

# Binding Theory in LTAG

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## Abstract

This paper provides a unification-based implementation of Binding Theory (BT) for the English language in the framework of feature-based lexicalized tree-adjoining grammar (LTAG). The grammar presented here does not actually coindex any noun phrases, it merely outputs a set of constraints on co- and contraindexation that may later be processed by a separate anaphora resolution module. It improves on previous work by implementing the full BT rather than just Condition A. The main technical innovation consists in allowing lists to appear as values of semantic features.

## 1 Introduction

BT (see Büring (2005) for a recent overview) accounts for the distribution of reflexives, pronouns, and full noun phrases.<sup>1</sup>

The focus of this paper is on implementing all binding conditions in the classical formulation by Chomsky (1981) in a toy LTAG grammar of English. At first sight, this poses a problem for LTAG since at least Condition C makes reference to potential antecedents that may lie outside LTAG's local domain (the verbal elementary tree, see Frank (2002)). Even in the case of Conditions A and B, the local domains of BT and of LTAG do not always correspond: a local domain for the purposes

<sup>1</sup>This paper uses the term *reflexive* to denote a word like *himself* subject to Condition A (excluding reciprocals, which are not treated in this paper). The term *pronoun* is used for words like *him* that are subject to Condition B.

of BT may encompass more than just a verbal elementary tree, as shown by binding into adjuncts and binding of ECM subjects.

In all these cases, information on potential antecedents has to be transmitted across several elementary tree boundaries. This is analogous to the “missing link” problem well known in LTAG semantics. The analysis advocated here adopts the solution to the missing link problem introduced in Gardent and Kallmeyer (2003), in that information is transmitted across tree boundaries by repeated use of feature unification, as opposed to e.g. multicomponent sets.<sup>2</sup> Features also provide the expressive power required to encode cases in which the structural configuration does not correspond to classically defined c-command at the surface level (the only syntactic level available in LTAG), such as binding into PPs that adjoin at VP (*John saved Mary<sub>i</sub> from herself<sub>i</sub>*) (Pesetsky, 1995) or topicalization (*Himself<sub>i</sub>, he<sub>i</sub> likes.*).

## 2 Previous Work

There are two previous attempts at implementing BT in LTAG syntax: Ryant and Scheffler (2006) and Kallmeyer and Romero (2007). Both restrict themselves to Condition A.<sup>3</sup>

Ryant and Scheffler (2006) propose a multicomponent lexical entry for reflexives and reciprocals. One of the components is the reflexive and

<sup>2</sup>(Kallmeyer and Romero, 2004; Kallmeyer and Romero, 2008) analyze a wide variety of semantic phenomena in English, using a notational variant of Gardent and Kallmeyer (2003). Once list-valued features are adopted (see below), the present analysis is compatible with all incarnations of their framework.

<sup>3</sup>See also Steedman (2000) for an early account that mixes LTAG and CCG and introduces a level of logical form to handle both binding and semantics.

the other one is a degenerate NP tree which has no phonological content and which adjoins into its antecedent. Tree-local MCTAG (Weir, 1988) together with flexible composition (Joshi et al., 2007) and a number of specialized constraints concerning subject interveners and c-command ensure that the structural configuration in which the two components stand corresponds exactly to the local domain of standard BT.

Kallmeyer and Romero (2007) use almost the same approach but allow the degenerate tree to tree-locally adjoin directly into the *host tree* (i.e. the tree into which the reflexive and its antecedent substitute). This is achieved by changing the label of the degenerate tree from “NP” to “VP” and making sure that the host tree will always contain a VP node for each potential antecedent. Features on the relevant places of the host tree propagate the individual variable from the antecedent to the reflexive via the degenerate tree. This move is an attempt to avoid flexible composition and to show that “tree-local MCTAG display exactly the extended domain of locality needed to account for the locality of anaphora binding in a natural way” (Kallmeyer and Romero, 2007).

### 3 This Proposal

This analysis uses the standard framework of feature-based LTAG (Vijay-Shanker, 1987), that is: Each node  $n$  has (possibly empty) top and bottom feature structures. If  $n$  is a substitution slot, then its bottom feature structure must be empty. Substituting a tree with root  $r$  into  $n$  will trigger unification of the top feature structures on  $n$  and  $r$ . If  $n$  is an adjunction site, then adjoining a tree with root  $r$  and foot node  $f$  into  $n$  will unify the top features on  $n$  and  $r$ , and separately, the bottom features on  $n$  and  $f$ . Finally, for any node  $n$  on which neither substitution nor adjunction takes place throughout the derivation, the top and bottom feature structures on  $n$  are unified.

The only way in which this analysis extends the standard framework consists in using lists as values of features (as in HPSG, Pollard and Sag (1994)), as well as simple list operations such as creating a list from one ( $\langle \cdot \rangle$ ) or two ( $\langle \cdot, \cdot \rangle$ ) elements, adding elements ( $::$ ), and appending a list to another one ( $\cup$ ). All these operations can be given computationally tractable implementations. Allowing lists (or sets) as values of features may

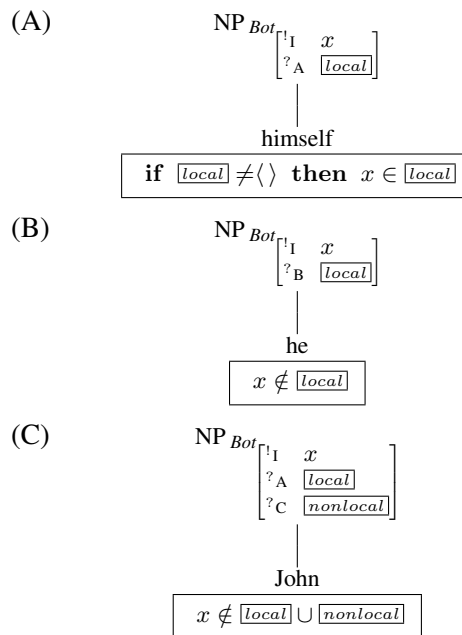


Figure 1: Noun phrases

perhaps look like a theoretically undesirable step. But this move seems unavoidable if potential antecedents of a noun phrase are to be encoded compactly in the output of the grammar. This in turn is necessary in order to avoid a combinatorial explosion of indexations (see Section 7).

Through the features on its root node, every noun phrase receives several items from the tree it attaches to (Branco, 2002): a list A of potential local antecedents for the purpose of condition A, a list B of potential local antecedents for the purpose of condition B, and a list C of potential nonlocal antecedents. (Keeping two separate lists A and B is necessary since there exist environments in which reflexives and pronouns are not in complementary distribution, as will be discussed later.)<sup>4</sup>

As is independently needed for semantic purposes (Gardent and Kallmeyer, 2003; Kallmeyer and Romero, 2008), every noun phrase provides a different I(NDIVIDUAL VARIABLE) to its envi-

<sup>4</sup>A fourth BT constraint, Condition Z, has been proposed for long-distance reflexives (LDRs): “a LDR must be (locally or nonlocally) bound” (Xue et al., 1994). A reviewer remarks that unlike condition C items, LDRs may sometimes accept only subject antecedents, or only within the domain of subjunctive tense. To the extent that such restrictions cannot be locally checked on the antecedent, a fourth list may need to be introduced. See Section 6.

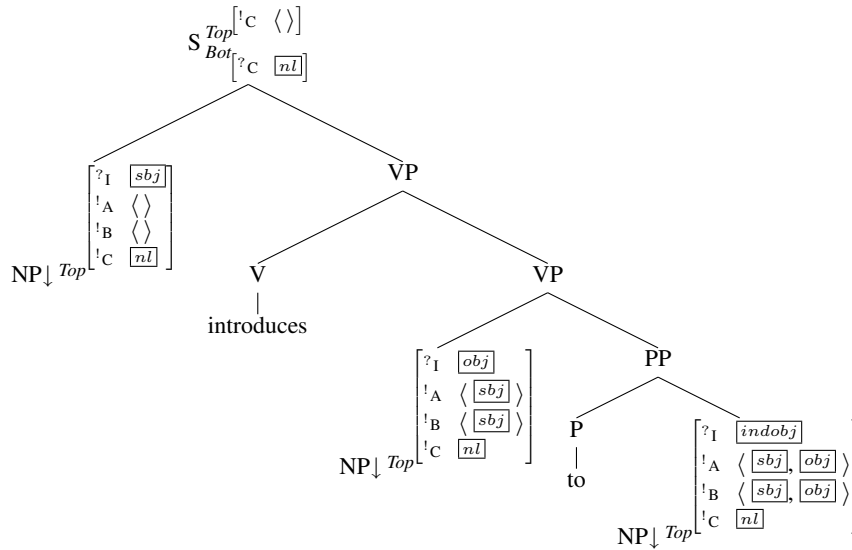


Figure 2: Finite ditransitive verb

ronment. Note that these variables do not correspond to BT indices, as each of them is assumed to be unique to its noun phrase even if another noun phrase ends up having the same referent. (This can be achieved by renaming before parsing starts.) They are thus more comparable to the reference markers of DRT (Kamp and Reyle, 1993). Finally, every noun phrase is associated with pseudocode that states the applicable BT condition (Fig. 1).<sup>5</sup> It is assumed that a separate resolution module will interpret this pseudocode in the obvious way. Take for example the statement for reflexives:

$$\text{if } \overline{local} \neq \langle \rangle \text{ then } x \in \overline{local} \quad (1)$$

This statement constrains the resolution module to equate the variable  $x$  with one of the members of the value of  $\overline{local}$ , provided that that value is not the empty list.<sup>6</sup> (This analysis does not use the order of the lists, but the grammar could be set up

<sup>5</sup>Metavariables in the feature structures have been given names like *sbj*, rather than just numbers as usual. Also, the direction of information flow has been indicated by annotating features that *receive* information from another tree with ? and features that *send* information to another tree with !. These annotations are only there for clarity of exposition and have no formal significance.

<sup>6</sup>This formulation implements the idea of exemption (Pollard and Sag, 1992; Pollard and Sag, 1994): A reflexive has to be bound locally only if its local domain is not empty. Reflexives whose domain is empty are argued there to fall outside of the scope of syntactic BT. Examples are reflexives within picture NPs in subject position. The following example is from Pollard and Sag (1992):

to use it to rank potential antecedents according to recency or grammatical prominence for the benefit of the resolution module.)

The rest of the grammar is responsible for providing the correct A, B and C lists to the noun phrase substitution slots. The next two sections describe how this is done in the verbal and nominal domains, respectively.

## 4 The Verbal Domain

In the standard case, the verb tree will collect the variables from its substitution slots and include them into A and B lists at these same substitution slots as appropriate (Fig. 2).

C lists are transmitted across clauses via their root nodes. If a verbal tree is a subordinate clause, then its C list is supplied by the matrix verb via the bottom feature on its S node. If it is a matrix clause, then the top and bottom features on its S node will unify and cause its C list to be empty. If

- (2) a. John<sub>i</sub> was going to get even with Mary. That picture of himself<sub>i</sub> in the paper would really annoy her, as would the other stunts he had planned.  
b. Mary was quite taken aback by the publicity John<sub>i</sub> was receiving. \*That picture of himself<sub>i</sub> in the paper had really annoyed her, and there was not much she could do about it.

Besides illustrating that BT-exempt *himself* may find its antecedent across sentences, this example also shows that the licensing conditions on BT-exempt *himself* are subject to nonsyntactic restrictions. For this reason, they have been set aside in this paper.

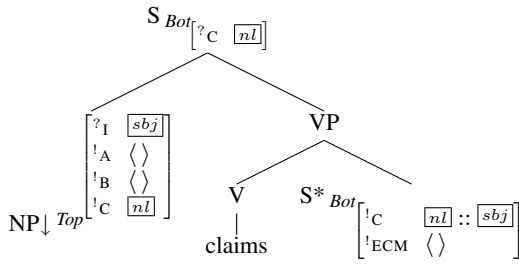


Figure 3: Sentential complement verb

a verbal tree subcategorizes for a sentential complement, then it appends its own argument(s) to its C list and makes the result available to the sentential complement (Fig. 3).

A special case are ECM verbs. The subject of an ECM verb is in the local domain of the subject of the verb's complement clause (*John<sub>i</sub> believes himself<sub>i</sub> to be the best candidate*). However, due to the LTAG version of the theta criterion (Frank and Kroch, 1995), the subject of the complement clause belongs to the LTAG local domain of the lower clause. ECM verbs therefore make their subject available via a special ECM feature (Fig. 4). In non-ECM verbs, the value of the ECM feature is the empty list (Fig. 3).

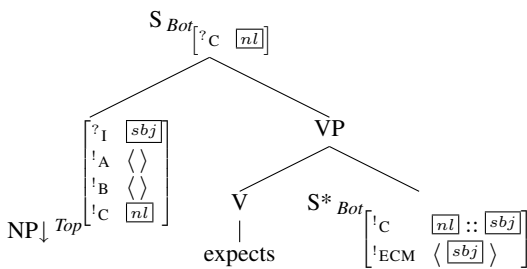


Figure 4: ECM verb

Nonfinite verbs (Fig. 5) function like finite verbs except for their subject position: If the matrix clause is headed by an ECM verb, its subject will be added to their A and B lists via the ECM feature. This gets the desired effect in *John<sub>i</sub> expects himself<sub>i</sub>/\*him<sub>i</sub> to win the game*.

LTAG's local domain only encompasses the arguments of a verb, not its adjuncts nor any raising verbs, because all recursion is factored away into separate elementary trees (Frank, 2002; Joshi,

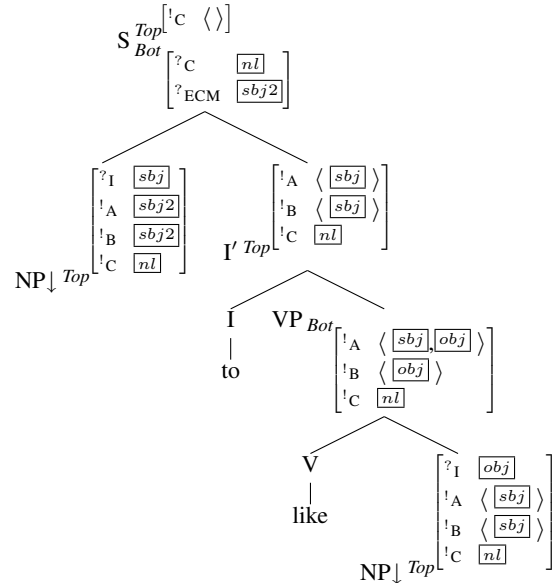


Figure 5: Nonfinite transitive verb

2004). Verbs therefore have to extend their local binding domain by propagating their A, B and C values to trees that adjoin on the VP spine,<sup>7</sup> This includes raising verbs with PP complements (Fig. 6) in order to derive *John<sub>i</sub> seems to himself<sub>i</sub>/\*him<sub>i</sub> to be a decent guy*<sup>8</sup>, and PP adjuncts (Fig. 7), in order to derive *John<sub>i</sub> saved Bill<sub>j</sub> from himself<sub>i</sub>/j*.

For those prepositions that take both reflexives and pronouns as locally-referring complements (*John<sub>i</sub> wrapped a blanket around himself<sub>i</sub>/him<sub>i</sub>*), differing A and B lists are made available. In these PP trees, the value of the B feature on the NP node (the asterisk in Fig. 7) will be  $\underline{b}$ , while in those PP trees that do not allow pronouns in this position (*John<sub>i</sub> speaks with himself<sub>i</sub>/\*him<sub>i</sub>*), the value of that feature will be  $\underline{a}$ .<sup>9</sup> Finally, the PP adjunct tree carries an additional set of features on its root node that enables local binding from one adjunct to another, as in *Mary spoke to Bill<sub>i</sub> about himself<sub>i</sub>*.

<sup>7</sup>For clarity of exposition, the feature structures on the VP spine have been omitted in the figures other than Fig. 5.

<sup>8</sup>See also Storoshenko (2006) for the syntax of this construction in LTAG.

<sup>9</sup>The generalization (Marantz, 1984; Reinhart and Reuland, 1993) is that a locally referring PP complement may be a pronoun only if the PP as a whole, rather than just the complement, is assigned a thematic role. How to implement this syntax-semantics interaction is left for future work.

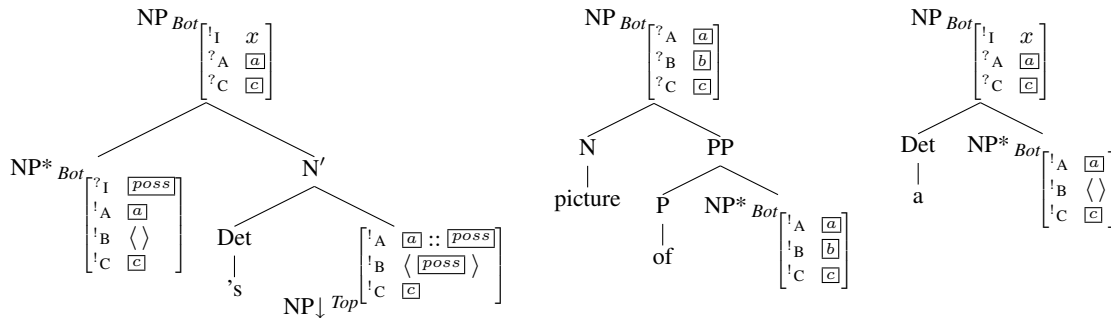


Figure 8: Picture NP components

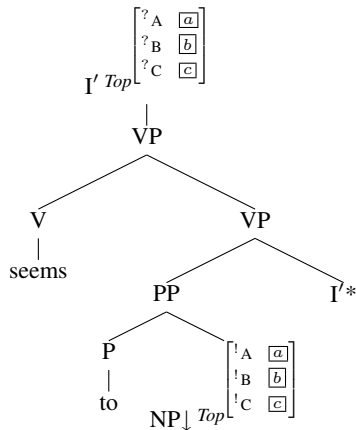


Figure 6: Raising verb with PP complement

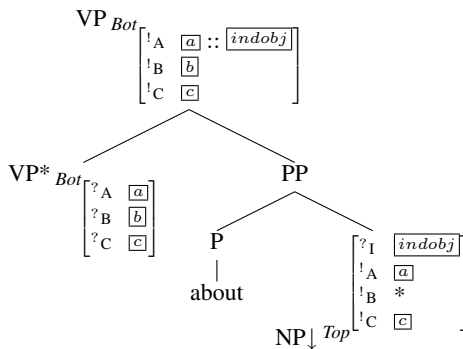


Figure 7: PP adjunct. See text for an explanation of the asterisk.

## 5 The Nominal Domain and Picture NPs

Complex NPs (Fig. 8) allow possessors (“*John’s friend*”). Following the syntactic analysis of (Kallmeyer and Scheffler, 2004; Kallmeyer and Romero, 2007), the “possessed” argument substi-

tutes into a tree anchored in ‘s, which in turn adjoins into the possessor. The possessed argument may, for example, be a simple noun<sup>10</sup>, or a constituent that contains an NP complement, such as “picture of X”, where X can be any NP. Following the same authors, this constituent is analyzed as an NP tree whose yield is X, and into whose root a “*picture of*” tree is adjoined.

Both possessors and picture NP complements behave nonuniformly with respect to the different binding conditions.<sup>11</sup> Possessors count as locally bound within their clause only for the purpose of condition A, but not B (Huang, 1983):

- (3) a. They<sub>i</sub> saw each other<sub>i</sub>’s friends.  
b. John<sub>i</sub> saw his<sub>i</sub> friend.

As for picture NP complements, for the purpose of condition A, their local domain includes the c-commanding arguments of the verb (here: the subject) and the possessor:<sup>12</sup>

- (4) a. John<sub>i</sub> finally saw Mary’s picture of himself<sub>i</sub>.  
b. Mary finally saw John<sub>i</sub>’s picture of himself<sub>i</sub>.

For the purpose of condition B, however, the local domain of a picture NP complement only includes the possessor:

<sup>10</sup>Because the label of the argument slot is NP and not N, this possibility is actually wrongly ruled out. This defect is a part of the syntactic analysis imported here from the literature.

<sup>11</sup>So-called exempt reflexives like *John<sub>i</sub> thinks that the pictures of himself<sub>i</sub> are horrid* are discussed in fn. 6.

<sup>12</sup>The example sentences in the rest of this section are taken from a series of experiments (Keller and Asudeh, 2001; Runner et al., 2002; Runner, 2003), as discussed in Jaeger (2004). Note that local binding across possessors as in (4a) is incorrectly reported (and predicted) to be ungrammatical in many treatments of BT, including Kallmeyer and Romero (2007).

- (5) a. John<sub>i</sub> finally saw Mary's picture of him<sub>i</sub>.  
 b. \*Mary finally saw John<sub>i</sub>'s picture of him<sub>i</sub>.

These facts are straightforwardly represented by the values of the A and B features on the NP complement node of the "'s" tree.

Of course, picture NPs can also occur without a possessor. Again, the local domain of the picture NP complement includes the c-commanding arguments of the verb for the purpose of condition A, but not condition B.

- (6) John<sub>i</sub> found a picture of him<sub>i</sub>/himself<sub>i</sub>.

In other words, whether or not a possessor is present, both pronouns and reflexives may be the complement of a picture NP and be bound by the subject.<sup>13</sup> This is modeled by letting the determiner trees pass on only the A but not the B list.

## 6 Other Constraints on Anaphora

Apart from the Chomskyan binding conditions, there are other syntactic constraints on anaphoric relations, including agreement (7) and accessibility relations when the antecedent is a quantifier (8).

- (7) \*John<sub>i</sub> likes myself<sub>i</sub>/themselves<sub>i</sub>/herself<sub>i</sub>.  
 (8) Every man loves [a woman]<sub>i</sub>. Her<sub>i</sub> name is Mary.  $(\exists > \forall, *\forall > \exists)$

The implementation of these constraints is outside of the scope of BT and is therefore not treated in this paper. Note, though, that the existence of these constraints does not mean that the number of lists passed around needs to be multiplied, as long as the constraints apply in addition to the binding conditions and can be locally computed and passed on to the anaphora resolution module.<sup>14</sup> For example, it is not necessary to keep separate lists of potential first, second, and third person antecedents since it is possible to check locally on the antecedent whether it has a given person feature. As for accessibility constraints of quantifiers,

<sup>13</sup>It is possible to make the pronoun less acceptable in this position by changing the sentence so that the subject is more likely interpreted as a creator of the picture NP, for example by using a verb of creation: *John<sub>i</sub> painted a picture of himself<sub>i</sub>/#him<sub>i</sub>*. As (Jaeger, 2004) shows by experiment, this effect also occurs if a possessor is present, and it can even be triggered by merely changing the subject to a salient creator. Thus, it is not (or at least not primarily) syntactic in nature.

<sup>14</sup>Thanks to an anonymous reviewer for raising this point.

these constraints interact with scope, and can be integrated with scope resolution by using underspecified dynamic semantics in the style of Koller and Niehren (2000).

## 7 Improvements on Previous Work

The present account improves on previous BT implementations in LTAG (Ryant and Scheffler, 2006; Kallmeyer and Romero, 2007) in a number of ways:

1) All conditions are implemented. The previous approaches only implemented Condition A and do not generalize well to the other conditions. For example, consider Condition B: The degenerate tree that picks out the antecedent of a pronoun would have to adjoin nonlocally and be barred from adjoining locally.

2) It is well known (Fong, 1990) that a sentence with  $n$  (independent) noun phrases corresponds to an exponential number of referentially distinct indexations. Therefore, it becomes crucial to avoid producing a separate parse tree for every possible indexation. Unlike the previous approaches, a parser that uses the present grammar on unindexed input will return a compact set of constraints on co- and contraindexation, rather than an exhaustive forest of indexed trees. This constraint set can then be sent to an anaphora resolution module. Thus, the present approach integrates well with computational approaches to coreference resolution. This insight has been taken from Branco (2002), who provides an HPSG implementation similar to the present one.

3) Mismatches between BT's and LTAG's local domains are encoded using the feature mechanism. There is no need to resort to nonstandard extensions of the framework such as flexible composition or subject intervention constraints, as Ryant and Scheffler (2006) do. Two examples of such mismatches are ECM verbs and binding into adjuncts. The latter poses a problem for Kallmeyer and Romero (2007), who would have to introduce flexible composition to handle it – the very same operation that their analysis was designed to avoid.

4) Binding from possessors into picture NPs (*John<sub>i</sub>'s picture of himself<sub>i</sub>*) is problematic for the analysis in Kallmeyer and Romero (2007), as the host tree for the possessor (in this case, the tree anchored in 's) would have to contain a VP (or S) node so that the antecedent tree for *himself* can

adjoin into it. But apart from stipulation, no such node is present in the  $S'$ 's tree. For the present analysis, this case raises no particular problem.

5) Each noun phrase introduces only one tree. Previous approaches stipulated that every reflexive introduces a set of two trees, one of which is degenerate and lacks independent syntactic motivation. Cf. an analogous move in the analysis of quantifiers (Gardent and Kallmeyer, 2003).

6) Finally, there is no need to stipulate any lexical ambiguity. Previous approaches required two separate lexical entries for each reflexive in order to handle special cases of ECM (Kallmeyer and Romero, 2007) or extraction (Ryant and Scheffler, 2006). ECM has been discussed above. As for extraction, (*Himself<sub>i</sub>, he<sub>i</sub> likes.*), due to the inverted c-command relation, it could previously (Ryant and Scheffler, 2006) only be handled by an *ad hoc* lexical entry for the reflexive. In contrast, in the present analysis, object slots can simply be made to carry identical features in base (e.g. Fig. 5) and extraposed (Fig. 9) position. More generally, the notion of c-command plays no role in the present implementation. This is actually an advantage, given that c-command as classically defined is not empirically adequate for BT purposes (Pollard and Sag, 1992; Pollard and Sag, 1994), even less so in a system like LTAG which does not make D-Structure or LF available as additional levels on which c-command relationships could be checked.

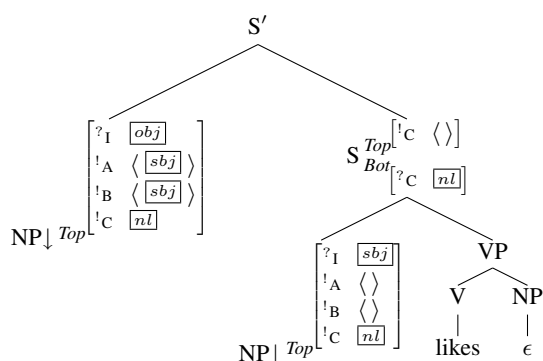


Figure 9: Transitive verb with extraposed object

## 8 Conclusion

The analysis presented in this paper implements binding conditions A, B, and C in LTAG. The non-local behavior of Condition C, as well as mis-

matches between the LTAG and BT local domains, do not align well with LTAG's notion of locality. The solution adopted here addresses this problem by using feature unification to pass information across boundaries of elementary trees. Following Branco (2002), specification of binding constraints has been kept apart from anaphora resolution.

This solution achieves descriptive adequacy at the cost of stipulating a great number of features. Admittedly, this method does not restrict the range of crosslinguistic options very much. For example, it would be easy to write a nonsensical grammar in which reflexives must c-command (!) their antecedents. Future work might look for concise statements of the possible positions and values of the features used here. The feature lists might also provide the right kind of structure to define a notion analogous to HPSG's o-command (Pollard and Sag, 1994). It appears promising to formulate such statements within a metagrammar framework (Kinyon et al., 2006).

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