UNIVERSITY OF CALIFORNIA

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# Logical Forms for English Sentences

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Linguistics

by

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1990

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1990

To Janis L.

Awo amot a pu gwot nekep.
"One hand cannot tie a bundle."
- Kenyang proverb

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## ACKNOWLEDGMENTS

For a number of years, I have struggled with the desire to live two seemingly contradictory lifestyles. Studying computer science as an undergraduate, I was intrigued by the way in which formal methods might be applied to human languages. I applied for graduate study in UCLA's Linguistics Department, because I thought that the emphasis of "computational linguistics" should be on *linguistics*. I still think so. I actually believe that linguistic research can contribute lasting knowledge and understanding of the amazing phenomena of natural languages spoken by billions of people around the world. On the other hand, there is an engineer inside of me who loves to work with complete models, applying theoretical results *now* in a functional (maybe even useful) system.

For the most part, I have played out these fantasies in two different locations. Although it is the theoretical side of my life which is represented in this dissertation, its completion owes significantly to my engineering colleagues. Therefore, I wish to express my thanks to David Liu, Jim Cheung, and Julie Irvine. While developing software (on time and under budget!) for use on the factory floor, I had some scheduling flexibility to pursue my interests in linguistics. Furthermore, their persistence and striving for excellence has been an inspiration to me.

Many of the ideas in this dissertation began in Ed Keenan's semantics courses and Eric Wehrli's computational linguistics courses. It was there that I became interested in developing a computational model of a semantic theory. One of the advantages of being a graduate student for too many years is that I have benefitted from enumerable conversations and consultations with Ed Keenan. I want to thank him for guiding me to interesting questions concerning the interaction of syntax and semantics.

I also want to thank the other members of my committee. Dominique Sportiche helped clarify my thinking on the level of LF within the GB framework. Since coming to UCLA a year ago, Ed Stabler has read everything I have given him (now that's a committee member!) and offered much helpful criticism. David Kaplan was always quick to challenge my scope judgments and forced me to think through my examples carefully. Stott Parker gave me some much needed practical advice when I was rewriting my parser. While I was thinking through some of the issues on higher-order referentially dependent noun phrases, I benefitted from a seminar on anaphora taught jointly by Kit Fine, Irene Heim, and Ed Keenan. Every committee member disagrees with some portion of this dissertation (subject-wide scope reading intended), but as a whole it has benefitted from their input.

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I would like to thank my parents for the many years of emotional and financial support they provided throughout my education. My mother often encouraged me to keep working on my dissertation, so I am especially sorry that she died before having a chance to celebrate its completion.

I started these acknowledgments by mentioning my interest in two areas, theoretical linguistics and software development. There is actually a third area of my life which is much more important than these two. I would like to thank my wife, Jan, and my two daughters, Jenny and Pam, for the sense of purpose they provide to me. We have had many good times while I was working on this dissertation. Each of us

has also had times of emotional struggle, negotiation of priorities, and delay of personal goals in order to help one of the other family members at the moment. I appreciate Jan's support through these times. Although she did not contribute to the technical content of this dissertation, she has contributed significantly to its completion.

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## PUBLICATIONS AND PRESENTATIONS

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ABSTRACT OF THE DISSERTATION

# Logical Forms for English Sentences

by

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This dissertation investigates the relationship between syntactic structure and semantic interpretation. The goal of this study is to develop an explicit model of the mapping from surface syntactic forms to a level of Logical Form (LF) and finally to truth values. The mapping from surface structure to LF is done within the framework of the Government and Binding (GB) theory of grammar. A computationally tractable interpretation algorithm is then given for mapping logical forms onto truth values within an extensional model-theoretic semantics.

The interaction between quantifiers and Boolean operators is used as a diagnostic for the types of structures implicitly required for correct semantic interpretation of English sentences. Most current work on LF assumes that logical forms are ambiguous with regard to quantifier scope. However, two such analyses (May 1985, Aoun and Li 1989) are shown to give incorrect predictions of scope interactions when sentences with more than two quantifiers are considered. An

alternative model within the GB framework is proposed in which surface structures are mapped onto unambiguous logical forms. Besides providing a correct description of complex operator interactions, this approach has the advantage that entailment may be defined at the level of LF.

The algorithm for interpreting logical forms is based on work in generalized quantifiers (Barwise and Cooper 1981, Keenan and Stavi 1986). There are two important results of this algorithm. First, an explicit interpretation is provided for verb phrase (VP) adjunction. Such structures have been assumed in the GB literature, although a method has never been given for interpreting them. Second, the use of generalized quantifiers allows one to provide a uniform interpretation for a wide range of determiners, including those which are not first-order definable (e.g. 'most') and those constructed from Boolean combinations of determiners (e.g. 'some but not all', 'at least six but not more than twelve').

After considering generalized quantifiers, an analysis is given of referentially dependent noun phrases which inherently require a higher-order analysis. It is shown that these noun phrases may be grouped into four semantic classes which correlate with differences in syntactic distribution.

# Chapter 1

# Introduction

## 1.1 Statement of problems

This dissertation investigates the relationship between syntactic structure and semantic interpretation. The goal of this study is to develop an explicit model of the mapping from surface syntactic forms to a level of Logical Form (LF) and finally to truth values. The mapping from surface structure to LF is done within the framework of the Government and Binding (GB) theory of grammar. Within this theory, much of the motivation for the level of LF is syntactic (May 1977, Huang 1982). However, LF has always been seen as a level for representing quantifier scope and recent work relies heavily on scope judgments for determining general characteristics of LF (Aoun and Li 1989). While there has been some effort to give a model-theoretic interpretation of logical forms (May 1985, 1989), the semantics of LF has not been a primary interest of researchers working within the GB paradigm. For example, there has not been an account of the interpretation of coordination or negation in various categories. Certain constructions, such as noun phrases adjoined to verb phrases, have been assumed in the literature, although the interpretation for such structures has not been made explicit.

In this dissertation, I will not have much to say about the syntactic motivation for a level of LF. However, I will consider LF as a level of representation which may be interpreted by a model-theoretic semantics. One of the primary sources of data will be judgments concerning the ambiguity of quantifier scope (or lack thereof). After reviewing the literature on quantifier scope interaction and extending judgments to more complex cases, I will conclude that two of the prominent GB analyses of LF (May 1985, Aoun and Li 1989) do not correctly represent judgments about scope interactions involving three quantified noun phrases.

Another area which has not received much attention is the interaction of quantifier scope and Boolean operators. There have been numerous analyses of negation within the framework of generative grammar (Heny 1970, Lasnik 1972, Jackendoff 1972, Kroch 1974). However, these analyses have not been incorporated into the theory of LF. Similarly, little has been said about the lack of interaction between quantified phrases in coordinate structures. Therefore, one of the goals of this dissertation is to consider how coordination and negation interact with an algorithm that assigns scope to a quantified noun phrase.

In addition to quantifier scope, referential dependence is another phenomenon where semantic classifications are reflected in the syntax of natural languages. Some studies have given an interpretation for the simple reciprocal noun phrase each other (Fiengo and Lasnik 1973, Langendoen 1978, Heim, Lasnik, and May 1988). However, they do not provide a general semantic analysis which extends to complex reciprocals like each other's houses or each other but not each other's sisters. In chapter 5, I give a semantic interpretation for these complex reciprocals along with other referentially dependent noun phrases which do not contain pronouns.

## 1.2 Overview of the analysis

In chapter 2, I discuss several ways of representing semantic ambiguity at a level of representation which is semantically interpreted. One method is to have logical forms which are semantically ambiguous (May 1985, Williams 1986, Keenan 1989, Aoun and Li 1989). The interpretation procedure is nondeterministic under such an analysis. A single logical form may be mapped to more than one interpretation.

After considering judgments of quantifier scope interactions in chapter 3, I will argue that current theories which depend on ambiguous logical forms do not correctly characterize the range of possible quantifier scopes for complex sentences. One alternative is to map ambiguous surface structures onto unambiguous logical forms. I demonstrate how such an analysis can be given within the Government and Binding framework. The analysis depends on a rule of Quantifier Raising to move noun phrases to a position where their scope is directly represented by the c-command relation. Structures output by Quantifier Raising are filtered by several well-formedness conditions, including the Empty Category Principle (Chomsky 1981), the Condition on Proper Binding (May 1977), and the Invariant Scope Independence Principle.

The interpretation algorithm for these unambiguous logical forms is given in chapter 4. A model-theoretic semantics is given where a sentence in the language denotes a truth value. Much of this analysis relies on the interpretation of Boolean operators in Boolean Semantics (Keenan and Faltz 1985) and the interpretation of determiners in the generalized quantifiers framework (Barwise and Cooper 1981, Keenan and Stavi 1986). The analysis is then extended to higher-order referentially dependent noun phrases in chapter 5.

### 1.3 Results

The analysis of Logical Form in this dissertation leads to several significant results. First, it provides a descriptively adequate treatment of scope ambiguity judgments when more than two quantified noun phrases are in a sentence. While scope judgments are notoriously slippery and a source of disagreement among linguists, this analysis is based on solid widespread judgments about dative constructions and PP modifiers within an NP. Furthermore, this analysis stands in contrast to previous algorithms for generating interpretations from semantically ambiguous logical forms. Those algorithms are shown to be inadequate when more than two quantified noun phrases are considered.

Second, interpretation of determiners is consistent across quantificational environments. Determiners always receive the same denotation whether the NP is adjoined to IP, VP, or PP. Using the insights from work on generalized quantifiers, complex determiners are easily handled in this system.

Third, an interpretation is given for a noun phrase adjoined to a verb phrase. This construction has been assumed in the GB literature on LF, although its interpretation has never been explicitly stated. When the object is adjoined to the VP node, the sentence receives an object-narrow interpretation. Similarly, an interpretation is given for a noun phrase adjoined to a prepositional phrase. This structure gives the reading where the object of the preposition is bound within the N' constituent containing the PP modifier.

Fourth, the analysis of referentially dependent noun phrases provides a uniform semantics for simple and complex reciprocals, as well as other higher-order noun phrases. Given this analysis, four semantic classes of noun phrases may be defined and these semantic classes are shown to correspond to differences in syntactic distribution.

# Chapter 2

# Levels of representation

In this chapter, I will examine the requirements for a level of representation which serves as input to an interpretation module of the grammar. I begin by presenting the types of operations and relations to be defined on this level of representation. Based on these considerations, I will argue that surface structure is not the appropriate level of representation for semantic interpretation. In addition to the general semantic criteria for a level of logical form, I will consider several practical requirements which should be satisfied in order to build an automaton which interprets English sentences.

## 2.1 Semantic requirements for logical forms

### 2.1.1 Interpretation

In the model of grammar previously presented, there are two sources of input for the semantic component, a level of representation called logical form and a model of the world. It may appear obvious that a primary requirement for a logical form is for it to be interpretable by the semantic component. While no one disputes this claim, much recent work in the government and binding framework has presented arguments about the level of LF without saying how those hypothesized structures are interpreted. One of the goals of this dissertation is to remedy this situation by providing a formal statement of the interpretation of a substantial range of LF structures. The actual statement of interpretation is presented in chapter 4. For now, it is sufficient to note that discussing the advantages of one type of logical form over another is only completely meaningful in a situation where the interpretation of each logical form is explicit.

### 2.1.2 Truth in a model

I will assume that a minimal requirement for a semantic component is to be able to determine whether a simple declarative sentence is true with respect to a given model of the world. Natural language semantics must consist of much more than assigning simple truth values. I would not claim to be presenting an exhaustive semantic analysis of English sentences in this current study. However, human speakers certainly have the ability to determine the truth conditions of sentences. Therefore, the semantic model presented here is simply offered as a necessary, but not sufficient, portion of a natural language semantics module. In the following section, I will argue that the ability to calculate the truth of a sentence with respect to a model allows one to say a surprising number of interesting things about English sentences.

### 2.1.3 Entailment

Given the ability to calculate truth values with respect to a model, we can also make use of the entailment relation between sentences. Entailment is a relation that holds between two sentences just in case one sentence is true whenever the other is true. We say that logical form P *entails* logical form Q, written $P \models Q$, if Q is true in every model in which P is true. This allows us to judge the adequacy of the interpreter against our pretheoretical judgments about the meanings of English sentences. Therefore, entailment is used as a diagnostic tool to evaluate the adequacy of a given interpretive system.

Another reason to represent entailment is that it is one type of knowledge that people have about language. That is, people are able to make judgments about the conditions under which two distinct sentences might be true or false. For example, in any situation in which (1a) is true, (1b) must also be true. Therefore, "At least three students greeted Alice" entails "At least one student greeted Alice."

(1) a. At least three students greeted Alice
    b. At least one student greeted Alice.

It is possible to define the entailment relation on units smaller than an entire sentence (Keenan and Faltz 1985). The example in (1) indicates some type of relationship between the determiners at least three and at least one. However, at this point, it is sufficient to note that an entailment relation may be defined on sentences. Furthermore, it is desirable to do so, since speakers exhibit knowledge of entailments.

Additional examples are given below. The pairs illustrate the effect of an adjective, an adverb, and conjunction, respectively.[1] In each of the pairs of sentences, the (b) member must be true in any model in which the (a) member is true. These are easy judgments for a speaker to make. Since this is one type of knowledge that speakers have about their language, we would like to model it in our semantics.

(2) a. A black dog bit Alice.
    b. A dog bit Alice.

(3) a. Bob laughed loudly.
    b. Bob laughed.

(4) a. Chris ate spaghetti and drank Chianti.
    b. Chris ate spaghetti.

We may loosely say that one English sentence entails another, but due to the problem of ambiguity (discussed in the next section) entailment is not defined as a relation between English sentences. Entailment is a pre-order relation[2] defined at the

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[1] In this dissertation, I will only be concerned with extensional contexts. The statement of entailment becomes more complicated in intensional contexts, even for pairs of sentences which seem structurally similar to those illustrated in (2) - (4). For example, sentence (i) does not entail (ii), although they seem quite similar to the sentences in (2).

(i) An alleged murderer called Alice.
(ii) A murderer called Alice.

[2] A binary relation $\leq$ is called a pre-order iff it is reflexive ($x \leq x$) and transitive ($(x \leq y \;\&\; y \leq z) \rightarrow x \leq z$).

level of logical form. One logical form entails another just in case every model which makes the first logical form true also makes the second logical form true.

### 2.1.4 Ambiguity

Artificial languages, such as computer programming languages, are typically designed to be unambiguous in the lexicon, syntax, and semantics. This greatly simplifies the problem of determining the interpretation for a given input sentence. In contrast, ambiguity is one of the crucial problems which must be handled by any natural language processing system. Ambiguity occurs at all levels of natural language analysis. However, given the previous requirements for determining truth in a model and defining the entailment relation, it makes sense to define a logical form which is unambiguous. This means that an ambiguous input sentence must be mapped onto more than one logical form. Each reading of a sentence will be represented by a distinct logical form.

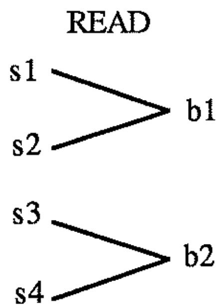
For example, consider sentences (5) and (6) below with two possible readings listed in (a) and (b), using an informal notation based on first-order predicate calculus. Reading (5b) entails (6b). In any model where (5b) is true, (6b) will also be true.

(5) At least two students read every book.
  a. For at least two students x, for every book y, x read y
  b. For every book y, for at least two students x, x read y

(6) Some student read every book.
  a. For some student x, for every book y, x read y
  b. For every book y, for some student x, x read y

However, (5b) does not entail (6a). In the simple model illustrated in (7), reading (5b) is true, since book $b_1$ was read by at least two students and $b_2$ was read by at least two students. However, reading (6a) is not true, since there is no student who read every book. The point of this simple exercise is to argue that entailment should be defined on an unambiguous level of representation.

(7)



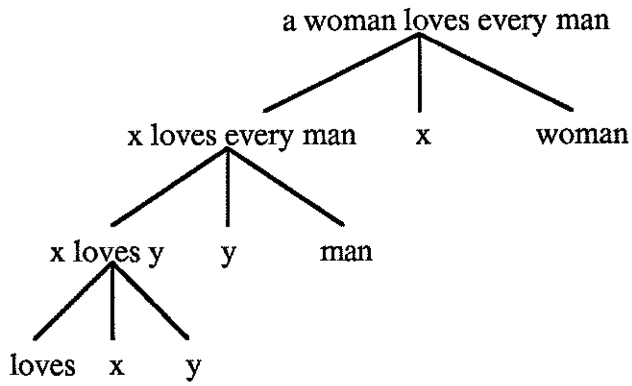

## 2.2 Surface structure as a logical form

In the previous sections we considered several requirements for logical form. Logical form is the level of representation to be processed by an interpretation module. We will limit our discussion to interpretations which lead to an assignment of a truth value. The entailment relation will be defined at the level of logical form and we will use this relation as a diagnostic for evaluating the adequacy of proposed semantic analyses. Finally, the mapping to logical form or the interpreter must be sensitive to the widespread ambiguity found in natural language.

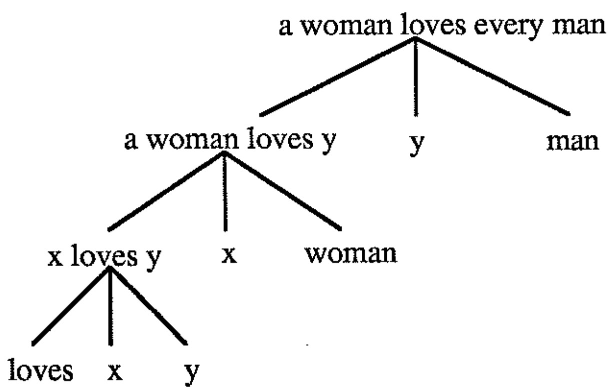
At this point we can consider the hypothesis that the level of surface structure is adequate as a level of logical form. Montague (1970) made such a proposal. His analysis of NPs is particularly interesting, since he showed how to interpret an NP as a constituent, rather than breaking it into a quantifier and predicate. However, in order to handle ambiguity, Montague had to assume that ambiguous sentences had distinct surface structures ( = logical forms in his model). Montague gave two analyses to sentence (8). The structure in (8a) represents the subject-wide scope reading ("there exists a woman such that she loves every man"), where the object NP, every man, combines with the transitive verb love. The object-wide scope reading ("for every man there exists a woman who loves him") is represented in (8b), where the subject NP, a woman, combines first with the verb to form a constituent.

(8) A woman loves every man.

(a)




(b)




This analysis is unappealing from a linguistic point of view, since there is no syntactic evidence that a semantically ambiguous sentence like (8) has two different (surface) syntactic structures. However, the trees represent distinct semantic analyses of a single input string. To summarize, Montague (1970) derives semantic analyses directly from an input string. Ambiguity is handled by generating more than one semantic analysis tree for a given input string. The interpretive component then interprets the analysis tree unambiguously.

Williams (1988) takes a slightly different approach to the ambiguity problem. In his analysis, a single syntactic structure may have several interpretations. The syntactic structure ( = logical form in Williams' model) is underspecified with respect to quantifier scope ordering. A rule of *Scope Assignment* determines the scope of a quantified NP and coindexes the NP with the phrase in which it has scope. For example, "John saw every car" has the following structure in which the quantified NP, every car, is shown to have scope over the entire sentence:

$[\text{John saw [every car}]_i]_{S:i}$

In the case of ambiguous quantifier scope orderings, as in (9), both quantified NPs are shown to have scope over the entire sentence. The relative order of the two quantifiers is not indicated in the structure.[3]

(9) $[\text{Everyone}_i \text{ saw someone}_j]_{S:i,j}$

Williams mentions in a footnote that it would be possible to attach ordering significance to the quantifier indices in the scope assignment S:i,j. However, as presented, there is no such ordering and the interpretive component will be able to interpret the single structure as having either subject-wide or object-wide scope.[4]

Williams does not give an explicit interpretation for the structures he proposes, so more work would be required to examine the adequacy of his analysis, especially with respect to quantifier scope interactions in more complex constructions. Keenan (1989) gives a similar model for handling ambiguity which includes an explicit algorithm for interpreting sentences. According to Keenan, a semantically

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[3] In previous work, van Riemsdijk and Williams (1986) had formulated the rule of Scope Assignment so that different scope orderings were represented as distinct structures:

Every man loves some woman

(a) $[_S \text{ i } [_S \text{ j } [_S \text{ every man}_i \text{ loves some woman}_j ]]]$

(b) $[_S \text{ j } [_S \text{ i } [_S \text{ every man}_i \text{ loves some woman}_j ]]]$

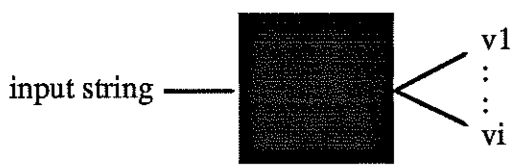
This is like Montague's approach, which was illustrated in (8) above. However, Williams' more recent statement of Scope Assignment, illustrated in (9) above, is a different analysis, because possible scope assignments are not disambiguated at any structural level. The interpretation procedure is responsible for disambiguating the structure. In this way, a single surface structure could be both true and false in the same model.

[4] Williams is not the only one to propose that different scope orderings are not represented by distinct structures. For example, Heny (1970), May (1985), Aoun and Li (1989), and Keenan (1989) have very different analyses, but they all propose that quantifier scope ambiguities are not represented by distinct logical forms.

ambiguous sentence like, "Every student kissed some teacher", has a single syntactic structure. There are two possible interpretations for this sentence which are consistent with the axioms of Keenan's Semantic Case Theory. The interpretations correspond roughly to the two analysis trees that Montague grammar would assign to this sentence. However, there are *not* two (syntactic) analysis trees in Keenan's model. Rather, the interpretation module is free to map a single structure onto more than one truth value.

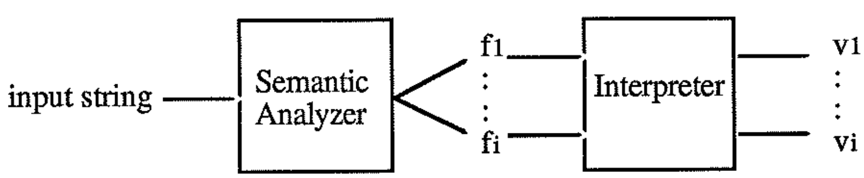
The basic problem of ambiguity is that a single input string may be associated with more than one truth value. This is illustrated in (10), where the black box represents a syntactic and semantic processor yet to be defined. A single input string enters the system from the left and this may be mapped onto truth values $v_1, \dots, v_i$.

(10) Mapping an ambiguous input string onto multiple truth values



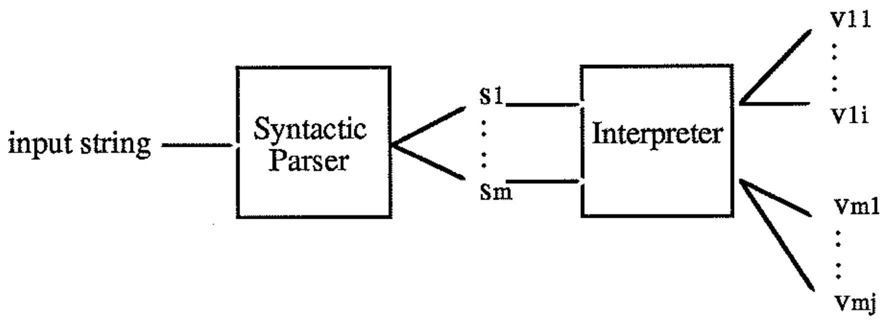

Montague's and Keenan's analyses illustrate two basic approaches to using surface structure as a logical form. Their analyses provide different architectures for the black box of (10). Under one approach, ambiguity is handled by the semantic analyzer which maps a single input string into semantically unambiguous formulas. Each such "surface structure" is then uniquely (unambiguously) mapped onto a truth value by the interpreter. This approach is schematized in Figure (11) below.

(11) Montague's analysis of ambiguity



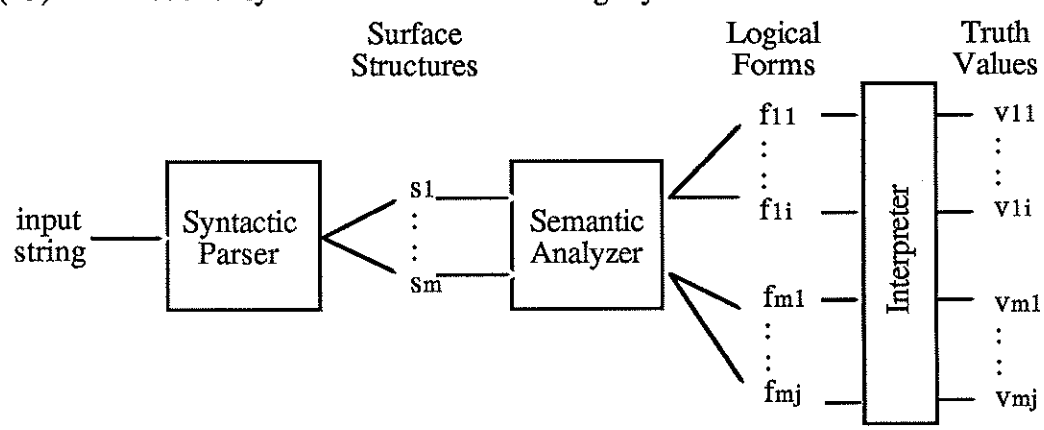
On the other approach, ambiguity is handled by the interpreter, which may assign more than one truth value to a single syntactic structure. In this model, schematized in (12), syntactic and semantic ambiguity are treated separately.

(12) Keenan's analysis of ambiguity




Another model, which I will use in the chapters that follow, separates syntactic and semantic ambiguity as in Keenan's model. However, semantic ambiguity is handled by mapping surface structures to unambiguous logical forms. The interpreter then maps these formulas one-to-one onto truth values. The advantage of this model is that there is a syntactic level of representation, Logical Form (LF), on which to define semantic relations such as entailment.

(13) A model of syntactic and semantic ambiguity




Previously, I said that sentence P entails sentence Q, if Q is true in every model in which P is true. In order for this notion to be meaningful, the sentences P and Q need to be unambiguous. Otherwise, one of the sentences could be both true and false with respect to a model. In figure (13), the entailment relation may be defined on the logical forms. In Keenan's model, there is no syntactic level of unambiguous representations. In order to incorporate entailment into this framework, it is necessary to give the definition of entailment relative to a particular interpretation. For example, the object-wide interpretation of (14a) entails the object-wide interpretation of (14b).

(14) a. Every child watched two cartoons.
b. Every child watched a cartoon.

The problem comes in trying to define "the object-wide interpretation." It is some function from input strings to truth values, but which function is it? It may be possible to define the function in a procedural way. In Keenan's terms this function interprets the subject by its nominative case extension, i.e. the subject NP denotation maps the relation denoted by the verb onto a property. The object NP is then interpreted as a generalized quantifier that maps the property to true or false. Let's call the interpretation function defined in this way $g_{nom}$, since it interprets the subject by its nominative case extension. Then we can say that (14a) entails (14b) relative to $g_{nom}$. This means that in any model in which $g_{nom}$ interprets (14a) as true, $g_{nom}$ will also interpret (14b) as true.

Suppose we define $g_{acc}$ as the object-narrow interpretation derived by interpreting the direct object by its accusative case extension. Then we could say that (14a) relative to $g_{nom}$ entails (14b) relative to $g_{acc}$. That is, the object-wide scope reading of (14a) entails the subject-wide scope reading of (14b).

As long as we can pick out the functions in this way, it may be useful to define the entailment relation relative to an interpretation. Note that there are many such interpretation functions. We could define $g_x$ to be the same as $g_{acc}$ on all sentences, except that it interprets (14b) with object-wide scope. In this case (14a) does not entail

(14b) relative to $g_x$. From a linguistic perspective, we are really only interested in "consistent" interpretations, i.e. those which interpret all sentences in the "same manner." For example, we would like to be able to refer to the interpretation function that gives an object-wide scope interpretation to every transitive clause. The entailment relation would have to be defined on the results of applying the interpretation function:

(15) Definition: For all expressions P, Q and all interpretations $g_i$, $g_j$, we say that P relative to $g_i$ *entails* Q relative to $g_j$, written as $g_i(P) \models g_j(Q)$, iff for every model in which P is true under $g_i$, Q is also true under $g_j$.

In this section, I have discussed several analyses of ambiguity. There are two basic alternatives. Either multiple unambiguous forms are generated or a single ambiguous form receives multiple interpretations. Defining an entailment relation on unambiguous forms is straightforward. When multiple interpretations are available, the entailment relation is more complex, since it must be defined with respect to a logical form *and* an interpretation. I sketched how this might be done in Keenan's Semantic Case theory.

## 2.3 Computational requirements for logical forms

The requirements on logical form that we have considered up to this point are stative requirements which define certain properties that are desirable for a logical form. Now let us consider several other procedural requirements which influence the way in which a logical form will be derived or evaluated. Whereas the first set of requirements defined what a logical form should look like, this set of requirements determines how procedures will act upon logical forms. The purpose of specifying these additional requirements is to enable us to create a working model which generates and evaluates logical forms.

### 2.3.1 Derivation from surface structure

The first computational requirement to be imposed on logical form is that it must be possible to derive the logical form from the surface structure. Thus, one must be able to write a set of procedures which will convert the surface structure into a logical form. All current work in computational linguistics assumes that one can construct a set of procedures to model a human listener's ability to determine the meaning of a sentence. Needless to say, there are many areas for which there is not yet a good model. However, I will assume that in principle it is possible to construct such a model.

I will assume a sequential processing model in which an input sentence is first assigned one or more parse structures, each of which is then mapped onto one or more logical forms. However, this requirement of deriving a logical form from a surface structure is also consistent with other processing models. The basic issue is whether a finite number of rules can derive a logical form from an input sentence in a finite amount of time. The actual parsing architecture to accomplish this can vary. For example, one might try to derive a logical form directly from an input sentence without passing through an intermediate level of syntactic structure (Small and Rieger 1982). Another possibility is for the syntax and semantics to be interleaved, processing cooperatively to derive well-formed syntactic and/or semantic representations (Mellish 1985). It would also be possible for the syntax and semantics to build structures in parallel (Gawron et al. 1982).

### 2.3.2 Interpretive complexity

This dissertation is primarily concerned with developing an algorithm for mapping surface structures to logical forms which are then mapped to truth values. A broader task, which I will not address, is to consider how logical forms are used by human reasoning processes. Interpretive complexity will depend on the representation chosen for logical forms, the representation of world knowledge, and the structure of the reasoning device. Thus, we can only evaluate the computational issues of Logical Form against a particular system of knowledge representation taken with a particular reasoning device. Within the Government and Binding framework, the level of Logical Form should be evaluated against the mind's representation of knowledge and its use in human reasoning. However, it is not possible to make such an evaluation at this time, due to the lack of knowledge concerning the nature of knowledge representation in the human mind. In chapter 4, I will undertake a much more modest task of showing how Logical Form can be evaluated in an extensional model-theory semantics.

# Chapter 3

# Boolean operators and quantifier scope

This chapter presents an algorithm for generating logical forms from English sentences. I will focus on the phenomena of quantifier scope ambiguities in order to demonstrate how the algorithm generates multiple unambiguous logical forms from a single ambiguous input sentence. In section 3.1, I discuss the linguistic facts to be treated. Section 3.2 reviews several other syntactic approaches to this data, followed by my algorithm in section 3.3. The interpretation of these logical forms is presented in the next chapter.

## 3.1 Quantifier scope ambiguities

It has long been observed that certain constructions with two NPs may be interpreted ambiguously. The different readings may be represented by the order in which the quantified noun phrases are assigned scope in the logical form. In this section, I will review some of these well known observations. In addition, I will present some new observations about how quantifier scope is affected by the presence of boolean operators.

The observations are grouped according to four types of constructions. Scope ambiguities within a clause are considered with respect to subject-object scope ambiguity in transitive sentences and with respect to two object NPs in the double object and dative constructions. Scope ambiguities within an NP are presented for prepositional phrase modifiers.

### 3.1.1 Transitive sentences

In this section, I will first examine simple transitive sentences of the form $[_S$ NP V NP$]$. This is the simplest environment in which to examine quantifier scope ambiguities. Then I will consider additional complexity in the form of coordination and negation of the various constituents of a simple transitive sentence.

#### 3.1.1.1 Simple structures

Quantifier scope ambiguity is often illustrated with simple transitive sentences that have quantified NPs in subject and object position as in (1). This sentence has two readings which are represented in first-order logic by (1a) and (1b).

(1) Every student read a book.
  a. $\forall x(\text{STUDENT}(x) \rightarrow \exists y(\text{BOOK}(y) \ \& \ \text{READ}(x,y)))$
  b. $\exists y(\text{BOOK}(y) \ \& \ \forall x(\text{STUDENT}(x) \rightarrow \text{READ}(x,y)))$

Logical form (1a) represents the subject-wide reading where it is possible that each student read a different book. However, in the object-wide reading of (1b), there must be a single book which every student read.

In this study, I am interested in defining all possible scope orderings, as opposed to trying to select the "preferred" order. In general, simple sentences of this sort are ambiguous no matter which two quantifiers are used in subject and object position. In some cases, there may be a strong preference for giving one of the quantifiers wide scope over the other. Some authors use heuristics to assign quantifier scopings. Colmerauer (1982) suggests several structural criteria for selecting the preferred reading when more than one quantified NP is present. Saint-Dizier (1985) derives quantifier scope preferences from the linear order of quantifiers. Moran (1988) gives an algorithm for determining scope preferences. The procedure uses a set of rules that define preferences for individual determiners, pairs of determiners, and scope preferences for different surface structure configurations. Hurum (1988) defines heuristic scoping weights to indicate preferred scope readings. For example, Hurum claims that the determiner no in subject position strongly disfavors an object-wide scope reading for the sentence. Hurum's example (27), given below as (2), illustrates this tendency.

(2) Nobody read every article.

It is difficult to imagine a context in which this sentence could be uttered with the intended reading that "Every article is such that nobody read it." We might expect Hurum's observation to generalize from no to other monotone decreasing determiners, as long as the object NP is limited to the universal quantifier every:

(3) a. Less than three students read every article.
b. Not more than six children carried every bench.
c. At most four professors reviewed every application.

These examples favor a subject-wide scope reading, although the object-wide scope reading is certainly not ruled out. It has often been observed that subjects tend to receive a wide-scope interpretation. In my judgment, the sentences in (3) do not force a subject-wide scope reading any more than the comparable sentences in (4) below, where the subject NP is monotone increasing:

(4) a. Not less than three students read every article.
b. More than six children carried every bench.
c. At least four professors reviewed every application.

When the object NP does not contain the universal quantifier, Hurum's claim that "no ... [has] a strong tendency to trap subsequent operators" seems less justified. In the following sentences, the object-wide scope reading is more accessible than in (2) and (3) above. The relevant object-wide scope reading is paraphrased in the (b) portion of each example.

(5) a. No graduate students applied for at least three fellowships.

b. There are at least three fellowships such that no graduate students applied for any of them.

(6) a. No professor read three articles that I submitted.
b. There are three articles that I submitted such that no professor read any of them.

(7) a. No lawyer visited more than half the inmates in the week following the riot.
b. For each member of a set of more than half the inmates, no lawyer visited him in the week following the riot.

While these studies of the "preferred" order of quantifiers may represent a listener's tendency to interpret a sequence of quantifiers, I do not want to rule out the other less preferred readings. Therefore, I will assume that one should derive both orders of quantifiers, subject-wide and object-wide, from a simple transitive sentence.

Some authors have suggested that the quantifier a certain and some instances of any are exceptions to this general principle. Evans (1980) notes that these quantifiers may take scope wider than the clause that contains them. Examples (8) and (9) (Evans' (28) and (29)) illustrate that a certain and any take scope over the second clause, so that the pronoun he is bound.

(8) If a certain friend of mine comes, he will tell the police.

(9) If any man loves Mozart, he admires Bach.

The ability of these quantifiers to bind the pronoun in this environment contrasts with other quantifiers (Evans' (18)):

(10) If many men come to the ball, Mary will dance with them.

Giving many men wide scope over the entire sentence would result in a reading paraphrased as, "For many men x, if x comes to the ball, Mary will dance with x." However, sentence (10) does not have this reading. It is more appropriately paraphrased as, "If many men come to the ball, Mary will dance with the men who come to the ball."

It is important to note that these quantifiers *almost* always, but not always, take wide scope. The bold face emphasis in the following quotes is mine:

> The principle I have stated effectively restricts the scope of a quantifier to those elements which it precedes and c-commands. However, there are quantifiers in English which are **almost** always given wide scope, and the principle must be qualified to exclude them. The two most important examples are a certain and any. (Evans 1980:343)

> Certain quantifiers are **relatively** insensitive to their logical environments as far as their interpretations are concerned. (Hornstein 1984:26)

Hintikka (1986) argues that a certain may take narrower scope than another quantifier in the same simple sentence. I agree with Hintikka's judgment that (11a) can be interpreted with everyone having wide scope, similar to the reading for (11b).

(11) a. Everyone loves a certain woman.
b. According to Freud, every man unconsciously wants to marry a certain woman – his mother.

The narrow scope reading for a certain is forced in (11b) by the presence of the bound variable pronoun his. However, (11a) may also have this narrow scope reading for a certain, even without the overt presence of the bound variable pronoun.[1]

While a certain strongly favors a wide scope interpretation, some ... or other strongly favors a narrow scope interpretation (David Kaplan, personal communication). In the following sentence, the normal preference for subject-wide scope is overridden by the presence of the "... or other" expression.

(12) Some professor or other reviewed every application.

---

1 Hornstein (1988) disputes these judgments. He claims that (11a) may not have a narrow scope reading for a certain woman. Under his analysis, $[_{NP}$ a certain woman$]$ remains *in situ* at LF, although it is interpreted with wide scope (no explicit algorithm is given for this proposed method of interpretation). In contrast, the object NP of (11b), $[_{NP}$ a certain woman – his mother$]$, will undergo Quantifier Raising, due to the presence of the bound variable pronoun, and may be interpreted as having narrower scope than the subject, $[_{NP}$ everyone$]$.

However, this is a preference and not an absolute requirement that some professor or other be interpreted with narrow scope.

To summarize, I will not attempt to prioritize scope orderings. I will assume that both the subject and object are capable of taking wide scope in a simple transitive sentence. As other studies have shown, there may be certain lexical combinations which strongly favor one of the readings. For example, a sentence of the form $[_S [_{NP}$ no __] V $[_{NP}$ every __]] strongly favors the subject-wide scope reading. The quantifier a certain strongly favors a wide-scope reading, no matter what its position. NPs of the form "some student or other" strongly favor a narrow scope interpretation. However, even with these combinations, an alternative reading is not completely ruled out. Therefore, the algorithm for mapping surface structures to logical forms should allow for both orders of quantifiers.

#### 3.1.1.2 Coordination

Let's consider slightly more complicated sentence structures involving coordinate noun phrases. Transitive sentences with coordinate NPs as subject or object exhibit two readings, just as in the previous section. Examples (13) and (15) show coordinate object NPs, while (14) and (16) illustrate coordinate NPs in subject position.

Conjunction (and)
(13) Object NP
  a. Every student read a book and two plays.
  b. At least three officers monitored two suspects and a lawyer.

(14) Subject NP
  a. Two coaches and three players reviewed every film.
  b. Most professors and some research assistants applied for a grant.

Disjunction (or)
(15) Object NP
  a. Every child drank from two glasses of juice or a small carton of milk.
  b. At least three voters sent two postcards or a letter.

(16) Subject NP
  a. One professor or two students reviewed every article.
  b. More than half the players or some representatives will sign two new contracts.

Sentence (13b) has a subject-wide scope reading in which there exists a group of officers, each of which monitored 2 suspects and a lawyer, so that there is a possibility that 6 suspects and 3 lawyers were involved. There is also an object-wide scope reading for this sentence in which possibly nine officers were involved in the monitoring (3 for each of 2 suspects and a lawyer).

The same subject-wide vs. object-wide ambiguity is observed in sentences with a coordinate NP as the subject as in (14a). There is a subject-wide reading where the same five individuals reviewed every film. The object-wide scope is also available where every film was reviewed by five individuals, but it does not have to be the same five individuals for each film.

When we consider algorithms for assigning the scope of an NP, it will be important to remember that there are several readings which are *not* available in the types of sentences considered above. In particular, the two conjuncts must be interpreted independently. That is, neither conjunct may be interpreted as having scope over the other conjunct. Consider the following example with the two readings expressed in first-order logic:

(17) Every student read a book and every article.
  a. $\forall s\ (STUDENT(s) \rightarrow$
     $(\exists b\ (BOOK(b)\ \&\ READ(s,b))\ \&\ \forall a\ (ARTICLE(a) \rightarrow READ(s,a)))$
  b. $\exists b\ (BOOK(b)\ \&\ \forall s\ (STUDENT(s) \rightarrow READ(s,b)))\ \&$
     $\forall a\ (ARTICLE(a) \rightarrow \forall s\ (STUDENT(s) \rightarrow READ(s,b)))$

In both representations, neither quantifier phrase, $\exists b$ nor $\forall a$, has scope over the other. It is possible to construct logical representations in which one of the quantifier phrases does have scope over the other, but such a form would not represent a possible reading for the original English sentence. In the following representation, each element corresponds to a portion of the English, but if nothing else, the interaction of the $\forall a$ and $\exists b$ quantifier phrases leads to a reading not available from "Every student read a book and every article."

$$\forall a\ (\text{ARTICLE}(a) \rightarrow \exists b\ (\text{BOOK}(b)\ \&\ \forall s\ (\text{STUDENT}(s) \rightarrow \text{READ}(s,b))))$$

This representation incorrectly allows the book that was read to vary according to the choice of article. The point is that not all orders of quantifiers are possible from the English sentence. The algorithm that assigns scope to an English NP will have to be sensitive to its position relative to the Boolean operators and and or.[2]

Turning now to coordinate verb phrases, we find that object NPs in such constructions do not take wide scope over the subject. May (1985) says that (18a) "seems to strongly favor a specific, broad scope construal for the subject phrase." In my judgment, the subject-wide scope is required. It is not possible for every student to take wide scope over some professor.

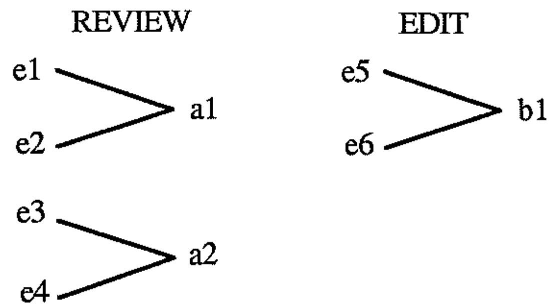
(18) Conjunction (and)
  a. Some professor admires every student and despises the Dean. (May 1985:59)
  b. Two associate editors reviewed every article and edited every book.

Similarly, the subject in (18b), two associate editors, must have wide scope over the object NPs. It must be the same two editors, call them $e_1$ and $e_2$, who reviewed every article and who edited every book. In my judgment, sentence (18b) is not true in the following model which corresponds to an object-wide scope reading:

2 Although there is no quantifier scope interaction between conjuncts, one of the conjuncts may bind a pronoun in the other conjunct:

(i) Most students and their parents attended the orientation meeting.

I will consider this difference between quantifier scope and pronominal binding at the end of the chapter.




I believe that an analysis of these judgments will be related to Keenan and Faltz's (1985) and Partee and Rooth's (1983) observations that verb phrase conjunction is only equivalent in general to sentential coordination when the subject denotes an individual. Thus, (19a) is logically equivalent to (19b), although (20a) is not logically equivalent to (20b).[3]

(19) a. John sang and danced.
b. John sang and John danced.

(20) a. Some student sang and danced.
b. Some student sang and some student danced.

Under Keenan and Faltz's analysis of complex VPs, the conjunction cannot be distributed against the quantified NP. Therefore, in examples like my (18b) above, the subject NP must have wide scope over both of the object NPs. I will assume that this restriction on potential scope ambiguity should be handled by an algorithm for semantic interpretation.[4]

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[3] Certain choices of quantifiers and coordinate conjunctions will lead to sentences which are logically equivalent. Example (ia) is logically equivalent to (ib) and (iia) is logically equivalent to (iib).

(i) a. Some student sang or danced.
b. Some student sang or some student danced.
(ii) a. Every student sang and danced.
b. Every student sang and every student danced.

However, one may not depend on this relationship in general, as illustrated by (20).

[4] If the sentence does not refer to specific events, it may be possible to get an object-wide scope reading with certain combinations of quantifiers. Sentence (i) requires subject-wide scope, but (ii) and (iii) do not.

(i) Two referees summarized every article and reviewed every book.
(ii) Most of the time, two referees summarize every article and review every book.
(iii) This journal requires that two referees summarize every article and review every book.

Verb phrases joined by the disjunction or allow for an additional reading that is not possible with the conjunction examples just presented. This type of difference between and and or has been discussed by Rooth and Partee (1982) and Larson (1985) with respect to opaque contexts. Limiting our discussion to scope ambiguities in a main clause, it is still evident that VP disjunction allows one reading in which the object NPs have scope over the subject NP. Example (21) below illustrates this ambiguity.

(21) Disjunction (or)
Every student will make a presentation or write a paper.

This sentence has a subject-wide scope reading in which for each student either he/she will make a presentation or he/she will write a paper. Different students may satisfy the course requirements in different ways under this reading. However, there is also a reading where the or takes wide scope over the subject. For example, a professor who is discussing possible course requirements might utter (21) followed by "... but I haven't decided which yet.", meaning that all of the students will perform the same task to satisfy the course requirements, but the professor is still choosing between two possible requirements. That is, either every student is such that he/she will make a presentation or every student is such that he/she will write a paper.

One reading which is *not* available in this sentence is a wide scope interpretation for either of the NPs in object position. Let's consider another example in which it would be more plausible pragmatically to interpret an object NP with wide scope. Suppose I am planning a game for my daughter's birthday party and I say:

(22) Every child will roll an egg or hold a spoon.

---

Since I am not considering aspectual distinctions at this time, I will continue to assume that object NPs in a conjoined VP may not take wide scope over the subject, at least in sentences describing a specific set of events. This appears to hold true for the extensional semantics under consideration here.

The subject-wide scope reading is certainly available in which for each child x, x will roll an egg or x will hold a spoon. It is also possible for the disjunction to take wide scope over the subject to produce a reading where for each child x, x rolls an egg *or* for each child x, x holds a spoon. However, I do not believe there are any other readings. In particular, there is no object-wide scope reading in which there is some egg y such that every child will roll y.

This means that an object NP may not take wide scope from within a coordinate VP, even though the coordinate conjunction or may sometimes be allowed to have wide scope over the subject. However, as I will show, the cases in which or may take wide scope seem to be limited to sentences in which the subject NP is universally quantified.

The wide scope or reading is not always available, as demonstrated by the following examples. The (a) member of each pair does not have a reading that is equivalent to the (b) member. This would be surprising if the or always had the option of taking wide scope. The four determiners in these examples have been chosen from different semantic classes.

(23) Persistent and monotonic increasing
  a. More than five students made a presentation or wrote a paper.
  b. More than five students made a presentation or
     more than five students wrote a paper.

(24) Persistent and monotonic decreasing
  a. Not all students made a presentation or wrote a paper.
  b. Not all students made a presentation or not all students wrote a paper.

(25) Anti-persistent and monotonic decreasing
  a. Less than five students made a presentation or wrote a paper.
  b. Less than five students made a presentation or
     less than five students wrote a paper.

(26) Neither persistent nor monotonic
  a. Exactly half the students made a presentation or wrote a paper.
  b. Exactly half the students made a presentation or
     exactly half the students wrote a paper.

There may be other factors which influence variation in speakers' judgments with respect to wide scope <u>or</u>. For example, Ballmer (1980) claims that (27a,b) are logically equivalent, while also claiming that (28a,b) are *not* equivalent.

(27) a. Al and Bert sing or dance. (Ballmer 1980:169)
b. Al and Bert sing or Al and Bert dance.

(28) a. Every man sings or dances.
b. Every man sings or every man dances.

Ballmer has confused a collective reading for the conjunction of proper names with a distributive reading for individuals. Sentence (27a) has a reading equivalent to (27b) when <u>Al and Bert</u> is interpreted as the collective where the two individuals act together. But the first sentence is not logically equivalent to the second. The more natural reading for (27a) is that Al sang or danced and Bert sang or danced.

In contrast to Ballmer, I agree with Keenan and Faltz's judgments that neither (27) nor (28) represents a pair of logically equivalent sentences. Therefore, my algorithm for representing scope ambiguities will be designed to provide only a subject-wide scope reading for sentences with a coordinate VP.

#### 3.1.1.3 Negation

In the previous section, I presented data on the interaction between the scope of quantifiers and the boolean operators <u>and</u> and <u>or</u>. In this section, I want to consider the interaction between quantifier scopes and the boolean operation of negation. Some authors have suggested that negation in a verb phrase can take wide scope over a quantified subject. However, this is only true for universal quantification, as in (29) below.

(29) a. Everyone isn't here. (Hobbs and Shieber 1987)
b. Every dog didn't bark. (Ladusaw, n.d.)

When other quantifiers are considered, it is clear that the universal quantifier is exceptional in this regard. Geach (1962:84) points out that negation of the verb does not in general produce a contradiction of the original sentence, if the subject is a quantified NP. Thus, "Some men cannot laugh" is not equivalent to "It is not the case that some men can laugh." However, Geach notes that "Every man is not P" is often interpreted as "Not every man is P." Lasnik (1972:47) makes similar observations concerning the ability of totality quantifiers to be negated even when they precede not. He contrasts this property of the universal quantifier with all other quantifiers.

In the previous section, it was noted that the universal quantifier is exceptional in allowing disjunction in a verb phrase to take wide scope over the subject. The universal quantifier is also exceptional in allowing verb phrase negation to take wide scope over the subject. I do not have an explanation for why this might be so, but it indicates that there is a general distribution pattern between Boolean operators and the universal quantifier.

The following examples show that quantifiers other than every in subject position must take wide scope over the verb phrase negation. I have used the notation of generalized quantifiers to illustrate the different readings. For example, the logical form in (30c) represents the (unavailable) reading where negation has taken wide scope over the quantifier. The determiner some is interpreted as the function SOME that maps two properties to true or false (1 or 0, respectively). In particular, SOME(DOG,BARK) = 1 iff DOG $\cap$ BARK $\neq$ {}. That is, the intersection of the dogs and the barkers must be non-empty. Then the wide scope reading for negation in (30c) would be true when DOG $\cap$ BARK = {}. However, this is not a possible reading for (30a). Similarly, the logical form in (31c) is not a possible reading for the English sentence in (31a). In the readings where negation is applied to the bare intransitive verb, it is interpreted as the complement of the set denoted by the verb, i.e. $-$BARK = $\{x \mid x \notin \text{BARK}\}$.

Monotonic increasing determiners

(30) a. Some dog didn't bark.

b. $SOME(DOG,\sim BARK) = 1$ iff $DOG \cap (-BARK) \neq \{\}$

c. $\sim[SOME(DOG,BARK)] = 1$ iff $DOG \cap BARK = \{\}$

(31) a. More than three dogs didn't bark.

b. $(MORE\_THAN\ 3)(DOG,\sim BARK) = 1$ iff $|DOG \cap (-BARK)| > 3$

c. $\sim[(MORE\_THAN\ 3)(DOG,BARK)] = 1$ iff $|DOG \cap BARK| \leq 3$

Examples (32) - (36) illustrate this same phenomena with other classes of quantifiers and with a coordinate NP in subject position. The generalization is that predicate negation may not take wide scope over the subject, except when the subject is universally quantified. In each of the examples below, the logical forms in (c) are not possible readings for the English sentences in (a).

Monotonic decreasing determiners

(32) a. ? No dog didn't bark.

b. $NO(DOG,\sim BARK) = 1$ iff $DOG \cap (-BARK) = \{\}$

c. $\sim[NO(DOG,BARK)] = 1$ iff $DOG \cap BARK \neq \{\}$

(33) a. Less than three dogs didn't bark.

b. $(LESS\_THAN\ 3)(DOG,\sim BARK) = 1$ iff $|DOG \cap (-BARK)| < 3$

c. $\sim[(LESS\_THAN\ 3)(DOG,BARK)] = 1$ iff $|DOG \cap BARK| \geq 3$

Non-monotonic determiners

(34) a. Exactly one dog didn't bark.

b. $(EXACTLY\ 1)(DOG,\sim BARK) = 1$ iff $|DOG \cap (-BARK)| = 1$

c. $\sim[(EXACTLY\ 1)(DOG,BARK)] = 1$ iff $|DOG \cap BARK| \neq 1$

(35) a. More than two but less than six dogs didn't bark.

b. $(MORE\_THAN\ 2\ \&\ LESS\_THAN\ 6)(DOG,\sim BARK) = 1$ iff $2 < |DOG \cap (-BARK)| < 6$

c. $\sim[(MORE\_THAN\ 2\ \&\ LESS\_THAN\ 6)(DOG,BARK)] = 1$ iff $|DOG \cap BARK| \leq 2 \vee |DOG \cap BARK| \geq 6$

Coordinate noun phrase

(36) a. Spot and Fido didn't bark.

b. Spot didn't bark and Fido didn't bark.

c. ~[Spot and Fido barked]

Horn (1989:498) provides a functional explanation for the ambiguity of (29a) as opposed to the required narrow scope for not in (30) - (36). Horn did not consider this range of quantifiers, but I will consider how his observations might be extended to include these cases. Horn states that (37a) is ambiguous, having one reading equivalent to (37b).

(37) a. Everybody didn't come.
b. Not everybody came.

However, (38a) is unambiguous, because there exists a lexicalized inherently negative quantifier, nobody, which gives the equivalent wide-scope negation reading, as in (38b).

(38) a. Somebody didn't come.
b. Nobody came.

Horn's explanation is that (37a) is ambiguous, because there is no lexicalized counterpart to everybody. Only the complex expression, not everybody, can be used to give an equivalent wide scope negation reading, as in (37b). This explanation works for most of the previous examples. Some of the determiners which do not allow wide scope negation have lexicalized negative counterparts:

| Example | Determiner | "Lexicalized" negation |
|---|---|---|
| 29 | some | no |
| 30 | more than three | at most three |
| 31 | no | some |
| 32 | less than three | at least three |
| 34 | more than two but less than six | at most two or at least six |

The notion "lexicalized" must be stretched slightly to accommodate all of these cases. The some/no pair seems clear enough, but it seems a bit odd to say that "at most two or at least six' is the lexicalized (or "semilexicalized", as Horn says) negation of "more than two but less than six". It seems even stranger to say that exactly one has a lexicalized negative counterpart (no or at least two ??). Yet (34a) is one of the sentences which are unambiguous. An alternative characterization of these pairs is that an overt negation is not required, unlike the everybody / not everybody case. This characterization seems to work for quantified NPs, although the lack of ambiguity with the coordinate NP in (36) remains unexplained.

Regardless of the adequacy of Horn's explanation, the facts remain clear. The subject NP of a main clause may not fall within the scope of the predicate negation, except when the subject is universally quantified. As demonstrated above, the universal quantifier is exceptional by allowing each of the Boolean operators (and, or, not) in a verb phrase to take wide scope over the subject.

In general, a structure with a negated predicate and a quantified NP in object position is ambiguous. This is illustrated in (39) and (40). The object-wide scope reading is paraphrased in (a). Paraphrase (b) gives the reading where the negation has wider scope than the quantified NP.

(39) Bill did not shoot three of the elephants. (Heny 1970)
  a. There are three of the elephants such that Bill did not shoot them.
  b. It is not the case that there are three of the elephants such that Bill shot them.

(40) I couldn't solve many of the problems. (Lasnik 1972)
  a. There are many of the problems such that I couldn't solve them.
  b. It is not the case that I could solve many of the problems.

A few quantifiers, such as some and several, do not allow the object-narrow scope reading. In the following example from Lasnik (1972:56), the quantified NP several of the problems must be interpreted with scope wider than the negation (the # sign on reading (b) indicates that this is not a possible reading for the English sentence).

(41) I couldn't solve several of the problems.
  a. There are several of the problems such that I couldn't solve them.
  b. # It is not the case that I could solve several of the problems.

Since my current purpose is to describe the generally acceptable scope orderings, I will ignore these specific lexical exceptions. My approach is to describe the generalization, which is that predicate negation combined with a quantified object yields a semantically ambiguous structure. It would not be surprising then if certain lexical properties interact in such a way as to rule out a particular reading. Kroch (1974) simply marks these exceptional determiners with the feature [-neg], indicating that they may not be interpreted as being inside the scope of not. Whether or not this feature follows from more general principles, e.g. the referential nature of the determiner, is not crucial to the line of argumentation here.

So far, we have considered the interaction between (i) quantified subjects and quantified direct objects; (ii) quantified subjects and predicate negation; and (iii) quantified direct objects and predicate negation. With minor lexical exceptions, the scope ordering between subject and object is ambiguous; subjects are interpreted as lying outside the scope of predicate negation; and objects are ambiguously interpreted as either in or out of the scope of the predicate negation. If we consider sentences with all three types of logical operators (i.e. quantified subject, quantified object, and predicate negation), there are no new interactions. Sentence (42) has the expected subject-object ambiguity and object-negation ambiguity, along with the restriction that negation cannot take scope over the subject. This yields three possible readings shown in (a-c).

(42) Most $students_1$ didn't read a required $book_2$.
a. $QP_1$ - $QP_2$ - NOT
(most students s)(a book b)(not (s read b))
b. $QP_2$ - $QP_1$ -NOT
(a book b)(most students s)(not (s read b))
c. $QP_1$ - NOT - $QP_2$
(most students s)(not ((a book b)(s read b)))
d. # $QP_2$ - NOT - $QP_1$
e. # NOT - $QP_1$ - $QP_2$
f. # NOT - $QP_2$ - $QP_1$

Other orderings which are not appropriate readings for the English sentence are shown in (d-f). The absence of these three readings supports the generalization that the predicate negation cannot take scope over the quantified subject $QP_1$.

### 3.1.2 Double objects and datives

#### 3.1.2.1 Simple structures

In this section, I will consider the scope interactions for simple clauses containing NPs in three argument positions: subject, direct object, and indirect object. English has two such constructions, the dative construction illustrated in (43a) and the double object construction of (43b).

(43) a. Alice showed at least two incriminating photographs to every professor.
b. Alice showed every professor at least two incriminating photographs.

In the dative construction, I will refer to the object immediately following the verb as the direct object. The second object occurs in a prepositional phrase and is referred to as the indirect object. In the corresponding double object construction of (43b), I will still refer to <u>every professor</u> as the indirect object, even though it immediately follows the verb and, in a sense, acquires the status of a direct object. Similarly, I will continue to refer to <u>at least two incriminating photographs</u> as the direct object in (43b), even though it has been displaced from the canonical direct object position.

These two constructions are not identical with regard to the possible scope readings. Datives allow either object to have wide scope. Sentence (43a) has a reading where the direct object has wide scope, i.e. there are at least two photos such that Alice showed them to every professor. There is also a reading where the indirect object has wide scope, i.e. for every professor, Alice showed her at least two photos. Depending on the choice of verb, one of the readings may be pragmatically odd. For example, it is hard to imagine a context for the sentence (44a) in which the direct object would have wide scope. Somehow the same photos would have to be sent over and over again. Similarly, certain scope orderings are pragmatically strained in the other examples as well.

(44) a. Alice sent two photos to every professor.
b. Bill threw three packages to two mail carriers.
c. Chris wrote every letter to at least three firefighters.

As Ioup (1975) points out, the reading in which the indirect object has wide scope is the preferred reading. However, both readings are available. Furthermore, when the subject NP is also quantified, it appears that all possible quantifier orderings are available. In the following example, I have numbered the NPs and listed all possible orderings. In my opinion, all six orderings are possible readings for both English sentences.

(45) Most $dealers_1$ showed at least two obvious $forgeries_2$ to an undercover $agent_3$.
Every $student_1$ showed an original $design_2$ to three $professors_3$.

| | | | |
|---|---|---|---|
| a. | 1 | 2 | 3 |
| b. | 1 | 3 | 2 |
| c. | 2 | 1 | 3 |
| d. | 2 | 3 | 1 |
| e. | 3 | 1 | 2 |
| f. | 3 | 2 | 1 |

In contrast, the double object construction is limited in the range of possible quantifier scope ambiguities. The indirect object must have wide scope over the direct object. Aoun and Li (1989) give the following examples to illustrate this observation:

(46) a. I assigned someone every problem.
b. Mary gave someone every problem.
c. The committee gave some student every book in the library.
d. Mary showed some bureaucrat every document she had.
e. John asked two students every question.

In each of these cases, the indirect object quantified with <u>some</u>, or <u>two</u> in example (e), takes wide scope over the direct object quantified by <u>every</u>. Sentence (46c) entails that a single student was given every book in the library. In (47) below, I display a wider range of determiners than were considered by Aoun and Li. However, the same generalization holds. The indirect object has wider scope than the direct object in a double object construction.

(47) a. David offered two students more than five books.
b. Erin allotted every client a half-hour slot.
c. Fern rented most visitors two umbrellas.
d. Greg passed more than four jurors at least $100.
e. Harrison relayed a customer fewer than six messages during the conference.

There is one class of determiners which potentially constitute a counterexample to this general claim. A direct object with the indefinite article or a bare plural may take wide scope. This is clearest in a sentence in which the verb is pragmatically neutral with respect to the "transfer" involved from the initiator of the action to the recipient. Sentence (48a) has a reading where there is one sketch such that Alan showed it to every student. Similarly for (48b), the direct object, <u>two sketches of the suspect</u>, may take wide scope over the indirect object, <u>at least three officers</u>. In (48c), it may be the same story that Bob told most of his employees.

(48) a. Alan showed every student a sketch that he drew at the party.
b. Alan showed at least three officers two sketches of the suspect.
c. Bob told most of his employees a story about when he was young.

In considering the double object counterparts to the dative examples given in (45) above, we find an additional interaction with a quantified subject. I have kept the same numbers on the NPs, even though this no longer corresponds to the sequential order in the English sentence.

(49) Most dealers$_1$ showed an undercover agent$_3$ at least two obvious forgeries$_2$.
Every student$_1$ showed three professors$_3$ an original design$_2$.

| | | | | |
|---|---|---|---|---|
| a. | # | 1 | 2 | 3 |
| b. | | 1 | 3 | 2 |
| c. | # | 2 | 1 | 3 |
| d. | # | 2 | 3 | 1 |
| e. | | 3 | 1 | 2 |
| f. | # | 3 | 2 | 1 |

Additional examples which exhibit the same range of readings are:

(50) a. A protester brought every researcher two petitions.
b. Two lifeguards lowered most survivors a lifejacket.
c. Every librarian read at least two patrons most of the new regulations.
d. Less than five companies mailed some citizens two free disks.

In my judgment, four of the possible scope orderings are unavailable in the double object construction. Readings (49a), (49c), and (49d) are ruled out by the earlier observation that the indirect object has to have wider scope than the direct object. The lack of reading (49f) is perhaps surprising. However, it indicates that the direct object may not take wider scope than the subject. This lack of interaction between the subject and direct object positions can be seen in simpler examples where the indirect object is not quantified:

(51) a. Most children told Yolanda at least two stories.
b. An officer showed Ryan every picture of the suspect.

I only get one reading for each of these sentences and that reading gives the subject wide scope over the direct object. However, the same exception that was previously noted seems to hold here as well for direct objects with the indefinite article or a bare plural. A wide scope reading for the direct object seems more acceptable in the following sentences:

(52) a. Every officer showed Wilson a picture of the suspect.
b. No fewer than six realtors showed Carol two new houses in the Hollywood hills.

Sentence (52a) can be interpreted with object-wide scope where there was one picture of the suspect such that every officer showed it to Wilson. Similarly, (52b) can be interpreted as there being two houses such that no fewer than six realtors showed them to Carol.

To summarize, there are two English constructions in which three NPs appear in argument positions. Given three NPs there is a total of six distinct orderings that could potentially be represented in logical forms. The dative construction allows for all six possible readings. However, the double object construction only allows for two readings, where the subject and indirect object may vary in scope, but the direct object must have the narrowest scope.

#### 3.1.2.2 Negation

When we considered simple transitive clauses, we found that predicate negation and a direct object could vary with respect to their scopes. The preferred reading is usually given by the negation taking scope over the direct object, but it is also possible for the direct object to take wide scope over the negation. Now let's examine how the objects in a dative construction interact with predicate negation. The sentences in (53) just have one quantified NP, the direct object. In (54), the indirect object is the only quantified NP.

(53) a. Randy didn't send fewer than six letters to Alice.
b. Steve didn't give three flowers to Betty.
c. Tom didn't mail more than twelve messages to Carol.

(54) a. Vernon didn't send the letter to fewer than six clients.
b. Warren didn't give the flower to three children.
c. Xavier didn't mail the message to more than twelve department managers.

My judgment is that the scope of operators is ambiguous in each of these sentences. Either the predicate negation may have wide scope over the object or the object may have wide scope over the negation. For example, (53b) would be true with the direct object having wide scope, if Steve only gave Betty nine flowers out of a dozen. That is, there would be three flowers such that Steve did not give them to Betty. Although he gave her nine flowers, he *didn't give* her three flowers. The sentence would be true with the negation having wide scope in a model in which Steve only gave Betty two flowers. That is, it is not the case that there are three flowers such that Steve gave them to Betty. I believe both readings are available without using any special intonation, emphasis, or pauses.

The same judgments hold for the double object construction. The previous examples have been modified to show a single quantified NP in the double object construction:

(55) a. Randy didn't send Alice fewer than six letters.
b. Steve didn't give Betty three flowers.
c. Tom didn't mail Carol more than twelve messages.

(56) a. Vernon didn't send fewer than six clients the letter.
b. Warren didn't give three children the flower.
c. Xavier didn't mail more than twelve department managers the message about next week's meeting.

The same ambiguity holds for these sentences as for the datives. Either the predicate negation may have wide scope over the object or the object may have wide scope over the negation. In all constructions, it is slightly odd for monotone decreasing NPs to take wide scope over predicate negation. This is true for (53a) and (55a), as well as for a simple transitive sentence. However, the wide scope reading for such an NP is more accessible when more context is given: "Randy didn't send Alice fewer than six letters that had been subpoenaed." It seems to me that the reading where the direct object has wide scope over the negation is easier to get in this sentence than in (55a) above.

Judgments are difficult as we keep adding more logical operators to a sentence, but we would like to know what happens with two quantified objects and predicate negation:

(57) Jason didn't send an eviction letter to at least two tenants.

| | | | | | |
|---|---|---|---|---|---|
| a. | not | - | a letter | - | two tenants |
| b. | not | - | two tenants | - | a letter |
| c. | a letter | - | not | - | two tenants |
| d. | a letter | - | two tenants | - | not |
| e. | two tenants | - | not | - | a letter |
| f. | two tenants | - | a letter | - | not |

To the extent that one has judgments about a complex case like this, it seems plausible to assume that no new interactions are involved. I would suggest that all six orderings are possible in principle. If we were to consider a quantified subject as well, I am forced to predict 24 possible readings! It is unlikely that anyone will really be able to distinguish all these readings in practice. However, this may well be a processing limitation where three operators are difficult to process and four operators are just completely unmanageable. Thus, adding operators may cause problems similar to the well-known center embedding phenomenon in which (58a) is sensible, but (58b) is impossible to process:

(58) a. The cat that chased the rat that squeaked slipped.
b. The dog that bit the cat that chased the rat that squeaked slipped growled.

The two situations are not completely parallel. With center embedding, too much recursion makes the structures impossible to process. However, adding more quantifiers and Boolean operators only seems to make certain readings less accessible. Even a complex sentence like:

(59) At least two managers didn't show more than half the regulations to some of the new tenants.

can be processed if the quantifiers and operators are taken in sequential order. However, it becomes much harder to determine the truth conditions for other quantifier orderings. This makes me think that one might be able to relate the accessibility of ambiguities to processing issues. However, I do not have any concrete proposals at this time.

The same difficulty arises in trying to judge a double object construction with predicate negation and two quantified objects:

(60) Karen didn't show 20% of the residents every health notice.

| | | | | | | |
|---|---|---|---|---|---|---|
| a. | | not | - | 20% | - | every |
| b. | # | not | - | every | - | 20% |
| c. | | 20% | - | not | - | every |
| d. | | 20% | - | every | - | not |
| e. | # | every | - | not | - | 20% |
| f. | # | every | - | 20% | - | not |

Again, to the extent that any judgment is possible, it seems plausible to extrapolate from simpler cases and assume that there is no special interaction in this more complex case. Three readings are available for (60) in which either object may have scope over the negation, but the direct object must be in the scope of the indirect object.

### 3.1.4 PP modifiers within N'

Given three quantified NPs, there are six possible sequences of quantifiers. Hobbs and Shieber (1987) point out that one of these sequences is not acceptable if one of the NPs occurs within a PP modifier. In sentence (61), there is no reading where the quantifiers are interpreted in the order most-two-some.

(61) Most teachers on some committee vetoed two new proposals.

Such a sequence of quantifiers could be satisfied where the committee on which a teacher serves varies according to the proposal that was vetoed. This is not a possible reading for the English sentence. All of the other possible quantifier sequences do correspond to a possible reading. Either the subject or the object may have wide scope. The NP within the PP modifier may either be interpreted within the containing NP or outside of it. These combinations give five of the six possible sequences of quantifiers. In the following example, the unavailable reading is marked with a pound sign (#).

(62) [Three professors on [every committee]$_2$]$_1$ reviewed [an application]$_3$

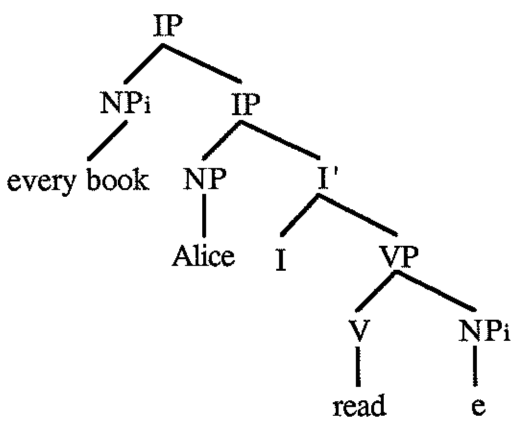
| | | | | |
|---|---|---|---|---|
| a. | | 1 | 2 | 3 |
| b. | # | 1 | 3 | 2 |
| c. | | 2 | 1 | 3 |
| d. | | 2 | 3 | 1 |
| e. | | 3 | 1 | 2 |
| f. | | 3 | 2 | 1 |

## 3.2 LF representations of scope ambiguity

Having considered the quantifier interactions to be accounted for, I now turn to the analysis given by current theories of Logical Form. Within the Government and

Binding (GB) theory of grammar (Chomsky 1981, 1986), Logical Form (LF) is a syntactic level of representation which serves as the input to the interpretive component. One semantic aspect of LF is that quantifier scope is identified at this level of representation (May 1977). Quantifier Raising (QR) is a rule that maps surface structures to LF by moving an NP to a position where it has scope over a clause or some other constituent. For example, "Alice read every book" has the surface structure in (63a). By QR the surface structure is mapped to the logical form shown both in labelled brackets and as a tree in (63b).

(63) a. [$_{IP}$ Alice [$_{I'}$ I [$_{VP}$ read every book]]]
b. [$_{IP}$ every book$_i$ [$_{IP}$ Alice [$_{I'}$ I [$_{VP}$ read $e_i$]]]]

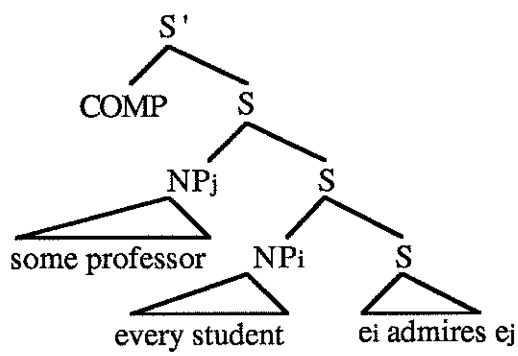



The logical form contains $e_i$, which is an empty category that is coindexed with the NP that was moved by the rule of QR. The empty category functions as a variable bound by the quantifier phrase every book. The scope of the quantifier is determined by its c-command domain. A constituent Y is within the scope of a quantifier phrase X just in case X c-commands Y according to the following definition.

(64) X c-commands Y iff for all Z, Z a maximal projection, Z dominates X only if it dominates Y, and $X \neq Y$. (Aoun and Sportiche 1983)

From this definition, we see that the NP every book has scope over the entire clause. In particular, the variable $e_i$ is within its scope, because every book c-commands $e_i$.

Starting with May (1985), some linguists have assumed that a logical form is ambiguous with respect to quantifier scope. According to May's analysis, there is only one LF representation for the semantically ambiguous sentence "Every student admires some professor":




By definition, the entire set of S nodes in this structure forms a maximal projection. Since $NP_i$ is not dominated by each member of the set, it is not dominated by the S projection. S' is the only maximal projection that dominates $NP_i$. Similarly, S' is the only maximal projection that dominates $NP_j$. Therefore, $NP_i$ and $NP_j$ mutually c-command each other. In this configuration, May says that the quantifier phrases may be interpreted in any order (or independently).

In chapter 2, I argued that this type of approach prevents one from defining an entailment relation on the logical forms.[5] However, in the following discussion, I will turn to a more serious drawback of this approach. Aoun and Li (1989) suggest several principles related to the well-formedness of LF structures. However, their adherence to the assumption that quantifier scope ambiguity must be represented with a single LF representation leads to an incorrect model of the English facts. After considering Aoun

[5] Actually, I discussed the problem with respect to interpreting surface structures, but the same problem exists under May's analysis. Regardless of whether one interprets surface structure or a level of representation called Logical Form, it is awkward to define entailment "relative to an interpretation".

and Li's analysis, I will present an alternative account in the following section which correctly models the quantifier scope ambiguity (or lack thereof) in complex English constructions.

Aoun and Li (1989) try to account for differences between comparable Chinese and English sentences. While the simple transitive sentence, "Someone loves everyone", is scope ambiguous in English, a Mandarin Chinese sentence like (65) is not ambiguous. The subject, meigeren, must have wide scope.[6]

(65) Meigeren dou xihuan yige nuren.
everyone all like one woman
'Everyone loves a woman.'

Aoun and Li's analysis of this difference has three main features. First, Chinese and English differ in basic constituent structure. Then there are two general characteristics of LF which exploit this difference between English and Chinese in order to account for the scope differences:

(66) Minimal Binding Requirement (MBR): Variables must be bound by the most local potential A'-binder.

(67) The Scope Principle (SP): A quantifier A has scope over a quantifier B in case A c-commands a member of the chain containing B.

The effect of the MBR is to rule out logical forms like '$QP_j\ QP_i \ldots t_i \ldots t_j$' in which $QP_i$ is the most local[7] *potential* antecedent for $t_j$, yet $t_j$ is not bound by $QP_i$:

(68) A qualifies as a *potential A'-binder* for B iff A c-commands B, A is in an A'-position, and coindexing of (A,B) would not violate any grammatical principle. (Aoun and Li 1989:169)

[6] I am simply reporting Aoun and Li's discussion here in order to give a brief background for their analysis. I have no judgments about Mandarin and I have not checked this sentence with other Mandarin speakers.

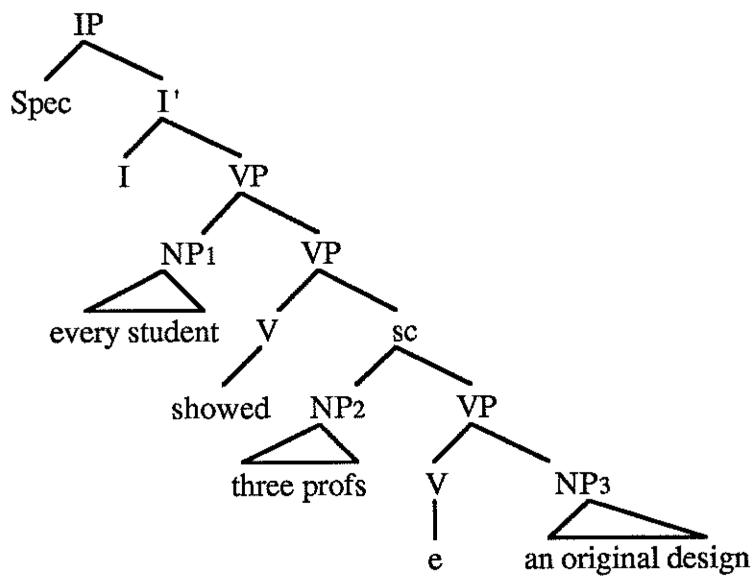
[7] In Aoun and Li's footnote 11, they refer to Chomsky's (1981:59) definition for locality:

A *locally binds* B if A and B are coindexed, A c-commands B, and there is no C coindexed with A that is c-commanded by A and c-commands B.

Rather than discuss the motivation for these principles, I would like to immediately consider an example and show that the analysis does not correctly characterize quantifier interactions in English sentences.

According to Aoun and Li, the deep structure for an English sentence with a bitransitive verb is:[8]

(69) Every student showed an original design to at least three professors.
Deep structure:



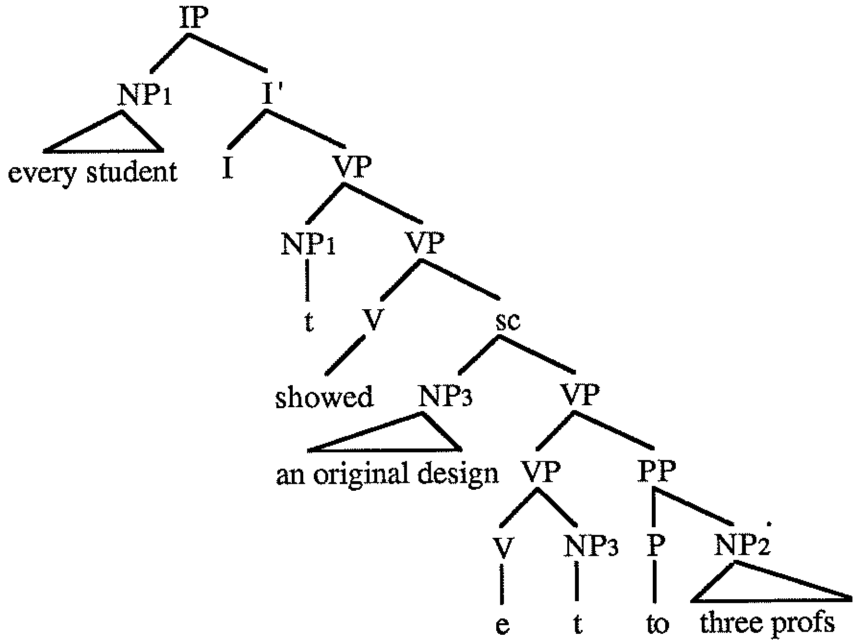

The subject, every student, originates in the Spec-VP position. The bitransitive verb, show, takes a small clause (sc) as its complement. The indirect object is the subject of the small clause, which contains an empty verb. The surface structure for this English dative is:[9]

---

[8] They do not give this particular example in the article. Their discussion of the dative focuses on the structure of VP. However, I have used their analysis of Subject Raising to generate this tree for an entire clause.

[9] The structure of the indirect object is not made explicit in the article (cf. Aoun and Li's figures (58) and (62)). I have assumed that the indirect object is a prepositional phrase. However, none of my arguments rely on this assumption. The indirect object could just as well be an NP with the preposition to merely serving as case marking.

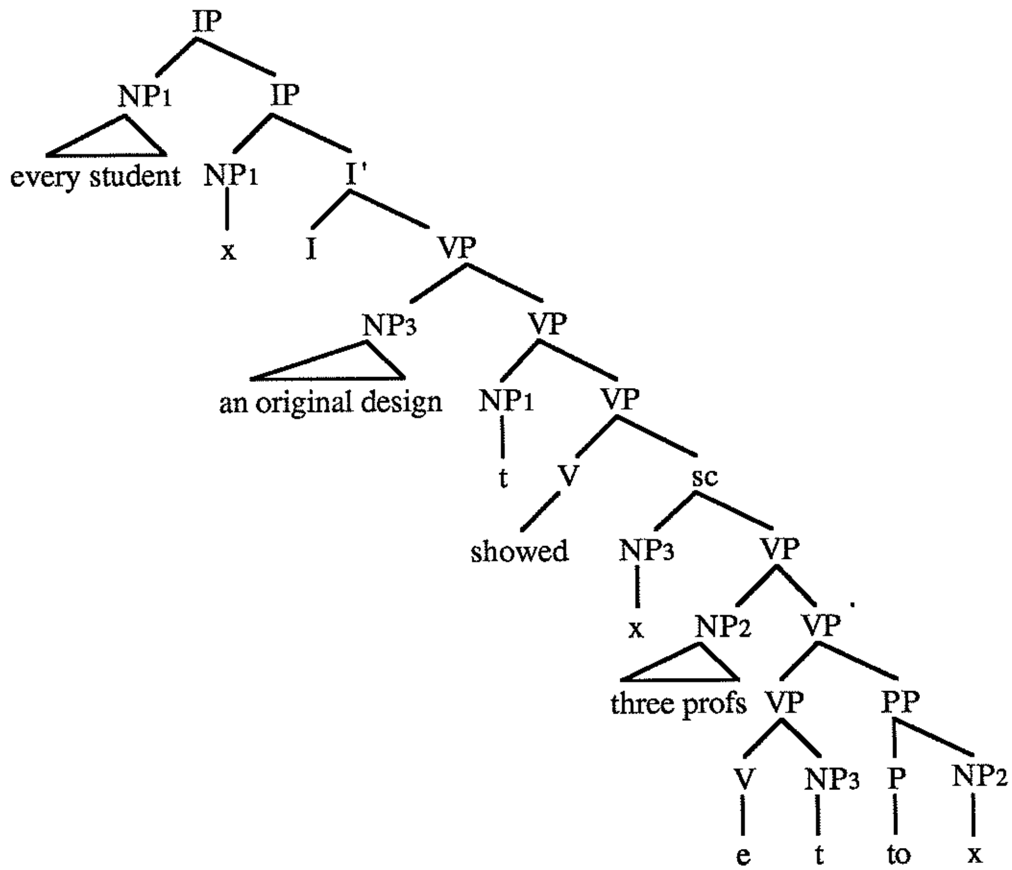
(70) Every student showed an original design to at least three professors.
Surface structure:




The subject NP has been raised from the Spec-VP position leaving a coindexed trace. The small clause has undergone the passive, so that an original design is now the subject of the small clause and is coindexed with a trace in the VP.

Up to this point, we have just made use of Aoun and Li's analysis of the constituent structure of English. The Minimal Binding Requirement, (66) above, constrains the output of QR so that the logical form for this sentence is shown below. In this framework, traces left by QR are subject to the Minimal Binding Requirement, but surface structure traces are not. Therefore, I have labelled QR traces as x and surface structure traces as t in order to help distinguish the two types of empty categories.

(71) Every student showed an original design to at least three professors.
Logical form:




Now we can use the logical form to calculate the scope dependencies. According to the Scope Principle, (67) above, the following scope relations exist:[10]

$NP_1$ has scope over $NP_2$
$NP_1$ has scope over $NP_3$
$NP_2$ has scope over $NP_3$
$NP_3$ has scope over $NP_1$
$NP_3$ has scope over $NP_2$

10 According to Aoun and Li's definition, every NP will have scope over itself, since it c-commands a member of the chain containing it. However, I have left these out of the table, since the reflexive nature of the 'has scope over' relation does not seem to play a part in the interpretation possibilities for a logical form.

There is only one ordered pair missing from this table: $NP_2$ does not have scope over $NP_1$. Therefore, Aoun and Li's analysis predicts that the English sentence, "Every student showed an original design to at least three professors", will not have a reading in which the indirect object takes wide scope over the subject. However, as discussed in section 3.1.2, dative sentences have two such readings which can be paraphrased for this particular sentence as:

(72) a. For at least three professors, every student showed him/her an original design.
b. For each of at least three professors, there is an original design such that every student showed it to him/her.

I admit that (72b) is pragmatically odd and may not be available as a possible scope order for this sentence. However, the order of indirect object - subject - direct object in (72a) seems perfectly acceptable even if one substitutes other quantifiers.

To summarize the problem for Aoun and Li's analysis, the interpretation module should generate at least one reading for (71) in which the indirect object has wide scope over the subject. However, according to the Minimal Binding Requirement and the Scope Principle, $NP_2$ (the indirect object) does not have scope over $NP_1$ (the subject). How might we modify the analysis in order to avoid this problem? Let's consider the Scope Principle. The correspondence between this principle and the interpretation component is left unstated by Aoun and Li. Although the principle states when a quantifier A "has scope over" a quantifier B, the reference to scope is syntactic. Presumably, a quantifier A can be interpreted as having wide (semantic) scope over a quantifier B just in case A has (syntactic) scope over B.

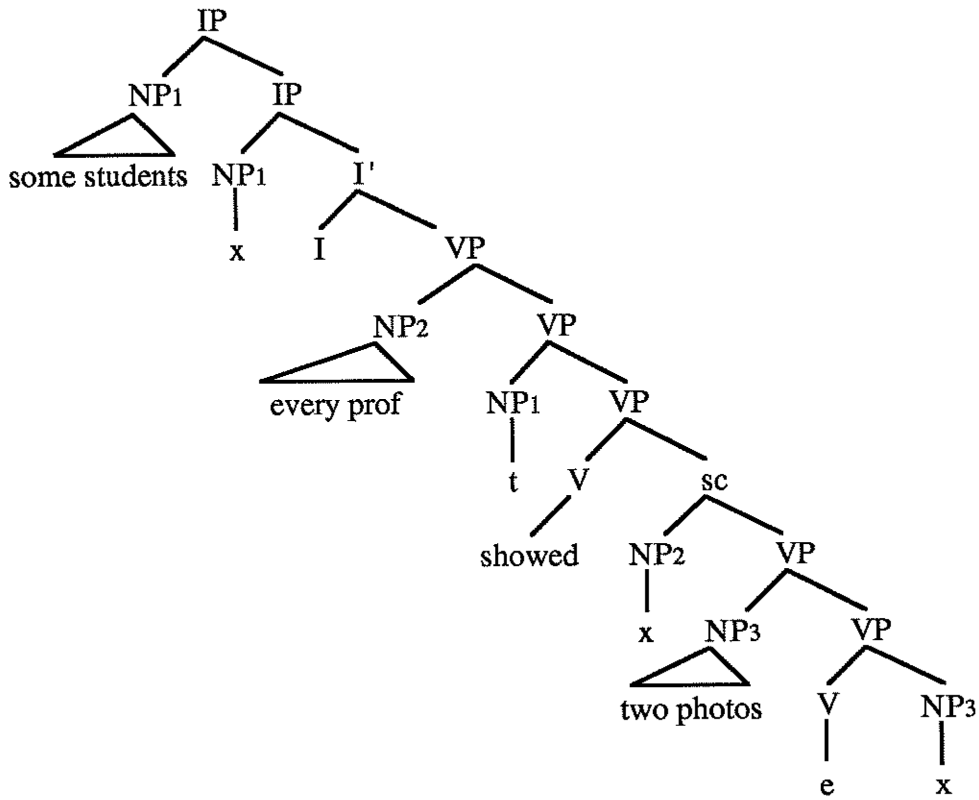
Let's assume that the interpretation of quantifier orderings is based on Aoun and Li's 'has scope over' relation, but need not be identical to it. We will define this semantic ordering, call it $\geq$, as follows. If A has scope over B, then $A \geq B$. Furthermore, if A has scope over B and B has scope over C, then $A \geq C$. That is, $\geq$

is the transitive closure of Aoun and Li's 'has scope over' relation. Suppose the interpretation module makes use of the semantic ≥ relation to derive interpretations from a logical form. If $NP_i \geq NP_j$, then $NP_i$ may (but need not) be interpreted as having wide scope over $NP_j$. Returning to (71), I noted that $NP_2$ does not have scope over $NP_1$ in the sense of the Scope Principle. However, $NP_2 \geq NP_1$, since $NP_2$ has scope over $NP_3$ and $NP_3$ has scope over $NP_1$. Therefore, by defining the semantic ≥ relation as the transitive closure of the syntactic 'has scope over' relation, we now correctly predict all six possible quantifier orderings.

The point is that $NP_2$ can be interpreted as having wider scope than $NP_3$ according to the Scope Principle. Furthermore, $NP_3$ can be interpreted as having wider scope than $NP_1$ according to the Scope Principle. Therefore, if we put these two facts together, surely we should conclude that $NP_2$ can be interpreted as having wider scope than $NP_1$. As we observe English datives, all quantifier orderings are in fact possible, so this seems to be a sensible move.

This proposal does not adversely affect Aoun and Li's analysis of double object constructions. Their analysis correctly predicts only two readings for the double object construction. The definition of ≥ has no influence on that analysis, as shown by the following logical form:

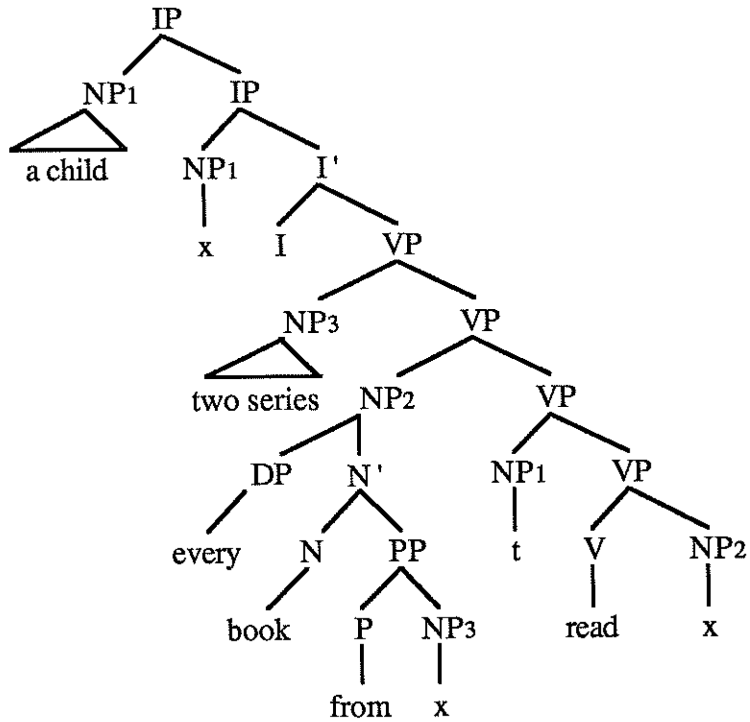
(73) Some students showed every professor at least two photos.
Logical form:




Since $NP_3$ does not c-command a member of any chain (other than its own), it does not have scope over any quantifier (other than itself). So there is no $QP \neq NP_3$ such that $NP_3 \geq QP$. This correctly predicts that the direct object can only take narrowest scope in a double object construction.

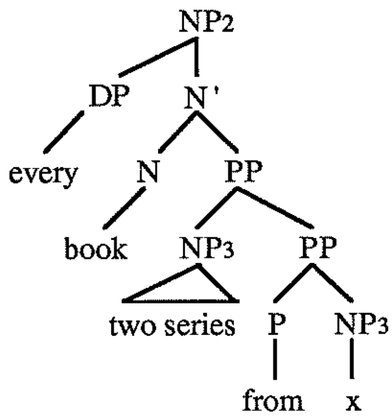
Unfortunately, there is another construction which poses problems for the 'has scope over' relation. As noted previously in section 3.1.3, prepositional phrase (PP) modifiers within the N' constituent must be interpreted adjacent to their containing NP. In the following logical form, the subject, a child, cannot be interpreted as having narrower scope than every book from x yet wider than at least two "Beginning Reader" series.

(74) [A child]$_1$ read [every book from [at least two "Beginning Reader" series]$_3$]$_2$.
One possible logical form:




Before considering the Scope Principle, let me justify this structure within Aoun and Li's framework. Suppose NP$_3$ had only been raised to the level of PP, as in (75) below. If we use the definition of c-command in (64), then NP$_2$ would have scope over NP$_3$. However, NP$_3$ would not have scope over NP$_2$, because there is a maximal projection, NP$_2$, which dominates NP$_3$ and which does not dominate NP$_2$ (assuming that 'dominates' is not a reflexive relation).

(75)




The structure in (75) is one of the possible logical forms in Aoun and Li's system, but it is not the only one. It would not allow a reading in which $NP_3$ is interpreted with wider scope than $NP_2$. However, we know that such a reading exists. In fact, it is the preferred one. So it is desirable to have a structure like (74) for semantic reasons. Furthermore, the structure in (74) satisfies the Minimal Binding Requirement and is a well-formed logical form. Even though $NP_2$ c-commands the variable $[_{NP}\ x]_3$ (according to definition (64) above), $NP_2$ is *not* a potential binder for this variable. The reason is that coindexing $NP_2$ and $[_{NP}\ x]_3$ would violate the i-within-i condition, which is generally assumed in the GB framework to rule out structures of the type $[_{\alpha}\ldots[_{\alpha}\ldots]_i\ldots]_i$. Therefore, according to definition (68), $NP_2$ is not a potential binder for $[_{NP}\ x]_3$. Thus, $[_{NP}\ x]_3$ is bound by its most local potential A'-binder, $NP_3$, as required.[11]

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[11] For other commonly accepted definitions of c-command, $NP_2$ does *not* c-command $[_{NP}\ x]_3$, since it dominates the variable. Under those definitions, $NP_2$ would not be a potential binder for $[_{NP}\ x]_3$. Therefore, the logical form of (74) is well-formed even for other common definitions of basic structural relations.

According to the Scope Principle, the following relations hold between NPs in logical form (74):[12]

(76) $NP_1$ has scope over $NP_2$
$NP_1$ has scope over $NP_3$
$NP_2$ has scope over $NP_1$
$NP_2$ has scope over $NP_3$
$NP_3$ has scope over $NP_1$
$NP_3$ has scope over $NP_2$

Given this set of scope relations, our previous experience with the dative would lead us to predict that all possible quantifier orderings are possible. In particular, $NP_2$ has scope over $NP_1$ and $NP_1$ has scope over $NP_3$, so we predict a $NP_2$ - $NP_1$ - $NP_3$ reading which does not in fact exist. That quantifier ordering would correspond to a reading where for every book there is a child such that for at least two series, the book is from both series and the child read it. Even ignoring the pragmatic oddness that a single book usually does not belong to two different series, this is not a possible interpretation for sentence (74). Such a reading would allow the series to which a book belonged to vary according to the choice of student. While we could imagine a real-world situation of personal instruction where this type of variation takes place, it simply is not one of the possible interpretations for the English sentence. Therefore, Aoun and Li's analysis gives us the wrong predictions for the scope of NPs within a PP modifier.

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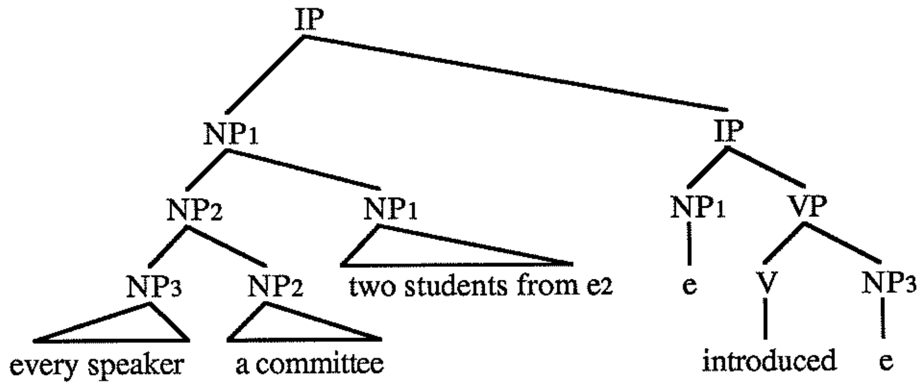
12 The entries in this table depend crucially on the definition of *c-command*, which in turn relies on the definitions for *maximal projection* and *dominates*. The place where commonly accepted definitions differ is whether or not $NP_2$ c-commands a member of the chain headed by $NP_3$. Given the definition of c-command that I have been using from (64) above, $NP_2$ c-commands the trace of $NP_3$. Therefore, $NP_2$ has scope over $NP_3$, according to the Scope Principle. Other definitions of c-command would exclude the trace of $NP_3$ from the c-command domain of $NP_2$, since $NP_2$ dominates the trace. However, according to May's (1985) definition of *maximal projection*, $NP_2$ governs $NP_3$ (although $NP_2$ does not c-command or govern the trace of $NP_3$). Therefore, $NP_2$ may be interpreted as having wider scope than $NP_3$ within May's framework as well. In any case, the presence of this particular entry does not affect the discussion to follow and all of the other table entries are uncontroversial with respect to definitions of c-command that have been proposed in the literature (Aoun and Sportiche 1983).

One might argue that the interpretive component should rule out the $NP_2$-$NP_1$-$NP_3$ reading. An interpretation of $NP_2$ which is independent of $NP_3$ would somehow have to deal with the free variable $[_{NP}\ x]_3$ embedded inside of $NP_2$. Perhaps such a free variable would invalidate the interpretation and thus avoid the unwanted reading. However, relying on the interpretive component to rule out possible scope orderings goes against the basic assumption that quantifier scope is represented at LF and thus constitutes a radical departure from existing work on LF. Later, I will argue that LF *is* the level of representation for quantifier scope, but one must rely on unambiguous logical forms in order to correctly enumerate all and only the possible scope orderings.

We have reached a paradox with respect to Aoun and Li's analysis. One cannot derive all of the possible interpretations for the dative without extending the 'has scope over' relation. That is, the 'has scope over' relation does not allow for enough interaction between the NPs in a dative construction. One solution to that problem is to define $\geq$ as the transitive closure of 'has scope over'. On the other hand, 'has scope over' allows too much interaction between NPs having a PP modifier. So in one case the Scope Principle is too strict; in the other, it is too lenient.

I have examined Aoun and Li's theory in detail, because their proposals are the most clearly defined account of LF representations for sentences containing three argument NPs. However, the problems encountered in Aoun and Li's analysis will also be present in other theories of LF, such as May's, which rely on ambiguous logical forms. May (1985) suggested that two NPs which govern each other at LF may be interpreted in any order. We have seen that one must consider the scope interaction of more than two NPs in order to test this hypothesis in anything but the most trivial environment. Consider the following sentence along with one of the LF structures that May's system generates for it:[13]

(77) Two students from a campus committee introduced every speaker.




This English sentence does not have a reading corresponding to an $NP_1$ - $NP_3$ - $NP_2$ sequence of quantifiers. That reading would correspond to "for each of two students, for every speaker, there exists a committee such that ...". Under that reading, the committee from which the student comes may vary with the speaker that was introduced.

In May's (1985:34) terms, $NP_1$, $NP_2$, and $NP_3$ form a $\Sigma$-sequence and "members of a $\Sigma$-sequence are free to take on any type of relative scope relation." May refers to this as the *Scope Principle* (not to be confused with Aoun and Li's Scope Principle mentioned above). This principle of interpretation is adequate for considering the scope interaction of argument NPs in simple transitive clauses and datives. However, it also allows an interpretation of (77) in which the sequence of

13 Another logical form is generated by May's system when QR adjoins the object NP to the VP. That structure is unproblematic for the situation under consideration, because an NP that is adjoined to the VP receives object-narrow scope (May 1985:59).

operators is $NP_1$-$NP_3$-$NP_2$. As noted above, this is not a possible reading for the English sentence.[14]

So we have seen two quite different views of LF, both of which rely on semantically ambiguous logical forms. May's system allows a wide range of adjunction possibilities. The interaction between quantifiers resulting from his Scope Principle is not sufficiently constrained. Therefore, his system generates certain readings from the logical forms which are not available from the original English sentence. Aoun and Li provide a much more constrained theory of LF. The output of QR is tightly constrained by the Minimal Binding Requirement. While these additional constraints receive some support from cross-linguistic data, Aoun and Li's Scope Principle is both too strict and too lenient for the English data. Not enough quantifier interaction is allowed in dative constructions, but too much interaction is allowed with PP modifiers. Therefore, both theories of LF, which rely on ambiguous logical forms, are empirically inadequate for complex quantifier interactions in English. One solution for this problem is not to squeeze all of the interpretations out of a single logical form. By relaxing the Minimal Binding Requirement, we will be able to generate multiple unambiguous logical forms for semantically ambiguous surface structures. This is the analysis that will be presented in the next section. One of the motivations for the Minimal Binding Requirement was to account for cross-linguistic facts in both Chinese and English. By removing the MBR, I will lose Aoun and Li's account of the Chinese facts. However, since the theory does not correctly account for the English data, this is a necessary step.

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14 Other versions of May's theory have this same problem. In May (1989), he assumes multiple adjunction to an S node, rather than operators adjoining to operators as in (77) above. However, the $\Sigma$-sequences and predictions of his Scope Principle work out the same for this example.

### 3.3 Mapping surface structure to unambiguous logical forms

In this section, I will provide an alternative to May's (1985) and Aoun and Li's (1989) analyses of Logical Form which require ambiguous logical forms. However, their basic assumptions will remain unchanged. First, Quantifier Raising (QR) will be the means by which the semantic scope of an NP is identified at LF. Second, the Empty Category Principle (ECP) will be invoked to rule out certain applications of QR. That is, QR will apply freely, but some of the resulting structures will be filtered out and marked as ill-formed by the ECP.

One new feature that I will bring to the analysis of LF is the principle of Invariant Scope Independence. I will argue that this principle is required in addition to the ECP in order to correctly account for the lack of scope interactions in coordinate structures. Finally, I will argue that logical forms should be unambiguous, as in May (1977), in order to generate the correct range of interpretations for sentences with three interacting quantifier phrases.

#### 3.3.1 Conditions on logical forms

Following May (1977), I will assume that a rule of Quantifier Raising (QR) applies to surface structures in order to map them onto Logical Form (LF). The rule may be stated as follows:

(78) For A an NP and B a maximal projection such that A ≠ B, adjoin A to B leaving a coindexed empty category, $[_{NP}\ e]$, in the original position of A.

In the following discussion, I will assume that QR adjoins an NP to IP, VP, or PP for the structures under consideration.[15] An NP will have semantic scope over the phrase to which it is adjoined. An algorithm for interpreting logical forms will be given in the

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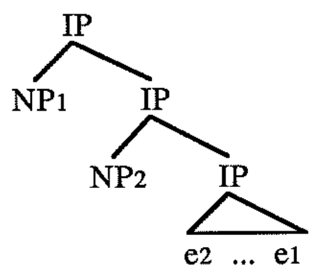
[15] Chomsky (1986:6) assumes that, "Adjunction is possible only to a maximal projection (hence, X'') that is a nonargument."

next chapter but this means that $NP_1$ will be interpreted as having wider scope than $NP_2$ in the following configuration:




I will assume that QR applies obligatorily in order to map a surface structure to a logical form. That is, every NP must undergo QR, although QR may move any particular NP to several potential landing sites, generating multiple logical forms from a single surface structure.

This rule is an instance of the Move-$\alpha$ rule in GB theory (Chomsky 1981). In order to constrain the output of this rule, well-formedness conditions must be stated for LF. Of primary importance is the need to specify when an NP binds the variable that was left behind by the application of QR. The appropriate condition for binding is defined in terms of c-command:

(79) Definition: A *c-commands* B iff A does not dominate B and every maximal projection C that dominates A also dominates B.

Variables at LF will be subject to the Empty Category Principle (Kayne 1981, Aoun, Hornstein, and Sportiche 1981, Chomsky 1981). The ECP was formulated in Chomsky (1981) as:

(80) ECP: $[_\alpha\ e]$ must be properly governed.

where proper government is defined as (Chomsky 1986):

(81) A *properly governs* B iff A $\theta$-governs or antecedent-governs B.

For the cases we will consider below, θ-government will hold between a lexical verb or preposition and the complement to which it assigns a thematic role:

(82) A *θ-governs* B iff A is a zero-level category that θ-marks B, and A, B are sisters. (Chomsky 1986)

Antecedent government will hold between a quantified NP and its trace (where c-command is defined as in (79) above):

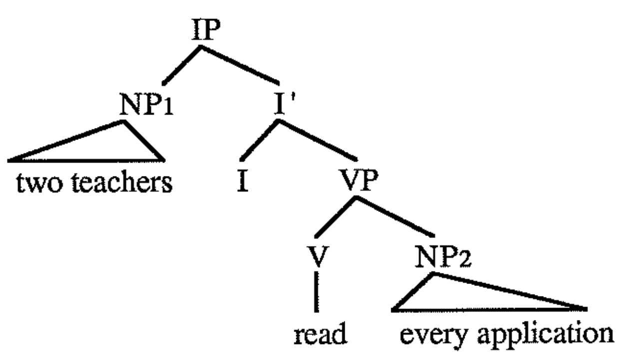
(83) (Preliminary)
XP *antecedent-governs* YP iff XP c-commands YP and XP is coindexed with YP.

These rules and principles act together to provide an account of the scope ambiguities that were previously described. We will consider each case below.

### 3.3.2 Simple transitive clauses

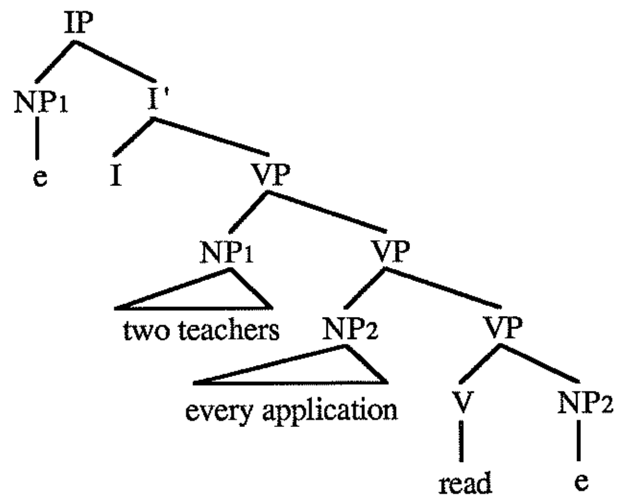
The quantifier scope ambiguity of a simple transitive clause arises from two distinct logical forms. Consider the following sentence.

(84) Two teachers read every application.
Surface structure:




When QR applies to the subject, it must be adjoined to IP. If QR adjoined $NP_1$ to VP, then the resulting variable would be unbound, violating the Empty Category Principle:[16]

[16] I assume here that the VP node dominating $NP_1$ blocks the c-command relation between this quantifier phrase and the variable $[_{NP}\ e]_1$. In May's (1985:34) analysis, the VP node does not block




The two logical forms which can be correctly derived by QR are given below. In (85a), the subject has been adjoined to IP and the object has been adjoined to VP. In the next chapter, I will show how this is interpreted to give the subject-wide scope reading. Each of the variables is properly bound, since $NP_1$ c-commands $[_{NP}\ e]_1$ and $NP_2$ c-commands $[_{NP}\ e]_2$. Furthermore, each of the empty categories is properly governed. $[_{NP}\ e]_1$ is antecedent governed by the adjoined subject and $[_{NP}\ e]_2$ is both θ-governed by the verb and antecedent-governed by the adjoined object.

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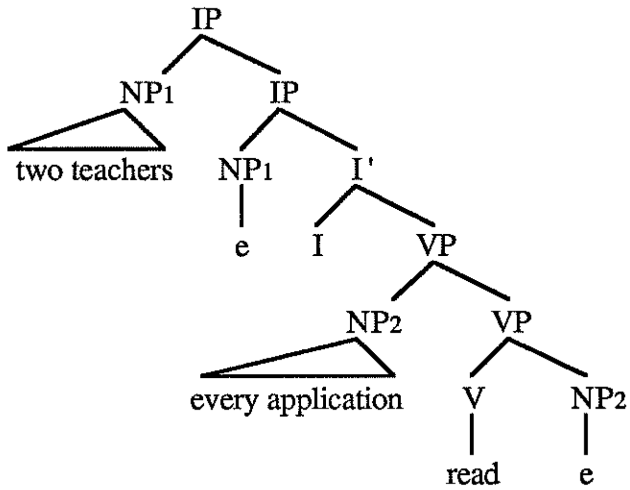
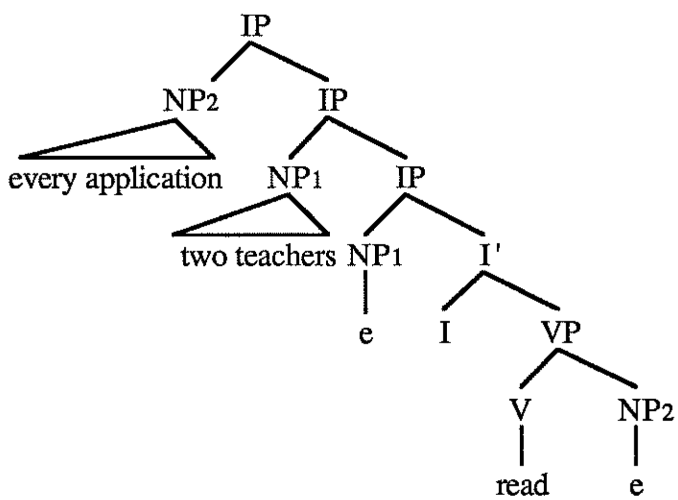
the c-command relation, but it does block government. So under either set of definitions, VP-adjunction from the subject position is not-well formed.

(85) a. Subject-wide scope




b. Object-wide scope




Logical form (85b) is also well-formed. It corresponds to the object-wide scope reading. Both variables are properly governed. $[_{NP}\ e]_1$ is antecedent-governed by $NP_1$ and $[_{NP}\ e]_2$ is $\theta$-governed by the verb <u>read</u>. Following Aoun and Li's (1989) suggestion, I will say that $NP_1$ blocks antecedent-government between $NP_2$ and the variable $[_{NP}\ e]_2$, because $NP_1$ is a "closer" potential governor:

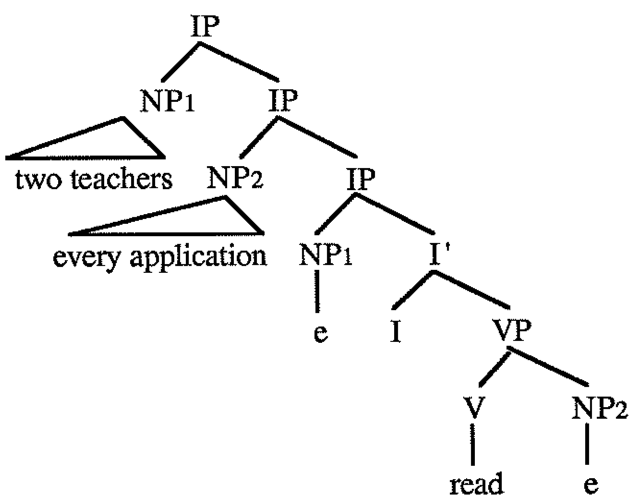
(86) A lexical phrase A qualifies as a *potential governor* for B iff A c-commands B and coindexing of (A,B) would not violate any grammatical principal.

The potential governor must be lexical. Thus, a trace will not serve as a potential governor. The justification for this requirement will show up later in more complex constructions. I now revise the definition of antecedent-government, in order to enforce a minimality condition on the antecedent:

(87) (Revised)
XP *antecedent-governs* YP iff XP c-commands YP, XP is coindexed with YP, and there is no potential governor G of YP such that XP c-commands G.

This revised definition rules out the case where QR first adjoins the object to IP and then adjoins the subject to IP:

(88) Ill-formed logical form:




This is *not* a well-formed logical form, because $[_{NP}\ e]_1$ is not properly governed. First, it is not $\theta$-governed according to (82) above. Second, $[_{NP}\ e]_1$ is not antecedent-governed according to (87), because $NP_2$ as a potential governor of $[_{NP}\ e]_1$ blocks government by $NP_1$.

We need one more condition now to be sure that logical forms are well-formed. In some cases, the occurrence of a variable will be licensed by the ECP. When the variable is antecedent-governed, it will be properly bound by an antecedent

NP. However, even when a variable is licensed by θ-government, it must still be licensed by the presence of a quantifier phrase:

In order for an NP to bind a variable, the NP must c-command the variable:[17]

(89) Definition: A variable x is *properly bound* by an NP A iff A c-commands x and A is coindexed with x.

One of the conditions on LF is that QR cannot move an NP so as to leave an unbound variable:

(90) Condition on Proper Binding (May 1977): Every variable in an argument position of a predicate must be properly bound.

Returning to the previous example, the variables in (85a,b) are properly bound and properly governed. The variables in (88) are properly bound, but they are not properly governed. When we get to the discussion of PP modifiers, we will see the need to rule out structures with variables which are properly governed, but not properly bound.

### 3.3.3 Datives

When we consider an additional argument NP, as with datives, the number of possible logical forms increases. Due to the ECP, QR can only adjoin the subject NP as the "lowest" of the IP adjunctions. The trace of the indirect object is properly governed by the preposition. Therefore, it may be adjoined to VP for narrow scope or to IP for wide scope. Whether or not the direct object is properly governed by the verb depends on the structure assumed for datives. Under Kayne's (1983) analysis, this is unproblematic:

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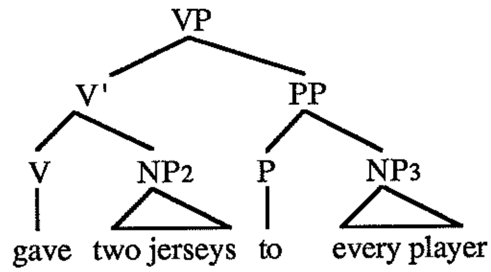
17 This definition is based on May's (1977:9), although he makes no reference to the fact that the two NPs must be coindexed:

"A variable is PROPERLY BOUND by a binding phrase P iff it is c-commanded by P."

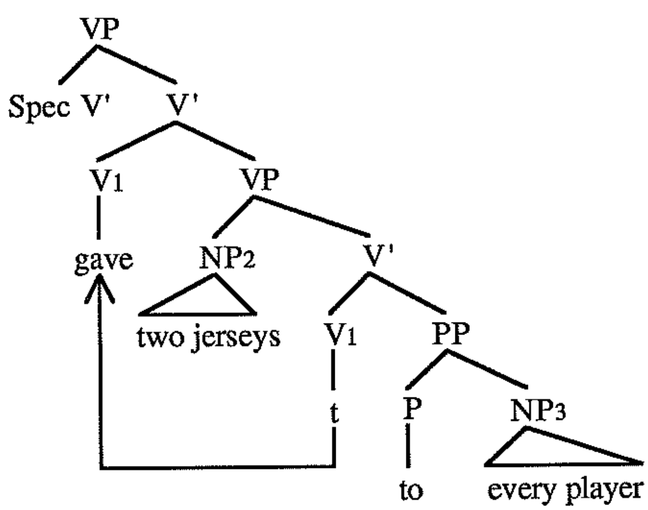
Perhaps the notion "binding phrase" implies coindexing, but I have chosen to include coindexing as an explicit part of the definition.

(91)




$NP_2$ is a sister to the verb that θ-marks it. Therefore, the trace left by QR will be properly governed.

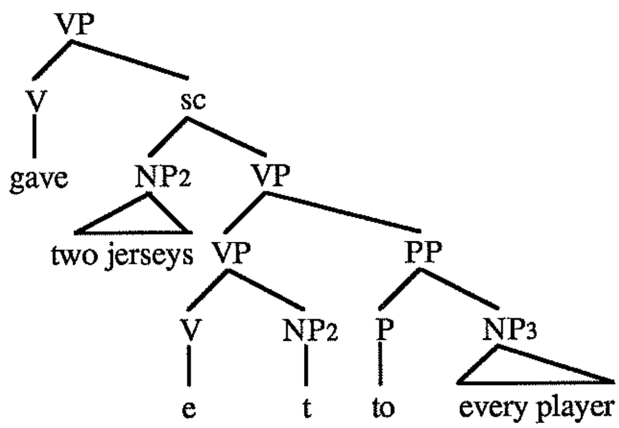
Larson (1988) presents a more complex structure for datives. However, he argues that the direct object is governed by the lexical verb at surface structure, since the verb is to the left of the object NP and the NP is the specifier of a maximal projection sister to the verb. This extends the range of government beyond that of definition (82), which required sisterhood.




I am not arguing for or against this particular analysis. I simply want to point out that the direct object can freely undergo QR within Larson's analysis, because give θ-marks and assigns objective case to two jerseys. Thus, according to Larson's arguments about government in this structure and definition (81) above, the variable left by QR of the direct object will be properly governed.

Similarly, Aoun and Li (1989) argue that the direct object is case- and θ-marked by the lexical verb in a dative construction. Thus, QR can freely apply to the direct object in the structure they propose for datives:

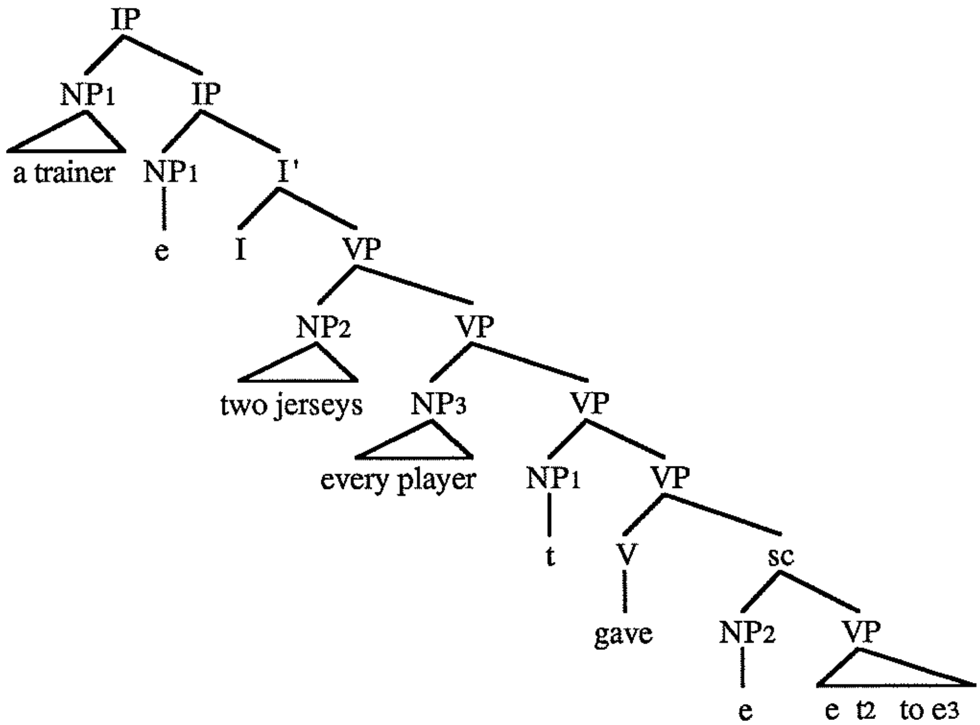
(92)




In any of these three recent analyses of datives, QR may raise the direct and indirect objects either to IP or VP, because the remaining variables will be properly bound and properly governed. The subject can only be raised to the "lowest" IP adjunction site in order for its variable to be properly governed. As a concrete example, a surface structure is given in (93), using Aoun and Li's analysis. This surface structure will yield six interpretations, as desired. I show the labelled bracketing and tree in (93a) for the reading where the scope order is $NP_1$-$NP_2$-$NP_3$. The other five readings are shown in labelled brackets in (93 b-f).

(93) A trainer$_1$ gave two jerseys$_2$ to every player$_3$.
$[_{IP}$ a trainer$_1$ $[_{I'}$ I $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ two jerseys$_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to every player$_3$]]]]]]]

a. $NP_1$-$NP_2$-$NP_3$
$[_{IP}$ a trainer$_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ two jerseys$_2$ $[_{VP}$ every player$_3$ $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ $e_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to $e_3$]]]]]]]]]]




b. $NP_1$-$NP_3$-$NP_2$
$[_{IP}$ a trainer$_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ every player$_3$ $[_{VP}$ two jerseys$_2$ $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ $e_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to $e_3$]]]]]]]]]]

c. $NP_2$-$NP_1$-$NP_3$
$[_{IP}$ two jerseys$_2$ $[_{IP}$ a trainer$_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ every player$_3$ $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ $e_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to $e_3$]]]]]]]]]]

d. $NP_2$-$NP_3$-$NP_1$
$[_{IP}$ two jerseys$_2$ $[_{IP}$ every player$_3$ $[_{IP}$ a trainer$_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ $e_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to $e_3$]]]]]]]]]]

e. $NP_3$-$NP_1$-$NP_2$
$[_{IP}$ every player$_3$ $[_{IP}$ a trainer$_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ two jerseys$_2$ $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ $e_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to $e_3$]]]]]]]]]]

f. $NP_3$-$NP_2$-$NP_1$
$[_{IP}$ every player$_3$ $[_{IP}$ two jerseys$_2$ $[_{IP}$ a trainer$_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ $t_1$
$[_{VP}$ gave $[_{sc}$ $e_2$ $[_{VP}$ $[_{VP}$ e $t_2$]$[_{PP}$ to $e_3$]]]]]]]]]]

Each of these six logical forms is well-formed and will be interpreted unambiguously to yield the six possible readings for "A trainer gave two jerseys to every player."

Given the constraints that have been proposed so far, several other logical forms could potentially be generated. Look at the dative structure in (92) again and you will see that $NP_3$ could have been adjoined to PP or the VP node that is immediately dominated by sc. From either of those positions, $NP_3$ would properly bind and properly govern its trace. However, for purposes of semantic interpretation, I want $NP_3$ to c-command gave. I will give more justification for this in the following chapter, but the basic idea is that the argument NPs must be QR'd to positions which c-command the predicate which is subcategorized for those arguments. Then the interpretation procedure will work its way down the tree, encountering quantifier phrases as it goes along. By the time it reaches the verb, which is interpreted as a relation, all the argument positions must have been bound (in a sense to be made precise later). I use the term "argument position" here in the semantic sense of arguments to a relation, not in the syntactic sense of subject or object positions which are θ-marked. For example, z occupies the third argument position in the relation GAVE(x,y,z).

### 3.3.4 Double objects

In the previous two sections, all possible quantifier orderings were possible for transitive clauses and datives. However, double objects have a more restricted range of readings. The direct object must always take narrower scope than the subject and indirect object. Either of the subject and the indirect object may take scope over the other. These observations are accounted for in this system, since neither the subject nor the direct object variables are θ-governed in any of the three analyses being considered here.

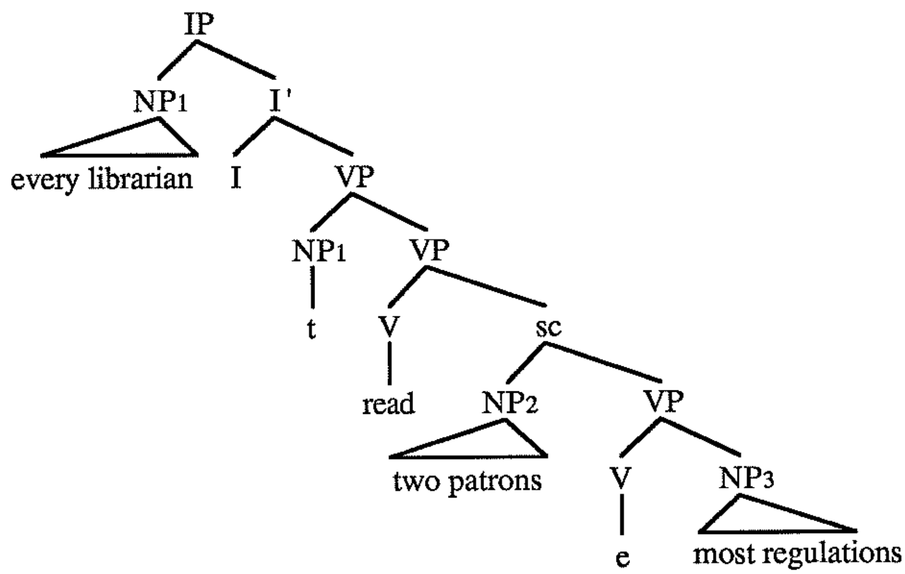
In Kayne's (1983) analysis, the direct object functions as the predicate of a small clause and is not governed nor assigned case by the verb. In Larson's (1988) analysis, the direct object is not a sister to the verb. It is assigned case by the V' constituent. Thus, according to definition (82), the direct object is not θ-governed. Finally, in Aoun and Li's (1989) analysis, the direct object is governed by an empty verb. That verb assigns case to the direct object. If the empty verb θ-marks (and therefore θ-governs) the direct object, then a variable in that position would be properly governed. This poses a problem for my system, because according to judgments of English sentences, the direct object must have narrower scope than the indirect object. One way to prevent the direct object from taking wide scope is to say that its trace is not θ-governed and therefore it must be (minimally) antecedent-governed. I see three alternatives. First, I could reject Aoun and Li's analysis of the surface structure in favor of Kayne's or Larson's. Second, I could assume that the empty verb does not θ-mark the direct object, but then it is not clear how it does get θ-marked. Third, definition (82) could be amended to say that the governor must be a lexical item. This last option seems the most plausible to me, since a potential antecedent governor must also be lexical, as in definition (86).

This option also provides a way to account for variation in scope judgments for double object constructions. for speakers who find that the second object may take wide scope, we could say that the empty verb θ-governs its complement. This would license structures in which the second object position was not antecedent-governed (e.g. when the second object has wider scope than the subject).

For speakers, like myself, who find that the second object must have narrow scope, a governor must be a lexical item. I will henceforth assume that the subject and direct object positions are not properly governed in a double object construction.

Therefore, the variables left as a result of QR applying to the subject and direct object must be antecedent-governed. As proposed in (87) above, antecedent-government must be "minimal" in the sense that there cannot be an intervening potential governor. This means that QR can only raise the subject to the lowest IP adjunction site. Similarly, direct objects in a double object construction can only be raised to the lowest VP adjunction site. The indirect object will either adjoin to VP (above the direct object) or IP (above the subject) in order to derive the two possible readings for the double object construction. Aoun and Li's surface structure is shown below.

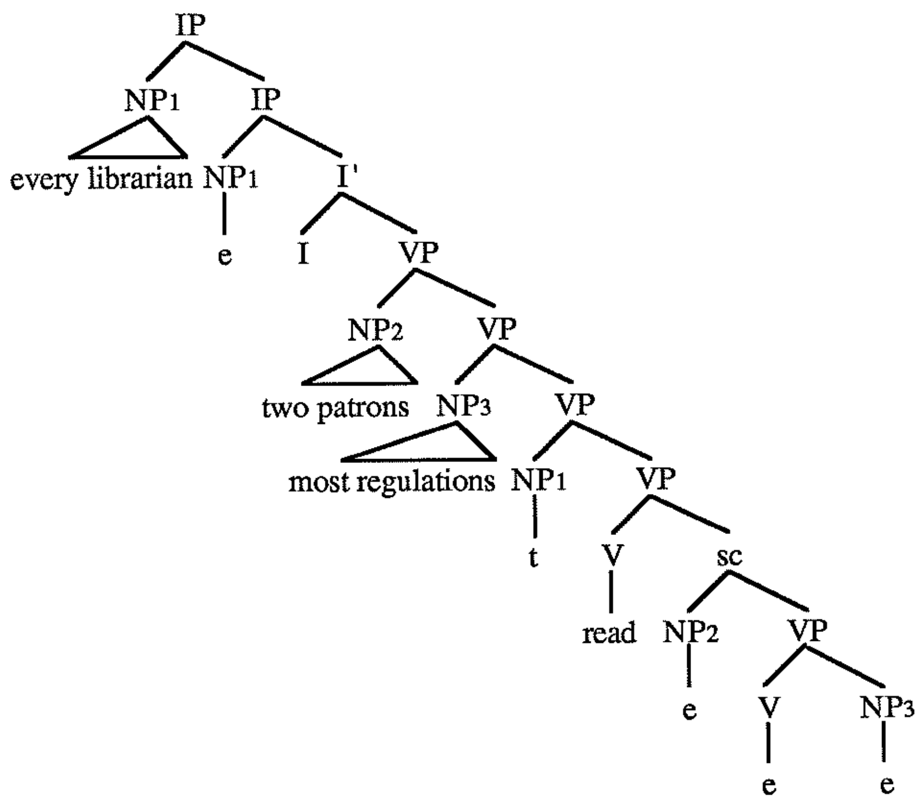
(94) Every $librarian_1$ read at least two $patrons_2$ most of the new $regulations_3$.
Surface structure:



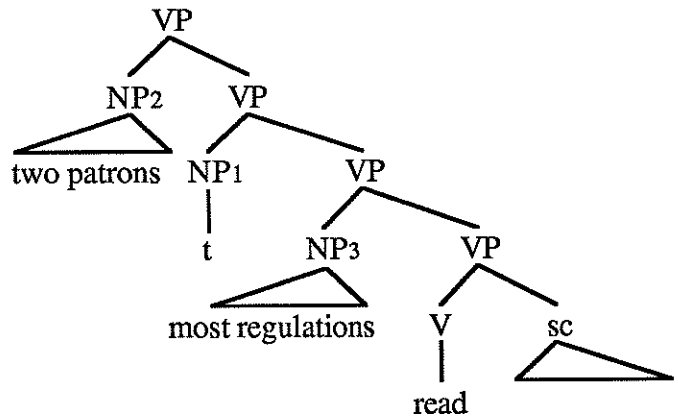

The two logical forms which can be derived from this structure are given in (95) and (96). The logical form of (95) below is similar to the one derived by Aoun and Li. However, $NP_3$ has been raised to a point where it c-commands the LF trace of $NP_2$. This configuration is ruled out by Aoun and Li's Minimal Binding Requirement, given in (66) above. The reason for moving $NP_3$ that high, as explained in the account of datives, is to have the quantifier phrase c-command the verb. The interpretation procedure requires this in order to bind all the arguments of the verb before evaluating the verb denotation.

I want to point out that $[_{NP}\ e]_3$ is antecedent governed in this structure. According to definition (86), $[_{NP}\ e]_2$ does not serve as a potential governor, since it is not lexical. Therefore, $[_{NP}$ most regulations$]_3$ antecedent-governs $[_{NP}\ e]_3$ according to definition (87).

(95) Every librarian$_1$ read at least two patrons$_2$ most of the new regulations$_3$.
Logical form interpreted with subject-wide scope:



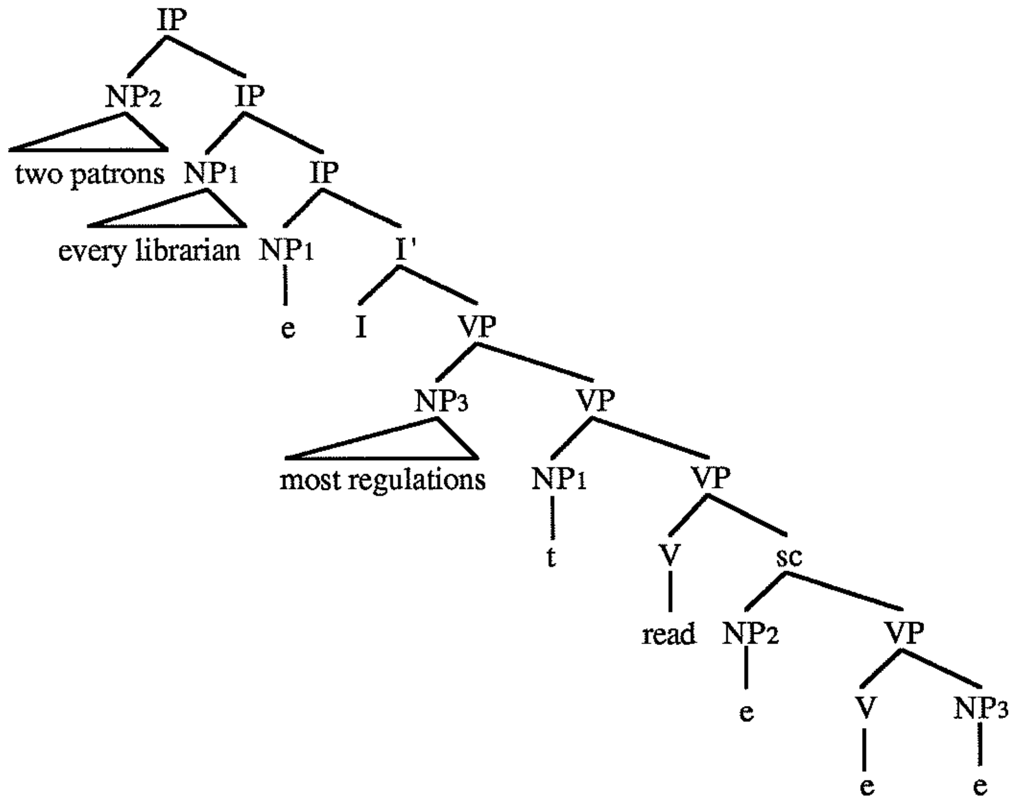

There are other logical forms which are consistent with the constraints on LF and which would also yield a subject-wide scope reading. For example NP$_3$ could have been adjoined to the VP that immediately dominates $[_{VP}$ read … ]:




So there are several logical forms which will all receive an interpretation corresponding to the $NP_1$-$NP_2$-$NP_3$ quantifier ordering. The alternative structure given above receives the same interpretation as (95), because the trace $[_{NP}\ t]_1$ does not enter into the interpretation. The portions of the logical form which are crucial to the interpreting procedure are the quantifier phrases and the verb with its associated θ-grid. The deep structure position of the subject is relevant only in so far as it allows the θ-grid to be properly determined.

In order to give the indirect object wide scope, it can be adjoined to IP. Its trace will be properly bound and properly governed, even if $NP_2$ is adjoined higher than the subject $NP_1$. $NP_1$ will block antecedent-government in this situation, but $[_{NP}\ e]_2$ will be θ-governed, and thus properly governed, by the verb.

(96) Every librarian$_1$ read at least two patrons$_2$ most of the new regulations$_3$.
Logical form interpreted with indirect object wide scope




At this point, we have examined the interaction of quantified NPs in several constructions. Transitive clauses and datives allow all combinations of scope orderings. An unambiguous logical form is generated for each of these readings. Scope interactions are much more restricted in double object constructions. I accounted for this by requiring the direct object to be (minimally) antecedent-governed. This forces the double object to take narrowest scope. In contrast, the trace left by the indirect object is properly governed by the verb. Therefore, the indirect object is free to adjoin to IP for a wide scope reading. Or, the indirect object may adjoin to VP where it will be interpreted within the scope of the subject.

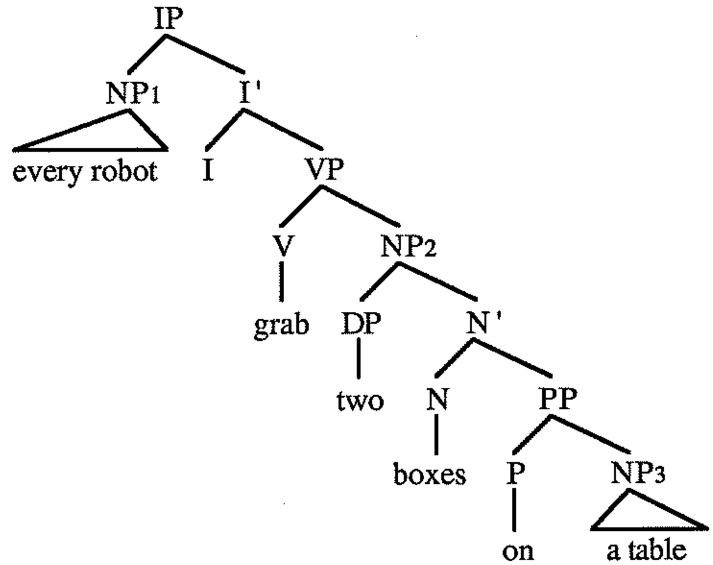
### 3.3.5 PP modifiers

Earlier, I showed that the scope of an NP within a PP modifier is problematic for theories of LF that rely on ambiguous logical form. However, the correct scope possibilities can be derived in a theory which uses unambiguous logical forms. Consider the possible scope ambiguities for the following sentence.

(97) [Every robot]$_1$ grabbed [two boxes on [a table]$_3$]$_2$.

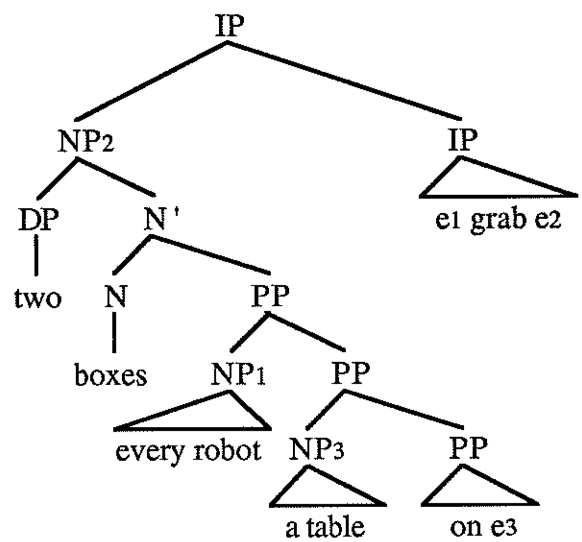
The one ordering of quantifiers which is not allowed is $NP_2$-$NP_1$-$NP_3$. That is, there is no way to interpret (97) as saying that the table on which two boxes are located varies with the choice of robot. That is the reading which would be required if for two boxes, every robot is such that there is a table from which the robot picked up the two boxes. The sentence, "Every robot grabbed two boxes on a table", may have several surface structures, depending on where the prepositional phrase is attached. For the reading where on a table restricts the boxes to be considered, I assume that the PP is part of the N' constituent. Once we consider the surface structure for the intended reading of (97), given in (98), it is clear how the analysis should proceed. We simply should not allow QR to move $NP_1$ inside of $NP_2$.

(98) Surface structure:



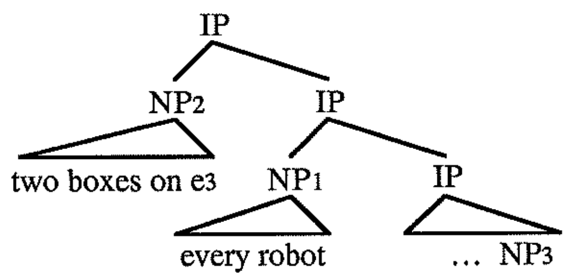

However, this already follows from previous assumptions about LF. If $NP_1$ adjoins to any node that is dominated by $NP_2$, then $NP_1$ will not c-command any nodes which are not dominated by $NP_2$. This means that the variable $[_{NP}\ e]_1$ will be unbound and the resulting logical form will not be well-formed:

(99) Ill-formed logical form:



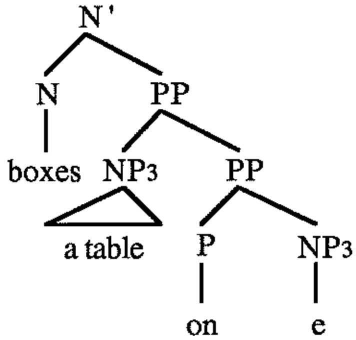
Even if the PP modifier had been in the subject NP, the same problems would arise. If the object NP is moved inside the subject NP, it will not properly bind its trace. The object trace would be properly governed by the verb, but it would not be properly bound by its antecedent. Thus, we must require both proper government and proper binding, in order to generate well-formed logical forms.

One could also attempt to get a $NP_2$-$NP_1$-$NP_3$ ordering from (98) by adjoining $NP_2$ to IP and $NP_3$ to VP. However, this logical form is not well-formed, because the variable $[_{NP}\ e]_3$ inside $NP_2$ is not properly bound:




Five logical forms which correspond to the valid readings for this sentence will be derived. $NP_1$ must always adjoin to the lowest IP adjunction site. $NP_2$ can adjoin either to VP, where it will have scope inside the subject, or IP, where it will have scope outside the subject. $NP_3$ may adjoin to the PP to give the reading where different boxes need not be on the same table. That is, the structure in (100) will evaluate to a property which is essentially a list of the boxes, where each box on the list satisfies the condition that it is on some table (but not necessarily the same table as all the other boxes):

(100)




Moving $NP_3$ outside of $NP_2$ gives the reading where the boxes *are* on the same table, i.e. "there is a table t such that for two boxes on t ...". As shown in the following list of possible readings, there will be three logical forms where $NP_3$ has wider scope than $NP_2$:

(101) a. 1 2 3
$[_{IP}$ every $robot_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ $[_{NP}$ two boxes $[_{PP}$ a $table_3$ $[_{PP}$ on $e_3]]]_2$
$[_{VP}$ grab $e_2]]]]]$

b. 1 3 2
$[_{IP}$ every $robot_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ a $table_3$ $[_{VP}$ $[_{NP}$ two boxes on $e_3]_2$
$[_{VP}$ grab $e_2]]]]]]$

c. *2 1 3

d. 2 3 1
$[_{IP}$ $[_{NP}$ two boxes $[_{PP}$ a $table_3$ $[_{PP}$ on $e_3]]]_2$ $[_{IP}$ every $robot_1$ $[_{IP}$ $e_1$ grab $e_2]]]$

e. 3 1 2
$[_{IP}$ a $table_3$ $[_{IP}$ every $robot_1$ $[_{IP}$ $e_1$ $[_{I'}$ I $[_{VP}$ $[_{NP}$ two boxes on $e_3]_2$
$[_{VP}$ grab $e_2]]]]]]$

f. 3 2 1
$[_{IP}$ a $table_3$ $[_{IP}$ $[_{NP}$ two boxes on $e_3]_2$ $[_{IP}$ every $robot_1$ $[_{IP}$ $e_1$ grab $e_2]]]]$

Thus, the free application of the rule of Quantifier Raising, along with the constraints on LF, derive all and only the possible readings for complex quantifier interaction involving NPs in PP modifiers.

### 3.3.6 Predicate negation

In the previous sections, I have shown how QR and constraints on LF derive the correct range of unambiguous logical forms to account for the observed scope ambiguities (or lack thereof) between quantified noun phrases. Now I turn to the interaction between quantified NPs and the Boolean operators. In this section, I will consider negation and in the following section, I will consider coordinate structures.

Recall from the earlier discussion of negatives in main clauses that the subject must always be outside the scope of predicate negation (the universal quantifier is treated as a lexical exception, because it may be interpreted as having narrower scope than the negation). The direct object and indirect object may take either wide or narrow scope with respect to the negation.

These facts are accounted for in a straightforward way, if we assume that the negation operator does not move. QR can only adjoin the subject to IP, so the quantified subject will not come within the scope of negation. The objects may adjoin to VP within the scope of negation or they may adjoin to IP outside the scope of negation.[18]

The exact placement of the negation operator is not important for this analysis. For simplicity, I will assume it is adjoined to VP as an operator:

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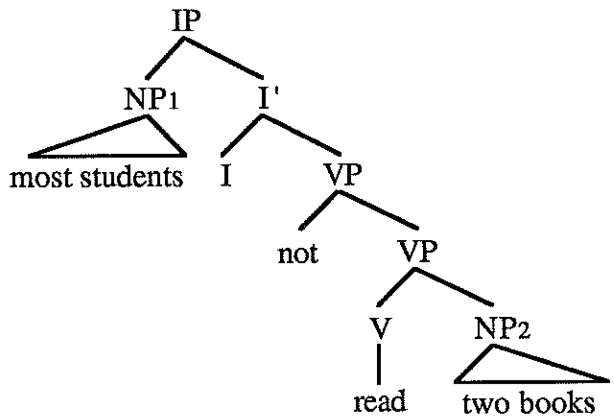
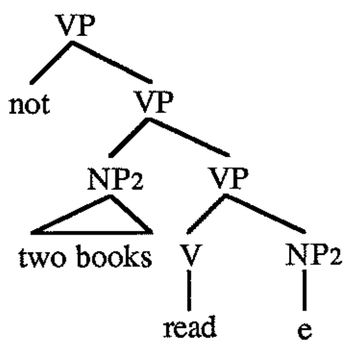
18 The analysis that I give is not inconsistent with movement of the negation operator. Suppose that one wants to use movement of operators to account for scope ambiguities between negation and modals. Then I would want to block the movement of the negation past the subject, perhaps by reference to the Empty Category Principle and the notion of a minimal potential binder discussed earlier.

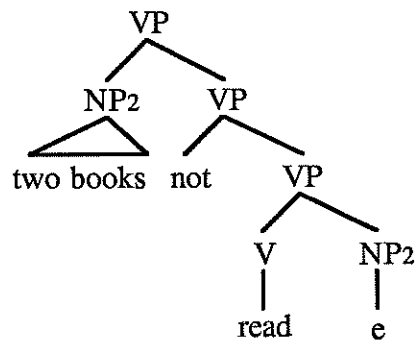
(102) Most students didn't read two required books.
Surface structure:



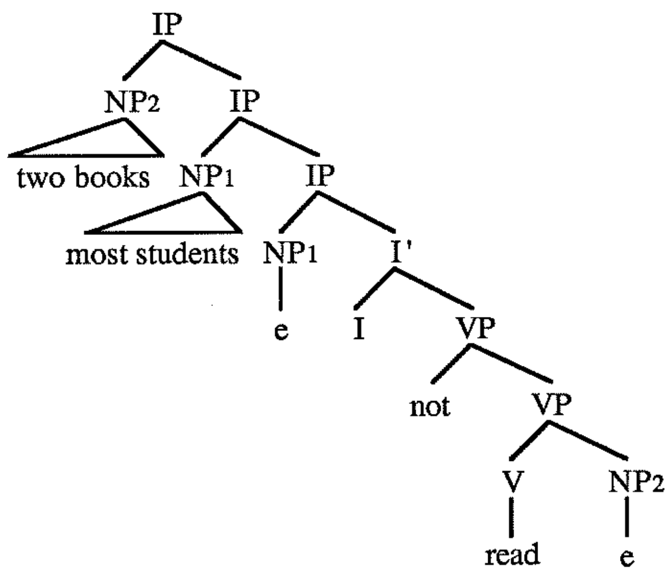

If the object NP is adjoined to the lowest VP node, it will have narrower scope than the negation:




When the object NP is adjoined to the highest VP node, it will have scope wider than the negation but narrower than the subject:




The third reading will be generated when the object NP is adjoined to IP in order to take scope over the subject:




As illustrated above, the three valid operator orderings are correctly derived, while the three invalid orderings (those where <u>not</u> takes scope over the subject) will not be derived.

### 3.3.7 Coordination

The final set of structures to be considered involve coordination of verb phrases. In the discussion of possible scope ambiguities, I argued that a quantified

NP in a conjoined verb phrase may not take wide scope over the subject. Furthermore, there is no scope interaction between the two conjuncts.

Since I am using a movement rule to account for scope, the obvious conclusion is that this rule obeys the Coordinate Structure Constraint:

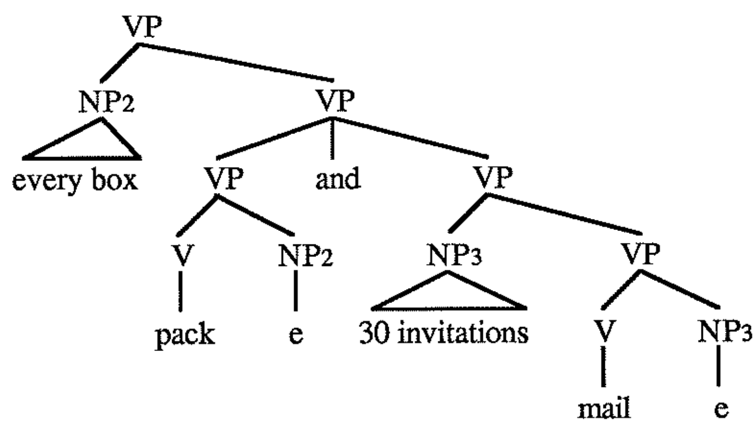
> In a coordinate structure, no conjunct may be moved, nor may any element contained in a conjunct be moved out of that conjunct. (Ross 1967:1961)

Therefore, in a sentence like (103), the object NPs may only have scope within their own VP.

(103) A secretary packed every box and mailed 30 invitations.

QR should only raise the objects to the lowest VP nodes, otherwise they would not be interpreted independently. This is illustrated in (104) where $NP_2$ has scope over the entire conjoined VP.

(104) A $secretary_1$ packed every $box_2$ and mailed 30 $invitations_3$.
Ill-formed logical form:




Since $NP_3$ is within the scope of $NP_2$, this structure has the interpretation that the invitations may vary for each box. This is not a possible reading for (103). However, none of the LF conditions that we have considered so far will rule out this structure. For example, each of the variables is properly bound and properly governed.

The generalization that I would like to formalize is that NPs which are scope independent at surface structure must also be scope independent at LF. This seems like an uncontroversial claim to me. We know that surface structure encodes the logical relations that are used by the interpretive component. For example, the arguments to a verb are identified by the thematic roles and case that it assigns. Similarly, it is possible to identify the potential scope of an NP by its surface structure position (Williams 1986).[19] In effect, QR just serves to make that scope explicit in the representation while enumerating the valid quantifier scope interactions. So it seems intuitively reasonable that the mapping from surface structure is not free to rearrange logical relations between constituents. Chomsky's (1981) *Projection Principle* captures this fact for the relationship between a verb and its arguments. One cannot switch arguments around in moving from surface structure to LF.

Another way in which the LF mapping should preserve relations is in the area of scope independence. Scope dependency is related to the c-command relation in the following way:

(105) Definition: For all NPs A,B, A is *scope dependent* on B iff
- i. B c-commands A; or
- ii. there exists an NP C such that
  - a. C dominates B; and
  - b. A is scope dependent on C.

The recursive clause in this definition extends scope dependence beyond the c-command relation. The intuition is that if A is dependent on C, it is potentially dependent on NPs embedded in C.[20] The PP modifier examples considered earlier

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[19] Williams did not consider all of the complex quantifier interactions that have been presented in this chapter. His rule of Scope Assignment is likely to encounter problems where not all possible permutations are available (e.g. the PP modifier cases discussed previously). However, the point is that scope relations depend crucially on surface structure relations, since surface structure serves as the input to the mapping to LF.

[20] This is similar to Haïk's (1984) notion of indirect binding where an NP may bind a pronoun without c-commanding it. Loosely speaking, embedded NPs inherit the scope of the NPs in which they are embedded.

exhibit this characteristic. Another example would be the embedded NP in a possessive construction; e.g. "Every child's mother signed two petitions" where the possessor <u>every child</u> may enter into scope ambiguities with the direct object <u>two petitions</u>.

The term "scope dependent" is intended to indicate a syntactic relation that may hold between two NPs. It says nothing about how they will be interpreted or whether one NP is interpreted as having wide (semantic) scope over the other. Later, when we look at the algorithm for interpreting LF, semantic scope dependencies will result from the interpretation procedure. The point is that semantic scope is reflected in the syntactic structure. At this point, we are trying to constrain syntactic operations, such that they will preserve certain features of the syntactic structure as they map from one level of representation to another.

Given definition (105) for scope dependence, I now define independence in the obvious way:

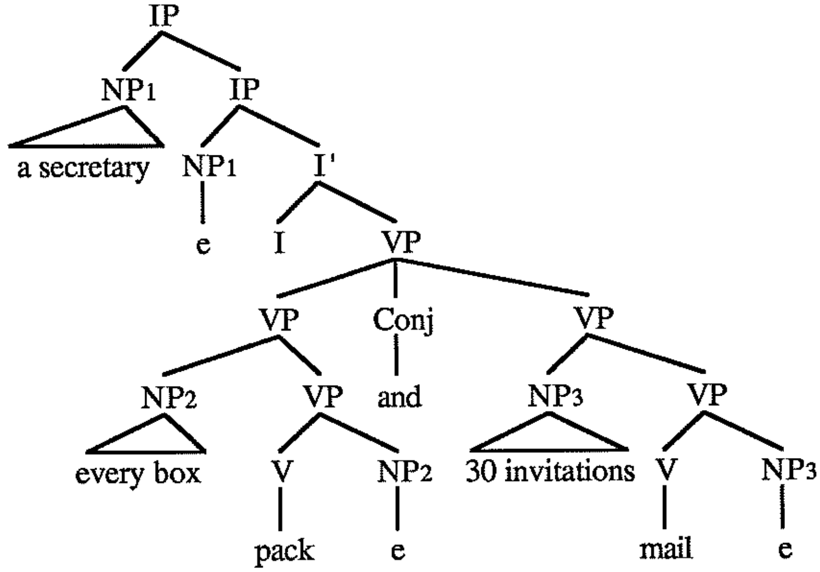
(106) <u>Definition</u>: For all NPs A, B,
A and B are *scope independent* iff
i. A is not scope dependent on B; and
ii. B is not scope dependent on A.

Now I would like to make an empirical claim about the mapping from surface structure to LF. The claim is that the mapping may not introduce dependencies where there were none:

(107) Invariant Scope Independence Principle (ISIP)
If two NPs A, B are scope independent at surface structure, they must also be scope independent at LF.

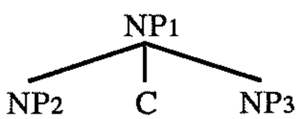
Returning to the earlier example, "A $\text{secretary}_1$ packed every $\text{box}_2$ and mailed 30 $\text{invitations}_3$", the two object NPs are scope independent at surface structure. There will only be one acceptable LF structure which satisfies the Invariant Scope Independence Principle:

(108) Logical form:




In this structure, the object NPs have been raised as high as possible without introducing scope dependencies (in the formal sense defined above) which do not exist in the surface structure.

It is worth noting that the ISIP has nothing to say about scope interactions between coordinate NPs. The two conjuncts are not scope independent according to definition (106), because there is a mutual c-command relation between the two nodes:

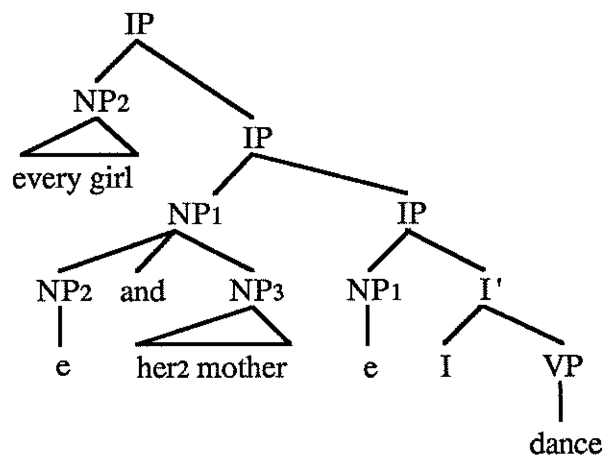



When discussing coordinate subjects and coordinate objects at the beginning of this chapter, I said that the two conjuncts need to be interpreted independently. I believe this is true in general. However, it is possible to induce a dependent reading if one conjunct contains a bound variable pronoun:

(109) Every girl and her mother danced.

The interpretation of the second conjunct is dependent on the interpretation of the first. One way to generate such a reading is to let the one conjunct, every girl, take wide scope over the entire coordinate VP:

(110)




I do not think this type of dependency is possible with two quantified NPs. When the first conjunct is universally quantified and the second conjunct contains a relational noun (sister, friend), there may be a dependency:

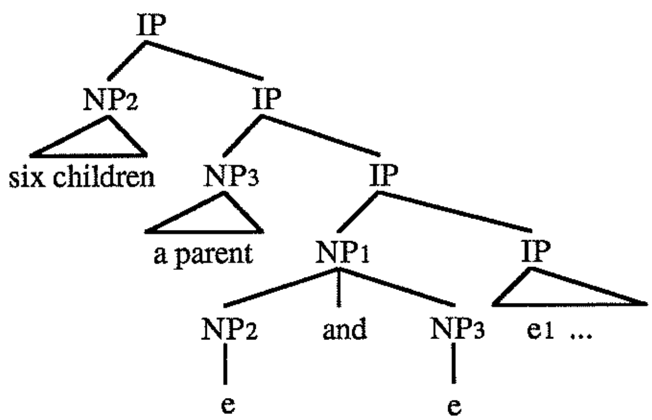
(111) Every child and a parent attended the meeting.

Perhaps this has a reading where for every child there is a parent (of that child) such that they attended the meeting. It has already been noted that the universal quantifier is exceptional with regards to its interaction with Boolean operators. Dependency across conjuncts seems completely impossible with other quantifiers:

(112) a. Six children and a parent attended the meeting.
b. Two girls and older brothers were invited.
c. A student and every teacher met the principal.
d. Most defendants and two lawyers appealed the decision.

All of these sentences sound very odd when trying to force a dependent reading between the two conjuncts, although there is no problem interpreting them independently.

So in general, conjoined NPs should be interpreted independently. However, it is not the ISIP which forces the independent interpretation. In the case of two quantified NPs, the dependent reading will be ruled out by the ECP. In the following structure, $[_{NP}\ e]_2$ is not properly governed, because $NP_3$ intervenes as a potential governor between $[_{NP}$ six children$]_2$ and its trace:




Crucially, the ISIP does not apply to coordinate NPs, so one of the conjuncts can take wide scope over another containing a bound variable pronoun, as in the well-formed logical form in (110) above.[21] Therefore, it is not simply the presence of a conjunction which forces an independent interpretation. Rather, there is something about the additional structure in a coordinate VP which rules out the scope dependent reading between the objects. For whatever reason, the ISIP appears to describe scope judgments better than a simple reference to coordinate structures.

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21 It seems to me that the equivalent type of pronominal binding is more difficult across VP conjuncts:

(i) The teacher called every girl and talked to her mother.
(ii) The foreman fired three striking workers and sold their tools.
(iii) The foreman sold their tools and fired three striking workers.

Examples (i) and (ii) sound much better to me, although the exact same c-command relations would hold for (iii) both at surface structure and LF.

## 3.4 Summary of Chapter Three

I have attempted to increase our knowledge of quantifier scope interactions by rendering judgments on sentences containing more than two logical operators. Wherever possible, I have given several examples with quantifiers other than the standard universal every and existential some. It is not easy to draw generalizations in all cases, especially when lexical exceptions enter into the picture. However, I believe it is possible (and useful) to state general conditions on quantifier scope interactions based on structural properties of English sentences. It seems to me that all possible quantifier orderings are possible in simple transitive clauses and in dative constructions. Double object constructions are not completely ambiguous, since the indirect object must take wide scope over the direct object. Structures with a PP modifier in the N' constituent also do not allow all permutations of quantifiers. A quantifier external to the modified NP may not take scope between the initial quantifier and the quantifier in the PP. My consideration of coordination was primarily focused on coordinate VPs where the objects must be interpreted independently in each conjunct and neither may take scope over the subject. Predicate negation may not take wide scope over the subject, except in the case of a universal quantifier.

After presenting judgments on these constructions, I pointed out several problems for theories of LF that rely on ambiguous structures. The dative construction was shown to be a problem for Aoun and Li's Minimal Binding Requirement and Scope Principle. Neither Aoun and Li's analysis nor May's seems to be able to account for observed lack of readings with a PP modifier.

I then provided an alternative account in which surface structures are mapped to unambiguous logical forms. Observed ambiguity was accounted for by having QR raise NPs to various levels in the representation. The lack of certain readings corresponds to illicit movement which is ruled out by the Empty Category Principle. In the case of coordinate verb phrases, the ECP does not rule out undesirable forms. Therefore, I suggested that a principle of Invariant Scope Independence forces the mapping from surface structure to LF to preserve certain scope relations. Furthermore, I argued that this principle was more descriptively adequate than use of the Coordinate Structure Constraint, since coordinate noun phrases showed different effects than coordinate verb phrases.

## Chapter 4

## Interpreting logical forms

In the preceding sections, I defined a fragment of English and gave some rules for converting surface structures into logical forms. We now turn to a set of rules for interpreting these logical forms. The procedure for evaluating a logical form proceeds from the root of the tree and works its way down to the lexical items. Quantifier phrases are always adjoined to the phrase over which they have scope. So as the evaluation procedure encounters quantifier phrases, the corresponding variables in the adjoined phrase will be bound. Truth values are only assigned when predicates and their θ-grids are encountered. For my purposes, I will simply assume that a θ-grid is a means to identify the arguments of a predicate, where the arguments are written in parentheses after the verb:

laugh(i)
buy(i,j)
give(i,j,k)

A verb will denote an n-place predicate and the θ-grid identifies the predicate's arguments.

There are two important features of this system. First, determiners are interpreted within the framework of generalized quantifiers. This provides a very simple method for evaluating complex determiners formed with Boolean operators (e.g. 'some <u>but</u> <u>not</u> all', 'less than six <u>or</u> more than twelve'). Second, truth values are calculated on the basis of a verb and its θ-grid, not on the basis of the structural position of argument NPs. Therefore, this algorithm provides a straightforward analysis of verb phrase adjunction. Even though some authors have assumed that QR can adjoin an NP to a VP (May 1985, Aoun and Li 1989), they have not given the interpretation for such structures.

I begin by defining the denotation set for each lexical category. The denotations for particular determiners are then presented in more detail, followed by the rules for assigning truth values to sentences.

### 4.1 Denotation sets

The denotation sets are essentially those of standard first-order logic, except for the determiners. The basis of the model is a non-empty set **E** which is referred to as the universe of discourse. Variables denote elements of **E**. Nouns, adjectives, and intransitive verbs denote subsets of **E**. Intuitively, these categories denote properties of individuals and they are represented as sets of individuals from the universe of discourse. Transitive verbs denote binary relations. That is, each verb denotes a set of ordered pairs of individuals from **E**. For example, the denotation of <u>kiss</u> will contain the ordered pair <bill,alice> in order to represent the fact that "Bill kissed Alice".

Following current work with generalized quantifiers, determiners are the one category which are treated quite differently than systems of first-order logic. They are treated as functions from pairs of properties into truth values. The interpretation of determiners is given in more detail in the next section.

The denotation sets are summarized in table (1) below. **E** is the set representing the universe of discourse. **E*** refers to the powerset of **E** (i.e. the set of all subsets of **E**). The cross product **ExE** is the set of all ordered pairs whose members are both elements of **E**. The cross product **E*xE*** is the set of ordered pairs of properties.

(1)

| Syntactic Category | Denotation Set |
|---|---|
| Sentence, Verb Phrase | **2** = {0,1} |
| Variables | **E** |
| Nouns, Adjectives, Intransitive Verbs | **P** = **E*** |
| Transitive Verbs, Prepositions | (**E** x **E**)* |
| Bitransitive Verbs | (**E** x **E** x **E**)* |
| Determiners | [(**E*** x **E***) → **2**] |

A meaning function, m, is defined to map syntactic structures into the denotation sets. The meaning of lexical items will be determined by the model. Suppose we have a universe of discourse **E** = {a,b,c}. In one model, it may be that m([$_N$ man]) = {a,b}, while in another model m([$_N$ man]) = {b,c}. The lexical item and the category label serve as inputs to the meaning function. Both the lexeme *and* the label are required to assign the proper denotation. For example, the string test functioning as a noun will denote a property, whereas test as a transitive verb will denote a two-place predicate:

m([$_N$ test]) = {$test_1$,$test_2$,$test_3$}

m([$_V$ test]) = {<alice,bill>, <fred,greg>}

## 4.2 Determiner denotations

In the generalized quantifier (GQ) framework, noun phrases are interpreted as functions from properties to truth values (Barwise and Cooper 1981, Keenan and Moss 1985, Keenan and Stavi 1986). The truth value of a simple sentence can be calculated compositionally by applying the denotation of the subject noun phrase to the denotation of the verb phrase. This is illustrated in (2) below, where the noun phrase every student is interpreted as a GQ and the intransitive verb laugh is interpreted as a property (i.e. a set of elements from the universe of discourse).

(2) a. Every student laughed.
b. |[every student]| |[laugh]|

The GQ can itself be further analyzed by deriving its denotation from the denotations of the determiner and the common noun phrase. |[every]| can be interpreted as a function which maps properties into GQs. Equivalently, the determiner can be interpreted as a function which maps pairs of properties to a truth value. The definitions for determiners are defined in set-theoretic terms, as illustrated in (3) below, for a few of the simple determiners.

(3) a. $\|[\text{every}]\|\,(P)(Q)$ iff $P \cap Q = P$
 b. $\|[\text{some}]\|\,(P)(Q)$ iff $P \cap Q \neq \{\}$
 c. $\|[\text{no}]\|\,(P)(Q)$ iff $P \cap Q = \{\}$
 b. $\|[\text{most}]\|\,(P)(Q)$ iff $|P \cap Q| > |P \cap -Q|$

Consider how these definitions would apply to calculate the truth value of a sentence like (2) above. One must look up the denotation of the common noun and the verb with respect to a model. Substituting these properties into the definition in (3a) yields a truth value:

$$\|[\text{every}]\|\,(\|[\text{student}]\|, \|[\text{laugh}]\|) = \text{True iff } \|[\text{student}]\| \cap \|[\text{laugh}]\| = \|[\text{student}]\|$$

If the set of students happens to be a subset of the set of laughers, then the sentence "Every student laughed" will be true. Otherwise, it will be false.

### 4.2.1 Classifications of generalized quantifiers

Given this framework for analyzing determiners, one can classify the different natural language determiners according to the type of function they denote. In this paper, I will consider the classifications which depend on the notion of monotonicity:

(4) a. Definition: A function f is *increasing* with respect to the relation $\leq$ iff for all x, y $x \leq y \Rightarrow f(x) \leq f(y)$.

 b. Definition: A function f is *decreasing* with respect to the relation $\leq$ iff for all x, y $x \leq y \Rightarrow f(y) \leq f(x)$.

 c. Definition: A function f is *monotonic* with respect to the relation $\leq$ iff f is either increasing or decreasing with respect to the relation $\leq$.

 d. Definition: A function f is *non-monotonic* with respect to the relation $\leq$ iff f is neither increasing nor decreasing with respect to the relation $\leq$.

Determiners may be analyzed as denoting functions from pairs of properties to truth values. Therefore, we can examine the monotonicity of a determiner with respect to either its first argument or its second argument. "Monotonicity on the first argument" refers to the monotonicity of the function denoted by the determiner. "Monotonicity on the second argument" refers to the monotonicity of the function denoted by the entire noun phrase when interpreted as a generalized quantifier. Following Barwise and Cooper (1981), I will use the term *persistent* to indicate that a determiner is increasing on the first argument (*anti-persistent* = decreasing on its first argument). The terms *monotone increasing* (*decreasing*) are used when a determiner is increasing (decreasing) on its second argument.

Considering the definitions in (3) again, it can be shown that |[some]| is increasing on both arguments. Following van Benthem (1986), I write this as ↑some↑. The function denoted by <u>every</u> is decreasing on its first argument, but increasing on its second argument, written as ↓every↑. This classification leads to the Square of Opposition (van Benthem 1986:12). In diagram (5), the connecting lines indicate the relationship of negation.

(5)

| | | |
|---|---|---|
| ↑ some ↑ | ╲ ╱ | ↑ not all ↓ |
| ↓ all ↑ | ╱ ╲ | ↓ no ↓ |

Löbner (1987) provides a more detailed account of the effects of negation. He refers to the following diagram as the duality square. The relationship of negation in (5) is represented as outer negation in (6a). Löbner (1987:84) gives the following definitions for inner negation (Q~), outer negation (~Q), and duality (~Q~):

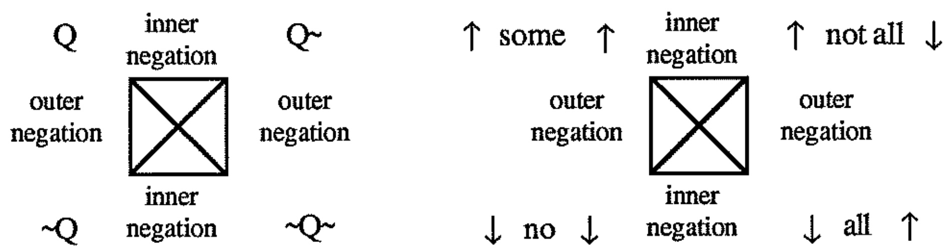
Q~ is {P | Q(–P)}

~Q is {P | ~Q(P)}

~Q~ is {P | ~Q(–P)}

Instantiating Q to some results in the duality square of (6b). Note that (6b) is not identical to (5).

(6) a. b.




As shown in (6b), outer negation reverses monotonicity on both arguments, while inner negation only reverses monotonicity on the second argument. Duality reverses monotonicity on the first argument.

### 4.2.2 Monotonicity on the first argument

There are a couple of straightforward intuitive tests to determine whether a determiner is increasing or decreasing. With respect to a determiner's first argument, we need two common noun phrase denotations, one of which denotes a proper subset of the other. For example, suppose that $P' \supseteq P$. Then for a determiner D to be persistent, it must be the case that $D(P,Q) \Rightarrow D(P',Q)$. We can create a concrete example to test our intuitive judgments about the persistence of determiners. Requiring the conditional statement to hold is equivalent to saying that the following argument must be valid, where D is some determiner:

(7) Every American student is a student.
D American(s) student passed the exam.
∴ D student(s) passed the exam.

Replacing D with the determiner some yields a valid argument, indicating that some is increasing on its first argument. However, substituting no will not yield a valid argument. To see this, consider a model with some American students and some non-

American students. Suppose no American students passed the exam, as stated in the second premise of (7). This does not allow one to conclude that no students passed the exam. It may very well be that some of the non-American students passed. Thus, replacing D in (7) by no does not yield a valid argument and no is not increasing on its first argument.

There is a similar test to check if a determiner is anti-persistent. Given P' $\supseteq$ P, it must be the case that D(P',Q) $\Rightarrow$ D(P,Q). This is exemplified by the following English example:

(8) Every American student is a student.
D student(s) passed the exam.
∴ D American student(s) passed the exam.

Substituting no, every, or less than three for D in (8) results in a valid argument, showing that no, every, and less than three are decreasing on their first argument. In contrast, more than three is not decreasing on its first argument, as demonstrated by the invalidity of (8) when this substitution is made.

### 4.2.3 Monotonicity on the second argument

There are similar arguments to help decide if a determiner is increasing or decreasing on its second argument. In these cases, we keep a fixed first argument P and look for two verb phrases denoting properties Q and Q' such that Q' $\supseteq$ Q. A determiner D is increasing on its second argument iff D(P,Q) $\Rightarrow$ D(P,Q'). If a determiner D is monotone increasing, then the following argument will be valid:

(9) D student(s) left early.
∴ D student(s) left.

In the previous section, we saw that every was decreasing on its first argument. However, substituting every into (9) demonstrates that it is increasing on its second argument. If every student left early, then it must be the case that every student left.

To check for determiners that are decreasing on their second arguments, the order of the test sentences is reversed:

(10) D student(s) left.
∴ D student(s) left early.

By inspection, determiners such as not all, no, less than five, and not more than five are decreasing on their second argument.

### 4.2.4 Evaluating generalized quantifiers

Following van Benthem (1986), I interpret determiners as functions from pairs of properties to truth values. The first property in the ordered pair corresponds to the property determined by the common noun phrase (category N') within the full NP. When the NP consists of a determiner followed by a simple common noun, e.g. "three dogs", the common noun (dogs in this case) denotes a property. Complex common noun phrases also denote a property. It is the property formed from the intersection of the adjective phrase denotation with the denotation of the common noun. For example, the property denoted by the N' "male American student" is determined by taking the intersection of the properties denoted by male, American, and student. Letting 'm' represent the meaning assignment function, we have:

$$m(\text{male American student}) = m(\text{male}) \cap m(\text{American}) \cap m(\text{student})$$

Relative clauses are part of the N' constituent and they also denote a property. The denotation of "American man who Alice kissed" is calculated by taking the intersection of the denotations for American, man, and who Alice kissed.

(11) $[_{N'}$ $[_{Adj}$ American]
$[_{N}$ man]
$[_{CP}$ $[_{NP}$ who$]_i$ $[_{IP}$ Alice kissed $[_{NP}$ e$]_i$]]]

The intersection of these three properties results in a property that is the denotation of the N'.

The second property in the ordered pair of determiner arguments corresponds to the property denoted by an open sentence which contains one unbound variable. Thus, we can represent the meaning of "Three students laughed" as:

m(three)( m(student), m($e_i$ laugh))

The lexical item student and the open sentence '$e_i$ laugh' both denote properties, so m(student) and m($e_i$ laugh) are both subsets of **E**. three denotes a function from pairs of properties, m(student) and m($e_i$ laugh) in this case, to truth values. A formal description of the method used to evaluate quantifiers is given in section 4.3.

The definitions for some of the quantifiers handled by this system are presented below. The two English determiners the and some correspond to four quantifier denotations depending on the number of the head noun. I distinguish these forms as '$the_{sg}$' and '$some_{sg}$' which occur with a singular head noun and '$the_{pl}$' and '$some_{pl}$' which occur with a plural head noun. The determiners every, each, and all are treated as synonyms. '$some_{sg}$' and a are also logically equivalent.

(12) a. every(p,q) iff $p \cap q = p$
b. $some_{sg}$(p,q) iff $p \cap q \neq \{\}$
c. $some_{pl}$(p,q) iff $|p \cap q| > 1$
d. no(p,q) iff $p \cap q = \{\}$
e. $the_{sg}$(p,q) iff $p \cap q = p$ and $|p| = 1$
f. $the_{pl}$(p,q) iff $p \cap q = p$ and $|p| > 1$
g. several(p,q) iff $|p \cap q| > 2$
h. two(p,q) iff $|p \cap q| \geq 2$
i. three(p,q) iff $|p \cap q| \geq 3$
j. exactly n (p,q) iff $|p \cap q| = n$
k. the n (p,q) iff $|p \cap q| = n$ and $|p| = n$
l. less than n (p,q) iff $|p \cap q| < n$
m. at most n (p,q) iff $|p \cap q| \leq n$
n. at least n (p,q) iff $|p \cap q| \geq n$
o. more than n (p,q) iff $|p \cap q| > n$
p. most(p,q) iff $|p \cap q| > |p \cap -q|$

This list contains the quantifier most, which is not definable within a first-order logic. Barwise and Cooper (1981) give a proof that most in the sense of "more than half" is not first-order definable. Similarly, other proportional quantifiers such as ten percent of the, less than one-third of the, etc. are not first-order definable. That is, no combination of ∀, ∃, the Boolean connectives, and first-order properties and relations could be used to define one of these quantifiers.

### 4.3 Evaluation of sentence denotations

Truth values are calculated from a verb denotation taken together with the variable assignments of its θ-grid. The verb itself denotes an n-place predicate and the θ-grid identifies the verb's arguments. In order to interpret the variables, we must first consider the notion of an assignment function which maps variables to elements of **E**.

#### 4.3.1 Assignment functions

Let a be any assignment function from the set of variables to the set **E**, so that $a \in [\text{VAR} \rightarrow \mathbf{E}]$.

Then we define the (x,b)-variant of an assignment function a as follows.

(13) For all $x,y \in \text{VAR}$, all $b \in \mathbf{E}$, and all $a \in [\text{VAR} \rightarrow \mathbf{E}]$,

$$a_{(x,b)}(y) =_{def} \begin{cases} a(y) & \text{if } y \neq x \\ b & \text{if } y = x \end{cases}$$

Therefore, $a_{(x,b)}$ differs at most from the original assignment function a at the variable x, where $a_{(x,b)}$ must map the variable x onto the element b of **E** (the original function a may also have made this assignment, but that is irrelevant).

The (x,b)-variant of an assignment function is itself an assignment function. Therefore, it is possible to create a variant of an assignment function which is already a variant of some other assignment function. This "stacking" of variants occurs as new quantifier phrases are encountered during the evaluation procedure. Suppose that the current assignment function is $a_{(i,b)}$ when a quantifier that binds variable j is encountered. As part of the evaluation procedure, we may want to bind element c to variable j. That is, we want to create the (j,c)-variant of the assignment function $a_{(i,b)}$. This can be done by simple substitution into definition (13), yielding:

For all i,j,y ∈ VAR, all b,c ∈ **E**, and all a ∈ [VAR → **E**],

$$a_{(i,b)(j,c)}(y) =_{def} \begin{cases} a_{(i,b)}(y) & \text{if } y \neq j \\ c & \text{if } y = j \end{cases}$$

Given the meaning function m, we now define a function $m_a$ which is an interpretation with respect to the assignment function 'a'. For e an expression in one of the lexical categories, $m_a(e) = m(e)$. However, for e ∈ VAR, $m_a(e) = a(e)$. Thus, when the meaning function $m_a$ is applied to a variable, it will pick out the value assigned to that variable by the assignment function a.

### 4.3.2 Simple sentences

Simple sentences are categorized according to the number of arguments to the verb. The verb may be transitive, intransitive, or bitransitive. An intransitive clause evaluates to true if the variable bound by the denotation of the subject is a member of the property denoted by the intransitive verb.

(14) Intransitive verb
For x ∈ VAR and R ∈ $V_i$

$$m_a(R(x)) =_{def} \begin{cases} 1 & \text{if } m_a(x) \in m_a(R) \\ 0 & \text{otherwise} \end{cases}$$

For example, $m_a(slept(x)) = 1$ iff $m_a(x) \in m_a(slept)$. Suppose that $m_a(x) = g$ and $m_a(slept) = \{a,b,f,g\}$. Then the logical form 'slept(x)' will evaluate to true under the assignment function a, since $g \in \{a,b,f,g\}$.

A transitive clause evaluates to true if the ordered pair formed from the variables bound by the subject and object is a member of the relation denoted by the transitive verb.

(15) Transitive verb
For x,y ∈ VAR and R ∈ $V_t$

$$m_a(R(x,y)) =_{def} \begin{cases} 1 & \text{if } \langle m_a(x),m_a(y)\rangle \in m_a(R) \\ 0 & \text{otherwise} \end{cases}$$

For example, $m_a(\text{kissed}(x,y)) = 1$ iff the ordered pair $<m_a(x),m_a(y)>$ is in the relation defined by $m_a(\text{kissed})$. Suppose that $m_a(x) = b$, $m_a(y) = a$, and $m_a(\text{kissed}) = \{<b,c>, <a,f>\}$. Then the logical form 'kissed(x,y)' will evaluate to false under the assignment function a, because the ordered pair $<b,a>$ is not in the relation $\{<b,c>, <a,f>\}$.

Bitransitive verbs simply extend this analysis to three arguments. A bitransitive verb will denote a set of ordered triples:

(16) Bitransitive verb
For $x,y,z \in VAR$ and $R \in V_b$

$$m_a(R(x,y,z)) =_{def} \begin{cases} 1 & \text{if } <m_a(x),m_a(y),m_a(z)> \in m_a(R) \\ 0 & \text{otherwise} \end{cases}$$

### 4.3.3 Quantified sentences

The interpretation of simple quantifiers will be discussed first, including the interpretation of proper nouns as quantifiers. I then present the interpretation for Boolean combinations of quantifiers.

#### 4.3.3.1 Simple quantifiers

The denotation of a quantified sentence depends on the results of determining the value of the embedded sentence under a series of (x,b)-variant variable assignments:

(17) For $Q \in DP$, $p \in N'$, $x \in VAR$, and $W \in IP$,

$$m_a([_{IP}\,[_{NP}\,Q\,p]_x\,W]) =_{def}$$
$$\begin{cases} 1 & \text{if } m_a(Q)(\,m_a(p), \{b \in m_a(p) \mid m_{a(x,b)}(W) = 1\}) = 1 \\ 0 & \text{otherwise} \end{cases}$$

This means that in order to evaluate the quantified sentence, one should apply the denotation of the determiner phrase Q to the pair of properties (p,q) where q is a certain subset of p. In particular, the set $q = \{b \in m_a(p) \mid m_{a(x,b)}(W) = 1\}$ contains those elements of p which satisfy the truth conditions of the sentence W when the variable x is interpreted as one of those elements. The variable x occurs in this formula, because it is the subscript of the NP which binds an argument position in the sentence W.

As an example, consider the evaluation of the logical form for "Two students laughed":

$[[\text{two students}]_i\ [e_i\ \text{laugh}(i)]]$

This sentence will denote the value 'true' ( = 1) relative to an assignment a if

$m_a(\text{two})(\ m_a(\text{students}), q) = 1$, where

$q = \{\ b \in m_a(\text{students}) \mid m_{a(i,b)}(\text{laugh}(i)) = 1\ \}$

Roughly speaking, q will be the set of students who laughed. The denotation of two was given in (12h) above and is repeated here:

$\text{two}(p,q)$ iff $|p \cap q| \geq 2$

The sentence "Two students laughed" will denote 'true' just in case this set q contains two or more elements. This is intuitively correct. More than two students may have laughed, but as long as at least two students laughed, then the sentence "Two students laughed" should evaluate to 'true'.

The same type of analysis is given for proper nouns, except that there is no explicit quantifier present in the logical form. Since proper nouns denote individuals, it is sufficient to verify that the noun phrase denotation is in the set denoted by the open sentence. Let $p \in$ Proper Noun, $x \in$ VAR, and $W \in$ IP, then:

$$m_a([_{IP}\ [_{NP}\ p]_x\ W]) =_{def} \begin{cases} 1 & \text{if } m_{a(x,m_a(p))}(W) = 1 \\ 0 & \text{otherwise} \end{cases}$$

For example, the logical form for "Chris laughed" is evaluated by checking to see if $m_a(\text{Chris})$ satisfies the open sentence over which the NP Chris has scope:

$m_a([_{IP}\ \text{Chris}_i\ [_{IP}\ e_i\ \text{laugh}(i)]]) = 1$ iff
$m_{a(i,m_a(\text{Chris}))}([_{IP}\ e_i\ \text{laugh}(i)]) = 1$

Given the previous definitions for interpreting simple sentences and for interpretation under an (x,b)-variant of an assignment function, this is equivalent to saying that the sentence "Chris laughed" is true if and only if $m_a(\text{Chris}) \in m_a(\text{laugh})$.

#### 4.3.3.2 Boolean combinations of quantifiers

Now we turn to the interpretation of Boolean combinations of quantifiers. These logical forms arise from Boolean combinations of determiners in sentences like (18a) with logical form (18b):

(18) a. Some but not all parents cried.
b. $[_{IP}\ [_{NP}\ [_{DP}\ [_{Det}$ Some] but $[_{Det}$ not $[_{Det}$ all]]] parents$]_i\ [_{IP}\ e_i$ cried(i)]]

Schematically, we still have a logical form of the type that we have been considering:

$[_{IP}\ [_{NP}\ Q\ p]_i\ W]$

However, in this case, Q is the complex determiner phrase <u>some but not all</u>. So we need to define how the Boolean operators <u>and</u>, <u>or</u>, and <u>not</u> are interpreted with respect to the determiners. Keenan and Stavi (1986) have argued that the Boolean operators are defined pointwise in the algebra of determiner denotations. For example, (19a) is equivalent to (19b).

(19) a. Most but not all parents cried.
b. Most parents but not all parents cried.

In general, the Boolean operators <u>and</u> and <u>or</u> may be "multiplied out" in this way and still preserve truth conditions:[1]

(20) a. Bill saw not less than twelve but not more than fifteen demonstrators.
b. Bill saw not less than twelve demonstrators and not more than fifteen demonstrators.

(21) a. More than six but less than twelve students passed the exam.
b. More than six students and less than twelve students passed the exam.

---

[1] <u>but</u> and <u>and</u> are assumed to be logically equivalent.

Only certain environments allow negation to get multiplied out in English surface structure, but it can be treated analogously to the other Boolean operators in the logical form. In the framework of this chapter, where determiners are functions in $[(E^* x E^*) \rightarrow 2]$, this results in the following definitions:

(22) For all determiner phrases $Q_1, Q_2 \in$ DP, all properties $p, q \in E^*$,

a. $m_a(Q_1 \text{ and } Q_2)(p)(q) =_{def} m_a(Q_1)(p)(q) \wedge m_a(Q_2)(p)(q)$

b. $m_a(Q_1 \text{ or } Q_2)(p)(q) =_{def} m_a(Q_1)(p)(q) \vee m_a(Q_2)(p)(q)$

c. $m_a(\text{not } Q_1)(p)(q) =_{def} \sim m_a(Q_1)(p)(q)$

Apply (22a) to the earlier example, "Some but not all parents cried" will evaluate to true if and only if:

$m_a(\text{some})(m_a(\text{parents}), q) = 1$ and $m_a(\text{not all})(m_a(\text{parents}), q) = 1$,
where $q = \{b \in m_a(\text{parents}) \mid m_{a(i,b)}(\text{cry}(i)) = 1\}$.

The second clause still contains a complex determiner, not all. Applying (22c) to this form yields:

$m_a(\text{not all})(m_a(\text{parents}), q) = 1$ iff
$\sim m_a(\text{all})(m_a(\text{parents}), q) = 1$ iff
$m_a(\text{all})(m_a(\text{parents}), q) = 0$

Therefore, the sentence "Some but not all parents cried" will be true just in case:

$m_a(\text{some})(m_a(\text{parents}), q) = 1$ and $m_a(\text{all})(m_a(\text{parents}), q) = 0$,
where $q = \{b \in m_a(\text{parents}) \mid m_{a(i,b)}(\text{cry}(i)) = 1\}$.

An important feature of this analysis is that logical forms for complex determiners are basically the same as for simple determiners:

$[_{IP} [_{NP} Q\ p]_i\ W]$

The difference between these two structures is in their interpretation. Simple determiners are lexical items which are assigned a denotation by the meaning function. Complex determiners also denote the same type of function. Thus, all determiners, simple and complex, denote functions in $[(E^* x E^*) \rightarrow 2]$. However, the function denoted by a complex determiner is not an arbitrary member of $[(E^* x E^*) \rightarrow 2]$. Its denotation is fixed by the denotation of the lexical determiners that it contains and the definition of Boolean operators in the algebra of determiner denotations. Unlike first-order logic and some computational systems (Colmerauer 1982, Pereira 1983), the determiner phrase constitutes a single constituent in the logical form. Logical differences between determiner phrases are captured in the semantics of lexical items (Woods 1978) and the rules for interpreting Boolean operators, rather than by positing distinct logical forms for lexically distinct determiners.

#### 4.3.3.3 Quantifiers adjoined to VP

In a simple transitive clause, the object narrow scope is obtained when the object NP is adjoined to the verb phrase (VP). When all of the variables in the verb's θ-grid are properly bound, the VP denotes a truth value. Even though the subject position lies outside of this constituent, the subject will bind one of the positions in the θ-grid. Therefore, the verb and the bound variables of its θ-grid are sufficient to determine a truth value.

The essential features of this analysis have already been presented. At this point, we simply need to extend the rule for interpreting adjoined quantifier phrases. Rule (17) above gave the interpretation for quantifier phrases adjoined to IP, but the same rule may be applied to quantifier phrases adjoined to VP. The only difference between (17) and (23) is the category to which constituent W belongs.

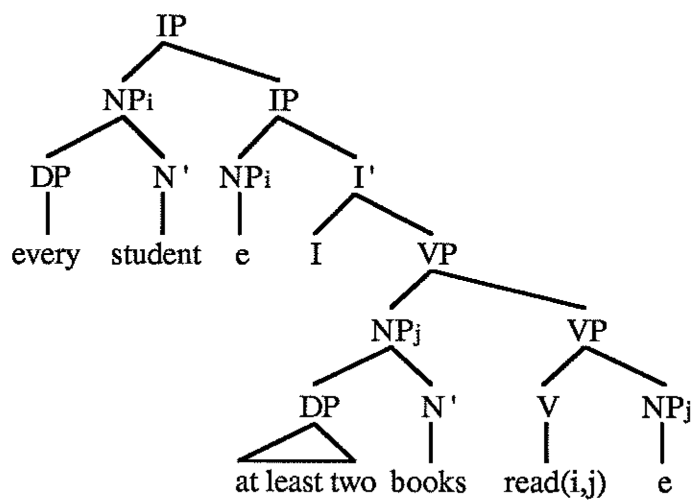
(23) For $Q \in DP$, $p \in N'$, $x \in VAR$, and $W \in VP$,

$$m_a([_{VP}\,[_{NP}\,Q\,p]_x\,W]) =_{def} \begin{cases} 1 & \text{if } m_a(Q)(\,m_a(p), \{b \in m_a(p) \mid m_{a(x,b)}(W) = 1\}) = 1 \\ 0 & \text{otherwise} \end{cases}$$

As noted previously, the argument positions are ignored, so for any transitive verb V, $m_a([_{VP}\,V(i,j)\,e_j]) = m_a(V(i,j))$. The argument positions are necessary at the syntactic level for determining well-formedness and for binding variables in the θ-grid. However, in terms of the interpretation procedure, the argument positions are ignored.

These rules are sufficient to give the object narrow scope reading of VP adjunction. Let's consider the procedure for evaluating the following logical form.

(24) Every student read at least two books.
Logical form:




According to (17), this logical form will evaluate to true if the function denoted by <u>every</u> maps two properties to true. The first property is the one denoted by <u>student</u>. The second property is the one denoted by the open sentence:

(25) $[_{IP}\ [_{NP}\ e]_i\ [_{I'}\ I\ [_{VP}\ [_{NP}$ at least two books$]_j\ [_{VP}$ read(i,j) $e_j]]]]$

As part of the procedure for calculating this property, the variable i will be bound to different elements of the |[student]| property. Given an assignment function in which i is bound, e.g. $a_{(i,s1)}$, the interpretation of the sentence in (25) will lead to a truth value. Ignoring the trace in subject position, we evaluate the verb phrase. According to rule (23), the verb phrase will evaluate to true iff the denotation of <u>at least two</u> maps two properties to true. The two properties are the denotation of <u>books</u> and the set:

$$\{ b \in m_{a(i,s1)}(books) \mid m_{a(i,s1)(j,b)}(read(i,j)) = 1 \}$$

The full substitution of applying rule (23) to this sentence reads as follows:

$$m_{a(i,s1)}([_{VP}\ [_{NP}\ \text{at least two books}]_j\ [_{VP}\ \text{read}(i,j)\ e_j]]) = 1 \text{ iff}$$
$$m_{a(i,s1)}(\text{at least two})(\ m_{a(i,s1)}(\text{books}),\ \{\ b \in m_{a(i,s1)}(\text{books}) \mid m_{a(i,s1)(j,b)}(\text{read}(i,j)) = 1\ \}) = 1$$

For some particular student s1, the verb phrase will evaluate to true just in case the intersection of the set of books with the books that s1 read has cardinality greater than or equal to two.

This analysis fills a void in the GB literature by providing an interpretation for VP adjunction. By assuming that the θ-grid of a verb contains variables bound by the verb's arguments, I have extended the generalized quantifiers approach to verb phrase adjunction. Furthermore, this allows object NPs to be interpreted without reference to functions of a different type than those denoted by subject NPs. Determiners are always evaluated as functions from pairs of properties to truth values, regardless of the original position of their containing NP.

#### 4.3.3.4 Quantifiers adjoined to PP

Prepositions are interpreted as two-place predicates. One of the preposition's argument positions is bound by the object of the preposition. The other argument position remains locally unbound. The evaluation procedure will bind this argument to different values in order to determine the property denoted by the entire prepositional phrase (PP). In the following definition, a preposition P is shown as a two-place predicate with arguments i and j. In order to evaluate the PP after Quantifier Raising has applied, the assignment function must supply a value for j, the variable corresponding to the object of the preposition.

(26) Denotation of a simple prepositional phrase
$$m_{a(j,c)}([_{PP}\ P(i,j)\ [_{NP}\ e]_j]) =_{def} \{b \mid m_{a(j,c),(i,b)}(P(i,j)) = 1\}$$

This is indicated by $m_{a(j,c)}$ at the far left end of the equation, where the meaning function m is applied relative to an assignment function $a_{(j,c)}$, which binds variable j to some element c of the universe of discourse. The choice of 'c' is arbitrary here. The algorithm for selecting bindings of the variable j will be given shortly.

Suppose that we want to evaluate the logical form $[_{PP}$ in(i,j) $[_{NP}$ e$]_j]$ when j is bound to $house_1$, an element of the universe of discourse. According to definition (26), this form will denote a property:

$$\{b \mid m_{a(j,house_1),(i,b)}(in(i,j)) = 1\}$$

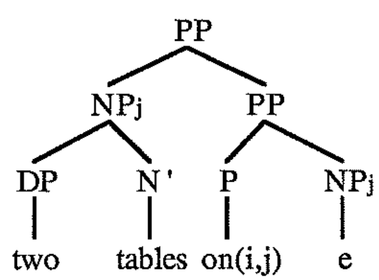
By further substitution for the variables, this simplifies to:

$$\{b \mid in(b,house_1) = 1\}$$

Thus, when the second argument is bound, the prepositional phrase denotes the set of elements which bear the relation <u>in</u> to this second argument. In this case, the set will be those things which are in $house_1$.

In the preceding discussion, I assumed that the variable associated with the object of the preposition had already been bound. Let's examine how that variable gets bound. Suppose we want to evaluate the following logical form:

(27)




This structure will evaluate to a property. It will be the set of objects, each of which is on two tables. For example, if $box_1$ is on $table_1$ *and* on $table_2$, then $box_1$ will be in the set denoted by $[_{PP}$ $[_{NP}$ two tables$]_j$ $[_{PP}$ on $[_{NP}$ e$]_j]]$. If $box_2$ is only on $table_1$ and not on any other table, then $box_2$ will *not* be in the set.

The determiner phrase will be evaluated as previously described. The DP denotes a function from pairs of properties to truth values. As before, the first property will be the denotation of the N' constituent which is a sister to the DP. The second property will be derived from the evaluation of the PP over which the quantifier phrase has scope. In this example, it will be the set of tables on which a particular object rests:

(28) $m_{a(j,c)}([_{PP}\ [_{NP}\ \text{two tables}]_j\ [_{PP}\ \text{on}\ [_{NP}\ e]_j]]) =$
$\{b \mid m_a(\text{two})(\ m_a(\text{tables}),\ S) = 1\},$
where $S = \{c \in m_a(\text{tables}) \mid b \in m_{a(j,c)}([_{PP}\ \text{on}\ [_{NP}\ e]_j])\}$

The second line of this evaluation represents the set of elements b such that the quantifier $m_a$(two) applied to (i) the set of tables and (ii) the set of tables which b is on will yield the value 'true'. $m_a$(tables) is just the set of tables. The set S is the set of tables which element b is on, i.e. it is the set of tables c such that on(b,c) is true.

The general definition for evaluating an NP adjoined to a PP is given in (29) below. The basic intuition is that a PP always denotes a property. In the case of a simple PP, this property is trivial to evaluate (see (26) above). In the case where an NP has been adjoined to the PP, the evaluation of the highest level PP is slightly more complicated, because an additional layer of quantification is involved:

(29) Denotation of a quantified prepositional phrase
For $Q \in DP$, $p \in N'$, and $W \in PP$,
$m_{a(j,c)}([_{PP}\ [_{NP}\ Q\ p]_j\ W]) =_{def} \{b \mid m_a(Q)(\ m_a(p),\ S) = 1\},$
where $S = \{c \in m_a(p) \mid b \in m_{a(j,c)}(W)\}$

An advantage to this analysis is that determiner phrases receive a uniform analysis in the three adjunction environments that I have considered: IP, VP, and PP. A determiner phrase is always evaluated as a function that maps a pair of properties to a truth value. As demonstrated in section 4.3.3.2 above, this leads to a simple account of Boolean combinations of determiners.

### 4.3.4 Boolean combinations of sentences

The final type of sentences we must consider are complex sentences built up from Boolean combinations of simpler sentences. The interpretations for the three possibilities are shown below. For all V, W $\in$ S,

(30) $m_a(\text{V and W}) =_{def} m_a(V) \wedge m_a(W)$

(31) $m_a(\text{V or W}) =_{def} m_a(V) \vee m_a(W)$

(32) $m_a(\text{not W}) =_{def} - m_a(W)$

## 4.4 Summary of Chapter Four

This chapter has provided a model-theoretic semantics for unambiguous logical forms generated by the algorithm presented in the previous chapter. The interpretation algorithm relies on the notion of a θ-grid which links a verb's subcategorized argument positions to noun phrase positions in the sentence. Indices in the θ-grid serve as variables which are bound by the quantified noun phrases. This means that the original positions of the noun phrases (e.g. the trace in subject position) need not be considered by the interpretation algorithm. Instead, a truth value will be determined by an n-place predicate when each of its arguments is bound. By interpreting the verb and its θ-grid indices as denoting a truth value, there is a straightforward interpretation of a quantified NP adjoined to a VP node.

Similarly, a preposition will be interpreted along with its two θ-grid indices as denoting a truth value. One of the indices remains unbound in the logical form, so a prepositional phrase denotes a property. By analogy with VP adjunction, a noun phrase may be adjoined to a PP, resulting in a structure which still denotes a property.

# Chapter 5

## A semantic hierarchy of referentially dependent noun phrases

Montague's (1970) ground-breaking work provided a unified semantics for proper names and quantified noun phrases in which all noun phrases (NPs) are uniformly interpreted as functions of a particular sort. Similarly, work in generalized quantifiers (Barwise and Cooper 1981) has led to a number of interesting generalizations concerning the types of functions that may be denoted by natural language determiners (Keenan and Stavi 1986, Keenan and Moss 1985). In the preceding chapters, I presented a computationally tractable representation of logical form that makes use of the generalized quantifiers analysis. In this section, I will examine a class of NPs which require a higher-order analysis. At this point, it is not clear if these NPs have a tractable representation in a computer model. However, I will argue that an analysis of referentially dependent NPs within this general framework allows one to state semantic restrictions on the types of denotations expressed by natural language. In particular, I categorize higher-order NPs of the type illustrated in (1) according to four semantic conditions.

(1) a. Bob and Chris read <u>a total of nine plays</u>.
    b. Three students read <u>the same books</u>.
    c. Every student read <u>a different book</u>.
    d. No students saw <u>each other's scores</u>.

Although I do not have a precise statement of the licensing conditions for each class, this semantic classification correlates with restrictions on the syntactic distribution of these referentially dependent NPs.

NPs of the type illustrated in (1) will combine with a transitive verb to form a predicate which is true or false of a set of individuals. In (2a), each other combines with hit to form a predicate hit each other, which might be true of the set of men, but false of the set of women. Similarly, the complex reciprocal each other's scores will combine with saw in (2b) to form a predicate saw each other's scores. This predicate might be true of one set of students, but false of another set of students.

(2) a. The men hit each other.
b. Some students saw each other's scores.
c. At least three politicians criticized each other but not each other's spouses.

I refer to these NPs as higher-order in contrast to the analysis for lower-order anaphors like herself. The singular reflexive herself combines with a transitive verb to form a predicate with is true or false of individuals. For example, criticize herself might be interpreted as being true of Alice, but false of Betty. This contrasts with a predicate, like criticize each other, which is true or false of sets of individuals.

This higher-order analysis extends to a much larger class of NPs than just the reciprocals examined so far. Work by Stump (1982), Clark and Keenan (1986), and Carlson (1987) has shown that NPs with same and different exhibit a bound reading. The anaphoric properties of these NPs will be examined in more detail later. For now, I simply point out that the object NPs in (3) may be bound by the subject NPs. The bound reading for (3b) is true in a situation where suspect $s_1$ belongs to gang $g_1$, suspect $s_2$ belongs to $g_2$, and furthermore gangs $g_1$ and $g_2$ are rivals. Following Carlson, I will refer to this as the sentence internal reading.

(3) a. Alice and Bob reviewed different books.
b. The two suspects belong to rival gangs.
c. The witnesses gave conflicting evidence.

As discussed previously for reciprocals, the object NP combines with the transitive verb to form a predicate which is true or false of sets of individuals. For example, belong to rival gangs might be true of one set of suspects, but false of another set. Similarly, in (4a), read the same books is interpreted as a predicate which is true or false of a set of individuals. The same analysis extends to NPs in (5) as well.

(4) a. Three editors read the same books.
    b. Most applicants submitted the same number of references.
    c. The reviewers selected the same student's papers.

(5) a. Two authors wrote a total of nine plays.
    b. The guards fired a minimum of six rounds.
    c. The carrels in the reading room accommodate a maximum of 12 students.

## 5.1 Anaphoric properties of referentially dependent NPs

The term "anaphor" has traditionally been used for a very limited set of natural language expressions, namely pronouns whose occurrence is licensed by another noun phrase. The anaphoric pronoun "refers back" to the licensing NP as in the case of a bound variable pronoun (6a), reflexive pronoun (6b), or a reciprocal pronoun (6c):

(6) a. Every player claimed he was the fastest.
    b. Each girl bought herself a calendar.
    c. The supervisors phoned each other yesterday.

This very limited class of NPs in English exhibits several properties. First the interpretation of simple pronouns is ambiguous. The pronoun in (6a) may be interpreted deictically as referring to some male individual identified in context. Or the pronoun may be interpreted as a bound variable in which its interpretation varies with the interpretation of the expression every player. This bound reading can be paraphrased as, "for every player x, x claimed that x was the fastest". A second property of these NPs is that there must be a licensing (or antecedent) NP. The exact statement of the configurations in which a pronoun may be bound or free has been an important part of the work on Government and Binding (GB) theory (e.g. Chomsky 1981, 1986). Third, we note that the anaphoric pronouns agree in number and gender with the licensing NP.[1] A fourth characteristic of anaphors is that there may be an ambiguity in terms of which NP serves as the antecedent. In the sentences in (7), either of the underlined NPs may serve as an antecedent for the underlined pronoun.

(7) a. Alan told Bob that he had to leave.
    b. Two salesmen persuaded some customers to buy each other's cameras.

There is another class of English expressions which exhibit these same characteristics. The underlined expressions in (8) (Carlson's (1)) are interpreted deictically as depending on some referent supplied by the context of utterance.

(8) a. The man went to the same play tonight.
    b. Smith went to a different place on his vacation this year.

However, in some sentences, expressions involving same and different also have a "sentence internal" reading in which the referentially dependent NP may be interpreted without referring to any context outside of the sentence:

(9) a. Yolanda and Zoe ate the same number of candy bars.
       (e.g. Yolanda ate 3 candy bars and Zoe ate 3 candy bars)
    b. Every student read a different play.
       (e.g. Alan read 'Hamlet', Bob read 'King Lear', ...)
    c. Every counselor told the same story to two campers.

As with simple pronouns, these expressions are ambiguous between a deictic interpretation and a bound interpretation in certain syntactic environments. Example (9c) demonstrates that there may also be more than one potential antecedent. When the same story is bound by every counselor, the sentence has a reading where counselor $c_1$ told story $s_1$ to two campers, counselor $c_2$ also told $s_1$ to two campers, etc. The

[1] Even though each other only has one form, we can say that it has number agreement, since it requires a syntactically plural antecedent:
(i) Alice and Bill saw each other.
(ii) All of the students saw each other.
(iii) * Every student saw each other.
In other languages, such as French, the reciprocal NP agrees in both number and gender:
(iv) Ils s'aident les uns les autres.
(v) Elles s'aident les unes les autres.

indirect object two campers is also a potential antecedent. When it binds the same story, counselor $c_1$ told story $s_1$ to two campers, counselor $c_2$ told $s_2$ to two campers, etc. where $s_1$ and $s_2$ may be different stories.

Carlson discusses several licensing elements for same and different NPs, including distributive NP antecedents, coordinate structures, and certain adverbs. At this point, I will just mention that there are locality constraints which govern the relationship between the licensing element and the referentially dependent NP. Carlson claims that a "licensing NP must appear within the same 'scope domain' as the dependent expression, (e.g. that the two NP positions must be relatable by Move Alpha, in a GB framework (Chomsky, 1981))." Carlson's empirical test for this scope domain relationship is that Wh-movement is allowed from the position of the referentially dependent NP to the same clause as the licensing NP. For example, sentence (10a) has a sentence internal reading for different painters, whereas this reading is impossible for (11a). I use the pound sign (#) here to indicate that a sentence internal reading is not available. I will reserve the asterisk (*) for its standard usage to indicate that a sentence is ungrammatical.

(10) a. Bob and Mike are more impressive than different painters (e.g.each has such a distinct style, they can be compared meaningfully only to different groups of painters).
b. Who are Bob and Mike more impressive than __?

(11) a. #Bob and Mike are more impressive than different painters are.
b. *Who are Bob and Mike more impressive than __ are?

Carlson's claim is that different painters is in the same scope domain as the licensing NP, Bob and Mike, in (10a) as shown by the acceptability of the corresponding Wh-movement in (10b). However, the Wh-question of (11b) is ill-formed and this corresponds to the lack of a sentence internal reading in (11a).

This characterization of the locality constraints for same and different fails in two ways. First, there are cases where the appropriate Wh-movement is allowed, yet an NP cannot license a sentence internal reading. This is illustrated in (12a), where her teachers cannot license a sentence internal reading for different books. However, (12b) is perfectly acceptable with Wh-movement to the same clause as her teachers.

(12) a. #Alice promised her teachers to read different books.
b. What did Alice promise her teachers to read __?

Note that it is not sufficient to say that only the controller of the subordinate clause subject is a potential antecedent. In the case of object control verbs, like persuade, both NPs in the main clause may license a referentially dependent NP in the subordinate clause:

(13) a. Alice persuaded every teacher to read a different book.
b. Every teacher persuaded Alice to read a different book.

A second way in which Carlson's proposal fails is when a referentially dependent NP is licensed for a sentence internal reading, but Wh-movement is not allowed. For example, referentially dependent NPs may occur embedded in a coordinate structure from which Wh-movement is not allowed, as in (14a,b).[2] Only one of the conjuncts has been questioned in (14a') and that is obviously ill-formed. In (14b'), the Wh-movement has occurred from the referentially dependent NP positions in both conjuncts. However, across-the-board extraction is not possible from this structure. Similarly, (14c,d) allow a sentence internal reading, although Wh-movement is not allowed from the embedded subject positions.[3]

(14) a. The jurors heard the same arguments but drew different conclusions.
a'. *What did the jurors hear __ but draw different conclusions.

[2] This observation is made in Dowty (1985), although these examples are mine.
[3] I assume that the same baby sitter is the dependent phrase in (14c), rather than the entire prepositional phrase for the same baby sitter, which would allow a valid Wh-movement structure:
For whom is it hard __ to watch both kids?

b. The paintings should be hung in separate rooms or on opposite walls of the same room.
b'. *Which room should the paintings be hung in __ or on opposite walls of __?

c. It is hard for the same baby sitter to watch both kids.
c'. *Who is it hard for __ to watch both kids?

d. The technicians claimed that different machines were causing the problem.
d'. *What did the technicians claim that __ were causing the problem?

So far, we have seen that referentially dependent NPs are similar to anaphoric pronouns by allowing a deictic/bound ambiguity and by requiring certain locality constraints to hold between the licensing NP and the referentially dependent NP. However, the constraints on binding this larger class of referentially dependent NPs is not as well understood as for pronouns. A third area of similarity is that of number agreement (Stump 1982). Referentially dependent NPs with same can take either a singular or plural antecedent, but many other dependent expressions require number agreement as shown in (15) and (16). The examples in (15) show that a singular subject licenses a singular referentially dependent object. With plural subjects in (16), only the plural NPs in object position yield the sentence internal reading.

(15) a. Every technician monitors a different machine.
a'. " #different machines
b. Each author has a very distinct style.
b'. " #very distinct styles
c. Every department maintains a separate computing facility.
c'. " #separate computing facilities

(16) a. The technicians monitor different machines.
a'. " #a different machine
b. Those three authors have very distinct styles.
b'. " #a very distinct style
c. None of the departments maintain separate computing facilities.
c'. " #a separate computing facility

The sentence in (15a') does not have a bound reading where technician $t_1$ monitors machines that are different from the machines monitored by technician $t_2$. In order to express that situation, one would use sentence (16a).

There is a fourth similarity between bound variable pronouns and same and different NPs which has not been discussed in previous work. Examples in (17) demonstrate Strong Crossover structures in which a pronoun cannot be coindexed with a variable that it c-commands. Thus, if (17a) were a valid logical form for the English sentence, "Who did he see?", then that sentence would have a reading equivalent to "Who saw himself." Similarly, the trace in (17b) may not be coindexed with any of the preceding pronouns.

(17) a. *$\text{Who}_i$ did $\text{he}_i$ see $t_i$?
b. $\text{Who}_i$ did he think that he said he saw $t_i$?

In Weak Crossover structures, as in (18), the pronoun does not c-command the trace, but it still may not be coindexed with it. For example, the English sentence "Who does his mother love?" cannot be interpreted as having the logical form (18a) which has a reading equivalent to "Who is such that his mother loves him?"

(18) a. *$\text{Who}_i$ does $\text{his}_i$ mother love $t_i$?
b. *$\text{Who}_i$ did the man that $\text{he}_i$ called complain to $t_i$?

These crossover facts have been much discussed in the literature. There are a number of different analyses to account for the distributional properties of bound variable pronouns and Wh-trace in these structures (e.g. the Leftness Condition of Chomsky (1976), the Bijection Principle of Koopman and Sportiche (1982), and the Parallelism Constraint on Operator Binding of Safir (1984)). However, what is of interest here is that the crossover phenomena extend to other referentially dependent NPs, such as the ones we have been considering with same and different. For example, (19a) is perfectly acceptable with a sentence internal reading, yet (19b) may only have a reading where the same professor is interpreted deictically. The acceptability of the crossover structure improves slightly with a more complex Wh-phrase, although the sentence in (19c) still sounds odd to me.

(19) a. The same professor failed at least three students.
b. #Who$_i$ did the same professor fail $t_i$?
c. ?# Which three students$_i$ did the same professor fail $t_i$?
d. Who$_i$ $t_i$ failed the same students?
e. Which professors$_i$ $t_i$ failed the same students?

Note that there is nothing inherently wrong with a referentially dependent NP having a Wh-trace as an antecedent, as shown in (19d,e), which are not crossover structures. In example (20), the crossover environment results from the structure of the relative clause. Examples (21) and (22) show that similar judgments hold for NPs with different.

(20) a. The same volunteers called three prospective donors.
b. #George talked to three donors that$_i$ the same volunteers called $t_i$.
c. George talked to the volunteers that$_i$ $t_i$ called the same prospective donors.

(21) a. A different number of detectives followed Chris and David.
b. #Who$_i$ did a different number of detectives follow $t_i$?
c. Who$_i$ $t_i$ followed a different number of suspects?

(22) a. Different demonstrators wanted to harass the candidates.
b. #Burt protected the candidates that$_i$ different demonstrators wanted to harass $t_i$.
c. Burt arrested demonstrators that$_i$ $t_i$ wanted to harass different candidates.

The crossover example in (21b) clearly does not have a reading where the subject NP is bound by the object. An appropriate answer for that reading would be to give a list of individuals such that the number of detectives who followed individual 1 is different from the number of detectives who followed individual 2, etc. Part of the problem may be that questions with this bound reading are pragmatically very odd anyway. So (21c) is a very strange question to ask, although I think it can be interpreted with the bound reading. The oddness may come from the fact that there is no unique correct answer for this question. This contrasts with NPs containing total, same, or each other. In those cases, one can give a complete answer.

Judgments are more difficult with Weak Crossover structures, because of the complexity involved. However, the sentence internal reading appears to be unavailable for same and different NPs in these structures, as in the possessives of (23) and (24). Example (23a) has a reading where assistant $a_1$ called juror $j_1$, $a_2$ called $j_2$, $a_3$ called $j_3$ and furthermore, $a_1$, $a_2$, and $a_3$ are assistants to the same lawyer. This bound reading is not available for the Wh-question of (23b), nor is it available with the relative clause of (23c).

(23) a. The same lawyer's assistants called three jurors.
b. #$Who_i$ did the same lawyer's assistants call $t_i$?
c. #The judge interviewed three jurors $that_i$ the same lawyer's assistants called $t_i$.

(24) a. Different professors' students called the administrators.
b. #$Who_i$ did different professors' students call $t_i$?
c. #The Dean reprimanded the administrators $that_i$ different professors' students called $t_i$.

These examples illustrate a slight difference between pronouns and the other referentially dependent NPs with respect to crossover phenomena. Crossover effects are generally assumed to hold for NP movement at any level, including Quantifier Raising at the level of Logical Form. May (1985) uses the contrast in grammaticality between the following two sentences as evidence that a quantified NP, like everyone, undergoes QR, while proper names like John do not.

(25) a. $His_i$ mother saw $John_i$.
b. *$His_i$ mother saw $everyone_i$.

However, as illustrated in the following example, the broader class of referentially dependent NPs seems to be insensitive to crossover effects at LF. This example has the bound reading, even though every athlete presumably undergoes QR. Thus, there is no crossover structure at Surface Structure, but there would be a crossover environment at Logical Form.

(26) A different team's trainer examined every athlete.

To summarize, some NPs with same and different exhibit four properties of anaphoric pronouns. I will continue to use the term 'referentially dependent NP' for the broader class of NPs that exhibit one or more of the properties of deictic vs. bound ambiguity, antecedent licensing conditions, number agreement with the antecedent, and crossover phenomena. Intuitively, these are the NPs whose interpretation (on the sentence internal reading) "refers back" to a licensing NP somewhere else in the sentence.

### 5.2 Semantic interpretation in simple transitive sentences

In this section, I will present a model-theoretic interpretation for some referentially dependent NPs when they occur as a direct object in a simple transitive sentence. A more complete analysis should account for a wider range of environments. It should also account for licensing elements other than antecedent NPs, such as coordinate structures and adverbs. However, for the purposes of this paper, it will be sufficient to consider the limited domain where a referentially dependent NP occurs as a direct object which is licensed by the subject NP. This will be sufficient to categorize the NPs according to the semantic conditions in section 5.3.

#### 5.2.1 The semantics of total

First, let's consider NPs of the form a total of n N, where n is some natural number and N is a common noun. One of the readings available with this expression also occurs with a bare numeral determiner by adding the expression between them as illustrated below.

(27) a. Less than a dozen girls sold a total of 243 calendars.
b. Alan and Bob washed five cars between them.
c. Three demonstrators broke (a total of) nine windows (between them).

The reading of interest in (27a) is the one which simply adds up the number of calendars that were sold, regardless of which girls actually did the selling. This is distinct from a simple object-wide scope reading which would entail that each calendar was sold a number of times. Furthermore, it is not equivalent to a collective reading in which the girls somehow worked together to sell each calendar. Partee (1975) refers to this additional reading as the "total-total" reading. Scha (1981) refers to it as "cumulative quantification".

We can represent the interpretation of <u>a total of 243 calendars</u> in the following way. Suppose we have a non-empty set, **E**, called the universe of discourse. Objects in this set will correspond to objects in the world that we want to model. A transitive verb will denote a two-place relation represented as a set of ordered pairs. For example, SELL might denote the relation $\{ \langle a,c_1\rangle, \langle a,c_2\rangle, \langle b,c_{23}\rangle, \ldots, \langle z,c_{567}\rangle \}$, where $\langle x,y\rangle \in$ SELL represents the fact that 'x sold y'. We call the set of all such relations **R**, where **R** = (**ExE**)*, i.e. **R** is the powerset of **ExE**. Common nouns denote subsets of **E**, called properties. For example, CALENDAR might denote the set $\{c_1, c_2, \ldots, c_{567}\}$. The set of all such properties is called **P**, where **P** = **E***.

The entire NP, <u>a total of 243 calendars</u>, will denote a function that maps the SELL relation onto a set of properties. Intuitively, these properties are the sets of individuals which sold a total of 243 calendars. The general case is defined as follows:

(28) Definition of 'A TOTAL OF n': For all A, Q $\in$ **P**, all R $\in$ **R**, and all n $\in$ **N**,
$$A \in ((\text{A TOTAL OF } n)(Q))(R) \text{ iff } \left| \left( \bigcup_{a \in A} aR \right) \cap Q \right| = n$$
where $aR =_{def} \{b \mid \langle a,b\rangle \in R\}$.

Suppose we want to know if Yolanda and Zoe sold a total of 243 calendars. By the definition above,

$$\{y,z\} \in ((\text{A TOTAL OF } 243)(\text{CALENDAR}))(\text{SELL}) \text{ iff}$$
$$|(y\text{SELL} \cup z\text{SELL}) \cap \text{CALENDAR}| = 243.$$

First, we take the union of ySELL (the things that Yolanda sold) with zSELL (the things that Zoe sold). Then we take the intersection of that set with CALENDAR (the extension of calendars in the model) to get the set of calendars that were sold either by Yolanda or Zoe. The cardinality of this set must be 243 in order for it to be true that Yolanda and Zoe sold a total of 243 calendars.

There are other English quantifier phrases like a total of which combine with a numeral and a common noun to form a referentially dependent NP. Formal definitions for the functions denoted by a minimum of and a maximum of are given below. In section 5.4, I will discuss the relationship of these types of NPs to partitive and pseudopartitive constructions, which also have a referentially dependent reading.

(29) Definition of 'A MINIMUM OF n': For all A, Q $\in$ **P**, all R $\in$ **R**, and all n $\in$ **N**,
A $\in$ ((A MINIMUM OF n)(Q))(R) iff $|(\bigcup_{a \in A} aR) \cap Q| \geq n$

(30) Definition of 'A MAXIMUM OF n': For all A, Q $\in$ **P**, all R $\in$ **R**, and all n $\in$ **N**,
A $\in$ ((A MAXIMUM OF n)(Q))(R) iff $|(\bigcup_{a \in A} aR) \cap Q| \leq n$

### 5.2.2 The semantics of same

Using this notation, it is relatively straightforward to give the denotations for some of the other referentially dependent NPs that we are considering. To determine whether "Fred and Greg read the same books" is true, we simply need to compare the books that Fred read to the books that Greg read. In order for the sentence to be true, the two sets of books must be the same. This intuition is formalized in the following definition.

(31) Definition of 'SAME': For all A, Q $\in$ **P**, and all R $\in$ **R**,
A $\in$ (SAME(Q))(R) iff for all a,b $\in$ A, aR $\cap$ Q = bR $\cap$ Q.

Applying this definition to the sentence "Fred, Greg,and Harvey read the same books", we must determine whether $|\{f,g,h\}| > 1$ and fREAD $\cap$ BOOK = gREAD $\cap$ BOOK = hREAD $\cap$ BOOK. Thus, in order to determine if {f,g,h} $\in$ ||[read the same books]||, we determine if the things that Fred read which are books (i.e. $fREAD \cap BOOK$) are the same things that Greg read which are books (i.e. $gREAD \cap BOOK$). Furthermore, these must be the same as the things that Harvey read which are books (i.e. $hREAD \cap BOOK$). Remember that for all $x \in \mathbf{E}$, xREAD is the set of things that x read, i.e. $xREAD = \{b \mid \langle x,b\rangle \in READ\}$.

### 5.2.3 The semantics of <u>different</u>

The definition for the function DIFFERENT requires that each member of the "antecedent" participate in the relation. For example, "Fred and Greg read different books" entails that Fred read books and Greg read books. In addition, the set of books that Fred read must be different from the set of books that Greg read.[4] These aspects of the meaning of <u>different</u> are represented in the following definition.

(32) Definition of 'DIFFERENT': For all $A, Q \in \mathbf{P}$, and all $R \in \mathbf{R}$,
$A \in (DIFFERENT(Q))(R)$ iff
- (a) for all $a \in A$, $aR \cap Q \neq \{\}$; and
- (b) for all $a,b \in A$, if $a \neq b$, then $aR \cap Q \neq bR \cap Q$.

To determine if $\{f,g\} \in$ |[read different books]|, we check (32a) to see that $fREAD \cap BOOK \neq \{\}$, i.e. Fred read at least one book, and $gREAD \cap BOOK \neq \{\}$, i.e. Greg read at least one book. Then using (32b), we check that $fREAD \cap gREAD \cap BOOK = \{\}$, i.e. Fred and Greg did not read any of the same books. If each of the three clauses is satisfied, then $\{f,g\} \in$ |[read different books]| and |[Fred and Greg read different books]| = 1.

[4] My own intuition is that a stronger condition applies. It seems to me that the two sets of books should be mutually exclusive. However, many people do not agree with this judgment, saying that the sets may overlap. Therefore, I have formalized the majority intuition in definition (32). If one wanted to impose the stricter condition that the sets must be mutually exclusive, condition (b) should be stated as:

(b) for all $a,b \notin A$, if $a \neq b$ then $(aR \cap Q) \cap (bR \cap Q) = \{\}$.

### 5.2.4 Generalizing the notion of "reciprocal"

Finally, I would like to give the interpretation for reciprocal NPs. Langendoen (1978) discussed semantic representations of the form 'A R r', where A is a set with $|A| > 1$, R is a relation on AxA, and r is a reciprocal element which is the denotation of each other or one another. Langendoen considered a number of possible interpretations for English reciprocals and concluded that the appropriate interpretation is a relation of "weak reciprocity". Essentially, each element of the set A must bear the relation R to at least one other element of A and at least one other element must bear the relation R to it. For example, "Alan, Bob, and Chris pushed each other" would be true in a model where PUSH = {<a,b>, <b,c>, <c,a>}. That is, each boy pushed at least one other boy and each boy was pushed by at least one other boy. Langendoen gave the following formalization to represent this notion of weak reciprocity:

(33) Langendoen's (1978) definition of Weak Reciprocity.
Given a set A with $|A| > 1$, R a relation on AxA, and r a reciprocal element,
$ARr = 1 \text{ iff } (\forall x \in A)(\exists y,z \in A)(x \neq y \;\&\; x \neq z \;\&\; xRy \;\&\; zRx)$.

Judgments on the truth conditions of reciprocals are somewhat difficult and other authors have adopted different definitions (Fiengo and Lasnik 1973, Dougherty 1974). I will use Langendoen's definition. However, the analysis that I give for complex reciprocals could just as well be stated using another definition for simple reciprocals. What is of interest here is the way in which a definition for simple reciprocals can be extended to cover complex reciprocals.

We would like to generalize definition (33) to cover more than just the basic reciprocals each other and one another. We also want to be able to give an interpretation to complex reciprocals like the ones illustrated below:

(34) a. No students saw each other's scores.
b. Some politicians criticized each other but not each other's wives.
c. At least three lawyers praised each other and the judges.

These examples illustrate two ways in which definition (33) must be extended. First, we need to have a method for evaluating possessives, like each other's scores. Second, there should be a method for evaluating Boolean combinations of reciprocals, i.e. complex NPs constructed from simpler NPs with and, or, and not. Furthermore, the analyses of possessives and Boolean combinations must be recursive, since any number of combinations is possible (e.g. each other, each other's wives, each other's wives' sisters, etc.). Under this analysis of directly interpreting NPs, a complex NP will be considered a reciprocal NP, even though some of its constituents may not be reciprocals. As shown in (34c), each other and the judges will be treated as a reciprocal NP, even though the judges is not reciprocal. Since we want the denotation of the complex NP to be a function of the denotations of its constituents, this will require us to state how basic NPs get interpreted in a reciprocal context.

We can formalize the class of syntactic structures under consideration with the following definition:

(35) Syntactic definition of "reciprocal NP"
  a. each other is a reciprocal NP.
  b. If H is a reciprocal NP and N is a common noun, then H's N is a reciprocal NP.
  c. If H is a reciprocal NP, then not H is a reciprocal NP.
  d. If either H or K is a reciprocal NP and C is one of the coordinating conjunctions {and, or, but}, then H C K is a reciprocal NP.

Using this recursive definition, all of the following NPs are identified as reciprocal NPs:

(36) a. each other
  b. each other's books
  c. each other's teacher's books
  d. not each other's wives
  e. each other but not each other's wives
  f. the teacher and each other
  g. each other's lawyers or two consultants

In order to extend definition (33), I will reformulate it in terms of generalized quantifiers. Rather than referring to entities x, y, and z in the universe of discourse, the new definition will refer to the *individuals* generated by these elements, $I_x$, $I_y$, and $I_z$. Proper names denote individuals, which form a proper subset of the full set of generalized quantifiers. The function denoted by an individual $I_b$ is defined as follows:

$$\forall b \in \mathbf{E}, \forall q \in \mathbf{P}, I_b(q) = 1 \text{ iff } b \in q$$

The set of individuals $\mathbf{I}$ is simply the set of all such $I_b$ for b in the universe of discourse:

$$\mathbf{I} = \{I_b \mid b \in \mathbf{E}\}.$$

Definition (33) uses the notation xRy to signify that x bears the relation R to y. Using Keenan's (1989) notation, this is rewritten as $(I_x)((I_y)_{acc})(R))$, where the generalized quantifier $I_y \in [\mathbf{P} \rightarrow \mathbf{2}]$ has been extended to accept relations as an argument, so that $(I_y)_{acc} \in [\mathbf{R} \rightarrow \mathbf{P}]$ is defined as follows:

(37) $F_{acc}$ or the *accusative case extension* of F is that extension of F which sends each binary relation R to $\{a: F(aR) = 1\}$, where $aR =_{def} \{b: (a,b) \in R\}$.

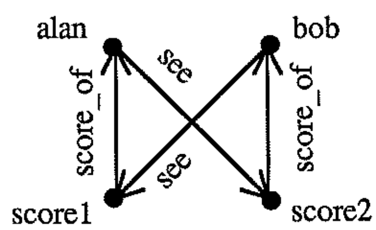
Using this notation, Langendoen's definition of weak reciprocity can be rewritten equivalently as:

(38) Reformulation of Langendoen's definition with generalized quantifiers.
Given a set A with $|A| > 1$, R a relation on AxA, and r a reciprocal element,
$ARr = 1$ iff $(\forall x \in A)(\exists y,z \in A)$
$(I_x \neq I_y \;\&\; I_x \neq I_z \;\&\; (I_x)((I_y)_{acc}(R)) = 1 \;\&\; (I_z)((I_x)_{acc}(R)) = 1)$

Definition (38) is just a reformulation of (33), using a different notation. However, now we are ready to extend the notion of "reciprocal element", so that the definition will hold for possessives like <u>each other's scores</u> or <u>each other's students' scores</u>, as well as for simple reciprocals like <u>each other</u>. In a simple sentence like "Alan and Bob saw each other's scores", there is not a direct reciprocal relation between Alan and

Bob. The reciprocity is indirect, because Alan saw Bob's score and Bob saw Alan's score. The relation expressed by the verb <u>saw</u> does not hold reciprocally between Alan and Bob except through the intermediate relation "score of", which relates individuals to their scores. This indirect reciprocity can be illustrated schematically as in the figure below.

(39)




With a more complex reciprocal like "Chris and Diane saw each other's children's scores", the reciprocity is one more level removed, because the possessive introduces two relations, "score of" and "children of". I will formalize this notion of the possessive below, but first consider the effect this analysis has on the definition of reciprocity. We can modify (38) by referring to a function H that relates individuals to generalized quantifiers. The new definition, given in (40) below, captures the notion of indirect reciprocity. In the clause $(I_x)((H(I_y))_{acc}R) = 1$, individuals $I_x$ and $I_y$ are not directly related by the relation R. However, element x bears the relation R to something that is related to y. Similarly, in the clause $(I_z)((H(I_x))_{acc}R) = 1$, z bears the relation R to something that is related to x.

(40) Generalized definition of Weak Reciprocity.
Given $H \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$, define the reciprocal element $H^r \in [\mathbf{R} \rightarrow \mathbf{P}^*]$ such that for all $R \in \mathbf{R}$, all $A \in \mathbf{P}$, $A \in H^r(R)$ iff $(\forall x \in A)(\exists y,z \in A)$ $(I_x \neq I_y \ \& \ I_x \neq I_z \ \& \ (I_x)((H(I_y))_{acc}R) = 1 \ \& \ (I_z)((H(I_x))_{acc}R) = 1)$

Given this definition for deriving a reciprocal function $H^r \in [\mathbf{R} \rightarrow \mathbf{P}^*]$ from a function $H \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$, I will refer to the set of all such functions $H^r$ as **REC**:

(41) Definition: $\mathbf{REC} =_{def} \{H^r \mid H \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]\}$

I will argue that English reciprocals denote in this set. This means that the set **REC** is at least large enough to be the denotation set for English reciprocals. However, it is possible that **REC** is too large a set in the sense that there may be some functions in **REC** which cannot be denoted by English expressions. At this point, I do not have a proof that every function in **REC** can be denoted by an English expression. Given a universe of discourse with n elements, the cardinality of this set of functions is: $|\mathbf{REC}| = 2^{n \cdot 2^n}$. I will discuss the size of this set later, when I examine other characterizations of reciprocal functions.

Before showing how definition (40) applies to possessives, let's make sure that it still correctly characterizes the simplest reciprocal, each other. Suppose we let the function EO $\in$ $[\mathbf{I} \to [\mathbf{P} \to \mathbf{2}]]$ be that function which maps every individual onto itself, so that $\forall I_b \in \mathbf{I}$, $EO(I_b) = I_b$. Now let H = EO in definition (40). In this case, the truth conditions for $EO^r$ are equivalent to Langendoen's Weak Reciprocity which I reformulated as (38) above. Therefore, let |[each other]| = $EO^r$. This demonstrates that at least one English expression, each other, denotes in the set **REC**.

### 5.2.5 Possessor reciprocals

Now let's reconsider the formal details for reciprocal possessives and we will see that they also denote in **REC**. An NP like Bob's students denotes a generalized quantifier. That is, |[Bob's students]| $\in$ $[\mathbf{P} \to \mathbf{2}]$. I will refer to this function as STUDENTS_OF(|[Bob]|). Therefore, |[ 's students]| = STUDENTS_OF is a function from individuals to generalized quantifiers, written as STUDENTS_OF $\in$ $[\mathbf{I} \to [\mathbf{P} \to \mathbf{2}]]$. In this case, STUDENTS_OF will map the individual denoted by |[Bob]| onto the generalized quantifier which is, loosely speaking, the students of Bob or "the students who are Bob's students".

Given this function STUDENTS_OF from individuals to generalized quantifiers, we extend its domain, so that it can map the full set of generalized quantifiers onto generalized quantifiers. This extension is required for an NP like <u>at least three professors' students</u> where the possessor, <u>at least three professors</u>, is an NP that does not denote an individual. Given STUDENTS_OF $\in [\mathbf{I} \to [\mathbf{P} \to \mathbf{2}]]$, we simply extend it to accept generalized quantifiers as arguments and we call the extended function $STUDENTS\_OF_{gq}$. The statement of this extension is given below:[5]

(42) Definition: Given $G \in [\mathbf{I} \to [\mathbf{P} \to \mathbf{2}]]$, define $G_{gq} \in [[\mathbf{P} \to \mathbf{2}] \to [\mathbf{P} \to \mathbf{2}]]$ such that for all increasing $F \in [\mathbf{P} \to \mathbf{2}]$ and for all $A \in \mathbf{P}$,

$$(G_{gq}(F))(A) = 1 \quad \text{if } \exists B \in \mathbf{P} \text{ such that } F(B) = 1 \ \& \bigcap_{b \in B} (G(I_b))(A) = 1$$
$$= 0 \quad \text{otherwise}$$

I will demonstrate how this definition applies to the sentence in (43a), which has the logical form given in (43b).

(43) a. At least three professors' students failed.
b. $(STUDENTS\_OF_{gq}((AT\_LEAST, 3)(PROF)))(FAIL)$

The noun phrase <u>at least three professors</u> translates into the generalized quantifier represented as ((AT_LEAST, 3)(PROF)). This NP denotation maps properties to True or False (1 or 0, respectively). It maps a property to True if the cardinality of the intersection of that property with the PROF property is greater than or equal to 3. Otherwise, it maps the property to False:

$$\forall q \in \mathbf{P},\ ((AT\_LEAST, 3)(PROF))(q) = 1 \quad \text{if } |PROF \cap q| \geq 3$$
$$= 0 \quad \text{otherwise}$$

[5] This definition is not completely general, since it is limited to the case where the argument F is an increasing generalized quantifier. This is sufficient for the discussion to follow concerning reciprocals. However, more work is required to extend the treatment to all generalized quantifiers, including monotone decreasing NPs and nonmonotonic NPs. The current definition will not handle expressions like <u>less than three libraries' catalogs</u> (a decreasing NP) and <u>exactly five authors' submissions</u> (a nonmonotonic NP).

Given a function STUDENTS_OF, definition (42) tells us how to evaluate the NP denotation, $STUDENTS\_OF_{gq}((AT\_LEAST, 3)(PROF))$. That function will map the property FAIL to True just in case (i) there is some property B such that $((AT\_LEAST, 3)(PROF))(B) = 1$, i.e. the property holds for at least three professors; and (ii) for all $b \in B$, $(STUDENTS\_OF_{gq}(I_b))(FAIL) = 1$. This last condition looks at each individual generated by $b \in B$. It says that the students of each of these individuals failed. So applying definition (42) to logical form (43b) corresponds with my intuitions that this sentence is true in a model where there are at least three professors such that their students failed.

We also need to extend a basic possessor function to accept the denotations of reciprocal NPs as in each other's wives. Definition (44) states that applying a reciprocal extension $G_{rec}$ to a reciprocal function $H^r$ yields a new reciprocal function, $(G_{gq} \bullet H)^r$, which is formed by composition of the generalized quantifier extension $G_{gq}$ with the function H. As we will see shortly, this final step of composition is what allows the definition to be applied recursively in order to build up the interpretation of embedded possessives like each other's wives' sisters.

(44) Definition: Given $G \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$, define
$G_{rec} \in [[\mathbf{R} \rightarrow \mathbf{P}^*] \rightarrow [\mathbf{R} \rightarrow \mathbf{P}^*]]$ such that for all $H \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$,
$G_{rec}(H^r) = (G_{gq} \bullet H)^r$.

Using this definition and the generalized definition (40) for reciprocity, we can evaluate a sentence like "The men called each other's wives." As previously noted, let $EO \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$ be the function that maps each individual onto itself, so that $EO(I_e) = I_e$ for all $I_e \in \mathbf{I}$. Then we let $|[\text{each other}]| = EO^r$. The expression 's wives is interpreted as $WIFE\_OF \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$. Therefore, the entire possessive each other's wives is interpreted as $WIFE\_OF_{rec}(EO^r)$, which by definition

(44) is equal to the reciprocal function $(\text{WIFE\_OF}_{gq} \bullet \text{EO})^r$. This composition is well-formed, since

$$\text{EO} \in [\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]] \text{ and}$$
$$\text{WIFE\_OF}_{gq} \in [[\mathbf{P} \rightarrow \mathbf{2}] \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$$

The composition $(\text{WIFE\_OF}_{gq} \bullet \text{EO})$ is a function in $[\mathbf{I} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$, so the reciprocal function $(\text{WIFE\_OF}_{gq} \bullet \text{EO})^r$ is well-defined. Since $\text{EO}(I_b) = I_b$ for all $I_b \in \mathbf{I}$, the composition $(\text{WIFE\_OF}_{gq} \bullet \text{EO})$ is equivalent to $\text{WIFE\_OF}_{gq}$. However, I will continue to write out the full expression to explicitly show the relationship between the complex English expressions and the functions they denote.

In order to decide if some set A is one of the properties in ||[called each other's wives]||, we substitute $(\text{WIFE\_OF}_{gq} \bullet \text{EO})$ wherever H occurs in the generalized definition of reciprocity (40) and we substitute CALL for the relation R:

(45) For all $A \in \mathbf{P}$, $A \in$ ||[called each other's wives]|| iff
$A \in (\text{WIFE\_OF}_{gq} \bullet \text{EO})^r(\text{CALL})$ iff
$(\forall x \in A)(\exists y,z \in A)$
$(I_x \neq I_y \ \& \ I_x \neq I_z \ \&$
$(I_x)(((\text{WIFE\_OF}_{gq} \bullet \text{EO})(I_y))_{acc}(\text{CALL})) = 1 \ \&$
$(I_z)(((\text{WIFE\_OF}_{gq} \bullet \text{EO})(I_x))_{acc}(\text{CALL})) = 1)$

Since $\text{EO}(I_e) = I_e$ for all $I_e \in \mathbf{I}$, we can reduce these clauses slightly. For example, $(\text{WIFE\_OF}_{gq} \bullet \text{EO})(I_y) = (\text{WIFE\_OF}_{gq})(\text{EO}(I_y)) = (\text{WIFE\_OF}_{gq})(I_y) = \text{WIFE\_OF}(I_y)$. Simplifying in this way leads to the following statement of the truth conditions:

(46) For all $A \in \mathbf{P}$, $A \in$ ||[called each other's wives]|| iff
$A \in (\text{WIFE\_OF}_{gq} \bullet \text{EO})^r(\text{CALL})$ iff
$(\forall x \in A)(\exists y,z \in A)$
$(I_x \neq I_y \ \& \ I_x \neq I_z \ \&$
$(I_x)((\text{WIFE\_OF}(I_y))_{acc}(\text{CALL})) = 1 \ \&$
$(I_z)((\text{WIFE\_OF}(I_x))_{acc}(\text{CALL})) = 1)$

In words (and mixing levels of analysis slightly), this says that for every $x \in A$, there is some y such that x called y's wife and there is some z such that z called x's wife.

As long as one accepts the original definition (40) of weak reciprocity for simple each other, then I have shown how to extend the definition appropriately for possessives with each other.

Let's consider how the definition applies when the reciprocal is embedded one level deeper in the possessive, as in (47). The reciprocal function denoted by each other's wives books is constructed compositionally. As noted previously, |[each other]| = $EO^r$. Using (44) for the reciprocal extension of WIFE_OF yields the reciprocal function |[each other's wives]| = $(WIFE\_OF_{gq} \cdot EO)^r$. Definition (44) applies again for the reciprocal extension of BOOK_OF to yield the reciprocal function $(BOOK\_OF_{gq} \cdot WIFE\_OF_{gq} \cdot EO)^r$.

(47) The men read each other's wives' books.
For all $A \in \mathbf{P}$, $A \in$ |[read each other's wives' books]| iff
$A \in (BOOK\_OF_{gq} \cdot WIFE\_OF_{gq} \cdot EO)^r(READ)$ iff
$(\forall x \in A)(\exists y,z \in A)(I_x \neq I_y \ \& \ I_x \neq I_z \ \&$
$(I_x)(((BOOK\_OF_{gq} \cdot WIFE\_OF_{gq} \cdot EO)(I_y))_{acc}(READ)) = 1 \ \&$
$(I_z)(((BOOK\_OF_{gq} \cdot WIFE\_OF_{gq} \cdot EO)(I_x))_{acc}(READ)) = 1)$

I want to emphasize again that the functions $BOOK\_OF_{gq}$ and $WIFE\_OF_{gq}$ map generalized quantifiers onto generalized quantifiers. Therefore, $WIFE\_OF_{gq}(I_y)$ need not denote an individual. In the case where $I_y$ has two wives, refer to them as $I_a$ and $I_b$, then $WIFE\_OF_{gq}(I_y) = (I_a \wedge I_b)$, i.e. the generalized quantifier defined by the meet of individuals $I_a$ and $I_b$. This generalized quantifier is clearly not an individual. However, the function $BOOK\_OF_{gq}$ may be applied to yield a new generalized quantifier, $BOOK\_OF_{gq}(I_a \wedge I_b)$, e.g. "Alice and Betty's books".[6]

[6] More work remains to be done concerning the nature of the functions denoted by the generalized quantifier extensions given in (42). For example, one reading of "Alice and Betty's books" is equivalent to "Alice's books and Betty's books". Therefore, we can analyze $BOOK\_OF_{gq}$ as a homomorphism which preserves meets in the generalized quantifier algebra, so that:

$$BOOK\_OF_{gq}(I_a \wedge I_b) = BOOK\_OF_{gq}(I_a) \wedge BOOK\_OF_{gq}(I_b)$$

However, there is another collective reading of "Alice and Betty's books" where one is referring to the books that are jointly possessed by both individuals or the books that were co-authored by both individuals. This reading would not be available under this analysis of the generalized quantifier

### 5.2.6 Boolean combinations of reciprocals

In section 5.2.4, I generalized Langendoen's notion of a "reciprocal element" and extended his semantics for Weak Reciprocity. I then showed how the generalized definition of Weak Reciprocity applied to the simple reciprocal each other. In the previous section, I demonstrated how possessor reciprocals could be interpreted within this framework. Now I would like to show how Boolean combinations are interpreted. I use the term "Boolean combination" to refer to NPs constructed with and, or, and not.

In (48a), the entire object NP, $[_{NP}$ $[_{NP}$ each other] and $[_{NP}$ each other's advisors]], will be interpreted as a reciprocal NP. The fact that (48a,b) have the same truth conditions suggests a way in which conjoined reciprocals may be interpreted with respect to the individual conjuncts.

(48) a. Three students criticized each other and each other's advisors.
b. Three students criticized each other and criticized each other's advisors.

The conjunction and is interpreted as the Boolean operator *meet* ($\wedge$), which is defined pointwise in the algebra of reciprocal denotations:

(49) Definition. For all $H^r, K^r \in \mathbf{REC}$, all $R \in \mathbf{R}$,
$(H^r \wedge K^r)(R) =_{def} H^r(R) \wedge K^r(R)$

Since $H^r(R)$ is a set of properties and $K^r(R)$ is a set of properties, $H^r(R) \wedge K^r(R) = H^r(R) \cap K^r(R)$ is the intersection of these two sets.

The steps for interpreting the verb phrase criticized each other and each other's advisors in (48a) is as follows:

extension of possessive functions as homomorphisms. These are interesting questions to be answered concerning possessives, but they are not directly related to the issue of reciprocity, so I will not pursue them further here.

For all $A \in \mathbf{P}$, $A \in$ |[criticized each other and each other's advisors]|

iff $A \in (EO^r \wedge ADVISORS\_OF_{rec}(EO^r))(CRITICIZE)$

iff $A \in [EO^r(CRITICIZE) \cap ADVISORS\_OF_{rec}(EO^r)(CRITICIZE)]$; by def. (49)

iff $A \in [EO^r(CRITICIZE) \cap (ADVISORS\_OF_{gq} \bullet EO)^r(CRITICIZE)]$; by def. (44)

iff $A \in EO^r(CRITICIZE) \;\wedge\; A \in (ADVISORS\_OF_{gq} \bullet EO)^r(CRITICIZE)$

Each conjunct of the last line can be expanded using definition (40) for the interpretation of reciprocal elements. In words, this shows that the VP denotation |[criticized each other and each other's advisors]| will be true of a set A, if the individuals in set A criticized each other and if they criticized each other's advisors. In a particular model, if it is possible to find such a set A of three students, then the English sentence, "Three students criticized each other and each other's advisors", will evaluate to True in that model.

A similar line of reasoning holds for coordinate reciprocals joined by the disjunction <u>or</u>. In (50a), the object NP, $[_{NP}\ [_{NP}$ each other's shirts] or $[_{NP}$ each other's shoes]], will be interpreted as a reciprocal NP.

(50) a. The children painted <u>each other's shirts</u> <u>or</u> <u>each other's shoes</u>.
b. The children painted <u>each other's shirts</u> or painted <u>each other's shoes</u>.

Given the equivalence of (50a,b), the disjunction <u>or</u> may be interpreted as the Boolean operator *join* ($\vee$), which is defined pointwise in the algebra of reciprocal denotations:

(51) <u>Definition</u>. For all $H^r, K^r \in \mathbf{REC}$, all $R \in \mathbf{R}$,
$(H^r \vee K^r)(R) =_{def} H^r(R) \vee K^r(R)$

We use this definition to interpret (50a) as follows:

For all $A \in \mathbf{P}$, $A \in$ |[painted each other's shirts or each other's shoes]|

iff $A \in (SHIRTS\_OF_{rec}(EO^r) \vee SHOES\_OF_{rec}(EO^r))(PAINT)$

iff $A \in [SHIRTS\_OF_{rec}(EO^r)(PAINT) \cup SHOES\_OF_{rec}(EO^r)(PAINT)]$; by (51) iff $A \in [(SHIRTS\_OF_{gq} \cdot EO^r)(PAINT) \cup (SHOES\_OF_{gq} \cdot EO)^r(PAINT)]$; by (44)

iff $A \in (SHIRTS\_OF_{gq} \cdot EO^r)(PAINT) \vee A \in (SHOES\_OF_{gq} \cdot EO)^r(PAINT)$

This last line says that |[painted each other's shirts or each other's shoes]| is true of a set A, if the individuals in that set painted each other's shirts or if the individuals in that set painted each other's shoes. This VP denotation would *not* be true of a set containing some individuals who painted another's shirt and some individuals who painted another's shoes. My intuition is that (50a) does not have the same truth conditions as (52) below. I will return to this point when I discuss alternative analyses of reciprocals involving movement of each.

(52) Each child painted another's shirts or another's shoes.

The other Boolean operator, not, may also be defined pointwise, as illustrated by the truth conditional equivalence of (53a,b).

(53) a. Three professors criticized each other's assistants but not each other.
b. Three professors criticized each other's assistants but didn't criticize each other.

Therefore, English not will be interpreted as the Boolean operator *complement* (–), which is defined pointwise in the algebra of reciprocal NP denotations:

(54) Definition. For all $H^r \in \mathbf{REC}$, all $R \in \mathbf{R}$, $(-H^r)(R) =_{def} -(H^r(R))$.

Sentence (53a) is interpreted as follows:[7]

For all $A \in \mathbf{P}$, $A \in$ |[criticized each other's assistants but not each other]|

iff $A \in (ASSTS\_OF_{rec}(EO^r) \wedge -EO^r)(CRITICIZE)$

iff $A \in [ASSTS\_OF_{rec}(EO^r)(CRITICIZE) \cap (-EO^r)(CRITICIZE)]$; by def. (49)

iff $A \in [ASSTS\_OF_{rec}(EO^r)(CRITICIZE) \cap -(EO^r(CRITICIZE))]$; by def. (54)

iff $A \in ASSTS\_OF_{rec}(EO^r)(CRITICIZE) \wedge A \in -(EO^r(CRITICIZE))$

[7] but is interpreted identically to and in this case, so the object NP is interpreted as a conjunction of reciprocal NPs. The second conjunct is itself complex, consisting of the unary Boolean operator *complement* and the simple reciprocal $EO^r$.

The last line indicates that ||[criticized each other's assistants but not each other]|| is true of a set A if the individuals in A criticized each other's assistants *and* it is not the case that the individuals criticized each other.

### 5.2.7 Quantified antecedents

Up to this point, I have ignored the subject NP with respect to the truth conditions of reciprocal sentences. Having shown that the referentially dependent NPs map a relation onto a set of properties, I now want to show how the subject NP combines with that set of properties to yield a truth value. The examples in (55) are illustrative of the types of quantified NPs which are typically ignored in analyses of reciprocals. The underlined subject NPs represent a variety of generalized quantifiers other than definite descriptions.

(55) a. <u>At least three dogs</u> bit each other.
b. <u>Less than five dogs</u> bit each other.
c. <u>No dogs</u> bit each other.
d. <u>Exactly four dogs</u> bit each other.

Higginbotham (1980) suggests a way of interpreting quantified antecedents. He gives example (56a) with logical form (56b):

(56) a. All critics praise each other's books.
b. [all critics]$_i$ [e$_i$ praise [each other]$_i$'s books]

If a set P satisfies the quantifier [all critics] (i.e. P contains all of the critics) and P satisfies the matrix [e$_i$ praise [each other]$_i$'s books], then sentence (56a) will evaluate to True.

Higginbotham suggests that a similar analysis is valid for the standard first-order quantifiers <u>some</u> and <u>no</u>. However, he did not give a general statement for evaluating quantifiers other than <u>all</u>, so let's consider how that might be done. Let's assume that quantified NPs are of the form Det + N', where the N' constituent evaluates to a property and the determiner is interpreted as a function from properties to generalized quantifiers. So for any determiner denotation d, $d \in [\mathbf{P} \rightarrow [\mathbf{P} \rightarrow \mathbf{2}]]$. However, in reciprocal sentences, the subject NP denotation will not have a property as its argument. Under the analysis that I gave previously, the verb phrase will evaluate to a set of properties. This higher-order analysis of verb phrases is required to get the correct entailments for the referentially dependent NPs in object position. So we need to extend the domain of the subject NP denotations to map sets of properties to truth values.

First, I will consider increasing NPs[8] like <u>at least three dogs</u>, which was given in example (55a):

<u>At least three dogs</u> bit each other.

The verb phrase, <u>bit each other</u>, will denote a set of properties. Loosely speaking, each property in the set is a set of individuals who bit each other. We say that the sentence is true if we can find a set of dogs having cardinality of at least 3 which is in this set of properties. So the extended function, $\|[\text{at least three dogs}]\|^\wedge$, should map a set of properties Q to True, if there is some $q \in Q$ of dogs[9], i.e. $DOG \supseteq q$, such that $\|[\text{at least three dogs}]\|(q) = 1$. The general statement of this higher-order extension[10] is given for all increasing noun phrases in the following definition.

(57) <u>Definition</u>. For all $p \in \mathbf{P}$, all increasing $d(p) \in [\mathbf{P} \rightarrow \mathbf{2}]$, define $d(p)^\wedge$, the <u>higher-order extension</u> of d(p), as that function in $[\mathbf{P}^* \rightarrow \mathbf{2}]$ such that for all $Q \in \mathbf{P}^*$, $d(p)^\wedge(Q) = 1$ iff $\exists q \in Q, p \supseteq q$ & $d(p)(q) = 1$.

---

8 An NP denotation $d(p) \in [\mathbf{P} \rightarrow \mathbf{2}]$ is <u>increasing</u> iff for all q, $q' \in P$, $q' \supseteq q \Rightarrow d(p)(q) \leq d(p)(q')$. Examples of increasing NPs are those constructed with the determiners <u>every</u>, <u>some</u>, <u>most</u>, <u>at least n</u>, and <u>more than n</u>.

9 Higginbotham did not have to worry about this additional reference to the property denoted by the N' in the antecedent NP, because he was assuming a condition of Strong Reciprocity for reciprocals. However, with Weak Reciprocity it is possible for a set $q \in Q$ to have more than three dogs in it, even though those three dogs did not bite each other.

10 The terminology "higher-order" may be somewhat confusing here. I am trying to avoid the traditional term "second-order", which refers to quantification of predicates. On the other hand, I want to use a term to distinguish between functions on properties and functions on sets of properties.

We also want to be able to interpret decreasing NPs[11] when they occur in subject antecedents. I gave the example of less than five dogs in (55b):

Less than five dogs bit each other.

Judgments about truth conditions seem to be slightly more difficult with decreasing noun phrases. However, the sentence above would clearly be false if we could find a set of five dogs that bit each other. In order for the sentence to be true, every set of dogs in the set of properties denoted by |[bit each other]| must be of cardinality less than 5. The general statement for the higher-order extension of a decreasing noun phrase is given as follows:

(58) Definition. For all $p \in \mathbf{P}$, all decreasing $d(p) \in [\mathbf{P} \to \mathbf{2}]$, define $d(p)^\wedge$, the higher-order extension of d(p), as that function in $[\mathbf{P}^* \to \mathbf{2}]$ such that for all $Q \in \mathbf{P}^*$, $d(p)^\wedge(Q) = 1$ iff $\forall q \in Q, p \supseteq q \Rightarrow d(p)(q) = 1$.

More work remains to show how the higher-order extension applies to non-monotonic noun phrases, Boolean combinations of determiners, and antecedents consisting of Boolean combinations of proper names and Det + N' sequences. However, these definitions for increasing and decreasing NPs already cover a great many structures and they significantly extend the type of antecedents that can be treated beyond definite descriptions and conjunctions of proper names.

### 5.2.8 Summary

In this section, I have given a model-theoretic interpretation for some referentially dependent NPs. Keenan (1989) defined an extension for generalized quantifiers in order to interpret NPs in object position. This extension is a function which maps relations onto properties. However, when the referentially dependent

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[11] For all $p \in P$, an NP denotation $d(p) \in [\mathbf{P} \to \mathbf{2}]$ is decreasing iff for all $p, q, q' \in P$, $q \supseteq q' \Rightarrow d(p)(q) \leq d(p)(q')$. Examples of decreasing NPs are those constructed with the determiners no, not every, less than n, and at most n.

NPs occur in object position, they are interpreted as functions which map relations onto sets of properties. Thus, I used higher-order functions in order to give a proper account of the semantics of these NPs. This additional structure will allow us to distinguish several classes of functions that are denoted by English expressions. In the following section, I provide a semantic characterization of these classes of functions. Then in section 5.4, I will show that these semantic classes are reflected in the syntactic distribution of the referentially dependent NPs.

## 5.3 Semantic conditions

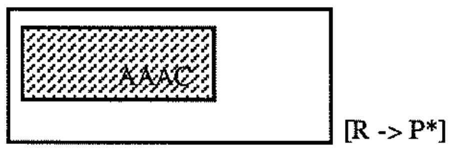
In this section, I will consider four semantic conditions which characterize classes of functions denoted by referentially dependent NPs. The motivation for looking at these conditions is to determine whether there may be semantic universals which limit the possible denotations of natural language expressions.

In the previous section, I gave some English examples and showed how to characterize their truth conditions using functions that map relations onto sets of properties. I use the notation [$\mathbf{R} \rightarrow \mathbf{P}^*$] to designate the set of all such functions. However, it appears that not all such functions may be denoted by English expressions. Therefore, my purpose here is to characterize just those functions which may be denoted by natural language expressions.

The strategy will be to propose a set of conditions which define subsets of [$\mathbf{R} \rightarrow \mathbf{P}^*$]. One such condition is the Additive Accusative Anaphor Condition (AAAC). I will show that some English expressions, such as a total of five books, denote in this set. This situation is represented by a Venn diagram in (59). Functions that satisfy the AAAC lie within the shaded rectangle. This is a subset of the total space of functions from **R** to **P***, which is represented by the outer rectangle.

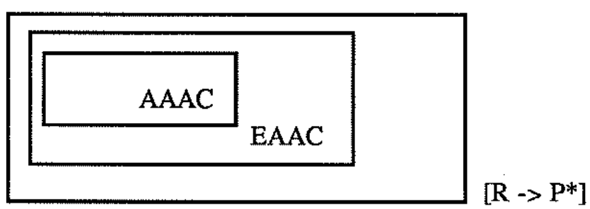
Functions within the subset will be referred to as Additive Accusative Anaphors (AAAs).

(59)



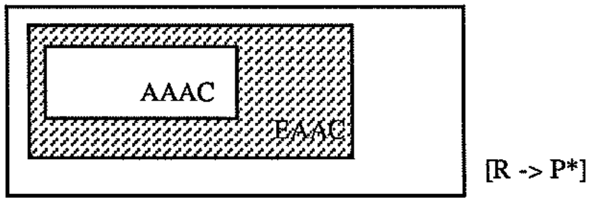

Some referentially dependent NPs may denote functions that lie outside of those which meet the AAAC. For example, the same two plays in "Each student read the same two plays", denotes a function that does not meet the AAAC. However, referentially dependent NPs with the same appear, empirically, to lie within the set defined by the Equative Accusative Anaphor Condition (EAAC). The EAAC defines a larger subset of [**R** → **P***] which properly includes the subset defined by the AAAC. As illustrated schematically in (60), a function which meets the AAAC will also meet the EAAC.

(60)




Therefore, we will say that a "proper" equative accusative anaphor is one which meets the EAAC, but which does not meet the AAAC. The proper Equative Accusative Anaphors (EAAs) are shown in the shaded region of (61). In the discussion that follows, I will normally drop the qualifying term "proper" and refer to the *proper EAAs* as simply *EAAs*.

(61)

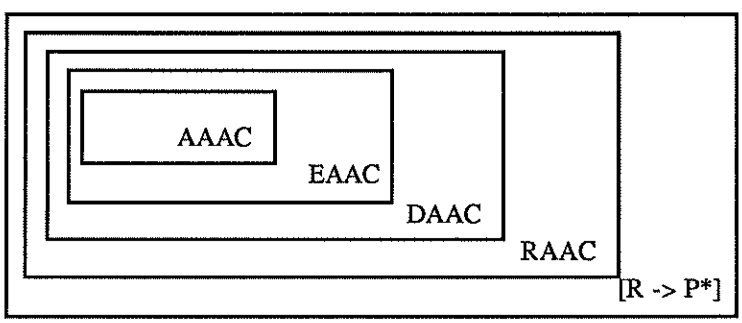



Two more conditions will be considered[12], resulting in an implicational hierarchy. This means that any function satisfying a condition which is lower on the hierarchy will also satisfy all of the conditions which are higher on the hierarchy. Such hierarchies are traditionally indicated with the '<' notation as follows:

AAAC < EAAC < DAAC < RAAC

The situation may also be depicted graphically as in the following diagram. The diagram is not intended to reflect the proportion of functions which fall into one class or another. It will be shown later that the set of functions that meet the RAAC is a very small subset of the entire set of functions in **[R → P*]**, even though the diagram makes it look as though nearly all functions satisfy the RAAC.

(62)




Before turning to the formal statement of the conditions, let us consider why they are significant. First, the different subsets of functions will be shown to correlate

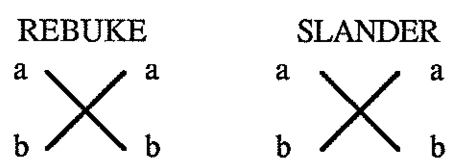
[12] The fourth and final condition, the Reducible Accusative Anaphor Condition (RAAC), was proposed by Keenan (1988).

with differences in syntactic distribution. This will be demonstrated in section 5.4. Second, these conditions represent a claim concerning a semantic universal. The claim is that nominal accusative anaphors must denote in the subset of [**R** → **P***] defined by the Reducible Accusative Anaphor Condition (RAAC). After giving the conditions below, I will show that most functions in [**R** → **P***] fail the RAAC. Thus, the RAAC is a strong condition which severely limits the range of possible denotations. This means that children learning how to interpret nominal anaphors need only choose possible denotations from a set which is very much smaller than the total number of logically possible ways of associating a binary relation with a higher-order property.

### 5.3.1 Reducible anaphors

Suppose, as in (63), that Alice rebuked the same people that she slandered and also assume that Betty rebuked the same people that she slandered.

(63)




When this condition holds, the sentence "Alice and Betty rebuked each other" must have the same truth value as "Alice and Betty slandered each other":

$\{a,b\} \in$ (EACH OTHER)(REBUKE) iff
$\{a,b\} \in$ (EACH OTHER)(SLANDER)

So one characterization of |[each other]| is that it is *invariant* under substitution of SLANDER for REBUKE in certain circumstances. Keenan (1988) characterized the invariance condition in the following way:

(64) Reducible Accusative Anaphor Condition (RAAC) (Keenan 1988)
A function $H \in [\mathbf{R} \rightarrow \mathbf{P}^*]$ is a reducible accusative anaphor iff
for all R, S $\in$ **R**, all B $\in$ **P**,
if bR = bS for all b $\in$ B then B $\in$ H(R) iff B $\in$ H(S).

Consider how this condition applies in a different example. Suppose that each boy ridiculed exactly the same things that he saw. That is, for all b $\in$ BOY, bRIDICULE = bSEE. The claim made by the RAAC is that reducible anaphors like each other, each other's scores, each other and the police officers, and each other but not each other's sisters will remain invariant under substitution of SEE for RIDICULE in this model. Therefore, "The boys ridiculed each other but not each other's sisters" must have the same truth value as "The boys saw each other but not each other's sisters":

BOYS $\in$ |[each other but not each other's sisters]|(RIDICULE) iff
BOYS $\in$ |[each other but not each other's sisters]|(SEE)

Empirically, this appears to be true. Therefore, the RAAC makes a significant claim about the range of functions in $[\mathbf{R} \rightarrow \mathbf{P}^*]$ which may be denoted by natural language expressions. Given a universe of discourse of size n, the total number of functions from **R** into **P*** is given by:

$$|\,[\mathbf{R} \rightarrow \mathbf{P}^*]\,| = 2^{2^{(n^2+n)}}$$

The number of functions satisfying the RAAC is:

$$|RAA| = 2^m, \text{ where } m = \sum_{j=0}^{n} [\binom{n}{j} \cdot 2^{n \cdot j}]$$

The summation in the exponent sums over subsets of **E** having cardinality j, where j ranges from 0 to n. The combinatorial expression $\binom{n}{j} = \frac{n!}{j! \cdot (n-j)!}$ is the number of subsets of **E** having cardinality j. The other factor in the summation, $2^{n \cdot j}$, is the number of equivalence classes of relations R, S meeting the condition of the RAAC given a set having cardinality j.

The table in (65) demonstrates that the set of functions in RAA is significantly smaller than the set of functions in [**R** → **P***]. For example, with n = 3, the number of functions in RAA is only[13] $2^{729}$, while the full set of functions in [**R** → **P***] has cardinality $2^{4096}$.

(65)

| | n = 2 | n = 3 |
|---|---|---|
| $2^m$ | $2^{25}$ | $2^{729}$ |
| $2^{2^{(n^2+n)}}$ | $2^{64}$ | $2^{4096}$ |

There are two important consequences of the RAAC. First, it makes a very strong claim about the possible denotations of natural language expressions as illustrated by the figures above. Second, it provides a language-independent semantic definition for the term "anaphor". The definition is independent of syntactic licensing conditions, reflecting the fact that the distribution of anaphors may differ across languages.

I would like to elaborate on one aspect of the RAAC. It was pointed out that RAAs remain invariant under substitution of one relation for another when certain conditions hold. NPs which do not satisfy this condition must somehow make reference to the relation. For example, predicate anaphors in an NP refer to the relation. Such an NP is given in (66a) with its interpretation in (66b). Since the NP denotation, $(\text{THREE}(\text{BOOK} \cap I_{chris}(R)))_{acc}$, refers directly to the relation R, this function will not satisfy the RAAC.

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[13] I use the term "only" in a relative sense here. The number $2^{729}$ is absurdly large in absolute terms. However, relatively speaking, this is miniscule compared to the full set of $2^{4096}$ functions.

(66) a. The students read <u>three books that Chris did</u>.
b. $\forall R \in \mathbf{R}, \forall A \in \mathbf{P}, A \in \|[\text{three books that Chris did}]\|(R)$ iff
$\forall a \in A, a \in (\text{THREE}(\text{BOOK} \cap I_{chris}(R)))_{acc}(R)$

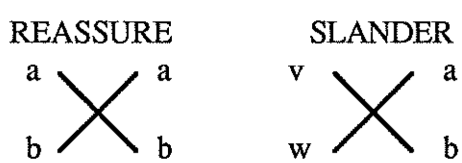
In general, the NP denotation, ||[three books that Chris did]||, will not remain invariant under substitution of one relation for another, even if those two relations satisfy the condition of the RAAC. Therefore, the RAAC is intended to characterize the class of functions which may be denoted by nominal anaphors. Noun phrases containing predicate anaphors will denote functions that lie outside of the set of RAAs.

When I defined the set of reciprocal functions in (41) above, I noted that there are $2^{n \cdot 2^n}$ such functions. This number is *much* less than the number of functions that satisfy the RAAC. It may be that the RAAC is too lenient by allowing functions to be called RAAs even though there are no natural language expressions which can denote those functions. On the other hand, the set **REC** with cardinality $2^{n \cdot 2^n}$ only contains reciprocal functions. The RAAC defines the larger set of all nominal anaphors. In addition to **REC**, there are other identifiable subsets of RAA which are denoted by English expressions. I will characterize these subsets in the following sections.

### 5.3.2 Distributive anaphors

In this section, I will give a semantic characterization of a subset of the RAAs. Consider the model in (67), where Alice reassured the same people that Vicki slandered and Betty reassured the same people that Wilma slandered. ||[each other]|| distinguishes between the two relations in this case, since "Alice and Betty reassured each other" is true, but "Vicki and Wilma slandered each other" is false.

(67)



However, there is another class of NPs, exemplified by different people, which remain invariant under this substitution. In model (67), "Alice and Betty reassured different people" has the same truth value as "Vicki and Wilma slandered different people":

{a,b} ∈ (DIFFERENT PEOPLE)(REASSURE) iff
{v,w} ∈ (DIFFERENT PEOPLE)(SLANDER)

For anaphors like |[each other]|, it is possible to substitute one relation for another under certain conditions and still preserve truth conditions. However, the "antecedent set" must remain invariant. With NPs like different people, one can vary the relation *and* the antecedent while still preserving truth conditions. The formal characterization of the invariance condition is given below.

(68) Distributive Accusative Anaphor Condition (DAAC)
A function $H \in [\mathbf{R} \rightarrow \mathbf{P}^*]$ is a distributive accusative anaphor iff
for all $R, S \in \mathbf{R}$, all $A, B \in \mathbf{P}$,
if there exists a bijection $\pi \in [A \rightarrow B]$ such that for all $a \in A$, $aR = \pi(a)S$
then $A \in H(R)$ iff $B \in H(S)$.

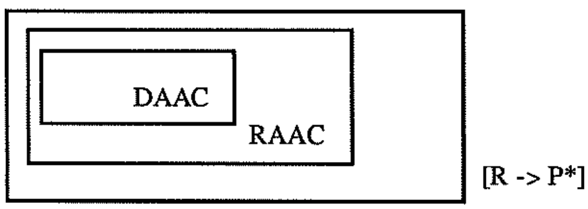
Some of the noun phrases that satisfy the DAAC are:

| | |
|---|---|
| a different book | (non-)adjacent apartments |
| a different student's book | neighboring buildings |
| two plays by different authors | (un)related dialects of Kenyang |
| distinct styles | parallel streets |
| separate facilities | streets that are parallel to each other |
| rival political parties | conflicting reports |
| warring factions | reports that conflict with each other |

The condition is applied to a specific model in the following way. Let's assume the previous model of (67), where Alice reassured the same person that Vicki slandered and Betty reassured the same person that Wilma slandered. The conditional part of the DAAC is satisfied, because aREASSURE = vSLANDER and bREASSURE = wSLANDER. The bijection between the two sets is that function which maps a to v and b to w. A function is called a distributive accusative anaphor if it must treat the two pairs A, R and B, S identically. That is, the function remains invariant under substitution of B for A and S for R, as long as the condition relating the sets and relations is satisfied. Clearly, "Alice and Betty reassured different people" must have the same truth value as "Vicki and Wilma slandered different people" when this condition is satisfied. That is, $\{a,b\} \in$ |[different people]|(R) iff $\{v,w\} \in$ |[different people]|(S).

Each of the NPs that satisfy the DAAC will also satisfy the RAAC. However, there are NPs which satisfy the RAAC, but do not satisfy the DAAC. This means that RAA $\supset$ DAA as illustrated in the following Venn diagram.

(69)

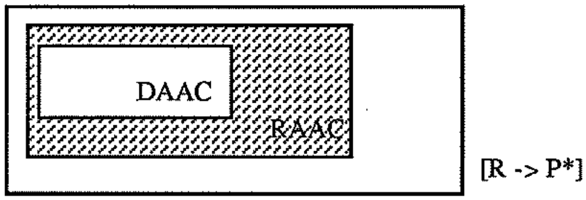



|[each other]| is an example of an NP denotation that is an RAA, but not a DAA. As shown previously for model (67), the conditions of the DAAC are satisfied, but

$\{a,b\} \in EO^r(REASSURE)$ and
$\{v,w\} \notin EO^r(SLANDER)$

That is, "Alice and Betty reassured each other" is true in this model, but "Vicki and Wilma slandered each other" is false, even though Alice reassured the same people that Vicki slandered and Betty reassured the same people that Wilma slandered. I will use the term *proper* reducible accusative anaphor to refer to an NP, like <u>each other</u>, which satisfies the RAAC but does not satisfy the DAAC. The class of proper reducible anaphors is shown in the shaded region in the following diagram.

(70)

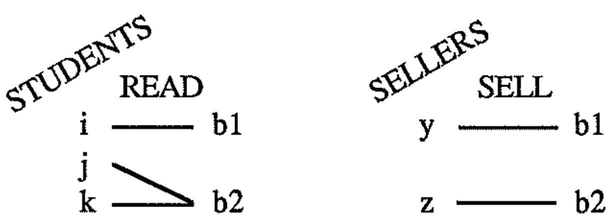



In the next section, I will propose another condition which further limits the set of functions to a subset of DAA.

### 5.3.3 Equative anaphors

Consider model (71) in which the students read books and booksellers sold books as shown. In this model, Ian read the book that Yolanda sold. Jim and Kate read the book that Zoe sold.

(71)




For each member a of {i, j, k}, there is a member b of {y, z} such that aREAD = bSELL. Similarly, for each member b of {y, z} there is a member a of {i, j, k} such that bSELL = aREAD. Given this "back and forth" condition, "The students read the same book" must have the same truth value as "The booksellers sold the same books":

{i,j,k} ∈ (SAME BOOK)(READ) iff
{y,z} ∈ (SAME BOOK)(SELL)

The function denoted by SAME BOOK remains invariant, i.e. yields the same value, under substitution of SELL for READ and BOOKSELLER for STUDENT. Note that DIFFERENT BOOKS is not invariant under this substitution. In this model, it is true that "The booksellers sold different books", but it is false that "The students read different books".

The formal statement of the condition that distinguishes SAME from DIFFERENT is given in (72) below. Previously, the DAAC required a certain type of bijection between the two sets A and B. However, in the EAAC, we simply require a function f from A to B such that $\forall a \in A$, $aR = f(a)S$ and another function g from B to A such that $\forall b \in B$, $bS = g(b)R$. Rather than using this functional notation in the definition of the EAAC, I have expressed the relationship between two sets.

(72) Equative Accusative Anaphor Condition (EAAC)
A function $H \in [\mathbf{R} \rightarrow \mathbf{P}^*]$ is an equative accusative anaphor iff
for all $R, S \in \mathbf{R}$, all $A, B \in \mathbf{P}$,
if $\{aR \mid a \in A\} = \{bS \mid b \in B\}$ then $A \in H(R)$ iff $B \in H(S)$.

The model in (71) satisfies the condition that $\{aR \mid a \in \{i,j,k\}\} = \{bS \mid b \in \{y,z\}\}$, because iREAD = ySELL = $b_1$ and jREAD = kREAD = zSELL = $b_2$. Therefore,

$$\{a\text{READ} \mid a \in \text{STUDENT}\} = \{\{b_1\},\{b_2\}\} = \{b\text{SELL} \mid b \in \text{BOOKSELLER}\}$$

Empirically, the NPs in (73) will satisfy the EAAC as can be demonstrated by comparing the truth values of the two sentences:

The students read ___.
The booksellers sold ___.

where both blanks are filled in by one of the following noun phrases:

(73)

| | |
|---|---|
| the same books | similar articles |
| the same number of books | articles that are similar to each other |
| the same student's papers | two plays by the same author |
| corroborating evidence | two papers from the same conference |
| evidence that corroborates each other's alibis | |

Formally, we can show that NPs like the same book satisfy the EAAC by using definition (31) of SAME, which is repeated here:

(31) Definition of 'SAME': For all A, Q $\in$ **P**, and all R $\in$ **R**,
A $\in$ (SAME(Q))(R) iff $|A| > 1$ and for all a,b $\in$ A, $aR \cap Q = bR \cap Q$.

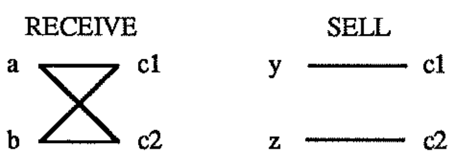
To show: For all Q $\in$ **P**, the function defined by (SAME)(Q) is an Equative Accusative Anaphor.

Proof: Given a non-empty universe of discourse **E**, let R, S $\in$ **R** and A, B $\in$ **P**.
Suppose $\{aR \mid a \in A\} = \{bS \mid b \in B\}$.
Then A $\in$ (SAME)(Q)(R)
iff for all $a_i, a_j \in A$, $a_iR \cap Q = a_jR \cap Q$ ; by the definition of 'SAME'
iff for all $b_i, b_j \in B$, $b_iS \cap Q = b_jS \cap Q$ ; since $\{aR \mid a \in A\} = \{bS \mid b \in B\}$
iff B $\in$ (SAME)(Q)(S) ; by the definition of 'SAME'
Q.E.D.

### 5.3.4 Additive anaphors

Finally, we reach the fourth class of anaphors, exemplified by A TOTAL OF and A MINIMUM OF. Suppose that Alan and Bob received the same two calendars as in (74). Furthermore, Yolanda sold one of those calendars and Zoe sold the other one. In this model, the girls sold a total of 2 calendars and the boys received a total of 2 calendars.

(74)




The function, ((A TOTAL OF 2)(CALENDARS)), remains invariant in this model for (RECEIVE, {a,b}) and (SELL, {y,z}). That is,

{a,b} $\in$ ((A TOTAL OF 2)(CALENDAR)(RECEIVE) iff
{y,z} $\in$ ((A TOTAL OF 2)(CALENDAR)(SELL)

The relevant condition for invariance is given by:

(75) Additive Accusative Anaphor Condition (AAAC)
A function H $\in$ [**R** $\rightarrow$ **P***] is an <u>additive accusative anaphor</u> iff for all R, S $\in$ **R**, all A, B $\in$ **P**,
if $\bigcup_{a \in A} aR = \bigcup_{b \in B} bS$ then A $\in$ H(R) iff B $\in$ H(S).

One way to think of this condition is to say that a function H that meets the AAAC is "invariant" under certain conditions. Suppose that A ∈ H(R). Then the AAAC says that H will not be able to distinguish another set B, just as long as

$$\bigcup_{a\in A} aR = \bigcup_{b\in B} bR$$

Furthermore, it is not even necessary to hold the relation R constant. In the case where

$$\bigcup_{a\in A} aR = \bigcup_{b\in B} bS$$

H will treat A and R just the same as it treats B and S.

We can prove that |[a total of 2 calendars]| is an AAA by using definition (28) for A TOTAL OF, which is repeated here:

(28) Definition of 'A TOTAL OF n': For all A, Q ∈ **P**, all R ∈ **R**, and all n ∈ **N**,
$A \in ((\text{A TOTAL OF } n)(Q))(R)$ iff $|(\bigcup_{a\in A} aR) \cap Q| = n$

<u>To show</u>: For all n ∈ **N**, all Q ∈ **P**, the function defined by (A TOTAL OF n)(Q) is an Additive Accusative Anaphor.

<u>Proof</u>: Given a non-empty universe of discourse **E**, let R, S ∈ **R** and A, B ∈ **P**.
Suppose $\bigcup_{a\in A} aR = \bigcup_{b\in B} bS$.
Then $A \in (\text{A TOTAL OF } n)(Q)(R)$
iff $|(\bigcup_{a\in A} aR) \cap Q| = n$ ; by the definition of 'A TOTAL OF'
iff $|(\bigcup_{b\in B} bS) \cap Q| = n$ ; by assumption, $\bigcup_{a\in A} aR = \bigcup_{b\in B} bS$
iff $B \in (\text{A TOTAL OF } n)(Q)(S)$ ; by the definition of 'A TOTAL OF'
Q.E.D.

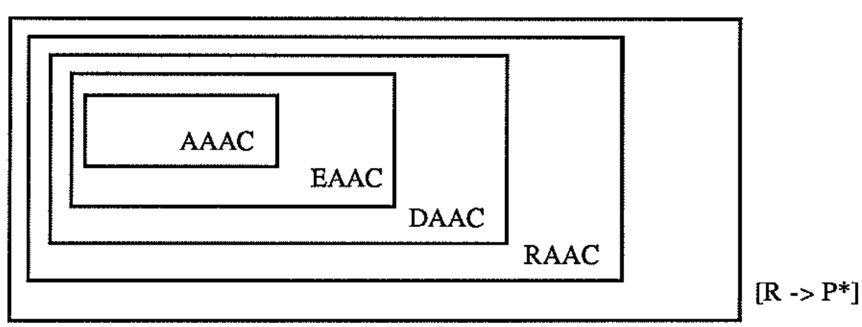
Similarly, it can be shown from the definitions of 'A MINIMUM OF' and 'A MAXIMUM OF' that the English expressions of the form <u>a minimum of n N</u> and <u>a maximum of n N</u> denote Additive Accusative Anaphors. Although I will not give a formal semantics for partitives (e.g. <u>a bunch of the plates</u>) and pseudopartitives (e.g. a cupful of jellybeans), one reading of these English constructions appears to require denotations which satisfy the AAAC. In section 5.4, I will discuss the similarities and differences between the total-like QPs and partitives.

### 5.3.5 A scale of anaphoricity

In the previous sections, I gave a sequence of conditions which categorize noun phrases according to a scale of anaphoricity:

additive anaphor < equative anaphor < distributive anaphor < reducible anaphor

At the left end of this scale, the additive anaphors are the least anaphoric. This means that their interpretation depends the least on the interpretation of the antecedent. Another viewpoint is that additive anaphors are the most invariant. That is, they preserve truth conditions under a wider range of substitution. At the other end of the scale is the reducible anaphors. These are the most anaphoric of the nominal anaphors. They require the most information about the antecedent in order to be properly interpreted. Alternatively, one may say that the reducible anaphors are the least invariant. That is, they preserve truth values only under the strictest conditions of substitution. As discussed previously, the conditions define progressively smaller subsets of the entire space of functions in $[\mathbf{R} \rightarrow \mathbf{P}^*]$. Figure (62) is repeated below along with a sample list of expressions from each class to show how the conditions are related to each other:



Additive anaphors:
- a total of five horses
- a minimum of six trees
- a maximum of seven dogs
- a cupful of jellybeans

Equative anaphors:
- the same books
- the same number of books
- the same student's papers
- two plays by the same author

Distributive anaphors:
- a different book
- a different student's book
- (un)related dialects of Kenyang
- parallel streets

Reducible anaphors:
- each other
- each other's scores
- each other and the police officers
- each other but not each other's sisters

This type of relationship among classes is often referred to as an implicational hierarchy, since every additive anaphor is an equative anaphor, every equative anaphor is a distributive anaphor, and every distributive anaphor is a reducible anaphor. I used the term *proper* to refer to distinct subsets of [**R** → **P***]. A *proper reducible anaphor* is an NP denotation which meets the RAAC, but which does not meet the DAAC. Similarly, a *proper distributive anaphor* is an NP denotation which meets the DAAC, but which does not meet the EAAC. A *proper equative anaphor* is an NP denotation that meets the EAAC, but does not meet the AAAC. I have not given a condition which would distinguish *proper additive anaphors* like <u>a total of three books</u> from non-anaphoric NPs like the simple quantified NP <u>at least three books</u>.

## 5.4 Syntactic distribution

In this section, I will address two syntactic issues related to the semantic analysis that I have just presented. First, I will argue that the classification of noun phrases by the four semantic conditions is not merely a semantic property. Although much work remains to be done, it is clear that NPs from the four classes do not have the same syntactic distribution. Second, I will give some syntactic evidence for my analysis of quantifier phrases in the additive anaphors. Additive anaphors like a total of five books are superficially similar to partitive expressions like a bunch of the books and pseudopartitives like a bunch of books. However, I will argue that additive anaphors have a different syntactic structure than the partitives and this provides evidence for treating a total of five as a semantic constituent.

### 5.4.1 Syntactic correlates of the anaphor conditions

I want to briefly consider some evidence that the semantic conditions proposed in the previous section correlate with differences in syntactic distribution. I will present some of the syntactic environments which distinguish between the semantic classes. The results are summarized in a table at the end of the section.

Previous work on referentially dependent NPs has always noted that total, same, and different NPs differ from the reciprocals in being able to occur as the subject of a main clause:

(76) a. A total of 5 agents saw the intruders.
b. The same 5 agents saw the intruders.
c. Different agents saw the intruders.
d. *Each other saw the intruders.
e. *Each other's agents saw the intruders.

In embedded clauses, only same, different, and complex reciprocals may occur as the subject. My intuition is that (77a) does not have a bound reading. Such a reading would be satisfied in a model where $man_1$ believed that lawyers $l_1$ and $l_2$ called Alice, $man_2$ believed that lawyers $l_3$ and $l_4$ called Alice, and $man_3$ believed that lawyer $l_5$ called Alice.

(77) a. #The men believed a total of 5 lawyers called Alice.
b. The men believed the same lawyers called Alice.
c. The men believed different lawyers called Alice.
d. *The men believed each other called Alice.
e. The men believed each other's lawyers called Alice.

Intuitively, the total NPs are the least anaphoric of the referentially dependent NPs considered here. This intuition is captured in the semantic conditions, since the additive anaphors are the least discriminating, i.e. they are invariant under a wider range of substitutions. The weak anaphoricity of total NPs shows up in the syntax as well. These are the only referentially dependent NPs that occur in crossover constructions. In my judgment, the following two sentences have a bound reading, although it is not the preferred one.

(78) a. Which donors$_i$ did a total of 5 volunteers call $t_i$?
b. The potential donors that$_i$ a total of 12 volunteers in California called $t_i$ were just as likely to contribute more than $100 as those who$_j$ $t_j$ were called by a total of 15 volunteers in New York.

Equative anaphors are the only ones that may be bound in the indirect object position of the double object construction:

(79) a. #Ben told a minimum of twelve children three stories.
b. Ben told the same children three stories.
c. #Ben told different children three stories.

If the four classes of referentially dependent NPs were completely independent with respect to syntactic distribution, it should be possible to find 16 different combinations of them. For example, there should be one environment where only additive anaphors occur, one environment where only equative anaphors occur, etc. In the following table, I show 7 environments which distinguish between the different semantic classes of anaphors. Sample sentences contain a blank ( __ ) for one noun phrase position and an underlined NP to serve as a potential antecedent (e.g. they). If one of the higher-order NPs can fill in the blank and be bound by the other underlined NP, then a plus sign (+) is shown in the appropriate column. The letter c in the 'each other' column indicates that a complex reciprocal, such as each other's sisters, is acceptable in this position, although the bare reciprocal each other may not be.

(80) Distribution of higher order NPs

| | total | same | different | each other |
|---|---|---|---|---|
| Strong Crossover<br>Who$_i$ did __ call $t_i$? | + | | | |
| Agent by-phrase in subordinate clause<br>Mike and Bob think that America was discovered by __.<br><br>Double object<br>Ben told __ every story. | | + | | |
| Subject of main clause<br>__ saw the students.<br><br>Antecedent in subordinate clause<br>__ verified that the athletes were eligible. | + | + | + | |
| Subject of infinitival clause<br>The men wanted __ to be hired. | + | + | + | + |
| Object of infinitival clause<br>The men wanted Alice to hire __. | | + | + | +/c |
| Subject of tensed clause<br>They said __ had called the customers. | | + | | +/c |
| Object of tensed clause<br>The lab managers hoped that the NSF would fund __. | | | | c |

Although speakers' judgments may vary on particular cases, it appears that the four semantic classes correlate with differences in syntactic distribution. It remains to show the exact syntactic licensing conditions for each class.

### 5.4.2 Additive anaphors are not partitives

In this section, I would like to provide some evidence for my syntactic treatment of quantifier phrases in the additive anaphors. It may seem odd that I am interpreting expressions like a total of five as a constituent. NPs with total, minimum, and maximum quantifier phrases (QPs) look very much like the partitive construction in that they consist of a 'Det N of Det N' pattern. For example (81a) would appear to require the same structure as the partitive construction of (81b).

(81) a. A minimum of three dogs bit the mail carrier.
b. A number of the dogs bit the mail carrier.

One property of partitives is that they are syntactically ambiguous with a 'Det $N_1$ of Det $N_2$' construction in which the first noun, $N_1$, is the head of the NP. Selkirk (1977) gives examples where this ambiguity is demonstrated by number agreement with the verb, pronominalization, and selectional restrictions. For example, a bunch of those flowers may be interpreted as a partitive with a plural head, flowers, as in (82a). Or it may be a simple NP with a singular head, bunch, as in (82b) (Selkirk's (98)).

(82) a. A bunch of those flowers were thrown out on the back lawn.
b. A bunch of those flowers was thrown out on the back lawn.

Similarly, determining the exact syntactic structure of the total-type QPs is complicated somewhat by this ambiguity. The structures under consideration in this paper are where total occurs as part of the quantifier phrase and not as the head noun. Examples (83a,b) show that the same string of lexical items may receive more than one syntactic structure. When total or minimum is the head noun, there is singular number agreement. When the plural noun is interpreted as the head noun, there is plural number agreement.

(83) a. A total of five dissenting votes was/were recorded in the minutes.
b. A minimum of 7 council members would be a quorum, wouldn't it/they?

As shown by Selkirk, selectional restrictions can also distinguish between the two syntactic structures. Example (84a) illustrates this point, where indict must take an NP that denotes individuals as its object and it cannot take a quantity expression. However, it is difficult to come up with examples which exclude the total-like QP reading and force maximum to be interpreted as the head noun. The sentence in (84b) sounds slightly odd, but it illustrates the case where the QP reading is excluded. This sentence only makes sense where maximum is the head noun.

(84) a. A maximum of three officers were/*was indicted on bribery charges.
b. A maximum of two functions occurs/*occur where the second derivative of at least one of the functions is zero.

In other respects, the total-type QPs have different distributional properties than other nouns that occur in the partitive construction. In partitives, the specifier following of must be either the definite article (the), a demonstrative (e.g. this, those), or a possessive NP (e.g. her, some man's) (Selkirk 1977, Jackendoff 1977). However, these specifiers do not cooccur with the total-type QPs:

(85) a. *A total of the letters were processed immediately.
b. *A minimum of these children must attend the orientation meeting.
c. *A maximum of her experience was related to marketing.

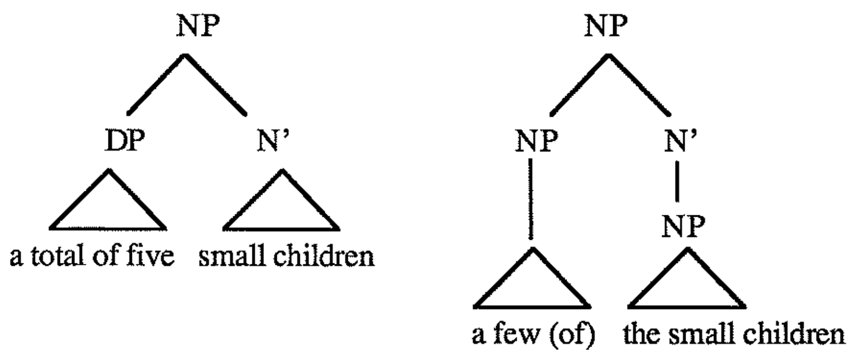
Another difference between the total-type quantifiers and partitives concerns the ability to extrapose the of-NP sequence. This extraposition is possible for partitives (Akmajian and Lehrer 1976), but not for a total of. Examples (86a,b) are from Selkirk (1977). However, the corresponding extraposition in (87b) is ungrammatical.

(86) a. Only a handful of those questions concerning electromagnetism were asked.
b. Only a handful were asked of those questions concerning electromagnetism.

(87) a. A total of six border guards involved in smuggling were convicted.
b. *A total were convicted of six border guards involved in smuggling.

Selkirk used this movement diagnostic as an argument that those questions should be treated as a constituent. Similarly, the lack of movement in (87) argues against treating six border guards as a constituent. Therefore, it seems plausible that expressions like a total of n form a syntactic constituent which may be interpreted as a unit.[14] The difference between these quantifiers and a partitive is illustrated below.

(88) a. complex quantifier    b. partitive




## 5.5 Comparison with other approaches

Previous analyses of referentially dependent NPs have tried to interpret the antecedent and the dependent NP as a unit. Part of the motivation for such an approach is to relate the two NP positions by syntactic movement. Another reason for interpreting the two NPs as a unit is to be able to express the semantic differences between referentially dependent NPs and independent NPs.

In the preceding sections, I gave an alternative analysis in which referentially dependent NPs are interpreted independently of the antecedent NP. However, in order to correctly represent the truth conditions of sentences containing these NPs, it was necessary to use higher-order functions. This approach is based on Langendoen's

[14] Coordination is another test for constituency. However, the evidence does not clearly favor one analysis over another in this case. Examples like (i) argue against always treating a minimum of n as a constituent. On the other hand, (ii) argues against always treating 'n N' as a constituent.

(i) A minimum of [[two students] and [three professors]] attend the meeting.

(ii) [[A minimum of 10] and [a maximum of 15]] new students are admitted each year.

(1978) analysis of simple reciprocal expressions, although I have extended the analysis to a much broader range of expressions. In the following sections, I will discuss some of the differences between my analysis and other approaches.

### 5.5.1 Each-movement

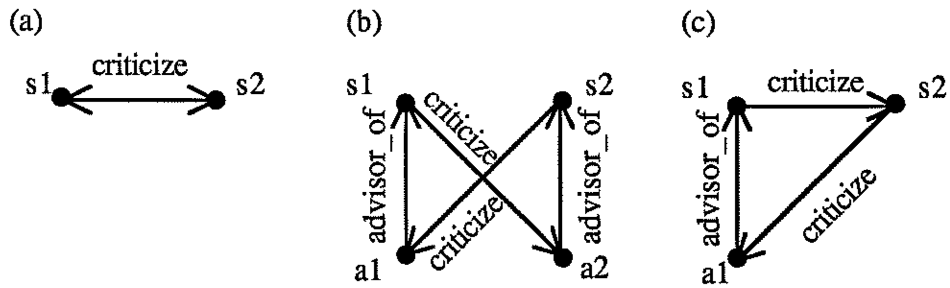
One approach to reciprocals has been to relate the antecedent and the reciprocal by movement of each (Dougherty 1974, Belletti 1982). Heim, Lasnik, and May (1988) use this approach and interpret each other compositionally based on the semantics of each and the semantics of other. They discuss a wider range of syntactic structures than presented for my analysis, especially with respect to complement clauses. However, I would like to point out three advantages to directly interpreting reciprocals.

First, direct interpretation yields correct results for coordinate structures, where movement of *each* does not preserve meaning. For example, an across-the-board extraction of each in (89a) would result in a logical form that corresponds roughly to the structure of (89b).

(89) a. The students criticized each other or each other's advisors.
b. Each student criticized another or another's advisor.

According to my intuition, these two sentences do not have the same truth conditions. Both sentences are true in models (90a,b). Sentence (89a) is false with model (90c), where student $s_1$ criticized student $s_2$ and student $s_2$ criticized student $s_1$'s advisor. However, (89b) is true in that model.

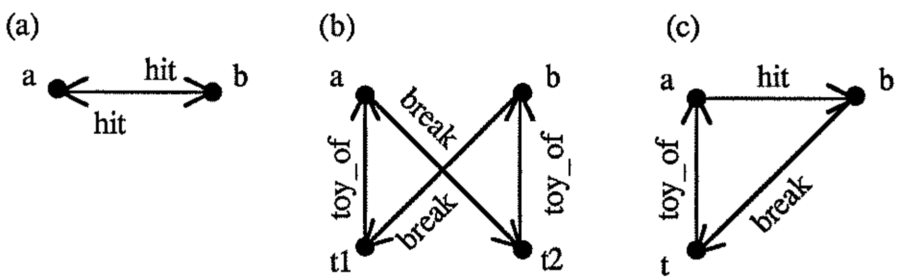
(90)




A similar situation holds for extraction of each from coordinate verb phrases. Sentences (91a,b) are both true in models (92a,b). However, only (91b) is true in model (92c).

(91) a. The children hit each other or break each other's toys.
b. Each child hits the other or breaks the other's toys.

(92)




The analysis that I gave in section 5.2.6 for coordinate reciprocals correctly captures the truth conditions of the coordinate structures in (89a) and (90a). Example (50a) was similar in structure to (89a) and I demonstrated how the pointwise definitions of the Boolean operators correctly applied to interpret the complex reciprocal.

A second difference between direct interpretation and the each-movement analysis is that direct interpretation allows one to interpret a variety of generalized quantifiers as subject NPs. In section 5.2.7, I demonstrated how to interpret antecedents of the form Det + N', where the determiner is interpreted as either increasing or decreasing. More work is required to show how to define a higher-order extension for non-monotonic determiners, Boolean combinations of determiners, and antecedents consisting of Boolean combinations of proper names and Det + N' sequences. However, the analysis of increasing and decreasing determiners already significantly extends the type of antecedents that can be treated beyond definite descriptions and conjunctions of proper names.

A third difference between direct interpretation and the each-movement analysis is that direct interpretation does not crucially depend on a two-part NP consisting of a distributor, each, and a reciprocator, other. Therefore, the semantic analysis of reciprocals as functions in **[R → P*]** extends naturally to other referentially dependent NPs, as was demonstrated for total, same, and different. Furthermore, this analysis should extend to languages such as Choctaw, Malagasy, and Palauan where reciprocity is represented in the verb morphology. More study is required to determine if there are essential differences between languages representing reciprocity in the verbal morphology as opposed to those representing reciprocity in independent NPs.

### 5.5.2 Binary quantifiers

Several authors have used binary quantifiers to interpret referentially dependent NPs (Scha 1981, Clark and Keenan 1986, Keenan 1987, Choe 1987). Those analyses interpret the subject and object NP together as a single quantifier which binds both argument positions of a binary relation. For example, Keenan (1987) interprets a simple sentence like "Every student read a different book" as having a logical form:

(EVERY, DIFFERENT)(STUDENT, BOOK, READ)

The complex quantifier (EVERY, DIFFERENT) maps a pair of properties, STUDENT and BOOK, to a function which maps the two-place relation READ to a truth value. One of the advantages to this approach is that it allows one to compare the formal properties of binary quantifiers like (EVERY, DIFFERENT) to formal properties of simple generalized quantifiers like EVERY. For example, Keenan (1987) shows that certain binary quantifiers, including (EVERY, DIFFERENT), cannot be reduced to a sequence of simple quantifiers.

Directly interpreting the object NP as a function in [**R** $\rightarrow$ **P***] has one main advantage over an analysis involving binary quantifiers. Under direct interpretation, Boolean operators receive essentially the same analysis as for first-order NPs. It is clear that referentially dependent NPs can be conjoined, as demonstrated by the examples in (93) below.

(93) a. Alice and Bill read <u>the same articles</u> <u>but</u> <u>different books</u>.
b. Some of the clients called each other's accountants and each other's lawyers.

As discussed in section 5.2 for reciprocals, <u>and</u>, <u>or</u>, and <u>not</u> may be interpreted as the Boolean operators meet, join, and complement in the denotation set of referentially dependent NPs. This provides a straightforward compositional account of coordination.

In contrast, Keenan (1987:143) states that coordination would be difficult to handle within his framework and does not give any suggestions for how it might be done. The binary quantifier analysis must develop a new type of formula to handle coordinate structures. For example, (94b) would be a possible extension of Keenan's formalism to represent the sentence in (94a), which contains a coordinate noun phrase.

(94) a. Every student read a different book but the same article.
b. (EVERY, <AND, <DIFF,SAME>>)(STUDENT, <BOOK,ARTICLE>, READ)

The truth conditions for this formula would be stated in terms of the interpretation previously defined for the simpler formulas:

(EVERY, DIFF)(STUDENT, BOOK, READ) and
(EVERY, SAME)(STUDENT, ARTICLE, READ)

However, the formalism must also be extended to cover negation and coordination of categories other than NP in order to handles sentences like:

> Three student reviewed the same books but didn't read the same number of articles.

One can certainly devise another structure to represent this sentence, but the treatment of Boolean operators will not be completely uniform across categories. While it seems likely that the binary quantifiers analysis could be extended to cover the complex cases, it appears that the incorporation of Boolean operators is not as straightforward as for the direct interpretation analysis.

## 5.6 Summary of Chapter Five

In this chapter, I have presented a uniform analysis of referentially dependent NPs. The framework defined here is a generalization of Keenan's (1989) Semantic Case Theory in which an object NP that denotes a generalized quantifier is extended to map a relation to a property. For referentially dependent NPs, I gave a higher-order analysis in which an NP is interpreted as mapping a relation to a *set* of properties. I demonstrated how this approach works for a number of expressions which have been identified in the literature as "referentially dependent". In particular, I extended Langendoen's (1978) definition of "reciprocal element" in order to provide an analysis of complex reciprocals. This analysis allows one to interpret reciprocals in possessive NPs, coordinate reciprocals, negated reciprocals, and Boolean combinations of reciprocal and non-reciprocal NPs. Furthermore, this approach provides a way to interpret quantified antecedents for reciprocals. This extends the class of structures normally discussed with respect to reciprocals, since previous work has concentrated on the bare reciprocal each other with a definite description as its antecedent.

After giving the semantics for selected referentially dependent NPs, I gave four semantic conditions which categorize the types of functions denoted by natural language expressions. These conditions demonstrate that natural language is constrained in the types of functions within [**R** $\rightarrow$ **P***] which may be denoted. It was shown that the largest class of nominal anaphors, the Reducible Anaphors, is much smaller than the full set of functions in [**R** $\rightarrow$ **P***]. In section 5.4.1, I presented some evidence which suggests that these semantic conditions correlate with differences in syntactic distribution.

In comparing the analysis presented in this chapter to previous work on referentially dependent NPs, several important consequences were noted. First, directly interpreting anaphoric NPs allows one to accurately represent our intuitions about the interpretation of coordinate structures. Previous analyses, including syntactic treatments of each-movement and semantic analyses of binary quantifiers, have not been able to represent these entailment judgments. Second, this analysis provides a framework for interpreting a full range of noun phrases as an antecedent for a reciprocal. Finally, direct interpretation of referentially dependent NPs allowed us to define a scale of anaphoricity which is reflected in the syntax.

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