure 2: Abstract specification of derivational control in prosody

First consider the top half of Figure 2. If a constituent is marked with either a θ - or ρ -tune, the atomic result category of the (possibly complex) category is marked with *ip*. Prosodically unmarked constituents are marked as *up*. The lexical entries in (12) illustrates this idea.³

$$\begin{array}{ccc}
(12) & \text{MARCEL} & \text{proved} & \text{COMPLETENESS} \\
& H^* & & L+H^* \\
\hline
& s_{ip} / (s_{up} \setminus np) & (s_{up} \setminus np) / np & s_{ip} \$ \setminus (s_{up} \$ / np)
\end{array}$$

This can proceed in two ways. Either the marked MARCEL and the unmarked *proved* combine to produce an intermediate phrase (13), or *proved* and the marked COMPLETENESS combine (14).

$$\begin{array}{ccc}
(13) & \text{MARCEL} & \text{proved} & \text{COMPLETENESS} \\
& H^* & & L+H^* \\
\hline
& s_{ip} / (s_{up} \setminus np) & (s_{up} \setminus np) / np & s_{ip} \$ \setminus (s_{up} \$ / np) \\
& \hline
& s_{ip} / np & &
\end{array}$$

³The \$'s in the category for COMPLETENESS are standard CCG schematizations: s\$ indicates all functions into s, such as $s \setminus np$ and $(s \setminus np) / np$. See Steedman (2000b) for details.

$$\begin{array}{ccc}
(14) & \text{MARCEL} & \text{proved} & \text{COMPLETENESS} \\
& H^* & & L+H^* \\
\hline
& s_{ip} / (s_{up} \setminus np) & (s_{up} \setminus np) / np & s_{ip} \$ \setminus (s_{up} \$ / np) \\
& \hline
& s_{ip} \setminus np & &
\end{array}$$

For the remainder of this paper, we will suppress *up* marking and write s_{up} simply as *s*.

Examples (13) and (14) show that prosodically marked and unmarked phrases can combine. However, both of these partial derivations produce categories that cannot be combined further. For example, in (14), $s_{ip} / (s \setminus np)$ cannot combine with $s_{ip} \setminus np$ to yield a larger intermediate phrase. This properly captures the top half of Figure 2.

To obtain a complete analysis for (12), boundary tones are needed to complete the intermediate phrases tones. For example, consider (15) (based on example (70) in Steedman (2000a)):

$$\begin{array}{ccc}
(15) & \text{MARCEL} & \text{proved} & \text{COMPLETENESS} \\
& H^* & L & L+H^* & LH\%
\end{array}$$

To capture the bottom-half of Figure 2, the boundary tones L and LH% need categories which create complete phrases out of those for MARCEL and *proved* COMPLETENESS, and thereafter allow them to combine. Figure 3 shows the appropriate categories and complete analysis.

We noted earlier that downstepped phrasal tunes form an exception to the rule that intermediate phrases cannot combine. To enable this, we not only should mark the result category with *ip* (tune), but also any leftward argument(s) should have *ip* (downstep). Thus, the effect of (lexically) combining a downstep tune with an unmarked category is specified by the following template: add marking $\times_{ip} \$ \setminus y_{ip}$ to an unmarked category of the form $x \$ \setminus y$. The derivation in Figure 5 illustrates this idea on example (64) from (Steedman, 2000a).

To relate prosody to information structure, we extend the strategy used for constructing logical forms described in §2.3, in which a simple index feature

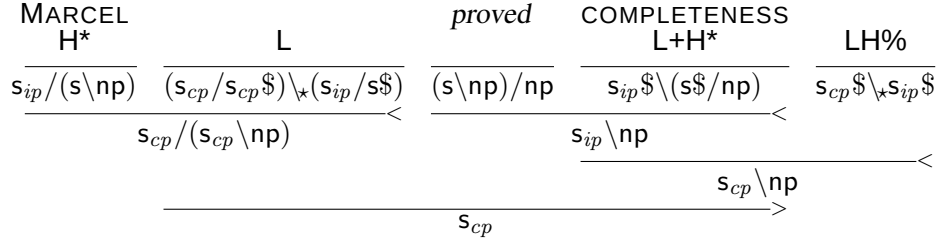


Figure 3: Derivation including tunes and boundary tones; (70) from (Steedman, 2000a)

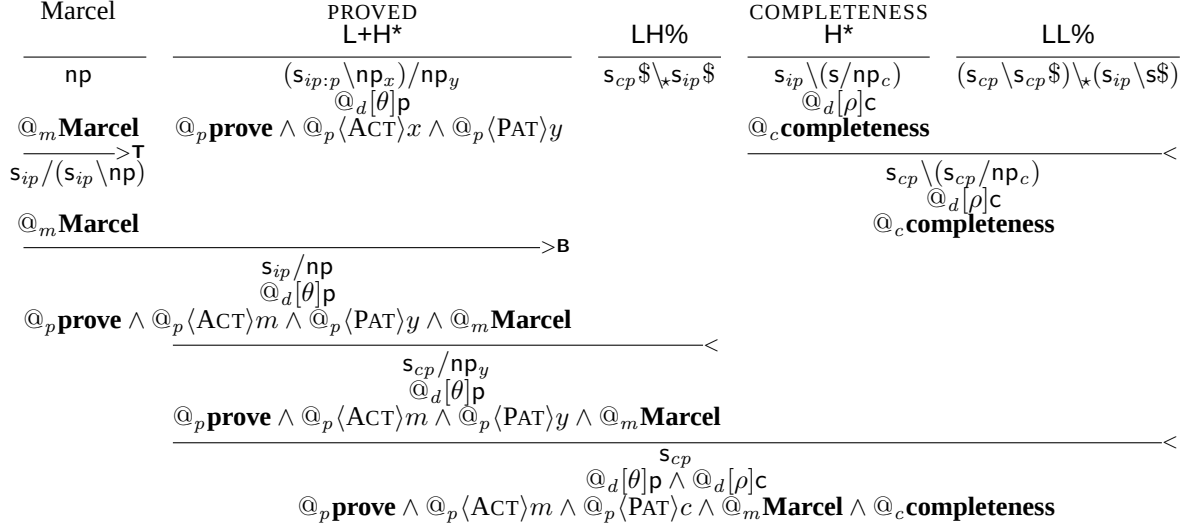


Figure 4: Information structure for derivation for (67)-(68) from (Steedman, 2000a)

on atomic categories makes a nominal (discourse referent) available. We represent information structure as a formula $\textcircled{a}_d[i]r$ at a dimension separate from the syntactic category. The nominal r stands for the discourse referent, which has informativity i with respect to the current point in the discourse d (Kruijff, 2003). Following Steedman, we distinguish two levels of informativity, namely θ (theme) and ρ (rheme).

We start with a minimal assignment of informativity: a theme-tune on a constituent sets the informativity of the discourse referent r realized by the constituent to θ and a rheme-tune sets it to ρ . This is a minimal assignment in the sense that we do not *project* informativity; instead, we only set informativity for those discourse referents whose realization shows explicit clues as to their information status. The derivation in Figure 4 illustrates this idea and shows the construction of both logical form and information structure.

Indices can also impose constraints on the informativity of arguments. For example, in the downstep example (Figure 5), the discourse referents corresponding to ANNA and SAYS are both part of the

theme. We specify this with the constituent that has received the downstepped tune. The referent of the subject of SAYS (indexed x) must be in the theme along with the referent s for SAYS. This is satisfied in the derivation: a unifies with x , and we can unify the statements about a 's informativity coming from ANNA ($\textcircled{a}_d[\theta]a$) and SAYS ($\textcircled{a}_d[\theta]x$ with x replaced by a in the >B step).

5 Conclusions

In this paper, we generalize the traditional Sausurian sign in CCG with an n -dimensional linguistic sign. The dimensions in the generalized linguistic sign can be related through indexation. Indexation places constraints on signs by requiring that co-indexed material is unifiable, on a per-dimension basis. Consequently, we do not need to overload the syntactic category with information from different dimensions.

The resulting sign structure resembles the signs found in constraint-based grammar formalisms. There is, however, an important difference. Information at various dimensions can be related through co-indexation, but dimensions cannot be directly

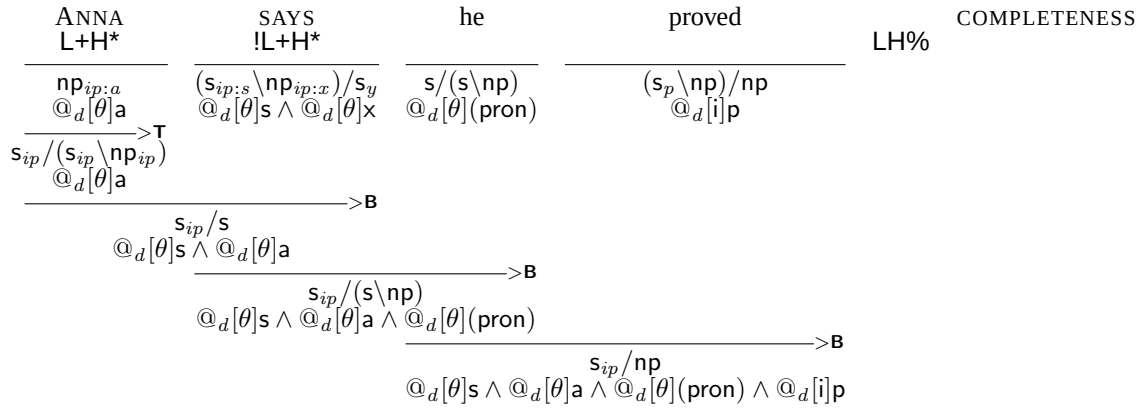


Figure 5: Information structure for derivation for (64) from (Steedman, 2000a)

referenced. As analysis remains driven only by inference over categories, only those constraints triggered by indexation on the categories are imposed. We do not allow for re-entrancy.

It is possible to conceive of a scenario in which the various levels *can* contribute toward determining the well-formedness of an expression. For example, we may wish to evaluate the current information structure against a discourse model, and reject the analysis if we find it is unsatisfiable. If such a move is made, then the complexity will be bounded by the complexity of the dimension for which it is most difficult to determine satisfiability.

Acknowledgments

Thanks to Ralph Debusmann, Alexander Koller, Mark Steedman, and Mike White for discussion. Geert-Jan Kruijff's work is supported by the DFG SFB 378 *Resource-Sensitive Cognitive Processes*, Project NEGRA EM 6.

References

- Jason Baldridge and Geert-Jan Kruijff. 2002. Coupling CCG and Hybrid Logic Dependency Semantics. In *Proc. of 40th Annual Meeting of the ACL*, pages 319–326, Philadelphia, Pennsylvania.
- Jason Baldridge and Geert-Jan Kruijff. 2003. Multi-Modal Combinatory Categorical Grammar. In *Proc. of 10th Annual Meeting of the EACL*, Budapest.
- Jason Baldridge. 2002. *Lexically Specified Derivational Control in Combinatory Categorical Grammar*. Ph.D. thesis, University of Edinburgh.
- Patrick Blackburn. 2000. Representation, reasoning, and relational structures: a hybrid logic manifesto. *Journal of the Interest Group in Pure Logic*, 8(3):339–365.
- Beryl Hoffman. 1995. Integrating "free" word order syntax and information structure. In *Proc. of 7th Annual Meeting of the EACL*, Dublin.
- Ronald M. Kaplan and Joan Bresnan. 1982. Lexical-functional grammar: A formal system for grammat-

- ical representation. In *The Mental Representation of Grammatical Relations*, pages 173–281. The MIT Press, Cambridge Massachusetts.
- Geert-Jan M. Kruijff. 2001. *A Categorical-Modal Logical Architecture of Informativity: Dependency Grammar Logic & Information Structure*. Ph.D. thesis, Charles University, Prague, Czech Republic.
- Geert-Jan M. Kruijff. 2002. Formulating a category of informativity. In Hilde Hasselgard, Stig Johansson, Bergljot Behrens, and Cathrine Fabricius-Hansen, editors, *Information Structure in a Cross-Linguistic Perspective*, pages 129–146. Rodopi, Amsterdam.
- Geert-Jan M. Kruijff. 2003. Binding across boundaries. In Geert-Jan M. Kruijff and Richard T. Oehrle, editors, *Resource Sensitivity, Binding, and Anaphora*. Kluwer Academic Publishers, Dordrecht.
- John T. III Maxwell and Ronald M. Kaplan. 1993. The interface between phrasal and functional constraints. *Computational Linguistics*, 19(4):571–590.
- Janet Pierrehumbert and Julia Hirschberg. 1990. The meaning of intonational contours in the interpretation of discourse. In J. Morgan P. Cohen and M. Pollack, editors, *Intentions in Communication*. The MIT Press, Cambridge Massachusetts.
- Carl Pollard and Ivan A. Sag. 1993. *Head-Driven Phrase Structure Grammar*. University of Chicago Press, Chicago IL.
- Mark Steedman. 2000a. Information structure and the syntax-phonology interface. *Linguistic Inquiry*, 31(4):649–689.
- Mark Steedman. 2000b. *The Syntactic Process*. The MIT Press, Cambridge, MA.
- Enric Vallduví and Elisabet Engdahl. 1996. The linguistic realization of information packaging. *Linguistics*, 34:459–519.
- Michael White. 2004. Efficient realization of coordinate structures in Combinatory Categorical Grammar. *Research on Language and Computation*. To appear.