

# Semantics of Pied-Piping and Stranding of Embedded wh-Phrases in LTAG

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## 1 Introduction

In questions where the wh-word is embedded into a larger NP, there are two structural possibilities:

- (1) Which boy's father did you see?
- (2) Which boy did you see the father of?

The larger NP containing the question word can be pied-piped as in (1) to the beginning of the sentence together with the wh-word. This requires some kind of syntactic or semantic *reconstruction*, i.e.: For scopal purposes, the matrix NP must contribute its semantics (at least in one of the readings) approximately in the position of its trace, while the wh-word itself has of course the widest possible scope.

In another construction, shown in (2), the matrix NP can be stranded in its object position, yielding potential problems for semantic compositionality in frameworks that do not use transformations.

In this paper we show how scopal underspecification in the semantics of Tree Adjoining Grammar provides the correct variable bindings for both types of questions. First, we will briefly introduce the TAG formalism and its framework of semantic composition (section 2). In section 3, we discuss the syntactic analysis of wh-extraction from NP in (Kroch, 2001). We show that contrary to his claim, compositional semantics is possible with a less complex syntactic analysis if one makes use of semantic underspecification.

Section 4 briefly discusses the other kind of complex question, *pied piping* of NPs that contain embedded wh-words. We adopt the analysis of (Han, 2002) for relative clauses and apply it to questions.

## 2 Semantics of Lexicalized Tree Adjoining Grammar

### 2.1 Lexicalized Tree Adjoining Grammar

Lexicalized Tree Adjoining Grammar (LTAG) is a tree rewriting system whose formal basis was first developed by Joshi et al. (1975). It has proven to be very useful for representing natural language grammar (see Kroch and Joshi, 1985).

An LTAG consists of a finite set of trees (the *elementary trees*) associated with lexical items. It has furthermore two composition operations, *substitution* and *adjunction* (or *adjoining*) for combining elementary trees into larger structures. The operations are depicted in figure 1.

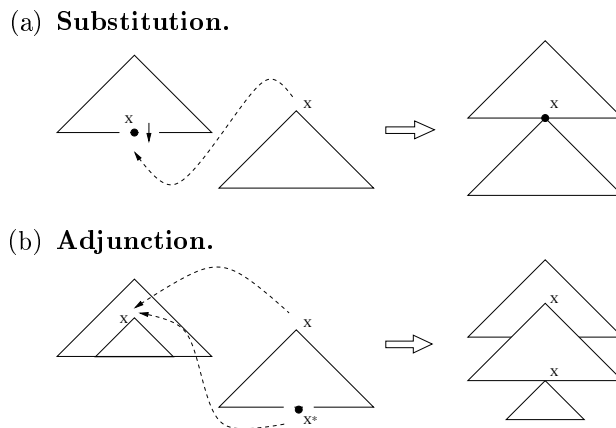


Figure 1: Substitution and Adjunction.

An LTAG analysis of a sentence is commonly represented not by the *derived tree*, i.e. the complete phrase structure tree that results from combining all the involved elementary trees. Instead, a *derivation tree* is given, which has as its vertices the names of elementary trees, and the combination operations (substitution or adjunction) between them as its edges. A TAG derivation and derivation tree<sup>1</sup> for the sentence “John always loves Mary.” is shown in figure 2.

A TAG has several desirable formal properties that make an elegant description of natural language possible. The two most important ones are (1) an extended domain of locality as compared to traditional phrase-structure grammars—in a TAG, the semantic and syntactic arguments of a lexical item are realized *locally* in that item’s elementary tree—, and (2), the factoring of

<sup>1</sup>Full lines in the derivation trees denote the adjunction operation, dashed lines substitution. The numbers on the edges are the Gorn addresses (Gorn, 1967) of the adjunction resp. substitution targets in the outer tree.

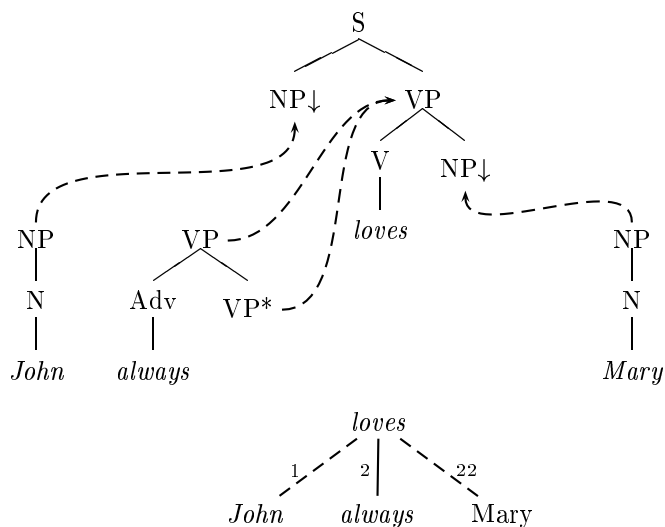


Figure 2: Derivation of the sentence *John always loves Mary*.

recursion into separate trees, the auxiliary trees. This second property, along with the operation of adjunction, allows for an elegant account for unbounded dependencies such as wh-questions.

## 2.2 Semantics

It is commonly argued that semantic composition in TAG should be done with respect to the derivation tree, not the derived tree. This is possible because semantic arguments of a lexical item (i.e., an *anchor*) are encapsulated in the elementary tree of that item. Thus, each elementary tree is associated with its appropriate semantic representation, and semantics of bigger chunks of the sentence are composed incrementally in parallel with the syntactic composition.

We choose a flat semantic representation with unification variables (similar to MRS, Copestake et al., 1999). Each elementary tree is assigned one semantic representation. Furthermore, variables in the semantics can be linked to nodes in the elementary tree. In this way, e.g. the variables whose values will be provided by the subject resp. the object of a transitive verb can be distinguished. See figure 3 for an example LTAG lexicon with semantic representations.

### 2.2.1 Semantic Underspecification in TAG

As laid out in (Kallmeyer and Joshi, 2003), semantic representations in TAG can be underspecified, to account for example for scope ambiguities.

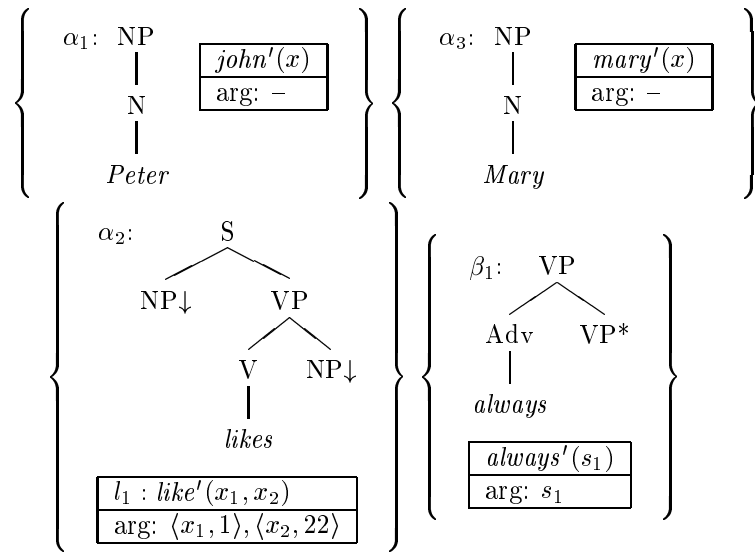


Figure 3: Example lexicon with semantics.

In addition to predications, the semantics also include propositional metavariables called *holes* ( $h_1, h_2 \dots$ ). Holes are variables over propositional labels ( $l_1, l_2 \dots$ ); here, they are used to provide underspecified representations of scope ambiguities. Semantic representations can contain constraints on the relative scope of holes and labels, providing an ambiguous semantics. At the end of a derivation, all possible *pluggings*, i.e. bijections between holes and labels, must be found to obtain the different possible scopings of the sentence.

### 2.2.2 Notation

In the remainder of this paper, we will use a notation for the derivation of TAG semantics that uses feature structures to keep track of the variable unifications. A simple derivation for the sentence “Every dog barks.” is shown in figure 4.

Note that the lexical item “every” is split into two separate elementary trees, as suggested for example in (Kallmeyer, 1999). One tree is substituted into the appropriate NP node and provides the predicate-argument information; the other tree is a degenerate auxiliary tree that consists only of a single S node, and which is used to obtain the correct scope constraints.

The figure shows the derivation tree for “Every dog barks”, but instead of the names of elementary trees, the nodes contain the semantic information associated with these elementary trees. Each tree is associated with a set of formulae and/or scope constraints. In addition, a feature structure specifies semantic top (T) and bottom (B) features associated with nodes in the syntactic



### 3 Stranding

In his manuscript on long-distance (wh-) extraction in TAG, Kroch (2001) also discusses extraction of the wh-word from object NPs as a special case. He gives syntactic analyses for example for the following sentences:

- (5) Which painting did you see?
- (6) Which painting did you see a copy of?
- (7) Which painting did you see a photograph of a copy of?

Here, we will follow this analysis in part, but diverge from Kroch's proposals in important ways.

#### 3.1 Different types of auxiliary trees

Auxiliary trees in TAG are used for two different syntactic purposes: modification and complementation. I.e., not all complementation can be covered by substitution, so that some auxiliary trees do not modify the trees they adjoin into, but take them as their complements. Examples for the two types of auxiliary trees are given in figure 5.

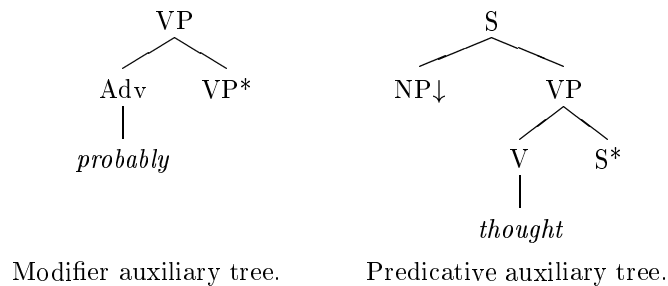


Figure 5: Different types of auxiliary trees in TAG.

For NPs, a similar distinction among syntactically non-obligatory elements exists:

- (8) a copy of a book
- (9) a child from New York

In the first NP, the prepositional phrase *of a book* is a complement of the head noun, whereas *from New York* is a modifier of the head noun *child* in the second example. This difference in status can be observed when we try to extract from those NPs—it is generally argued that extraction of an NP complement is possible, but not extraction out of an NP modifier:

- (10) Which book did you borrow a copy of?

(11) \* Which city did you meet a child from?

Thus, these two constructions must have different syntactic treatments. In the current XTAG grammar for English (XTAG Research Group, 2001), both PPs are analysed as modifying PPs. Instead, we follow Kroch's line in proposing a predicative auxiliary tree for the first NP, and a modifier auxiliary tree for the second (see figure 6).

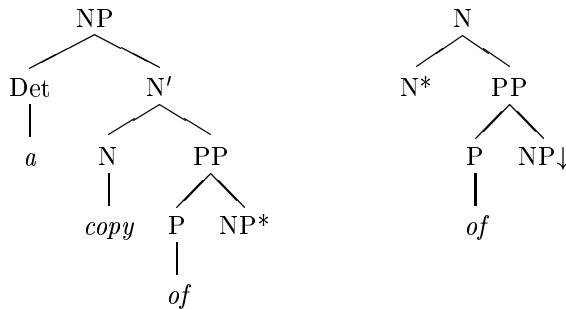


Figure 6: Complex NPs: complement vs. modifier.

### 3.2 Multi-Component TAG

Kroch claims that in order to obtain a compositional semantic analysis of a sentence like (6), a multi-component elementary tree set like the one in figure 7 has to be introduced.<sup>3</sup> A multi-component tree set is a lexical entry in an

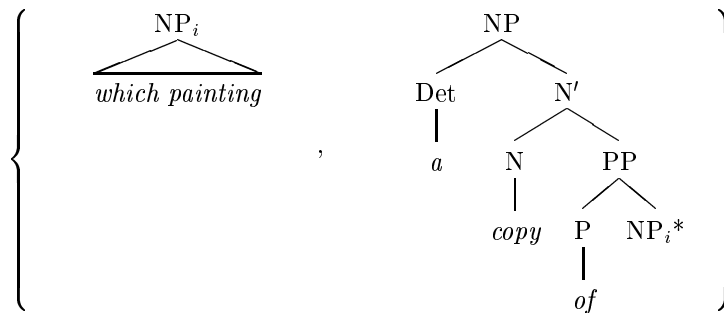


Figure 7: A multi-component lexical entry for extraction from NP.

extended version of TAG called Multi-Component Tree Adjoining Grammar (MC-TAG). This formalism differs from traditional TAG in that lexical entries can consist of more than one elementary tree. The composition operations of

<sup>3</sup>This tree set is constructed in the spirit of Kroch's paper, although it differs in the treatment of the wh-extraction itself, which is done by adjunction to  $\bar{S}$  in (Kroch, 2001), but by substitution into a verbal question tree here.

substitution and adjunction work just as in LTAG, with the additional constraint that all elementary trees of one multi-component tree set must combine with the same elementary tree (*tree-local* MC-TAG).

However, to include a tree set like that as an entry in the lexicon is less than desirable. The reason is that the set is not actually *minimal*, a requirement on elementary trees that states that all recursion must be factored out. The tree set contains two noun phrases. Also, Kroch himself argues that the trees of the type of the auxiliary tree in the tree set must exist as separate lexical entries in order to produce sentences such as (7) from sentence (6). Thus, we provide here a semantic representation and analysis that makes use of underspecification to produce the right variable unifications without the need to resort to syntactic representations with multiple components.

### 3.3 Underspecification

Kroch argues (see Kroch, 2001, p. 11) that an analysis which doesn't make use of multiple components will not be able to account for the correct semantic relations compositionally.

In fact, if one makes use of underspecified semantics as in the representations introduced in the beginning of this paper, a compositional semantics is possible even without multiple components.

Nevertheless, one criticism of underspecified representations applies (see Schabes and Shieber, 1994, for a criticism of underspecification in TAG syntax): an underspecified representation only has a specific meaning after the complete derivation has been carried out. That is, in any step of the semantic derivation of a sentence like (7), we won't have a *wrong* thematic role assignment (as Kroch claims), but there will be no thematic role assignment at all, i.e. it can not be known which variable fills a certain argument slot.

This sounds unappealing at first, but the nature of predicative auxiliary trees make it very clear that this is necessary. It has been noted before in the TAG literature, that predicative adjoinings are different from modifier adjoinings and substitutions in that the *outer* tree (the adjunction target) actually depends on the *inner* tree (the auxiliary tree). In addition, Kroch has shown that two different kinds of auxiliary trees are needed in order to account for the extraction phenomena, and one of them is a predicative auxiliary tree.

### 3.4 Analysis

We propose the lexicon entries given in figure 8 to account for sentences (5)–(7).<sup>4</sup> The element which will provide the “object” argument of *see* is underspecified with respect to the derivation. As can be seen from the semantics associated with the tree for *see*, if nothing adjoins to the NP<sub>1</sub> dominating the trace, top and bottom feature unification at the end of the derivation will correctly assign the variable provided by the wh-phrase as the participant in the predicate *see*.

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<sup>4</sup>ignoring the syntactic and semantic contributions of *did* and *you*



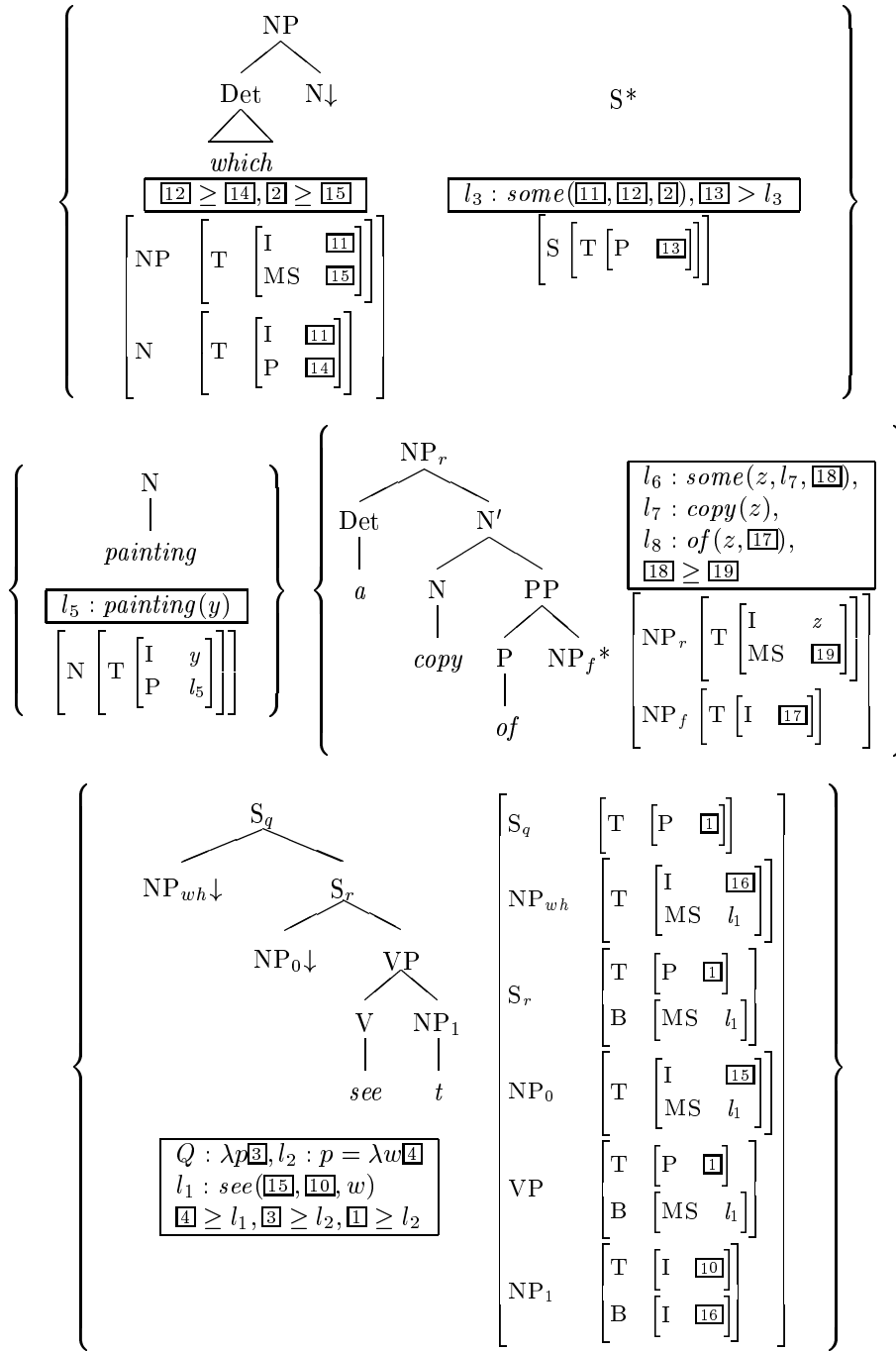
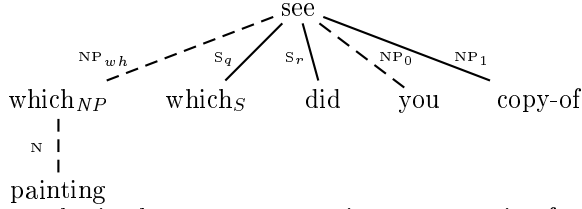


Figure 8: Lexicon.

However, adjunction into  $NP_1$  will dislocate the top and bottom metavariables ( $\boxed{10}$  and  $\boxed{16}$ ), such that the participant of *see* can be provided by the NP that adjoins into  $NP_1$ .

Given the following derivation tree:



we obtain the correct semantic representation for sentence (6):

(12) at the end of the derivation:

$$\begin{aligned}
 Q &: \lambda p \boxed{3} \\
 l_2 &: p = \lambda w \boxed{4} \\
 l_1 &: \text{see}(\text{you}, z, w) \\
 l_3 &: \text{some}(y, \boxed{12}, \boxed{2}) \\
 l_5 &: \text{painting}(y) \\
 l_6 &: \text{some}(z, l_7 \wedge l_8, \boxed{18}) \\
 l_7 &: \text{copy}(z) \\
 l_8 &: \text{of}(z, y) \\
 \boxed{4} &\geq l_1, \boxed{3} \geq l_2, \boxed{1} \geq l_2, \boxed{18} \geq l_1, \boxed{12} \geq l_5, \boxed{2} \geq l_1, \boxed{1} > l_3
 \end{aligned}$$

mapping from holes to labels:

$$\begin{aligned}
 \boxed{1} &\rightarrow Q \\
 \boxed{3} &\rightarrow l_3 \\
 \boxed{12} &\rightarrow l_5 \\
 \boxed{2} &\rightarrow l_2 \\
 \boxed{4} &\rightarrow l_6 \\
 \boxed{18} &\rightarrow l_1
 \end{aligned}$$

final semantic representation:

$$\begin{aligned}
 Q &: \lambda p. \text{some}(y, \text{painting}(y), \\
 &\quad p = \lambda w. \text{some}(z, \text{copy}(z) \wedge \text{of}(z, y), \text{see}(\text{you}, z, w)))
 \end{aligned}$$

The semantic construction for sentence (7) works accordingly and is left as an exercise for the reader.

## 4 Pied-Piping

As an alternative to question forming by extracting the wh-phrase from the embedding NP, the complete complex NP can be pied-piped to the beginning of the sentence. This yields sentences such as:

- (13) Whose father did you see?
- (14) Which boy's father did you see?
- (15) A copy of which painting did you see?

## 4.1 Problem

These sentences are potentially problematic for semantic composition in TAG because a first approach at the syntax would suggest an adjunction of genitive determiners (the possessive expressions). This would give the correct variable bindings for the sentence predicate (here, *see*), but the *wh*-phrase would combine with its head noun, not the verbal tree. Even disregarding that this would not even be possible with our lexical entry for *which* above (remember that the tree set contains a tree that adjoins to an S node), the correct scopings and variable bindings could not be achieved, because there is no connection in the derivation between the embedded *wh*-phrase and the verbal question tree.

## 4.2 Relative Clauses

(Han, 2002) discusses a TAG analysis of relative clauses with complex *wh*-phrases such as:

(16) the problem whose solution is difficult

(17) the problem whose solution's proof is difficult

The structure of these relative clauses is almost identical to our questions above, so solutions to the relative clause problem will carry over to the direct questions.

Han proposes<sup>5</sup>, similar to our treatment for *a copy of* above, a different lexical entry for the genitive 's, a predicative auxiliary tree where the outer NP adjoins into the embedded *wh*-phrase. The elementary tree for 's is given in figure 9, along with an appropriate semantics.<sup>6</sup>

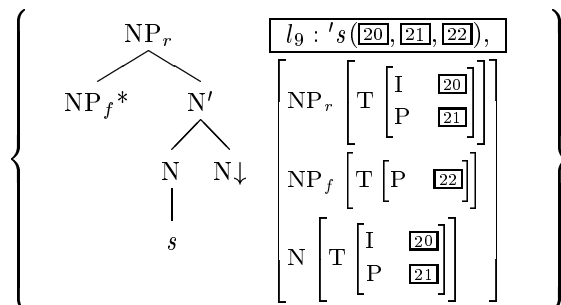


Figure 9: Lexical entry for 's.

This elementary tree adjoins into the root node of the initial tree for *which*. It has no scopal effects, so the scopal properties of simple questions are kept. In particular, the question word continues to have the widest possible scope.

One constraint that must be ensured is that  $l_9$  gets the smallest possible scope. This can be done by adding a constraint that says  $[23] \geq l_9$ , where  $[23]$

<sup>5</sup>in an unpublished presentation given at the Institute of Research in Cognitive Science, University of Pennsylvania, on July 3, 2003

<sup>6</sup>We modified the semantic representation Han gave to fit with our formalism and notation.

is the minimal scope (MS) noted in the root node. This would force  $l_9$  to have exactly the same scope as  $l_1$  (the sentence predicate) in the derivation of example (14).

What the semantic representation accounts for, though, is the correct bindings of the individual variables. As the variable inherited up to the root comes from the substituted argument of 's, it is ensured that the verb of the sentence will predicate over the head noun of the complex NP, while the restriction of the question is the embedded noun.

## 5 Conclusions

In this paper we dealt with questions in which the wh-phrase is embedded into a larger noun phrase. We identified two possible syntactic constructions, that correspond to the stranding of the matrix NP (extraction from NP) and pied-piping of the complete NP to the front of the sentence.

Partly following a previous analysis of the syntax involved in extractions from NP by Kroch (2001), we showed that semantic compositionality and the right variable bindings can also be achieved with a simpler syntactic structure if one makes use of semantic underspecification. We provided appropriate lexical entries with associated semantics and gave an example derivation of a question with extraction from NP.

For the pied-piping structure, we employed a recent idea by Han to account for relative clauses with complex wh-phrases. We used a similar syntactic analysis to the one approaching the stranding case (using predicative auxiliary trees) and showed that the relative clause ideas carry over to the more complex semantic framework that we chose here.

Semantic underspecification, along with the powerful feature unification formalism in feature-based TAG, has been shown to provide elegant analyses of a range of scopal phenomena. Here we presented how it makes an account of complex wh-phrases possible.

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