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A Lexical Theory of Quantification in Ambiguous Query Interpretation

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Abstract

Although the connection between natural language syntax and semantics has received serious attention in both linguistics and computational linguistics for the last several decades, it does not appear that it has yet been entirely satisfactorily identified. The present dissertation focuses on quantifier scope ambiguity in an attempt to identify such a connection. We show that there are some readings that are incorrectly allowed by the theories and that other readings that are available are allowed for the wrong reason.

First, we distinguish referential NP interpretations from quantificational NP interpretations. Most traditional theories of scope do not, and they are shown to significantly overgenerate readings and/or miss a crucial generalization regarding quantificationally available readings. We present a hypothesis based on the notion of surface constituency to predict quantificationally available readings. The hypothesis is tested on core English constructions, including transitive verbs, dative alternation (ditransitive) verbs, attitude verbs, complex NPs containing prepositional phrases, possessives, and subject or non-subject *Wh*-relatives also with pied-piping and various coordinate structures. We argue that the scopings allowed under the hypothesis are the ones that are available.

We then present a competence theory of quantifier scope, couched in a combinatory categorial grammar framework. The theory defines the connection between syntax and semantics in a precise way, utilizing the dual quantifier representation. We show theoretical predictions on the core English constructions, and verify that the theoretical predictions are consistent with the predictions made by the hypothesis and that there are further reasonable theoretically predicted readings.

Finally, we describe an implementation of the theory in Prolog. The implemented system takes English sentences as ambiguous queries (regarding scope), generates logical forms that are associated with them, and evaluates those logical forms with respect to a predefined database of facts. The system also works as a proof-checker of the theory.

Comments

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A Lexical Theory of Quantification in Ambiguous Query Interpretation (Ph.D. Dissertation)

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A LEXICAL THEORY OF QUANTIFICATION IN AMBIGUOUS QUERY INTERPRETATION

JONG CHEOL PARK

A DISSERTATION

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Supervisor of Dissertation

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Graduate Group Chairperson

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ABSTRACT

A LEXICAL THEORY OF QUANTIFICATION IN AMBIGUOUS QUERY INTERPRETATION

JONG CHEOL PARK

MARK STEEDMAN

Although the connection between natural language syntax and semantics has received serious attention in both linguistics and computational linguistics for the last several decades, it does not appear that it has yet been entirely satisfactorily identified. The present dissertation focusses on quantifier scope ambiguity in an attempt to identify such a connection. We show that there are some readings that are incorrectly allowed by the theories and that other readings that are available are allowed for the wrong reason.

First, we distinguish referential NP interpretations from quantificational NP interpretations. Most traditional theories of scope do not, and they are shown to significantly overgenerate readings and/or miss a crucial generalization regarding quantificationally available readings. We present a hypothesis based on the notion of surface constituency to predict quantificationally available readings. The hypothesis is tested on core English constructions, including transitive verbs, dative alternation (ditransitive) verbs, attitude verbs, complex NPs containing prepositional phrases, possessives, and subject or non-subject *Wh*-relatives (also with pied-piping), and various coordinate structures. We argue that the scopings allowed under the hypothesis are the ones that are available.

We then present a competence theory of quantifier scope, couched in a combinatory categorial grammar framework. The theory defines the connection between syntax and

semantics in a precise way, utilizing the dual quantifier representation. We show theoretical predictions on the core English constructions, and verify that the theoretical predictions are consistent with the predictions made by the hypothesis and that there are further reasonable theoretically predicted readings.

Finally, we describe an implementation of the theory in Prolog. The implemented system takes English sentences as ambiguous queries (regarding scope), generates logical forms that are associated with them, and evaluates those logical forms with respect to a predefined database of facts. The system also works as a proof-checker of the theory.

Contents

List of Tables

List of Figures

Chapter 1

INTRODUCTION

The main thesis of the dissertation is that correctly restricted possibilities for quantifiers to give rise to differently scoped interpretations (or readings) can be determined from an extended notion of surface structure. The thesis is based on new evidence for the way in which people consider readings as available, which shows that the syntactically available range of readings for a natural language sentence is actually much more linguistically constrained and cognitively intuitive than that assumed in most theories of quantifier scope. This evidence is captured by a novel hypothesis that predicts available readings based on the surface structure constituency of natural language sentences. The dissertation also presents a theory of quantifier scope that incorporates this new hypothesis to elucidate the connection between syntax and semantics, with explanatory and predictive capabilities regarding readings of natural language sentences. Many of the available theories of quantifier scope do not appear to meet this criteria.

For instance, consider Quantifying-in, a technique originally motivated in Montagovian semantics (Montague, 1974) for *de re* NP interpretations so that such NP quantifiers can “fly off” to take the matrix scope. This technique (or rule schema) would allow the NP *at least three companies* to take matrix scope, no matter how the rest of the scope order has been already determined (see Figure 1.1).[1] It is clear that the resulting reading is

[1]For those who believe that the English object quantifiers such as *most* or *few* cannot outscope English subject quantifiers, it is suggested that they replace those offending quantifiers with other quantifiers, such as *every*, as the present thesis is not about classifying quantifiers according to their scope-taking behaviors. This does not necessarily mean however that we also share this belief. Further comments will follow.

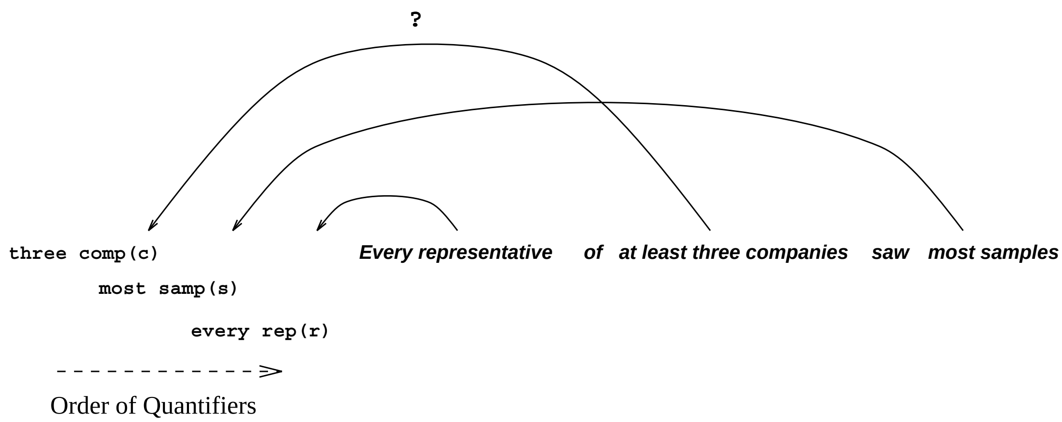


Figure 1.1: The scope order is incorrectly endorsed by Quantifying-in.

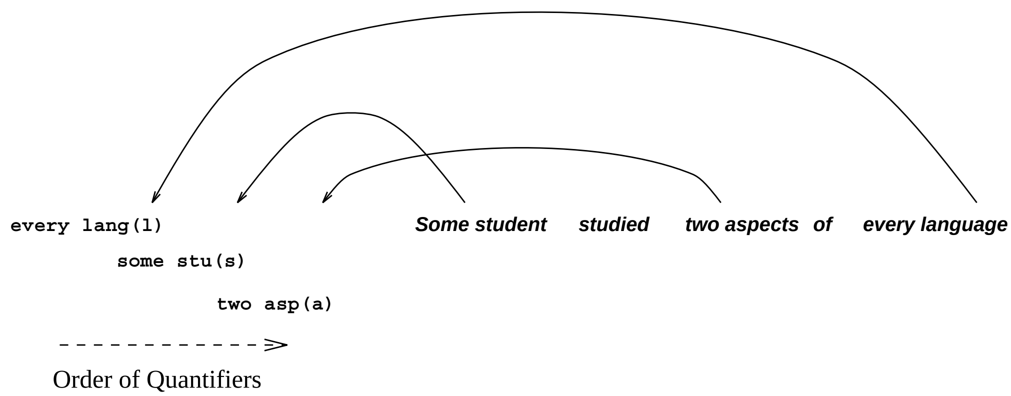


Figure 1.2: The scope order results in an available reading.

not available from the natural language sentence, if we notice the unrelated functional dependency that the logical form induces for its truth-conditional semantics. This is why Quantifying-in, or its variants, is not adequate for predicting available readings, though one can certainly add stipulation to its application.

Notice also that there is a potential condition we can derive from the data shown in Figure 1.1, namely, that arrowed lines should not intersect. This condition is reminiscent of May (1985)'s use of the Path Containment Condition (PCC, Pesetsky, 1982)) for a version of Quantifier Raising, though the "path structures" endorsed by the PCC can still be ambiguous in his formulation. A condition such as this must be formulated with care, since we do not want to exclude the available reading shown in Figure 1.2, where the arrowed line of *two aspects* apparently intersects that of *some student*. Although such attempts as refining the syntactic/logical structures and minimizing the amount

$$\ldots \overbrace{\mathbf{NP}_1 \underbrace{\cdots}_{A} \mathbf{NP}_2}^{B} \ldots.$$

Figure 1.3: The two NPs can alternate their relative scope order.

of stipulation would precisely fall in the spirit of Government and Binding theories on which May's theory is based, it remains a burden for the resulting formulation(s) with so many theory-internal conditions to explain, in general terms, why some scope readings are available and some are not.

1.1 OVERVIEW OF THE THESIS

The dissertation is divided into three parts.

Part I lays out two theses and studies core English constructions with a novel hypothesis on quantificational readings.

- **Thesis 1**: Quantificational NP interpretations should be distinguished from referential NP interpretations at the level of semantics, following Fodor and Sag (1982).

- **Thesis 2**: Quantificational scope readings always show a functional dependency among scope-related NP interpretations. This property can be utilized to see if a reading is available.

- **Hypothesis**: In quantificational readings of a grammatical sentence S, quantifiers inside NP_1 and those inside NP_2 in S can alternate their relative scope order if and only if both A and B, shown in Figure 1.3, are phonologically realized c-constituents. The fragment A includes everything between NP_1 and NP_2, and B includes NP_1, A, NP_2, and nothing else. These readings have all the quantifiers inside A outscoped by other quantifiers inside NP_1 and NP_2. A c-constituent s is a string of words in a language L such that L has a grammatical sentence in which s is coordinated with another string s' of words that share the same syntactic function with the string s.

The hypothesis correctly predicts that the sentence in Figure 1.1 does not have the said scope ordering. It also correctly predicts that the sentence in Figure 1.2 *does* have the said scope ordering, since the fragment *studied two aspects of* is a c-constituent, as evidenced in the following grammatical English sentence.

> Some student studied two aspects of, but collected most cases of coordination in, every language.

The hypothesis is checked against core English constructions that may syntactically introduce multiple NPs to a sentence. These include: transitive verbs, dative alternation (ditransitive) verbs, attitude verbs that subcategorize for complement `that`-clauses, complex NPs containing prepositional phrases and/or possessives, complex NPs containing subject or non-subject *Wh*-relatives (with or without pied-piping), and coordinate structures that may split standard constituent boundaries. Constructions that are not discussed include: negation, intension, adverbial adjunction, pair-list answers, and referential NPs.[2]

There are certainly other remaining constructions to consider, but it appears that those constructions above already provide a non-trivial justification for the plausibility of the proposed hypothesis. If we try to explain why it works in cognitive terms, it would be that when people are willing to use coordination with NPs on its sides in a sentence, each such conjunct, or the single A in Figure 1.3, behaves as a semantic function that can take the two NPs as its arguments. Since it is crucial in this case that the entire fragment, containing both NPs and the A fragment, be relatively self-sufficient in a sentence, the additional clause is also needed, that the entire fragment, or B in Figure 1.3, should be able to coordinate.

Part II of the dissertation presents a competence theory of quantifier scope, couched in a Combinatory Categorial Grammar (CCG) framework, in order to model the hypothesis in a grammar formalism. Since the theory is competence-based, it does not attempt to

[2]The interaction between qualifiers (such as negation) and quantifiers is not studied in the dissertation, as it appears to take more than purely structural information that the present thesis is concerned with. The interaction between intension (such as *de dicto* NP interpretations) and quantifiers is also not studied for a similar reason. Constructions containing adverbial adjunction are not studied either. The simple representation we use in the dissertation is inadequate for the study of adverbial adjunction that modifies VP, which would require situational indices at the least. The reader is referred to Sections 2.2.2 and 2.1.1 for the discussion of why we believe that pair-list answers and referential NPs are irrelevant to the present thesis.

provide a theoretical distinction between readings that are contextually preferred and those that are not, though it should be straightforward to augment the proposed theory with such a performance-oriented distinction. The CCG framework is chosen for the task, as the notion of c-constituency in the hypothesis is exactly the notion of CCG constituency (Steedman, 1990). However, it should also be possible for other grammar formalisms to incorporate the proposed hypothesis, as long as they have a theory-internal means of distinguishing those fragments that are c-constituents from those that are not.

For a correct formulation of the hypothesis in the CCG framework, we need to make sure that the two NPs, or NP_1 and NP_2 in Figure 1.3, can have their quantifiers alternate their relative scope order. We claim, and prove by example derivations, that this is done by utilizing Type Raising in CCG. More specifically, we need the following:

- TYPE RAISING: The CCG categories for NP include unraised and raised NPs. The unraised NP category is notated as `np`. There are a limited number of raised NP categories, such as `s/(s\np)`, `s\(s/np)`, etc. These categories contain elementary categories such as `np` or `s`, along with the directional symbols `/` and `\` (cf. Section 4.1). Notice that these categories are needed on independent syntactic grounds, and not just for the present proposal.

- DUAL QUANTIFIER REPRESENTATION: Raised NPs are associated with a wide-scope quantifier semantics, which is represented in a modified generalized quantifier format (Barwise and Cooper, 1981): `Quantifier(Mode, Variable, Restriction, Body).`

  Unraised NPs are associated with a degenerate quantifier semantics, which lacks the scope information, or `Body` in the format shown above: `*Quantifier(Restriction).`

  The syntax and semantics of these logical forms will be defined in Section 4.2, but they are just as standard as anyone else's. The only new claim is that we need two different formats for the semantic representation of quantifiers.

- LEXICAL ENCODING: For the specification of lexical semantics, the use of a first-order term unification is implicitly assumed, so that the lexicon can be directly used by a standard Prolog. We also utilize partial execution (Pereira and Shieber, 1987) to overcome the lack of a higher-order term unification. For example, the β-reduction of the lambda term $\lambda P.P(X).(\lambda Y.man(Y))$ to $man(X)$ is performed by unifying the two patterns `X^S` and `Y^man(Y)` and using the value of the term `S` for the result category. Our technique of linking first-order variables in the lexical entries always ensures logical transparency.

Part III of the dissertation presents an interpreter, implemented in Prolog, incorporating the afforementioned theory. The interpreter takes English sentences as input and generates their available readings as logical forms. These logical forms are subsequently evaluated against a small database of facts. The interpreter works as a proof-checker for the theory. Since the point of this system is not related to efficiency, we use a standard shift-reduce parser for CCG.

1.2 STRUCTURE OF THE DISSERTATION

The dissertation is structured as follows.

1. INTRODUCTION

After laying out two motivating examples to suggest the connection between syntax and semantics, we explain the main thesis and show the structure of the dissertation.

Part I SCOPE READINGS

2. CHARACTERISTICS OF SCOPE READINGS

We argue that quantificational and referential NP interpretations must be distinguished in semantics, and explain readings that involve either referential NP interpretations or interactions of quantified NPs with other components of language not to be considered further in the dissertation. We show how to utilize functional dependency to see if a reading is available.

3. QUANTIFICATIONAL SCOPE READINGS

We present a hypothesis based on the notion of surface constituency to predict quantificationally available readings. We explain assumptions on assessing scope readings and then examine core English constructions to check if their available readings are correctly predicted by the hypothesis.

Part II SCOPE THEORY

4. A LEXICAL THEORY OF QUANTIFIER SCOPE

We present a competence theory of quantifier scope, by couching it in a Combinatory Categorial Grammar framework. We propose to use the dual quantifier representation, in which quantifiers are assigned not only a wide-scope semantics (with scope) but also a degenerate semantics (without scope). We define the syntax and semantics of the proposed language of semantic representation and briefly explain the proposed method of connecting semantics and syntax. We also review traditional approaches to quantifier scope.

5. THEORETICAL PREDICTIONS

We use the theory to predict readings on core English constructions.

Part III SCOPE INTERPRETATIONS

6. GENERATION OF SCOPED LOGICAL FORMS

The theory is implemented in Prolog into a system of generating logical forms that correspond to available readings of input English sentences.

7. EVALUATION OF SCOPED LOGICAL FORMS

A Prolog program is described to evaluate logical forms generated by the system.

8. CONCLUSION

We conclude that the new hypothesis and theory provide a precise analysis of quantificationally available readings.

Part I

SCOPE READINGS

Chapter 2

CHARACTERISTICS OF SCOPE READINGS

This chapter introduces two theses regarding scope readings. Section 2.1 shows the first thesis that quantificational NP interpretations should be distinguished from referential NP interpretations at the level of semantics, following the old observation by Fodor and Sag (1982). Section 2.2 examines other scope-related phenomena that result from the interactions of quantified NPs and other components of language, such as pronouns and *Wh*-phrases, in particular to explain why they are not discussed further in the dissertation. Section 2.3 shows the second thesis that quantificational scope readings always exhibit a kind of functional dependency among scope-related NP interpretations. Both of the theses are not new. However, their significance with respect to the available range of readings is often ignored, and this results in overgenerating logical forms in most theories of quantifier scope. This chapter provides the needed justification for treating only quantificational NP interpretations in the forthcoming chapters.

2.1 REFERENTIAL NP INTERPRETATIONS

This section presents the thesis that the distinction between quantificational NP interpretations and referential NP interpretations should be made at the level of semantics, and in particular that the distinction should not be deferred to the level of pragmatics or discourse.

Section 2.1.1 reviews the old argument by Fodor and Sag (1982), whose main reason for the distinction to be made at the level of semantics is the relative parsimony of the resulting theory of NP semantics. This justifies the assumption that referential NP interpretations do not participate in the kind of scope order relations for quantificational NP interpretations.[1]

Quantificational NP interpretations show the characteristics that they participate in (partial) scope order that can be derived from surface structure alone. This is the topic of Chapter 3. There are however readings that do not show this characteristics. These include one of Hobbs and Shieber (1987)'s readings and cumulative readings. These would work as counterexamples to the main thesis of the dissertation if the involved NPs have quantificational interpretations. We claim in Section 2.1.2 that they all involve referential NP interpretations.

2.1.1 Referential NP Interpretations

This section presents a claim, originally due to Fodor and Sag (1982), that one must distinguish referential and quantificational NP-interpretations at the level of semantics. We discuss three supporting pieces of evidence for this claim, in which the two kinds of interpretations clearly show distributional differences. The data in (1), (2), and (3) are taken from Fodor and Sag (1982). The reader is referred to the insightful paper for further details.

First, consider the sentence below.

(1) A student in the syntax class cheated on the final exam.

When the speaker of the sentence has a particular person in mind for the student in question, say John, the subject NP is taken to be used referentially. In this reading, the sentence would be false if John didn't cheat on the final exam, even if there was another

[1]This implies that a theory that does not distinguish them in semantics must be ready to deal with the resulting complexity of the data. For instance, since quantifying-in is essentially for referential NP interpretations, it is designed to take any NP interpretations out of the rest of the sentential semantics, so that such NP denotations are computed relatively independently. This approach does not appear adequate for the characterization of the exact nature of quantificational NP interpretations.

student, say Bob, who did the deed. On the other hand, when the speaker used the sentence to simply assert the fact that there was one, possibly more, such student, the sentence would be true as long as there is/was one such individual, even if the individual is not the one whom the speaker had in mind. In this reading, the subject NP is taken to be used quantificationally.[2] In this sentence, however, surface structure does not appear to make much difference. For this, consider the following sentences.

(2) (a) John overheard the rumor that every student of mine had been called before the dean.

(b) John overheard the rumor that a student of mine had been called before the dean.

The embedded subject position of a complex NP is known to be a syntactic island (Ross, 1967), which explains why the sentence **John met every student$_i$ who(m) each teacher overheard the rumor that t_i had been called before the dean* is ungrammatical. This fact has also been utilized at the level of semantics to disallow the movement of a quantifier from a syntactic island position to its scope-taking position in GB theories, explaining why the sentence (2) (a) does not have a reading in which *every student* outscopes *the rumor*, or the reading in which there is a possibly different rumor for each student. However, it is apparent that this constraint is not at work for a referential NP, as the sentence (b) *does* have an interpretation such that there is a certain student (of the speaker) such that John overheard the rumor that he or she had been called before the dean. In this reading, the denotation of the NP *a student of mine* is not dependent upon the kind of rumor that John overheard. This shows an instance where referential NP interpretations do not seem to be so much constrained as quantificational NP interpretations are in taking matrix scope.

(3) (a) Each teacher overheard the rumor that every student of mine had been called before the dean.

(b) Each teacher overheard the rumor that a student of mine had been called before the dean.

The sentence (3) (a) has two readings, one with the same rumor for all the teachers,

[2]This reading obviously improves with *some student*. In fact, it is questionable if the sentence (1) has this reading with *a student*. The point is still clear, though. One could use *two students* to strengthen the ambiguity.

and the other with a possibly different version of rumor for each teacher. In both of the readings, we know that the embedded subject NP *every student of mine* does not outscope *the rumor*, let alone outscoping *each teacher*. Compare this with the sentence (2) (b), in which the referential NP *a student of mine* appears to outscope *the rumor*. We also know that the referential NP can take matrix scope, regardless of where it is in surface structure. A question arises then as to how flexible it will be to place the interpretation of the referential NP *a student* in scope order. In other words, the question is if it is possible for the sentence (3) (b) to have a reading in which *each teacher* outscopes *a student*, which in turn outscopes *the rumor*. This is impossible. The only readings that are possible are ones in which *a student* appears to outscope both *each teacher* and *the rumor*. This casts a strong doubt to the presumption that referential NP interpretations can be related to normal scope ordering at all. In this sense, it may not be appropriate to call a referential NP to *outscope* other NPs. In any case, it is clear that we would gain a much clearer understanding of scope phenomena if we distinguish referential and quantificational NP interpretations at the level of semantics.

For this reason, we will consider in the following chapters only the aspect of quantificational NP interpretations in an attempt to account for scope phenomena, and in the interest of identifying the connection between syntax and semantics as manifested by quantificational NP interpretations. As to the aspect of referential NP interpretations, there are also renewed interests in dynamic NP interpretations, following the lead of a discourse representation theory by Kamp (1981) or the file change semantics by Heim (1983). There have also been recent attempts to combine the two aspects, for instance in theories of scope by Poesio (1991) and Reyle (1993). While the quantificational side of these theories does not appear to present a comprehensive and explanatory answer to the kind of data the dissertation is concerned with, there is no doubt that a unified theory for both referential and quantificational NP interpretations is one of the ways to go.

One thing that the preceding discussion suggests is that it is not clear that the representation in (4) (b) is the right one for the sentence (a), where the NP *a certain sample* has a referential interpretation.

(4) (a) Every man saw a certain sample.

(b) `a(S,samp(S),every(R,man(R),saw(R,S)))`

In a sense, this representation is misleading, since it implies that referential NP interpretations participate in scope taking behavior. Rather, since it is context and surface word order that influence the referential interpretation of NPs, the following representation for the NP appears more appropriate. In order to interpret such a representation as `+two(sample)` properly, a different rule or rules than that for the rest would need to be utilized. In this dissertation, however, we will not be concerned with the issue of interpreting referential NPs any further.[3]

(5) `every(R,man(R),saw(R,+two(sample)))`

2.1.2 Other Referential Readings

This section shows two kinds of readings that have a better linguistic explanation if we assume that the involved NPs have referential interpretations.

First, consider the sentence (6). When Hobbs and Shieber (1987) examined the sentence, they implicitly assumed that there is a reading in which *a company* outscopes *most samples*, which in turn outscopes *every representative*.

(6) Every representative of a company saw most samples.

The reading is true of a situation in which there are a group of most samples each of which was seen by all the representatives of the same company. It is crucial for this reading to have the denotation of the company not to be dependent upon those of the other NPs, in particular that of *most samples*. This reading is certainly available.[4] Looking ahead, this

[3]Note that this representation with the plus symbol in front of the quantifier has nothing to do with the forthcoming representation with the star symbol in front of the quantifier for the degenerate quantifier semantics.

[4]There are recent theories such as Beghelli (1995) or Szabolcsi (1995) that are based on an assumption that some quantifiers in an object NP do not outscope the subject quantifier. While we certainly believe that there is a salient reading in which *most samples* outscopes *every representative* in the sentence (6), we should also note that the point here is not about the possibly differential scope-taking behavior among quantificational quantifiers. For those who can never get such a reading, it is suggested that they replace the object quantifier with something like *every*, since *any* theory will need to account for the structural behavior of such quantifiers as *every* anyway, and the point we are making is that (even) such quantifiers are not freely placed in scope order.

reading is not predicted to be available by the hypothesis to be proposed in Chapter 3. We will claim in Section 2.3 that the corresponding reading becomes unavailable when the NP *a company* is replaced with other NPs whose denotation contains multiple individuals, such as *(at least) three companies* or *every company*. The reason that the argument presented there does not also go through to the sentence (6) is that since the denotation of *a company* is just a single entity, we just need a single group of samples for the reading in question (just like when *most samples* takes matrix scope, if it were not for *a company*) and that the fact that *a company* outscopes *most samples* does not affect the rest of the scope relation in any other way. Stipulating that this kind of reading is available only for NPs such as *a company*, *some company*, or *one company* as an exception to the hypothesis is not desirable, since the hypothesis will then immediately lose the ability to *explain* why some scope readings are available.

This apparent exception to the hypothesis has a natural explanation, however, if we suppose that *a company* is used referentially. As we have shown earlier in Section 2.1.1, there is a good reason that referential NP interpretations are better dealt with separately than jointly. Notice that the situation that supports the reading in question also supports the reading in which *a company* is used referentially. The only difference would be that in the latter reading, there must be a specific company that the speaker has in mind to make the sentence truthful. If this company is very salient in the context, there is in fact no need to modify the subject NP further, as the following sentence would suffice to describe the situation.

(7) Every representative saw most samples.

In any case, this explains away the reading in question, and there is no need to amend the hypothesis. As for the corresponding reading for a related sentence in which *a company* is replaced with *one company*, there is no intuitive way of deciding if the reading is available with a quantificational interpretation of the NP. Occam's razor rules that it is not.

Now, consider the sentence (8). The prominent reading is called conjunctive or cumulative, where there are three hunters and five tigers such that the said event happened between the two parties.

(8) Three hunters shot at five tigers.

Most importantly, the reading of this kind can not be addressed by assuming a linear order between the two NP denotations. This is why Hintikka (1974) defined the notion of branching quantifiers in his game-theoretic semantics, subsequently endorsed and extended by Barwise (1979) and Westerståhl (1987), among others. A similar reading appears to be available from the following sentence (Partee, 1975; Webber, 1979).

(9) Three Frenchmen visited five Russians.

It is interesting to note however that conjunctive or cumulative readings of this kind do not obtain when there is a strong lexical preference of quantifiers towards taking functional scope or when there is no possibility for a referential NP interpretation, as argued also by Higginbotham (1987). Notice that the following sentences do not have a cumulative reading.

(10) (a) Each Frenchman visited five Russians.

(b) Few Frenchmen visited five Russians.

Krifka (1992) makes a similar argument on cumulative readings. We believe that it is thus reasonable to assume that cumulative readings are not in the range of scope readings to be predicted by the hypothesis, since the involved NPs, either one of them or both, must be interpreted referentially.

We have so far examined two possible counterexamples to the hypothesis to be proposed in the following chapter. We have shown that they are not, since they all have a natural explanation with referential NP interpretations. While we need to uncover more examples of this sort, we believe that this gives us a strong reference material towards potential counterexamples.

2.2 OTHER SCOPE-RELATED INTERPRETATIONS

The data that we will examine in the following chapters include core English constructions that contain various quantificational NP quantifiers. There are also interactions between these quantifiers and other components of language, such as pronouns working as bound variables, *Wh*-phrases, and qualifiers such as negation. We consider these as beyond the scope of the dissertation, but this section presents some discussion. The reader is encouraged to skip this section altogether on a first reading, since it does not constitute the main thesis.

2.2.1 Pronouns and Quantifiers

When there is a new framework for quantifiers, it is natural to expect also a compatible account of pronouns bound by quantifiers. The following shows an example pronoun of the sort. The subscript i indicates co-reference.

(11) Every soldier$_i$ loves his$_i$ mother.

While we will not be obligated to present such an account in the dissertation as there is already one proposed by Steedman (1997) that is compatible with the theory to be proposed later in the dissertation, there are other phenomena such as Weak Crossover (WCO) violations that are traditionally considered to be best explained at the level of semantics.

WCO is a much studied phenomenon in the literature, but it is still a subject that needs further investigation. Here we will review the data discussed in the literature, and conclude that the framework to be proposed can afford to explain such violations by assuming a further condition such as the bound pronoun rule as proposed by Reinhart (1983) applied to predicate-argument structure.

The following contrast is frequently used to illustrate the nature of WCO.

(12) (a) #His$_i$ mother loves every soldier$_i$.

(b) His$_i$ mother loves John$_i$.

While the sentence (b) is acceptable, the sentence (a) is considered unacceptable. Incidentally, this gives another reason why we need to distinguish referential NP interpretations from quantificational ones at the level of semantics. In movement-based theories such as GB, it appears that the distinction between the sentences (11) and (12) (a) can be explained by a condition such that quantifiers should not cross over the pronouns that they bind when they move to the front. Notice that unlike strong crossover violations (Postal, 1971), the sentence (12) (a) does not present a syntactic problem. This is noted by the hash mark in front of the sentence.

Notice that standard syntactic accounts of pronouns, a version of which is shown in (13) below, do not apply to rule out sentences such as (12) (a) (cf. Chomsky (1981), Lasnik and Uriagereka (1988)). The only condition that is potentially relevant is Condition C, if we assume that quantified NPs are R-expressions, but since the quantified NP *every soldier* in the sentence (12) (a) is not *c*-commanded by the the pronominal, the sentence can not be ruled out.

(13) (A) An anaphor must be bound in its governing category.

(B) A pronominal must be free in its governing category.

(C) An R-expression must be A-free.

Koopman and Sportiche (1982)'s proposal, known as the Bijection Principle, is one of the first attempts to explain why the sentence (12) (a) is out.

(14) (a) Every variable must be bound by exactly one operator.

(b) Every operator must bind exactly one variable.

For example, the sentence (12) (a) is considered unacceptable since its logical form (15) violates the BP due to the two variables, his_i and t_i, bound by the single operator 'every soldier_i'.

(15) Every soldier_i [his_i mother loves t_i]

Haïk (1983) is cited to present a counterexample to the BP, shown in (16) (a) below (Lasnik and Uriagereka, 1988). If the sentence is interpreted to the logical form shown in (b), the sentence would incorrectly be ruled out by the BP, since there are two variables, he_i and t_i, that 'every man_i' binds, violating the BP.

(16) (a) Every man_i likes some symphony he_i heard.

(b) $[_S$ Every man_i $[_S$ [some symphony he_i heard $]_j$ $[_S$ t_i liked t_j]]]

(c) $[_S$ Every man_i $[_S$ t_i $[_{VP}$ [some symphony he_i heard $]_j$ $[_{VP}$ liked t_j]]]

The BP is saved, however, when the object NP can alternatively be adjoined to the VP node, as in (c) above, since the logical form does not violate the BP (cf. Koopman and

Sportiche (1982)). Notice though that the advantage of the BP would nevertheless be considerably weakened by this further assumption, if VP-adjunction is otherwise unmotivated. Even if VP-adjunction can be justified on independent grounds, this results in allowing multiple semantic structures for the same reading. This is another burden for the theory to justify.[5]

The VP-adjunction analysis is noted to have further problems, as shown in the following sentences (Higginbotham, 1983; Lasnik and Uriagereka, 1988).

(17) (a) Every man_i asked some actress_j that he_i met about some play that she_j appeared in.

(b) Someone_i gave [every actress that he_i met $]_j$ a book that she_j appreciated.

(c) Which man_i [t_i liked [which symphony he_i heard]] ?

As for the sentence (c), the VP-adjunction analysis is in trouble if we assume that every *wh*-phrase must be placed in a Comp position (Higginbotham, 1983). Lasnik and Uriagereka (1988) suggest that in order to accommodate these data, LF may have to be split into two levels. Details aside, this again is a burden for the theory to justify the reason.

There are many related proposals. For instance, in a slightly different framework, van Riemsdijk and Williams (1981) argued that WCO can be explained at NP-Structure (cf. Section 4.3.2). The sentence (18) (a) has the NP-Structure representation (b).

(18) (a) Which of his_i pictures does everyone_i like t best ?

(b) Everyone_i likes which of his_i pictures best (NP-Structure)

If we assume a rule such as (19), the structure (b) is correctly explained to be perfect.

(19) The Bound Pronoun Rule: The antecedent, whether or not it is quantified, must *c*-command the pronoun that it binds (Reinhart, 1983).

In other words, the bound pronoun rule that is applied to NP-structure accounts for the reading in which *everyone* outscopes *which of his pictures*. The sentence (20) (a) shows another case that does not violates the rule. The sentence (b) is also ruled in correctly, since he_i is *c*-commanded by its antecedent at NP-Structure. The sentence (c) is also

[5]In a sense, the theory to be presented later in the dissertation is not entirely devoid of such logical redundancy, due to the degenerate quantifier semantics, though the source of such redundancy does not appear related to the one under discussion here.

correctly predicted to be unacceptable since its NP-Structure representation violates the bound pronoun rule.

(20) (a) Everyone$_i$ thinks he$_i$ is sick.

(b) Every man$_i$ liked some symphony that he$_i$ heard.

(c) * Which picture of everyone$_i$ does he$_i$ like ?

Incidentally, since quantifiers in a PP complement position of subject NP are not in a position to *c*-command pronouns in object NP, the binding relation between such quantifiers and pronouns violates the bound pronoun rule. While this prediction makes sense intuitively, it has occasionally been challenged in the literature. Consider the sentence (21) (a) (cf. Higginbotham (1980)).

(21) (a) Everybody in some city$_i$ hates its$_i$ climate.

(b) Every friend of a member$_i$ of a club$_j$ visits it$_j$ with him$_i$.

The sentence (a) is apparently acceptable, though the binding structure appears to violate the bound pronoun rule. On the other hand, this sentence also appears to have a referential NP *some city*, as pointed out by Reinhart. If sentences of this kind always involve referential NPs, they may not be genuine counterexamples to such a rule, as we have argued earlier. Sentence (b) is another example of this kind where the involved NPs appear to be referential (cf. Pereira and Pollack (1990)).

Now consider the following sentences, where (a) is due to Safir (1984) and (b) due to Williams (1986).[6]

(22) (a) Someone in every western city$_i$ hates its$_i$ weather.

(b) *A picture of everyone$_i$ upset him$_i$.

In particular, the NP *every western city* in (a) does not appear to allow a referential interpretation, unlike sentences (21) (a) and (b). Williams pointed out, on the other hand, that a similar sentence (b) is unacceptable. First of all, it appears that the sentence (b) is unacceptable due to the strong referential interpretation of *a picture*, unlike *some picture*. This interpretation blocks the reading in which each person is in a different picture, making the binding structure of the sentence (b) unacceptable. As for the sentence (a), it appears

[6]Williams considers the sentence (b) unacceptable.

that the pronoun is E-type (Evans, 1977a; Evans, 1977b). If so, the sentence may be an instance of a different phenomenon. This means that the sentence (22) (a) is not a genuine counterexample to the bound pronoun rule.

As we have seen so far, it appears that WCO violations can be dealt with a condition such as the bound pronoun rule. In the proposed framework, the rule must apply at predicate-argument structure in which the subject is in the most oblique position of the semantic argument hierarchy, since CCG does not preserve the standard syntactic structure (Steedman, 1997).[7]

2.2.2 *Wh*-Phrases and Quantifiers

The interaction between *Wh*-phrases and quantifiers is another important aspect of scope phenomena. In particular, when natural language sentences are considered as queries, the importance of providing a way of accounting for *Wh*-phrases can not be emphasized enough. Nevertheless, we will not attempt to propose a specific account of *Wh*-phrases in the present framework. First, the standard data analysis regarding the interaction between *Wh*-phrases and quantifiers seems to be at odds with the predictions under the proposed hypothesis, when we naïvely treat *Wh*-phrases as normal quantified phrases. Second, it is not clear either that they can be identified with referential NPs, since there is again an apparent discrepancy between the behavior of referential NPs and that of *Wh*-phrases. This implies that *Wh*-phrases are some new creature, distinct from quantificational NPs and referential NPs. While we leave the study of the exact nature of *Wh*-phrases under the present framework as future work, we should note that the nature of *Wh*-phrases in theories such as GB has been discussed extensively. This section shows the standard data analysis.

The following shows one of the characteristic contrasts that involve *Wh*-phrases.

(23) (a) Who will read what ?

(b) * What will who read t ?

[7]In the present dissertation, we will use a more intuitive argument order in which subject precedes object, but this is just a matter of presentational style. When binding relations become relevant, the argument order should be arranged so that subject *c*-commands object in the lexical specification of predicates (Jackendoff, 1972).

The accepted judgment appears to be that while the sentence (a) is perfect, the sentence (b) is not acceptable. In order to account for this contrast, Chomsky (1973) proposed the following condition, to be applied at S-Structure.

(24) Superiority Condition: If a construction has two sources of *Wh*-movement, and one is superior to (or asymmetrically *c*-commands) the other, then *Wh*-movement must pick up the superior one.

As designed, only the sentence (b) violates the condition. It is also claimed that this condition is subsumed by the extended ECP (Kayne, 1981), if we assume that *Wh*-movement occurs not only from D-Structure to S-Structure but also from S-Structure to LF (Aoun, Hornstein, and Sportiche, 1980; Lasnik and Saito, 1984). According to this claim, the sentence (23) (a), whose S-Structure analysis is shown in (25) (a), is analyzed at LF as in (25) (b), where both traces are properly governed. Incidentally, we need to assume a complex indexation scheme for this explanation. On the other hand, the sentence (23) (b) has S-Structure analysis shown in (25) (c), which at LF violates the extended ECP, as shown in (d), since the trace t_i is not antecedent governed. Again, we need to assume the specific way complex indices are interpreted.

(25) (a) $[_{\text{Comp}}$ Who$_i$ $]_i$ [t_i will read what] (S-Structure)
(b) $[_{\text{Comp}}$ What$_j$ $[_{\text{Comp}}$ Who$_i$ $]_i$ $]_i$ [t_i will read t_j] (LF)
(c) $[_{\text{Comp}}$ What$_j$ $]_j$ [will who read t_j] (S-Structure)
(d) * $[_{\text{Comp}}$ Who$_i$ $[_{\text{Comp}}$ What$_j$ $]_j$ $]_j$ [will t_i read t_j] (LF)

While this would explain the way the extended ECP subsumes superiority condition, there is a question however as to how relevant the extended ECP is to the present phenomenon. Williams (1986) points out that the account of superiority effects with the extended ECP is not applicable to all the related examples. For instance, both of the sentences in (26) have only lexically governed traces, but only the sentence (b) is out.

(26) (a) Who did you give *t* what ?
(b) * What did you give who *t* ?

Hence the data appear to suggest that it may not be the extended ECP that is relevant. The interested reader is referred to Williams (1986) for further details of e.g. how he explains binding at NP-Structure and quantification at S-Structure.

As for the interaction between quantifiers and *Wh*-phrases, the following contrast is a well-discussed one.

(27) (a) Who$_i$ t_i saw every student?

(b) Who$_i$ did every student see t_i?

Again, the usual judgment is that while the sentence (a) is unambiguous, the sentence (b) is ambiguous. More specifically, the sentence (a) is taken to be a question about the identity of an individual or individuals who saw all the students. If we can regard *Wh*-phrases as participating in scope order, this reading would be the one in which *Who* outscope *every student*. The reading is a question about the identity of individuals who saw every student. As for the sentence (b), it is claimed that there are two readings. In one reading, the question is about the identity of an individual or individuals whom every student saw. The other reading is a question regarding the identity of individuals for each student such that there is a pairing of individuals with respect to each student. Chierchia (1991) argues that the difference can be explained by the way quantified NPs cross over traces of *Wh*-phrases.

2.3 FUNCTIONAL DEPENDENCY

This section shows that quantificational readings always exhibit a kind of functional dependency between the scope related NP denotations. This property can be utilized to sharpen people's intuition to determine the availability of a particular reading by maximizing the way scope-related NP denotations are laid out. Note that the kind of scope-related functional dependency that we are interested in here is distinct from the kind of semantic dependency that makes the sentence "*Every mother has at most three babies*" semantically unambiguous (Hobbs, 1983).

The claim is that in quantificational readings, the semantic objects denoted by an outscoped quantified NP depend functionally upon the semantic objects denoted by the outscoping quantified NP. For instance, consider the sentence (28).

(28) Every man loves some woman.

(29) shows two possible logical forms of the sentence in first-order logic.

(29) (a) $\forall m.man(m) \rightarrow \exists w.woman(w) \wedge loves(m, w)$

(b) $\exists w.woman(w) \wedge \forall m.man(m) \rightarrow loves(m, w)$

In order to evaluate the logical form (a) truth-conditionally, we should make the choice of an individual for w functionally dependent upon the choice of each individual for m since otherwise, there would be no semantic (truth-conditional) difference between (a) and (b). This is usually captured by skolemizing the variable w in (a). We argue that this kind of scope-related functional dependency shows up between any two NPs connected by an outscoping relation, regardless of whether the reading has a group interpretation or a distributive interpretation. To see this, consider the sentence (9) again, repeated below.

(30) Three Frenchmen visited five Russians.

Partee (1975) claimed that this sentence has 8 readings (also cf. Webber (1979)).[8] Among them is a conjunctive reading. We have shown that this involves referential NP interpretations. (31) shows scope relations that correspond to the remaining 7 readings. The subscripts d and g indicate *distributive* and *group* interpretations of the corresponding NPs, respectively.

(31)

(a) three Frenchmen$_d$ > five Russians$_g$ (b) three Frenchmen$_d$ > five Russians$_d$

(c) three Frenchmen$_g$ > five Russians$_d$ (d) three Frenchmen$_g$ > five Russians$_g$

(e) five Russians$_d$ > three Frenchmen$_d$ (f) five Russians$_d$ > three Frenchmen$_g$

(g) five Russians$_g$ > three Frenchmen$_d$

The situations that support these readings are explained in Table 2.1. For instance, reading (a) is true of a situation in which there are three Frenchmen, each of whom visited a possibly different group of five Russians. This implies that each Frenchman had one chance of visiting Russians, so that there are just three different visiting events that are being talked about. On the other hand, reading (b) may have 15 different visiting events, since each Frenchman could have paid an individual visit to each member of a group of five Russians. Regardless of this difference, however, we can clearly see that there

[8] Bunt (1985) shows why a finer grained semantics reveals 30 distinct readings for the sentence. We believe that this extra level of detail is not needed for the study of the connection between syntax and semantic as manifested by quantifier scope.

(a) *three Frenchmen*$_d$ > *five Russians*$_g$
There are three Frenchmen each of whom visited a (possibly different) group of five Russians. For example, in this situation, the number of visiting events is 3, and the maximum number of involved Russians is 15.

(b) *three Frenchmen*$_d$ > *five Russians*$_d$
There are three Frenchmen each of whom visited each of five Russians. The number of visiting events is 15.

(c) *three Frenchmen*$_g$ > *five Russians*$_d$
There are three Frenchmen who as a single group visited each of five Russians. The number of visiting events is 5.

(d) *three Frenchmen*$_g$ > *five Russians*$_g$
There are three Frenchmen who as a single group visited a group of five Russians. The number of visiting events is just one.

(e) *five Russians*$_d$ > *three Frenchmen*$_d$
There are five Russians each of whom was visited each of three Frenchmen. The number of visiting events is 15, and the maximum number of involved Frenchmen is 15.

(f) *five Russians*$_d$ > *three Frenchmen*$_g$
There are five Russians each of whom was visited by a (possibly different) group of three Frenchmen. The number of visiting events is 5.

(g) *five Russians*$_g$ > *three Frenchmen*$_d$
There are five Russians who as a group were visited by each of three Frenchmen. The number of visiting events is 3, and the maximum number of involved Frenchmen is 3.

Table 2.1: Seven different situations for the Frenchmen sentence.

should always be a functional dependency of each group of five Russians (or individual five Russians) upon the choice of a Frenchman in order that each reading be assigned a distinct truth condition. That is, if one takes any scope relation from (32) (a) through (g), the number of individuals or groups that correspond to an outscoped NP is always functionally dependent upon the number of individuals or groups that correspond to the outscoping NP, as shown below.

(32) (a) *three Frenchmen*$_d$ > *five Russians*$_g$:

There may be *three* different groups of five Russians.

(b) *three Frenchmen*$_d$ > *five Russians*$_d$:

There may be *three* different groups of five Russians.

(c) *three Frenchmen*$_g$ > *five Russians*$_d$:

There is a *single* group of five Russians.

(d) *three Frenchmen*$_g$ > *five Russians*$_g$:

There is a *single* group of five Russians.

(e) *five Russians*$_d$ > *three Frenchmen*$_d$:

There are *five* different groups of three Frenchmen.

(f) *five Russians*$_d$ > *three Frenchmen*$_g$:

There are *five* different groups of three Frenchmen.

(g) *five Russians*$_g$ > *three Frenchmen*$_d$:

There is a *single* group of three Frenchmen.

If we take the first reading of (32), for instance, this reading would be true of a situation in which there are just five Russians, say r_1, r_2, r_3, r_4 and r_5, who were all visited by each of the three Frenchmen, say f_1, f_2 and f_3. However, this is just a coincidence, as there may be different such Russians for each Frenchman. If this reading is genuine, then we must be able to find a situation in which there are completely different three groups of such five Russians and still be able to describe the situation by the sentence "Three Frenchmen visited five Russians." The same is true of the other readings as well.

What is significant with this functional dependency is that it amplifies the connection between individuals related by scope ordering to such a degree that it becomes evident that some connections (and therefore the related scope ordering) are not warranted by the sentence at hand. Consider the following sentence, a variant of (6).[9]

(33) Two representatives of three companies saw four samples.

The following shows six logical forms in a generalized quantifier format (Barwise and Cooper, 1981; Hobbs and Shieber, 1987). Each logical form is preceded by the corresponding scope ordering.[10]

(34) (a) three companies > two representatives > four samples

`three(c,comp(c),two(r,rep(r)&of(r,c),four(s,samp(s),saw(r,s))))`

(b) (two representatives > three companies) > four samples

`two(r,rep(r)&three(c,comp(c),of(r,c)),four(s,samp(s),saw(r,s)))`

(c) four samples > three companies > two representatives

`four(s,samp(s),three(c,comp(c),two(r,rep(r)&of(r,c),saw(r,s))))`

(d) four samples > (two representatives > three companies)

`four(s,samp(s),two(r,rep(r)&three(c,comp(c),of(r,c)),saw(r,s)))`

(e) # three companies > four samples > two representatives

`three(c,comp(c),four(s,samp(s),two(r,rep(r)&of(r,c),saw(r,s))))`

(f) # two representatives > four samples > three companies

`two(r,rep(r)&of(r,c),four(s,samp(s),three(c,comp(c),saw(r,s))))`

Notice that the reading corresponding to the logical form (f) would be immediately excluded by Hobbs and Shieber (1987) due to the impossibility of constructing a sensible model for it. Since this is the only reading whose logical form has a free variable, an unbound variable constraint (or UVC) might work as a semantic filter for *available* logical

[9]For simplicity of presentation, we will assume, without losing generality, that *three companies* is actually a simplified expression of *exactly three companies*, in order to avoid its referential interpretation. There are in fact a number of possible premodifiers for numerals working as quantifiers, including *exactly*, *at least*, *at most*, *more than*, *all the*, etc. The possibility of these alternative implicit premodifiers makes the expression *three companies* semantically ambiguous. There is also a recent argument that the presence of these premodifiers affects the availability of readings (Beghelli, 1995). For instance, *most samples* or *few samples* in an object position is predicted not to take matrix scope. However, Beghelli's claim is based on sentences with neutral intonation and one can still get those readings with a proper intonation. Any competence theory of scope must therefore be able to predict such readings, no matter how marginally available they are.

[10]The hash mark on scope ordering means that the particular scope ordering is not related to the sentence at hand, to be discussed shortly. The reason that the format is called *generalized* is that the form itself is not sensitive to the semantics of each quantifier, as in $\forall x.A \rightarrow B$ or $\exists x.A \wedge B$, where the relation between the terms A and B is syntactically specified according to the specific operator.

forms provided that all the other five readings were available. Incidentally, the need to embed this kind of a logical condition in a system has also been pursued in much subsequent work including Keller (1988), Carpenter (1989; 1994), Pereira (1989; 1990). We should also point out that this kind of condition is needed in one form or another in order to explain natural language pronouns as bound variables. This is a separate issue, however.

We claim that in addition to the unavailable reading (f), there is another reading, or (e), that is also unavailable, due to the impossible functional dependency it requires of its model. We have already suggested that the corresponding reading for Hobbs & Shieber's original sentence (6) does have a reasonable interpretation in which the NP *a company* is used referentially. Let us check if it is possible for a quantificational *three companies* to lead to the reading (e). Notice first that unlike the other four readings, this reading has a striking property such that it has the object quantifier intercalating or interposing subject quantifiers. The problem with this property is that the associated functional dependency is so unusual that no human language understanders would relate it to the natural language sentence at hand. To see this, let us first assume that all the relevant quantified NPs have a distributive sense, as group senses will only simplify the matter. The reading would be true of the following situation.

(35) *There were three companies such that there were four samples for each such company such that each of those samples was seen by two representatives of that company. Crucially, samples seen by representatives of different companies were not necessarily the same.*

We claim that this is not what the sentence says. The reader is urged to use their own intuition to verify this.[11] The reason for dismissing the reading is due to the surface structure '$\mathbf{NP}_1$ of $\mathbf{NP}_2$ verb$_{tv}$ $\mathbf{NP}_3$', and not so much to the lexical semantics of the

[11] The present observation is not entirely new. For example, Fodor (1982) points out that the sentence "*Each diplomat spoke to a representative of an East European country*" lacks a reading with scope relation *some representative* > *each diplomat* > *some country* due to the kind of functionality that *each diplomat* requires of the NP denotation under its scope. Furthermore, she also argues that the sentence "*A diplomat spoke to a representative of each East European country*" lacks a reading with scope relation *some representative* > *each country* > *some diplomat*, due to the same kind of functionality requirement associated with *each*. The dissertation invokes an explicit functional dependency to generalize the functionality requirement that is specific to *each* and the like.

(a) *three companies > two representatives > four samples*
`three(c, comp(c), two(r, rep(r) & of(r,c), four(s, samp(s), saw(r,s))))`
There are three companies such that each such company has two representatives such that each such representative saw four samples.

(b) (*two representatives > three companies*) > *four samples*
`two(r, rep(r) & three(c, comp(c), of(r,c)), four(s, samp(s), saw(r,s)))`
There are two representatives such that each such representative is one of three companies such that he/she saw four samples.

(c) *four samples > three companies > two representatives*
`four(s, samp(s), three(c, comp(c), two(r, rep(r) & of(r,c), saw(r,s))))`
There are four samples such that each such sample is related to three companies such that each such company has two representatives such that they saw that sample.

(d) *four samples >* (*two representatives > three companies*)
`four(s, samp(s), two(r, rep(r) & three(c, comp(c), of(r,c)), saw(r,s)))`
There are four samples such that each sample was seen by two representatives such that each such representative is one of three companies.

Table 2.2: Four readings of the representative sentence.

involved nouns and the verb. Notice though that the UVC is unable to exclude this unavailable reading.

The remaining readings are self-evidently available. The readings and their supporting situations are stated in Table 2.2. For instance, the logical form (a) is true of a situation in which there are three companies such that each such company has two representatives such that each such representative saw four samples. Likewise, the logical form (d) is true of a situation in which there are four samples such that each sample was seen by two representatives such that each such representative is one of three companies. The following chapter will show further examples.

2.4 CHAPTER SUMMARY

In this chapter, we have shown that referential NP interpretations must be distinguished from quantificational NP interpretations, following Fodor and Sag (1982). We have also shown that there are readings that are best explained by referential NP interpretations.

We have discussed that there are other phenomena, arising from the interactions of other natural language components with quantified NPs, such as pronouns and *Wh*-phrases. These include weak crossover violations and superiority effects, among others. They will not be considered further in the rest of the dissertation.

As to quantificational NP interpretations, we have shown that there is a kind of functional dependency between denotations of scope-related NPs, and that this can be utilized to verify the availability of quantificational scope readings. We have used one example sentence to substantiate this. The next chapter will implicitly assume this technique in assessing quantificational readings that are available from given English sentences.

Chapter 3

QUANTIFICATIONAL SCOPE READINGS

This chapter presents a new hypothesis on quantificational readings (Section 3.1) and check this hypothesis with core English constructions (Section 3.3), including transitive verbs, dative alternation (ditransitive) verbs, attitude verbs that subcategorize for complement `that`-clauses, complex NPs containing prepositional phrases and/or possessives, complex NPs containing subject or non-subject *Wh*-relatives (with or without pied-piping), and coordinate structures that split standard constituent boundaries. All of these constructions can syntactically introduce multiple NPs to a sentence and thus create a potential scope ambiguity. Our assumptions on assessing scope readings are stated in Section 3.2.

3.1 THE SURFACE CONSTITUENCY HYPOTHESIS

The most obvious problem quantifier scope ambiguity raises for natural language semantics, and natural language processing in general, is simply that most of the available theories make far too many readings available for sentences with even a few quantifiers. For instance, a sentence with five quantifiers such as (36) below gives rise to 120 different scope interpretations, if we simply assume that the quantifiers translate into standard logical quantifiers and can be arbitrarily linearized (Hobbs, 1983).

(36) In most democratic countries most politicians can fool most of the people on almost every issue most of the time.

Although we certainly doubt that all the combinatorial ordering of quantifiers always result in readings that are semantically available, there are so many interacting factors in scope phenomena that it has been extremely difficult to precisely identify the relation between the specific forms of natural language sentences and their readings. Such factors usually operate on semantics and ontological details, and can endorse many more readings than the surface word string of a sentence alone would. In this regard, compare the claim that the sentence (37) has 8 readings (Partee, 1975) and the claim that it has 30 readings (Bunt, 1985), as discussed in Section 2.3.

(37) Three Frenchmen visited five Russians.

So one begins to wonder if it is possible at all to slice up the scope phenomena to reveal readings that are available only due to the specific forms of natural language sentences, and not due to the semantic details of each lexical item. Although readings would of course simply cease to make sense if all the semantic details of a lexical item are completely stripped off, the success of this task will certainly provide us a stronger intuition over the scope phenomena. The literature shows that this is a challenging but nevertheless often-forgotten task. For instance, Hobbs and Shieber (1987) pointed out that sentence (38) has one fewer than the six readings that the aforementioned simple quantification model would suggest.

(38) Every representative of a company saw most samples.

What they pointed out was that the reading of (38), in which *every representative* outscopes *most samples*, which in turn outscopes *a company*, was not available due to the impossibility of constructing a sensible semantic model, and that it might be so because only readings of this form translated into a logical form with an unbound variable.[1] This means that (39) has many fewer than 120 readings.

[1]The impossible model would have a situation in which every representative saw a possibly different group of most samples, and furthermore (or crucially) each such sample is related to a possibly different company so that the representative who saw it is from that company.

(39) Some representative of every department in most companies saw a few samples of each product.

There is truth to this observation since it is odd anyway to think of natural language sentential semantics containing a free variable. However, their consequent suggestion to utilize an unbound variable constraint (or UVC) to exclude readings that are unavailable would work only if *all* unavailable readings are accounted for by this constraint. As we have shown in Chapter 2, there are missing readings that are not excluded by the UVC alone. Besides, it is somewhat counter-intuitive to assume that a logical constraint such as the UVC can fully explain the way people choose a particular expression, among others, to influence possible readings. We would rather expect to see that the way people express, or the way they arrange a particular string of words, makes subtle changes in the possible range of interpretations. In other words, we predict that surface structure, rather than deep structure, plays a crucial role in the range of available readings.

To explain why we believe that surface structure affects available readings, consider the following pairs of sentences.[2]

(40) (a) Every representative of two companies saw most samples.

(b) Some student studied two dialects of every language.

(41) (a) Two professors who interviewed every student wrote a letter.

(b) Two professors whom every student admired wrote a letter.

Notice first that it is impossible to get a reading for (40) (a) in which *two companies* outscopes *most samples*, which in turn outscopes *every representative*, unlike (38) (see Section 2.3). While (40) (a) has only four readings, (40) (b) apparently has an additional reading, in which *every language* outscopes *some student*, which in turn outscopes *two dialects* (May, 1985). And the only clue for this difference between readings of sentences (a) and (b) is in the surface structure, or in the surface position of the complex NP containing two quantifiers.

[2]We owe the example (41) (a) to Janet D. Fodor (p.c.). Thanks are also due to Bonnie Webber and Anthony Kroch for the suggestion to replace *two dialects* in (40) (b) with *two aspects*, where the semantic connection between *aspects* and *languages* is much more independent that that between *dialects* and *languages*. We assume that no NPs in the examples are interpreted referentially. For this, it helps to assume further that *three* has an implicit premodifier *exactly*, among other possibilities. Notice of course that we do not mean to imply by this assumption that *two companies* is synonymous to *exactly two companies*. The latter is just one disambiguated expression out of many for the former.

Now consider sentences in (41). (41) (a) has readings in which *every student* outscopes *two professors*, though they are marginally available.[3] These pertain to the situations in which for each student there are possibly different two professors who wrote a letter, jointly (the same letter) or independently (a different letter). On the other hand, (41) (b) does not have corresponding readings in which the embedded subject quantifier outscopes the head quantifier. The latter is syntactically mirrored by the fact that it is impossible to syntactically extract embedded subject NPs from a relative clause. Again, the only clue for the difference between (41) (a) and (b) appears to be in the surface structure. One way of explaining these differences is to invoke English subject-object asymmetry, but the hypothesis below explains why there is (English) subject-object asymmetry at the level of semantics in the first place, as well as why there are differences in the range of available readings in (40) and (41). We claim that the hypothesis works to predict available readings for other core English constructions, as shown in Section 3.3.

We need the following notion of *c-constituency* to simplify the statement of the hypothesis. C-constituency extends the usual notion of surface constituency.[4]

Definition 1 C-CONSTITUENCY*: A string s of words in a language L is a* c-constituent *if and only if L has a grammatical sentence in which s is coordinated with another string s' of words that share the same syntactic function with the string s.*

For example, both *loves* and *will marry* are c-constituents in English as *Every man loves and will marry some woman* is a grammatical sentence in English.

[3]We are not trying to contradict the old belief in the literature that dates back to Ross (1967) regarding the island status of relative clauses. The point here is that there is a perceivable difference (between embedded subject quantifiers and embedded object quantifiers) in acceptability of readings in which embedded quantifiers outscope their head quantifiers. This distinction has not been discussed in the literature, as far as we are aware of. The theory to be presented in Chapter 4 can also explain theory-internally why there are differences in people's judgments. According to the coordination test we have, this reading is indeed hard to get. But by comparison, it is absolutely impossible for *every student* in the sentence (41) (b) to outscope *two professors*.

[4]This is exactly the notion of constituency in CCG, to be discussed later.

Hypothesis 1 QUANTIFICATIONAL READINGS: *Consider the following surface structure of a grammatical sentence, in which the fragment A includes everything between* $\mathbf{NP}_1$ *and* $\mathbf{NP}_2$*, and the fragment B includes* $\mathbf{NP}_1$*, A,* $\mathbf{NP}_2$*, and nothing else:*

$$\cdots \overbrace{\mathbf{NP}_1 \underbrace{\cdots}_{A} \mathbf{NP}_2}^{B} \cdots.$$

In quantificational readings, quantifiers inside $\mathbf{NP}_1$ *and those inside* $\mathbf{NP}_2$ *can alternate their relative scope order iff both A and B are phonologically realized c-constituents. In these readings, quantifiers inside A are outscoped by all the quantifiers that are inside* $\mathbf{NP}_1$ *and* $\mathbf{NP}_2$*.*

This hypothesis will henceforth be referred to as either "the hypothesis" or "the Surface Constituency hypothesis". The fragment A must be phonologically or linguistically realized since it works as a semantic function that takes two NPs as its arguments, to be explained shortly.

To show briefly how the hypothesis works, consider the sentences in (40) again. (a) is predicted to have exactly four readings by two applications of the hypothesis. First, if we focus on the subject complex NP for B, the hypothesis predicts that *every representative* and *two companies* can alternate their relative scope order, since both *of* and *every representative of two companies* are c-constituents. Also, if we consider the entire sentence for B, the hypothesis predicts that the two quantifiers in the subject NP and *most samples* can alternate their relative scope order, since both *saw* and the entire sentence are c-constituents. These allow four different ways of ordering quantifiers, each resulting in a distinct reading. In particular, the reading in which *every representative* outscopes *most samples*, which in turn outscopes *two companies*, is not endorsed by the hypothesis, as *of two companies saw* is not a c-constituent, as evidenced below.[5]

(42) *Every representative of two companies saw, but of five universities touched, most samples.

[5]The annotation '*' on sentences means that they are ungrammatical.

As we noted, the reading is in fact unavailable.

The hypothesis also correctly predicts that (40) (b) has five readings. First, both *studied* for A and the entire sentence for B are c-constituents, allowing *some student* and the two quantifiers in the object complex NP to alternate their relative scope order. As for the two quantifiers in the object complex NP, both *of* for A and *two dialects of every language* for B are c-constituents, so they can alternate their relative scope order. These two applications make up for the four readings similar to those for (40) (a). In addition, there are possibilities in which *some student* and *every language* can alternate their relative scope order, with *two dialects* outscoped by both, since both *studied two dialects of* for A and the entire sentence for B are c-constituents. The fact that *studied two dialects of* is a c-constituent can be evidenced by sentence (43). These make up for two readings, and only one of them introduces a new one, in which *every language* outscopes *some student*, which in turn outscopes *two dialects*.

(43) Some student studied two dialects of, but collected most cases of coordination in, every language.

Consider sentences (41). (41) (a) is predicted to have four readings by the hypothesis, like (40) (a), since both *who interviewed* for A and *two professors who interviewed every student* for B are c-constituents. For speakers who are against the coordination *who interviewed and who liked*, the hypothesis would predict that there is no difference in the number of readings between (41) (a) and (b).[6] The same possibilities are not allowed for (41) (b), however, since *two professors whom every student* for B can not be a c-constituent, as shown below, though *whom* for A may be a c-constituent.[7]

(44) *Two professors whom every student, and most deans whom every girl, admired wrote a letter.

[6]The sentence *Two professors who interviewed and liked every student wrote a letter* is perfect but irrelevant to the present discussion. According to the theory to be proposed, the fragment *two professors who interviewed* must also be a c-constituent, in order to allow *every student* to outscope *two professors.* This is perhaps why it is hard to get this reading.

[7]Needless to say, the fragment *every student admired wrote a letter* is not a constituent, so that the hypothesis correctly disallows a reading in which *a letter* comes between *two professors* and *every student.*

We have considered so far *how* the hypothesis works. Let us step back and consider *why* the hypothesis works. The hypothesis predicts when quantifiers, e.g. those in $\mathbf{NP}_2$, are allowed to outscope temporally preceding quantifiers, e.g. those in $\mathbf{NP}_1$, in a grammatical sentence. The hypothesis operates on an assumption that scope relations are always binary. The reason it works can be attributed to the fragments A and B being c-constituents: (1) that B is a c-constituent assures the relative autonomy of the fragment itself, and (2) that A is a c-constituent implies that $\mathbf{NP}_1$ and $\mathbf{NP}_2$ work as two semantic arguments of the fragment, much like a transitive verb having two semantic arguments. In order to speculate on how the hypothesis explains subject-object asymmetry in English, consider the following simplified surface structures:

(45) (a) $\underbrace{\overbrace{Quantifier\ Head}^{NP_1}}_{S}\ \underbrace{TV}_{V}\ \underbrace{\overbrace{Quantifier\ Head}^{NP_2}}_{O}$

(b) $$\underbrace{\overbrace{Quantifier\ Head}^{NP_1}\ P\ \overbrace{Quantifier\ Head}^{NP_{10}}}_{S}\ \underbrace{TV}_{V}\ \underbrace{\overbrace{Quantifier\ Head}^{NP_2}\ P\ \overbrace{Quantifier\ Head}^{NP_{20}}}_{O}$$

English is a configurational language, in which the standard word order of a grammatical sentence is SVO, as shown in (45) (a) above. Transitive verbs normally expect two arguments, S and O, on its two sides. When the NPs are modified further, as in (b), the transitive verb still expects to receive two arguments, or NP_1 and NP_2, but these two arguments are first modified by NP_{10} and NP_{20}, respectively, before they are available for the transitive verb. The fact that English allows the fragment $TV\ NP_2\ P$, but not the fragment $P\ NP_{10}\ TV$, to be a c-constituent implies not only that NP_2 is still the same argument that TV can accept, but also that NP_{10} is not.[8] This makes sense, since we expect a post-modifier, such as $P\ NP$, to be something like a transducer function, that takes a normal NP to yield a normal NP, so that its presence does not affect neither the grammaticality nor the semantic integrity of the rest of the sentence. It is thus natural to expect that the transitive verb will not be able to accept such a complex object directly as one of its arguments. In sum, what we see is that English has subject-object asymmetry

[8]We must include the preposition P in considering the fragment, as in $TV\ NP_2\ P$ or $P\ NP_{10}\ TV$, since otherwise the fact that the fragment expects further argument(s) can not be made to reflect in its semantics.

in semantics due to its standard word order, where the modified part of a complex object is temporally adjacent to the transitive verb. We need a thorough cross-linguistic study to substantiate this observation, but it is beyond the scope of the dissertation.

We have shown that the hypothesis makes a reasonable prediction on the number of available quantificational readings for a small selected group of English sentences. Section 3.3 considers a wider range of English constructions to check the hypothesis.

3.2 ASSUMPTIONS ON SCOPE ASSESSMENT

In the following discussion of scope readings, we assume the following:

- The studied readings involve only quantificational NP interpretations, as explained in Chapter 2. For example, *a man* is interpreted to be either *exactly one man* or *at least one man* and so on, but it is not interpreted to refer to a specific established individual who happens to be an adult male.

- Proper nouns are assumed to be unambiguous. This is not necessarily true, as the semantic domain may include multiple individuals whose "names" happen to be the same. This kind of ambiguity however is orthogonal to the kind of scope ambiguity considered here.

- NPs with bare numerals are assumed unambiguous by themselves. For example, *three companies*, without a premodifier, may have a context-dependent premodifier assigned to it. These premodifiers include: *at least*, *exactly*, *more than*, and so on. This kind of ambiguity is also considered orthogonal to the present scope ambiguity.

- We will not consider readings that depend only on the details of the NP semantics and not on the surface structure. In other words, we do not consider those readings that are available only when the NP semantics is fine-grained. As for the distinction between group NP interpretations and distributive NP interpretations, we choose to consider only distributive NP interpretations, since group NP interpretations only simplify the involved functional dependency. There are NPs that admit only one kind of interpretations. For example, *every man* does not have a group interpretation.

We will assume that this kind of special properties can be dealt with case by case. The proposed lexical theory is particularly suitable to handle it, to be discussed in Chapter 4.

3.3 CONSTRUCTION-SPECIFIC SCOPE READINGS

This section examines the following English constructions: Transitive verbs, dative alternation (ditransitive) verbs, attitude verbs that subcategorize for complement `that`-clauses, complex NPs containing prepositional phrases, complex NPs containing possessives, complex NPs containing subject or non-subject *Wh*-relatives (with or without subject and object pied-piping), and coordinate structures that split standard constituent boundaries. The order of presentation is slightly changed to make a natural progression for the discussion.

3.3.1 Transitive Verbs

The following sentences are ambiguous in different ways.

(46) (a) Every man admires some woman.

(b) Three Frenchmen visited five Russians.

In the sentence (a), the reading in which *some woman* outscopes *every man* is a special case of the reading in which *every man* outscopes *some woman*, due to the combined characteristics of *every man* and *some woman*.[9] In the sentence (b), there could be seven readings, even if we do not consider the conjunctive reading, as pointed out by Partee (1975) and others. As we have assumed before, however, we will regard these sentences as ambiguous only in exactly two ways: Either the subject NP outscopes the object NP (and therefore the denotation of the subject NP is determined before that of the object NP) or the object NP outscopes the subject NP. Moreover, this observation appears to carry over to transitive verbs of any tense and aspect.

[9]The denotation of *every man* coincides with the restriction set, and the denotation of *some woman* contains only one individual.

(47) (a) Three Frenchmen will visit five Russians.

(b) Three Frenchmen have visited five Russians.

(c) Three Frenchmen had visited five Russians.

The fact that there are two readings in sentences such as (46) (a) or (b) is immediately predicted by the SC Hypothesis. For example, the hypothesis predicts that the two NPs in the sentence (46) (b) can alternate their relative scope order, since the A fragment, or the transitive verb *visited*, is a c-constituent and the B fragment, or the entire sentence, is also a c-constituent. This correctly results in two readings.

(48) Three Frenchmen visited and will invite five Russians.

3.3.2 Control Verbs

Sentence (49) (a) has the raising verb *seems*, and (b) has the equi verb *tries*.

(49) (a) Every man seems to admire some woman.

(b) Every man tries to admire some woman.

Sentence (a) has two obvious readings and another pair of readings that are of a different nature. The two obvious readings are similar in structure to readings considered in the previous section, in the sense that the fragment *seems to admire* works as a normal transitive verb in scope relations. This is evidenced by the following sentence.

(50) Every man seems to admire and will court some woman.

To paraphrase the two readings of sentence (49), they are as follows.

(51) (a) *every man* > *some woman*

For each man, there is a possibly different woman whom he seems to admire.

(b) *some woman* > *every man*

There is a woman such that every man seems to admire her.

The other pair of readings is actually derived from the sentence below, which is considered syntactically related to the sentence at hand in old transformational theories of grammar.

(52) It seems that every man admires some woman.

The difference between these readings and the earlier ones is that in earlier ones, the semantics of the fragment *seems to admire* works as a relation between two groups of individuals, whereas in the present readings, the semantics of *seems* is applied to the set of relations for *admires* between two groups of individuals.

We will consider this matter unrelated to the phenomena at hand though, since it is a further special characteristics of the raising (or equi) verb, just like the verb *seeks* introduces an opaque context and intensionality to the sentential semantics.

The sentence (49) (b) is analyzed to have two similar readings. In particular, the presence of an extra agent in the sentence, one who tries and another who admires, does not appear to contribute to further semantic ambiguities.

(53) Every man tries to admire and will court some woman.

Thus, while the semantic details of raising and equi verbs are different, the number of available readings they are associated with is predicted to be the same.

3.3.3 Complex NPs with PP

The sentence (54) has two quantifiers inside a complex NP.

(54) Two representatives of three companies showed up.

This sentence is semantically ambiguous between two readings, excluding the rest of the readings assumed unrelated in the beginning of this discussion.

(55) (a) *two representatives > three companies*

There are two representatives, each of whom works for three different companies at the same time, such that they showed up.

(b) *three companies > two representatives*

There are three companies such that two different representatives of each such company showed up.

The hypothesis predicts the two readings correctly, since prepositions can coordinate.

The following two sentences have a complex NP in a different syntactic position.

(56) (a) Two representatives of three companies saw four samples.

(b) Some student studied two aspects of every language.

As for the sentence (56) (a), we have shown earlier that it has only four readings. We have also pointed out that (b) has five readings, with an additional reading in which *every language* outscopes *some student*, which in turn outscopes *two aspects*. That the hypothesis makes a correct prediction for each of the two sentences has been discussed as well. Notice that the hypothesis would predict (incorrectly) more than four readings for the sentence (56) (a) if the following sentence were grammatical. Since it is not, the hypothesis has no further readings to predict.

(57) *Two representatives of three companies saw, but of three colleges (also) touched, four samples.

The contrast we have shown with the sentences (56) (a) and (b) suggests that there is a semantic difference between active and passive sentences that are truth-conditionally related. Consider the following pair of sentences.

(58) (a) Some student studied two aspects of every language.

(b) Two aspects of every language was studied by some student.

The prediction is that one of the readings for (58) (a), in which *every language* outscopes *some student*, which in turn outscopes *two aspects*, will not be available from the sentence (b). The sentence (b) is predicted to have only four readings, just like the sentence (56) (a). This confirms the belief in the literature that passivization does change the semantics.

Two of the readings for the sentence (58) (b) have *some student* outscope the other quantifiers. In a framework that depend on a theory-internal device to move quantifiers around for semantic interpretation, as in GB theories, there is an interesting phenomenon that may require a constraint over such movement (Horn, 1974; Bach and Horn, 1976). Horn proposed a condition called the NP constraint, which states that no constituent dominated by NP can be moved or deleted from that NP by a transformational rule. This constraint explains the contrast between (a) and (b) below, where (a) is considered ungrammatical, unlike (b). The extracted *Wh*-phrase apparently violates the constraint in (a), but not in (b).

(59) (a) * Who did they destroy a book about ?

(b) Who did John write a book about ?

To see why the constraint is not at work for (b), Bach & Horn pointed out the semantic ambiguities in the sentence (60) (a).

(60) (a) John wrote his first five books about Nixon in 1965.

(b) John destroyed his first five books about Nixon.

(c) Who did John write his first five books about ?

The sentence (a) is considered semantically ambiguous between (at least) two readings. In one reading, John's first five books happened to be about Nixon. In the other reading, these books may be John's sixteenth through twentieth books. Bach & Horn attribute this ambiguity to the ambiguous representations of the two VPs. In one representation, PP is immediately dominated by S, whereas in another representation, it is dominated by NP. They also pointed out that the sentence (60) (b) is not ambiguous for a similar reason, as it has only one syntactic representation, where PP is dominated by NP. The fact that (c) is unambiguous is explained with reference to "the principle of interpretation of quantifiers" such that "the scope of the quantifier can only be *books* and not *books about who*." Except for the fact that they use transformational theories to explain the data, there is not much difference between the phenomena captured by the present hypothesis and those abstracted by their constraint.

3.3.4 NPs Containing Possessives

Consider the sentence (61) with a possessive noun modifier.

(61) Every student's picture of most monuments pleased exactly two judges.

The semantic relation between students and pictures depends partially on whether each picture shows "most monuments" or a single monument. There is a further subtlety in this relation. The sentence may actually be "paraphrased" to either (a) or (b) below (cf. Emonds (1985)).

(62) (a) The picture of most monuments of every student's pleased exactly two judges.

(b) A picture of most monuments of every student's pleased exactly two judges.

The translation (a) has a certain uniqueness (or saliency) condition imposed by the definite article *the*. Such a condition is not present in (b), which only requires the existence of each such picture. Carpenter (1994) assumed that the NP *every kid's toy* can mean either the same toy or different toys for kids, implicitly endorsing the translation (a). However, we can not take this as evidence for a genuine semantic ambiguity, since the two meanings (within the translation (a), and similarly within the translation (b)) can not be generalized to show a genuine functional dependency and in particular there is always a semantic entailment property between the two meanings. While we understand this type of further potential ambiguities, we will thus leave it aside from the ongoing discussion.

The fact that the sentence (61) has four readings follows from the argument shown for the sentence (56) earlier. The hypothesis makes a prediction on available readings similarly.

3.3.5 Complex NPs with *Wh*-Relatives

The following sentences contain examples of *Wh*-relative clauses, emphasized in italic. In particular, (d) and (e) show examples of pied-piping.

(63) (a) Two professors *who interviewed every student* wrote a letter.

(b) Two professors *whom every student admired* wrote a letter.

(c) Two professors *whose students admired most deans* wrote several letters.

(d) Two professors interviewed three students *most pictures of whom pleased exactly two judges.*

(e) Two professors *a biography of whom three journalists wrote* interviewed most students.

We have argued earlier that there is a contrast in readings between the sentences (a) and (b), in the sense that while the embedded subject quantifier can not outscope the head quantifier, the embedded object quantifier may not have such a strict "restriction." The readings that are available from the sentence (63) (a) are explained below.

(64) (a) *every student* > *two professors* > *a letter*

For each student, there is a separate letter (about her/him), written by each of the two professors who interviewed her/him.

(b) (*two professors* > *every student*) > *a letter*

There are two professors such that each of whom interviewed every student and each wrote a single letter (about all the students).

(c) *a letter* > *every student* > *two professors*

A single letter was written for all the students jointly by those professors such that each such student was interviewed by two different professors in that group of professors.

(d) *a letter* > (*two professors* > *every student*)

A single letter was (jointly) written by two professors each of whom interviewed every student.

On the other hand, the sentence (63) (b) has only two readings.

(65) (a) (*two professors* > *every student*) > *a letter*

There were two professors such that each professor interviewed all the students and wrote a letter (about them).

(b) *a letter* > (*two professors* > *every student*)

There was a single letter jointly written by two professors such that each professor interviewed all the students.

That the sentence (63) (a) has four readings is predicted by the hypothesis, since the following sentences are grammatical.

(66) (a) Two professors who interviewed, and who liked, every student wrote a letter.

(b) Two professors who interviewed every student, and most teaching assistants who knew every student, wrote a letter.

That the sentence (63) (b) has only two readings, or that it does not allow alternating readings for *two professors* and *every student*, is also predicted by the hypothesis, since the following sentence is ungrammatical and thus the B fragment is not a c-constituent.

(67) *Two professors whom every student, and most teaching assistants whom every student, admired wrote a letter.

This contrast between the two sentences (63) (a) and (b) cannot be explained by theories that simply assume that relative clauses are scope islands. For instance, Rodman (1976) observed that the sentence (68) (a) always has the wide scope *every woman*, with respect to *a fish*. Rodman also attributed the "strangeness of (68) (b)" to the claim that "in a relative clause the element that is relativized always has wider scope than any other element in that relative clause (Rodman, 1976, page 168)." Rodman also cited (c) next to (b), implying that (c) does have an interpretation in which *every corner* outscopes *a bone*, which does not have the strangeness.

(68) (a) John dates every woman who loves a fish.

(b) Guinevere has a bone that is in every corner of the house.

(c) Guinevere has a bone in every corner of the house.

Rodman has consequently proposed to incorporate an appropriate constraint into the rules in his Montagovian system. It appears however that this proposal is odd both theory-internally and theory-externally. First, we know that when an NP is used referentially, its denotation must be computable relatively independent of those of the rest of the NPs (and other structural details) (cf. Fodor and Sag (1982)). Since Montagovian semantics has quantifying-in for *de re* interpretations, one would also expect that theory-internally, it should be able to take the NP *a fish* (or its abstraction) in (a) out to the front to take matrix scope, just as Montague (1974) himself suggested quantifying-in also for purely extensional ambiguities. Constraining the rule (S14) appears to forfeit this general function of quantifying-in. Second, the contrast between (b) and (c) does not explain the accepted convention in English that we can delete the fragment '*that is*' more or less freely without changing the semantics and that it is in fact encouraged to drop it. The "strangeness of (68) (b)" appears to come from the violation of a Gricean maxim, by explicitly using the semantically near-empty '*that is*'.

The following sentences show examples in which the embedded quantifier outscopes the head quantifier.[10]

[10]These examples indicate that it is not necessarily the object NP but a relative-clause-final NP that can outscope the head quantifier.

(69) (a) Two FBI agents visited at least three relatives who have, during the past three years, once lived with every murder victim of the infamous Dr. Lector.

(b) Most businessmen who have been in almost every big city talk fast, but most businessmen who have been in Chicago talk rather slowly.

Incidentally, Hendriks (1993), following Rodman's observation, assumed a similar condition, such as the Complex Noun Phrase Constraint (CNPC in short), to block embedded quantifiers from outscoping the head quantifier. Unlike Rodman, Hendriks notes that a referential NP such as *a producer I know* in the sentence (70) is exempt from this condition, since, following Fodor and Sag (1982), it "shines through a scope island (page 102)."

(70) Mary dates every man who knows a producer I know.

However, the fact that the same system must host not only this kind of exemption for referential NPs but also a variant of the quantifying-in mechanism (originally motivated for referential NP interpretations) appears problematic to the consistency of his general program (cf. Section 4.3.1).

3.3.6 Attitude Verbs

The sentences in (71) are all unambiguous.[11]

(71) (a) Mary thinks that John danced with more than four women.

(b) Mary thinks that exactly three men danced with Susan.

(c) At least two girls think that John danced with Susan.

The sentence (a) has a reading such that there are more than four women such that Mary thinks that John danced with her.[12] The reading of (b) is that there are exactly three men such that Mary thinks that he danced with Susan. The reading of (c) is that at least two girls (independently) think that John danced with Susan.

The following sentences contain two quantifiers each.

[11] In order to consider extensional readings only, we assume in this section that `that` complements describe a situation that has happened, in the sense that the time/world for it is accessible from the present situation and that the time/world is not backward branching, with reference to the possible world semantics.

[12] Other readings are ignored, as usual.

(72) (a) Mary thinks that exactly three men danced with more than four women.

(b) At least two girls think that John danced with more than four women.

(c) At least two girls think that exactly three men danced with Susan.

For the sentence (a) to be semantically ambiguous, the semantic ambiguity would come from the two scope possibilities in which *exactly three men* either outscopes or is outscoped by *more than four women*. The argument holds similarly for (b) and (c).[13] It is not clear however if this observation can be intuitively verified. In this connection, the hypothesis makes an interesting prediction on these sentences. First, it predicts that (a) may or may not be ambiguous, depending on the grammaticality of the sentence (73) (a). Compare it with the `that`-less sentence (b) or the sentence (c).

(73) (a) Mary thinks that exactly three men danced with more than four women and exactly five boys talked to more than three girls.

(b) Mary thinks exactly three men danced with more than four women and exactly five boys talked to more than three girls.

(c) Mary thinks that exactly three men danced with more than four women and that exactly five boys talked to more than three girls.

That is, if the sentence (73) (a) is semantically equivalent to the sentence (c), then the prediction is that the sentence (72) (a) is ambiguous. As for the sentence (72) (b), the hypothesis predicts that it has two readings, since the following sentence is grammatical.

(74) At least two girls think that John danced with, and doubt that Bob (even) talked to, more than four women.

As for the sentence (72) (c), the hypothesis predicts two available readings, since the following sentence is grammatical.

(75) At least two girls think that exactly three men, and at least three boys think that more than two men, danced with Susan.

[13] As for the sentence (72) (b) being ambiguous, Lasnik and Uriagereka (1988) talk about why the sentence (a) below is ambiguous, while (b) is not.

(a) Someone thinks that Mary solved every problem.

(b) Someone thinks that every problem, Mary solved.

According to them, "a quantifier in an embedded clause can, marginally, take matrix scope, as in (a). But if the quantifier has been topicalized, as in (b), its scope is limited to the embedded clause. Incidentally, the present hypothesis (and the proposed theory) exactly predict this difference.

Consider the sentence (76), which contains three quantifiers.

(76) At least two girls think that exactly three men danced with more than four women.

The hypothesis predicts the following readings.

(77) (a) *two girls > three men > four women*

This reading is predicted to be available if the sentence (78) (a) is grammatical.

(b) *two girls > four women > three men*

This reading is predicted to be available when the sentence (78) (a) is grammatical. There is another related reading, with the same scope order, which is predicted to be available since the sentence (78) (b) is grammatical.

(c) *four women > two girls > three men*

This reading is predicted to be available since the sentence (78) (b) is grammatical.

(78) (a) At least two girls think that exactly three men danced with more than four women and (that) exactly five boys talked to more than ten girls.

(b) At least two girls think that exactly three men danced with, but doubt that exactly two boys talked to, more than four women.

3.3.7 Dative Alternation Verbs

The sentence (79) has two 'quantifiers'.

(79) Mary gave every dog a bone.

It is ambiguous, in the sense that the bone each dog received may or may not be the same one. In the former reading, *a bone* outscopes *every dog*, and in the latter, the relation is reversed. The oddness of the former reading is due to the semantics of *gave*, since the act of giving something semantically entails a consequent exclusive ownership. The scope ordering improves with the following sentence.

(80) Mary showed every dog a bone.

The following sentence has three quantifiers.

(81) Every dealer shows most customers at most three cars.

In order to think of how the hypothesis predicts readings for this sentence, consider the following.

(82) (a) Every dealer shows most customers, and every mechanic shows at least five customers, at most three cars.

(b) Every dealer shows most customers at most three cars but most mechanics every car.

(c) Every dealer shows most customers, but gives most mechanics, at most three cars.

The sentence (82) (a) is grammatical, which means that *every dealer shows most customers* is a c-constituent and also that *every dealer* and *most customers* can alternate their relative scope order. As for the relation between the two NP quantifiers and the remaining one, however, the hypothesis does not appear applicable, since there is no phonologically realized fragment between the two NPs to form the A c-constituent. Recall that the A c-constituent works semantically as a function that takes two arguments. The fact that the sentence (82) (b) is grammatical implies that *most customers at most three cars* is a c-constituent. If we can somehow regard it as a sort of complex NP, then the quantifiers inside it are predicted to alternate their scope order with the quantifier *every dealer*. The trouble is that the hypothesis can not be used to predict the relation between *most customers* and *at most three cars*, since, again, there is no phonologically realized element between them. Finally, the sentence (82) (c) is grammatical, which means that the hypothesis predicts two readings, in which *every dealer* and *at most three cars* can alternate their relative scope order. *Most customers* is outscoped by both NPs. While the hypothesis does not appear to be quite helpful for this sentence, the theory to be proposed in Chapter 4 within the CCG framework makes a reasonable theory-internal prediction.

3.3.8 Coordinate Structures

We have seen many examples of coordination in earlier sections. Coordination appears to further constrain the way syntactic fragments are composed to form a grammatical constituent, standard or non-standard.

To study how coordinate structures semantically affect scope readings, consider the following pair of sentences.

(83) (a) Some man shouted and left.

(b) Some man shouted and some man left.

The *obvious* reading of the sentence (a) has the same man for both actions, and the *obvious* reading of the sentence (b) has a different man for each action. These readings support the belief that VP-coordination is distinct from S-coordination. In order to substantiate the belief on semantic grounds, however, we must also show that the sentence (a) can never have a reading in which a different man performed each action. The present hypothesis is not applicable to the sentence (a), however, as the sentence does not have two NPs.

The hypothesis predicts that the sentence (84) (a) has two readings since the fragment *talked to* is a c-constituent, as shown in (b).

(84) (a) Every man talked to at least three women.

(b) Every man talked to and danced with at least three women.

For the same reason, the sentence (b) is predicted to have two readings.

The sentence (84) (b) shows V-coordination, but there are also cases where coordination forces some unconventional (or nonstandard) way of dividing constituent boundaries. For instance, the sentence (a) below has a coordination of nonstandard constituents which are an object-NP-missing sentence, while the sentence (b) has a coordination of VP constituents.

(85) (a) Every girl admired, but most boys detested, one saxophonist.

(b) Every man talked to at least five women and danced with exactly three women.

According to Geach (1970), there are exactly two readings for the sentence (85) (a). These readings are shown below.

(86) (a) *one saxophonist* > (*every girl* & *most boys*)

The same saxophonist was admired by every girl and detested by most boys.

(b) (*every girl* > *one saxophonist*) & (*most boys* > *one saxophonist*)

Every girl admired a possibly different saxophonist, and most boys also detested a possibly different saxophonist.

For a similar reason, the sentence (85) (b) would have exactly two readings. The hypothesis does not apply to these sentences, since we can not isolate two participating NPs from the sentences. Section 5.8 shows how the proposed theory predicts these readings.

The following sentences show further examples.

(87) (a) Some student studied two aspects of, and collected most cases of coordination in, every language.

(b) Exactly two girls think that more than five men danced with, but doubt that more than three boys (even) talked to, more than four women.

Based on these sentences, the hypothesis predicts that the sentence (88) (a) has readings in which *some student* and *every language* have alternating relative scope orders, and that the sentence (88) (b) has readings in which *exactly two girls* and *more than four women* have alternating relative scope orders.

(88) (a) Some student studied two aspects of every language.

(b) Exactly two girls think that more than five men danced with more than four women.

The hypothesis predicts, however, that other scope relations that are possible in the sentences (88) are no longer possible in the sentence (87). For instance, the hypothesis predicts that *two aspects* can no longer outscope *every language* in the sentence (87) (a) due to the coordination. Likewise, the sentence (87) (b) is predicted *not* to have a reading or readings in which *more than five men* outscopes *more than four women* for the same reason.

3.4 CHAPTER SUMMARY

In this chapter, we have presented a novel hypothesis on quantificational readings that are available due to surface structure. This hypothesis explains many contrasts in English readings, especially those that are supposedly arising from subject-object asymmetry. We have stated our assumptions on assessing readings, and considered many core English constructions that allow multiple instances of NPs, including transitive verbs, dative alternation (ditransitive) verbs, attitude verbs that subcategorize for complement `that`-clauses, complex NPs containing prepositional phrases, complex NPs containing possessives, complex NPs containing subject or non-subject *Wh*-relatives (with or without subject and object pied-piping). We have shown that in nearly all the cases, the predictions made by the hypothesis are intuitively correct. There are cases where the hypothesis does not appear to be applicable. This includes sentence with dative alternation verbs or some sentences with coordination, where the two objects have no phonologically realized element in between for the hypothesis to work. The theory to be presented in the following chapters however makes reasonable predictions even on these sentences.

Part II

SCOPE THEORY

Chapter 4

A LEXICAL THEORY OF QUANTIFIER SCOPE

This chapter presents a theory of quantifier scope that incorporates the surface constituency hypothesis.[1] Section 4.1 introduces a version of Combinatory Categorial Grammar framework in which the theory is couched. Section 4.2 motivates two different representations for the quantifier semantics and defines the syntax and semantics of the proposed representation. Section 4.3 reviews traditional theories of quantifier scope.

4.1 COMBINATORY CATEGORIAL GRAMMAR

Categorial Grammars, or CGs, are a class of grammar formalisms, originally proposed by Ajdukiewics (1935) and further developed by Bar-Hillel (1953). The reader is referred to Wood (1993) for a general introduction to CGs. CGs encode syntactic information in a categorial lexicon, where each lexical entry specifies how the corresponding lexeme is to be treated syntactically. The lexicon below shows two sample entries, one for the proper noun *John* and the other for the intransitive verb *slept*. For convenience of exposition, the in-fix operator '`:-`' will be used to relate lexemes and their categories.

(89) (a) `john :- np` (b) `slept :- s\np`

[1] An earlier idea of part of the material in the present chapter, along with some of the material in Chapter 2, appeared in Park (1995).

(a) encodes the fact that `john` is syntactically a noun phrase, or `np`.[2] (b) encodes the fact that `slept` is a syntactic constituent that when combined with another constituent of category `np` on its left results in a constituent of category `s`. Since CG considers a fragment to be a constituent when it can be assigned a single category, we shall use the expressions *a constituent of category* `x` and *a constituent* `x` interchangeably. The directional symbols, '`\`' in (89) and and '`/`' in future examples, have the following intended interpretations in rules of function application.[3] The symbols, `>` and `<`, abbreviate the corresponding rules.

(90) (a) Function application (forward, `>`) (b) Function application (backward, `<`)

$$\frac{X/Y \quad Y}{X}> \qquad\qquad \frac{Y \quad X\backslash Y}{X}<$$

In the rule (90) (a), if the constituent `X/Y` is adjacent to another constituent `Y` on its right, then the argument category `Y` is cancelled out to leave the functor category `X` for the combined constituent.

The sentence *John slept* is thus correctly analyzed by a CG as a constituent `s`.

(91)

$$\frac{\dfrac{\text{John}}{np} \quad \dfrac{\text{slept}}{s\backslash np}}{s}<$$

The derivation `np s\np => s` is achieved by replacing the values `np` and `s\np` with the patterns `Y` and `X\Y`, respectively, in the backward function application rule (90) (b), where the pattern `Y` is *unified* with the value `np`, and likewise the pattern `X` with the value `s`.[4]

We assume that two expressions e_1 and e_2 are be unifiable iff

(a) They are both atomic constants and $e_1 = e_2$;

[2]The category `np` is itself a bundle of features and values, including such features as *gender*, *number*, *case*, etc. A particular feature or features can be emphasized by unfolding the category into a more elaborate one, e.g. `np(Gender)` or `s(Tense)`.

[3]The notation to be used in this thesis is due to Steedman. There is another long standing proposal, by Professor Lambek, to use a *staircase* notation. In this proposal, forward function application is defined as usual, as in `X/Y Y => X`. But backward function application is defined as `Y Y\X => X`. Here, two instances of the category `Y` can cancel each other if one instance is part of a bigger category where it is in the "leaning" side of the directional symbol. The pros and cons of the two proposals have been discussed quite for a while. The present notation is linguistically more helpful, or perspicuous, whereas the Lambek notation is more favored by logicians.

[4]We are implicitly following the Prolog convention of using upper-case letters for variables and lower-case letters for constants.

(b) One of them is a simple variable; or

(c) They are complex expressions $f_1(a_1, a_2, \cdots, a_n)$ and $f_2(b_1, b_2, \cdots, b_n)$ and f_1, a_1 through a_n are unifiable with f_2, b_1 through b_n, respectively. For a first-order term unification, f_1 and f_2 should be atomic constants.

There are a fixed number of *elementary* categories, such as `s`, `np`, and `n`. Categories are defined recursively as the smallest set that contains elementary categories or categories separated by a directional symbol, such as `s/np`. Categories associate to the left. For instance, `s\np/np` is equivalent to `(s\np)/np`. While the primary function of parentheses is to change the default association, complicated categories are usually notated with parentheses for reasons of added clarity. The following shows another syntactic derivation for a sentence with determiners.

(92)
$$
\begin{array}{ccccc}
\text{every} & \text{man} & \text{loves} & \text{some} & \text{woman} \\
\hline
np/n & n & (s\backslash np)/np & np/n & n \\
\multicolumn{2}{c}{\underline{\qquad\qquad}>} & & \multicolumn{2}{c}{\underline{\qquad\qquad}>} \\
\multicolumn{2}{c}{np} & & \multicolumn{2}{c}{np} \\
& & \multicolumn{3}{c}{\underline{\qquad\qquad\qquad\qquad}>} \\
& & \multicolumn{3}{c}{s\backslash np} \\
\multicolumn{5}{c}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad}<} \\
\multicolumn{5}{c}{s}
\end{array}
$$

Combinatory CGs, or CCGs, extend the purely applicative CGs described above to include a limited set of combinators, such as type raising `T`, function composition `B`, function substitution `S`, etc, for the combination of two adjacent linguistically realized (or phonetically non-empty) categories (Steedman, 1987; Steedman, 1997). Rules of type raising and function composition are shown below with their semantics on the right.

(93)

(a) Type Raising (forward, `>T`)

$$\frac{X}{T/(T\backslash X)}{>}T \qquad \frac{A}{\lambda F.F(A)}{>}T$$

(b) Type Raising (backward, `<T`)

$$\frac{X}{T\backslash(T/X)}{<}T \qquad \frac{A}{\lambda F.F(A)}{<}T$$

(c) Function Composition (`>B`)

$$\frac{X/Y \quad Y/Z}{X/Z}{>}B \qquad \frac{F \quad G}{\lambda x.F(G(x))}{>}B$$

(d) Function Composition (`<B`)

$$\frac{Y\backslash Z \quad X\backslash Y}{X\backslash Z}{<}B \qquad \frac{G \quad F}{\lambda x.F(G(x))}{<}B$$

With the combinators `T` and `B`, (92) can have the following derivation, among others.

(94) every man loves some woman

np/n n $(s\backslash np)/np$ np/n n

every man: np/n n $\Rightarrow_{>}$ np; some woman: np/n n $\Rightarrow_{>}$ np

$np \Rightarrow_{>T} s/(s\backslash np)$

$s/(s\backslash np)$ $(s\backslash np)/np$ $\Rightarrow_{>B}$ s/np

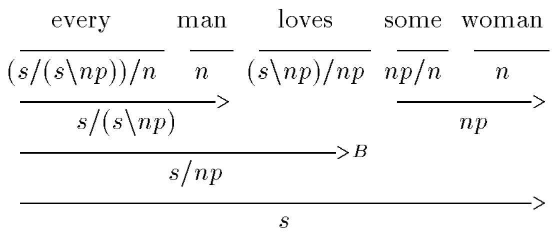
s/np np $\Rightarrow_{<}$ s

In this derivation, the category of *every man* is type raised from `np` to `s/(s\np)`, using the forward type raising rule in (93) (a), where the place-holders `X` and `T` are replaced with `np` and `s`, respectively. The new category `s/(s\np)` is consistent with the syntactic characteristics of English subject NPs, which normally expect a VP constituent `s\np` on their *right* to result in a sentence constituent `s`. In the derivation (94), the fragment *every man loves* is analyzed to be of category `s/np`, or one that expects a constituent `np` on its right to result in a constituent `s`. Other than that the missing NP is expected at a different side, the two fragments `s/np` and `s\np` are perfect constituents.

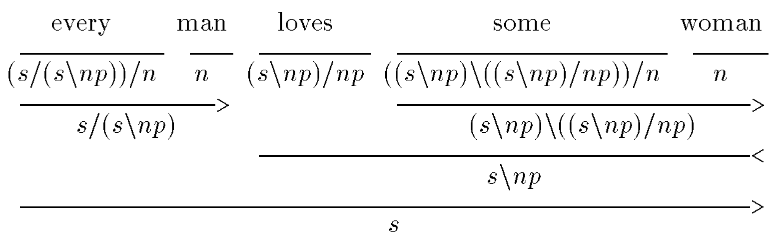
Whereas type raising in derivation (94) is used as a syntactic rule, it can also be defined lexically. Such a lexical definition would involve, among others, assigning proper nouns the category `s/(s\np)` in the lexicon. Steedman (1992) argues why some (forward) type raising could benefit from lexicalization, in order to control overgeneration of categories and to make the derivations decidable. The idea of lexical type raising can be implemented in the present framework by treating English determiners as having essentially ambiguous categories among type-raised alternatives, including the following for *every*, for instance. For convenience of reference, `np` will be called the unraised category for NPs, and the other categories such as `s/(s\np)` or `((s\np)\((s\np)/np))` their type-raised alternatives.

(95) *every*: np/n *every*: $(s/(s\backslash np))/n$ *every*: $(s\backslash(s/np))/n$ *every*: $((s\backslash np)\backslash((s\backslash np)/np))/n$ ...

The derivation in (94) can then be replaced with the following.

(96) 

The last entry of (95) shows a type-raised syntactic category for object NP quantifiers. For instance, *loves some woman* can be derived with *some woman* type raised as follows.

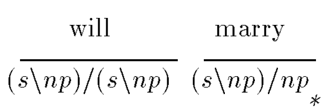
(97) 

The fact that there is an alternative derivation such as (94) or (96) is crucial in dealing with sentences containing coordination or parasitic gap (Steedman, 1990).

(98) (a) Every man loves and will marry some woman.

(b) Every man loves, but most women hate, a dog.

Consider the sentence (a) first. It is reasonable to assign the category `(s\np)/(s\np)` to the auxiliary *will*, which expects an infinitival VP on its right to yield a tensed VP. It would normally combine with a full verb phrase, such as *marry some woman*, of category `s\np`, via function application. However, coordination in (a) forces the fragment *will marry* to be computed first, and the object NP *some woman* supplied afterwards. But the derivation will be incorrectly blocked, as shown below, without the combinator `B`.

(99) 

Also, since coordination forces the fragment *every man loves* to be combined first in the sentence (b), without type raising (and function composition), there is no way of completing the derivation for the fragment without perhaps stipulating empty categories.

4.2 THE DUAL QUANTIFIER REPRESENTATION

A proper characterization of the range of grammatical scopings would depend crucially on how we choose to define the syntax for the semantic representation. The goal here is to make the connection between syntax and semantics as transparent as possible. This section introduces the kind of representations we propose to use for this purpose and shows how to connect syntax and semantics under the present framework.

4.2.1 Quantifier Semantics and Type Raising

We propose the following dual quantifier representation. (a) encodes the wide-scope quantifier semantics, in which the scope information is made explicit, and (b) the degenerate quantifier semantics, in which there is no corresponding scope information. The symbol '*' in front of the degenerate operator in (b) is for a syntactical distinction from the wide-scope operator in (a).[5]

(100) (a) `Quantifier(Mode,Var,Restriction,Body)`

(b) `*Quantifier(Restriction)`

In the present framework, the representation (a) is associated with type-raised NP categories, such as `s/(s\np)`, which always contain the `s` category to be associated with a full sentential semantics that contains the required scope body. The representation (b) is used for unraised NP category, or `np`, which does not have the category `s` in it. This degenerate quantifier representation, since it does not come with a built-in scope information, will always take narrow scope with respect to other syntactically surrounding NP semantics in a scoped logical form. Notice that this degenerate quantifier semantics is completely unrelated to referential NP semantics or specific indefinites whose denotations are determined contextually. Notice also that the degenerate representation (100) (b) is a syntactic sugar for a wide-scope quantifier representation in (a) that is only missing the scope information corresponding to `Body`. Just as the wide-scope quantifier semantics does not commit to the semantics-internal distinction between group vs distributive NP interpretations, the degenerate quantifier semantics does not commit to such a distinction

[5] This use of the symbol '*' is completely unrelated to the annotation on ungrammatical sentences.

either. One can alternatively think of the degenerate quantifier semantics as introducing a kind of DRT-style existential variable, whose denotation is determined according to where it appears in a logical representation.

Incidentally, the representation (a) further generalizes the generalized quantifier format such as (34) shown earlier in that the optional premodifier is put into one of the argument positions, i.e. `Mode`, of an operator that corresponds to a natural language quantifier. This allows the operator completely determined even when the numeral has a missing premodifier and thus is considered potentially ambiguous. In the representation, this ambiguity is carried over in a variable, which may be instantiated by choice later on with a context-dependent information. In the present description of the theory, we will choose to translate a missing premodifier into the symbol `#`. (101) shows an example representation.

(101) (a) More than three men sneezed.

(b) `three(>,M,man(M),sneezed(M))`

There are two ways of associating semantic information with syntactic information under the present framework, as shown below.

(102) (a) `loves :- (s\np)/np : \x,y.loves(x,y)`

(b) `loves :- (s:loves(X,Y)\np:X)/np:Y`

The method (102) (a) relates each (whole) lexical category with an appropriate semantic form, which is usually a higher-order expression. The symbol '\' is a "keyboard" substitute for the lambda operator 'λ'. This representation requires an ability to perform a higher-order term unification, albeit limited. Categorial rules of combination should be revised to accommodate this extension, where the revised function composition rules are shown below.

(103) (a) `X/Y:F   Y:A     => X:F(A)`

(b) `Y:A     X\Y:F   => X:F(A)`

The method (102) (b) relates each elementary category with an appropriate semantic form. The semantic form itself does not involve a higher-order expression, and the representation can be manipulated by a first-order term unification alone.[6] Also, this method allows β-reduction at compile time, a trick known as partial execution (Pereira and Shieber, 1987; Jowsey, 1990; Steedman, 1990; Park, 1992).

These two approaches are logically equivalent, as long as the unification for (a) and (b) above are higher-order. We choose to show an implementation based on the second approach (method (102) (b)) in the dissertation.[7]

With lexical type raising, each quantifier is assigned a number of lexical entries (cf. (95)). Numeral quantifiers that can optionally have a premodifier need further entries. (104) (a) and (b) show two lexical entries, among many others, for a numeral quantifier that is missing a premodifier.

(104) (a) `three :- (s:three(#,X,N,S)/(s:S\np:X))/n:X^N`

(b) `three :- (s:three(#,X,N,S)\(s:S/np:X))/n:X^N`

The derivation (106) simply shows how the premodifier *at least* can be related to the numeral *three* in this framework with an additional entry (105) for *three*, among others.

(105) `three :- ((s:three(M,X,N,S)/(s:S\np:X))/n:X^N)\ql:M`

(106)

$$\begin{array}{ccc}
\text{at} & \text{least} & \text{three} \\
\hline
ql:'{>=}'/qm:least & qm:least & ((s:three(M,X,N,S)/(s:S\backslash np:X))/n:X\hat{}N)\backslash ql:M \\
\hline
\multicolumn{2}{c}{ql:'{>=}' \quad (>)} & \\
\hline
\multicolumn{3}{c}{(s:three(>=,X,N,S)/(s:S\backslash np:X))/n:X\hat{}N \quad (<)}
\end{array}$$

(107) shows how the wide scope subject NP semantics is derived.

(107)

$$\begin{array}{cc}
\text{every} & \text{man} \\
\hline
(s:every(\#,X,N,S)/(s:S\backslash np:X))/n:X\hat{}N & n:X\hat{}man(X) \\
\hline
\multicolumn{2}{c}{s:every(\#,X,man(X),S)/(s:S\backslash np:X) \quad (>)}
\end{array}$$

To explain briefly how the derivation (107) works, the pattern `X^N` is unified with the pattern `X^man(X)`, in which the variable `N` is unified with `man(X)`. This value of `N` is carried over to the other instance of `N` in the pattern `every(#,X,N,S)`, hence the result.

[6] But see below for the degenerate quantifier semantics. The reader is referred to the discussion of (the significance of) first-order unification in Moore (1989) and Park (1992), among others.

[7] The present implementation simulates a restricted higher-order unification, or a second-order term matching, via the univ (`=..`) operator in Prolog.

This process of achieving the result is called partial execution (Pereira and Shieber, 1987; Jowsey, 1990; Steedman, 1990; Park, 1992).

The derivations in (108) and (109) show how the wide and narrow scope interpretations of *some woman* are respectively obtained from the sentence *Every man loves some woman.* Each derivation is split into two separate derivations due to typographical reasons.

(108) (a)

$$\dfrac{\dfrac{\text{every man}}{s:every(\#,X,man(X),S)/(s:S\backslash np:X)} \quad \dfrac{\text{loves}}{(s:lov(X,Y)\backslash np:X)/np:Y}}{s:every(\#,X,man(X),lov(X,Y))/np:Y}>$$

(b)

$$\dfrac{\dfrac{\text{every man loves}}{s:every(\#,X,man(X),lov(X,Y))/np:Y} \quad \dfrac{\text{some woman}}{s:some(\#,Y,wmn(Y),S)\backslash(s:S/np:Y)}}{s:some(\#,Y,wmn(Y),every(\#,X,man(X),lov(X,Y)))}<$$

(109) (a)

$$\dfrac{\dfrac{\text{loves}}{(s:lov(X,Y)\backslash np:X)/np:Y} \quad \dfrac{\text{some woman}}{(s:some(\#,Y,wmn(Y),S)\backslash np:X)\backslash((s:S\backslash np:X)/np:Y)}}{s:some(\#,Y,wmn(Y),lov(X,Y))\backslash np:Y}<$$

(b)

$$\dfrac{\dfrac{\text{every man}}{s:every(\#,X,man(X),S)/(s:S\backslash np:Y)} \quad \dfrac{\text{loves some woman}}{s:some(\#,Y,wmn(Y),lov(X,Y))\backslash np:X}}{s:every(\#,X,man(X),some(\#,Y,wmn(Y),lov(X,Y)))}>$$

In each of the derivations, *loves* works as the constituent A in the hypothesis, while the entire sentence corresponds to the constituent B. The derivations appear to suggest that readings are derivation-dependent. For instance, when *loves* is combined first with *some woman*, it leads to a reading in which *some woman* is outscoped, but when *loves* is combined first with *every man*, it leads to a reading in which the scope ordering is reversed. This prediction is in general true, but the availability of the degenerate quantifier semantics gives a result that may change the apparent derivation-dependency of readings. The next chapter shows further details on other constructions.

4.2.2 The Syntax

This section defines the syntax of the proposed language for semantic representation. We proceed to define logical symbols, parameters, and (well-formed) formulas.

First, logical symbols are defined as follows.

(110) (a) propositional connectives: `&`, `v`

(b) variables: `X`, `Y`, `Z`, `X`n, `Y`n, and `Z`n for a positive integer n

(c) parenthesis: `(`, `)`

(d) logical determiners: `some`, `one`, `two`, $\cdots$, `every`

(e) modifiers: `>`, `>=`, `=`, `<`, `<=`, `#`

(a) shows connectives for conjunction (`&`) and disjunction (`v`). The language does not use sorted variables.

Non-logical symbols, or parameters, are defined as follows.

(111) (a) constant symbols: `john`, `mary`, $\cdots$

(b) unary relation symbols, or predicate symbols: `sleep`, `sneeze`, `man`, `rep`, $\cdots$

(c) binary relation symbols: `see`, `cook`, `of`, $\cdots$

(d) ternary (3-ary) relation symbols: `give`, `show`, $\cdots$

(e) non-logical determiners: `most`, `afew`, $\cdots$

There are no function symbols, so the set of *terms* is just the set of variables and constants. Atomic formulas are defined as follows.

(112) If R is an n-ary relation symbol and t_1, t_2, $\cdots$, t_n terms, then $R(t_1, t_2, \cdots, t_n)$ is an atomic formula.

The set of well-formed formulas (wffs, or formulas) is inductively defined as the minimal set that satisfies the following conditions (113) through (115).

(113) Atomic formulas are wffs.

(114) If D is a determiner, M a modifier, u a variable, and η and ϕ wffs, $D(M, u, \eta, \phi)$ is a wff.

(115) Wffs are closed under the propositional connectives.

For convenience, we call wffs as defined in (113) and (114) atomic wffs and quantified wffs, respectively.

The following shows examples of various wffs, where the line break in (d) is added only for the purpose of presentation. Notice that there are wffs that are not coherent.

(116) (a) `rep(X)`

(b) `three(=,X1,comp(X2),of(X3,X4))`

(c) `rep(X)&three(=,X1,comp(X2),of(X3,X4))`

(d) `two(>=,X,rep(X)&three(=,X1,comp(X2),of(X3,X4)),`
`four(>,X4,samp(X4),see(X,X4)))`

As we can see, (b), (c), and (d) do not show coherent uses of variables, since for example the variable `X1` should have appeared in the wffs `comp(X2)` and `of(X3,X4)` for the quantification to go through non-vacuously. The set of logical forms that are generated from grammatical English sentences in the CCG framework we have described in this chapter is actually a subset of the set of wffs that do not show this kind of vacuous quantification. Nor does it contain free variables. In fact, the (logical) sentences the system generates are not just devoid of vacuous quantification and free variables, as the following example (logical) sentences that the system *would not* generate indicate.

(117) (a) `two(=,X1,man(X1)&rep(john),sleep(X1))`

(b) `two(=,X1,man(X1),sleep(X1)&sleep(john))`

In order to precisely define this subset, or the set of (logical) sentences, we need to first define what it means for a variable x to *occur free* in a wff α. Clauses in (118) define the notion recursively.

(118) (a) x occurs free in an atomic wff α if and only if (iff) x occurs in α.

(b) x occurs free in a quantified wff $D(M, u, \eta, \phi)$ iff (1) x occurs free in either η or ϕ and (2) $x \neq u$.

(c) x occurs free in a wff $\eta\&\phi$ iff x occurs free in either η or ϕ.

(d) x occurs free in a wff $\eta\texttt{v}\phi$ iff x occurs free in either η or ϕ.

A variable x is bound in a wff α if it does not occur free in α. For example, `X1` occurs free in (a) below, but not in (b).

(119) (a) `rep(X1)`

(b) `two(=,X1,man(X1),sleep(X1))`

The conditions in (113) through (115) can be further constrained to syntactically define the logical sentences that the system generates. Clauses in (120) show the first attempt.

(120) (a) Atomic wffs with no variables are sentences.

(b) If D is a determiner, M a modifier, u a variable, and η and ϕ wffs in which exactly one variable u occurs free, $D(M, u, \eta, \phi)$ is a sentence. For determiners that are not normally associated with modifiers, such as `every` or `most`, or for determiners that are missing modifiers, the symbol `#` is used for M.

(c) The sentences are closed under the propositional connectives.

The following shows some example (logical) sentences, according to the conditions in (120). The line break in (d) is again solely for the purpose of presentation.

(121) (a) `rep(john)`

(b) `three(=,X,comp(X),of(john,X))`

(c) `rep(john)&three(=,X,comp(X),of(john,X))`

(d) `two(>=,X1,rep(X1)&three(=,X2,comp(X2),of(X1,X2)),`
`four(>,X3,samp(X3),see(X1,X3)))`

However, we have not still succeeded in excluding the kind of logical sentences in (117). For this purpose, we define the notion of a variable being meaningfully free, or *m-free*, in a wff α.

(122) (a) x occurs m-free in an atomic wff α iff x occurs free in α.

(b) x occurs m-free in a quantified wff α iff x occurs free in α.

(c) x occurs m-free in a wff η&ϕ iff x occurs free in both η and ϕ.

(d) x occurs m-free in a wff ηvϕ iff x occurs free in both η and ϕ.

The conditions in (120) can be revised as follows.

(123) (a) Atomic wffs with no variables are sentences.

(b) If D is a determiner, M a modifier, u a variable, and η and ϕ wffs in which exactly one variable u occurs m-free, $D(M, u, \eta, \phi)$ is a sentence. Again, for determiners that are not normally associated with modifiers, such as `every` or `most`, or for determiners that are missing modifiers, the symbol `#` is used for M.

(c) The sentences are closed under the propositional connectives.

This correctly excludes the sentences (117). For convenience, η and ϕ in (b) above will be called the *restriction* and the *body* (of the sentence), respectively. u is called the quantified variable (of the sentence).

Degenerate NP semantics, such as `*two(X^rep(X))`, are syntactically just terms. To avoid confusion with other terms, we will call them l-terms. Notice that the argument expression, such as `X^rep(X)`, is actually a restricted lambda expression that has a wff, which contains exactly one variable `X` occurring m-free, bound by the lambda operator.

4.2.3 The Semantics

This section defines the semantics of the proposed language of logical forms. The goal is to define the way the truth value of an expression of the language is computed with respect to a certain layout of the (possibly restricted) universe under consideration. This layout, or a *structure*, pertains to the number (and kind) of individuals in that universe and how they are related to each other.

In order to define the truth conditions for a logical sentence σ of the language in a structure $\mathcal{M}$, notated as $\models_{\mathcal{M}} \sigma$, we first need a valuation function s, whose domain and range are the set V of variables and $|\mathcal{M}|$, or the universe of $\mathcal{M}$, respectively, notated as $s : V \rightarrow |\mathcal{M}|$. For instance, $s(\texttt{X1}) \in |\mathcal{M}|$.

Turning to the conditions for the structure $\mathcal{M}$ to satisfy a wff ϕ with the valuation function s, notated as $\models_{\mathcal{M}} \phi[s]$, the domain of s is extended from V to terms and wffs as follows. First, we extend s to $\bar{s}$ for terms T.[8]

(124) (a) For each variable x, $\bar{s}(s) = s(x)$.

(b) For each constant symbol x, $\bar{s}(c) = c^{\mathcal{M}}$.

For atomic wffs, we extend s to $\bar{s}$ as follows, where R is an n-place relation symbol and t_i, for each i, is a (simple) term.

(125) $\models_{\mathcal{M}} R(t_1, t_2, \cdots, t_n)[s]$ iff $\langle \bar{s}(t_1), \cdots, \bar{s}(t_n) \rangle \in R^{\mathcal{M}}$.

For other wffs, s is extended recursively, as shown in (126) through (130).

(126) For atomic wffs, see (125) above.

[8] For simplicity, we assume that constant symbols are rigid designators.

(127) $\models_{\mathcal{M}}$ `every(#,`x, η, ϕ`)` $[s]$ iff

for every d such that $\models_{\mathcal{M}} \eta[s(x|d)]$, we have $\models_{\mathcal{M}} \phi[s(x|d)]$.

The function $s(x|d)$ is exactly like s except that at the variable x it assumes the value d, as defined below:

$$s(x|d)(y) = \begin{cases} s(y) & \text{if } y \neq x \\ d & \text{if } y = x \end{cases}$$

(128) $\models_{\mathcal{M}}$ `one(M,`x, η, ϕ`)` $[s]$ iff

the set S which contains only and every d such that $\models_{\mathcal{M}} \eta$&$\phi[s(x|d)]$ satisfies the following constraint, depending on the value of `M`:

if `M` = `>=`, $|S| \geq 1$ (i.e., non-empty); if `M` = `>`, $|S| > 1$;

if `M` = `<`, $|S| < 1$ (i.e., empty); if `M` = `<=`, $|S| \leq 1$;

if `M` = `=`, $|S| = 1$; if `M` = `#`, $|S| \geq 1$.

Conditions for other numerals can be similarly defined.

(129) $\models_{\mathcal{M}}$ `most(#,`x, η, ϕ`)` $[s]$ iff

the set S, which contains only and every d such that $\models_{\mathcal{M}} \eta[s(x|d)]$, satisfies the following constraint, with a simplifying assumption that more than two-thirds of a set count as *most*:

more than 2/3 of the members d of S is such that $\models_{\mathcal{M}} \phi[s(x|d)]$.

(130) $\models_{\mathcal{M}} \eta$&$\phi[s]$ iff $\models_{\mathcal{M}} \eta[s]$ and $\models_{\mathcal{M}} \phi[s]$.

(f) $\models_{\mathcal{M}} \eta$`v`$\phi[s]$ iff $\models_{\mathcal{M}} \eta[s]$ or $\models_{\mathcal{M}} \phi[s]$.

The valuation function s can also be defined for atomic wffs which contain an l-term. Other atomic wffs that contain an l-term in a different argument position can be defined similarly.[9]

(131) $\models_{\mathcal{M}} R(t_1^*, t_2, \cdots, t_n)[s]$ where t_1^* = `*`q`(X^`α`)` iff $\models_{\mathcal{M}}$ q`(#,X,`α`,`R`(X,`$t_2, \cdots, t_n$`))`$[s]$.

[9]The formulation does not take into account the suggestion made in Section 5.8 regarding the idea that two instances of the same l-term are really pointers to the same representation.

4.3 COMPARISONS TO RELATED WORK

This section reviews traditional accounts of quantifier scope. For convenience of discussion, they are divided into three categories: (1) Quantifying-in and its variants, (2) quantifier raising (QR) and its variants, and (3) scope-neutral logical forms. There is another possible category, which would include computational approaches, such as Schubert and Pelletier (1982), Hobbs and Shieber (1987), Vestre (1991), and so on. Computational accounts are usually concerned with computability and efficiency, but they are also based on variants of semantic theories such as Quantifying-in or QR.

Quantifying-in provides a compositional way of logically lifting the semantics of NPs and QR utilizes a syntactic movement operation for lifting the semantics of NPs. They are closely related to each other, in the sense that they both provide an abstraction for the same NP, letting it logically bind a variable created in place of the original NP. Approaches that use scope-neutral logical forms are primarily motivated for delaying scope-disambiguation for pragmatic purposes, but they also utilize the same kind of logical abstraction for NP semantics.

4.3.1 Quantifying-in and its variants

This section reviews four related approaches to quantifier scope ambiguity, all within the same paradigm which Montague (1974) started out with the rule schemata called *quantifying-in*, originally for *de re* readings but also for wide-scope quantifier semantics. The main goal of this paradigm is to provide a compositional semantics.

4.3.1.1 PTQ Theory

Montague has presented in 1970 a theory of quantification that is later referred to as the theory (or grammar) of PTQ, named after the title "The Proper Treatment of Quantification in Ordinary English (1974)." The paper introduced many ambitious goals, including that of providing a rigorous logical translation of English into a language of semantics. The rigor of translation comes from the compositional property of the translation procedure itself for the model-theoretic interpretation of fragments of English sentences. Although the notion of compositionality has recently been challenged, the preciseness of the translation was original enough to subsequently form a school of thought in the area. The paper is considered theoretically dense, especially due to the treatment of intensionality, and is reviewed in a great detail in Dowty, Wall, and Peters (1981). The focus of this section is on introducing part of the theory for the express purpose of examining the nature of quantifying-in that Montague proposed to address quantifier scope ambiguity and making materials available for the exposition of future developments of the theory.

(132) (a) e and t are two fixed objects.

(b) Categories are e, t, A/B or $A//B$ where both A and B are categories.

(c) Traditional syntactic categories, such as IV or CN, can be regarded as abbreviations of categories, such as t/e or $t//e$. In particular, T is a category of terms, or $t/$IV.

(d) Syntactic rules define the category of each English constituent, from basic expressions, such as *run* or *man*, to sentential expressions.

(133) (a) Types are e, t, $\langle a, b\rangle$, or $\langle s, a\rangle$ where a and b are types. s, for possible worlds, is another fixed object distinct from e and t.

(b) Meaningful expressions are typed expressions of intensional logic, or IL.

(c) A mapping function f from English categories to the types of IL is defined as: $f(e) = e$, $f(t) = t$, and $f(A/B) = f(A//B) = \langle\langle s, f(B)\rangle, f(A)\rangle$.

(d) Translation rules define the mapping from English expressions to meaningful expressions of IL.

Syntactic rules and translation rules are numbered for ease of reference, and among them are S14-S16 and T14-S16, that define rules of quantification. T14 defines quantifying-in, and is utilized to capture *de re* readings, as shown below:

(134) T14: If α and ϕ are expressions of categories T and t, respectively, and translate into α' and ϕ', respectively, then $F_{10,n}(\alpha, \phi)$ (the syntactic combination of the two expressions) translates into $\alpha'(\hat{x}_n \phi')$.

With T14, the sentence (135) (a) would translate into (b), where $\mathbf{seek'}_*$ is a first-order relation between individuals.

(135) (a) John seeks a unicorn.

(b) $\exists x[\mathbf{unicorn'}(x) \wedge \mathbf{seek'}_*(j, x)]$

(b) asserts the existence of a unicorn and the fact that j, or a certain John, is in a "seeking" relation to this unicorn. Compare this to the result below of a non-specific reading, or *de dicto* reading, that does not require T14. (136) asserts the fact that a specific individual named John is in a seeking relation to the property of being a property that some unicorn has.

(136) $\mathbf{seek'}(j, \hat{}\lambda Q \exists x[\mathbf{unicorn'}(x) \wedge Q\{x\}])$

It is clear that T14 generates expressions of IL by lifting the semantics of *a unicorn* out of the semantics of the rest of the sentence. Although this still leaves unanswered the question of how multiple *referential* NPs are ordered, the distinction between *de re* and *de dicto* readings are crucially, and well, made by a selective application of quantifying-in rule schema.

If we turn to the treatment of the translation of sentences containing extensional transitive verbs, the use of T14 becomes questionable. Consider the sentence (137) (a), and its translations into expressions of IL, shown in (b) and (c).

(137) (a) John finds a unicorn.

(b) $\exists x[\mathbf{unicorn'}(x) \wedge \mathbf{find'}_*(j, x)]$

(c) $\mathbf{find'}(j, \hat{}\lambda Q \exists x[\mathbf{unicorn'}(x) \wedge Q\{x\}])$

Since *finds* is extensional, (a) is semantically not ambiguous. The generation of two expressions of IL appears to indicate otherwise. To ensure the soundness of the translation procedure, one could either filter (c) out or make it semantically redundant to (b). Montague chose the latter option, by introducing *meaning postulates.* The relevant meaning postulate is shown below.

(138) $\exists S \forall x \forall \mathcal{P} \Box[\delta(x, \mathcal{P}) \leftrightarrow \mathcal{P}\{\lambda y[S\{x, y\}]\}]$ where δ translates **find**, **lose**, etc.

For the proof that (b) and (c) are equivalent under the meaning postulate (138) the reader is referred to Dowty, Wall, and Peters (1981), pp. 226 – 227.

Although it appears that (137) (b) is the correct translation of (137) (a), we can expect that the use of quantifying-in in the process will be overgenerating. The reason is that whereas quantifying-in is the only way of making syntactically embedded NPs, such as English object NPs in a canonical position, take the matrix scope, those NPs may not necessarily be *referential*. There are two kinds of overgeneration. One is the generation of *ungrammatical* expressions where some variables are left unbound. The other is the generation of grammatical expressions that are *not available*. The former kind is addressed by Keller (1988) and Carpenter (1994), among others, by extending the original theory of PTQ, and by Hobbs and Shieber (1987) in another framework. The latter kind has not been pointed out elsewhere, as far as we are aware of, except indirectly by Fodor and Sag (1982). The present thesis directly addresses, and provides an explanation and a solution for, both kinds.

To address how approaches with quantifying-in rule schema handle sentences with PP complements, suppose that there is a sentence in natural language that has the form "[NP_1 [$prep_2$ [NP_2 [$prep_3$ NP_3]]]] $verb_{trans}$ [NP_4 [$prep_5$ NP_5]]," where all the NP_i's have quantifiers, and all the $prep_i$'s are prepositions that head PP-complements of a noun phrase.[10] Any system that incorporates the quantifying-in rule schema will allow a semantics that has an intercalating quantifier scope such as $NP_3 > NP_5 > NP_2 > NP_4 > NP_1$, among others.[11] The order of discharging assumptions for this particular quantifier scope does not violate the unbound variable constraint, since dependent assumptions are always discharged before independent ones.

4.3.1.2 Quantifier Store

Montague (1974) relied on different syntactic analysis trees for computing multiple interpretations in his PTQ theory. This is due to the fact that *de re* interpretations of NPs are joined to the sentential interpretations at the latest, whereas *de dicto* interpretations of NPs can join the sentential interpretations directly at their original syntactic positions.

[10] The square brackets indicate a particular syntactic analysis.

[11] Hobbs & Shieber gave an example sentence: *Some representative of every department in most companies saw a few samples of each product.* The relevant quantifier ordering is: *most companies* > *each product* > *every department* > *a few samples* > *some representative.*

The following analysis trees show this difference: (a) computes the *de dicto* interpretation, and (b), the *de re* interpretation, of the semantically ambiguous sentence *John seeks a unicorn.*

(139)
```
(a) John seeks a unicorn          (b)      John seeks a unicorn
          /\                                      /\
      John  seek a unicorn               a unicorn   John seeks him0
                 /\                         /\              /\
            seek  a unicorn               a  unicorn    John  seek him0
                      /\                                        /\
                    a  unicorn                              seek  he0
```

In particular, one must make use of a syncategorematic rule schemata, or quantifying-in, for the *de re* interpretation of NPs. This is not a problem by itself, since it is also known that referential NPs require a different treatment from non-referential ones. However, Montague's proposal of utilizing quantifying-in for non-referential (especially quantificational) NP interpretations, such as for the wide scope object reading of *Some woman loves every man* is not desirable, since this implies that a purely semantic ambiguity needs to be captured by a syntactic ambiguity that is not motivated. There is also the potential problem of infinitely applying quantifying-in before any result is achieved, when variables are simply substituted with variables.

Cooper (1975; 1983) was concerned with these problems in Montague's original proposal, though he did not distinguish referential NP interpretations from quantificational NP interpretations. He was also concerned with the efficiency of the resulting parser, and favored instead for a direct definition, or interpretation, of the relation between natural language phrases and meaning representations. In order to provide a mechanism that can let structurally embedded NPs take wide scope (or Cooper's 'wide-scope mechanism'), he proposed to use a kind of semantic storage as a way of storing and retrieving the semantics of structurally embedded NPs. The following quote describes the purpose of the storage in a figurative way (Cooper, 1983).

> If we think of the structural description as a tree and the semantics as working from the bottom of the tree (where the words are) to the top, the storage technique involves putting an NP interpretation on ice for a while until you have interpreted enough of

> the tree to represent the scope you want to give the NP. At that point you may take the NP-interpretation out of storage and quantify it in. (p. 55)

It will take us too far afield into the notational details to discuss further specifics of Cooper's storage mechanism, but the basic idea is to utilize a pair of NP-storage and NP-retrieval interpretation rules to put aside the semantics of an NP as a binding operator into a store that can be taken out of the store to take scope later in the interpretation of higher constituents. Cooper shows how to compute the two interpretations of *A man admires every woman* using intension and interpretation rules (cf. Cooper (1983) p. 63, Exercise III B, Problem 1 (a) with solutions on pp. 205 – 206).

Although Cooper's proposal is closer to the principle of compositional derivation of semantics than Montague's original proposal, there are still several unaddressed problems. The most serious one is an overgeneration of semantic expressions, the kind the present dissertation is concerned with. NP-semantics, once put into a store, can be retrieved at any time later, to take scope over the constituent whose semantics is available at the moment. Since the stored operators do not have any specific order among them, it is possible to have intercalating interpretations, such as the reading (b) for (a) below.

(140) (a) NP_1 of NP_2 is fond of NP_3 of NP_4.

(b) $NP_4 > NP_2 > NP_3 > NP_1$

The other problem of Cooper's proposal is that it may generate ungrammatical semantic expressions, in particular semantic expressions with unbound variables, due to the lack of a suitable structure in the storage mechanism. This requires an additional step of ensuring grammaticality of semantic expressions.

4.3.1.3 Nested Cooper Store

We have seen that Cooper's storage mechanism, or Cooper store, can handle simple quantified NPs. Although Cooper (1983) only talks about complex NPs with a relative clause containing proper nouns, as in *every man who kissed Mary*, it should be straightforward to extend his revised NP-storage and NP-retrieval interpretation rules (p. 89) to accommodate other syntactic structures such as complex NPs with PP modifiers containing quantified NPs. In considering this extension, Keller (1988) noticed a potential problem in Cooper's proposal of using a simple storage mechanism.

Consider the following sentence.

(141) John seeks an agent of a company.

Keller correctly points out that the sentence has three readings. The two readings are *de re* and *de dicto* interpretations of the object complex NP, and the remaining one has a matrix scope *a company* and *de dicto* interpretation of *an agent (of it)*. These readings can be computed by Cooper store without much modification.

There is another reading, however, that is licensed by Cooper store, as Keller observes. Although this reading is not only unavailable but also ungrammatical, it is generated when the interpretations of both *a company* and the whole complex NP are stored and the former gets retrieved before the latter. The resulting semantic expression contains an unbound variable for the *it* part in *an agent (of it)*. One may use a grammaticality constraint to filter this out. Although this would be a working solution, the resulting Cooper store will become less explanatory.

We can get around this problem by ensuring that the stored interpretation of a modifying NP gets retrieved only *after* any stored interpretations of NPs that contain the modifying NP are retrieved. Keller suggested to give a nested structure to Cooper store so as to "make explicit the order in which binding operators may be retrieved (p. 443)." Keller's revised rules are shown below.

(142) (a) (NP-Storage): If α is an NP node, and the sequence $\langle \alpha', \sigma \rangle$ is an interpretation for α, then the sequence $\langle \lambda P.P\{x_i\}, [\langle \alpha', \sigma \rangle]_i \rangle$ for some unique index i is also an interpretation for α.

(b) (S-Retrieval): If α is an S node and the sequence $\langle \phi, \sigma^1, [\langle \beta, \sigma \rangle]_i, \sigma^2 \rangle$ is an interpretation for α, then so is the sequence $\langle \beta(\hat{}\lambda x_i, \phi), \sigma^1 \sigma \sigma^2 \rangle$.

If one decides to store the denotation of *an agent of a company*, the NP-Storage rule first computes the logical form (143) (a) for the complex NP, and stores it into the (nested) Cooper store as shown in (b).

(143) (a) $\langle \mathbf{some'}(\mathbf{agent'}(\hat{}\lambda P.P\{x_o\})), [\langle \mathbf{some'}(\mathbf{company'}) \rangle]_0 \rangle$

(b) $\langle \lambda Q.Q\{x_1\}, [\langle \mathbf{some'}(\mathbf{agent'}(\hat{}\lambda P.P\{x_o\})), [\langle \mathbf{some'}(\mathbf{company'}) \rangle]_0 \rangle]_1 \rangle$

There is consequently no way of generating unbound variables, since the denotation for *a company* cannot be retrieved prior to that for the whole complex NP. Hence this correctly rules out the unwanted readings endorsed by Cooper's original storage mechanism, without relying on the unbound variable constraint.

However, we can still show that this nested Cooper store generates unavailable readings that are associated with impossible functional dependency to human language understanders. This is due to the unbounded nature of the distance between the retrieved denotation for *a company* and the retrieved denotation for *an agent of a company*. For example, this unboundedness results in generating the following (unavailable) scope order (144) (a) for the sentence (b).

(144) (a) most companies > every department > at least two agents (of each of them)

(b) Every department seeks at least two agents of most companies.

4.3.1.4 Compositional Semantics

Pereira (1989) wanted to show that a free variable constraint can be embedded into type checking rules, as shown below. (148) shows quantifying-in rules.

(145) Curry Rules

$$\frac{u : A \quad v : A \rightarrow B}{v(u) : B}[app] \qquad \frac{\begin{array}{c}(x : A)\\ \vdots \\ u : B\end{array}}{\lambda x.u : A \rightarrow B}[abs]$$

(146) Relative Clause Rules

$$\frac{x : trace}{x : e}[trace+] \qquad \frac{\begin{array}{c}(x : trace)\\ r : t\end{array}}{\lambda x.r : e \rightarrow t}[trace-]$$

(147) Bound Anaphora Rules

$$\frac{x : pron}{x : e}[pron+] \qquad \frac{\begin{array}{c}(x : pron) \quad y : B\\ s : A\end{array}}{(\lambda x.s)(y) : A}[pron-]$$

(148) Quantifier Rules

$$\frac{q : (e \rightarrow t) \rightarrow t \quad x : quant(q)}{x : e}[quant+] \qquad \frac{\begin{array}{c}(x : quant(q))\\ s : t\end{array}}{q(\lambda x.s) : t}[quant-]$$

(149) (a) shows that there is only one reading in which *every* takes wide scope, due to the pronoun *his* bound by quantified NP *every man*. By [$pron+$] the semantics of the pronoun *his* is abstracted into a variable. By [$quant+$] the whole object NP is abstracted over. There is only one way to discharge two quantifier abstractions, first object NP and then subject NP, since otherwise the variable for the pronoun will not be under its binder. Likewise, the fact that there is only one reading in (b), in which *every* takes narrow scope is explained in the system.

(149) (a) Every man$_i$ saw a friend of his$_i$.

(b) An author who John has read every book by arrived.

The following derivations show how the rules are used.

(150) *john owns t*

$$\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{}{y : trace}\,[trace]}{y : e}\,[trace+] \quad \dfrac{}{own : e \rightarrow e \rightarrow t}\,[lexical]}{own(y) : e \rightarrow t}\,[app] \quad \dfrac{}{john : e}\,[lexical]}{own(y)(john) : t}\,[app]}{\lambda y.own(y)(john) : e \rightarrow t}\,[trace-]$$

(151) *car that john owns*

$$\dfrac{\dfrac{(150) \quad \dfrac{}{that : (e \rightarrow t) \rightarrow (e \rightarrow t) \rightarrow (e \rightarrow t)}\,[lexical]}{\lambda n.\lambda x.n(x)\&own(x)(john) : (e \rightarrow t) \rightarrow (e \rightarrow t)}\,[app] \quad \dfrac{}{car : e \rightarrow t}\,[lexical]}{\lambda x.car(x)\&own(x)(john) : e \rightarrow t}\,[app]$$

We note that this system suffers from the same kind of problems that we pointed out to earlier systems. This system has an additional problem, as pointed out by Pereira and Pollack (1990), regarding the treatment of the sentences in (152). There are two readings in the sentence (152) (a). Under one reading, *every driver* outscopes *a jet*. This reading can be derived straightforwardly. For the other reading, in which *a jet* appears to outscope *every driver* (but nevertheless it is not the same jet that is being talked about), Pereira and Pollack (1990) assume that the quantifier *a* changes into *every*, and such '*every jet*' outscopes *every driver*. However, as they show, this account generates a reading that is not available for sentences such as (b).

(152) (a) Every driver that controls a jet closes it.

(b) Most drivers that control a jet closes it.

4.3.2 Quantifier Raising and its variants

Quantifier raising relies on a syntactic movement operation for generating available scope readings. In order to control the number of readings it makes available, it should be accompanied with various syntactic constraints. We review those suggestions by May and van Riemsdijk and Williams, in particular. For convenience of reference, May's proposal is called the LF theory and the proposal by van Riemsdijk and Williams the reduced theory.

4.3.2.1 Quantifier Raising

The LF theory is first advanced by May (1977), who explained quantifier scope ambiguity in terms of quantifier raising (QR). QR refers to a class of movement operations in which quantified NPs move from their surface syntactic positions to scope-taking positions. The landing site of a quantified NP is created by a left Chomsky-adjunction, which takes an argument X and its enclosing maximal projection other than $\bar{\text{S}}$ (or CP), such as S (or IP), as in $[_S \ldots\ X \ldots\ ]$, and makes a new expression $[_S\ X\ [_S \ldots\ x \ldots\ ]]$, where x is a variable bound by X.

(153) QR_I: Quantifier Raising is a left Chomsky-adjunction at LF that generates unambiguous LF expressions.

For example, the fact that (154) (a) is semantically ambiguous is explained by LF expressions (154) (b) and (c), which are created by QR I. (b) has wide scope *some*, and (c) has wide scope *every*.

(154) (a) Every man loves some woman.

(b) $[_S$ some woman$_j$ $[_S$ every man$_i$ $[_S$ t$_i$ loves t$_j$]]

(c) $[_S$ every man$_i$ $[_S$ some woman$_j$ $[_S$ t$_i$ loves t$_j$]]

DeCarrico (1983) explained why the maximal projection for QR must include VP. Koopman and Sportiche (1982) also suggested that some sentences have quantified NPs that must be VP adjoined, otherwise problematic to the Bijection Principle. Clark (1992) showed that, assuming that syntactic treatment of VP ellipsis phenomenon is viable, QR applies not only to quantified NPs but also names.[12]

May (1985) makes a revision to QR_I after Kayne proposed the extended ECP. According to the extended ECP, to be discussed shortly, (154) (c) is ruled out at LF, since t_i is not properly governed. This leaves only one LF expression (154) (b) for the semantically ambiguous (154) (a).

(155) QR_{II}: Quantifier Raising is a left Chomsky-adjunction that generates LF expressions subject to the extended ECP (May, 1985).

May suggests that LF expression (154) (b) can receive ambiguous semantic interpretation with his definition of Σ-sequence.

(156) (a) Σ-sequence Ψ: $\forall O_i, O_j \in \Psi$, O_i governs O_j.

(b) Example: { some $woman_j$, every man_i } for (154) (b).

Σ-sequence is interpreted by the following scope principle.

(157) The Scope Principle: Members of Σ-sequences are free to take on any type of relative scope relation.

May noticed several problems with the (extended) ECP, and consequently proposed a second revision to his QR theory, using Pesetsky (1982)'s Path Containment Condition (PCC).

(158) QR_{III}: Quantifier Raising generates LF representations that are filtered by the PCC.

The PCC is defined as follows.

(159) PCC: Intersecting Ā-categorial paths must embed, not overlap (Pesetsky, 1982).

According to the PCC, (160) (b), an LF expression for (160) (a), has intersecting Ā-categorial paths, and the path for t_i is embedded by the path for t_j, as shown in (c). On the other hand, (160) (d) has intersecting Ā-categorial paths, but the path for t_i overlaps the path for t_j, as shown in (e). Hence (d), but not (b), is ruled out. Note that one still needs the Scope Principle to generate two possibilities from (160) (b).

[12]According to the present thesis, names are referential, so they do not participate in scope ordering.

(160) (a) Every man loves some woman.

(b) $[_{S_1}$ some woman$_j$ $[_{S_2}$ every man$_i$ $[_{S_3}$ t$_i$ $[_{VP}$ loves t$_j]]]]$

(c) $t_i - S_3 - S_2 -$ every man$_i$, t_j – VP – $S_3 - S_2 - S_1 -$ some woman$_j$

(d) * $[_{S_1}$ every man$_i$ $[_{S_2}$ some woman$_j$ $[_{S_3}$ t$_i$ $[_{VP}$ loves t$_j]]]]$

(e) $t_i - S_3 - S_2 - S_1 -$ every man$_i$, t_j – VP – $S_3 - S_2 -$ some woman$_j$

Williams (1986) points out problems of the PCC in making wrong predictions. Williams defines Q-Superiority as an alternate condition. The rest of this section introduces Kayne's extended ECP, in order to see why May was forced to revise his original QR.

In order to discuss Kayne's modification of the original ECP, we must first show a proper characterization of the ECP itself. For the purpose of this section, some core characterization of the ECP are shown, even though they are known to be problematic. The ECP has first been proposed by Chomsky (1981).

(161) The Empty Category Principle (ECP) : A trace must be properly governed.

For example, the sentence (162) (a) is correctly ruled out by the ECP, since the trace is not in a governed position. Proper government is required since otherwise the sentences (162) (b), (c) and (d) will all be perfect. The difference between the sentences (b) and (c) on the one hand and the sentence (d) on the other is if the trace is governed by a head. Since the sentence (d) has a trace governed by Agr, not by a head, it can be ruled out if we stipulate that proper government is a lexical government. However, this still does not explain why the sentence (e) is perfect. The sentences (d) and (e) together show *that*-trace paradigm.

(162) (a) * John is crucial t to see this.

(b) Who do you think that John saw t ?

(c) Who do you think John saw t ?

(d) * Who$_i$ do you think that t_i saw John ?

(e) Who$_i$ do you think t_i saw John ?

These considerations motivate the following disjunctive definition of proper government, where lexical and antecedent governments are defined as in (163) (b) and (c). (c) is taken from Lasnik and Saito (1984).

(163) (a) Proper government is either lexical government or antecedent government.

(b) Lexical Government : A head lexically governs its complements.

(c) Antecedent Government : α antecedent-governs β iff α binds β and S$'$ does not intervene α and β (except that the head of S$'$ is accessible).

Lexical government explains (162) (b) and (c). It is not relevant to (162) (d) and (e), since the trace is governed by Agr. Antecedent government explains the two sentences, if we assume that there is only one head position of S', which in the case is either occupied by 'that' or an intermediate trace t_i, as in (164) (a) and (b), respectively.

(164) (a) Who$_i$ do you think [$_{S'}$ that [$_S$ t$_i$ saw John]] ?

(b) Who$_i$ do you think [$_{S'}$ t$_i$ [$_S$ t$_i$ saw John]] ?

The above characterization of the ECP leaves open several issues, including that the intermediate trace in (164) (b) violates the ECP when the sentence is still perfect. Also, it appears that some generalization is missing with the disjunctive definition (cf. Lasnik and Uriagereka (1988)).

Kayne (1981) suggested to use the ECP not only as a S-Structure constraint but also at LF, pointing out that variables at LF are also subject to the same kind of constraints that traces at S-Structure would be.

(165) The ECP, or the extended ECP, applies not only to traces at S-Structure but also to variables at LF.

The extended ECP has been motivated by the following French sentences.

(166) (a) Je n'ai exigé qu'ils arrêtent personne.

(b) * Je n'ai exigé que personne soit arrêté.

(c) [$_S$ personne$_i$ [$_S$ je ne ai exigé [$_{S'}$ que [$_S$ x$_i$ soit arrêté]]]]

(d) J'ai exigé que personne ne soit arrêté.

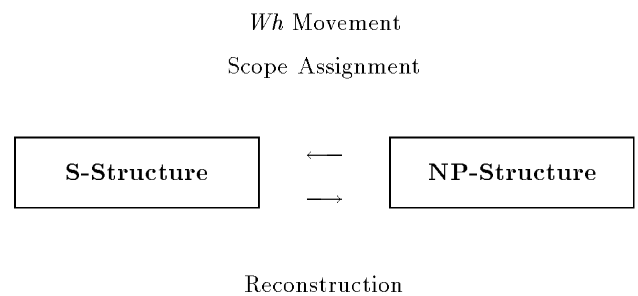
(166) (a) has only one grammatical interpretation, or wide scope *personne*. Kayne explains it by assuming that *personne* moves at LF to take the matrix scope. By comparison, (b) does not have any grammatical interpretation. In order to explain this, Kayne claimed that the ECP works also at LF, since its only logical form (c) has a variable x$_i$ not properly bound (due to *que* between personne$_i$ and x$_i$), preventing antecedent government and thus

violating the ECP. This also explains, Kayne claimed, why (d) is interpreted as having only narrow scope (or clause-bound) *personne*.

4.3.2.2 Quantification and Reconstruction

The reduced theory is proposed by van Riemsdijk and Williams (1981), Williams (1986; 1988). While it still has the ECP, it does not endorse QR. Its general architecture is shown below.

(167)



NP-Structure is about A-positions and their constraints, and S-Structure is about constraints on $\bar{\mathrm{A}}$-positions. NP-Structure is closely related to Function-Argument Structure of the present proposal.

(168) (a) NP-Structure is the level at which A-positions and relations between A-positions are characterized. In particular, Reconstruction, Binding Theory, θ Theory and NP-traces are defined at this level.

(b) S-Structure is the level at which $\bar{\mathrm{A}}$-positions and $\bar{\mathrm{A}}$-binding are characterized. In particular, Logical Interpretation, Quantification and *Wh*-Movement are defined at this level.

Scope Assignment (SA) rules in (169) generate unambiguous representation without moving quantified NPs.

(169) (a) A variable is an A-position with index i.

(b) The quantifier is the determiner in the position of the variable.

(c) The restriction is the N′ in the position of the variable.

(d) The scope is the phrase bearing the index : i.

For example, an S-Structure representation (170) shows how the object quantifier achieves the matrix scope by SA rules.

(170) [John saw [every car]$_i$]$_{S:i}$

In a sense, the use of indexing in the reduced theory is equivalent to the use of movement in LF theory. In this regard, if we just take this indexing aspect, one could argue that this very representation that deals with indices is LF.

* * *

Williams argues that the core data that prompted the Extended ECP can be explained otherwise. For example, although Kayne attributed the semantic ungrammaticality of (171) (a) to a movement of personne$_i$ into an operator position at LF as in (b), one can also explain the data in the reduced theory without involving movement of personne. According to this theory, *ne* and *personne* are base generated together at NP-Structure, as in (c), and as a result of the movement of ne$_i$ at S-Structure, as in (d), t$_i$ is not properly bound. Crucially, t$_i$ is not a variable but a trace, so that the original ECP suffices.

(171) (a) * Je ne demande que personne parte.

(b) LF: Personne$_i$ [Je ne demande que t$_i$ parte]

(c) NP-Structure: Je demande que { ne personne } parte

(d) S-Structure: Je ne$_i$ demande que t$_i$ personne parte

Williams also shows how the other data Kayne used to motivate the extended ECP can be explained otherwise.

4.3.3 Scope-Neutral Logical Forms

Accounts of quantifier scope that use some intermediate, or even final, logical forms that are neutral with respect to scope are discussed in this section. We argue that scope-neutral forms may or may not make it difficult to retrieve the exact range of available readings, and point out that the focus should be on identifying the underlying machinery for a proper characterization of quantifier scope.

4.3.3.1 Typical Elements

Hobbs (1983)'s scope-neutral representation can be manipulated by an inferencing component. His use of scope-neutral representation is always temporary, as in most scope-neutral approaches, ready to be conjoined with additional dependency information whenever it becomes available that will enforce further scoping constraints. His use of scope-neutral representation is thus primarily motivated for convenience of suspending the need to generate too many possible scoped forms at once, not for arguing that it is required for an *a priori* reason. To facilitate this process of adding constraints, he developed the notion of *typical elements*. With typical elements, a predicate such as `is-asleep` always takes an individual of type e, which includes typical elements, but never a full quantified NP of type $(e \rightarrow t) \rightarrow t$. The typical element $\tau(m)$ of a set m of individuals has all the *common* characteristics of each of the individuals in m. The ranges of these typical elements are provided by conjoining their quantifying information, just as further scoping constraints are provided by conjoining dependency information. For example, (172) (a) has the scope-neutral logical form (b).

(172) (a) Most men love several women.

(b) $love(\tau(m),\tau(w))$ & $most(m,m1)$ & $man(\tau(m1))$ & $several(w)$ & $woman(\tau(w))$

To explain what (b) means, it is a conjunction of five conditions: (1) the typical member of a set m of individuals loves the typical member of a set w of individuals, (2) the set m contains "most" members of another set $m1$, (3) the typical member of the set $m1$ has the property "man," (4) the cardinality of the set w is "several," and finally (5) the typical member of the set w has the property "woman." Notice that we do not need an additional reference set, such as $w1$, to indicate the entire set of "woman" individuals, since we do not need to know the size of such a set for the predicate *several* to work. Notice also that we do not need to resolve the relative scope ordering between quantifiers *most* and *several*.

4.3.3.2 DRT-Based Approaches

We discuss two approaches based on Kamp (1981)'s Discourse Representation Theory (or DRT). First, Poesio (1991) describes an extension to the original DRT so that discourse representation structures (DRSs) may not have to be fully disambiguated with respect to quantifier scope. An independent suggestion with a similar goal is made by Reyle (1993; 1995). Reyle's proposal is discussed after Poesio's proposal. We need some DRT-related terminology to discuss Poesio's proposal.

A DRS is comprised of a pair, *markers* and *conditions*. Markers are used to refer to discourse entities, and conditions make explicit what constraints these discourse entities referred to by markers have. For example, the DRS for "*Pedro owns a donkey*" can be graphically represented as follows, where x and y are markers.

(173) A DRS for *Pedro owns a donkey*

x y
pedro(x)
donkey(y)
owns(x,y)

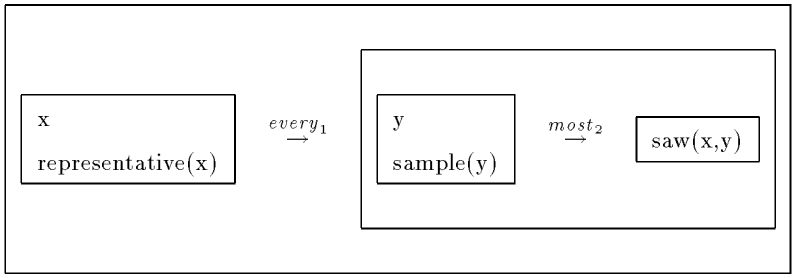
A sentence with subclauses, such as "*If A, B,*" has a DRS in the form of $\boxed{\boxed{D_1} \rightarrow \boxed{D_2}}$, where D_1 and D_2 are DRSs for clauses A and B, respectively. As an example, the DRS for sentence (174) (a) is shown in (b).

(174) (a) *If a farmer owns a donkey, he beats it.*

(b)

x y farmer(x) donkey(y) owns(x,y)	→	u v u = x v = y beats(u,v)

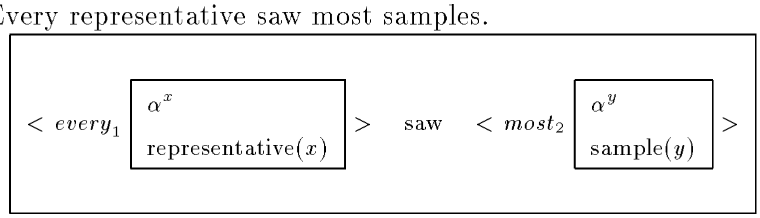
In (b), u is a new marker for the pronoun *he*, and v is for the pronoun *it*. Each marker for pronoun has a set of candidate markers to be able to be equated with, if they are accessible from the current DRS. A marker m is accessible from DRS D if m is introduced in DRS D_1 which either includes D or is an antecedent of D. If one follows a generalized quantifier format for DRT, the sentence "*Every representative saw most samples*" would have (175) as one of its disambiguated DRSs.

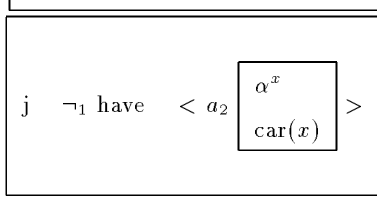
(175) 

Quantifiers are subscripted for the purpose of identification, which is not necessary for this particular case.

Poesio's proposal is to use undisambiguated DRSs (or scope forests) when there is no need or clue for disambiguation, and to reason with those undisambiguated DRSs directly. For this purpose, he introduces several devices. First, fully or partially disambiguated DRSs are represented by ordering constraints among quantifiers with their indices, not by directly rearranging quantifiers. These ordering constraints extend to negation, as in *John doesn't have a car,* for a uniform treatment of ambiguities. (176) (b) and (c) show two example scope forests for (a). In (b) and (c), α^x is a sentence that *introduces* marker x.

(176) (a) Every representative saw most samples.

(b) ϕ  $\{2 < 1\}$

(c) ϕ  $\emptyset$

Second, it is assumed that for every marker x, either *atom(x)* or *group(x)* but not both, where x denotes an element of a complete semi-lattice $\langle E, \vee \rangle$ (Link, 1987) where E is the universe of discourse, so that it contains every sum of the atomic individuals of a set A, $A \subseteq E$. They are used in defining inference rules for disambiguating scope forests, the rules being: (1) for two referential NPs the specific order of them is immaterial (Referential Over Referential), (2) for a quantified NP and a referential NP where *atom(x)* is true the referential NP always takes wide scope (Referential Atom Over Quantifier), and

(3) for a quantified NP and a referential NP where *group(x)* is true the quantifier takes wide scope (Quantifier Over Referential Group). The rest of his formalism shows how to make inference over scope forests for reference disambiguation.

Reyle (1993; 1995) proposes a way of dealing with ambiguities in natural language by extending the standard Discourse Representation Theory (cf. Kamp (1981), Heim (1983)). The goal of his proposal is to approximate human reasoning that apparently works even in the absence of further clues as to the various ambiguities in natural language. Reyle (1993) introduces the language of *under-specified* DRSs, or UDRSs, to represent natural language and describes the proof system for UDRSs to show how deductions are made in this language. Reyle (1995) further extends the language of UDRSs to handle various phenomena related to plural NPs and pronouns. The discussion will focus on the aspect of his theory of UDRS regarding quantifier scope.

Every NP receives a label in the language of UDRSs. Unlike Poesio's labels, Reyle's are more fine-grained, in the sense that other DRS conditions, including possible referents, are also labeled. These labels are used in the specification of ordering constraints. Some ordering constraints can be inferred from those that are explicitly specified in the lexicon. There are three kinds of labeled elements: (a) relations, as in $\mathbf{l}_1\!:\, \Rightarrow (\mathbf{l}_2, \mathbf{l}_3)$, (b) referents, as in $\mathbf{l}_2$:x, and (c) DRS conditions, as in $\mathbf{l}_2$:*book(x)*. The subordination relation $\mathbf{l}_1\!:\, \Rightarrow (\mathbf{l}_2, \mathbf{l}_3)$ is an abbreviation for two separate conditions $\mathbf{l}_2 \leq \mathbf{l}_1$ and $\mathbf{l}_3 \leq \mathbf{l}_1$, which together stipulates that, among others, those elements directly under the label $\mathbf{l}_1$ are not under the scope of those under either $\mathbf{l}_2$ or $\mathbf{l}_3$.

Reyle makes a distinction between quantified NPs and non-specifically used indefinite NPs. (177) shows 'minimality' conditions on the latter.

(177) (a) The discourse referent corresponding to the indefinite NP should be introduced in a DRS that is accessible from a verb that takes the NP as one of its arguments. This sets a minimal position with respect to verb, or $\mathbf{l}_{min_{verb}}$.

(b) If there is a scope-bearing element that must have narrow scope than the indefinite NP, this sets another minimal position, $\mathbf{l}_{min_{syntax}}$.

(c) If there is a subsequent pronoun that has the indefinite NP as its antecedent, then the description for the NP should be accessible from the description for the pronoun, $\mathbf{l}_{min_{anaph}}$.

Indefinite NPs also have a maximality condition such that if indefinites cannot be interpreted as specific, then they cannot take scope outside of the clause they are in. This clause is justified with the sentence (178) below, where the italicized object NP does not have a specific interpretation and hence the maximality condition correctly prevents it from being put directly under the global DRS.

(178) Every student to whom every professor recommends *a certain book which the student has already read* is lucky.

As an example of the conditions, consider the lexical entries for *a book* below.

(179) (a) $\mathbf{l}$:y

(b) $\mathbf{l}$:*book(y)*

(c) $\mathbf{l}_{min_{verb}} \leq \mathbf{l}$

(d) $\mathbf{l}_{min_{anaph}} \leq \mathbf{l}$

(e) $\mathbf{l} \leq \mathbf{l}_{max_{anaph}}$

Although the meaning of an indefinite NP such as *a book* above is position-wise underspecified, its position is bound by its minimal and maximal positions.

Quantified NPs need a different maximality condition so that the scope of proper quantifiers is restricted syntactically to its local domain, by which Reyle assumes the clause in which it occurs. For instance, the fact that (180) does not have a reading in which *every politician* outscopes *some people*, which in turn outscopes *a problem* can be explained by this condition.

(180) Some people believe that a problem about the environment preoccupies every serious politician.

4.3.4 Section Summary

In this section, we have reviewed traditional approaches to quantifier scope, classifying them into three different categories. Quantifying-in accounts are motivated towards providing a compositional way of lifting the semantics of NPs, making them bind variables that are created in place of the original NPs. These include Montague (1974), Cooper (1975; 1983), Keller (1988), and Pereira (1989). Quantifier raising accounts utilize a syntactic movement operation, which is required on independent syntactic grounds, for moving the NPs, thus effectively lifting the semantics of NPs. The traces that are left work as bound variables. These include May (1985), van Riemsdijk and Williams (1981), and Williams (1986; 1988). Approaches with scope neutral logical forms are concerned with generating and disambiguating logical forms at the right time of the processing, but are in general based on variants of semantic theories of quantification, such as Quantifying-in or QR.

Although we have reviewed these approaches in a different category, we should note that they are, including the present approach that utilizes type raising operations for encoding wide-scope semantics and narrow-scope semantics of quantifiers, essentially incorporating the same machinery, that of providing an abstraction for quantifiers, into a certain grammar formalism. We see however that interesting problems (such as generating unavailable readings) arise when this machinery interacts with the rest of the grammar formalism in which it is couched.

4.4 CHAPTER SUMMARY

In this chapter, we have presented a theory of quantifier scope, by connecting syntax and semantics in a Combinatory Categorial Grammar framework. In particular, we have introduced the dual quantifier representation, so that both type-raised and unraised NPs are assigned appropriate semantics. Their syntax and model-theoretic semantics have also been defined. Finally, we have reviewed traditional approaches to quantifier scope, classifying them into three categories: Quantifying-in (and its variants), quantifier raising (and its variants) and approaches that utilize scope-neutral logical forms. The next chapter shows predictions on scope readings that the proposed theory makes with respect to the core English constructions discussed in Chapter 3.

Chapter 5

THEORETICAL PREDICTIONS

This chapter shows how the theory accounts for the core constructions considered in Chapter 3. Each section will show the data, present relevant lexical entries, and describe crucial derivations utilizing the lexical entries. Most of the new ideas are presented in the encoding of lexical entries. For completeness of presentation, this chapter includes portions of materials in the previous chapter.

5.1 TRANSITIVE VERBS

We have shown in Chapter 4 that the theory generates two readings for each of the following sentences.

(181) (a) Every man admires some woman.

(b) Three Frenchmen visited five Russians.

As we have shown earlier, the following lexical entries and combinators are what we need to interpret these sentences.

```
(182) (a) admires :- (s:admires(X,Y)\np:X)/np:Y
      (b) man     :- n:X^man(X)
      (c) every   :- (s:every(#,X,N,S)/(s:S\np:X))/n:X^N
      (d) some    :- (s:some(#,X,N,S)\(s:S/np:X))/n:X^N
      (e) some    :- ((s:some(#,X,N,S)\np:Y)\((s:S\np:Y)/np:X))/n:X^N
```

Since we choose to use lexical type raising, it means that we need separate entries for quantifiers (and nouns in the future examples). The entries (c), (d), and (e) show example entries, (c) for subject type-raised quantifiers, and (d) and (e) for object type-raised quantifiers. The entry (d) will combine, after the noun of category `n`, with the rest of the sentence of category `s/np`, and the entry (e) will combine, after the noun of category `n`, with a transitive verb of category `(s\np)/np`. For the sentences in (181), we do not need to make use of entries for unraised quantifiers, such as the one shown below.

(183) `some :- np:*some(X^N)/n:X^N`

This entry for *some*, along with a similar entry for *every*, will generate the following logical forms for the sentence (181), in addition to the other two logical forms with a wide-scope quantifier semantics.

(184) (a) `every(#,X,man(X),admires(X,*some(Y^woman(Y))))`

(b) `some(#,Y,woman(Y),admires(*every(X^man(X)),Y))`

(c) `admires(*every(X^man(X)),*some(Y^woman(Y)))`

Since the denotation of `*some(Y^woman(Y))` or `*every(X^man(X))` defines a set of individuals (a singleton set for the former, and a set of all men for the latter), the semantics of logical forms such as (a) or (b) above is equivalent to that of logical forms with a wide-scope quantifier semantics only.[1] The logical form (c) does not make it clear which scope order it takes. It is not clear either if this logical form is related to a particular available reading at all. In the present dissertation, we leave unresolved the nature of such logical forms in which all quantifiers are assigned degenerate semantics.

5.2 CONTROL VERBS

The following sentences are ambiguous, and we argued earlier that they have two readings.

[1]It is the problem with the present proposal that it generates logically redundant readings, due to the degenerate quantifier semantics. We believe however that a further study of the nature of degenerate quantifier semantics will localize and dissolve the problem.

(185) (a) Every man seems to admire some woman.

(b) Every man tries to admire some woman.

The theory predicts these readings, since the fragment *seems to admire* is a constituent, as shown in the derivation (187). We assume the following lexical entries for the raising verb *seems* and the equi verb *tries*. The category `s'` is for a sentence without tense so that the category `s'\np` works syntactically as an abstraction for infinitival VPs.[2]

(186) (a) `seems :- (s:seem(S)\np:X)/(s':S\np:X)`

(c) `tries :- (s:try(X,S)\np:X)/(s':S\np:X)`

(b) `to    :- (s':S\np:X)/(s:S\np:X)`

(187)

seems	to	admire
(186)(a)	(186)(c)	$(s : admire(X,Y)\backslash np : X)/np : Y$

$\overline{(s : seem(S)\backslash np : X)/(s : S\backslash np : X)}^{>B}$

$\overline{(s : seem(admire(X,Y))\backslash np : X)/np : Y}^{>B}$

Notice that the semantics of *seems to admire* has the category `(s\np)/np`, or that of a transitive verb. The derivation (188) results in a similar semantics, in which the agent is explicitly shown for the relation `tries`.

(188)

tries	to	admire
(186)(b)	(186)(c)	$(s : admire(X,Y)\backslash np : X)/np : Y$

$\overline{(s : tries(X,S)\backslash np : X)/(s : S\backslash np : X)}^{>B}$

$\overline{(s : tries(X, admire(X,Y))\backslash np : X)/np : Y}^{>B}$

Unlike transitive verbs of the original category `(s\np)/np`, however, the lexical entry for *seems* (or *tries* also for that matter) contains two sentential semantics, so that there may be a third reading in which the entire infinitival VP semantics, including the wide-scope quantifier semantics for the object NP, may be under the scope of the operator `seem`. This reading is particular to the semantics of the raising verb.

[2]This treatment of infinitival VPs is proposed by Steedman, among others.

5.3 COMPLEX NPS WITH PP

The subject NP in the following sentence has two quantifiers.[3]

(189) Two representatives of three companies showed up.

The following category for the preposition *of* encodes that fact that it is the head of a PP.

(190) `of :- (n:X^(N & of(X,Y))\n:X^N)/np:Y`

The grammaticality of the following sentence indicates that the noun category for *representatives*, for instance, should be type raised from `n` to `n/(n\n)` so that *representatives* and *of* will be able to combine (by function composition).[4]

(191) [At least two representatives of] and [more than five applicants of] three companies came to the party.

The category of *three companies*, which is inside the PP, can either take the rest of the complex NP as an argument, or work as an argument of the preposition. The following shows the category for the former.

(192)

$$\begin{array}{llll}
\text{two} & \text{representatives} & \text{of} & \text{three companies} \\
\hline
(s/(s\backslash np))/n & n/(n\backslash n) & (n\backslash n)/np & ((s/(s\backslash np))\backslash((s/(s\backslash np))/np)) \\
 & \multicolumn{2}{c}{\overline{\quad n/np \quad}{}^{>B}} & \\
\multicolumn{3}{c}{\overline{\quad (s/(s\backslash np))/np \quad}{}^{>B}} & \\
\multicolumn{4}{c}{\overline{\quad s/(s\backslash np) \quad}{}^{<}}
\end{array}$$

(193) and (194) below show how the derivation (192) yields an interpretation in which *three companies* outscopes *two representatives.*

(193)

$$\begin{array}{lll}
\text{two} & \text{representatives} & \text{of} \\
\hline
(s:two(\#,X,N,S)/(s:S\backslash np:X))/n:X\hat{}N & n:X\hat{}N/(n:X\hat{}N\backslash n:X\hat{}rep(X)) & \textit{see}\ (190) \\
 & \multicolumn{2}{c}{\overline{\quad n:X\hat{}(rep(X)\&of(X,Y))/np:Y \quad}{}^{>B}} \\
\multicolumn{3}{c}{\overline{\quad (s:two(\#,X,rep(X)\&of(X,Y),S)/(s:S\backslash np:X))/np:Y \quad}{}^{>B}}
\end{array}$$

[3]We will continue to assume that quantifiers do not have referential interpretations.

[4]The square brackets show the intended coordination.

(194) two representatives of three companies

$$\dfrac{\text{see (193)} \quad (s:three(\#,Y,comp(Y),S1)/(s:S\backslash np:X))\backslash((s:S1/(s:S\backslash np:X))/np:Y)}{s:three(\#,Y,comp(Y),two(\#,X,rep(X)\&of(X,Y),S))/(s:S\backslash np:X)}<$$

Notice that this interpretation behaves just like a simple NP. In other words, a further combination of this interpretation with that of the verb *saw* in the sentence (198) (a) below would result in a scope ordering in which both quantifiers in the subject NP are outscoped by the object quantifier. Similarly, a further combination of this interpretation with that of the verb phrase *saw four samples* would yield a scope ordering in which both quantifiers in the subject NP outscope the object quantifier.

The other possibility for the category of *three companies* should allow the derivation of the CCG constituent *of three companies* so that *two representatives* may outscope *three companies*. With the category `(n\n)/np` for the preposition *of*, the immediate solution is to use the base category `np` for *three companies*. We have seen earlier that this category is applicable to a degenerate quantifier. Since other quantifiers can outscope a degenerate quantifier, this gives the result we expect, as shown below, in which *two representatives* outscopes *three companies*. While it is true that in this form *three companies* would not be able to outscope any other quantifiers in the object NP, this is not a problem since it does not participate in any further scope ordering due to its placement inside the restriction, not inside the body.

(195) two representatives of three companies

two: see (193)

representatives: $n:X\hat{}N/(n:X\hat{}N\backslash n:X\hat{}rep(X))$

of: see (190)

three companies: $np:*three(comp)$

$$(n:X\hat{}(N\&of(X,*three(comp)))\backslash n:X\hat{}N) \quad >$$

$$n:X\hat{}(rep(X)\&of(X,*three(comp))) \quad >$$

$$s:two(\#,X,rep(X)\&of(X,*three(comp)),S)/(s:S\backslash np:X) \quad >$$

As an alternative for the latter ordering, we can think of another category for the preposition *of*, as shown below, where it takes a type-raised argument.

(196) `of :- (n:X^(N&S)\n:X^N)/(s:S\(s:of(X,Y)/np:Y))`

The derivation (197) shows how this category is utilized.

(197)

$$\begin{array}{cccc}
\text{two} & \text{representatives} & \text{of} & \text{three companies} \\
\hline
see\ (193) & see\ (195) & see\ (196) & s : three(\#, Y, comp(Y), S)\backslash(s : S/np : Y)
\end{array}$$

$$\underline{\qquad\qquad\qquad\qquad}{>}\quad (n : X\hat{}(N\&three(\#, Y, comp(Y), of(X, Y)))\backslash n : X\hat{}N)$$

$$\underline{\qquad\qquad\qquad\qquad}{>}\quad n : X\hat{}(rep(X)\&three(\#, Y, comp(Y), of(X, Y)))$$

$$\underline{\qquad\qquad\qquad\qquad}{>}\quad s : two(\#, X, rep(X)\&three(\#, Y, comp(Y), of(X, Y))), S)/(s : S\backslash np : X)$$

Both (195) and (197) produce logically equivalent semantic forms, so the new category (196) makes available a more standard logical form at the expense of redundancy of derived semantic forms.

The sentence (198) (a) has four readings and the sentence (b) has five readings.

(198) (a) Two representatives of three companies saw four samples.

(b) Some student studied two aspects of every language.

First, the two derivations, (194) and (195) (or (197)), in conjunction with the derivations of the kinds in (108) and (109), correctly give rise to four different semantic forms or readings for the sentence (198) (a). So the prediction made by the hypothesis is exactly matched by the theoretical prediction.

As for the sentence (198) (b), the question is if the theory correctly predicts (and derives) the reading in which *every language* outscopes *some student*, which in turn outscopes *two aspects*. For this reading, it is crucial that the theory considers the fragment *studied two aspects of* as a constituent. The following shows that it does.

(199)

$$\begin{array}{cccc}
\text{studied} & \text{two} & \text{aspects} & \text{of} \\
\hline
(s : studied(X, Y)\backslash np : X)/np : Y & np : *two(N)/n : N & n : N/(n : N\backslash n : Y\hat{}aspt(Y)) & see\ (190) \\
\hline
\multicolumn{4}{c}{(s : studied(X, *two(Y\hat{}(aspt(Y)\&of(Y, Z))))\backslash np : X)/np : Z}
\end{array}$$

The derived category syntactically works just like that of a transitive verb, except that the semantic association is different. Notice the use of a degenerate category for the quantifier *two*. As the following complete derivation for the reading in question shows, *two aspects* are outscoped by both *some student* and *every language*. The details of the initial lexical entries for them are suppressed for typographical reasons.

(200) some student — studied two aspects of — every language

$s/(s\backslash np)$ $\quad (s : studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z))))\backslash np : X)/np : Z$ $\quad s\backslash(s/np)$

$$\overline{s : some(\#, X, stu(X), studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z)))))/np : Z}^{>B}$$

$$\overline{s : every(\#, Y, lang(Y), some(\#, X, stu(X), studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z))))))}^{<}$$

Notice that the following related sentence does not have a corresponding reading.

(201) (At least) two aspects of every language confused some student.

The successful derivation for such a reading would require the recognition of the following fragment as a constituent. This is syntactically impossible, since the category `n` is completely unexpected by, and thus can not be combined with, the category of a transitive verb *confused*.

(202) of — every — language — confused

$(n\backslash n)/np \quad np/n \quad n \quad (s\backslash np)/np$

$$\overline{n\backslash n}$$

$$\overline{\qquad\qquad\qquad}^{*}$$

5.4 NPS CONTAINING POSSESSIVES

We argued that the following sentence has four readings.[5]

(203) Every student's picture of most monuments pleased exactly two judges.

Notice that the genitive marker "*'s*" must take the whole NP *every student* as an argument, since it is attached to the NP, as in *John's*, and not to the noun only. There are several lexical entries for the marker, depending on the case of the NP and the type-raised status of the NP. The following shows an entry for type-raised subject NPs.[6]

(204) `'s :- ((s:the(#,Y,N,S1)/(s:S\np:Y))/n:Y^N)\(s:S1/(s:own(X,Y)&S\np:X))`

[5] See the discussion in Chapter 3 for other possibilities.

[6] The choice of the operator `the`, corresponding to the definite article in English, is not theory-internal, as the operator `some` would also do, as we have discussed in Chapter 3. The context-dependent decision on an appropriate operator is beyond the scope of the dissertation.

(205)
$$\begin{array}{lll} \text{every} & \text{student} & {}'\text{s} \\ \hline (182)(c) & n : X\hat{}stu(X) & (204) \\ \hline \multicolumn{2}{l}{s : every(\#, X, stu(X), S)/(s : S\backslash np : X)} \; > & \\ \hline \multicolumn{3}{l}{(s : the(\#, Y, N, every(\#, X, stu(X), own(X, Y)\&S))/(s : S\backslash np : Y))/n : Y\hat{}N} \; < \end{array}$$

Notice that the result is the category of type-raised subject quantifiers, or `(s/(s\np))/n`. The following shows one possible derivation for the subject NP in which *most monuments* outscopes the head quantifier, which is, in this case, '*the*'.

(206)
$$\begin{array}{llll} \text{every student }{}'\text{s} & \text{picture} & \text{of} & \text{most monuments} \\ \hline (205) & n : Y\hat{}N/(n : Y\hat{}N\backslash n : Y\hat{}pic(Y)) & (190) & \textit{see } (194) \text{ for a related category} \\ \hline \multicolumn{4}{l}{s : most(\#, Z, mon(Z), the(\#, Y, pic(Y), every(\#, X, stu(X), own(X, Y)\&S)))/(s : S\backslash np : Z)} \end{array}$$

We have shortened the derivation for typographical reasons. Notice again that the result is the category of raised subject NPs. The derivation (206) leaves open the two possibilities for the entire sentence, as in any other sentences with a transitive verb with two NPs. The following shows the final logical form in which *exactly two judges* outscopes the subject NP quantifier. We have shown in Chapter 4 how to process the premodifier *exactly*.

(207) $most(\#, Z, mon(Z), the(\#, Y, pic(Y)\&of(Y, Z), every(\#, X, stu(X), own(X, Y)\&$
$two(=, W, jud(W), pls(Y, W)))))$

5.5 COMPLEX NPS WITH *WH*-RELATIVES

5.5.1 Subject *Wh*-Relatives

Consider the following sentences with subject *Wh*-relatives.

(208) (a) Two professors *who interviewed every student* wrote a letter.

(b) Two professors *whose students admired most deans* wrote several letters.

(c) Two professors interviewed three students *most pictures of whom pleased exactly two judges.*

We have argued that the sentence (208) (a) has a reading in which *every student* outscopes *two professors*, (which in turn outscopes *a letter*). And the hypothesis predicts this as long as *who interviewed* is a c-constituent. In order to see if the theory predicts this as well, let us consider first how the lexical entries corresponding to *Wh*-relatives are defined.

(209) shows the category for a subject *Wh*-relative *who* (Steedman, 1997).

(209) `who :- (n:X^(N&S)\n:X^N)/(s:S\np:X)`

The theory does consider the fragment *who interviewed* as a constituent, as the following two derivations show.

(210)

$$
\begin{array}{ccccc}
\text{two} & \text{professors} & \text{who} & \text{interviewed} & \text{every student} \\
\hline
(s/(s\backslash np))/n & n/(n\backslash n) & (209) & (s: interv(X,Y)\backslash np:X)/np:Y & \textit{see (194) for reference} \\
 & & \multicolumn{2}{c}{\overline{(n:X\hat{}(N\&interv(X,Y))\backslash n:X\hat{}N)/np:Y}\ {>}B} & \\
 & \multicolumn{3}{c}{\overline{n:X\hat{}(prof(X)\&interv(X,Y))/np:Y}\ {>}B} & \\
\multicolumn{4}{c}{\overline{(s:two(\#,X,prof(X)\&interv(X,Y),S)/(s:S\backslash np:X))/np:Y}\ {>}B} & \\
\multicolumn{5}{c}{\overline{s:every(\#,Y,stu(Y),two(\#,X,prof(X)\&interv(X,Y),S))/(s:S\backslash np:X)}\ {<}}
\end{array}
$$

(211)

$$
\begin{array}{ccccc}
\text{two} & \text{professors} & \text{who} & \text{interviewed} & \text{every student} \\
\hline
(s/(s\backslash np))/n & n/(n\backslash n) & (209) & (s: interv(X,Y)\backslash np:X)/np:Y & np:every(stu) \\
 & & \multicolumn{2}{c}{\overline{(n:X\hat{}(N\&interv(X,Y))\backslash n:X\hat{}N)/np:Y}\ {>}B} & \\
 & & \multicolumn{3}{c}{\overline{n:X\hat{}(N\&interv(X,every(stu)))\backslash n:X\hat{}N)}\ {>}} \\
 & \multicolumn{4}{c}{\overline{n:X\hat{}(prof(X)\&interv(X,every(stu)))}\ {>}} \\
\multicolumn{5}{c}{\overline{s:two(\#,X,prof(X)\&interv(X,every(stu)),S)/(s:S\backslash np:X)}\ {<}}
\end{array}
$$

Compare the derivation (211) with (195), both of which utilize a degenerate quantifier semantics. But unlike the derivation (197), which needs an additional category for the preposition *of* as in (196), the corresponding reading for (211) can be derived by combining *interviewed* with *every student* first, where *every student* is of category `(s/np)\((s\np)/np)`.

Since the sentence in which the embedded object quantifier outscopes the head quantifier requires the composition of fragments such as the conjuncts in (212), we can predict that speakers who do not tolerate those readings would not regard the sentence (191) as grammatical. In CCG terms, this level of tolerance is measured by the willingness of type-raising the noun category (from `n` to `n/(n\n)`), or by the willingness of combining common noun with a relative pronoun.

(212) ? [Two professors who interviewed], and [three deans who visited], every student wrote a letter.

Consider now the sentence (208) (b). As with normal readings, one can think of several relations between professors and students that participate in the readings that are available from the sentence. In the following formulation of the lexical item *whose*, we assume that all the available readings involve a relation in which for each such professor, *every* student of hers admired deans.[7] This decision is arbitrary, as far as the thesis of the dissertation is concerned, and not theory-internally motivated.

(213) `whose :- ((n:Z^(N&every(#,X,N1&of(X,Z),S))\n:Z^N)/(s:S\np:X))/n:X^N1`

The fragment *whose students admired* in the sentence (208) is processed as follows.

(214)

whose	students	admired
(213)	$n : X\hat{\ } stu(X)$	$(s\backslash np)/np$

$$\frac{}{(n : Z\hat{\ }(N\&every(\#, X, stu(X)\&of(X, Z), S))\backslash n : Z\hat{\ }N)/(s : S\backslash np : X)}>$$

$$\frac{}{(n : Z\hat{\ }(N\&every(\#, X, stu(X)\&of(X, Z), adm(X, Y)))\backslash n : Z\hat{\ }N))/np : Y}>B$$

Consider the pied-piping sentence (208) (c). Following Szabolcsi (1989), Morrill (1988), and Steedman (1997), we need to assume extra categories for *whom*, so that the fragment *every picture of whom* may work as a normal subject *Wh*-relative. This is done by raising the type of *whom*, as shown below. Notice that this category takes as one of the arguments a type-raised category, `s/(s\np)`, instead of the unraised category `np`, as in `((n\n)/(s\np))\(np/np)` (Steedman, 1997). Although the difference is that the category (215) makes use of a wide-scope semantics for the embedded subject quantifier, such as *every*, whereas Steedman's suggestion would requires a degenerate semantics for it in the present theory, they are semantically equivalent.[8]

(215) `whom :- ((n:Z^(N&S1)\n:Z^N)/(s:S\np:X))\((s:S1/(s:S\np:X))/np:Z)`

[7]For a more appropriate semantic translation, we need a mapping function that converts one-place predicate, such as `stu(X)`, into two-place predicates, such as `stu(X,Z)`. Such a two-place predicate will replace the conjoined restrictions, `N1&of(X,Z)`, in the formulation. The present use of a first-order term unification does not make this option available. This problem is in fact manifested in many places, such as using the expression `rep(X)&of(X,Y)` instead of the more appropriate `rep(X,Y)` in the 'representative' sentence.

[8]We should note that Steedman's use of an unraised NP category is motivated to minimize the introduction of new categories. The use of a type-raised NP category for this purpose would be equally acceptable in his general proposal.

(216) every picture of whom

$$\frac{\text{every}}{(s : every(\#,X,N,S)/(s : S\backslash np : X))/n : X\hat{\ }N} \quad \frac{\text{picture}}{n : X\hat{\ }N/(n : X\hat{\ }N\backslash n : X\hat{\ }pic(X))} \quad \frac{\text{of}}{(190)} \quad \frac{\text{whom}}{(215)}$$

$$\frac{n : X\hat{\ }N/(n : X\hat{\ }N\backslash n : X\hat{\ }pic(X)) \quad (190)}{n : X\hat{\ }(pic(X)\&of(X,Z))/np : Z}>B$$

$$\frac{}{(s : every(\#,X,pic(X)\&of(X,Z),S)/(s : S\backslash np : X))/np : Z}>B$$

$$\frac{}{(n : Z\hat{\ }(N\&every(\#,X,pic(X)\&of(X,Z),S))\backslash n : Z\hat{\ }N)/(s : S\backslash np : X)}<$$

(217) every picture of whom pleased

$$\frac{\text{every picture of whom}}{(216)} \quad \frac{\text{pleased}}{(s : plsd(X,Y)\backslash np : X)/np : Y}$$

$$\frac{}{(n : Z\hat{\ }(N\&every(\#,X,pic(X)\&of(X,Z),plsd(X,Y)))\backslash n : Z\hat{\ }N)/np : Y}>B$$

5.5.2 Non-Subject *Wh*-Relatives

The following sentences contain non-subject *Wh*-relatives.

(218) (a) Two professors *whom every student admired* wrote a letter.

(b) Two professors *whose students most janitors liked* wrote a letter.

(c) Two professors *a biography of whom three journalists wrote* interviewed most students.

The lexical entry (219) shows the category for a subject *Wh*-relative *who(m)* (Steedman, 1997). The category expects an argument of category `s/np`, which is a sentence missing an object NP.

(219) `who(m)  :- (n:X^(N&S)\n:X^N)/(s:S/np:X)`

The surface constituency hypothesis predicts that the sentence (218), unlike the sentence (208), does not have a reading or readings in which the embedded quantifier outscopes the head quantifier. We have shown that the hypothesis predicts this without invoking a constraint, such as the Complex Noun Phrase Constraint and the like. Consider how the present theory predicts this as well.

First, the relative pronoun *whom* cannot be combined directly with the embedded subject NP, since the following derivation is impossible. The derivation is impossible even with unraised embedded subject NP categories.

(220) whom every student

$$\frac{\frac{\text{whom}}{(n : X\hat{\ }(N\&S)\backslash n : X\hat{\ }N)/(s : S/np : X)} \quad \frac{\text{every student}}{s : every(\#,Y,stu(Y),S)/(s : S\backslash np : Y)}}{}*$$

Ignoring the left-hand part of the relative pronoun *whom* for the moment, the only case in which the derivation is successful is when *whom* combines with the entire embedded clause, or *every student admired.* The following shows the derivation.

(221) whom — every student — admired

$$\frac{\text{whom}}{(219)} \quad \frac{\text{every student}}{s : every(\#, Y, stu(Y), S)/(s : S\backslash np : Y)} \quad \frac{\text{admired}}{(s : admired(Y, X)\backslash np : Y)/np : X}$$

$$\xrightarrow{>B} s : every(\#, Y, stu(Y), admired(Y, X))/np : X$$

$$\xrightarrow{>} n : X\hat{\ }(N\&every(\#, Y, stu(Y), admired(Y, X)))\backslash n : X\hat{\ }N$$

Notice that the combination of *every student* and *admired* forces the operator *every* to take the narrow scope with respect to the remaining quantifiers, including the head quantifier, as shown below.

(222) two — professors — whom every student admired

$$\frac{\text{two}}{(s/(s\backslash np))/n} \quad \frac{\text{professors}}{n/(n\backslash n)} \quad \frac{\text{whom every student admired}}{n : X\hat{\ }(N\&every(\#, Y, stu(Y), admired(Y, X)))\backslash n : X\hat{\ }N}$$

$$\xrightarrow{>} n : X\hat{\ }(prof(X)\&every(\#, Y, stu(Y), admired(Y, X)))$$

$$\xrightarrow{>} s : two(\#, X, prof(X)\&every(\#, Y, stu(Y), admireddo(Y, X)), S)/(s : S\backslash np : X)$$

When the result combines with the rest of the sentence, it will give rise to only two readings. Notice that the result does not change even if we invoke the degenerate semantics for the head quantifier, as shown below.

(223) two — professors — whom every student admired

$$\frac{\text{two}}{np : *two(X\hat{\ }N)/n : X\hat{\ }N} \quad \frac{\text{professors}}{n/(n\backslash n)} \quad \frac{\text{whom every student admired}}{n : X\hat{\ }(N\&every(\#, Y, stu(Y), admired(Y, X)))\backslash n : X\hat{\ }N}$$

$$\xrightarrow{>} n : X\hat{\ }(prof(X)\&every(\#, Y, stu(Y), admired(Y, X)))$$

$$\xrightarrow{>} s : *two(X\hat{\ }(prof(X)\&every(\#, Y, stu(Y), admired(Y, X))))$$

Notice that the quantifier *every* is inside the degenerate quantifier **two.* Thus the theory never generates logical forms in which the embedded subject quantifier outscopes the head quantifier.

As for the sentence (218) (b), the lexical entry of *whose* is shown below.

(224)
```
whose :- ((n:Z^(N&every(#,X,N1&of(X,Z),S))\n:Z^N)/(s:S/np:X))/n:X^N1
```

The corresponding derivation for the sentence (218) (b) is similarly done.

Finally, consider the object pied-piping sentence (218) (c). The following entry shows the category for *whom.*

(225) `whom :- ((n:Z^(N&S1)\n:Z^N)/(s:S/np:X))\((s:S1/(s:S\np:X))/np:Z)`

Again, the derivations are similarly done and will not be shown here.

5.6 ATTITUDE VERBS

Consider the following sentence with the attitude verb *think*.

(226) (At least) two girls think that (exactly) three men danced with (more than) four women.

In order to minimize the possibly superfluous effect of semantic details on scope readings, we will assume the following simplified category for *think*, the semantic form of which takes two arguments. The elementary category `s''` is for `that` complements.

(227) (a) `think :- (s:think(X,S)\np:X)/s'':S`

(b) `that  :- s'':that(S)/s:S`

The theory predicts three readings from the sentence (226). These have the following scope orders. What is interesting is that the matrix subject quantifier always outscopes the embedded subject quantifier while the embedded object quantifier is relatively free. This fixed ordering does not change even when the matrix subject quantifier is assigned a degenerate semantics.

(228) (a) *two girls > three men > four women*

(b) *two girls > four women > three men*

(c) *four women > two girls > three men*

The reading (228) (a) can be derived if the embedded subject quantifier is assigned a wide-scope semantics and *danced with* is combined *four women*. The following shows one of the derivations for this reading.

(229)

two girls	think	that	three men	danced with	four women
$s/(s\backslash np)$	$(s\backslash np)/s''$	s''/s	$s/(s\backslash np)$	$(s\backslash np)/np$	$(s\backslash np)\backslash((s\backslash np)/np)$

$$s : four(\#, Z, wmn(Z), dan(Y, Z))/np : Z \quad <$$

$$s : two(\#, X, girl(X), think(X, that(three(\#, Y, man(Y), four(\#, Z, wmn(Z), dan(Y, Z))))))$$

The reading (b) can be derived by combining *three men* and *danced with* first and then combining it with *four women*.

(230)

$$
\begin{array}{cccccc}
\text{two girls} & \text{think} & \text{that} & \text{three men} & \text{danced with} & \text{four women} \\
s/(s\backslash np) & (s\backslash np)/s'' & s''/s & s/(s\backslash np) & (s\backslash np)/np & s\backslash(s/np)
\end{array}
$$

$$s : three(\#, Y, man(Y), dan(Y, Z))/np : Z \quad >B$$

$$s : four(\#, Z, wmn(Z), three(\#, Y, man(Y), dan(Y, Z))) \quad <$$

$$s : two(\#, X, girl(X), think(X, that(four(\#, Z, wmn(Z), three(\#, Y, man(Y), dan(Y, Z))))))$$

Finally, the reading (c) can be derived by combining *four women* with the rest of the sentence.

(231)

$$
\begin{array}{cccccc}
\text{two girls} & \text{think} & \text{that} & \text{three men} & \text{danced with} & \text{four women} \\
s/(s\backslash np) & (s\backslash np)/s'' & s''/s & s/(s\backslash np) & (s\backslash np)/np & s\backslash(s/np)
\end{array}
$$

$$s : three(\#, Y, man(Y), dan(Y, Z))/np : Z \quad >B$$

$$s : two(\#, X, girl(X), think(X, that(three(\#, Y, man(Y), dan(Y, Z)))))/np : Z$$

$$s : four(\#, Z, wmn(Z), two(\#, X, girl(X), think(X, that(three(\#, Y, man(Y), dan(Y, Z)))))) \quad <$$

As discussed in Section 5.2 regarding the third reading from the raising sentence, this sentence also allows a fourth reading, in which (a) the wide-scope semantics of *three men* is under the scope of the operator `think`, (b) the wide-scope semantics of *four women* is outside of it, and (c) *four women* is outscoped by *two girls*. Compare this with the reading (228) (b). This is also due to the particular semantics of the verb *think*.

5.7 DATIVE ALTERNATION VERBS

The following sentence has three quantifiers.

(232) Every dealer shows most customers (at most) three cars.

We have noted earlier that the SC hypothesis does not apply to this sentence, since there is no phonologically realized element between *most customers* and *three cars*. Let us examine what the present theory predicts. First, we assume the following standard lexical entry for the ditransitive verb *shows*.

(233) `shows :- ((s:show(X,Y,Z)\np:X)/np:Z)/np:Y`

The theory predicts that the sentence (232) has five readings, as shown below. Notice that *three cars* always outscopes *most customers* (shown in readings (a), (b), and (c)), unless the NP *three cars* is a degenerate quantifier (shown in readings (d) and (e)).

(234) (a) *every dealer* > *three cars* > *most customers*

(b) *three cars* > *every dealer* > *most customers*

(c) *three cars* > *most customers* > *every dealer*

(d) *every dealer* > *most customers* > *three cars*

(e) *most customers* > *every dealer* > *three cars*

The reading (a) is derived when the semantics of the VP is retrieved first. The following shows one of the possible derivations.

(235)

every dealer	shows	most customers	three cars
$s/(s\backslash np)$	$((s\backslash np)/np)/np$	$((s\backslash np)/np)\backslash(((s\backslash np)/np)/np)$	$(s\backslash np)\backslash((s\backslash np)/np)$

$$\text{shows most customers} \;\Rightarrow_{<}\; (s: most(\#,Y,cst(Y),show(X,Y,Z))\backslash np : X)/np : Z$$

$$\text{shows most customers three cars} \;\Rightarrow_{<}\; s: three(\#,Z,car(Z),most(\#,Y,cst(Y),show(X,Y,Z)))\backslash np : X$$

$$\text{every dealer} \ldots \;\Rightarrow_{>}\; s: every(\#,X,dlr(X),three(\#,Z,car(Z),most(\#,Y,cst(Y),show(X,Y,Z))))$$

There is another way of deriving the semantics of the VP, by combining the two NPs *most customers* and *three cars* first. It may not be obvious at first how the two NPs combine. The standard approach is to think of abstract categories, such as `T` or `T'`, and trying to instantiate them with concrete categories.[9] For instance, consider the fragment below. Starting back from the result, it is clear that the result should be the category `s\np`, since the fragment is a VP.

(236)

shows	most customers	three cars
$((s\backslash np)/np)/np$	$(T/np)\backslash(T'/np)$	$T\backslash(T/np)$

$$\text{most customers three cars} \;\Rightarrow_{<B}\; T\backslash(T'/np)$$

$$\text{shows most customers three cars} \;\Rightarrow_{<}\; s\backslash np$$

In order to have this category, the fragment *most customers three cars* must be a category that takes the category of a ditransitive verb as an argument. Hence the backward looking category `T\(T'/np)`. The category `T'/np` should in fact be that of a ditransitive verb,

[9]This is in order to trace the derivation backwards (or upwards). A more standard way is to go forward (or downwards), by type-raised categories, instantiating abstract categories with concrete categories as needed.

and the category `T`, the final category, or `s\np`. The NP *most customers* can not have a forward looking category, since the only way for it to have such a category and at the same time yield the category `T\(T'/np)` with another NP that follows is to have a category `(T\(T'/np))/T''`, where `T''` is presumably the category of *three cars*. We know however that this is not possible, since the legitimate type raised NP category is of the order-preserving form `T/(T\np)` or `T\(T/np)` (Steedman, 1990). This leaves only the choice shown above, which utilizes a backward function composition rule. Both of the categories for *most customers* and *three cars* are legitimate. The following derivation shows concrete categories.

(237)

$$
\begin{array}{llll}
\text{every dealer} & \text{shows} & \text{most customers} & \text{three cars} \\
s/(s\backslash np) & ((s\backslash np)/np)/np & ((s\backslash np)/np)\backslash(((s\backslash np)/np)/np) & (s\backslash np)\backslash((s\backslash np)/np) \\
 & & \multicolumn{2}{l}{(s\backslash np)\backslash(((s\backslash np)/np)/np) \quad {<}B} \\
 & \multicolumn{3}{l}{s : three(\#, Z, car(Z), most(\#, Y, cst(Y), show(X, Y, Z)))\backslash np : X \quad {<}} \\
\multicolumn{4}{l}{s : every(\#, X, dlr(X), three(\#, Z, car(Z), most(\#, Y, cst(Y), show(X, Y, Z))))\quad {>}}
\end{array}
$$

The reading (b) is derived when *three cars* is combined with the rest of the sentence.

(238)

$$
\begin{array}{llll}
\text{every dealer} & \text{shows} & \text{most customers} & \text{three cars} \\
s/(s\backslash np) & ((s\backslash np)/np)/np & ((s\backslash np)/np)\backslash(((s\backslash np)/np)/np) & s\backslash(s/np) \\
 & \multicolumn{2}{l}{(s : most(\#, Y, cst(Y), show(X, Y, Z))\backslash np : X)/np : Z \quad {<}} & \\
\multicolumn{3}{l}{s : every(\#, X, dlr(X), most(\#, Y, cst(Y), show(X, Y, Z)))/np : Z \quad {>}B} & \\
\multicolumn{4}{l}{s : three(\#, Z, car(Z), every(\#, X, dlr(X), most(\#, Y, cst(Y), show(X, Y, Z)))) \quad {<}}
\end{array}
$$

The reading (c) is derived when *every dealer* and *shows* are combined, or when *every dealer* has a degenerate semantics. The following derivation shows the former.

(239)

$$
\begin{array}{llll}
\text{every dealer} & \text{shows} & \text{most customers} & \text{three cars} \\
s/(s\backslash np) & ((s/np)/np)/np & (s/np)\backslash((s/np)/np) & s\backslash(s/np) \\
\multicolumn{2}{l}{(s : every(\#, X, dlr(X), show(X, Y, Z))/np : Z)/np : Y \quad {>}B} & & \\
\multicolumn{3}{l}{s : most(\#, Y, cst(Y), every(\#, X, dlr(X), show(X, Y, Z)))/np : Z \quad {<}} & \\
\multicolumn{4}{l}{s : three(\#, Z, car(Z), most(\#, Y, cst(Y), every(\#, X, dlr(X), show(X, Y, Z)))) \quad {<}}
\end{array}
$$

The reading (d) is derived when *shows most customers* is first combined, and only *three cars* is assigned a degenerate quantifier semantics. The reading (e) is derived when *every dealer shows* is first combined, and only *three cars* is assigned a degenerate quantifier semantics. We omit the relevant derivations.

The reason for the fixed order between *most customers* and *three cars* in readings, unless the NP *most customers* is assigned a degenerate quantifier semantics, is that the indirect object NP *most customers* must always be combined with the verb, before the new fragment with the verb is combined with the direct object NP *three cars*. So it is impossible in the present theory to give rise to wide scope *most customers* when the two object NPs *most customers* and *three cars* are coordinated.

5.8 COORDINATE STRUCTURES

The earlier sections have shown many examples where coordination may further restrict scope possibilities by forcing a particular way of combining fragments. This section will consider some of the sentences with an explicit coordination. First, in the present framework with a first-order term unification, we need separate lexical entries for conjunction item '*and*' and '*but*' depending on the categories of the conjuncts. The following shows some examples.

(240) (a) Some man shouted and left.

(b) Every man admired and courted at least three women.

(c) Every girl admired, but most boys detested, one saxophonist.

(d) Some student studied two aspects of, and collected most cases of coordination in, every language.

(e) Exactly two girls think that more than five men danced with, but doubt that more than three boys (even) talked to, more than four women.

The lexical entries for the sentences in (240) can be defined as follows.[10]

[10] Notice the use of the same variables `X` (and `Y`) for both of the conjuncts. Other lexical entries can be similarly defined. These lexical entries generate strange parses when combined with the backward composition rule, as discussed in Chapter 6. One way of controlling such strange parses is to assume a syntactic rule for coordination such as `X X' => X''`, where the categories `X`, `X'`, and `X''` are syntactically identical (Steedman, 1990; Steedman, 1997).

(241) (a) `and :- ((s:S1&S2\np:X)\(s:S1\np:X))/(s:S2\np:X)`

(b) `and :- (((s:S1&S2\np:X)/np:Y)\((s:S1\np:X)/np:Y))/((s:S2\np:X)/np:Y)`

(c) `and :- ((s:S1&S2/np:X)\(s:S1/np:X))/(s:S2/np:X)`

(d) `and :- (((s:S1&S2\np:X)/(n:Z^N1\n:Z^N))\((s:S1\np:X)/(n:Z^N1\n:Z^N)))/`

`((s:S2\np:X)/(n:Z^N1\n:Z^N))`

The category (241) (b), which is for the coordination of transitive verbs, works for both of the sentences (240) (b) and (e).

To see how readings are derived from sentences with coordinate structures, consider the following derivation.

(242)

$$\begin{array}{cccc}
\text{someman} & \text{shouted} & \text{and} & \text{left} \\
\hline
s/(s\backslash np) & s\backslash np & (241)\ (a) & s\backslash np \\
\hline
 & \multicolumn{3}{c}{s : shout(X)\&left(X)\backslash np : X} \\
\hline
\multicolumn{4}{c}{s : some(\#, X, man(X), shout(X)\&left(X))} \ >
\end{array}$$

The result is the wide-scope reading of *some man*. Notice that even though the lexical entry (241) (b) associates the elementary category `s` with sentential coordination, or `S1&S2`, this does not necessarily generate an S-coordination (or conjunction reduction) reading, since neither `S1` nor `S2` is an abstraction for the whole sentential semantics including quantifiers.

The presence of a degenerate quantifier semantics however gives rise to another reading, as shown below.

(243)

$$\begin{array}{cccc}
\text{some man} & \text{shouted} & \text{and} & \text{left} \\
\hline
np : *some(X\hat{}\,man(X)) & s\backslash np & (241)\ (a) & s\backslash np \\
\hline
 & \multicolumn{3}{c}{s : shout(X)\&left(X)\backslash np : X} \\
\hline
\multicolumn{4}{c}{s : shout(*some(X\hat{}\,man(X)))\&left(*some(X\hat{}\,man(X)))} \ <
\end{array}$$

This is apparently a S-coordination reading, in which the quantifier semantics is obviously distributed over the conjuncts. However, we can assume that the two instances of the NP representation `*some(X^man(X))` are really pointers to the same NP representation, which is created when it is first associated with the NP in question.

Consider the following derivation.

(244) every man admired and courted at least three women

$$\frac{\text{every man}}{s/(s\backslash np)} \quad \frac{\text{admired}}{(s\backslash np)/np} \quad \frac{\text{and}}{(241)(b)} \quad \frac{\text{courted}}{(s\backslash np)/np} \quad \frac{\text{at least three women}}{s\backslash(s/np)}$$

$$(s : adm(X,Y)\&crt(X,Y)\backslash np : X)/np : Y$$

$$s : every(\#, X, man(X), adm(X,Y)\&crt(X,Y))/np : Y \quad >B$$

$$s : three(>=, Y, wmn(Y), every(\#, X, man(X), adm(X,Y)\&crt(X,Y))) \quad <$$

The derived reading is one in which *at least three women* outscopes *every man*. The other reading can be derived similarly. This much is intuitively correct.

Note again, however, that there are further logical forms due to the degenerate quantifier semantics. There are exactly three distinct such logical forms, one of which includes a degenerate quantifier semantics for both *every man* and *at least three women*. We will not be concerned with this reading, as discussed in Section 5.1. The other two logical forms correspond to the earlier two readings, according to the assumption stated earlier.

Consider the sentence (240) (c). We know that the sentence has exactly two readings. The reading in which *one saxophonist* outscopes both of the subject quantifiers can be derived in the following way.

(245) every girl admired but most boys detested one saxophonist

$$\frac{\text{every girl admired}}{s/np} \quad \frac{\text{but}}{(241)\ (c)} \quad \frac{\text{most boys detested}}{s/np} \quad \frac{\text{one saxophonist}}{s\backslash(s/np)}$$

$$s : every(\#, X, girl(X), adm(X,Y))\&most(\#, X, boy(X), det(X,Y))/np : Y$$

$$s : one(\#, Y, sax(Y), every(\#, X, girl(X), adm(X,Y))\&most(\#, X, boy(X), det(X,Y))) \quad <$$

Notice that as long as the wide-scope quantifier semantics is assigned to *one saxophonist*, it will always outscope the other two quantifiers, since the conjuncts are semantically arguments to the category of *one saxophonist*.

The other reading is derived if we use a degenerate quantifier semantics for *one saxophonist*.

(246) every girl admired but most boys detested one saxophonist

$$\frac{\text{every girl admired}}{s/np} \quad \frac{\text{but}}{(241)\ (c)} \quad \frac{\text{most boys detested}}{s/np} \quad \frac{\text{one saxophonist}}{np : *one(Y\hat{\ }sax(Y))}$$

$$s : every(\#, X, girl(X), adm(X,Y))\&most(\#, X, boy(X), det(X,Y))/np : Y$$

$$s : every(\#, X, girl(X), adm(X, *one(Y\hat{\ }sax(Y))))\&most(\#, X, boy(X), det(X, *one(Y\hat{\ }sax(Y)))) \quad >$$

The theory predicts no other readings.

As for the sentence (240) (d), the derivation (199) shows that the category of *studied two aspects of* is `(s\np)/np`, shown below. This is exactly the same category for transitive verbs.

(247) studied two aspects of

$$\overline{(s : studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z))))\backslash np : X)/np : Z}$$

Notice that the quantifier *two aspects* must be outscoped by both of the quantifiers in order for the fragment *studied two aspects of* to be combined in the present theory. This will give rise to exactly two readings, as expected, in which *some student* and *every language* can alternate their relative scope ordering. No other readings are possible due to the coordinate structure.

The sentence (240) (e) is predicted to have exactly two readings due to the same reason.

In summary, the theoretical predictions on available readings are affected by coordinate structures precisely because coordinate structures restrict the way fragments are combined.

5.9 EXTRACTION, COORDINATION, AND QUANTIFIER SCOPE

In this chapter, we have examined how specific constructions are theoretically predicted to give rise to available readings. Before closing this chapter, we will try to identify the relationship between extraction (and coordination) on quantifier scope in this section, partly summarizing the results collected so far but also laying out new constructions and arguments.[11]

5.9.1 Extraction and Quantifier Scope

This section considers the following types of extraction: Topicalization, Relativization, Heavy NP Shift, Extraposition, and Parasitic Extraction.

[11] The way we structure the data in this section follows that of Morrill (1988).

5.9.1.1 Topicalization

The following sentence shows an instance of topicalization.

(248) Some woman, every man likes.

We need to assume that topicalized NPs have a lexical category `s/(s/np)`, where the result category has a special feature associated with it to indicate the fact that the NPs with this category must appear sentence-initially (Steedman, 1987). We will simply ignore such a feature in the discussion.

The following derivation shows the only possibility in which the subject NP *every man* and the transitive verb *likes* can combine.

(249)
$$\dfrac{\dfrac{\text{every man}}{s: every(\#, X, man(X), S)/(s: S\backslash np: X)} \quad \dfrac{\text{likes}}{(s: likes(X,Y)\backslash np: X)/np: Y}}{s: every(\#, X, man(X), likes(X,Y))/np: Y}{>}B$$

The derivation (249) gives rise to the following result, where *some woman* is assigned a topicalized category.

(250)
$$\dfrac{\dfrac{\text{some woman}}{s: some(\#, Y, wmn(Y), S)/(s: S/np: Y)} \quad \dfrac{\text{every man likes}}{s: every(\#, X, man(X), likes(X,Y))/np: Y}}{s: some(\#, Y, wmn(Y), every(\#, X, man(X), likes(X,Y)))}{>}$$

The result is a reading in which *some woman* outscopes *every man*.

To see if the other scope order is predicted by the theory, notice first that the resulting semantics of (249) still allows a narrow object quantifier, as in the 'saxophonist' example (240) shows, provided that the object quantifier can be assigned a degenerate quantifier semantics. However, this option is not applicable to this sentence, since the topicalized NP is not on the side the verb expects it to be. The following shows an incomplete derivation.

(251)
$$\dfrac{\dfrac{\text{some woman}}{np: *some(Y\hat{\ }wmn(Y))} \quad \dfrac{\text{every man likes}}{s: every(\#, X, man(X), likes(X,Y))/np: Y}}{s: every(\#, X, man(X), likes(X, *some(Y\hat{\ }wmn(Y))))}{*}$$

The theory thus predicts that English topicalization *does* change the scope possibilities. The theoretical reason is that the object NP crosses over the subject NP at surface structure.

5.9.1.2 Relativization

We have seen earlier that an NP can be relativized. As shown below, the relativization has an unbounded nature. Relative clauses containing coordination will be discussed in Section 5.9.2.3.

(252) (a) Exactly four women whom every boy admired danced with some man.

(b) Exactly four women whom at least two girls doubt that every boy admired danced with some man.

(c) Exactly four women whom most students think that at least two girls doubt that every boy admired danced with some man.

We have shown that the theory predicts that the embedded subject NP *every boy* is always outscoped by the head quantifier *exactly four*. This is true of other embedded subject quantifiers, such as *at least two* in (b) and *most* in (c). We have also shown that the embedded subject quantifier in a complement `that` clause is always outscoped by the matrix subject quantifier. In the case of (b), this means that *every boy* is always outscoped by *at least two girls*. So for the sentence (252) (b), the theory predicts that there is a fixed linear scope order between the three NPs in the subject position. The same holds of the sentence (c). So as in topicalization, object relativization does change the scope possibilities of unrelativized original expressions. Notice though that the theory predicts four readings from the related sentence (253) below, unlike the sentence (252) (a).

(253) Exactly four women who danced with some man were admired by every boy.

The data shown here confirm the theoretical prediction shown earlier that English object relativization changes scope possibilities since the object NP crosses over the subject NP at surface structure to become relativized. The unbounded nature of relativization is analyzed locally. There are further interactions between extraction by relativization and across-the-board extraction, to be discussed in Section 5.9.2.3.

5.9.1.3 Heavy NP Shift

The following sentences contain NPs that are extracted to sentence-final position.

(254) (a) Every girl gave to most dogs *a bone which was made of plastic and fun to play with.*

(b) Every policeman visited yesterday *at least two murder suspects of Professor King.*

Steedman (1987) suggested the backward crossed composition rule `<Bx` for the fragment *gave to most dogs* to combine, as shown below.[12]

(255) `Y/Z  X\Y  =>  X/Z  (<Bx)`

The category `vp` below abbreviates `s\np` and `T`, `vp\(vp/pp)`. The category of the verb *gave* shows the canonical word order of English. The category of the preposition *to* has the result category type-raised from `pp` (cf. Steedman (1997)).

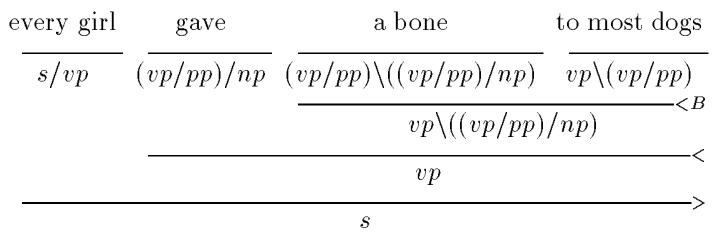
(256)
$$\begin{array}{ccc}
\text{gave} & \text{to} & \text{most dogs}\\
\hline
(vp/pp)/np & (vp\backslash(vp/pp))/np & T\backslash(T/np)\\
\hline
 & \multicolumn{2}{c}{vp\backslash(vp/pp) \quad <}\\
\hline
\multicolumn{3}{c}{vp/np \quad <B_x}
\end{array}$$

(257)
$$\begin{array}{ccc}
\text{every girl} & \text{gave to most dogs} & \text{a bone} \cdots\\
\hline
s/vp & vp/np & s\backslash(s/np)\\
\hline
\multicolumn{2}{c}{s/np \quad >B} & \\
\hline
\multicolumn{3}{c}{s \quad <}
\end{array}$$

As we have shown earlier, this particular derivation gives rise to a reading in which *a bone* outscopes *every girl*, which in turn outscopes *most dogs*. Another reading in which *every girl* outscopes *a bone*, which in turn outscopes *most dogs* can be derived similarly. However, since the heavy NP *a bone* $\cdots$ must always be type-raised, the theory predicts that readings in which *a bone* is outscoped by *most dogs* (or a reading in which dogs received different bones) are not available. Compare this prediction to that on the following, which does not have an extracted NP.

[12] See Steedman (1997) for various conditions on the applications of this rule.

(258)



5.9.1.4 Extraposition

It is not entirely clear that extraposition should be treated in the same way as extraction. The following analysis is tentatively included for the sake of completeness.

The following sentences have an extraposed relative clause.

(259) (a) Every man arrived who admired some woman.

(b) Every man arrived whom most girls admired.

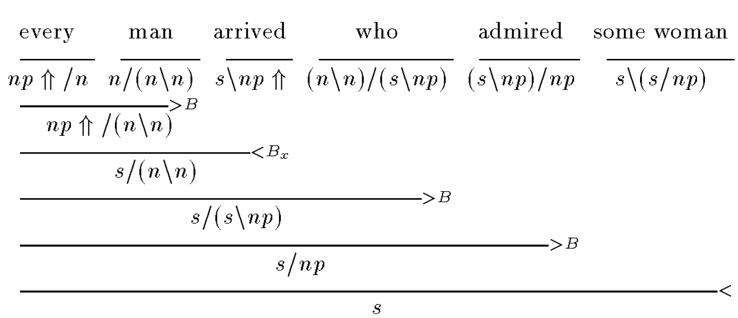
Although the fragment *who admired* may be a c-constituent, the fragment *arrived who admired* is not a c-constituent. Thus, the surface constituency hypothesis would predict that the sentence (259) (a), unlike the sentence (260) below, is not ambiguous.

(260) Every man who admired some woman arrived.

Likewise, since there is no way to combine two adjacent categories **s\np** and **n\n**, the fragment *arrived who admired some woman* is not recognized as a constituent by the theory.

In order to recognize such sentences as (259), the theory needs the backward crossed composition rule **<Bx**, as well as a type-raised argument such as *np* ⇑ (cf. Moortgat (1988), Morrill (1988)).

(261) The following derivation is *incompatible* with the present framework:



The backward crossed composition rule has been motivated for other construction, such as heavy NP shift and other extraction of non-subject arguments (Steedman, 1987; Steedman, 1997).[13] However, the use of a type-raised argument, for instance for the category of verbs, is against the thesis of the present framework, since it allows the resolution of scope ambiguity to be dependent upon the lexical semantics of verbs (or functions), rather than how the surface structure is laid out. The following lexical entries show some of the possible categories for the transitive verb *visited* under this proposal.

(262) Lexical entries that are *incompatible* with the present theory:

(a) `visited :- (s\np)/np⇑`

(b) `visited :- (s\np⇑)/np`

(c) `visited :- (s\np⇑)/np⇑`

Notice that in the lexical entry (c), where both of the arguments are type-raised, it all comes down to the sentential semantics of the result category `s` to resolve the scope ambiguity, possibly requiring two separate lexical entries. The following derivation, with a type-raised category for *every*, is also unacceptable in the present framework.

(263) The required rule for the last derivation step is not suited for English:

every	man	arrived	who	admired	some woman
$(s/(s\backslash np))/n$	$n/(n\backslash n)$	$s\backslash np$	$(n\backslash n)/(s\backslash np)$	$(s\backslash np)/np$	$s\backslash(s/np)$

$$(s/(s\backslash np))/(n\backslash n) \quad >B$$

$$s/(n\backslash n) \quad ?$$

The operation that is needed to complete the last derivation step must permute the arguments, as shown below. This is an unacceptable operation for configurational languages such as English, as word-order in such languages is completely collapsed by such an operation (if we regard rules as *generating*, as well as *accepting*, strings of words).

(264) `(X/Y)/Z  Y  => X/Z`

Hence the present framework allows only unraised category for subject quantifier, as shown below.

[13]The rule must be type-restricted, as Steedman (1997) shows.

(265) every man arrived who admired some woman

$$\underline{\text{every}}: np/n \quad \underline{\text{man}}: n/(n\backslash n) \quad \underline{\text{arrived}}: s\backslash np \quad \underline{\text{who}}: (n\backslash n)/(s\backslash np) \quad \underline{\text{admired}}: (s\backslash np)/np \quad \underline{\text{some woman}}: s\backslash(s/np)$$

$$\xrightarrow{>B} np : *every(X^\wedge N)/(n : X^\wedge N\backslash n : X^\wedge man(X))$$

$$\xrightarrow{<B_x} s : arrived(*every(X^\wedge N))/(n : X^\wedge N\backslash n : X^\wedge man(X))$$

$$\xrightarrow{>B} s : arrived(*every(X^\wedge(man(X)\&S)))/(s : S\backslash np : X)$$

$$\xrightarrow{>B} s : arrived(*every(X^\wedge(man(X)\&admired(X,Y))))/np : X$$

$$\xrightarrow{<} s : some(\#, Y, wmn(Y), arrived(*every(X^\wedge(man(X)\&admired(X,Y)))))$$

This reading shows a wide-scope reading of the embedded object quantifier over the matrix subject quantifier. When the embedded object quantifier is assigned a degenerate quantifier semantics, its scope will be under the operator `*every`. Since this corresponds to the other scope reading, the present theory predicts that the sentence (259) (a) is ambiguous. Since the original unextraposed sentence is also ambiguous, this would imply that English extraposition does not change scope possibilities. Our previous examples suggest, however, that when an NP is relocated from its original position to a new position, scope possibilities change when there is an intervening NP. Since there is no intervening NP inside the fragment *arrived who admired*, such predictions may not be valid. Consider the following sentence.

(266) Every man_i saw most samples who_i admired some woman.

Assuming that the use of extraposition in the sentence (266) is acceptable, this sentence raises two interesting questions. One is if the scope possibilities are changed by extraposition. The other is if the previously unavailable reading, in which *most samples* comes between *every man* and *some woman*, becomes available by extraposition.

First, the surface structure forces the composition of *saw most samples* before the two fragments of the subject NP can ever combine. The NP *most samples* can still outscope *every man*, since the latter would not be assigned a wide-scope quantifier semantics in our theory. However, this does not mean that *some woman* is also automatically outscoped by *most samples*. For instance, the theory predicts the reading in which *some woman* outscopes *most samples*, which in turn outscopes *every man*, as shown in the following derivation.

(267) every man saw most samples who admired some woman

$$\frac{\text{every man}}{np/(n\backslash n)} \quad \frac{\text{saw most samples}}{s\backslash np} \quad \frac{\text{who admired}}{(n : X\hat{}(N\&adm(X,Z))\backslash n : X\hat{}N)/np : Z} \quad \frac{\text{some woman}}{s\backslash(s/np)}$$

$$\overline{s : most(\#, Y, samp(Y), saw(*every(X\hat{}N), Y))/(n : X\hat{}N\backslash n : X\hat{}man(X))}^{<B_x}$$

$$\overline{s : most(\#, Y, samp(Y), saw(*every(X\hat{}(man(X)\&adm(X,Z))), Y))/np : Z}^{>B}$$

$$\overline{s : some(\#, Z, wmn(Z), most(\#, Y, samp(Y), saw(*every(X\hat{}(man(X)\&adm(X,Z))), Y)))}^{<}$$

Of course, this "intercalating" reading is impossible with embedded subject NPs. ALthough further research should uncover the details about the relationship between quantifier scope and extraposition, the theory predicts that extraposition may change scope possibilities in a limited way. Incidentally, this prediction is consistent with earlier predictions: That when an NP is relocated from its original position to a new position, the existence of an intervening NP may interfere with scope possibilities.

For completeness of discussion, the sentence (259) (b) has the following derivation. Since the quantifier `most` is inside the degenerate quantifier `*every`, the theory predicts that extraposition does not change the fact that embedded subject quantifier can not outscope its head quantifier.

(268) every man arrived whom most girls admired

$$\frac{\text{every}}{np/n} \quad \frac{\text{man}}{n/(n\backslash n)} \quad \frac{\text{arrived}}{s\backslash np} \quad \frac{\text{whom}}{(n\backslash n)/(s/np)} \quad \frac{\text{most girls}}{s/(s\backslash np)} \quad \frac{\text{admired}}{(s\backslash np)/np}$$

$$\overline{np : *every(X\hat{}N)/(n : X\hat{}N\backslash n : X\hat{}man(X))}^{>B} \qquad \overline{s : most(\#, Y, girl(Y), adm(Y,X))/np : X}^{>B}$$

$$\overline{s : arrived(*every(X\hat{}N))/(n : X\hat{}N\backslash n : X\hat{}man(X))}^{<B_x}$$

$$\overline{s : arrived(*every(X\hat{}(man(X)\&S)))/(s : S/np : X)}^{>B}$$

$$\overline{s : arrived(*every(X\hat{}(man(X)\&most(\#, Y, girl(Y), adm(Y,X)))))}^{>B}$$

As one can verify easily, the same is true of sentences with "intervening" NPs, such as the sentence (269).

(269) Every man_i saw most samples whom_i some woman admired.

5.9.1.5 Parasitic Extraction

The following shows that there are two missing NP positions inside the relative clause.[14]

(270) At least two men whom_i every friend of e_i tried to avoid e_i disappeared.

[14] Notice that the use of empty category e_i is purely for the purpose of clarifying the missing NP positions. In particular, we do not mean to imply by this representation that phonetically empty categories are assumed in the present theory.

In order to handle sentences of this kind, including the following, we need the rule(s) of function substitution (Steedman, 1987).

(271) Which papers did you file without reading?

(272) `(X/Y)/Z  Y/Z  =>  X/Z` (when `Y = S\NP` and `Z = NP`)

According to this rule, the following derivation gives rise to the category **s/np** for the fragment *every friend of tried to avoid*, as expected.

(273)

every friend of — tried to avoid

$$\dfrac{\dfrac{\text{every friend of}}{(s: every(\#, X, frn(X)\&of(X,Z), S)/(s: S\backslash np: X))/np: Z} \quad \dfrac{\text{tried to avoid}}{(s: tried(X, avd(X,Y))\backslash np: X)/np: Y}}{s: every(\#, X, frn(X)\&of(X,Z), tried(X, avd(X,Z)))/np: Z}{>}S$$

Notice that this derivation gives rise to narrow scope *every friend* with respect to the head quantifier *at least two*, as shown below.

(274)

two	men	whom	every friend of tried to avoid	disappeared
$(s/(s\backslash np))/n$	$n/(n\backslash n)$	$(n\backslash n)/(s/np)$	s/np	$s\backslash np$

$$\dfrac{(s/(s\backslash np))/n \quad n/(n\backslash n)}{(s/(s\backslash np))/(n\backslash n)}{>}B$$

$$\dfrac{(s/(s\backslash np))/(n\backslash n) \quad (n\backslash n)/(s/np)}{(s: two(\#, X, man(X)\&S1, S)/(s: S\backslash np: X))/(s: S1/np: Y)}{>}B$$

$$\dfrac{\ldots \quad s/np}{s: two(\#, X, man(X)\&every(\#, X, frn(X)\&of(X,Z), tried(X, avd(X,Z))), S)/(s: S\backslash np: X)}{>}$$

$$\dfrac{\ldots \quad s\backslash np}{s: two(\#, X, man(X)\&every(\#, X, frn(X)\&of(X,Z), tried(X, avd(X,Z))), disp(X))}{>}$$

As one can also verify with parasitic extraction from embedded object NP, the theory predicts that parasitic extraction behaves in exactly the same way as the other instances of relativisation with respect to quantifier scope do.

5.9.2 Coordination and Quantifier Scope

The data considered in this section include: Right-node-raising, Left-node-raising, and Across-the-board extraction. Instances of RNR and LNR have been discussed earlier. ATB extraction is a new one.

5.9.2.1 Right-Node-Raising

We have already shown that instances of right-node-raising such as the following do not change the scope possibilities.

(275) Every girl admired, but most boys detested, one saxophonist.

According to the theory, this is because the raised NP does not cross over the other NPs.

5.9.2.2 Left-Node-Raising

The following contains instances of left-node-raising (Schachter and Mordechai, 1983).

(276) (a) Some girl gave every dog a bone and most policemen a flower.

(b) Some girl showed every dog a bone and gave most policemen a flower.

In the sentence (a), the raised fragment is *some girl gave*, and in the sentence (b), it is *some girl*. The coordination in (a) forces the fragment *every dog a bone* to be combined, and likewise for the second conjunct. The coordination in (b) give an additional option for the theory to combine *showed every dog a bone*, which includes combining *showed every dog* first.

As we have shown earlier, the theory is unable to predict the wide scope reading of *every dog* (over *a bone*) when the coordination forces *every dog a bone* to be combined (as in the sentence (a)). This is because the semantics of *a bone* is necessarily a primary function that is composed with a secondary function for *every dog*, and not the other way around. Since *a dog* must be a function, we can not assign it a degenerate quantifier semantics either. This instance needs further study in the present framework. Notice that the goal is to derive both readings in which *every dog* and *a bone* alternates relative scope order and not just one of them.

Notice though that the sentence (b) makes a room for the fragment *showed every dog* to be combined. When *every dog* is assigned a wide-scope quantifier semantics and *a dog* a degenerate quantifier semantics, the theory can derive a reading or readings in which *every dog* outscopes *a bone*. The other scope order is also possible.

5.9.2.3 Across-the-Board Extraction

We have seen earlier that the sentence (275) has exactly two readings. The following sentence shows a relativization of the extracted NP.

(277) At least one saxophonist whom every girl admired, but most boys detested, managed to leave.

In this sentence, the theory predicts that there is only one reading, in which *at least one saxophonist* outscopes the embedded subject quantifiers. This is not surprising, since embedded subject quantifiers are already known not to outscope head quantifiers.

What is surprising is that the following sentence is also predicted to have only one reading.

(278) At least one saxophonist who played several tunes and hated most boys managed to leave.

In particular, the theory predicts only one reading, in which the head quantifier outscopes both of the embedded quantifiers. We know that (the theory predicts that) the following sentences have two readings each.

(279) (a) At least one saxophonist played several tunes and hated most boys.

(b) At least one saxophonist who played several tunes managed to leave.

The reason that the theory predicts only one reading for the sentence (278) is that the coordination forces the composition of *played* and *several tunes*, and similarly for the second conjunct, before the whole semantics of the relative clause is combined with the head quantifier. Recall that the reading in which *several tunes* outscopes *at least one saxophonist* in the sentence (279) (b) is when the fragment *at least one saxophonist who played* is combinable.

In summary, again, the theory predicts that quantifier scope possibilities are affected by coordination precisely because it restricts the way fragments are combined by the theory.

5.10 CHAPTER SUMMARY

In this chapter, we have shown CCG lexical entries for various English words, and described in detail how the theory derives logical forms from natural language sentences based on these lexical entries (and a limited set of combinators). We have considered all of the core constructions discussed in Chapter 3 to confirm that the theory makes a precise prediction on quantificational scope readings by generating all and only available logical forms.

Part III

SCOPE INTERPRETATIONS

Chapter 6

GENERATION OF SCOPED LOGICAL FORMS

This chapter describes an implementation of the theory presented earlier in Chapters 4 and 5. The main goal of this chapter is to show how to implement the theory in (regular) Prolog, in order to actually generate logical forms that correspond to available quantificational readings. The described system can also be regarded as a proof-checker for the proposed theory. The system takes English sentences as input, generates sets of logical forms that people consider available, and optionally evaluate these logical forms with respect to a small database of constructed facts. The system is tested by comparing the output logical forms with the readings on core English constructions as discussed in Chapters 3 and 5.

Ideally, this kind of a system should be combined with other modules of natural language processing that can handle natural language aspects such as intonation and context, since these aspects can also work to further narrow down semantic ambiguities in natural language expressions.

Section 6.1 shows the general architecture of the system. Section 6.2 explains the main components of the system in detail. Section 6.3 shows some sample generation of logical forms.

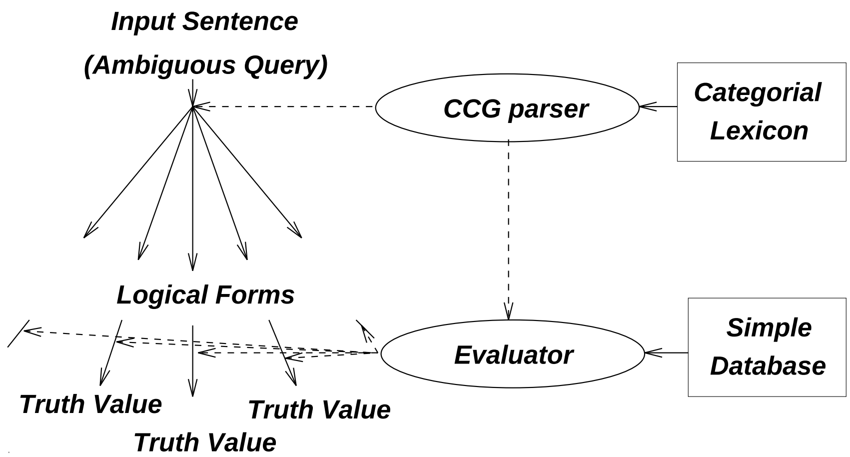


Figure 6.1: An Ambiguous Query Interpretation System

6.1 AMBIGUOUS QUERY INTERPRETATION

Figure 6.1 depicts the general architecture of the implemented system.

(a) The input sentence is an English sentence, grammatical or not.

(b) The categorial lexicon contains a collection of lexical entries for English words.

(c) The CCG parser employs a simple shift-reduce parsing technique.

(d) The logical forms have the syntax and semantics discussed in Chapter 4.

(e) A simple database is a collection of extensional denotations of various predicates.

(f) The evaluator is a Prolog program that evaluates logical forms with respect to the database.

6.2 A PROLOG IMPLEMENTATION

This section describes some preliminaries (Section 6.2.1), the organization of the CCG lexicon (Section 6.2.2), and the CCG parser (Section 6.2.4). This section goes over the Prolog code that generates the semantic forms from natural language sentences with CCG. In the following description, we will be using SICStus Prolog version 3.0.

6.2.1 Preliminaries

Functors that are specific to CCG and our language for logical representation are declared as Prolog infix operators.

(280) (a) `:- op( 800, xfy,  [&, v]).`

(b) `:- op( 500, yfx,  [\, /]).`

(c) `:- op( 480, xfx,  :).`

(d) `:- op( 460, xfy,  ^).`

The entry (a) declares coordination operators that are used in the logical language: `&` for conjunction and `v` for disjunction. They associate to the right. The entry (b) declares directional symbols in CCG: `\` for backward and `/` for forward. They associate to the left. The entry (c) declares the translation symbol that connect elementary CCG categories and their semantics. It is not associative. Finally, the entry (d) declares the argumentation symbol for the simulation of a limited higher-order unification. The entry (a) is a SICStus Prolog abbreviation for the following two separate entries.

(281) (a) `:- op( 800, xfy,  &).`

(b) `:- op( 800, xfy,  v).`

The system has the following main driver, which repeats the cycle of accepting a natural language (English) sentence, interpreting the sentence into a set of logical forms, and generating the logical forms, until the input becomes `exit`.

(282)
```
go :-   prompt(Buffer),
        if(Buffer = [exit], exit,
        (interpret(Buffer, LFs),
         output(LFs), !, go)).
```

(283)
```
prompt(Buffer) :- nl, write('Q:  '), read_in(Buffer).
```

(284)
```
exit :- write('exit'), nl, !, fail.
```

```
(285) interpret(Buffer, LFs) :-
            setof((LF, FreshLFs),
             setof(FreshLF, parse([], Buffer, s(_,_):FreshLF, LF),
                   FreshLFs), LFs).
(286) output(LFs) :- write('LF: '), length(LFs, L),
         if(L =:= 1, write('ungrammatical or unrecognized sentence'),
                     (M is L - 1, format("~d way ambiguous sentence", M),
                      prettywrite(LFs))).
```

The routine prompt/1 receives an input English sentence into the variable Buffer. The routine interpret/2 makes use of two setof/3 predicates. The one inside collects a list of logical forms that contain Prolog variables, such as _643. The one outside pairs each list with a logical form that has standardized variables, such as X2. The expressions with standardized variables are more readable, and the expressions with uninstantiated Prolog variables can be used to evaluate them (see Chapter 7). The routines write/1, flush_output/1, read_in/1, setof/3, length/2, and if/3 are all built-in commands in SICStus Prolog. The routine parse/4 is described in Section 6.2.4. prettywrite/1 is a formating routine for an output.

6.2.2 The Lexicon

This section describes how the categorial lexicon is designed. Elementary categories, such as s, np, or n, are augmented with basic features, as in s(T), np(P), n(P) etc, where T is a place-holder for tense information, and P is for plurality.

The lexicon will be a collection of entries in the following form, where the feature s indicates the fact that the NP is singular.

```
(287) category(john, np(s):john).
```

In order to reduce the size of the program (but not the lexicon), however, the lexical entries will be grouped together and asserted by a simpler Prolog call. For example, consider the clause below.

```
(288) pn(N) :- assertz(category(N, np(s):N)).
```

With this clause, a lexical entry such as (287) is added by the Prolog call (289).

(289) `:- pn(john).`

This technique will not be assumed however in the following description of the lexicon.

Common nouns are declared as follows.

(290)
```
category(men, n(p):X^man(X)).
category(woman, n(s):X^woman(X)).
```

Since we assume lexical type raising, the lexicon must also include type-raised entries for common nouns, as shown below.

(291)
```
category(men, n(p):X^N/(n(p):X^N\n(p):X^man(X))).
category(woman, n(s):X^N/(n(s):X^N\n(s):X^woman(X))).
```

Entries for quantifiers include the following. Notice that (292) (a) introduces the degenerate quantifier semantics of *every* to the lexicon.

(292)
```
category(every, np(s):*every(X^N)/n(s):X^N).
category(every, (s(T):every(#,X,N,S)/(s(T):S\np(s):X))/n(s):X^N).
category(every, (s(T):every(#,X,N,S)\(s(T):S/np(s):X))/n(s):X^N).
category(every, ((s(T):every(#,X,N,S)\np(P):Y)\((s(T):S\np(P):Y)/
                np(s):X))/n(s):X^N).
```

Lexical entries for various verbs are defined as follows. As for the sentential features, `pr` is for present tense, `pa` is for past tense, and `i` is for infinitival. Note the use of the feature value `p` and the place-holder `P` (`P1`, `P2` etc) in the NP categories.

(293)
```
category(sleeps, s(pr):sleeps(X)\np(s):X).
category(admire, (s(pr):admire(X,Y)\np(p):X)/np(P):Y).
category(admire, (s(i):admire(X,Y)\np(P1):X)/np(P2):Y).
category(gave, ((s(pa):gave(X,Y,Z)\np(P1):X)/np(P2):Z)/np(P3):Y).
```

Relative pronouns are assigned the following categories, as discussed in Chapter 5. Notice the use of different place-holders `P1` and `P2` for different NP (and N) categories.

(294)
```
category(who, (n(P):X^(N&S)\n(P):X^N)/(s(T):S\np(P):X)).
category(whom, (n(P):X^(N&S)\n(P):X^N)/(s(T):S/np(P):X)).
category(whose, ((n(P1):Z^(N&every(#,X,N1&of(X,Z),S))\n(P1):Z^N)/
                 (s(T):S\np(P2):X))/n(P2):X^N1)).
category(whom, ((n(P2):Z^(N&S1)\n(P2):Z^N)/(s(T):S\np(P1):X))\
                ((s(T):S1/(s(T):S\np(P1):X))/np(P2):Z)).
category(whose, ((n(P1):Z^(N&every(#,X,N1&of(X,Z),S))\n(P1):Z^N)/
                 (s(T):S/np(P2):X))/n(P2):X^N1).
category(whom, ((n(P1):Z^(N&S1)\n(P1):Z^N)/(s(T):S/np(P2):X))\
                ((s(T):S1/(s(T):S\np(P2):X))/np(P1):Z)).
```

The following two categories define the mode corresponding to *more than* for bare numerals. Other modes are defined similarly.

(295)
```
category(more, ql:'>'/qm:than).
category(than, qm:than).
```

Modified numerals must have separate entries to accommodate modifiers, in addition to the unmodified entries shown in (292).

(296)
```
category(two, (((s(T):two(M,X,N,S)/(s(T):S\np(s):X))/n(s):X^N))\ql:M).
category(two, ((s(T):two(M,X,N,S)\(s(T):S/np(s):X))/n(s):X^N)\ql:M).
category(two, (((s(T):two(M,X,N,S)\np(P):Y)\((s(T):S\np(P):Y)/
                 np(s):X))/n(s):X^N)\ql:M).
```

The following defines lexical entries for the preposition *of*. Notice that the second entry has a type-raised NP argument.

(297)
```
category(of, (n(P1):X^(N & of(X,Y))\n(P1):X^N)/np(P2):Y).
category(of, (n(P1):X^(N & S)\n(P1):X^N)/(s(S):S\(s(S):of(X,Y)/
              np(P2):Y))).
```

The following defines lexical entries for conjunction items.

(298)
```
category(and, (s(T):(P&Q)\s(T):P)/s(T):Q).
category(and, ((s(T):(P&Q)\np(P):X)\(s(T):P\np(P):X))
              /(s(T):Q\np(P):X)).
category(and, ((s(T):(P&Q)/np(P):X)\(s(T):P/np(P):X))
              /(s(T):Q/np(P):X)).
category(but, ((s(T):(P&Q)\np(P):X)\(s(T):P\np(P):X))
              /(s(T):Q\np(P):X)).
category(but, ((s(T):(P&Q)/np(P):X)\(s(T):P/np(P):X))
              /(s(T):Q/np(P):X)).
```

6.2.3 Explanations and Predictions

This section makes a brief comment on the difference between explanations and predictions on scope readings.

The lexicon shown in the previous section defines categories for various English words, including proper nouns, common nouns, verbs of various arity, relative pronouns, prepositions, quantifiers, and conjunction items. When they are defined in the lexicon, their categories are meant to explain how scope readings are derived.

(299) (a) Proper nouns have the category `np`, with the semantic form identical to the English words.

(b) Common nouns have the unraised category `n` and the raised category `n/(n\n)`. Their semantic forms are neutral with respect to scope possibilities.

(300) (a) Verbs of various arity are assigned categories `s\np`, `(s\np)/np`, `((s\np)/np)/np`, etc. The semantic forms associated with the categories make it clear that they are *function* items, in the sense that they simply relate arguments in a predicate-argument structure.

(b) Prepositions are assigned the categories `(n\n)/np` and `(n\n)/(s\(s/np)`. They are also function items.

(301) Quantifiers are assigned the unraised category `np/n` and the raised categories `(T/(T\np))/n` and `(T\(T/np)/n`, where `T` is a category whose result category is the elementary category `s`.

(302) (a) Relative pronouns have various categories, depending on what they are supposed to combine with for the final category `n\n`, or a noun modifying category.

(b) Conjunction items are assigned categories `(T\T)/T`, where `T` is any category whose result category is the elementary category `s`.

A derivation leading to a pariticular scope reading can be regarded as a direct projection from the categorial lexicon. In this sense, scope readings can be *explained* by the present version of combinatory categorial grammar: Whenever a quantifier with a raised category combines with a function item before the other quantifier with a raised category does, the former will always be outscoped by the latter. This is in fact a (partial) formulation of the surface constituency hypothesis, where the A constituent is encoded in the theory as a function item. In other words, whichever NP combines first with the A constituent is outscoped by the other. Notice that function items start out with verbs or prepositions, but they can have a quite complex internal semantic structure.

Novel predictions come up when a raised quantifier category is always forced to combine with a function item or when a raised quantifier category interacts with an unraised quantifier category. The former case refers to the sentences containing embedded subject quantifiers, such as (c) and (f). As for the latter, when an unraised quantifier category is associated with a degenerate quantifier semantics, we anticipate that the quantifier will always be outscoped by other raised quantifiers. However, the way fragments are combined according to the grammar gives rise to a novel range of readings. In particular, there are readings in which degenerate quantifiers may also *contain* (or outscope) other wide-scope quantifiers. The relevant readings come from the sentences that contain the pattern shown in (a) below, or relative clauses such as (b) through (f), among others.

(303) (a) Some student studied *two* aspects of every language.

(b) *Two* professors who interviewed every student wrote a letter.

(c) *Two* professors whom every student admired wrote a letter.

(d) *Two* professors whose students admired most deans wrote several letters.

(f) Two professors interviewed *three* students most pictures of whom pleased exactly two judges.

For instance, even when *two* in (b) is assigned a degenerate quantifier semantics, the embedded object quantifier *every student* may not outscope it when the fragment *professors who interviewed every student* is computed first. In (c), the degenerate quantifier *two* will always outscope the embedded subject quantifier *every student*. Notice that these different predictions are afforded by a grammar formalism that defines the way a new string of words is composed to become a grammatical sentence.

6.2.4 The Parser

The following shows a simple shift-reduce parser for CCG.

(304)
```
parse(Stack, [Word|Buffer], Answer, LF) :-
        category(Word, SynSem),
        parse([SynSem|Stack], Buffer, Answer, LF).
```
(305)
```
parse([Cat2, Cat1|Stack], Buffer, Answer, LF) :-
        reduce(Cat1, Cat2, Cat3),
        parse([Cat3|Stack], Buffer, Answer, LF).
```
(306)
```
parse([Cat1|Stack], Buffer, Answer, LF) :-
        raise(Cat1, Cat2),
        parse([Cat2|Stack], Buffer, Answer, LF).
```
(307)
```
parse([], _, _:[], []).
```

(304) is for shifting (pushing) new items onto the stack. (305) is for reducing two categories into a single category. (306) makes a provision for syntactic backward type raising. We do not need one for forward type raising, since the operation is encoded in the lexicon. (307) handles a parse error, where the result is an empty list `[]`.

The following rules define categorial reduction.

(308)
(a) `reduce(X/Y,   Y,   X).`
(b) `reduce(  Y, X\Y,   X).`
(c) `reduce(X/Y, Y/Z, X/Z).`
(d) `reduce(Y\Z, X\Y, X\Z).` (to be further conditioned)

However, there is a potential problem for the backward function composition rule as stated in (d). As shown below, this allows the italicized fragments to be assigned either a wrong category, as in (a), or a wrong semantics due to a wrong combination, as in (b).

(309) (a) * One woman who *talks and john walks* sleeps.

```
talks    and      john walks
-----   -------   ----------
s\np    (s\s)/s       s
        ------------------->
               s\s
---------------------------<B
          s\np
```

(b) # John talks *slowly but walks fast*.

```
slowly              but                  walks   fast
---------------   ---------------------  -----   ---------------
(s\np)\(s\np)   ((s\np)\(s\np))/(s\np)  (s\np)  (s\np)\(s\np)
                                         -----------------------<
                                                  s\np
                  ----------------------------------------------->
                              (s\np)\(s\np)
-----------------------------------------------------------------<B
                       (s\np)\(s\np)
```

The problem is caused by the mismatch in the *specification* of the lexical categories for conjunction items and in their actual *use*. When the category for a conjunction item such as `(s\s)/s` is first combined with a sentence category on its right, the new fragment is assigned a category `s\s`. While this must be combined with a full sentence constituent to further result in another sentence constituent, an unconstrained backward composition allows the argument category to be only partially consumed, as shown in the examples. This results in an incorrect analysis.

The standard trick is to use another feature for sentence categories, something like `C`.[1] It would define "combinability" of the categories, with values either `comb` or `nocomb`. When the sentence category somehow receives the value `nocomb`, then the afforementioned backward combination should be blocked. The conditioned backward composition rule in (a) below, along with those lexical entries for conjunction items, shown in (298) and repeated in (b) below for reference, implements this idea.

(310) (a) `reduce(Y\Z, X\Y, X\Z) :- Y \== s(T,nocomb):LF.`

(to be modified below)

(b) `category(and, (s(T,_):(P&Q)\s(T,nocomb):P)/s(T,_):Q).`

[1]Another solution is to use a syntactic coordination rule.

The intention behind (a) is that the reduction should go through unless `Y` is unifiable with `s(T,nocomb):LF`. This does not work as intended, however, since when `Y` already has a value, for example, `s(_23,nocomb):_34`, the condition merely tells the system that the variable `_23` should not be unified with the variable `T`, and so on, *when they are used subsequently.* As a result, it would not block anything. This problem is well-known in Prolog programming, and is traditionally handled by the combination of cut (`!`) and fail.

(311) `reduce(Y\Z, X\Y, X\Z) :- Y == s(T,nocomb):LF, !, fail.`

This condition works as intended. (311) defines only one instance of the backward function composition rule. The following rules further augment it.

(312) (a) `reduce(Y\Z, X\Y, X\Z) :- Y == s(_T,nocomb):_LF/_A, !, fail.`

(b) `reduce(Y\Z, X\Y, X\Z) :- Y == s(_T,nocomb):_LF\_A, !, fail.`

Finally, the following shows a backward type raising rule.

(313) `raise( np(C1):A, X\(X/np(C1):A)).`

6.3 GENERATION OF LOGICAL FORMS

In this section, we will consider how the system handles the following sentences, each of which is taken from the core English constructions considered in Chapters 3 and 5.

(314) (a) Every man admires some woman.

(b) Every man seems to admire some woman.

(c) Every representative of three companies saw most samples.

(d) Every student's picture of most monuments pleased exactly two judges.

(e) Two professors who interviewed every student wrote a letter.

(f) Two professors whom every student admired wrote a letter.

(g) Two professors whose students admired most deans wrote several letters.

(h) Two professors interviewed three students most pictures of whom pleased exactly two judges.

(i) Two girls think that three men admire four women.

The system asks for an English sentence with a prompt 'Q:', and then generates all the available logical forms provided that the sentence is grammatical. There are several levels of ungrammaticality that the current system does not distinguish. Consider the following three fragments, all of which are rejected by the system as *ungrammatical or unrecognized sentence*.

(315) (a) Every man sleep.

(b) Every sleeps.

(c) Every man sloops.

(a) shows an agreement failure, but the present CCG grammar can be easily modified to accept sentences of this kind without losing its ability to handle configurationality of languages like English. It is only rejected to show that the system can handle agreement. There is no way, however, that the system can be modified to accept (b), if we maintain (correctly) that the category of determiners, such as *every*, is a noun modifying function. (c) has an unknown lexical item *sloop*. Without a learning module, (c) would not be accepted as grammatical, even if it is.

In the following examples, we will show logical forms with wide-scope quantifier semantics only, by turning off the lexical entries for degenerate quantifier semantics, when those not-shown logical forms are equivalent to other shown logical forms.

(316)
```
Q:  every man admires some woman.
LF: 2 way ambiguous sentence
   (1) every(#,X1,man(X1),some(#,X3,woman(X3),admire(X1,X3)))
   (2) some(#,X1,woman(X1),every(#,X3,man(X3),admire(X3,X1)))
```

(317)
```
Q:  every man seems to admire some woman.
LF: 3 way ambiguous sentence
   (1) every(#,X1,man(X1),seem(some(#,X3,woman(X3),admire(X1,X3))))
   (2) every(#,X1,man(X1),some(#,X3,woman(X3),seem(admire(X1,X3))))
   (3) some(#,X1,woman(X1),every(#,X3,man(X3),seem(admire(X3,X1))))
```

(318) Q: every representative of three companies saw most samples.

```
LF: 4 way ambiguous sentence
   (1) every(#,X1,rep(X1)&three(#,X2,comp(X2),of(X1,X2)),
             most(#,X3,samp(X3),see(X1,X3)))
   (2) most(#,X1,samp(X1),
            every(#,X3,rep(X3)&three(#,X4,comp(X4),of(X3,X4)),
                  see(X3,X1)))
   (3) most(#,X1,samp(X1),
            three(#,X3,comp(X3),
                  every(#,X5,rep(X5)&of(X5,X3),see(X5,X1))))
   (4) three(#,X1,comp(X1),
             every(#,X3,rep(X3)&of(X3,X1),
                   most(#,X5,samp(X5),see(X3,X5))))
```

The sentence is correctly analyzed to have four readings, as discussed in Chapter 3. Notice that the sentence does not have a reading in which object quantifier comes between the two subject quantifiers.

The following has a possessive NP inside a complex NP.[2]

(319) Q: every student s picture of most monuments pleased exactly two judges.

```
LF: 4 way ambiguous sentence
   (1) most(#,X1,mon(X1),
            the(#,X3,pic(X3)&of(X3,X1),
                every(#,X5,stu(X5),
                      own(X5,X3)&two(=,X7,jud(X7),please(X3,X7)))))
   (2) the(#,X1,pic(X1)&most(#,X2,mon(X2),of(X1,X2)),
           every(#,X3,stu(X3),
                 own(X3,X1)&two(=,X5,jud(X5),please(X1,X5))))
   (3) two(=,X1,jud(X1),
           most(#,X3,mon(X3),
                the(#,X5,pic(X5)&of(X5,X3),
                    every(#,X7,stu(X7),own(X7,X5)&please(X5,X1)))))
   (4) two(=,X1,jud(X1),
           the(#,X3,pic(X3)&most(#,X4,mon(X4),of(X3,X4)),
               every(#,X5,stu(X5),own(X5,X3)&please(X3,X1))))
```

[2]Since the present system does not have a theory of morphology, we must put white space between *student* and *'s* in the input.

(320) Q: two professors who interviewed every student wrote a letter.

```
LF: 4 way ambiguous sentence
   (1) a(#,X1,let(X1),
          every(#,X3,stu(X3),
                two(#,X5,prof(X5)&interview(X3,X5),write(X5,X1))))
   (2) a(#,X1,let(X1),
          two(#,X3,prof(X3)&every(#,X4,stu(X4),interview(X4,X3)),
              write(X3,X1)))
   (3) every(#,X1,stu(X1),
              two(#,X3,prof(X3)&interview(X1,X3),
                  a(#,X5,let(X5),write(X3,X5))))
   (4) two(#,X1,prof(X1)&every(#,X2,stu(X2),interview(X2,X1)),
            a(#,X3,let(X3),write(X1,X3)))
```

Notice that readings (3) and (4) above disappear when nouns do not have the raised category, or `n/(n\n)`. On the other hand, even with the raised noun category, the sentence below does not have embedded subject quantifier outscope the head quantifier.

(321) Q: Two professors whom every student admired wrote a letter.

```
LF: 2 way ambiguous sentence
   (1) a(#,X1,let(X1),
          two(#,X3,prof(X3)&every(#,X4,stu(X4),admire(X3,X4)),
              write(X3,X1)))
   (2) two(#,X1,prof(X1)&every(#,X2,stu(X2),admire(X2,X1)),
            a(#,X3,let(X3),write(X1,X3)))
```

(322) Q: Two professors whose students admired most deans wrote several letters.

```
LF: 4 way ambiguous sentence
   (1) most(#,X1,dean(X1),
            two(#,X3,prof(X3)&every(#,X4,stu(X4)&of(X4,X3),admire(X4,X1)),
                several(#,X5,let(X5),write(X3,X5))))
   (2) several(#,X1,let(X1),
               most(#,X3,dean(X3),
                    two(#,X5,prof(X5)&every(#,X6,stu(X6)&of(X6,X5),admire(X6,X3)),
                        write(X5,X1))))
   (3) several(#,X1,let(X1),
               two(#,X3,
                   prof(X3)
                   &
                   every(#,X4,stu(X4)&of(X4,X3),
                         most(#,X6,dean(X6),admire(X4,X6))),
                   write(X3,X1)))
   (4) two(#,X1,
           prof(X1)
           &
           every(#,X2,stu(X2)&of(X2,X1),
                 most(#,X4,dean(X4),admire(X2,X4))),
           several(#,X3,let(X3),write(X1,X3)))
```

The "invisible" determiner *every* in the sentence above is always outscoped by the head quantifier *two*.

(323) Q: two professors interviewed three students most pictures of whom pleased exactly two judges.

```
LF: 4 way ambiguous sentence
   (1) three(#,X1,
             stu(X1)
             &
             most(#,X2,pic(X2)&of(X2,X1),
                  two(=,X4,jud(X4),please(X2,X4))),
             two(#,X3,prof(X3),interview(X3,X1)))
   (2) two(#,X1,prof(X1),
           three(#,X3,
                 stu(X3)
                 &
                 most(#,X4,pic(X4)&of(X4,X3),
                      two(=,X6,jud(X6),please(X4,X6))),
                 interview(X1,X3)))
   (3) two(#,X1,prof(X1),
           two(=,X3,jud(X3),
               three(#,X5,stu(X5)&
                          most(#,X6,pic(X6)&of(X6,X5),please(X6,X3)),
                               interview(X1,X5))))
   (4) two(=,X1,jud(X1),
           three(#,X3,stu(X3)&most(#,X4,pic(X4)&of(X4,X3),please(X4,X1)),
                 two(#,X5,prof(X5),interview(X5,X3))))
```

Since they are both inside the relative clause, *most pictures* and *two judges* can alternate their relative scope. However, *most pictures* is always outscoped by *three students*.

(324) Q: Two girls think that three men admire four women.

```
LF: 4 way ambiguous sentence
   (1) four(#,X1,woman(X1),
            two(#,X3,girl(X3),
                think(X3,that(three(#,X5,man(X5),admire(X5,X1))))))
   (2) two(#,X1,girl(X1),
           think(X1,that(four(#,X3,woman(X3),
                             three(#,X5,man(X5),admire(X5,X3))))))
   (3) two(#,X1,girl(X1),
           think(X1,that(three(#,X3,man(X3),
                        four(#,X5,woman(X5),admire(X3,X5))))))
   (4) two(#,X1,girl(X1),
           four(#,X3,woman(X3),
                think(X1,that(three(#,X5,man(X5),admire(X5,X3))))))
```

Notice that the reading (4) above is due to the semantics of the verb *think*, as discussed in Section 5.6.

Without a degenerate quantifier semantics, the system generates four distinct logical forms for the following sentence.

(325) Q: some student studied two dialects of every language.

```
LF: 4 way ambiguous sentence
   (1) every(#,X1,lang(X1),
             two(#,X3,dialect(X3)&of(X3,X1),
                 some(#,X5,stu(X5),study(X5,X3))))
   (2) some(#,X1,stu(X1),
            every(#,X3,lang(X3),
                  two(#,X5,dialect(X5)&of(X5,X3),study(X1,X5))))
   (3) some(#,X1,stu(X1),
            two(#,X3,dialect(X3)&every(#,X4,lang(X4),of(X3,X4)),
                study(X1,X3)))
   (4) two(#,X1,dialect(X1)&every(#,X2,lang(X2),of(X1,X2)),
           some(#,X3,stu(X3),study(X3,X1)))
```

There is a new logical form, shown below, when quantifiers are allowed to have a degenerate quantifier semantics. Other readings are logically equivalent to the four logical forms shown before.

(326)
```
(5) every(#,X1,lang(X1),
          some(#,X3,stu(X3),
              study(X3,two(X5^(dialect(X5)&of(X5,X1))))))
```

The following shows the 'saxophonist' sentence.

(327)
```
Q:  Every girl admired but most boys detested one saxophonist.
LF: 2 way ambiguous sentence
   (1) every(#,X1,girl(X1),admire(X1,*one(sax)))
       &
       most(#,X1,boy(X1),detest(X1,*one(sax)))
   (2) one(#,X1,sax(X1),
           every(#,X3,girl(X3),admire(X3,X1))
           &
           most(#,X3,boy(X3),detest(X3,X1)))
```

The sentence is correctly analyzed to have two readings, as predicted by the theory. Notice that we need a degenerate quantifier interpretation for one of the readings.

Chapter 7

EVALUATION OF SCOPED LOGICAL FORMS

We have shown in Chapter 6 that the system generates logical forms that correspond to available readings. This chapter describes how to evaluate these logical forms using Prolog.

Section 7.1 explains the basic idea for the evaluator. The evaluator is described in further detail in Section 7.2. Section 7.3 goes over some sample runs.

7.1 PROLOG EVALUATION OF SCOPE READINGS

The Prolog evaluator implements the model-theoretic semantics of the proposed logical forms defined in Chapter 4. The logical forms have the syntax shown below in BNF.

(328)
```
LF ::= QLF | PLF | CLF
QLF ::= Q(VAR,LF,LF) | QN(C,VAR,LF,LF)
PLF ::= P1(ARG) | P2(ARG,ARG) | P3(ARG,ARG,ARG)
CLF ::= LF & LF | LF v LF
ARG ::= NP | QNP
NP ::= VAR | PN
QNP ::= *Q(VAR^LF) | *Q(N)
VAR ::= {variables}
C ::= '>' | '>=' | '<' | '<=' | '=' | '#'
Q ::= every | most | ... | QN
QN ::= one | two | ...
N ::= man | woman | dog | cat | ...
PN ::= john | mary | ...
P1 ::= sneeze | sleep | ...
P2 ::= cook | find | ...
P3 ::= give | show | ...
```

Quantified logical forms, or `QLF`'s, have a predicate that corresponds to natural language quantifier. Conjoined logical forms, or `CLF`'s, have an infix conjunction operator that corresponds to natural language conjunction item '*and*' or disjunction item '*or*'. Predicate logical forms, or `PLF`'s, have a predicate that corresponds to a natural language verb. The well-formedness of the logical forms is guaranteed by the projection of CCG lexical entries which contain no unbound variables and no vacuous quantification. `Q(VAR,LF1,LF2)` is a syntactic sugar for `Q(#,VAR,LF1,LF2)`.

Logical forms are divided into three major patterns for the design of the evaluator.

(329) The base case includes `sleep(john)` and `find(mary,john)`, where the head corresponds to an English verb or a preposition and the arguments correspond to English proper nouns.

(330) The general case includes `two(>,man(X),sleep(X))`, where the head corresponds to the translation of an English quantifier. Logical forms that contain variables, such as `man(X)`, are a special case of the base case, but they are handled within the general case, since those logical forms always appear within quantified logical forms and Prolog offers a convenient framework for capturing them within the general case, as will be described shortly.

(331) The degenerate case is another special case of the base case, which includes `sleep(*two(X^man(X)))` or `sleep(*two(man))`. Here the argument has an NP semantics with a degenerate quantifier representation.

First, consider the base case. The logical forms of this kind can be evaluated by a simple database lookup, with the Prolog query `call(LF)`. The following simple clause implements the case, ignoring the condition checking.

(332)
```
eval(LF,V) :- if(call(LF), V = true, V = false).
```

In English, the clause reads: "In order to evaluate `LF`, run the query `call(LF)`. If the query is successful, the result is true, and false otherwise." (332) utilizes SICStus Prolog's built-in command `if/3` to combine the following two separate clauses.

(333)
```
eval(LF,true) :- call(LF).
eval(LF,false).
```

For the general case, consider (334) (a), which represents the English sentence (b).[1]

(334) (a) `two(>,X,man(X),sleep(X))`

(b) More than two men slept.

In order to evaluate (a), the size of the set of individuals that satisfy both the restriction and the body should be computed and compared with the number corresponding to the operator `two`, or 2, using the comparator `>`. The size of this set can be computed by the Prolog built-in predicate `setof/3`. Its syntax is defined as follows, where the value of the output variable `Set` is the set of individuals that satisfy the condition `Cond` whose expression syntactically contains the variable `V`.

(335)
```
setof(V, Cond, Set)
```

[1]Again, tense is ignored here.

The set members are collected by repeatedly trying to satisfy the condition and letting it fail for other remaining candidates. For instance, (b) below shows one of the responses to the query (a).

(336) (a) `| ?- setof(X, man(X), S).`

(b) `S = [bob,eric,john,mark,mike,tom]`

The following clause implements the evaluator for the pattern in (334).

(337)
```
eval(LF, V) :- LF =.. [Q,C,X,R,B],
               setof(X, (R&B), S),
               length(S, L),
               value(Q, N),
               {compare L and N with C and set V accordingly}.
```

The command `LF =.. [Q,C,X,R,B]` simulates the unification of `Q` with a second-order predicate via the operator `=..`, where the command succeeds with `LF` unified with `Q(C,X,R,B)`. `R` and `B` are unified with `man(X)` and `sleep(X)`, respectively. When the `setof` command is executed, each individual (the value of `X`) that satisfies both `man(X)` and `sleep(X)` is collected into the set whose name is `S`. `L` gives the size of the set `S`, and `N` returns the numeric value that corresponds to the operator (which is originally a determiner) `Q`.

The evaluation of `R` and `B` in (337) relies on the built-in Prolog evaluator. Since they can also take the form of other (user-defined) patterns, including the general case, we need to make a recursive call to `eval` in general. The modified clause is shown below.

(338)
```
eval(LF, V) :- LF =.. [Q,C,X,R,B],
               setof(X, (eval(R, true)&eval(B, true)), S),
               length(S, L),
               value(Q, N),
               {compare L and N with C and set V accordingly}.
```

Evaluation of logical forms that contain quantifiers such as *every* or *most* requires the value of the restrictor set as well. For example, the following implements the evaluator for *every*.

(339)
```
eval(every(X,R,B), V) :-
                    setof(X, eval(R, true), Sr),
                    setof(X, (eval(R, true)&eval(B, true)), S),
                    if(Sr == S, V = true, V = false).
```

Further details will be discussed in the following section.

Finally, consider the degenerate case. In order to evaluate logical forms that contain a degenerate representation for NP, such as `sleep(*two(X^man(X)))` or its η-reduced equivalent `sleep(*two(man))`, we use a trick to locally pull out the quantifier in question, as in the model-theoretic semantics for l-terms shown in Section 4.2.3, so that it will take an appropriate scope over the logical form in which the old quantified NP argument is replaced with a variable.[2] Again, further details will be discussed in the following section.

7.2 EVALUATING THE DUAL QUANTIFIER REPRESENTATION

This section examines the evaluator in more detail. The evaluator is coded to check for the following patterns in turn:

(340) (a) `eval((LF1&LF2),V) :- {clause body}.`

(b) `eval(LF,V) :- LF =.. [Q,C,X,R,B], {remaining clause body}.`

(c) `eval(LF,V) :- LF =.. [Pred,Arg], {remaining clause body}.`

(d) `eval(LF,V) :- LF =.. [Pred,Arg1,Arg2], {remaining clause body}.`

(a) handles conjoined logical forms. (b) handles quantified logical forms. (c) and (d) handle cases where the operator is a natural language predicate. Predicates of a higher arity, e.g. 3, should also be handled.

First, (341) shows the code for conjoined logical forms.

(341)
```
eval((LF1&LF2), V) :-
        eval(LF1, V1), eval(LF2, V2),
        if(V1, V = V2, V = false).
```

[2]As mentioned in Section 4.2.3, the program does not take into account the "pointer" idea.

LF1 is first evaluated to V1, and then LF2 is evaluated to V2. If V1 is true, then the result is the same as V2. Otherwise, the result is false.

(342) shows the code for quantified logical forms.

(342)
```
eval(LF, V) :-
        LF =.. [Q,C,X,R,B],
        if(Q = every, eval_every(X,R,B,V),
        if(Q = most, eval_most(X,R,B,V),
        if(numeric(Q), eval_num(Q,C,X,R,B,V),
        fail)))).
```

The logical form LF is decomposed and passed down to an individual evaluator routine for each operator, such as every and most. This is to give a visual structure to the code, and the code can alternatively be replaced with actual evaluator routines, as shown in (343) below.

(343)
```
eval(every(C,X,R,B),V) :- {clause body}.
eval(most(C,X,R,B),V) :- {clause body}.
eval(LF,V) :- LF =.. [Q,C,X,R,B],
              !, numeric(Q),
              eval_num(Q,C,X,R,B,V).
```

Each subroutine will be described shortly.

We will describe the evaluation of the base case, where the operator corresponds to a natural language predicate, and then describe the evaluation for the degenerate case. In the actual coding they are handled in the same clause body.

(344)
```
eval(LF, V) :- LF =.. [Pred, Arg],
               !, simple(Arg),
               if(call(LF), V = true, V = false).
```

When LF is of the form Pred(Arg) and Arg is simple, then the logical form LF is directly evaluated though the Prolog command call/1. If it returns successfully, the result V is set to true and otherwise to false.

The following shows the evaluation for the degenerate case.

(345)
```
eval(LF, V) :-
        LF =.. [Pred, Arg],  ~simple(Arg),
        !, functor(Arg, Name, 1),
        definedQ(Name), arg(1,Arg,R),
        !, atom(R), R = X^LF2, Pd =.. [Pred,X],
        LFa =.. [Name,#,X,LF2,Pd], eval(LFa, V).
```

The idea is to re-supply the evaluator routine with a new logical form, `LFa`, which has the same form as a quantified logical form. For instance, the task of evaluating (a) below is converted into that of evaluating (b).

(346) (a) `sleep(*most(X^man(X)))`

(b) `most(#,X,man(X),sleep(X))`

Evaluation of logical forms which contain predicates of arity 2 is handled similarly, only that it requires more case analysis.

Evaluation of quantified logical forms that have an operator *every* is done as explained in the previous section.

(347)
```
eval_every(X, R, B, V) :-
        setof(X, eval(R, true), Sr),
        setof(X, (eval(R, true)&eval(B, true)), Sb),
        if(Sr == Sb, V = true, V = false).
eval_every(_, _, _, false).
```

We assume that *more than two thirds* is a working measure for evaluating logical forms whose operator is `most`. A more realistic measure should perhaps be derived from the context.

(348)
```
eval_most(X, R, B, V) :-
        setof(X, eval(R, true), Sr),
        setof(X, (eval(R, true)&eval(B, true)), Sb),
        length(Sr, LSr), length(Sb, LSb),
        L is (2*LSr)//3, if(LSb >= L, V = true, V = false).
eval_most(_, _, _, false).
```

In order to evaluate quantified logical forms with a numeric operator, we need to compute the number of individuals that satisfy both the restriction and the body.

(349)
```
eval_num(Q, C, X, R, B, V) :-
        setof(X, (eval(R, true), eval(B, true)), Set),
        (length(Set, S),
        Qval =.. [Q, N], call(Qval),
        if(C = '>=', (if(S >= N, V = true, V = false)),
        if(C = '>',  (if(S > N, V = true, V = false)),
        if(C = '=',  (if(S =:= N, V = true, V = false)),
        if(C = '<=', (if(S =< N, V = true, V = false)),
        if(C = '<',  (if(S < N, V = true, V = false)),
        if(C = '#',
        % Missing modifier, assume 'at least'.
        if(S >= N, V = true, V = false),
        V = 'unknown modifier'))))))).
eval_num(_, _, _, _, _, false).
```

7.3 EVALUATION OF LOGICAL FORMS

This section goes over sample runs of the evaluator code with respect to the sample database defined in 7.3.1.

7.3.1 Sample Database

```
man(john). man(bob). man(tom). man(eric). man(mark). man(mike).
woman(susan). woman(jane). woman(mary). woman(kate).
rep(john). rep(bob). rep(tom). rep(susan). rep(jane).
boy(johnny). boy(bobby). boy(tommy). boy(mikey).
girl(julie). girl(susie). girl(katie).
sax(marsalis). sax(coltrane).
comp(ibm). comp(att). comp(hp). comp(msoft).
samp(s1). samp(s2). samp(s3). samp(s4). samp(s5).
of(john, ibm). of(bob, ibm). of(tom, ibm). of(susan, ibm). of(jane, att).
sleep(john). sleep(bob). sleep(tom). sleep(susan). sleep(jane).
sneeze(john). sneeze(susan). sneeze(jane). sneeze(mary). sneeze(kate).
see(john, susan). see(john, jane). see(bob, kate). see(bob, jane).
see(john, s1). see(john, s2). see(john, s3). see(john, s4).
```

```
see(bob, s1). see(bob, s2). see(bob, s3). see(bob, s5).
see(tom, s1). see(tom, s2). see(tom, s3). see(tom, s4).
see(jane, s1). see(jane, s2). see(jane, s3). see(jane, s4).
admire(julie, marsalis). admire(susie, marsalis). admire(katie, marsalis).
detest(johnny, coltrane). detest(bobby, coltrane). detest(tommy, marsalis).
one(1). two(2). three(3). four(4). five(5). six(6).
numeric(one). numeric(two). numeric(three). numeric(four).
numeric(five). numeric(six).
```

7.3.2 Sample Runs

The following shows sample outputs of the evaluator code with respect to the database shown earlier. Since the point in this section is to show how the evaluator works, we will use much fewer examples than the previous chapter.

(350) Q: John slept.

LF: 1 way ambiguous sentence

```
(1) sleep(john) : true
```

In the DB, there is a clause exactly matching the logical form `sleep(john)`, hence the logical form is considered true.

(351) Q: Every man slept.

LF: 1 way ambiguous sentence

```
(1) every(#,X1,man(X1),sleep(X1)) : false
```

There are six men in the DB, but only three of them slept. So the logical form is false.

(352) Q: Every woman sneezed.

LF: 1 way ambiguous sentence

```
(1) every(#,X1,woman(X1),sneeze(X1)) : true
```

All the four known women sneezed, making the logical form true.

(353) Q: At least two men slept.

LF: 1 way ambiguous sentence

```
(1) two(>=,X1,man(X1),sleep(X1)) : true
```

Out of the six known men, three men, `john`, `bob`, and `tom`, slept, satisfying the condition *at least two* and making the logical form true.

(354) Q: At least two men saw exactly one woman.

LF: 2 way ambiguous sentence

```
(1) one(=,X1,woman(X1),two(>=,X3,man(X3),see(X3,X1))) : true
(2) two(>=,X1,man(X1),one(=,X3,woman(X3),see(X1,X3))) : false
```

The sentence is ambiguous between readings (1) and (2). `jane` was seen by two men, `john` and `bob`, making (1) true. As for (2), `john` saw not only `jane`, but also `susan`. Likewise, `bob` saw not only `jane`, but also `kate`. Since `john` and `bob` are the only men who saw women, (2) is false, as the condition *exactly one* is not met. At the level of semantics, it is not clear which reading the speaker of the sentence intended, so we can not narrow down the reading(s) any further.

(355) Q: Exactly one woman saw most samples.

LF: 3 way ambiguous sentence

```
(1) most(#,X1,samp(X1),one(=,X3,woman(X3),see(X3,X1))) : true
(2) one(=,X1,woman(X1),see(*most(samp),X1)) : true
(3) one(=,X1,woman(X1),most(#,X3,samp(X3),see(X1,X3))) : true
```

The sentence has three readings. Reading (1) is true because there are there are five known samples, `s1` through `s5`, and each of the four samples `s1` through `s4` was seen by exactly one woman, `jane`. (2) and (3) always evaluate to the same truth value in the current implementation of the evaluator. In this case, the value is true.

(356) Q: Every representative of exactly one company saw more than three samples.

LF: 4 way ambiguous sentence

```
(1) every(#,X1,rep(X1)&one(=,X2,comp(X2),of(X1,X2)),
          three(>,X3,samp(X3),see(X1,X3))) : false
(2) one(=,X1,comp(X1),
        every(#,X3,rep(X3)&of(X3,X1),
              three(>,X5,samp(X5),see(X3,X5)))) : true
(3) three(>,X1,samp(X1),
          every(#,X3,rep(X3)&one(=,X4,comp(X4),of(X3,X4)),
                see(X3,X1))) : false
(4) three(>,X1,samp(X1),
          one(=,X3,comp(X3),
              every(#,X5,rep(X5)&of(X5,X3),see(X5,X1)))) : true
```

There are four readings in this sentence. There are five known representatives, `john`, `bob`, `tom`, `susan`, and `jane`. Among them, `john`, `bob`, `tom`, and `susan` are those of the company `ibm`. `jane` is a representative of `att`. All of them are representatives of exactly one company. That is, there are no one who represents two companies at the same time. Except for the others, `susan` didn't get to see any sample. Therefore reading (1) is false. Reading (2) is true, on the other hand, since there is one company, or `att`, such that every representative of it, in this case only one person, or `jane`, saw most samples, samples `s1` through `s4`. Reading (3) is false, there is no group of more than three samples such that each sample in the group was seen by all the representatives. Reading (4) is true though, since the condition now is if there is a group of more than three samples such that there is exactly one company so that every representative of it saw each sample in the group. In the DB, this group of samples is `s1`, `s2`, `s3` and `s4`, each of which was seen by `jane`, who is the only representative of a company `att`. Since no other company has representatives that satisfy the condition that everyone of them saw most samples, the clause *exactly one company* is likewise met.

(357) Q: Every girl admired one saxophonist.

LF: 3 way ambiguous sentence

```
(1) every(#,X1,girl(X1),admire(X1,*one(sax))) : true
(2) every(#,X1,girl(X1),one(#,X3,sax(X3),admire(X1,X3))) : true
(3) one(#,X1,sax(X1),every(#,X3,girl(X3),admire(X3,X1))) : true
```

There are three known girls, `julie`, `susie`, and `katie`. All of them admire the same saxophonist, `marsalis`. Hence reading (1), which evaluates to the same truth value as reading (2) in the present implementation, is true. Reading (3) is likewise true.

(358) Q: Most boys detested one saxophonist.

LF: 5 way ambiguous sentence

```
(1) detest(*most(boy),*one(sax)) : true
(2) most(#,X1,boy(X1),detest(X1,*one(sax))) : true
(3) most(#,X1,boy(X1),one(#,X3,sax(X3),detest(X1,X3))) : true
(4) one(#,X1,sax(X1),detest(*most(boy),X1)) : true
(5) one(#,X1,sax(X1),most(#,X3,boy(X3),detest(X3,X1))) : true
```

There are four boys, `johnny`, `bobby`, `tommy`, and `mikey`. `johnny` and `bobby` detested a saxophonist named `coltrane`. `tommy` detested `marsalis`. Since three boys, out of four, detested one saxophonist, readings (2) and (3) are true. Due to the algorithm we use for evaluating the condition *most*, two out of four is considered to satisfy the condition. Thus readings (4) and (5) evaluate to true as well, since `coltrane` was detested by two boys.

(359) Q: Every girl admired but most boys detested one saxophonist.

LF: 2 way ambiguous sentence

```
(1) every(#,X1,girl(X1),admire(X1,*one(sax)))
    &
    most(#,X1,boy(X1),detest(X1,*one(sax))) : true
(2) one(#,X1,sax(X1),
        every(#,X3,girl(X3),admire(X3,X1))
        &
        most(#,X3,boy(X3),detest(X3,X1))) : false
```

This is Geach (1970)'s sentence. Reading (1) is true, since reading (1) of (357) is true and so is reading (2) of (358). But reading (2) is false, since it was not the same saxophonist who was admired by every girl and detested by most boys.

Chapter 8

CONCLUSION

The main goals of this dissertation have been to develop a competence theory of quantification and to implement such a theory in a computational setting. In developing such a theory, we figured out that traditional approaches, linguistic or computational, tend to overgenerate logical forms. This led us to re-examine the way logical forms are mapped to scope readings, and also the way scope readings are considered available.

In the process, we have come to realize that whereas there is practically a plethora of theories for scope readings regarding fairly simple sentences, there is a relatively scarce interest in complex sentences with many quantifiers. This is understandable in many ways. For one, the abundance of theories for readings of simple sentences indicates the very fact that the consensus in the field is yet to be made. This only appears to make the study of complex sentences with many quantifiers a bit premature. For another, people rarely express or handle complex sentences with quantifiers more than say three. Even sentences with three quantifiers are normally considered torturous. This appears to suggest that the study of complex sentences with many quantifiers is unnecessary.

Nevertheless, there is a tantalizing glimpse of regularity in the way natural language syntax, especially surface structures, interacts with scope readings, and it appears that this regularity, if there is one, can be amplified by sentences with many quantifiers. A sensible approach to finding such regularity would be to somehow make it easy to determine whether a certain reading is available or not. As we have claimed in the thesis, the notion of functional dependency makes this task relatively straightforward. We have consequently proposed a novel hypothesis based on an extended notion of surface constituency. According to this hypothesis, two NPs can alternate their relative scope order if and only if the intervening fragment between the two NPs is a constituent in the extended sense and the entire fragment including the two NPs is also a constituent. We have shown that the scopings that are allowed under the hypothesis are the ones that are available. This means that the hypothesis can actually *explain* available scope readings.

While the hypothesis is tested against many natural language constructions that allow multiple NPs in a single grammatical sentence, the hypothesis must be encoded into a theory couched in a grammar formalism, so that it can be tested against novel language constructions, provided that the grammar can accept (or generate) such novel strings of words. The choice of a combinatory categorial grammar for this purpose is justifiable, as we have done in the dissertation, but there may be other grammar formalisms that are even more so. In a sense, it is surprising that CCGs can work to *predict* available readings with a dual quantifier representation, or two different kinds of lexical semantics for quantifiers. A further study into the matter should uncover why this is so, perhaps relating it to human cognitive abilities.

Although we have shown that our main goals are met in the dissertation, there are a number of obvious future work to be done. Improving the efficiency of the parser is the most urgent one. Incorporating other context-revealing information, such as intonation, into the framework, or porting the present theory to a framework that can handle such information, is also necessary.

Nonetheless, the preliminary results are encouraging. Some of such results are summarized below.

(a) There are many fewer readings than suggested by raw quantifier raising, quantifying-in, etc, even supplemented by the unbound variable constraint.

(b) The surface constituency hypothesis presents a reasonable account of what scope readings are available. An appropriate classification of quantifiers may result in further reduction of scope readings.

(c) The theory that encodes the hypothesis in a grammar formalism can predict available readings on novel sentences accepted by the grammar.

(d) The theory makes use of the dual quantifier representation in doing so. The coexistence of wide-scope quantifier semantics and degenerate quantifier semantics in a single theory is claimed to be necessary to characterize available scope readings. It is an open question, however, to assess the exact nature of degenerate quantifier semantics. We conjecture that other languages, including Icelandic and Hungarian, may shed light on the question.

(e) The theory supports an implementation, as demonstrated in Part III.

(f) While the theory generates many fewer distinct logical forms than most of the existing theories, the theory may generate logical forms that are redundant, due to the degenerate quantifier semantics. We predict that this redundancy may be reduced when we achieve a better understanding of the nature of degenerate quantifier semantics.

(g) The result lends tentative support to a model of human natural language understanding.

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