The Shape of Elementary Trees and Scope Possibilities in STAG

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Abstract

Work on the syntax-semantics interface in the TAG framework has grappled with the problem of identifying a system with sufficient power to capture semantic dependencies which also imposes formally and linguistically interesting constraint on the kinds of dependencies that can be expressed. The consensus in recent years appears to have shifted to the use of a system that is substantially more expressive than TAG. In this paper, we revisit some of the arguments in favor of more formal power, particularly those from Nesson and Shieber (2008). We show that these arguments can be defused once we adopt a different perspective on predicate-headed semantic elementary trees, namely that they are divided into scope and variable components like their quantificational counterparts. We demonstrate as well that this proposal provides an new perspective on scope rigidity.

1 TAG Semantics and Formal Power

Much of the interest in using Tree Adjoining Grammar as the structure-building component of syntactic theory stems from the combination of its formal and computational restrictiveness and its apparent sufficiency to express the kinds of patterns that are found in natural language. Over the past couple of decades, researchers have attempted to augment TAG models of syntax with mechanisms for assigning semantic interpretations. One line of work in this regard is that of Kallmeyer and Joshi (2003) and Kallmeyer and Romero (2008). In this approach, elementary trees are associated with underspecified semantic descriptions, which are combined using a combinatory mechanism that operates in parallel with TAG derivational steps, essentially a form of feature unification. Though this approach has had considerable empirical success, it does so by sacrificing the restrictiveness of the TAG formal system: unification over unbounded feature structures is Turing complete (Johnson, 1988).[1] An alternative line exploits the TAG combinatory machinery itself to construct semantic interpretations, through a synchronous derivation of syntactic representations and semantic terms (Shieber and Schabes, 1990). Though this Synchronous TAG (STAG) approach is appealing, because it maintains the constrained approach to grammatical combination embraced in TAG, it remains an open question whether it is sufficiently powerful to accomplish the task of assigning compositional interpretations. Indeed, in comparison to the wealth of work on the grammatical complexity of patterns found in natural language syntax, there is precious little work studying the complexity of semantic patterns, or of the syntax-semantics mapping.[2]

Recently, Nesson and Shieber (2008) have argued that there are empirical reasons to move

[1]As far as we are aware, Kallmeyer and colleagues have not proposed restrictions on their system which constrains its expressiveness. One interesting avenue to pursue in this connection could follow the work of Feinstein and Wintner (2008) who prove that the class of one-reentrant unification grammars generate exactly the Tree Adjoining Languages. Of course, it remains an open empirical question whether imposing this restriction on this approach would yield a system that is sufficiently expressive to assign meanings in a compositional fashion. We briefly return to this issue in Section 5 below.

[2]See Marsh and Partee (1984) for one notable exceptions, though questions remain about the empirical relevance of this result.

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beyond the tree-local multicomponent version of STAG advocated by Shieber and Schabes (1990) and in Schabes and Shieber (1994), to a system which is greater in power than simple TAG. In this paper, we suggest that Nesson and Shieber were mistaken: the examples that they use to motivate greater expressive power can in fact be dealt with using tree-local MCTAG, but only once we rethink the semantic representations of elementary trees for lexical predicates. We then move beyond English, showing that this new conception of semantic elementary tree set provides a natural way to characterize cross-linguistic variability in scopal flexibility, a variability that is unexpected under the multiple adjunction approach to scope ambiguity. Finally, we briefly discuss a potential analogy between scope and scrambling and the implications that this analogy has for the complexity of the syntax-semantics interface.

2 Puzzles for a Restrictive Semantics

Nesson and Shieber (2008) present a number of sentence types whose semantic derivations they take to require power beyond that possible under tree-local MCTAG. One of these involves "inverse linking", where a quantifier is syntactically embedded within another quantificational NP. Such a case is given in (1):

(1) Mitt courted every person at some fundraiser.
($\exists > \forall, \forall > \exists$)

To derive an interpretation for this sentence, Nesson and Shieber make use of what has become the standard TAG treatment of quantifiers, given in Figure 1, augmented with dominance links that are crucial only to the inverse linking case. A quantifier's interpretation is assigned two pieces of structure, a scope tree and a variable tree. To derive (1), the quantifier, *some fundraiser*, is combined into the *at*-headed tree set, of which it is

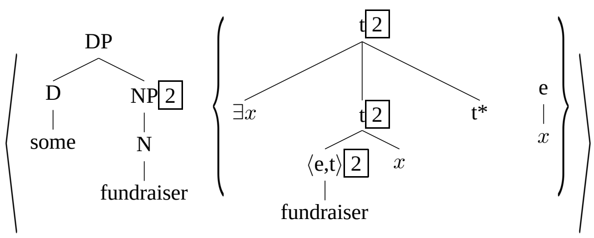

Figure 1: Tree Set for *some fundraiser*

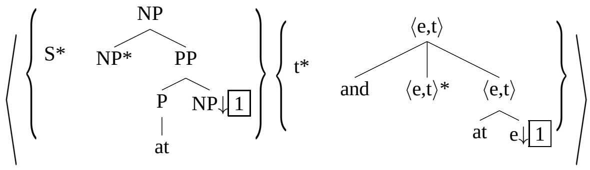

Figure 2: Tree Set for *at* proposed in Nesson and Shieber (2008)

the complement, given in Figure 2: on the semantic side, the variable component of the quantifier substitutes into the ⟨e,t⟩-recursive auxiliary tree, following the link in the syntactic tree. However, there is no place in the ⟨e,t⟩ recursive auxiliary to host the t-recursive scope component of the quantifier, meaning that tree local combination is impossible. It is only because of the presence of the degenerate t component of this tree set that the combination of the quantifier and preposition is even able to occur set locally. The derivation continues by adjoining the derived tree set into another quantifier tree set, representing *every person*, this time tree-locally, within the set's scope component.

Nesson and Shieber invoke a second kind of example to argue for the inadequacy of even set-local MCTAG. This case involves the interleaving of scopal elements from multiple clauses, of the sort seen in (2).

(2) Some professor remembered to review every paper (that he promised to review).
($\exists > \forall >$ remembered)

In the relevant reading of (2), the universal quantifier that is the object of the lower clause takes scope below the existential matrix subject, but above the matrix verbal predicate. This interpretation cannot be derived even set-locally under standard assumptions.[3] If the tree set associated with

[3]In fact, Shieber and Nesson's assumptions about the semantic elementary tree for the control predicate *remember* do not match the ones we are currently making. Instead, they invoke a three-part tree set for the semantics of control predicates like *remember*, including a lambda abstraction over the subject, the lexical predicate and a variable to be inserted into the (controlled) embedded subject position. This move allows them to generate the desired scope for (2), though it does not generalize to slightly more complex cases such as the following, involving a matrix adverbials, as they observe:

(i) Every boy always wants to eat some food.
(always $> \exists > \forall >$ wants)

The proposal we make in the current paper can be seen as

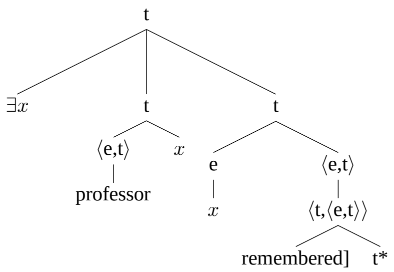

Figure 3: Derived matrix auxiliary tree for *some professor remembered*

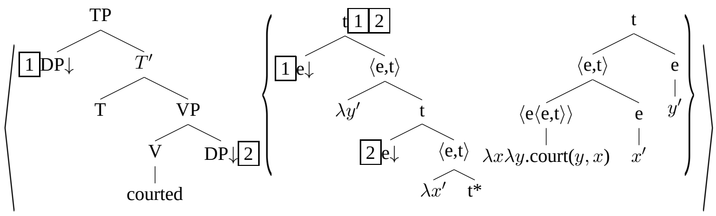

Figure 4: Two-Part Predicate Trees for *courted*

the existential quantifier *some professor* adjoins and substitutes into a single-component semantic elementary tree associated with *remembered*, as it must under tree-local or set-local MCTAG, the relative scope of these elements can be fixed (as $\exists >$*remembered*), forming a derived auxiliary tree that encapsulates these scopal elements, seen in Figure 3. However, because of the nature of the adjoining operation, there is no way the these two elements can be separated when this derived auxiliary tree into it complement *review*, which will also host the embedded quantifier *every paper*. As a result, this embedded quantifier will be able to take scope above all of the matrix scopal elements or below all of them, but crucially not between them, contrary to fact.

Nesson and Shieber also discuss a third type of example, involving pied-piped relative clauses:

(3) John saw a soccer player whose picture every boy bought.

On the relevant reading, the universal quantifier can take scope outside of the (implicit) existential provided by the pied-piped relative asserting the existence of a picture (i.e., each boy bough a distinct picture of the same soccer player). They argue that neither a tree-local nor a set-local analysis can generate this interpretation. In this case, however, the argument rests on what we take to be an implausible analysis of relative clause syntax and semantics, in which the syntactic head and core semantics of a pied-piped relative clause is provided by the possessive morpheme. Below, we discuss an alternative analysis of such pied-piped relatives in which the relative clause semantics and existential force is provided by a verbally-headed relative clause tree, and which allows this interpretation to be derived.

3 A Return to Tree-Locality: A New Proposal for Semantic Elementary Trees

Nesson and Shieber's arguments, interesting as they are, rest on assumptions about the nature of the elementary trees that contribute to the relevant derivations. Though the elementary trees they assume are largely in conformity with other proposals in the TAG literature, they provide no underlying theory of what semantic elementary trees should look like. As a result, it is simply unclear whether their arguments hold up if the constituent elementary trees and assumptions about their structure are changed. To get around their arguments and maintain tree-local combination, our proposal in this paper reconceptualizes the semantic elementary trees for predicates as multicomponent sets. These sets will consist of (at least) two pieces: a 'variable part' and 'scope part'. This division is familiar in the TAG semantics literature for quantifiers, and we propose that it be generalized to argument taking elements of all sorts.

Let us be specific about how this works. The semantic elementary tree set for transitive verb, such as *courted*, will contain two pieces. One, which we call the "variable part", will include the lexical predicate with each of its argument positions saturated by variables. The other, which we call the "scope part", contains a lambda operator binding each of the variables in the variable part, with substitution nodes to which each of the lambda operators applies. The resulting tree set is depicted in Figure 4. To use this tree set to derive an example like *Mitt courted some Detroiters*, the subject and object DP arguments will both combine tree-locally in the semantic derivation with the scope portion of the *courted* tree set,

a generalization of Nesson and Shieber's multicomponent treatment of control predicates to all lexical predicates. Furthermore, by assuming that temporal arguments license their own semantic component, the scope in (i) can be derived.

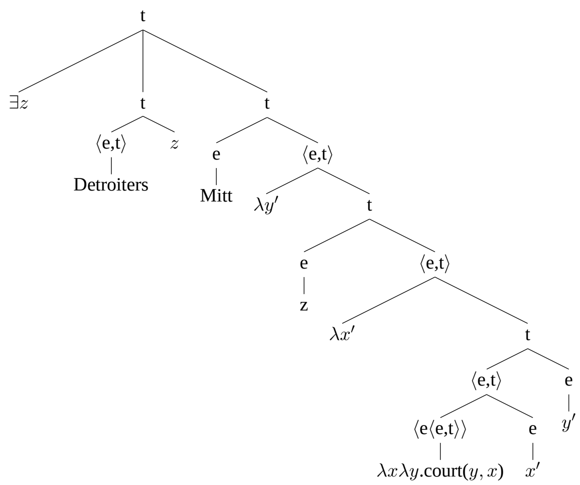

Figure 5: Derived semantic tree for derivation of *Mitt courted some Detroiters*

Mitt through substitution into the higher e node, and *some Detroiters* through substitution into the lower e and adjoining to the root t. When a derivation results with two trees in a single tree set, we assume that they may combine together, with the scope part adjoining to the variable part, resulting in the derived semantic structure in Figure 5. Turn now to the derivation of the putatively problematic inverse linking case (1), repeated here.

(1) Mitt courted every person at some fundraiser.
($\exists > \forall$, $\forall > \exists$)

Note first of all, that our multicomponent approach to the semantics of predicates can be applied to prepositions as well, as seen in Figure 6. Following the derivation tree in Figure 7, the components of *some fundraiser* compose tree-locally into the scope part of *at*, one via substitution and the other via adjoining, just as in the derivation just sketched. Next, both components of *at*'s semantics combine (tree locally) with the scope component of *every person*, via adjoining at either of the $\boxed{2}$-linked t nodes in the quantifier tree set of the same form as the one in Figure 1. If such adjoining targets the higher t node, the inverse linking obtains, while surface scope derives from the lower attachment. Now, the derived object quantifier *every person at some fundraiser* can combine with the verbal predicate as we saw, with scope ambiguity with respect to the subject determined by the ordering of the combinations into the verbal scope tree.

Our conception of predicate-headed elementary trees also yields a tree-local treatment of cases of scopal interleaving like (2), repeated here:

(2) Some professor remembered to review every paper (that he promised to review).
($\exists > \forall >$ remembered)

As before, the tree set representing the object quantifier (tree locally) adjoins and substitutes into the scope component of the (embedded) verb, whose representation will be like the verbal tree in Figure 4. The semantics of the matrix verb *remember* will also involve both scope and variable components, though this time there be an additional variable component corresponding to the controlled argument in the embedded clause. The resulting tree set is given in Figure 8. Interestingly, this tree set is in fact identical to the one adopted by Nesson and Shieber (2008) in their treatment of control. Although they do not explain their motivation for adopting this tree, it is clear that the use of lambda abstraction is driven by the need to have the subject argument of the matrix predicate to bind the variables saturating the external arguments of both the control and embedded predicates. What is less clear is why the lambda operator lies in a separate component from the lexical predicate, and it is this separation that is necessary to derive the scope interleaving. Under the current proposal, the separation of the lambda expression from the lexical predicate into two components is a general property of semantic elementary tree sets. Returning to the deriva-

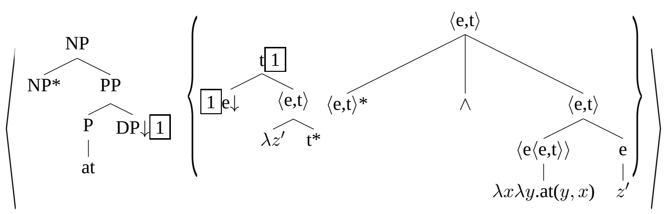

Figure 6: Two-Part Predicate Trees for *at*

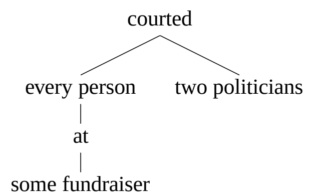

Figure 7: Derivation Tree for (1)

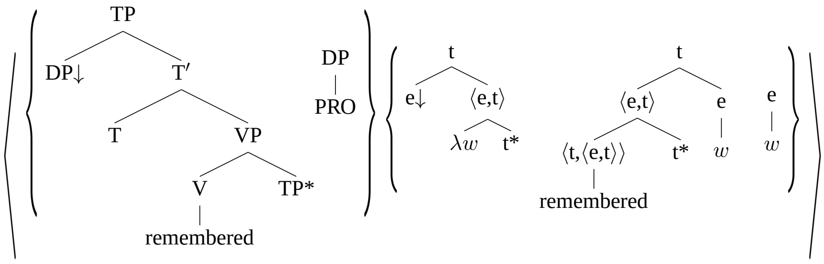

Figure 8: Elementary trees for control predicate *remembered*

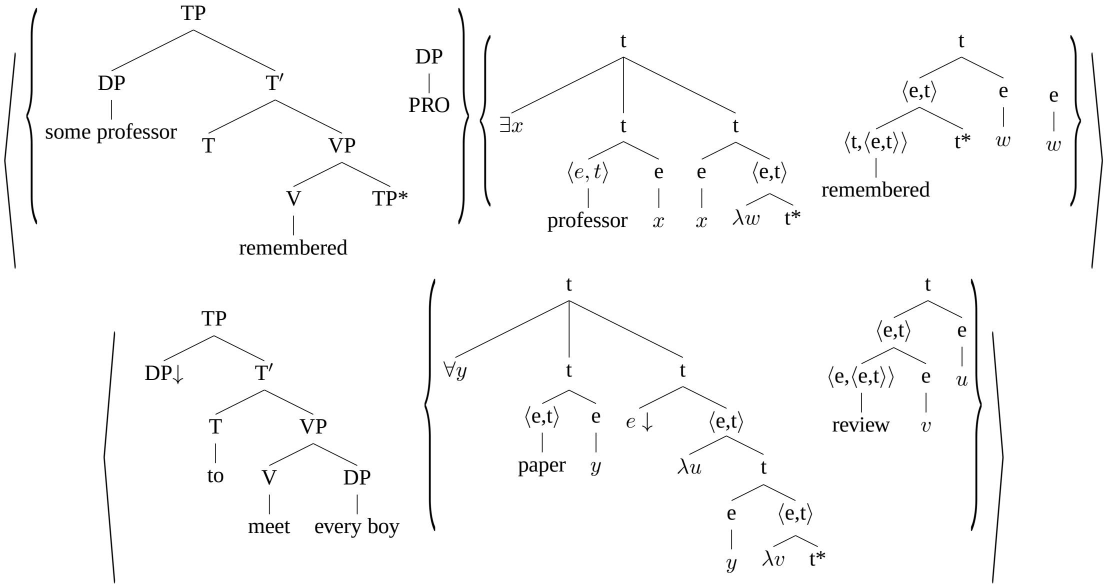

Figure 9: Matrix and embedded derived auxiliary trees for interleaving scope in (2)

tion of (2), the matrix quantifier *some professor* will combine tree-locally into the scope component of the *remembered* tree set. The result of these derivational steps is the two derived tree sets in Figure 9. The matrix clause's tree set will now combine tree locally into the scope component of the embedded clause's tree: because of the control relation, it must combine with this tree if we are to be able to substitute the e-type variable (contributed by the control predicate) into the external argument slot of *review*. Now, by adjoining the scope component of the matrix clause at the root of this scope component, and adjoining the predicate+variable component of the matrix at the foot node of this component, we derive the desired relative scopes. As before, we assume that the remaining components are composed to complete the derivation.

Our approach extends to cases discussed by Nesson and Shieber, where additional scopal interleaving arises because of matrix adverbials:

(4) Every boy always wants to eat some food.
(always $> \exists > \forall >$ wants)

The treatment of such cases depends crucially on the incorporation of temporal arguments into semantic elementary trees, about which see Storoshenko and Frank (this volume). We assume that such arguments are lambda bound in the same way as other e-type arguments, in distinct scope components, and this allows us to treat temporal dependencies in a manner similar to control. In the (semantic side of the) derivation of (4), *always* combines with the temporal scope component of *want*, while *every boy* combines with the e-type scope component. The resulting derived tree set then combines, again tree locally, with the scope component of the *eat* elementary tree set. The interleaving interpretation can now be derived if we adopt a version of delayed combination introduced by Freedman and Frank (2010), whereby the different components of a tree set need not be composed into an elementary tree at a single point in the derivation, even if they remain tree local. Specifically, we first adjoin the variable and e-type scope components of the matrix predicate to the scope component of the *eat* tree set. Then, we combine the scope component of *eats* together with its variable component, and finally we adjoin the temporal scope component.

As already noted, Nesson and Shieber argue that tree local derivations cannot generate interpretations for relative clauses with pied-piping, as in (3).

(3) John saw a soccer player whose picture every boy bought.
($\exists$ soccer player $>$ $\forall$ boy $>$ $\exists$ picture)

In fact, we can generate an interpretation for this example by making use of a relative clause tree rather different from the one assumed by Nesson and Shieber. First of all, we apply our split semantics to the verbally-headed relative clause tree set, shown in Figure 10. This tree includes the familiar structure of a t-recursive scope part, and the predicate component. We assume that the existential force associated with pied-piped relatives is in fact associated with this verbally-headed tree set, and is present in the scope part of this set. In addition, this tree set includes a component representing the relative operator, into which the remaining components may substitute. To a degree, this mirrors those accounts that treat the lambda operator associated with the relative as a part of the semantics of the relative pronoun in that the $\langle$e,t$\rangle$-recursive tree carries only that operator, and takes the remainder of the clause material as an argument via substitution. Though space prevents us form justifying this assumption, we take the semantics of a relativizing DP with a possessive wh-phrase to be of type $\langle$e,$\langle$e,t$\rangle\rangle$, so that a wh-phrase like *whose picture* is assigned an interpretation like $\lambda x \lambda y . y$ is a picture of x. The derivation of (3) proceeds by substituting such a relativizing DP and its associated semantics into the $\boxed{1}$-annotated nodes in Figure 10, and combining the universal quantifier at the $\boxed{2}$-annotated nodes. By adjoining the scope part of the quantifier to the higher t node, we can derive the scope indicated in (3), while adjoining at the lower t node will yield a narrow scope interpretation for the universal (where the choice of picture does not vary scope with the boy).

4 Scope Rigidity

In addition to providing a tree-local analysis of certain problematic cases, our proposal for the structure of semantic elementary trees also provides an account of a phenomenon that has received relatively little attention in the TAG literature (but cf. Freedman and Frank (2010), Freedman (2012)). In contrast to English, where subject and object quantifiers often permit both linear and inverse scope, languages like Japanese exhibit scope rigidity, where the scopal relation among quantifiers is fixed by hierarchical order. This is shown in the following example from Hoji (1985).

(5) Dareka-ga daremo-o aisiteiru.
someone-NOM everyone-ACC love
'Someone loves everyone.'
($\exists > \forall$, *$\forall > \exists$)

Such scope facts are challenging for any analysis which relies on multiple adjoining at a single t node for all arguments of a given predicate, as scope permutations are predicted to take place freely within a clause so long as the two arguments can combine with verb in either order.

Our analysis as presented thus far does not provide an account of this pattern either: the quantifiers would both combine with the scope part of the verbal elementary tree, in either order, leading to an expectation of scope ambiguity. However, it is straightforward to modify the verbal elementary tree set in Figure 4 to achieve the effect of scope rigidity. In particular, we propose that languages may differ in their representation of scope in predicate elementary trees. In languages like English, lambda operators binding argument variables are collected together in a single scope tree. In contrast, we take canonical clauses in languages like Japanese to be represented by elementary tree sets like the one in Figure 11. Here, the lambda abstraction for each e type argument takes place in its own scope tree. Furthermore, we assume that these scope trees are constrained to adjoin in a way that respects their syntactic hierarchical relation, with the result that the subject lambda abstraction component must be higher in the derived tree than the object lambda abstraction component. As before, we assume that the different components of this tree set, if they remain separate, will compose at the end of the derivation, in a manner that respects the specified hierarchical constraints. Now, if we continue to assume that all

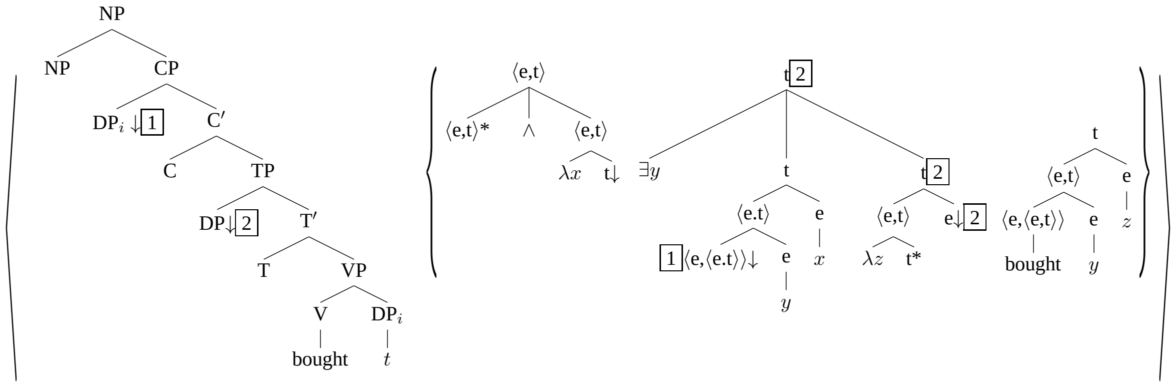

Figure 10: Elementary tree set for pied-piped relative clause in 3

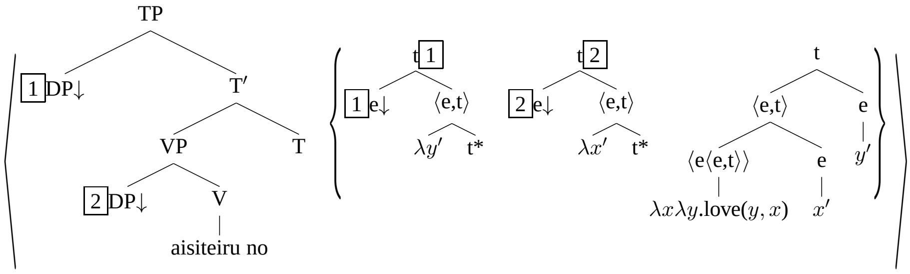

Figure 11: Split scope components for scope rigidity in (5)

combination must take place in a tree-local manner, we derive the unavoidable conclusion that the quantifiers cannot permute with one another: each quantifier tree set substitutes and adjoins to its associated verbal scope tree, with no possibilities for multiple adjoining.

Scope is however not always rigid in Japanese. When an object scrambles past the subject, as in (6), we find the kind of ambiguity familiar from English.

(6) Daremo-o$_i$ dareka-ga t_i
someone-NOM everyone-ACC
aisiteiru.
love
'Everyone, someone loves.'
($\exists > \forall, \forall > \exists$)

Such circumvention of canonical scope could of course be modeled by allowing clauses involving scrambling to be derived by an English-like tree set. However, a more intriguing possibility retains the idea of multiple scope trees in Japanese, as in in Figure 11, but removes the hierarchy constraint that we have imposed on the final positions of the scope trees. Scope ambiguity then results because of multiple possibilities for collapsing the verbal tree set at the end of the derivation. But why would the verbal tree underlying (6) differ in this way from the one underlying (5)? We propose that hierarchy constraints on components of a semantic multicomponent set are the reflection of syntactic hierarchy. In a canonical sentence, the syntax determines a unique hierarchical relation among the arguments, giving rise to a unique possibility for scope. With scrambling, where the object is represented syntactically in both a base and surface position, the hierarchical relation between subject and object is underdetermined, yielding scopal flexibility.

5 A Note on Expressiveness: Scope vs. Scrambling

Though our novel perspective on elementary trees yields a treatment of Nesson and Shieber's problematic cases, one might object that a wealth of other cases await us which cannot be so analyzed. After all, our proposed system for semantic combination remains a tree-local MCTAG, and as such is very limited in the kinds of dependencies that it can capture. Indeed, an anonymous reviewer argues that the kinds of dependencies possible among quantifiers and their variables resembles those between scrambled elements and their associated verbs. The reviewer cites examples of the form in 7, claiming that all scopal orderings of the quantifiers are possible.

(7) Every professor wanted to ask some TA to tell every student to stay at home.

If this is right, the results in Becker et al. (1992) concerning the complexity of scrambling would immediately tell us that scopal dependencies could not be completely captured using tree-local MCTAG.

We see a number of difficulties with this argument. The first of these concerns commutativity of quantifiers. As is well-known, two formulas of first order logic that are distinguished only by the relative order of two quantifiers of the same type (i.e., both universal or both existential) do not have distinct truth conditions. As a result, it is not possible on meaning grounds to distinguish between an ordering of the quantifiers in (7) under which the most embedded universal has scope above the matrix universal or immediately below it. Because of the limited number of quantifier types of natural language, the number of distinguishable scopes will be limited in way that does not parallel the situation with scrambling, where all word orders are easily distinguished. As a result, it remains to be determined whether Becker et al.'s arguments can be adapted to the case of scope, where the set of (semantically distinct) scopes is not equivalent to the set of permutations of the quantifiers.

A second problem for this argument parallels a similar one that has been pointed out for scrambling. As Joshi et al. (2000) note, all word order permutations up to a certain depth of embedding can be generated with tree-local MCTAG using elementary trees of a linguistically plausible sort. To show that a grammar for scrambling requires greater power, we must appeal to more complex cases, whose empirical status is not clear. And although it is not unreasonable to assume that the grammar of scrambling does indeed generalize in way that produces all permutations of arguments over arbitrary levels of embedding including the empirically murky cases (as Rambow (1994) does), Joshi et al. (2000) argue that it is equally sensible to assume that the grammar generates only a subset of the possible cases, because of limits on its generative capacity, so long as this includes all of the cases that are indisputably acceptable to speakers. The situation with scope seems to us completely parallel. Although many scopings are imaginable in examples like (7) and more complex cases along the same lines, the empirical situation is far from clear with respect to which interpretations are actually available to speakers. Therefore, the prudent course seems to us to be one which explores the empirical landscape of these cases, in an attempt to find cases that demand additional power.

Acknowledgments

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