Semantic Reconstruction for *how many*-Questions in LTAG

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Abstract

In this paper, we show how to formalize reconstruction effects in an LTAG semantics. We derive a lexical entry and semantic specification for *how many*, which introduces two quantificational elements. We also show how they interact compositionally with other scopal items, e.g. modal and attitude verbs in a question. The use of an underspecified semantics allows the compact representation of scope ambiguities. We demonstrate how this also enables us to obtain the correct readings in embedded questions.

1 Introduction

Semantic *reconstruction* is an effect that is appealed to if a scopal element seems to be interpreted "further down" in the syntactic tree than it actually occurs. One example are complex wh-questions, in which a part of the wh-phrase sometimes must be interpreted as if it occurred in the approximate position of its trace (in a transformation-based analysis).

How many-questions are such complex wh-questions, because *how many* introduces two quantifiers (basically, *what n* and *n-many*). Thus, sentence (1) is ambiguous with respect to whether reconstruction of the second quantifier (*n-many*) into the object position occurs or not.[1]

(1) How many students did Mary interview?
For what n: there are n-many people y_i, such that Mary interviewed y_i.
$\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{interview}(k, y, w)))]^{2,3}$

This ambiguity is made apparent if other scopal elements, like modal verbs, adjoin to the sentence. Example (2) has two separate meanings, with different relative scope of *n-many* and *should*.

(2) How many students should Mary interview?

(a) For what n: it should be the case that there are n-many students y_i such that Mary interviewed y_i.
$\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{should}(\mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{intv}(x, y, w) \wedge \mathsf{mary}(x))))]$

(b) For what n: there are n-many students y_i such that it should be the case that Mary interviewed y_i.
$\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{should}(\mathsf{intv}(x, y, w) \wedge \mathsf{mary}(x))))]$

The first meaning might be intended when Mary is known to make a representative survey among students, and the speaker wants to know how many students (no matter who they are) have to be interviewed in order for Mary to be able to make valid judgments. Meaning (b) is more salient if Mary has been assigned to ask certain students (e.g., Bill, Bob, and Susan), and the speaker wants to know how big the group of people whom Mary has to interview is exactly.

In earlier approaches to such semantics, the effect is accounted for by postulating a trace in the canonical position of the wh-element (Cresti, 1995). A part of the

[1] Note that reconstruction of a quantifier into a lower position in the tree does not deny that quantifier the possibility to raise by normal quantifier raising. In fact, in the case of *how many*, the *what n* is a wh quantifier which has to take the widest possible scope. The *n-many* quantifier is a normal non-wh quantifier which can be interpreted in the usual "scope window" for NP quantifiers such as "some" and "every". Alternatively, by way of appearing together in one word with the wh quantifier, *n-many* can take the higher wh-scope here.

[2] We loosely follow the view of (Karttunen, 2003) on the meaning of questions, which analyses a question denotation as a set of propositions, namely all those propositions that answer the question.

[3] stud^* means "a plurality of students".

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wh-phrase is then said to be reconstructed in that position, from which it can optionally raise across other, higher scopal elements. Thus, an ambiguity arises with respect to the relative scopings of scopal elements in the sentence.

These phenomena seem to pose problems for a semantics interface on top of a syntactic theory which, like TAG, does not make use of traces or movement. However, we demonstrate here that the use of feature structures not only makes an account possible, but also provides us with a compact underspecified representation of scope ambiguities that arise due to the optionality of reconstruction.

2 LTAG 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 each elementary tree is associated with its appropriate semantic representation, and the semantics of the sentence is composed incrementally in parallel with the syntactic composition (see e.g. Kallmeyer and Joshi, 2003; Joshi et al., 2003; Gardent and Kallmeyer, 2003).

In this paper we use the framework presented in Kallmeyer and Romero (2004): We use a flat semantic representation with unification variables (similar to MRS, Copestake et al., 1999). In addition to predications, the semantics contain propositional metavariables. Constraints on the relative scope of the metavariables and propositional labels are used to provide underspecified representations of scope ambiguities. The semantic representation is stored in semantic feature structures that are part of the lexical entry, together with the elementary tree. To keep track of the necessary variable unifications, semantic features are associated with each node position in the elementary tree.[4] The values of these features are feature structures that consist of a T and a B feature (top and bottom) whose values are feature structures with features I for individual variables, P for propositional labels etc.

The semantic composition follows the usual definitions for unification in Feature-Based TAG syntax: For each edge in the derivation tree from elementary tree γ_1 to γ_2 with position p: (1) the T feature of position p in γ_1 and the T feature of the root of γ_2 are identified, and (2) if γ_2 is an auxiliary tree, then the B feature of the foot node of γ_2 and the B feature of position p in γ_1 are identified. Furthermore, at the end of a syntactic derivation, the top and bottom feature structures at each node are unified. By these unifications, some of the variables in the semantic representations get values. Then, the union of all semantic representations is built which yields an underspecified representation with scope constraints.

[4]For the sake of readability, we use names np, vp, ... for the node positions instead of the usual Gorn adresses.

To obtain the different possible scopings of the sentence, all possible *disambiguations*, i.e. injective functions from the remaining propositional variables to labels, must be found. The disambiguated representations are interpreted conjunctively.

Quantifiers Following Joshi and Vijay-Shanker (1999); Kallmeyer and Joshi (2003) and in particular Romero et al. (2004), we assume that quantificational NPs as *every* in (3) and also *who* in (4) are syntactically split into two parts of one multicomponent set. 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 contributes the scope part. Figure 1 shows the syntax for sentence (3).

(3) Every dog barks.

(4) Who laughs?

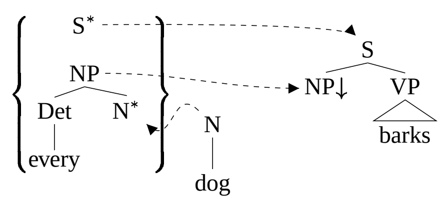

Figure 1: Syntax of (3) *Every dog barks*.

The semantic derivation for the simple quantified sentence (3) is shown in figure 2. The unifications lead to the following feature identities: $\boxed{1} = \boxed{6}$ (adjunction of the scope part), $\boxed{3} = x$ and $\boxed{7} = l_3$ (substitution of *dog* into determiner), $\boxed{2} = x$ and $\boxed{8} = l_1$ (substitution of the NP into *barks*). Replacing the variables by their values and building then the union of all semantic representations leads to (5):

(5) $l_1 : \mathsf{bark}(x),\ l_2 : \mathsf{every}(x, \boxed{4}, \boxed{5}),\ l_3 : \mathsf{dog}(x)$
$\boxed{1} \geq l_1, \boxed{4} \geq l_3, \boxed{5} \geq l_1, \boxed{1} \geq l_2$

There is only one disambiguation, $\boxed{1} \to l_2, \boxed{4} \to l_3, \boxed{5} \to l_1$, which leads to the final semantic representation: $\mathsf{every}(x, \mathsf{dog}(x), \mathsf{bark}(x))$.

Questions The feature *maximal scope* (MAXS) is needed to provide the correct maximal scope of quantifiers. This is important in questions, as we will see later. Furthermore, MAXS is also used to make sure that quantifiers embedded under attitude verbs such as *think* cannot scope over the embedding verb (see Kallmeyer and Romero, 2004, for further discussion).

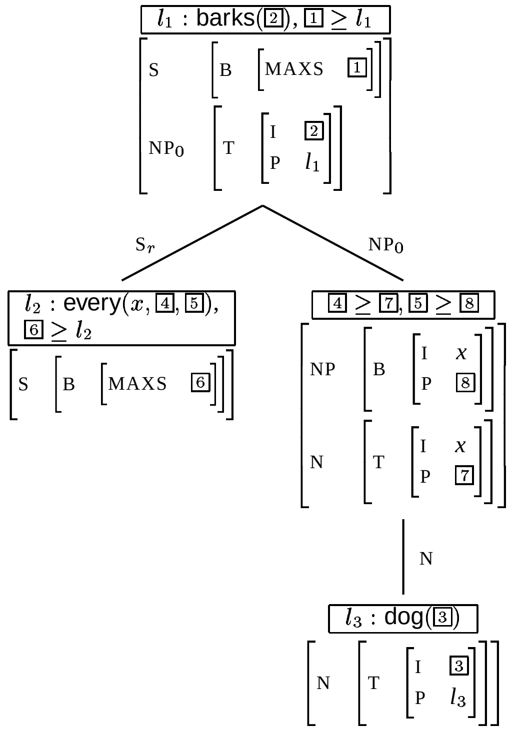

Figure 2: Semantic derivation of *Every dog barks.*

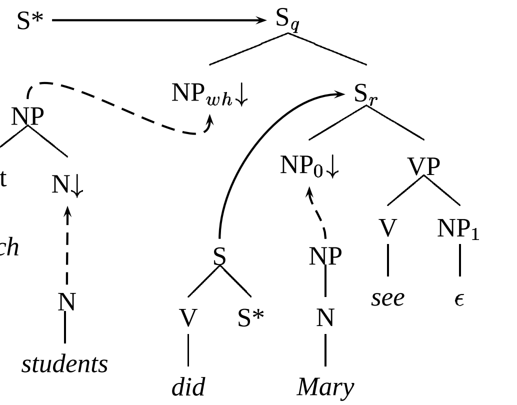

Figure 3: Syntactic derivation of *Which students did Mary see?*

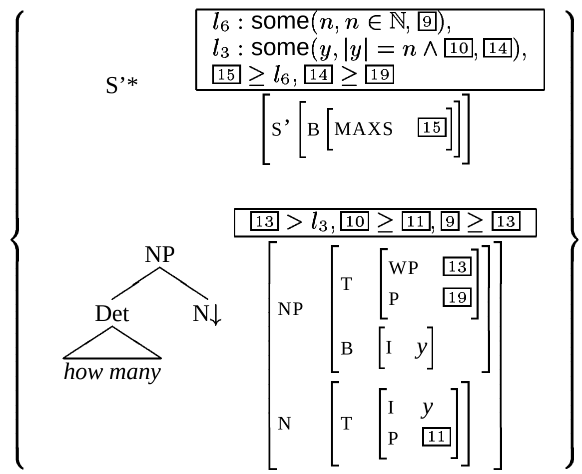

Figure 5: Lexical entry for *how many*.

Following Romero et al. (2004), we assume that wh-operators, like quantifiers, also have a separate scope part and they also have a MAXS scope limit. But their scope limit is provided by the S' node, not the S node. For an analysis of the question *Which students did Mary see?*, see figures 3 and 4.

The MAXS features together with the semantics of the question verb make sure that all wh-operators have scope over the question proposition (here l_2) and all quantifiers scope below this proposition. The minimal nuclear scope of the wh-operator (variable $\boxed{2}$) is provided by the question proposition l_2.

3 A Lexical Entry for *how many*

In this section, we give Multicomponent-TAG elementary trees and appropriate semantic representations that show how to derive the meaning of *how many* sentences in TAG.

As noted above, the phrase *how many* introduces two existential quantifiers. Both appear together in the semantic representation. As for all (wh-)quantifiers, the contribution is split up into a predicate-argument and a scope part. Here, the predicate-argument part is empty and contains only some constraints. This makes *how many* analogous to *which* (see the derivation in figure 4 above), in that the restriction is provided by the noun that substitutes into the quantifier. The lexical entry we propose for *how many* is shown in figure 5.

The additional complication of this lexical item is that the two quantifiers it contributes do not have exactly the same scope. One (l_6) is a wh-quantifier that needs to take scope over the question proposition in the verbal tree. The constraint $\boxed{9} \geq \boxed{13}$ guarantees that the wh-quantifier itself must stay on top of the tree and not be reconstructed.

The other quantifier is a “normal” one whose minimal scope is the elementary predication of the verbal tree. Thus, it is not enough to have one single feature P in the root node of the predicate-argument part to provide the minimal scope for both quantifiers (as was still sufficient in the case of *which* above). We introduce a feature WP

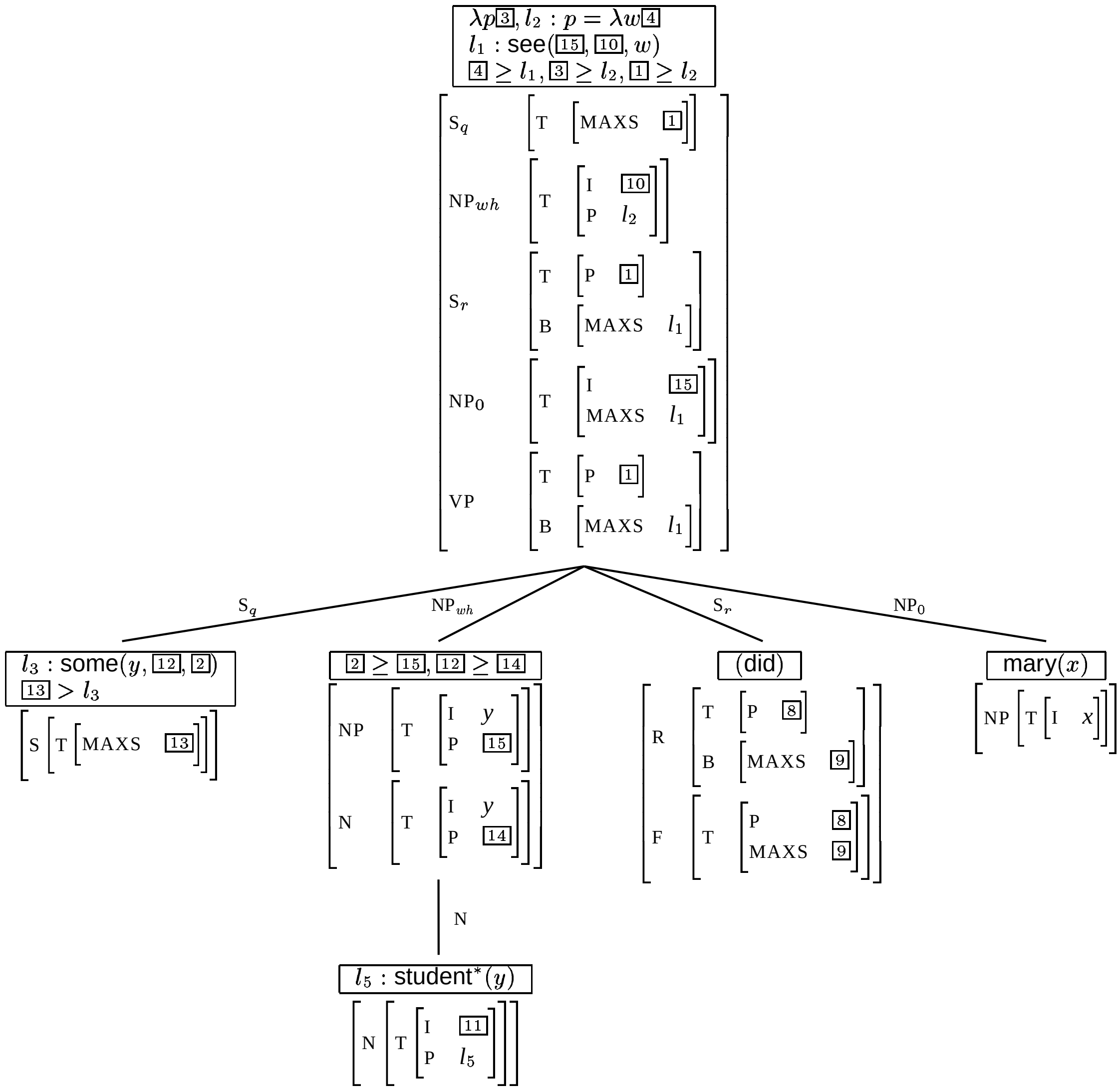

Figure 4: Semantic derivation of *Which students did Mary see?*

for this purpose, which provides the minimal scope for the wh-quantifier. Feature P is kept for the non-wh minimal scope. 19 will unify with the verb's basic predicate.

On the other hand, non-wh quantifiers are usually restricted by the MAXS feature of the S node their scope part adjoins into, which in turn is used during embedding under attitude verbs: In *Mary thinks John likes everybody*, the universal quantifier cannot scope over *thinks*. For the non-wh part of *how many*, however, this restriction does not seem to hold: *How many students does Mary think John likes?* is ambiguous between *many* scoping over *think*, or *think* over *many*.[5] This fact is captured in the proposed lexical entry by not giving a maximal scope restriction for the non-wh quantifier l_3. Of course, the constraints $\boxed{9} \geq \boxed{13}$ and $\boxed{13} > l_3$ ensure that l_3 is in the nuclear scope of the wh-quantifier l_6.

[5]This was also pointed out by one reviewer.

4 Interaction with other Scopal Elements

The interesting problem of scopal reconstruction is to obtain the two possible readings of a sentence like (2). The meaning in (b) is easily derivable, because no reconstruction occurs. Reading (a), however, must be obtained by reconstructing $\mathsf{some}(y, stud^*(y) \wedge |y| = n, ...)$ under $\mathsf{should}(...)$.[6] Figure 6 shows the semantic derivation for sentence (2).

[6]For simplicity, an abbreviated notation for the semantics of should is used in this paper. More accurately, the modal verb should introduce a universal quantifier over situations. We will not deal with the computations related to situations here.

Scope underspecification is obtained in the following way: both the *many*-quantifier and *should*'s minimal scopes are restricted by constraints ($\boxed{14} \geq \boxed{19}$ and $\boxed{16} \geq \boxed{17}$, respectively), which makes them both scope over l_1 eventually. Furthermore, the two scopal elements are maximally restricted to be in the scope of the question proposition. Their relative scope is left undetermined.

The feature identities that are derived during the semantic computation of (2) are $\boxed{15} = \boxed{1}, \boxed{13} = l_2, \boxed{19} = l_1, \boxed{4} = y, \boxed{12} = y, \boxed{11} = l_5, \boxed{2} = \boxed{18} = \boxed{6}, \boxed{17} = \boxed{7}, \boxed{3} = x, \boxed{7} = l_1$. Building the union of all semantic representations and substituting values for metavariables as possible leads to the underspecified semantic representation (6):

(6)
$$\begin{array}{l} \lambda p\boxed{1}, l_2 : p = \lambda w\boxed{2}, l_1 : \mathsf{intv}(x,y,w), \\ l_6 : \mathsf{some}(n, n \in \mathbb{N}, \boxed{9}), \\ l_3 : \mathsf{some}(y, |y| = n \wedge \boxed{10}, \boxed{14}), l_5 : \mathsf{student}^*(y), \\ l_7 : \mathsf{should}(\boxed{16}), \mathsf{mary}(x) \\ \boxed{1} \geq l_2, \boxed{2} \geq l_1, \boxed{1} \geq l_6, \boxed{14} \geq l_1, l_2 > l_3, \\ \boxed{10} \geq l_5, \boxed{9} \geq l_2, \boxed{16} \geq l_1, \boxed{2} \geq l_7 \end{array}$$

There is are two possible disambiguations, namely:

(a)	$\boxed{1}$	$\to$	l_6	(b)	$\boxed{1}$	$\to$	l_6
	$\boxed{9}$	$\to$	l_2		$\boxed{9}$	$\to$	l_2
	$\boxed{2}$	$\to$	l_7		$\boxed{2}$	$\to$	l_3
	$\boxed{16}$	$\to$	l_3		$\boxed{10}$	$\to$	l_5
	$\boxed{10}$	$\to$	l_5		$\boxed{14}$	$\to$	l_7
	$\boxed{14}$	$\to$	l_1		$\boxed{16}$	$\to$	l_1

which result in the two appropriate readings for the sentence:

(a) $\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{should}(\mathsf{some}(y, |y| = n \wedge \mathsf{stud}^*(y), \mathsf{intv}(x,y,w) \wedge \mathsf{mary}(x))))]$

(b) $\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{some}(y, |y| = n \wedge \mathsf{stud}^*(y), \mathsf{should}(\mathsf{intv}(x,y,w) \wedge \mathsf{mary}(x))))]$

Attitude Verbs In TAG, predicates that take clausal complements anchor auxiliary trees that adjoin into their embedded sentences. Figure 7 shows the lexical entry for the verb *think*[7].

A verb like *think* functions as a boundary for MAXS by projecting a different variable upwards. However, as we have seen above, the maximal scope of the non-wh quantifier of *how many* is not restricted by the MAXS feature of the S node. This ensures that even if a how-many question is embedded under an attitude verb, there is some freedom for the quantifier's scope with respect to other scopal elements, e.g., *should* and *think*. Therefore, sentence (7) still has at least the two meanings given along with it in (a) and (b). In addition, one meaning should be

[7]For simplicity, we have already combined *think* with *do* and *you* in this figure. So for all practical purposes, this would not be a lexical entry for any broad TAG-grammar, although nothing in the theory prohibits such lexical items.

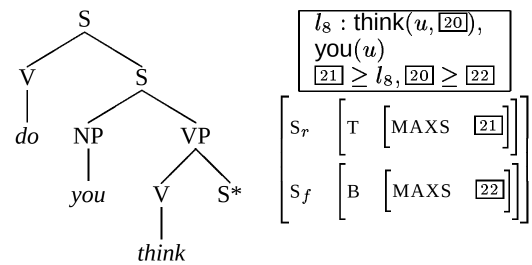

Figure 7: Lexical entry for *think*.

obtainable where *many* scopes over both *think* and *should* (c). This reading shall not concern us here.

(7) How many students do you think Mary should interview?

(a) $\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{think}(u, \mathsf{should}(\mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{intv}(x,y,w) \wedge \mathsf{mary}(x))))))]$

(b) $\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{think}(u, \mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{should}(\mathsf{intv}(x,y,w) \wedge \mathsf{mary}(x))))))]$

(c) $\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{think}(u, \mathsf{should}(\mathsf{intv}(x,y,w) \wedge \mathsf{mary}(x))))))]$

The syntactic analysis of example (7) is depicted in figure 8. The semantic derivation for the sentence is very similar to the non-embedded sentence (2), shown in figure 6. The only difference is the additional adjuntion of the semantic representation as shown in figure 6 with the semantic formulae and feature structure shown in figure 7, at the S_r node of the *interview* tree.

The feature unifications triggered by the semantic derivation are: $\boxed{15} = \boxed{1}, \boxed{13} = l_2, \boxed{19} = l_1, \boxed{4} = y, \boxed{12} = y, \boxed{11} = l_5, \boxed{18} = \boxed{6}, \boxed{17} = \boxed{7}, \boxed{3} = x, \boxed{7} = l_1, \boxed{21} = \boxed{2}, \boxed{22} = \boxed{6}$. (Note that because of the adjunction, some previous unifications are not carried out any more: $\boxed{2} \neq \boxed{6}$.) This yields the following semantic representation for the complete sentence *How many students do you think Mary should interview?*:

(8)
$$\begin{array}{l} \lambda p\boxed{1}, l_2 : p = \lambda w\boxed{2}, l_1 : \mathsf{intv}(x,y,w), \\ l_6 : \mathsf{some}(n, n \in \mathbb{N}, \boxed{9}), \\ l_3 : \mathsf{some}(y, |y| = n \wedge \boxed{10}, \boxed{14}), l_5 : \mathsf{student}^*(y), \\ l_7 : \mathsf{should}(\boxed{16}), \mathsf{mary}(x), \\ l_8 : \mathsf{think}(u, \boxed{20}), \mathsf{you}(u) \\ \boxed{1} \geq l_2, \boxed{2} \geq l_1, \boxed{1} \geq l_6, \boxed{14} \geq l_1, l_2 > l_3, \\ \boxed{10} \geq l_5, \boxed{9} \geq l_2, \boxed{16} \geq l_1, \boxed{6} \geq l_7, \boxed{2} \geq l_8, \boxed{20} \geq \boxed{6} \end{array}$$

The representation accounts for the fact that *think* necessarily scopes over *should*, but the *many*-quantifier can scope out of it.

Two of the possible disambiguations (where *think* has widest scope) are shown below, and they represent the two readings (a) and (b):

(a)	$\boxed{1}$	$\to$	l_6	(b)	$\boxed{1}$	$\to$	l_6
	$\boxed{9}$	$\to$	l_2		$\boxed{9}$	$\to$	l_2
	$\boxed{2}$	$\to$	l_8		$\boxed{2}$	$\to$	l_8
	$\boxed{20}$	$\to$	l_7		$\boxed{20}$	$\to$	l_3
	$\boxed{16}$	$\to$	l_3		$\boxed{10}$	$\to$	l_5
	$\boxed{10}$	$\to$	l_5		$\boxed{14}$	$\to$	l_7
	$\boxed{14}$	$\to$	l_1		$\boxed{16}$	$\to$	l_1

Islands Reconstruction is not always possible. In examples such as (9) with extraction out of weak islands (Ross, 1967), only the non-reconstructed reading (where Mary should interview specific students) is possible for *how many*.

(9) How many students do you wonder whether Mary should interview?

(b) $\lambda p.[\mathsf{some}(n, n \in \mathbb{N}, p = \lambda w.\mathsf{wonder}(u, \mathsf{some}(y, \mathsf{stud}^*(y) \wedge |y| = n, \mathsf{should}(\mathsf{intv}(x, y, w) \wedge \mathsf{mary}(x))))))]$

The status of weak islands is not completely clear. Many studies suggest that the factor that prohibits one of the possible interpretations in sentences such as (9), and which is traditionally attributed to the failure of *students* to reconstruct across a weak island barrier (see Cresti, 1995), is really a pragmatic rather than syntactic or semantic phenomenon.

The issue whether this effect can be accounted for compositionally with LTAG or whether it has to be resolved by a pragmatic process is left for further work.

5 Conclusion

In this paper we showed that using recently developed frameworks for representing semantics in LTAG, we can account for ambiguities that arise in *how many* questions in an elegant way. The use of underspecified semantics and the feature unification process as employed also in the syntactic composition in TAG together allow the reconstruction of non-wh quantifier lower in the tree.

We proposed a lexical entry and semantic specification for *how many* which introduces two quantifiers, one of the wh type, and one non-wh quantifier. We presented how these quantifiers obtain exactly the right scopal possibilities in simple and embedded questions. Furthermore, we showed how the proposed lexical entry interacts compositionally with other scopal elements in questions, such as modal verbs, and how two readings are obtained from a single semantic representation.

An account for weak island constraints is left for future work. We propose that weak island barriers in these contexts may actually be a pragmatic effect that should not affect our semantic analysis.

Acknowledgments

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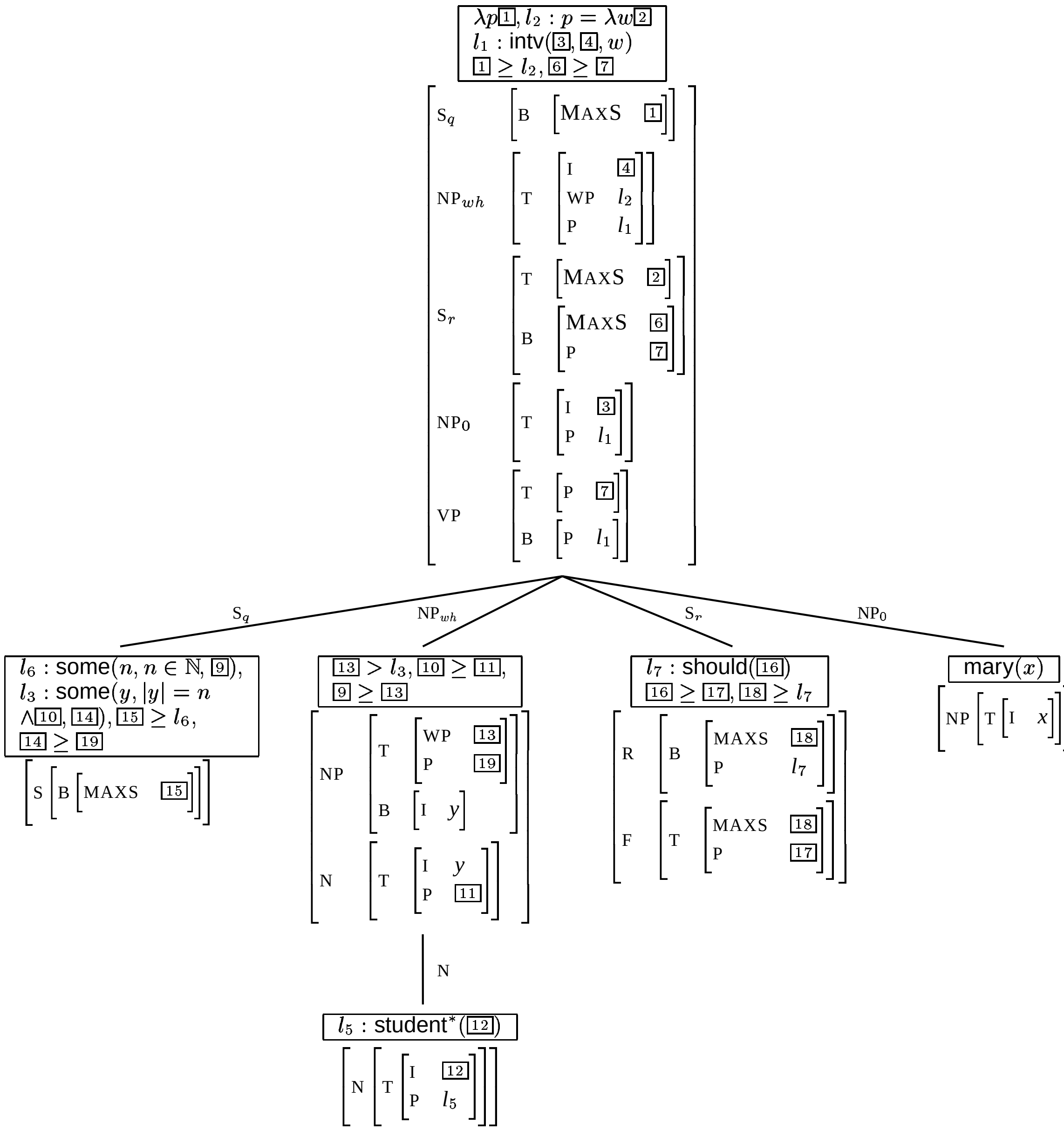

Figure 6: Semantic derivation tree for (2) *How many students should Mary interview?*

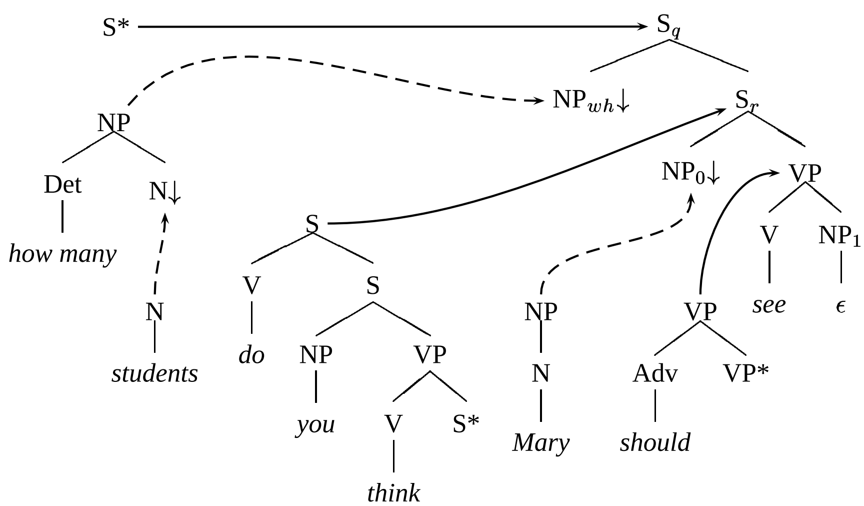

Figure 8: Syntactic derivation of *How many students do you think Mary should see?*

This papers presents a compositional semantic analysis of interrogatives clauses in LTAG (Lexicalized Tree Adjoining Grammar) that captures the scopal properties of wh- and nonwh-quantificational elements. It is shown that the present approach derives the correct semantics for examples claimed to be problematic for LTAG semantic approaches based on the derivation tree. The paper further provides an LTAG semantics for embedded interrogatives. View on ACL. anthology.aclweb.org.Â Semantic Reconstruction for how many-Questions in LTAG. Tatjana Scheffler. Mathematics, Computer Science. In this paper, we show how to formalize recon-struction effects in an LTAG semantics. We de-rive a lexical entry and semantic specification for how many, which introduces two quantifi-cational elements. We also show how they in-teract compositionally with other scopal items, e.g. modal and attitude verbs in a question. The use of an underspecified semantics allows the compact representation of scope ambiguities. We demonstrate how this also enables us to obtain the correct readings in embedded ques-tions. Discover the world's research. 19+ million members. LTAG Analysis for Pied-Piping and Stranding of wh-Phrases. Laura Kallmeyer UFRL. University Paris 7 2 place Jussieu.Â We consider questions involving pied piping and stranding and we propose elementary trees and semantic representations that allow to account for both constructions in a uniform way. 1 Introduction. In questions where the wh-word is embedded into a larger NP, there are two structural possibilities, shown in (1) and (2). Semantic Reconstruction for how many-Questions in LTAG. Article. Jan 2004. Tatjana Scheffler. In this paper, we show how to formalize recon-struction effects in an LTAG semantics. We de-rive a lexical entry and semantic specification for how many, which introduces two quantifi-cational elements. We also show how they in-teract compositionally with other scopal items, e.g. modal and attitude verbs in a question. The use of an underspecified semantics allows the compact representation of scope ambiguities. We demonstrate how this also enables us to obtain the correct readings in embedded ques-tions. The proposed network architecture for semantic 3D reconstruction is illustrated in Fig. 2. The input to our network is a set of semantically labeled depth maps aggregated into a 3D volume of truncated signed distance functions (TSDFs). More specically, we follow [12] and accumulate per label evidence, e.g., using depth maps from stereo and corresponding semantic image segmentations.Â In summary, our proposed approach makes it tractable to perform joint semantic 3D reconstruction for both larger scenes and signicantly more labels, as shown in the experiments. 4.2 Experiments on Synthetic 2D Data. Dataset.