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Quantifier Scope, Lexical Semantics, and Surface Structure Constituency

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We present a novel conjecture concerning the scope ambiguities that arise in sentences including multiple non-referential quantifiers. We claim that many existing theories of the phenomenon fail to correctly limit the set of readings that such sentences engender by failing to distinguish between referential and non-referential quantifiers. Once the distinction is correctly drawn, we show that surface syntax can be made, via an extended notion of surface constituency, to identify the set of available differently-scoped readings for such sentences. We examine various English constructions to show that the scopings predicted by the conjecture are the only ones that are available to human language understanders. We show how to incorporate this conjecture into a theory of quantifier scope, by couching it in a unification-based Combinatory Categorial Grammar framework and implementing it in SICStus Prolog. Finally, we compare the proposal with related approaches to quantifier scope ambiguity.

1. Introduction

The semantics of sentences containing quantifiers can be difficult to predict. Particularly when a sentence contains multiple quantifiers, the scope possibilities for each quantifier may interact in unexpected ways with each other and with other syntactic properties of the sentence. Many theories of quantifier scope have been proposed in the literature, most of them variants either of quantifier raising as proposed by May (1977) or of quantifying-in as proposed by Montague (1974). Both proposals operate under the assumption that the semantics of quantifiers can be characterized by *abstraction*, according to which NP semantics can be pulled out of the original NP position and take the rest of the sentential semantics, or some part thereof, under its scope. According to these proposals, whether two NPs may or may not alternate their relative scope order can only be determined after the two NPs are individually abstracted out. Despite numerous modifications of these original proposals they still appear to fall short of explanatory and descriptive adequacy, for reasons that are discussed in Section 2 below.

In this paper, we present a novel conjecture that predicts when two non-referential quantifiers are or are not ambiguous with respect to their relative scope. This approach ties scope ambiguity in a language to coordination in the language: Which substrings serve as scope islands can be predicted from which substrings can be coordinated.[1] We claim that the conjecture makes predictions that are both explanatory and descriptively adequate. To substantiate this claim, this paper focuses on three kinds of English constructions that allow multiple NPs in a single grammatical sentence: complex NPs con-

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1 A preliminary sketch appears in Park (1995).

taining PPs, complex NPs containing *Wh*-relatives, and transitive/attitude verbs. We also give a theory of quantifier scope that is couched in Combinatory Categorial Grammar (CCG) formalism and implemented in SICStus Prolog.

The paper is structured as follows. Section 2 motivates and lays out the conjecture for scope ambiguity. Section 3 argues why we need to distinguish referential NP interpretations from quantificational NP interpretations in semantics, following Fodor and Sag (1982). Section 4 presents a competence theory of quantifier scope, couched in a unification-based CCG framework. While CCG is chosen for this task since its notion of constituency meshes well with that assumed in the conjecture, it should also be possible to spell out the theory in other grammar formalisms. Section 5 lays out theoretical predictions on scope readings. Section 6 compares the present approach with traditional approaches to quantifier scope. Complete prolog code for the example sentences considered in this paper and some sample runs are given in an appendix.

2. Surface Constituency Conjecture

Consider the following sentences.

(1) (a) Every representative of a company saw most samples.
(b) Some student will investigate two dialects of every language.

Hobbs and Shieber (1987) made a claim, based on quantifier binding at LF, that out of the six combinatorial ways of ordering the three quantifiers (i.e. *every*, *a*, and *most*), sentence (1) (a) has one missing scope reading, in which *every representative* outscopes *most samples*, which in turn outscopes *a company*. This scope reading is certainly unavailable from sentence (1) (a). Notice that in this claim, Hobbs & Shieber implicitly assumed that among the available five readings is the one in which *a company* outscopes *most samples*, which in turn outscopes *every representative*. Let us call this Hobbs & Shieber's reading. The reading would be true of a situation in which there is a company such that most samples were individually seen by the entire representatives of that particular company. We agree that Hobbs & Shieber's reading is available from sentence (1) (a). May (1985) claimed that sentence (1) (b) has a reading in which *every language* outscopes *some student*, which in turn outscopes *two dialects*. Let us call this May's reading. This reading would be true of a situation in which for each language, there is a possibly different student such that he or she will investigate two dialects of that language.[2] Again, we agree that May's reading is available from sentence (1) (b). Notice that these two readings share an interesting pattern, where the two NPs, 'NP_1 prep NP_2' and NP_3, ignoring the word order, give rise to a scope order in which NP_2 outscopes NP_3, which in turn outscopes NP_1. This pattern suggests that standard English constituent structure (or even the extended notion of surface constituency, discussed below) does not limit the range of available readings.

Nevertheless, we show in Section 3.2 that the kind of scope relation implicated in Hobbs & Shieber's account of their reading is unavailable for quantificational NPs, e.g., *at least two companies* or *few companies* in place of *a company*. This is due to the kind of functional dependency inherent in quantificational scope relations, to be discussed later.

2 There is an inherent real-world connection between languages and dialects. This connection appears to interfere with the said scope relation in such a way that might override an otherwise unavailable scope relation. This potential interference would go away if we replace *two dialects* with *two aspects* (Bonnie Webber and Tony Kroch, p.c.). The change makes the fact clearer that the said scope reading is available independent of such a real-world connection.

The reason Hobbs & Shieber's reading is available for sentence (1) (a) is, we believe, that *a company* can be interpreted referentially (Heim, 1983). We know, following Fodor and Sag (1982), that while referential NPs appear to take matrix scope, they do not really participate in the kind of scope relations that quantificational NPs do. Most crucially, referential NPs are interpreted relatively independently of the rest of the NPs in the same sentence, and the rest of the NPs are interpreted as if referential NPs are more or less proper nouns. It is thus theoretically essential to distinguish referential NP interpretations from quantificational NP interpretations in semantics.[3]

Given this semantic distinction and setting referential readings aside, sentence (1) (a) has exactly four quantificational readings, whereas sentence (1) (b) has five quantificational readings, as shown below.[4] The symbol > refers to the outscoping relation.

Every rep of a company saw most samples	Some student will inv two dialects of every language
(every rep > a comp) > most samp	*(two dial > every lang) > some student*
a comp > every rep > most samp	*every lang > two dial > some student*
most samp > (every rep > a comp)	*some student > (two dial > every lang)*
most samp > a comp > every rep	*some student > every lang > two dial*
	every lang > some student > two dial

Table 1
Quantificationally Available Readings

We claim that the following conjecture precisely captures this difference in the number of available readings and especially the fact that only May's sentence allows a reading in which the quantifiers intercalate, in the sense discussed earlier for the said pattern. We first make the following definition.

(2) C-CONSTITUENT: A string s of words of a sentence S in a language L is a coordinating constituent (or *c-constituent*) under S if and only if L has a grammatical sentence S' which is exactly like S except that s is coordinated with another string s'.[5]

The qualification "under S" will be omitted whenever the context makes it obvious. For example, both *loves* and *will marry* are c-constituents as *Every man loves and will marry some woman* is a grammatical English sentence. We will use the term *q-quantifiers* (respectively *r-quantifiers*) to refer to quantificational quantifiers (respectively referential quantifiers). We also define c-patterns as follows.

3 While *plural* NPs show this functional dependency clearly, there is no comparable way of determining if non-referential *singular* NPs, such as *one company*, result in the same kind of scope order as in Hobbs & Shieber's reading. Occam's razor rules however that such NPs do not.
4 See the forthcoming discussion as to the object quantifier *most* outscoping subject quantifier.
5 Notice that this version of c-constituency is exactly the CCG notion of surface constituency (Steedman, 1990).

(3) C-PATTERN: Suppose that sentence S contains q-quantifiers Q_1 and Q_2. There is a constituency pattern (or *c-pattern*) for q-quantifiers Q_1 and Q_2 in S iff there is a choice of NP_1, NP_2, A, and B such that S has the form:

$$S: \cdots \overbrace{\mathrm{NP}_1 \underbrace{\cdots}_{A} \mathrm{NP}_2}^{B} \cdots.$$

where Q_1 (resp. Q_2) is the head quantifier of NP_1 (resp. NP_2), and A and B are both c-constituents.[6]

(4) CONJECTURE: Suppose that sentence S contains q-quantifiers Q_1 and Q_2. Then it is impossible for Q_1 and Q_2 to alternate in scope – i.e. their scope relative to each other is fixed – unless (a) there is a c-pattern in S for Q_1 and Q_2 or (b) there is a choice of q-quantifiers Q_3 and Q_4 in S, where Q_3 (resp. Q_4) may be Q_1 (resp. Q_2), such that there is a possibly different c-pattern in S for the pairs of q-quantifiers Q_3 and Q_4, Q_1 and Q_3, and Q_2 and Q_4. In the case of (a), the two q-quantifiers may alternate their relative scope and any q-quantifiers that may be present in A are outscoped by both Q_1 and Q_2. In the case of (b), the relative scope between Q_1 and Q_2 is determined indirectly by the relation between Q_3 and Q_4.

Note that this conjecture never states that a scope ordering is always possible; it can only rule readings out. We believe that scope orderings not ruled out by the conjecture usually are available, but there is at least one counterexample: The conjecture does not forbid ambiguity for *No printers print no documents* but the sentence happens to be unambiguous, so other factors, perhaps peculiar to *no*, seem to be at work. Notice also that according to recent claims, quantifiers like *few* or *most* do not outscope subject quantifiers when they are in the object position (Beghelli, 1995; Szabolcsi, 1996). The conjecture does not rule out this possibility either. While we leave further details to future work, it should be pointed out that the new *upper* bounds in scope possibilities set by the conjecture are meant for *all* quantifiers that are non-referentially used.

To see how the conjecture works, consider sentence (1) (a) again, whose c-patterns are shown in Table 2. The c-pattern (p1) indicates the possibility for *every rep* and *a company* to alternate their relative scope. (p2) indicates the possibility for *every rep* and *most samp* to alternate their relative scope. No other c-patterns are possible. Thus the sentence is predicted to have up to four readings. Notice that Hobbs & Shieber's reading is not among them. (p3) is the only c-pattern that might directly relate *a comp* to *most samp*, but *a comp saw most samp* is not a c-constituent under the sentence, as the structure in (5) (a) is ungrammatical. This does not mean however that the scope

	Left	NP_1	A	NP_2	Right
(p1)		every rep	of	a comp	saw most samp
(p2)		every rep of a comp	saw	most samp	
(p3)*	every rep of	a comp	saw	most samp	
(p4)*		every rep	of a comp saw	most samp	

Table 2
Four C-Patterns: Every representative of a company saw most samples

6 We need a further condition such that the fragment A has two neighbor NPs as its direct semantic arguments. This condition will be discussed with respect to the sentences in (7) and (11).

between *a comp* and *most samp* is necessarily fixed, since *every rep* works as Q_3 for the clause (b) in the conjecture, where Q_4 coincides with Q_2. The c-pattern (p4) does not apply for the scope relation between *every rep* and *most samp*, since *of a comp saw* is not a c-constituent, as the structure in (5) (b) is ungrammatical. Square brackets indicate the intended coordination.

(5) (a) *Every representative of [a company saw most samples] and [an institute inspected a few samples].
(b) *Every representative [of a company saw] and [of an institute inspected] most samples.

Consider now sentence (1) (b), whose c-patterns are shown in Table 3. The c-pattern

	Left	NP_1	A	NP_2	Right
(m1)		some stu	will inv	two dial of every lang	
(m2)	some stu will inv	two dial	of	every lang	
(m3)		some stu	will inv two dial of	every lang	

Table 3
Three C-Patterns: Some student will investigate two dialects of every language

(m1) indicates the possibility for *some stu* and *two dial* to alternate their relative scope. Likewise, (m2) tells us that *two dial* and *every lang* can alternate their relative scope. The c-pattern (m3) further indicates the possibility for *some stu* and *every lang* to alternate their relative scope, in which *two dial* is outscoped by both of the q-quantifiers. Together they tell us that the sentence can have up to five readings, correctly including May's reading. The c-pattern (m3) goes through, due to the structure implied in the following grammatical sentence.

(6) Some student will investigate two dialects of, but may collect most cases of coordination in, every language.

We can thus tentatively conclude that the conjecture explains the subject-object asymmetry at semantics in English with respect to the two sentences in (1). Let us examine a few more examples to see how and what the conjecture predicts, before explaining *why*.

(7) (a) Mary thinks that exactly three men danced with more than four women.
(b) At least two girls think that John danced with more than four women.
(c) At least two girls think that exactly three men danced with Susan.

It is obvious that sentence (7) (a) is semantically ambiguous. We believe that sentence (7) (b) is likewise semantically ambiguous (cf. Lasnik and Uriagereka (1988, page 156)). As for sentence (7) (c), there are conflicting semantic judgments by native speakers.[7]

The conjecture predicts that sentence (7) (a) can be ambiguous since *exactly three men* and *more than four women* may alternate their relative scope as *danced with* and

7 The well-known *that*-trace phenomenon, shown below, might suggest that embedded subject quantifier does not outscope matrix subject quantifier, assuming that *Wh*-traces and QR-traces are governed by the same constraint. However, it appears that native speakers do not base semantic judgments on the presence/absence of the complementizer (cf. Steedman (1997)).

(a) *Who do you think that *t* danced with Susan?
(b) Who do you think *t* danced with Susan?

the embedded clause are c-constituents.[8] The conjecture also predicts that sentence (7) (b) can be ambiguous since *think that John danced with* is a c-constituent, as evidenced below.

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

The conjecture, as constrained further in footnote 6, predicts that sentence (7) (c) is unambiguous. This is because, while the following structure in (9) is (marginally) acceptable, the semantics of the fragment *think that* takes two arguments, one NP-type but another S-type. For the condition to go through, they need to be two NP-types.

(9) At least two girls think that exactly three men, but most boys doubt that more than two men, danced with Susan.

Again, the conjecture thus predicts that there is a potential semantic asymmetry between embedded object quantifier and embedded subject quantifier in a `that`-clause complement of an extensional verb, such as *think*. Notice that Montagovian quantifying-in correctly generates the *de re* reading for the following sentence, apparently producing a scope order in which *a unicorn* outscopes the matrix subject quantifier.

(10) Every valiant knight believes that a unicorn is approaching from the mountain.

This appears to contradict the prediction by the conjecture. However, it is clear that *de re* interpretation of *a unicorn* inside an opaque context is strongly related to its referential interpretation, as the name suggests. Since there is a distributional difference between referential and quantificational NP interpretations, to be argued in the next section, this reading is not relevant to the present consideration regarding non-referential quantifiers.

Finally, consider the following pair of sentences.[9]

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

Recall that there is a well-known island condition on embedded NPs in a relative clause (Ross, 1967), so that the following syntactic extraction is considered ungrammatical.

(12) *I have met every student$_i$ who(m) two professors whom t_i admired wrote a letter.

Again, movement-based theories of quantifier scope, such as (variants of) quantifier raising accounts, make use of this condition in predicting the range of available scope readings. This kind of observation is considered theory-neutral, so that other theories, such as (variants of) quantifying-in, also consider it necessary to make use of a related stipulation, such as Complex Noun Phrase Constraint (CNPC), that blocks embedded quantifiers from outscoping head quantifiers (Rodman, 1976; Hendriks, 1993).

8 The sentence pattern "Mary thinks that P and Q" for embedded clauses P and Q is syntactically ambiguous between "[Mary thinks that P] and Q" and "Mary thinks that [P and Q]."
9 The sentence (11) (a) is due to Janet Fodor (p.c).

One can show, however, that unlike embedded *subject* NPs, embedded *object* NPs can outscope head quantifiers, though marginally, as shown in sentence (13) (a) below. And it does not appear that these NPs must be syntactic objects, as relative-clause final NPs also show this characteristics, as in (13) (b). Notice that referential NPs do not show this difference at all, to be discussed in Section 3.

(13) (a) FBI agent Starling contacted *more than three relatives* who knew *every victim* of the infamous Dr. Lector.

(b) *Most businessmen* who grew up in *almost every big city* talk fast, but most businessmen who grew up in Chicago talk rather slowly.[10]

The conjecture predicts that these sentences are ambiguous since *who knew* and *who grew up in* are all c-constituents and both of them take two NP-type arguments.[11] Notice that a contrary prediction is correctly made for sentence (11) (b), since the pattern *two professors who(m) every student* is not a c-constituent, as evidenced below.

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

There are many other English constructions that need to be tested, but the above constructions already provide good examples to identify the striking phenomenon.[12]

Let us now consider the implication of the conjecture. The conjecture predicts when an NP quantifier, such as NP_2, is allowed to outscope another temporally preceding NP quantifier, such as NP_1, in a grammatical sentence. The reason that this works can be attributed to the fragments A and B being c-constituents: (1) that B is a c-constituent assures the relative semantic *autonomy*, or self-sufficiency, of the fragment itself, and (2) that A is a c-constituent implies that NP_1 and NP_2 work as two semantic arguments of the fragment, much like a transitive verb having two semantic arguments.[13] In order to show why the conjecture explains English subject-object asymmetry in scope readings, consider the following simplified surface structures:

(15)

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

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

English is a configurational language, in which the standard word order of a grammatical sentence is SVO, as shown in (15) (a) above. Transitive verbs normally expect two arguments, S and O, on their two sides. When the NPs are modified further, as in (b), the transitive verb still expects to receive two arguments, or NP_1 and NP_2, but these

10 We appreciate Mark Steedman for this sentence structure.

11 In the CCG formulation to be shown shortly, the syntactic category of the fragments is $(N\backslash N)/NP$, i.e., one of the arguments is of noun type N. This is the result of the category of the relative pronoun *who*, which is assigned the category $(N\backslash N)/(S\backslash NP)$. Alternatively, we can adjust the categories for quantifiers and nouns to accommodate the category $(N\backslash NP)/(S\backslash NP)$ for relative pronouns in order to implement the conjecture more literally (at the expense of clarity of implementation).

12 The reader is referred to Park (1996) for further constructions, including control and ditransitive verbs, many more examples of extraction and coordinate structures.

13 We have seen also that we need to force the implication (2) above, since otherwise sentences like (7) (c) will be incorrectly determined to be ambiguous.

two arguments are first modified by NP_{10} and NP_{20}, respectively, before they are made available for the transitive verb. The fact that English allows the fragment $TV\ NP_2\ P$, but not the fragment $P\ NP_{10}\ TV$, to be a c-constituent implies not only that NP_2 is still the same argument that TV can accept, but also that NP_{10} is not.[14] This makes sense, since we expect a post-modifier, such as $P\ NP$, to be something like a transducer function, that takes a normal NP to yield another normal NP. In particular, the presence of such a post-modifier should affect neither the grammaticality nor the semantic integrity of the rest of the sentence. It is thus natural to expect that the transitive verb will not be able to accept such a complex object directly as one of its arguments. In other words, English subject-object asymmetry in scope readings is the direct result of its standard word order, where the modified (head) part of a complex *object* NP, but not that of a complex *subject* NP, is temporally adjacent to the transitive verb. We need a cross-linguistic study to see how this kind of observation works in languages other than English, but it is beyond the scope of the present paper.

3. Quantificational Readings and Functional Dependency

This section shows why referential readings should be distinguished from quantificational reading (§3.1), and why functional dependency bears significance with respect to quantificational readings (§3.2).

3.1 Referential NP Interpretations

This section presents a claim that one must distinguish referential and quantificational NP interpretations in semantics. We review some evidence for this claim, in which the two kinds of interpretations show distributional differences.[15]

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

When the speaker of the sentence has a particular person in mind for the student in question, say John, the subject NP is taken to be used referentially. In this reading, the sentence would be false if John didn't cheat on the final exam, even if there was another student, say Bob, who did the deed. A possible response to this sentence would be: *No, a student in the syntax class could not find the instructions on the final exam.* On the other hand, when the speaker used sentence (16) to simply assert the fact that there was one, possibly more, such student, the sentence would be truthful as long as there is/was one such individual, even if the individual is not the one whom the speaker had in mind. In this reading, the subject NP is taken to be used quantificationally.[16] It is granted however that the two readings of sentence (16) do not depend much on surface structure to make a convincing case for a distributional difference between them. For this, consider the following sentences.

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

14 If P is excluded from the fragments, that they expect further argument(s) is lost in the semantics.
15 The data (16), (17), and (19), as well as the related observations, are from Fodor and Sag (1982).
16 This reading improves with *some student*, in place of *a student*.

The embedded subject position of a complex NP is known to be a syntactic island (Ross, 1967), as mentioned before, which explains why sentence (18) is ungrammatical.

(18) *John met *every student*$_i$ who(m) each teacher overheard the rumor that t_i had been called before the dean.

This syntactic phenomenon has also been utilized in semantics to constrain the movement of quantifiers in Government and Binding theories, which can thus explain why sentence (17) (a) does not have a reading in which *every student* outscopes *the rumor* (a possibly different, but uniquely identifiable rumor for each student). However, it is obvious that this constraint does not apply to referential NPs, as sentence (17) (b) *does* have an interpretation in which there is a certain student such that John overheard the rumor that he or she had been called before the dean. In this reading, the denotation of the NP *a student of mine* is not dependent upon the kind of rumor that John overheard. As such, referential NP interpretations do not seem to be so much constrained as quantificational NP interpretations are in taking matrix scope.

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

Sentence (19) (a) has only two readings, one with the same rumor for all the teachers, and the other with a possibly different version of rumor for each teacher. Incidentally, this is exactly what the conjecture would predict. Notice that *every student of mine* can not outscope any of the two NPs. We know that *a student of mine* in (19) (b) can take matrix scope if it is referentially interpreted. The question is if it is possible for the NP to be outscoped by any of the two NPs, possibly placed between the two. This, as the reader can verify, is impossible. The only readings that are available are ones in which *a student* appears to outscope both *each teacher* and *the rumor*. In other words, referential NP interpretations can only take matrix scope, not intermediate scope.[17] Given the evidence presented so far, Fodor and Sag (1982) conclude that a theory of indefinites, in our case quantifiers, can be made parsimonious if referential and quantificational NP interpretations are distinguished in semantics.

Based on this semantic distinction, we will focus exclusively on quantificational NP interpretations in identifying the connection between syntax and semantics as manifested by quantifier scope. As for referential NP interpretations, including other types of NPs, there are renewed interests in dynamic NP interpretations, following the lead of a discourse representation theory by Kamp (1981) or the file change semantics by Heim (1983). There have also been recent attempts to combine the two aspects, for instance in theories of scope by Poesio (1991) and Reyle (1993). While the quantificational aspect of these theories does not appear to present a comprehensive and explanatory answer to

17 There are cases, especially in intensional contexts, where referential NPs do not necessarily take matrix scope, as exemplified in the sentences below (Dan Hardt, p.c.).

I dreamed that I was a teacher, and in my dream I overheard the rumor that a student of mine had been called before the dean.

See also the discussion with respect to sentence (94) where *de re* interpretations may not necessarily be equated with matrix scope. However, the point here is that the two types of NP interpretations show a noticeable difference regarding surface syntax.

the kind of data the current paper is concerned with, there is no doubt that a unified theory for both referential and quantificational NP interpretations is desirable.

There are some apparent counterexamples. We have shown earlier why Hobbs & Shieber's reading can be explained by a referential *a company*. This reading will be discussed in more detail in Section 3.2. Now, consider sentence (20) (a). The prominent reading, called conjunctive or cumulative, is true of a situation in which there are three hunters and five tigers such that the said event happened between the two parties.

(20) (a) Three hunters shot at five tigers.
(b) Three Frenchmen visited five Russians.

Most importantly, the reading of this kind can not be addressed by a linear order between the two NP denotations. This is why Hintikka (1974) defined the notion of branching quantifiers in his game-theoretic semantics, subsequently endorsed and extended by Barwise (1979) and Westerståhl (1987), among others. Sentence (20) (b) is argued to have a similar reading (Partee, 1975; Webber, 1979). It is interesting to note however that conjunctive or cumulative readings of this kind do not obtain when there is a strong lexical preference of quantifiers towards taking functional scope (e.g. (21) (a)) or when there is no possibility for a referential NP interpretation (e.g. (21) (b)) (Higginbotham, 1987; Krifka, 1992). Hence we believe that it is reasonable to assume that cumulative readings are not in the range of quantificational scope readings, since the involved NPs, either one of them or both, must be interpreted referentially.

(21) (a) Each Frenchman visited five Russians.
(b) Few Frenchmen visited five Russians.

There is another sentence, shown below in (22) (a), that May (1985) claimed has a related "branching" reading, citing the account of Hintikka (1974). May notes that for the reading to obtain, both of the the head quantifiers must be outscoped by the corresponding modifying quantifiers. Notice that this kind of reading does not obtain from sentence (22) (b), where both of the head quantifiers have a non-referential interpretation. We claim, therefore, that the reading in question, if it exists, is also an instance where the NPs are used referentially, though the denotations of the complex NPs have a little more structure than those of the simple NPs.

(22) (a) Some article by every author is referred to in some essay by every critic.
(b) Every article by some author is referred to in every essay by some critic.

While the data considered here are not sufficient to prove the validity of the conjecture fully, we believe that the conjecture is shown to behave reasonably on some of the most discussed apparent counterexamples.

3.2 Functional Dependency

This section shows that quantificational readings always exhibit a kind of functional dependency between the scope related NP denotations. We claim that this property can be utilized to sharpen people's intuition to determine the availability of a particular reading by maximizing the way scope-related NP denotations are laid out. Note that the kind of scope-related functional dependency that we are interested in here is truly semantic, and distinct from the kind of pragmatic dependency that makes sentence (23) <u>un</u>ambiguous.

(23) Every professional mother gives birth to at most two babies.

The claim is that in quantificational readings, the semantic objects denoted by an outscoped quantified NP depend functionally upon the semantic objects denoted by the outscoping quantified NP. For instance, consider sentence (24) (a). (24) (b) and (c) show its two possible logical forms in first-order logic.

(24) (a) Every man loves some woman.
(b) $\forall m.man(m) \rightarrow \exists w.woman(w) \wedge loves(m, w)$
(c) $\exists w.woman(w) \wedge \forall m.man(m) \rightarrow loves(m, w)$

To evaluate the logical form (24) (b) truth-conditionally, we should make the choice of an individual for w functionally dependent upon the choice of each individual for m since otherwise, there would be no semantic (truth-conditional) difference between (24) (b) and (24) (c). This is usually captured by skolemizing the variable w in (24) (b). We argue that this kind of scope-related functional dependency shows up between any two NPs connected by a scope relation, regardless of whether the reading has a group interpretation or a distributive interpretation.

What is significant with this functional dependency is that it amplifies the connection between individuals related by scope ordering to such a degree that it becomes evident that some connections (and therefore the related scope ordering) are not warranted by the sentence at hand. Consider the following sentence, a variant of (1) (a).[18]

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

The following shows six logical forms in a generalized quantifier format (Barwise and Cooper, 1981; Hobbs and Shieber, 1987).[19]

(26) (a) three companies > two representatives > four samples
`three(c,comp(c),two(r,rep(r)&of(r,c),four(s,samp(s),saw(r,s))))`
(b) (two representatives > three companies) > four samples
`two(r,rep(r)&three(c,comp(c),of(r,c)),four(s,samp(s),saw(r,s)))`
(c) four samples > three companies > two representatives
`four(s,samp(s),three(c,comp(c),two(r,rep(r)&of(r,c),saw(r,s))))`
(d) four samples > (two representatives > three companies)
`four(s,samp(s),two(r,rep(r)&three(c,comp(c),of(r,c)),saw(r,s)))`
(e) three companies > four samples > two representatives
`three(c,comp(c),four(s,samp(s),two(r,rep(r)&of(r,c),saw(r,s))))`
(f) two representatives > four samples > three companies
`two(r,rep(r)&of(r,c),four(s,samp(s),three(c,comp(c),saw(r,s))))`

The four readings (26) (a) through (d) are self-evidently available. For instance, the logical form (a) is true of a situation in which there are three companies such that each such company has two representatives such that each such representative saw four samples. Likewise, the logical form (d) is true of a situation in which there are four

18 Bare numerals are more likely to receive referential interpretations. On the other hand, they can also be assumed to have implicit premodifiers, such as *exactly*, *at least*, etc., which strengthen quantificational interpretations. For the following discussion, we will assume the premodifier *exactly*, without losing generality.
19 Each logical form is preceded by the corresponding scope ordering.

samples such that each sample was seen by two representatives such that each such representative is one of three companies.

Notice however that the reading corresponding to the logical form (26) (f) would be immediately excluded by Hobbs and Shieber (1987) or anyone else due to the fact that it is not possible to construct a sensible model related to the sentence. Notice, as Hobbs & Shieber pointed out, that among the six logical forms, *only* this one contains a free variable c (underlined). Hobbs and Shieber (1987)'s consequent suggestion to utilize an unbound variable constraint (or UVC) as a semantic filter for *available* logical forms would thus be acceptable, provided that all the other five readings were available. An approach to incorporating this kind of a logical condition in a logic-based system has also been pursued in much subsequent work including Keller (1988), Carpenter (1989; 1994), Pereira (1989; 1990). We should also point out that this kind of condition may be needed in one form or another in order to explain natural language pronouns as bound variables. This is a separate issue, however.

We claim that in addition to the reading (26) (f), the reading corresponding to (26) (e) is also unavailable, due to the kind of functional dependency it requires of its model. This reading shares the same scope order with Hobbs & Shieber's reading, in which the latter can be explained with a referential interpretation of *a company*. To see why it is impossible for a quantificational *three companies* to lead to the reading (26) (e), let us first assume that all the relevant quantified NPs have a distributive sense, as group senses will only simplify the matter. The following situation would support the reading.

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

We claim that this is not what the sentence says. The reader is urged to use his/her own intuition to verify this. Figure 1 shows a pictorial layout of a model supporting this reading.

According to the present theory, the reason that the reading is excluded is that the surface structure is 'NP_1 of NP_2 verb_{tv} NP_3'. It is not due to the lexical semantics of the nouns and the verb involved. Notice also that the UVC does not exclude this unavailable reading.

4. A Lexical Theory of Quantifier Scope

This section presents a theory of quantifier scope that captures the conjecture. Section 4.1 introduces a version of unification-based Combinatory Categorial Grammar framework in which the theory is couched. Section 4.2 proposes a dual quantifier representation for quantifier semantics.[20]

4.1 Combinatory Categorial Grammar

Categorial Grammars, or CGs, are a class of grammar formalisms, originally proposed by Ajdukiewics (1935) and further developed by Bar-Hillel (1953). The reader is referred to Wood (1993) for a general introduction to CGs. CGs encode syntactic information in a categorial lexicon, where each lexical entry specifies how the corresponding lexeme is interpreted syntactically. In the following sample lexical entries, the operator ':='

20 Park (1996) shows the formal definition of its syntax and semantics.

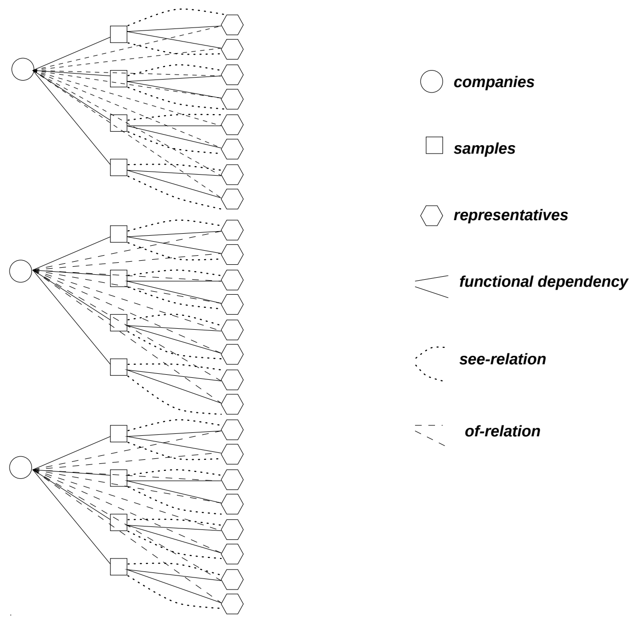

Figure 1
A Model Supporting the Reading *three companies* > *four samples* > *two representatives*

connects lexemes and categories.

(28) (a) john := np (b) slept := $s\backslash np$

(a) encodes the fact that *john* is syntactically a noun phrase, or np. (b) encodes the fact that *slept* is a syntactic constituent that when combined with another constituent of category np on its left results in a constituent of category s.[21] The directional symbols or slashes, '\' and '/', have the following intended interpretations in rules of function application. The symbols, > and <, abbreviate the corresponding rules.

(29) (a) $\dfrac{X/Y \quad Y}{X}>$ (b) $\dfrac{Y \quad X\backslash Y}{X}<$

When the constituent $X\backslash Y$ has another constituent Y on its left, the rule (29) (b) can be applied to cancel out the *argument* category Y with the constituent Y, leaving the *result* category X for the combined constituent, as shown below.

(30) John slept

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

The derivation np $s\backslash np$ => s is achieved by respectively replacing the values np and $s\backslash np$ with the patterns Y and $X\backslash Y$ in the rule <, where the pattern Y is *unified* with the value np, and the pattern X with the value s.[22]

21 We will use the expressions *a constituent of category x* and *a constituent x* interchangeably.
22 Notice that we are using the Prolog convention to distinguish variables from constants.

There are a fixed number of *elementary* categories, such as s, np, and n. Categories are defined recursively as the smallest set that contains elementary categories or categories separated by a directional symbol. Categories associate to the left by default. The following shows another derivation.

(31)
```
every  man     loves      some   woman
-----  ---  ------------  ----  ------
np/n    n   (s\np)/np     np/n     n
---------->               ------------>
    np                         np
            ------------------------->
                      s\np
----------------------------------------<
                    s
```

Combinatory CGs, or CCGs, extend the purely applicative CGs described above to include a limited set of combinatory rules corresponding to combinators such as type raising T, function composition B, function substitution S, etc, for the combination of two adjacent, linguistically realized (or phonologically non-empty) categories (Steedman, 1987). Rules of type raising and function composition are shown below.

(32) (a) Type Raising (forward, $> T$)
$$\frac{X}{T/(T\backslash X)}{>}T$$
(b) Type Raising (backward, $< T$)
$$\frac{X}{T\backslash(T/X)}{<}T$$
(c) Function Composition ($> B$)
$$\frac{X/Y \quad Y/Z}{X/Z}{>}B$$
(d) Function Composition ($< B$)
$$\frac{Y\backslash Z \quad X\backslash Y}{X\backslash Z}{<}B$$

With the combinatory rules based on combinators T and B, (31) can have the following derivation, among others.

(33)
```
every  man     loves      some   woman
-----  ---  ------------  ----  ------
np/n    n   (s\np)/np     np/n     n
---------->               ------------>
    np                         np
---------->T
 s/(s\np)
-------------------->B
       s/np
----------------------------------------<
                    s
```

In this derivation, the category of *every man* is type raised from np to $s/(s\backslash np)$, using the forward type raising rule in (32) (a), where the place-holders X and T are replaced with np and s, respectively. The new category $s/(s\backslash np)$ is consistent with the syntactic characteristics of English subject NPs, which normally expect a VP constituent $s\backslash np$ on their *right* to result in a sentence constituent s. In the derivation (33), the fragment *every man loves* is analyzed to be of category s/np, or one that expects a constituent np on its right to result in a constituent s. Both of the two fragments s/np and $s\backslash np$ are perfect CCG-constituents.

There is a lexical alternative to the syntactic type raising in (33). For instance, proper nouns can be assigned raised categories, such as $s/(s\backslash np)$ and $s\backslash(s/np)$ etc, in the lexicon. Likewise, quantifiers can be assigned similar raised categories expecting a noun category on their right, such as $(s/(s\backslash np))/n$ and $(s\backslash(s/np))/n$ etc. The derivation (34) shows an example with a raised subject NP quantifier, and the derivation (35) with a raised object NP quantifier.

(34) every : $(s/(s\backslash np))/n$ man : n loves : $(s\backslash np)/np$ some : np/n woman : n

$$\text{every man} \Rightarrow_{>} s/(s\backslash np) \qquad \text{some woman} \Rightarrow_{>} np$$
$$\text{every man loves} \Rightarrow_{>B} s/np$$
$$\text{every man loves some woman} \Rightarrow_{>} s$$

(35) every : np/n man : n loves : $(s\backslash np)/np$ some : $((s\backslash np)\backslash((s\backslash np)/np))/n$ woman : n

$$\text{every man} \Rightarrow_{>} np \qquad \text{some woman} \Rightarrow_{>} (s\backslash np)\backslash((s\backslash np)/np)$$
$$\text{loves some woman} \Rightarrow_{<} s\backslash np$$
$$\text{every man loves some woman} \Rightarrow_{<} s$$

The fact that there is an alternative derivation such as (33) or (34), in addition to the more standard derivation (31), is crucial for sentences containing coordination or parasitic gap, as pointed out by Steedman (1990), among others. For instance, the coordination in sentence (36) (a) forces the fragment *every man loves* to be combined first, and the coordination in (b) forces *loves a dog* to be combined first.

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

Both of the derivations (34) and (35) contain not only type-raised categories but also unraised category np/n. As far as this particular example goes, the unraised category can be avoided, as shown in the following derivations.

(37) every : $(s/(s\backslash np))/n$ man : n loves : $(s\backslash np)/np$ some : $(s\backslash(s/np))/n$ woman : n

$$\text{every man} \Rightarrow_{>} s/(s\backslash np) \qquad \text{some woman} \Rightarrow_{>} s\backslash(s/np)$$
$$\text{every man loves} \Rightarrow_{>B} s/np$$
$$\text{every man loves some woman} \Rightarrow_{<} s$$

(38) every : $(s/(s\backslash np))/n$ man : n loves : $(s\backslash np)/np$ some : $((s\backslash np)\backslash((s\backslash np)/np))/n$ woman : n

$$\text{every man} \Rightarrow_{>} s/(s\backslash np) \qquad \text{some woman} \Rightarrow_{>} (s\backslash np)\backslash((s\backslash np)/np)$$
$$\text{loves some woman} \Rightarrow_{<} s\backslash np$$
$$\text{every man loves some woman} \Rightarrow_{>} s$$

The immediate question is if it is always possible to find an alternative derivation without unraised categories. The following section proposes a dual quantifier representation, in which both raised and unraised categories are associated with a proper quantifier semantics. We argue that without unraised categories the resulting theory is not only more complicated to design but also unable to account for the full range of scope readings.

4.2 Connecting Syntax and Semantics

A proper characterization of the range of grammatical scopings would depend crucially on how we choose to define the syntax for the semantic representation. The goal here is to make the connection between syntax and semantics as transparent as possible, and we will try to use a minimal semantic representation. For this purpose, we propose the following dual representation for quantifier semantics.

(39) (a) *Quantifier(Mode, Var, Restriction, Body)*
(b) **Quantifier(Restriction)*

(39) (a) encodes the wide-scope quantifier semantics with explicit scope information, and (b) the *degenerate* quantifier semantics with no corresponding scope information.[23] We relate the representation (a) to type-raised NP categories, such as $s/(s\backslash np)$ or $s\backslash(s/np)$. These categories always contain s category, which can be associated with a full *sentential* semantics for the required scope body.[24] The quantifier in (b) is called *degenerate* in the sense that the operator corresponding to the quantifier lacks the general ability to take scope over something else. The representation (b) is used for unraised np category, which does not allow the specification of full sentential semantics for scope information.[25] (40) shows an example wide-scope quantifier representation.

(40) (a) More than three men sneezed.
(b) $three(>, M, man(M), sneezed(M))$

Examples of degenerate quantifier representation will be shown along with the relevant lexical encoding.

There are two ways of associating semantic information with syntactic information under the present framework, as shown below for the transitive verb *loves*.

(41) (a) loves $:= (s\backslash np)/np : \backslash x, y.loves(x, y)$
(b) loves $:= (s : loves(X, Y)\backslash np : X)/np : Y$

The method (41) (a) relates each *whole* lexical category to an appropriate semantic form, usually a higher-order expression, separated by the colon operator.[26] This representation

23 The symbol '*' in (b) is for a further syntactic distinction between wide-scope and degenerate operators. It should not be confused with the (usual) annotation on ungrammatical sentences.

24 Incidentally, the representation (a) further generalizes the generalized quantifier format such as (26) shown earlier in that the optional premodifier is put into one of the argument positions, i.e. $Mode$, of an operator that corresponds to a natural language quantifier. This allows the operator completely determined even when the numeral has a missing premodifier and thus is considered potentially ambiguous. In the representation, this ambiguity is carried over in a variable, which may be instantiated by choice later on with a context-dependent information. In the present description of the theory, we will choose to translate a missing premodifier into the symbol #.

25 While there is a clear characteristic distinction between degenerate quantifier semantics and referential quantifier semantics, to be noted shortly, they might turn out to be more closely related with each other than assumed here. We leave open the issue of further explicating the relation. For the moment, we should say that degenerate quantifier semantics is unrelated to referential NP semantics or specific indefinites whose denotations are determined contextually. In a sense, the degenerate representation (39) (b) is a syntactic sugar for a wide-scope quantifier representation in (a) in which the scope information corresponding to $Body$ is missing. Just as the wide-scope quantifier semantics does not commit to the semantics-internal distinction between group vs distributive NP interpretations, the degenerate quantifier semantics are not committed to such a distinction either. One can alternatively think of the degenerate quantifier semantics as introducing a kind of DRT-style existential variable, whose denotation is determined according to where it appears in a logical representation. We appreciate Matthew Stone for this suggestion.

26 The symbol \ in the semantics is a "keyboard" substitute for the lambda operator 'λ'.

requires an ability to perform a limited higher-order term unification. Categorial rules of combination can accommodate this method with the following revision.

(42) (a) $X/Y : F \quad Y : A => X : F(A)$
(b) $Y : A \quad X\backslash Y : F => X : F(A)$

The method (41) (b) relates each *elementary* category to an appropriate semantic form, separated by the colon operator. The semantic form itself does not involve a higher-order expression, and the representation can be manipulated by a first-order term unification alone.[27] Also, this method allows β-reduction at compile time via a Prolog programming technique known as partial execution (Pereira and Shieber, 1987; Jowsey, 1990; Steedman, 1990; Park, 1992).

These two approaches are logically equivalent, as long as the unification for (a) and (b) above are higher-order. We will show a theory based on the second approach (method (41) (b)) in the interest of implementing it in normal (i.e. not higher-order, though not pure) Prolog.[28]

With lexical type raising, each quantifier is assigned a number of lexical entries. Numeral quantifiers that can optionally have a premodifier need further entries. (43) (a) and (b) show two lexical entries, among many others, for a numeral quantifier that is missing a premodifier.

(43) (a) three := $(s : three(\#, X, N, S)/(s : S\backslash np : X))/n : X\hat{\ }N$
(b) three := $(s : three(\#, X, N, S)\backslash(s : S/np : X))/n : X\hat{\ }N$

The derivation (45) shows how the premodifier *at least* is combined with the numeral *three* in this framework with an additional entry (44) for *three*, among others, by the use of theory-internal elementary categories such as *ql* and *qm*. This technique can also handle idiomatic expressions.

(44) three := $((s : three(M, X, N, S)/(s : S\backslash np : X))/n : X\hat{\ }N)\backslash ql : M$

(45)

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

(46)

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

The derivation (46) shows how the wide scope subject NP semantics is derived. To explain procedurally how the derivation goes through, the pattern $X\hat{\ }N$ is first unified with the pattern $X\hat{\ }man(X)$, in which the variable N is unified with $man(X)$. This value of N is then carried over to the other instance of N in the pattern $every(\#, X, N, S)$ for the result.

27 But see below for the degenerate quantifier semantics. The reader is referred to the discussion of (the significance of) first-order unification in Moore (1989) and Park (1992), among others.
28 The present implementation simulates a second-order term matching, via the univ (`=..`) operator.

The derivations in (47) and (48) show how the wide and narrow scope interpretations of *some woman* are respectively obtained from the sentence *Every man loves some woman.* Each derivation is divided into two separate derivations for typographical reasons.

(47) (a)

$$\begin{array}{cc} \text{every man} & \text{loves} \\ \hline s: every(\#, X, man(X), S)/(s: S\backslash np: X) & (s: lov(X,Y)\backslash np: X)/np: Y \\ \hline \multicolumn{2}{c}{s: every(\#, X, man(X), lov(X,Y))/np: Y} \end{array} >B$$

(b)

$$\begin{array}{cc} \text{every man loves} & \text{some woman} \\ \hline s: every(\#, X, man(X), lov(X,Y))/np: Y & s: some(\#, Y, wmn(Y), S)\backslash(s: S/np: Y) \\ \hline \multicolumn{2}{c}{s: some(\#, Y, wmn(Y), every(\#, X, man(X), lov(X,Y)))} \end{array} <$$

(48) (a)

$$\begin{array}{cc} \text{loves} & \text{some woman} \\ \hline (s: lov(X,Y)\backslash np: X)/np: Y & (s: some(\#, Y, wmn(Y), S)\backslash np: X)\backslash((s: S\backslash np: X)/np: Y) \\ \hline \multicolumn{2}{c}{s: some(\#, Y, wmn(Y), lov(X,Y))\backslash np: Y} \end{array} <$$

(b)

$$\begin{array}{cc} \text{every man} & \text{loves some woman} \\ \hline s: every(\#, X, man(X), S)/(s: S\backslash np: Y) & s: some(\#, Y, wmn(Y), lov(X,Y))\backslash np: X \\ \hline \multicolumn{2}{c}{s: every(\#, X, man(X), some(\#, Y, wmn(Y), lov(X,Y)))} \end{array} >$$

In each of the derivations, *loves* works as the constituent A in the conjecture, while the entire sentence corresponds to the constituent B. The derivations appear to suggest that readings are derivation-dependent. For instance, when *loves* is combined first with *some woman*, it leads to a reading in which *some woman* is outscoped, but when *loves* is combined first with *every man*, it leads to a reading in which the scope ordering is reversed. This prediction is in general valid, but the availability of the degenerate quantifier semantics gives a result that may overcome the apparent derivation-dependency of readings. For instance, consider the following sentence (cf. Geach (1970)).

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

Without the degenerate interpretation of *one saxophonist*, it is predicted that *one saxophonist* can only be interpreted to outscope both *every girl* and *most boys*, since *every girl admired*, and likewise the second conjunct, must be interpreted before it is associated with the object NP. As Geach (1970) argues, this is not a valid prediction, since people get both wide scope reading and narrow scope reading of *one saxophonist.* The degenerate interpretation of *one saxophonist* takes care of the narrow scope reading of *one saxophonist*, as shown below. Notice that the unraised NP category for *one saxophonist* is used in the derivation.[29]

(50)

$$\begin{array}{cc} \text{every girl admired} & \text{one saxophonist} \\ \hline s: every(\#, X, girl(X), adm(X,Y))/np: Y & np: *one(Y\,\hat{}\,sax(Y)) \\ \hline \multicolumn{2}{c}{s: every(\#, X, girl(X), adm(X, *one(Y\,\hat{}\,sax(Y))))} \end{array} >$$

29 If *one saxophonist* were interpreted referentially, the resulting logical form would be interpreted in such a way that the denotation of *one saxophonist* is determined independent of the individual denotations of men. This shows why we need to distinguish referential and degenerate quantifier interpretations in semantics.

5. Theoretical Interpretations

This section shows how the constructions discussed in Section 2 are accounted for in the present theory. The data are discussed in three subsections: complex NPs containing PPs, complex NPs containing *Wh*-relatives, and attitude verbs.

5.1 Complex NPs containing PP

The subject NP in the following sentence has two quantifiers.[30]

(51) Two representatives of three companies showed up.

The category (52) for the preposition *of* encodes the fact that it is the head of a PP.

(52) of := $(n : X\hat{\ }(N\&of(X,Y))\backslash n : X\hat{\ }N)/np : Y$

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

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

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

(54)
two: $(s/(s\backslash np))/n$ — representatives: $n/(n\backslash n)$ — of: $(n\backslash n)/np$ — three companies: $((s/(s\backslash np))\backslash((s/(s\backslash np))/np))$

representatives + of $\Rightarrow_{>B}$ n/np

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

$(s/(s\backslash np))/np$ + three companies $\Rightarrow_{<}$ $s/(s\backslash np)$

(55) and (56) below show how the derivation (54) yields an interpretation in which *three companies* outscopes *two representatives.*

(55)
two: $(s : two(\#, X, N, S)/(s : S\backslash np : X))/n : X\hat{\ }N$ — representatives: $n : X\hat{\ }N/(n : X\hat{\ }N\backslash n : X\hat{\ }rep(X))$ — of: *see* (52)

representatives + of $\Rightarrow_{>B}$ $n : X\hat{\ }(rep(X)\&of(X,Y))/np : Y$

two + representatives of $\Rightarrow_{>B}$ $(s : two(\#, X, rep(X)\&of(X,Y), S)/(s : S\backslash np : X))/np : Y$

(56)
two representatives of: *see* (55) — three companies: $(s : three(\#, Y, comp(Y), S1)/(s : S\backslash np : X))\backslash((s : S1/(s : S\backslash np : X))/np : Y)$

$\Rightarrow_{<}$ $s : three(\#, Y, comp(Y), two(\#, X, rep(X)\&of(X,Y), S))/(s : S\backslash np : X)$

Notice that this interpretation is structurally identical to that of a simple NP. In other words, a further combination of this interpretation with that of the verb *saw* in sentence (60) (a) below would result in a scope ordering in which both quantifiers in the subject NP are outscoped by the object quantifier. Similarly, a further combination of this inter-

30 We will continue to ignore referential quantifier interpretations.

pretation with that of the verb phrase *saw four samples* would yield a scope ordering in which both quantifiers in the subject NP outscope the object quantifier.

The other possibility for the category of *three companies* should allow the derivation of the CCG constituent *of three companies* so that *two representatives* may outscope *three companies*. With the category $(n\backslash n)/np$ for the preposition *of*, the immediate solution is to use the base (or unraised) category np for *three companies*. We have argued earlier that this category is applicable to degenerate quantifiers. Since other quantifiers can outscope a degenerate quantifier, this gives the result we expect, as shown below, in which *two representatives* outscopes *three companies*.[31] While it is true that in this form *three companies* would not be able to outscope any other quantifiers in the object NP, this is not a problem since it does not participate in any further scope ordering due to its placement inside the restriction, not inside the body.

(57) two | representatives | of | three companies

see (55) | $n : X\hat{\ }N/(n : X\hat{\ }N\backslash n : X\hat{\ }rep(X))$ | see (52) | $np : *three(comp)$

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

As an alternative to the latter ordering, we can utilize another category for the preposition *of*, as shown below, with the desired derivation (59).

(58) of := $(n : X\hat{\ }(N\&S)\backslash n : X\hat{\ }N)/(s : S\backslash(s : of(X,Y)/np : Y))$

(59) two | representatives | of | three companies

see (55) | see (57) | see (58) | $s : three(\#,Y,comp(Y),S)\backslash(s : S/np : Y)$

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

Both (57) and (59) produce logically equivalent semantic forms, so the new category (58) makes available a more standard logical form at the expense of redundancy of derived semantic forms. Also, the theory that presupposes the category (58) has the burden of justifying the category $(n\backslash n)/(s\backslash(s/np))$ for the preposition on purely syntactic grounds.

We know that sentence (60) (a) has four readings and (b), five readings.

(60) (a) Two representatives of three companies saw four samples.
(b) Most students studied two aspects of every language.

First, the two derivations, (56) and (57) (or (59)), in conjunction with the derivations of the kinds in (47) and (48), correctly give rise to four differently scoped readings for sentence (60) (a). To show that the readings allowed under the conjecture are the only ones that are predicted by the theory, we must show that the theory does not derive the following scope relations:

(61) (a) *two representatives* > *four samples* > *three companies*
(b) *three companies* > *four samples* > *two representatives*

31 Notice that we show an η-reduced restriction for the degenerate semantics of *three companies*. The unreduced representation should be: $*three(X\hat{\ }comp(X))$, as similarly shown in (50).

To show that the reading (a) is not derived by the theory, notice first that as soon as *two representatives* outscopes *three companies*, the semantics of *three companies* is put into a restriction, whereas the semantics of *four samples* is put into a (scope) body. So it is syntactically impossible to derive such a scope relation where *four samples* comes between *two representatives* and *three companies* in that order.

As for the reading (b), when *three companies* outscopes anything, *three* must be assigned a wide-scope quantifier semantics. When the semantics for the subject complex NP – which includes that of *three companies* – is derived, nothing can come between *three companies* and *two representatives*, as shown in (56). This makes impossible for *four samples* outscope *two representatives*. Notice also that when *three companies* is assigned a wide-scope semantics, *two representatives* can not be assigned a degenerate semantics, as there is no type raised category T that allows the following derivation to go through.

(62)
$$\begin{array}{ccccc}
\text{two} & \text{representatives} & \text{of} & \text{three} & \text{companies} \\
\hline
np/n & n/(n\backslash n) & \text{(52) or (58)} & T/n & n \\
\hline
\multicolumn{3}{c}{np/np \text{ or } np/(s\backslash(s/np))} & \multicolumn{2}{c}{T} \quad > \\
\hline
\multicolumn{5}{c}{s/(s\backslash np)} \quad *
\end{array}$$

Since there is no other possible scope order, the theory correctly derives only and exactly four readings for sentence (60) (a).

As for sentence (60) (b), the question is if the theory can predict (and derive) the additional reading in which *every language* outscopes *most students*, which in turn outscopes *two aspects*. The following shows that it does.

(63)
$$\begin{array}{cccc}
\text{studied} & \text{two} & \text{aspects} & \text{of} \\
\hline
(s : studied(X,Y)\backslash np : X)/np : Y & np : *two(N)/n : N & n : N/(n : N\backslash n : Y\hat{}aspt(Y)) & see\ (52) \\
\hline
\multicolumn{4}{c}{(s : studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z))))\backslash np : X)/np : Z}
\end{array}$$

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

(64)
$$\begin{array}{ccc}
\text{most students} & \text{studied two aspects of} & \text{every language} \\
\hline
s/(s\backslash np) & (s : studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z))))\backslash np : X)/np : Z & s\backslash(s/np) \\
\hline
\multicolumn{2}{c}{s : most(\#, X, stu(X), studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z)))))/np : Z \quad >B} & \\
\hline
\multicolumn{3}{c}{s : every(\#, Y, lang(Y), most(\#, X, stu(X), studied(X, *two(Y\hat{}(aspt(Y)\&of(Y,Z)))))) \quad <}
\end{array}$$

The theory does not generate the reading whose scope relation is *two aspects* > *most students* > *every language* for a similar reason shown earlier for sentence (60) (a).

Notice that the following related sentence does not have a reading corresponding to the one derived in (64).

(65) At least two aspects of every language confused most students.

The successful derivation for such a reading would require the recognition of the fragment *of every language confused* as a constituent.[32] This is syntactically impossible. In CCG terms, this is explained by the fact that the category n is not an argument type of the category of a transitive verb *confused*.

(66)
$$\begin{array}{cccc}
\text{of} & \text{every} & \text{language} & \text{confused} \\
(n\backslash n)/np & np/n & n & (s\backslash np)/np \\
 & \multicolumn{2}{c}{np} & \\
\multicolumn{3}{c}{n\backslash n} & \\
\multicolumn{4}{c}{*}
\end{array}$$

The proposed theory thus explains the identified English subject-object asymmetry.

5.2 Complex NPs with *Wh*-Relatives

Consider the following sentences with subject *Wh*-relatives.

(67) (a) Two professors *who interviewed every student* wrote a letter.
(b) Two professors *whose students admired most deans* wrote several letters.
(c) Two professors interviewed three students *most pictures of whom pleased exactly two judges.*

We have argued that sentence (67) (a) may have a reading in which *every student* outscopes *two professors*, (which in turn outscopes *a letter*). And as shown earlier, the conjecture predicts this as long as *who interviewed* is a c-constituent. In order to see if the theory predicts this as well, we need to consider first how the lexical entries corresponding to *Wh*-relatives are defined.

(68) shows the category for subject *Wh*-relative *who* (cf. Steedman, 1997).

(68) who := $(n : X\hat{\ }(N\&S)\backslash n : X\hat{\ }N)/(s : S\backslash np : X)$

The theory does consider the fragment *who interviewed* as a constituent, as the following two derivations show.

(69)
$$\begin{array}{l}
\text{two}: (s/(s\backslash np))/n \quad \text{professors}: n/(n\backslash n) \quad \text{who}: (68) \quad \text{interviewed}: (s : interv(X,Y)\backslash np : X)/np : Y \quad \text{every student}: \textit{see (56) for reference} \\
\text{who interviewed} \Rightarrow_{>B} (n : X\hat{\ }(N\&interv(X,Y))\backslash n : X\hat{\ }N)/np : Y \\
\text{professors who interviewed} \Rightarrow_{>B} n : X\hat{\ }(prof(X)\&interv(X,Y))/np : Y \\
\text{two professors who interviewed} \Rightarrow_{>B} (s : two(\#, X, prof(X)\&interv(X,Y), S)/(s : S\backslash np : X))/np : Y \\
\text{+ every student} \Rightarrow_{<} s : every(\#, Y, stu(Y), two(\#, X, prof(X)\&interv(X,Y), S))/(s : S\backslash np : X)
\end{array}$$

(70)
$$\begin{array}{l}
\text{two}: (s/(s\backslash np))/n \quad \text{professors}: n/(n\backslash n) \quad \text{who}: (68) \quad \text{interviewed}: (s : interv(X,Y)\backslash np : X)/np : Y \quad \text{every student}: np : every(stu) \\
\text{who interviewed} \Rightarrow_{>B} (n : X\hat{\ }(N\&interv(X,Y))\backslash n : X\hat{\ }N)/np : Y \\
\text{who interviewed every student} \Rightarrow_{>} n : X\hat{\ }(N\&interv(X, every(stu)))\backslash n : X\hat{\ }N \\
\text{professors who interviewed every student} \Rightarrow_{>} n : X\hat{\ }(prof(X)\&interv(X, every(stu))) \\
\text{two professors who interviewed every student} \Rightarrow_{<} s : two(\#, X, prof(X)\&interv(X, every(stu)), S)/(s : S\backslash np : X)
\end{array}$$

32 In fact, this only guarantees a possible intercalation of quantifiers, not matrix scope for *every language*. Notice that this is the reading corresponding to Hobbs & Shieber's reading.

Compare the derivation (70) with (57), both of which utilize a degenerate quantifier semantics. As for the need to have an extra category such as (58) for a wide-scope semantics of *three companies* (but still equivalent to the reading derived in (57)), the present derivation does not need such an additional category, since *every student* can simply be assigned the category $(s/np)\backslash((s\backslash np)/np)$ for such a derivation. To complete such a derivation, *every student* must be combined with *interviewed* first.

Since the sentence in which the embedded object quantifier outscopes the head quantifier requires the composition of fragments such as the conjuncts in (71), we can predict that speakers who do not tolerate those readings would also regard sentence (53) as ungrammatical. In CCG terms, this level of tolerance could be measured by the willingness of type-raising the noun category (from n to $n/(n\backslash n)$), or by the willingness of combining a common noun with a relative pronoun.[33]

(71) ?[Two professors who interviewed], and [three deans who visited], every student wrote a letter.

Consider now sentence (67) (b). As with normal readings, one can think of several relations between professors and students for the readings that are available from the sentence. In the following formulation of the lexical item *whose*, we assume that all the available readings involve a relation in which for each such professor, *every* student of hers admired deans.[34] This decision is not motivated theory-internally.

(72) whose := $((n : Z\hat{}(N\&every(\#, X, N1\&of(X, Z), S))\backslash n : Z\hat{}N)/(s : S\backslash np : X))/n : X\hat{}N1$

The fragment *whose students admired* in sentence (67) is processed as follows.

(73) whose students admired

$$\begin{array}{lll} \text{whose} & \text{students} & \text{admired} \\ \hline (72) & n : X\hat{}stu(X) & (s\backslash np)/np \\ \hline \multicolumn{2}{l}{(n : Z\hat{}(N\&every(\#, X, stu(X)\&of(X, Z), S))\backslash n : Z\hat{}N)/(s : S\backslash np : X) \;\; >} & \\ \hline \multicolumn{3}{l}{(n : Z\hat{}(N\&every(\#, X, stu(X)\&of(X, Z), adm(X, Y)))\backslash n : Z\hat{}N))/np : Y \;\; >B} \end{array}$$

This gives exactly the same result as before, except that the implicit quantifier *every* is correctly outscoped by other quantifiers.

Consider pied-piping sentence (67) (c). Following Szabolcsi (1989), Morrill (1988), and Steedman (1997), we need to assume extra categories for *whom*, so that the fragment *every picture of whom* may work as a normal subject *Wh*-relative. This is done by raising the type of *whom*, as shown below.

(74) whom := $((n : Z\hat{}(N\&S1)\backslash n : Z\hat{}N)/(s : S\backslash np : X))\backslash((s : S1/(s : S\backslash np : X))/np : Z)$

33 It is clear that type-raising over island-inducing relative pronouns would be harder than type-raising over prepositions, as predicted also by Steedman (1997). Semantic island condition would stipulate the former as completely impossible (cf. Hendriks (1993)).

34 Ideally, we need a mapping function that converts one-place predicate, such as $stu(X)$, into two-place predicates, such as $stu(X, Z)$. Such a two-place predicate will replace the conjoined restrictions, such $N1\&of(X, Z)$. There are other instances that show this problem.

(75) and (76) show how to derive the semantics for the fragment *most pictures of whom pleased.*

(75) most — $(s: most(\#, X, N, S)/(s: S\backslash np: X))/n: X\hat{}N$; pictures — $n: X\hat{}N/(n: X\hat{}N\backslash n: X\hat{}pic(X))$; of — (52); whom — (74)

$$n: X\hat{}(pic(X)\&of(X,Z))/np: Z \quad (>B)$$

$$(s: most(\#, X, pic(X)\&of(X,Z), S)/(s: S\backslash np: X))/np: Z \quad (>B)$$

$$(n: Z\hat{}(N\&most(\#, X, pic(X)\&of(X,Z), S))\backslash n: Z\hat{}N)/(s: S\backslash np: X) \quad (<)$$

(76) most pictures of whom — (75); pleased — $(s: plsd(X,Y)\backslash np: X)/np: Y$

$$(n: Z\hat{}(N\&most(\#, X, pic(X)\&of(X,Z), plsd(X,Y)))\backslash n: Z\hat{}N)/np: Y \quad (>B)$$

The following sentences contain non-subject *Wh*-relatives.

(77) (a) Two professors *whom every student admired* wrote a letter.
(b) Two professors *whose students most janitors liked* wrote a letter.
(c) Two professors *a biography of whom three journalists wrote* interviewed most students.

The lexical entry (78) shows the category for a subject *Wh*-relative *who(m)* (Steedman, 1997). The category expects an argument of category s/np, which is a sentence missing an object NP.

(78) who(m) := $(n: X\hat{}(N\&S)\backslash n: X\hat{}N)/(s: S/np: X)$

The conjecture predicts that sentence (77), unlike sentence (67), does not have a reading or readings in which the embedded quantifier outscopes the head quantifier. We have shown that the characterization predicts this without invoking a constraint, such as the Complex Noun Phrase Constraint and the like. Consider how the present theory predicts this as well.

First, the relative pronoun *whom* cannot be combined directly with the embedded subject NP, since the following derivation is impossible. The derivation is impossible even with unraised embedded subject NP categories.

(79) whom — $(n: X\hat{}(N\&S)\backslash n: X\hat{}N)/(s: S/np: X)$; every student — $s: every(\#, Y, stu(Y), S)/(s: S\backslash np: Y)$

$$* $$

Ignoring the left-hand part of the relative pronoun *whom* for the moment, the only case in which the derivation is successful is when *whom* combines with the entire embedded clause, or *every student admired.* The following shows the derivation.

(80) whom — (78); every student — $s: every(\#, Y, stu(Y), S)/(s: S\backslash np: Y)$; admired — $(s: admired(Y,X)\backslash np: Y)/np: X$

$$s: every(\#, Y, stu(Y), admired(Y,X))/np: X \quad (>B)$$

$$n: X\hat{}(N\&every(\#, Y, stu(Y), admired(Y,X)))\backslash n: X\hat{}N \quad (>)$$

Notice that the combination of *every student* and *admired* forces the operator *every* to take the narrow scope with respect to the remaining quantifiers, including the head quantifier, as shown below.

(81)

two	professors	whom every student admired
$(s/(s\backslash np))/n$	$n/(n\backslash n)$	$n : X\hat{}(N\&every(\#,Y,stu(Y),admired(Y,X)))\backslash n : X\hat{}N$
	$n : X\hat{}(prof(X)\&every(\#,Y,stu(Y),admired(Y,X)))$ (>)	
$s : two(\#,X,prof(X)\&every(\#,Y,stu(Y),admired(Y,X)),S)/(s : S\backslash np : X)$ (>)		

When the result combines with the rest of the sentence, it will give rise to only two readings. Notice that the result does not change even if we invoke the degenerate semantics for the head quantifier, as shown below.

(82)

two	professors	whom every student admired
$np : *two(X\hat{}N)/n : X\hat{}N$	$n/(n\backslash n)$	$n : X\hat{}(N\&every(\#,Y,stu(Y),admired(Y,X)))\backslash n : X\hat{}N$
	$n : X\hat{}(prof(X)\&every(\#,Y,stu(Y),admired(Y,X)))$ (>)	
$s : *two(X\hat{}(prof(X)\&every(\#,Y,stu(Y),admired(Y,X))))$ (>)		

Notice that the quantifier *every* is inside the degenerate quantifier **two*. Thus the theory never generates logical forms in which the embedded subject quantifier outscopes the head quantifier.

As for sentence (77) (b), the lexical entry of *whose* is shown below.

(83) whose := $((n : Z\hat{}(N\&every(\#,X,N1\&of(X,Z),S))\backslash n : Z\hat{}N)/(s : S/np : X))/n : X\hat{}N1$

The corresponding derivation for sentence (77) (b) is similarly done.

Finally, the following entry shows the category for *whom* in the object pied-piping sentence (77) (c). Further details are omitted.

(84) whom := $((n : Z\hat{}(N\&S1)\backslash n : Z\hat{}N)/(s : S/np : X))\backslash((s : S1/(s : S\backslash np : X))/np : Z)$

5.3 Attitude Verbs

Consider the following sentences again.

(85) (a) Mary thinks that exactly three men danced with more than four women.
(b) At least two girls think that John danced with more than four women.
(c) At least two girls think that exactly three men danced with Susan.

We will assume the following simplified categories for *think* and the complementizer *that*. The elementary category *ss* corresponds to the $\bar{S}$ node in X-bar theories.

(86) (a) think := $(s : think(X,S)\backslash np : X)/ss : S$
(b) that := $ss : that(S)/s : S$

The theory generates two scope relations but three distinct readings for sentence (85) (a). (87) shows a class of possible derivations for the reading in which *exactly three men* outscopes *more than four women*.

(87)

Mary	thinks	that	exactly three men	danced with	more than four women
$s/(s\backslash np)$	$(s\backslash np)/ss$	ss/s	$s/(s\backslash np)$	$(s\backslash np)/np$	$(s\backslash np)\backslash((s\backslash np)/np)$
				$s : four(>,Z,wmn(Z),dan(Y,Z))\backslash np : Z$ (<)	
$s : think(mary',that(three(=,Y,man(Y),four(>,Z,wmn(Z),dan(Y,Z)))))$					

(88) shows another class of possible derivations for a reading in which *more than four women* outscopes *exactly three men*.

(88)
$$
\begin{array}{cccccc}
\text{Mary} & \text{thinks} & \text{that} & \text{exactly three men} & \text{danced with} & \text{more than four women} \\
\hline
s/(s\backslash np) & (s\backslash np)/ss & ss/s & s/(s\backslash np) & (s\backslash np)/np & s\backslash(s/np) \\
 & & & \multicolumn{2}{c}{\overline{s : three(=,Y,man(Y),dan(Y,Z))/np : Z}^{\;>B}} & \\
 & & & \multicolumn{3}{c}{\overline{s : four(>,Z,wmn(Z),three(=,Y,man(Y),dan(Y,Z)))}^{\;<}} \\
\multicolumn{6}{c}{\overline{s : think(mary',that(four(>,Z,wmn(Z),three(=,Y,man(Y),dan(Y,Z)))))}}
\end{array}
$$

There is another class of derivations for another reading in which *more than four women* outscopes *exactly three men*, as shown below.

(89)
$$
\begin{array}{cccccc}
\text{Mary} & \text{thinks} & \text{that} & \text{exactly three men} & \text{danced with} & \text{more than four women} \\
\hline
s/(s\backslash np) & (s\backslash np)/ss & ss/s & s/(s\backslash np) & (s\backslash np)/np & s\backslash(s/np) \\
 & & & \multicolumn{2}{c}{\overline{s : three(=,Y,man(Y),dan(Y,Z))/np : Z}^{\;>B}} & \\
\multicolumn{5}{c}{\overline{s : think(mary',that(three(=,Y,man(Y),dan(Y,Z))))/np : Z}} & \\
\multicolumn{6}{c}{\overline{s : four(>,Z,wmn(Z),think(mary',that(three(=,Y,man(Y),dan(Y,Z)))))}^{\;<}}
\end{array}
$$

The theory predicts two scope relations (and three distinct readings) for sentence (85) (b). The logical forms that are generated by the theory are shown below.

(90) (a) $two(>=,X,girl(X),think(X,that(four(>,Z,wmn(Z),dan(john',Z)))))$
(b) $four(>,Z,wmn(Z),two(>=,X,girl(X),think(X,that(dan(john',Z)))))$
(c) $two(>=,X,girl(X),four(>,Z,wmn(Z),think(X,that(dan(john',Z)))))$

The theory predict only one scope relation (and one reading) for sentence (85) (c). This is due to the fact that embedded subject quantifier never escapes the argument position of the *that* operator. The theory generates the following logical form.

(91) $two(>=,X,girl(X),think(X,that(three(=,Y,man(Y),dan(Y,susan')))))$

As a further example, consider the following sentence.

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

The theory predicts three scope relations (and four distinct readings) (cf. Appendix).

6. Comparisons with Related Work

This section compares the present account of quantifier scope with two paradigmatic accounts of quantifier scope.

6.1 Quantifying-in Accounts

Quantifying-in is a technique originally proposed by Montague (1974) for *de re* NP interpretations. Consider for instance the following sentence, which is traditionally regarded as semantically ambiguous due to the intensional operator associated with the verb *seeks*.

(93) John seeks a unicorn.

The idea is that in one of the readings of the sentence, there does not have to be a unicorn actually existing in the real world for the sentence to make sense. In order to represent this reading, or *de dicto* reading, Montague proposed to assign a function from possible worlds to sets of properties (where properties are functions from possible worlds to characteristic functions) to the object of the relation *seeks* (cf. Dowty, Wall, and Peters (1981)). The *de re* reading, on the other hand, appears to presuppose the existence of such a unicorn in the real world. The way Montague proposed to make the denotation for such a unicorn *rigid* with respect to possible worlds is to syntactically take apart the computation of the NP semantics for *a unicorn* from that of the rest of the sentence and to put back the two semantics together, via the quantifying-in rules S14 and T14. This effectively creates the logical form $P(\lambda x.S'(x))$, where P is the NP semantics, whose operator *quantifies in*to the opaque context $S'(x)$ to bind the variable x that replaces the NP in question. Notice that the operator is insensitive to the 'distance' between itself and the variable, and in particular to the intervening NP semantics. Montague further proposed to utilize this rule schemata to account for scope ambiguities due to extensional transitive verbs, such as *finds*. Again, quantifying-in makes any NP outscope the rest of the sentence, and the outscoping relation between NPs is determined by the arbitrary order of invoking quantifying-in.

Cooper (1975) proposed a model-theoretic version of quantifying-in by utilizing semantic storage, but the power of the two proposals is still equivalent. Keller (1988) has later proposed to structure the store mechanism, so that the order of retrieving the simple NP semantics from complex NP semantics does not create syntactically ill-formed logical forms. This issue has also been addressed by Hobbs and Shieber (1987) and Carpenter (1989), both of whom identified the problem as one of dealing with free variables. None of these revisions address the problem pointed out in this paper, especially regarding Hobbs & Shieber's reading that we related to sentence (1) (a). Carpenter (1994) proposed Natural Deduction scoping schemes that capture Montagovian quantifying-in, utilizing assumption introduction (Scope Introduction, SI) and assumption discharge (Scope Elimination, SE). SI (respectively SE) corresponds to Cooper's store (respectively retrieve) mechanism, and Carpenter's proposal overgenerates readings in the same way as Cooper's since no further surface structure information is checked at the time of SE (or Cooper's retrieve). All of the systems that utilize some version of quantifying-in, including the proposal by Hendriks (1993) below, generate both Hobbs & Shieber's reading and May's reading, since the modifying NP quantifier of a complex NP can be taken out of the rest of the NP semantics, except when it is inside a relative clause which has an explicit node such as a relative pronoun that is known to block such operation. Crucially, prepositions are not known to behave as such.

Hendriks (1993) proposed syntactic type shifting rules (argument raising/lowering and value raising), as a middle ground between Montagovian syncategorematic proposal and Cooper's model-theoretic proposal. Roughly speaking, if object argument raising is performed on the semantics of the transitive verb before subject argument raising, the object quantifier will be outscoped by the subject quantifier, and vice versa. Since argument raising can be done at any point of semantic derivation, one can always find a way of letting an NP quantifier 'escape' from a given semantics. The following shows an example, where Hendriks was able to derive 8 readings (95) from (94).

(94) Fred claims that every schoolboy believes that a mathematician wrote "Through the looking glass."

(95) (a) $claim(f, {}^\wedge\forall v[boy(v) \rightarrow believe(v, {}^\wedge\exists u[math(u) \wedge write(u, L)])])$
(b) $claim(f, {}^\wedge\forall v[boy(v) \rightarrow \exists u[math(u) \wedge believe(v, {}^\wedge write(u, L))]])$
(c) $claim(f, {}^\wedge\exists u[math(u) \wedge \forall v[boy(v) \rightarrow believe(v, {}^\wedge write(u, L))]])$
(d) $\exists u[math(u) \wedge claim(f, {}^\wedge\forall v[boy(v) \rightarrow believe(v, {}^\wedge write(u, L))])]$
(e) $\forall v[boy(v) \rightarrow claim(f, {}^\wedge believe(v, {}^\wedge\exists u[math(u) \wedge write(u, L)]))]$
(f) $\forall v[boy(v) \rightarrow claim(f, {}^\wedge\exists u[math(u) \wedge believe(v, {}^\wedge write(u, L))])]$
(g) $\forall v[boy(v) \rightarrow \exists u[math(u) \wedge claim(f, {}^\wedge believe(v, {}^\wedge write(u, L)))]]$
(h) $\exists u[math(u) \wedge \forall v[boy(v) \rightarrow claim(f, {}^\wedge believe(v, {}^\wedge write(u, L)))]]$

Notice the way *a mathematician* gradually escapes out of its *in situ* position from (a) through (d). The semantics of *a mathematician* is assigned a *de dicto* reading with respect to *believe* in (a); it is assigned a *de re* reading w.r.t. *believe* but is still outscoped by *every schoolboy* in (b); it is assigned a *de re* reading w.r.t. *believe*, but at the same time a *de dicto* reading w.r.t. *claim* in (c); and so on. If we regard *de re* interpretation of indefinites as a referential interpretation of indefinites, this prediction would be at odds with the discussion in Section 3.1, where Fodor and Sag (1982) showed that referential indefinites do not take intermediate scopes.[35] The embedded subject *every schoolboy* is interpreted either *in situ*, as in (a) through (d), or out of the operator *claim*, as in (e) through (h). This is surprising, since it implies that sentence (96) (a) below has a reading that sentence (b) doesn't have, i.e., *for every schoolboy, Fred claims that he left immediately.* Compare this with the present theory that predicts that both sentences are unambiguous.

(96) (a) Fred claims that every schoolboy left immediately.
(b) Fred makes a claim that every schoolboy left immediately.

In Hendriks' Flexible Montague Grammar, quantifying-in for a particular NP is simulated by successively raising the *other* argument type of the (derived) predicate that takes it as an argument. Since this is how the object quantifier outscopes the subject quantifier, argument raising (for an extensional verb) is necessarily a blind type-shifting rule, in the sense that both *de re* interpretations and quantificational interpretations must be computed by the same rule. If it is in the right direction to distinguish the two kinds of interpretations, the rule must be conditioned properly to accommodate this distinction.

6.2 Quantifier Raising Accounts

Quantifier Raising is proposed by May (1977) as an operation from S-Structure to LF in order to explain natural language quantification. The discussion in this section is based on May (1985) which explores three related proposals. According to May, quantified NPs undergo an autonomous syntactic operation called Chomsky-adjunction, which changes the structure (a) below to the structure (b), where x is a node such as S, NP, VP, or PP. Notice that the structure (b) can receive a direct logical interpretation $Q(X, Y)$, where Q, X, and Y are set-theoretic denotations of the quantifier, the noun, and the rest labeled as *scope*, respectively. The operation QR is thus analogous to Montagovian quantifying-in, in the sense that it creates an abstraction. However it is more syntactically restricted, since the operation can not jump over $\bar{S}$ node.

(97) (a) $[_x \ldots [_{np}$ quantifier noun$] \ldots]$
(b) $[_x [_{np}$ quantifier noun$]_n [_x \ldots e_n \ldots]_{scope}]$

35 But see also the discussion in footnote 17.

For example, sentence (98) (a) gives rise to two different structures (b) and (c).

(98) (a) Every spy suspects some Russian. (page 14)
(b) $[_s [_{np}$ every spy $]_2 [_s [_{np}$ some Russian $]_3 [_s e_2$ suspects e_3]]]
(c) $[_s [_{np}$ some Russian $]_3 [_s [_{np}$ every spy $]_2 [_s e_2$ suspects e_3]]]

While these logical forms may be taken to correspond to differently scoped readings, May noted that in the presence of the extended ECP suggested by Kayne (1981), we are forced to abandon the structure (b).[36] Consequently, May suggested to utilize the notions of government and Σ-sequence, according to which the two NPs in the structure (c) are members of the same sequence since there is no intervening maximal projection and they *c*-command each other. May proposed the Scope Principle such that "members of Σ-sequences are free to take on any type of relative scope relation (page 34)." Later, May abandoned the extended ECP in favor of the Path Containment Condition (Pesetsky, 1982) that makes the same prediction, but still maintained the Scope Principle. The present theory and May's theory would predict identical scope ambiguous readings if May's theory could put in the same Σ-sequence the two NPs that can be related in our conjecture, and vice versa. This is not the case, however, since May's theory does not incorporate the extended notion of surface constituency as assumed in this paper. As a result, the two theories make different predictions especially when surface constituents contain nodes that QR can not make NPs cross over, such as the complementizer `that`.

Consider sentence (99) (a), which May called an instance of "inverse linking." In the interest of letting *every city* bind the pronoun, May suggested the logical form (b), but immediately rejected it, since a similar logical form (c) must be rejected on the grounds that the binding is into a syntactic island, i.e. NP.

(99) (a) Somebody from every city despises it. (page 68)
(b) $[_s$ every city$_2$ $[_s [_{np}$ somebody from e_2 $]_3 [_s e_3$ despises it]]]
(c) $[_{s'}$ which city$_2$ $[_s [_{np}$ somebody from e_2 $]_3 [_s$ despises it]]
(d) $[_s [_{np} [_{np}$ every city$_2$ $]_2 [_{np}$ somebody from e_2 $]_3]_3 [_s e_3$ despises it]]

Noting that QR is not restricted to S-adjunction, May proposed the logical form (d) instead, in which *every city* remains inside NP_3 by NP-adjunction. It can bind the pronoun, since it is in a *c*-commanding position over the pronoun. Notice however that this makes it necessary to have an extra well-formedness constraint in the system, since by definition *somebody from* e_2 and *every city* can outscope each other, one of the resulting logical forms having an unbound empty category e_2. This does not mean though that the reading in which *somebody* outscopes *every city* is not derivable in the system, since *every city* can also PP-adjoin, as shown below. This particular logical form is ill-formed though, since *every city* can not bind the pronoun.

(100) $[_s [_{np}$ somebody $[_{pp}$ every city$_2$ $[_{pp}$ from e_2]] $]_3 [_s e_3$ despises it]]

Notice that while May's theory can derive both scopings, it can not rely on the Scope Principle for quantifiers inside NPs. On the other hand, the present theory makes use of the same machinery, for NP-internal quantifiers and S-internal quantifiers alike.

With this formulation, it is interesting to note that May's theory does not allow Hobbs & Shieber's reading either. Consider (101), which shows a well-formed and close

36 The details of the extended ECP are beyond the scope of the present paper.

but different structure. Notice that *a comp* must be NP-adjoined so that it does not bind into an island (cf. (99) (d)), and *most samp* must be S-adjoined after the complex subject NP so that it does not violate either the extended ECP or the PCC (depending on the version of May's theory). The Scope Principle still allows the narrow scope interpretation of *most samp* in this structure. In order to allow for Hobbs & Shieber's reading, *a comp* must be able to change the relative scope with respect to *most samp* independent of *every rep of* e_2, but this is impossible. Letting *most samp* VP-adjoin does not help either, since *most samp* will then be outscoped by both of the subject quantifiers.

(101) $[_s\ [_{np}$ most samp $]_4\ [_s\ [_{np}\ [_{np}$ a comp $]_2\ [_{np}$ every rep of $e_2\ ]_3\ ]_3\ [_s\ e_3$ saw e_4]]]

This raises a question if May's theory can actually account for May's reading. May gives the structure (102) (a) for the reading in question (May, 1985, page 83). Notice that the object NP is VP-adjoined, and furthermore that the modifying NP of the object complex NP is NP-adjoined to the S-adjoined subject NP. It is not clear however if this structure is indeed what May's theory can derive, since the proposed NP-adjunction is between two NPs of an unrelated case. We would rather expect that the structure (b) is what May's theory can actually derive and what is related to May's reading. Unfortunately though, both of these structures should be ruled out, since *every lang* binds into a syntactic island (cf. (99) (d)). Since there are apparently no other ways to construct a structure for the reading, this seems to mean that May's theory does not account for May's reading. While quantifying-in accounts derive both Hobbs & Shieber's reading and May's reading, May's QR accounts do not derive either one. Consequently, both accounts appear to miss the subject-object asymmetry identified here.

(102) (a) $[_s\ [_{np}$ every $\text{lang}_2\ [_{np}$ some stu] $]_3\ [_s\ e_3\ [_{vp}\ [_{np}$ two dial of $e_2\ ]_4\ [_{vp}$ study e_4]]]]
(b) $[_s\ [_{np}$ every lang $]_2\ [_s\ [_{np}$ some stu $]_3\ [_s\ e_3\ [_{vp}\ [_{np}$ two dial of $e_2\ ]_4\ [_{vp}$ study e_4]]]]]

Finally, we note that unlike the present proposal, both quantifying-in accounts and QR accounts crucially distinguish the status of prepositions and relative pronouns so that the following sentences are argued to have a different range of readings.

(103) (a) I know somebody from every metropolitan city in the States.
(b) I know somebody who is from every metropolitan city in the States.

7. Conclusion

In this paper, we have presented a novel conjecture that directly predicts when two quantificational NP quantifiers in a natural language sentence may be scope-ambiguous. In order to show how the conjecture works, we have chosen to examine three English constructions that allow multiple NPs in a single sentence: complex NPs containing PPs, complex NPs containing *Wh*-relatives, and transitive/attitude verbs. While the claim is that the data analysis allowed by the conjecture is both explanatory and descriptively adequate, the data we have examined in this paper are necessarily incomplete to show this properly. There are many other important and interesting English constructions that are known to influence scope-ambiguous readings. These include *Wh*-phrases, quantifier-bound pronouns, and other constructions such as complex NPs containing possessives, control and ditransitive verbs, and most importantly, various standard and non-standard coordination. There is also an interesting relationship between extraction (and coordination) and quantifier scope that can be verified with topicalization, relativisation, heavy NP shift, extraposition, and parasitic extraction, right-node-raising, left-node-raising, and across-the-board extraction, among others. There are also issues regarding weak crossover phenomenon and superiority. While Park (1996) contains an extensive discussion for most of these with respect to the proposed framework, it is evident that much work needs to be done in order to uncover the true nature of non-referential quantifiers, as opposed to referential quantifiers.

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Appendix

The following program, or a fuller version, is available upon request from park@linc.cis.upenn.edu.

Complete Prolog Code

```
:- op( 800, xfy,  [&, v]).
:- op( 500, yfx,  [\, /]).
:- op( 480, xfx,  :).
:- op( 460, xfy,  ^).

:- use_module(library(lists)).

go :-   prompt(Buffer),
        if(Buffer = [exit], exit,
        (interpret(Buffer, LFs),
         output(LFs), !, go)).

prompt(Buffer) :-
  nl, write('Q:  '), read_in(Buffer).

exit :- write('exit'), nl, !, fail.

output(LFs) :- write('LF: '), length(LFs, L),
  if(L =:= 1,
    write('unrecognized sentence'),
    uglywrite(LFs)).

uglywrite(LFs)      :- uwrite(LFs, 1).
uwrite([],_)        :- nl.
uwrite([[]|LFs],N) :- uwrite(LFs,N).
uwrite([LF|LFs],N) :-
  nl, format("(~d) ", N),
  write(LF), M is N+1, uwrite(LFs,M).

interpret(Buffer, LFs) :-
  setof(LF, parse([], Buffer, s:LF), LFs).

%% The Parser

parse([SynSem], [], SynSem) :-
  SynSem = Syn:Sem, standard(Sem).
parse(Stack, [Word|Buffer], Answer) :-
  category(Word, SynSem),
  parse([SynSem|Stack], Buffer, Answer).
parse([Cat2, Cat1|Stack], Buffer, Answer) :-
  reduce(Cat1, Cat2, Cat3),
  parse([Cat3|Stack], Buffer, Answer).
parse([], _, _:[]).

reduce(X/Y,    Y,    X).
reduce( Y,  X\Y,    X).
reduce(X/Y,  Y/Z,  X/Z).
reduce(Y\Z,  X\Y,  X\Z).

%% THE LEXICON

:- dynamic category/2.

%% VERBS. Features are suppressed.

%% Intransitive Verbs

category(slept, s:sleep(X)\np:X).

%% Transitive Verbs

category(saw, (s:see(X,Y)\np:X)/np:Y).
category(admired, (s:adm(X,Y)\np:X)/np:Y).
category(visited, (s:visit(X,Y)\np:X)/np:Y).
category(studied, (s:study(X,Y)\np:X)/np:Y).
category(confused, (s:conf(X,Y)\np:X)/np:Y).
category(interviewed,
  (s:intv(X,Y)\np:X)/np:Y).
category(wrote, (s:write(X,Y)\np:X)/np:Y).
category(pleased, (s:please(X,Y)\np:X)/np:Y).
% This is a computational trick to force
% the association of iv with prep for tv.
category(danced, ((s:dan(X,Y)\np:X)/np:Y)/p).
category(with, p).

%% Attitude Verbs

category(thinks, (s:think(X,S)\np:X)/ss:S).
category(think, (s:think(X,S)\np:X)/ss:S).
category(thought, (s:think(X,S)\np:X)/ss:S).

%% Preposition
```

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

%% Wh-Relatives (probably incomplete entries)

category(who, (n:X^(N&S)\n:X^N)/(s:S\np:X)).
category(whom, (n:X^(N&S)\n:X^N)/(s:S/np:X)).
category(whose,
  ((n:Z^(N&every(#,X,N1&of(X,Z),S))\n:Z^N)
  /(s:S\np:X))/n:X^N1).
category(whose,
  ((n:Z^(N&every(#,X,N1&of(X,Z),S))\n:Z^N)
  /(s:S/np:X))/n:X^N1).
category(whom,
  ((n:Z^(N&S1)\n:Z^N)/(s:S\np:X))
  \((s:S1/(s:S\np:X))/np:Z)).
category(whom,
  ((n:Z^(N&S1)\n:Z^N)/(s:S/np:X))
  \((s:S1/(s:S\np:X))/np:Z)).

%% THAT Complementizer

category(that, ss:that(S)/s:S).

%% Proper Nouns. There are missing entries.

category(john, np:john).
category(mary, np:mary).
category(susan, np:susan).
category(bob, np:bob).
category(john, s:S1/(s:S\np:john)).
category(mary, s:S1/(s:S\np:mary)).
category(susan, s:S1/(s:S\np:susan)).
category(bob, s:S1/(s:S\np:bob)).

%% Common Nouns.

cn(N, Nplural, LFn) :- LF =.. [LFn, X],
  assertz(category(N, n:X^LF)),
  assertz(category(N,
    n:X^LF2/(n:X^LF2\n:X^LF))),
  assertz(category(Nplural, n:X^LF)),
  assertz(category(Nplural,
    n:X^LF2/(n:X^LF2\n:X^LF))).

:- cn(representative, representatives, rep).
:- cn(woman, women, wmn).
:- cn(man, men, man).
:- cn(girl, girls, girl).
:- cn(boy, boys, boy).
:- cn(company, companies, com).
:- cn(sample, samples, sam).
:- cn(student, students, stu).
:- cn(professor, professors, prof).
:- cn(letter, letters, let).
:- cn(dean, deans, dean).
:- cn(picture, pictures, pic).
:- cn(judge, judges, jud).
:- cn(frenchman, frenchmen, frn).
:- cn(russian, russians, rsn).
:- cn(aspect, aspects, asp).
:- cn(dialect, dialects, dial).
:- cn(language, languages, lan).
```

```
%% Quantifiers

q(Q) :- LFq =.. [Q,#,X,N,S],
  assertz(det(Q)),
  assertz(category(Q,
    (s:LFq/(s:S\np:X))/n:X^N)),
  assertz(category(Q,
    (s:LFq\(s:S/np:X))/n:X^N)),
  assertz(category(Q,
    ((s:LFq\np:Y)\((s:S\np:Y)/np:X))/n:X^N)),
  assertz(category(Q,
    ((s:LFq/np:Y)\((s:S/np:Y)/np:X))/n:X^N)),
  assertz(category(Q, ((s:LFq/(s:S1\np:Y))
    \((s:S/(s:S1\np:Y))/np:X))/n:X^N)),
  assertz(category(Q, ((s:LFq\(s:S1/np:Y))
    \((s:S\(s:S1/np:Y))/np:X))/n:X^N)),
  assertz(category(Q,
    (((s:LFq\np:Y)\((s:S1\np:Y)/np:Z))
    \(((s:S\np:Y)\((s:S1\np:Y)/np:Z))/np:X))
    /n:X^N)).

:- q(one).   :- q(two).     :- q(three).
:- q(four).  :- q(every).   :- q(some).
:- q(most).  :- q(several). :- q(a).

%% READ_IN/1 is from Jowsey (1990).

read_in([W|Ws]) :-
  get0(C), readword(C,W,C1), restsent(W,C1,Ws).
restsent(_,10,[]). % stop on CR or a lastword
restsent(W,_,[]) :- lastword(W),!.
restsent(_,C,W2) :-
  readword(C,W1,C1), restsent(W1,C1,Ws),
  (\+ lastword(W1) -> W2 = [W1|Ws] ; W2=Ws).
readword(C,W,C1) :- single_character(C),
  !, name(W,[C]), get0(C1).
readword(C,W,C2) :-
  in_word(C,NewC),!, get0(C1),
  restword(C1,Cs,C2),name(W,[NewC|Cs]).
readword(_,W,C2) :-
  get0(C1), readword(C1,W,C2).
restword(C,[NewC|Cs],C2) :- in_word(C,NewC),
  !, get0(C1), restword(C1,Cs,C2).
restword(C,[],C).

single_character(44).  % ,
single_character(46).  % .

in_word(C,C) :- C > 96, C < 123.
in_word(C,L) :- C > 64, C < 91, L is C+32.
in_word(C,C) :- C > 47, C < 58.
in_word(39,39).
in_word(45,45).

lastword('.').

%% Standardize the logical form

standard(Phi) :- standard(Phi, 1), !.
standard(that(Phi), N) :-
  standard(Phi, N).
standard(think(X,Phi), N) :-
  standard(Phi, N).
standard(Phi&Psi, N) :-
  standard(Phi, N), standard(Psi, N).
standard(LF, N) :-
  LF =.. [Q, _Md, Var, Phi, Psi],
```

```
  det(Q), variable(N, Var),
  succ(N, M), standard(Phi, M),
  succ(M, L), standard(Psi, L).
standard(LF, N) :-
  LF =.. [Q, Phi], Phi = Var^Psi,
  variable(N, Var), succ(N, M),
  standard(Psi, M).
standard(_Phi, _N).

variable(N, Var) :-
  name(N, L), name(Var, [88|L]).

succ(M, N) :- L is M + 1, N = L.
```

Sample Runs

The following shows sample outputs of the system *without* the degenerate quantifier semantics.[37]

```
Q:  Two representatives of three companies
saw four samples.
(1) four(#,X1,sam(X1),three(#,X3,com(X3),
two(#,X5,rep(X5)&of(X5,X3),see(X5,X1))))
(2) four(#,X1,sam(X1),two(#,X3,rep(X3)&
three(#,X4,com(X4),of(X3,X4)),see(X3,X1)))
(3) three(#,X1,com(X1),two(#,X3,rep(X3)&
of(X3,X1),four(#,X5,sam(X5),see(X3,X5))))
(4) two(#,X1,rep(X1)&three(#,X2,com(X2),
of(X1,X2)),four(#,X3,sam(X3),see(X1,X3)))

Q:  Some student studied two aspects of
every language.
(1) every(#,X1,lan(X1),two(#,X3,asp(X3)
&of(X3,X1),some(#,X5,stu(X5),study(X5,
X3))))
(2) some(#,X1,stu(X1),every(#,X3,lan(X3),
two(#,X5,asp(X5)&of(X5,X3),study(X1,
X5))))
(3) some(#,X1,stu(X1),two(#,X3,asp(X3)&
every(#,X4,lan(X4),of(X3,X4)),study(X1,
X3)))
(4) two(#,X1,asp(X1)&every(#,X2,lan(X2),
of(X1,X2)),some(#,X3,stu(X3),study(X3,
X1)))

Q:  Two professors who interviewed every
student wrote a letter.
(1) a(#,X1,let(X1),every(#,X3,stu(X3),
two(#,X5,prof(X5)&intv(X5,X3),write(X5,
X1))))
(2) a(#,X1,let(X1),two(#,X3,prof(X3)&
every(#,X4,stu(X4),intv(X3,X4)),write(X3,
X1)))
(3) every(#,X1,stu(X1),two(#,X3,prof(X3)
&intv(X3,X1),a(#,X5,let(X5),write(X3,
X5))))
(4) two(#,X1,prof(X1)&every(#,X2,stu(X2),
intv(X1,X2)),a(#,X3,let(X3),write(X1,
X3)))

Q:  Two professors whom every student
admired wrote a letter.
(1) a(#,X1,let(X1),two(#,X3,prof(X3)
&every(#,X4,stu(X4),adm(X4,X3)),
write(X3,X1)))
(2) two(#,X1,prof(X1)&every(#,X2,
stu(X2),adm(X2,X1)),a(#,X3,let(X3),
write(X1,X3)))

Q:  Two professors interviewed three
students most pictures of whom pleased
two judges.
(1) three(#,X1,stu(X1)&most(#,X2,pic(X2)
&of(X2,X1),two(#,X4,jud(X4),please(X2,
X4))),two(#,X3,prof(X3),intv(X3,X1)))
(2) two(#,X1,jud(X1),three(#,X3,stu(X3)&
most(#,X4,pic(X4)&of(X4,X3),please(X4,
X1)),two(#,X5,prof(X5),intv(X5,X3))))
(3) two(#,X1,prof(X1),three(#,X3,stu(X3)
&most(#,X4,pic(X4)&of(X4,X3),two(#,X6,
jud(X6),please(X4,X6))),intv(X1,X3)))
(4) two(#,X1,prof(X1),two(#,X3,jud(X3),
three(#,X5,stu(X5)&most(#,X6,pic(X6)&
of(X6,X5),please(X6,X3)),intv(X1,X5))))

Q:  Two girls think that three men danced
with four women.
(1) four(#,X1,wmn(X1),two(#,X3,girl(X3),
think(X3,that(three(#,X5,man(X5),dan(X5,
X1))))))
(2) two(#,X1,girl(X1),think(X1,
that(four(#,X3,wmn(X3),three(#,X5,
man(X5),dan(X5,X3))))))
(3) two(#,X1,girl(X1),think(X1,
that(three(#,X3,man(X3),four(#,X5,
wmn(X5),dan(X3,X5))))))
(4) two(#,X1,girl(X1),four(#,X3,wmn(X3),
think(X1,that(three(#,X5,man(X5),dan(X5,
X3))))))
```

37 The line breaks and indentations are added for the output to fit inside the paper margin.

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