Reconstruction as delayed evaluation[1]

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[1] Thanks to Pauline Jacobson, Oleg Kiselyov, Chung-chieh Shan, and Yoad Winter. Special thanks to Pauline Jacobson for extensive and incisive discussion. The analysis presented in this paper is a modest extension of joint work with Chung-chieh Shan (see Shan and Barker 2006 and Barker and Shan 2006), and many of the insights here are due to inspiring conversations with Shan. However, I have drawn conclusions here that Shan may not necessarily endorse. Therefore I will speak of "our analysis", meaning Shan and Barker (2006), but I will express opinions about the interpretation of that analysis in the first person singular.

0.1 Quantificational binding in reconstruction examples

Not all logically coherent binding relationships are possible in English, of course. For instance, in weak crossover configurations, a quantifier cannot bind a pronoun without preceding it:

(1) a. Everyone$_i$ loves his$_i$ mother. $\forall x.\mathbf{loves}\,(\mathbf{mother}\,x)\,x$
b. *His$_i$ mother loves everyone$_i$. $\forall x.\mathbf{loves}\,x\,(\mathbf{mother}\,x)$

In certain reconstruction configurations, however, a quantifier can bind a pronoun that linearly precedes it:

(2) [Which of his$_i$ relatives] does everyone$_i$ love _?

One popular idea is that (at least part of) the bracketed *wh*-phrase moves ('reconstructs') into the indicated gap position before binding relationships are established:

(3) [Which _] does everyone$_i$ love [_ of his$_i$ relatives]?

In the reconstructed configuration in (3), the quantificational NP *everyone* c-commands the pronoun in question, and the binding relationship looks perfectly ordinary. (There is a variation of this approach on which the gap contains a silent copy of the fronted *wh*-phrase, but we will not need to distinguish between movement versus copy reconstruction in this paper.)

On a descriptive level, my goal is to show how the system in Shan and Barker (2006), which accounts for weak crossover contrasts like (1), can handle reconstruction examples like (2) as well. I will argue that the resulting analysis has a number of empirical advantages over the direct-compositional account in Jacobson (1994, 2003).

On an explanatory level, my goal is to search for a deeper understanding of what the phenomenon of reconstruction is. Following the lead of Sternefeld (1998), Shan and Barker (2006) and Barker and Shan (2006), I will explore the idea that reconstruction is a form of delayed semantic evaluation: roughly, that the evaluation of the fronted *wh*-phrase is delayed until the normal evaluation of the gap position. Sternefeld (1998) implements a delay mechanism by stipulating a formal distinction between variables and metavariables. In contrast to Sternefeld's analysis, on our account, delayed evaluation falls out automatically from the independently-motivated interaction of quantification and binding.

0.2 Four theories of reconstruction

I will briefly discuss four approaches to handling reconstruction facts. The first is classical syntactic reconstruction, on which a portion of the fronted material moves into gap position at LF, i.e., before semantic interpretation. There are many movement analyses that differ in important ways from one another (see, e.g., Heycock 1995 for a useful survey). What they all have in common that distinguishes them from the other three classes of analyses discussed here is that they make crucial use of a level of syntactic representation that is distinct from surface syntactic relationships.

The second class of analyses is a radically different approach on which the appearance of a binding relation is an illusion created by manipulating sets of functions. I will sometimes call this class of approaches 'apparent binding' accounts, or sometimes 'functionalist' accounts. Jacobson's (1994, 2003) is the most highly developed instance of this approach, and I will discuss it in some detail.

The third is an approach called 'semantic reconstruction', on which there is no syntactic movement. Instead, reconstructed pronouns are interpreted as a special type of complex variable that Sternefeld calls a pseudo-variable, so that all of the maneuvering takes place in the semantics rather than in the syntax.

The fourth approach, of course, is our own.

0.2.1 So what's wrong with syntactic reconstruction?

The main objection to the classical analysis is simply "Why?": why must some material reconstruct? Certainly it would be perfectly semantically coherent to interpret a fronted *wh*-phrase in its syntactic position, with no binding or reconstruction effects. Why also postpone binding, since binding relationships are normally established before covert movement at LF? On our account, such questions do not arise. In fact, because reconstruction effects fall out automatically for us, it would require special stipulation to prevent them.

As a more methodological objection, syntactic reconstruction fails to be directly compositional in the sense of, e.g., Jacobson (2002). In a directly compositional system, every syntactic constituent has a well-defined semantic interpretation. This is not the case for syntactic reconstruction. In particular, on the syntactic account, a fronted *wh*-phrase such as *which of his relatives* never receives a semantic value. On our account, every syntactic constituent has a meaning.

0.2.2 The apparent-binding strategy

Jacobson (1994, 2002), Sharvit (1999), and Winter (2004) propose that certain cases of quantificational binding depends on analyzing some NPs as denoting functions (instead of individuals or generalized quantifiers). Sharvit attributes a similar strategy to unpublished work of von Stechow from 1990; Jacobson also traces the central idea back to the analysis of functional questions of Engdahl and of Gronendijk and Stokhof.

I will compare our account in some detail to the funtionalist approach in Jacobson (1994, 2003):

(4) a. [The woman that every man loves] is [his mother]. SPEC. COP.
  b. the [relative of his] [that every man loves] NOM. MOD.

What these two constructions have in common is that a quantifier inside of a relative clause (here, *every man*) seems to bind a pronoun outside of the relative clause (*his*). Normally, relative clauses are scope islands, so these binding relationships require explanation.

Consider the nominal modifier case in (4b). On Jacobson's analysis, applying her **z** combinator to the denotation of *loves* yields an interpretation on which *that every man loves* denotes the set of functions f such that every man x loves fx (see Jacobson (2003) for technical details).

The ordinary denotation of a nominal does not have a type that allows it to combine with a set of functions, so Jacobson provides a combinator **m** such that $\mathbf{m}(\textit{relative of his}) = \lambda f \forall x.\mathbf{relative}\, x\, (fx)$. Roughly, **m** takes a relation and returns the set of functions that are subsets of that relation. In this case, **m** returns the set of (partial) functions f such that for all x in the domain of f, fx is a relative of x. (Actually, in Jacobson's system, **m** must be a family of operators, one for each number of pronouns participating in the apparent binding relation.)

Finally, the relative clause will combine semantically with the nominal head by means of set intersection. In the case in hand, this intersection will include all functions f such that f maps each x to a relative of x, and for every man x, x loves fx. Assuming that the only salient such function is the function that maps each man onto his mother, then the definite description as a whole will denote the **mother-of** function.

One remarkable property of the functionalist analysis is that there is no binding relationship between the quantifier and the pronoun. Rather, there is only the appearance of binding, brought about by equating sets of functions.

Sharvit (1999), Jacobson (2003), and Winter (2004) assume that the relative clause analysis can and should be generalized to at least some fronted *wh* cases. Sharvit (1999) in particular argues that there are strong parallels between the empirical behavior of functional relative clauses and *wh* reconstruction cases; for instance, both phenomena are sensitive to weak crossover violations (see section 6.4 below). However, none of these authors provide concrete details for the reconstruction cases:

(5) a. the [relative of his] [that every man loves _]
    b. Which [relative of his] [does every man love _]?

Presumably the semantics for *which* will result in a paraphrase such as 'tell me the function f such that for all x, fx is x's relative, and every man x loves fx'.

The apparent-binding strategy as developed by Jacobson is highly similar to ours in framework, philosophy, and a number of important assumptions. Both analyses are embodied in a combinatory categorial grammar obeying strict direct compositionality, and we rely heavily on the assumption that pronouns and other elements denote identity functions, an idea explored in detail in much of Jacobson's work.

On the empirical side, however, there are at least four significant differences between the apparent-binding approach and ours.

Radical context-dependency: plumbers and kittens. Consider the following example:

(6) The person that every plumber loves most is her mother.

Since $\mathbf{m}(\mathit{person})$ returns the set of all functions whose range is included in the set of people, the prediction is that (6) will be true only if the mother function maps each plumber onto a person. So far so good. But the semantics of $\mathbf{m}$ also guarantees that (6) will be true only if every mother is a person. The reason is that a function f only gets into the set returned by the $\mathbf{m}$ operator if f maps every object x in its domain into the set of people, whether x is a plumber or not. But of course all sorts of creatures have mothers; after all, (6) can be true at the same time that the cat that every kitten loves most is *her* mother. The fact is, when evaluating (6), we need to limit our attention to how the functions involved behave when applied to plumbers, and kittens should be completely ignored. But this restriction is not guaranteed by the truth conditions of the functionalist analysis.

Perhaps the context restricts the mother function to the domain of plumbers (or kittens) on a per-use basis. One way to do this would be to assume that uses of pronouns routinely contribute domain restrictions, as Jacobson has proposed in other work relating to contrastive focus on pronouns. Then (6) will be appropriately used in a context in which *her* is a partial function defined only on female plumbers. The problem, as pointed out by Dimitriadis (2002), is that figuring out the domain restriction for a pronoun depends on distant semantic material in an arguably non-compositional way.

Spurious readings. The following examples are based on observations that Jacobson (personal communication) attributes to Heycock (personal communication):

(7) a. Which woman [that he loves] [does every man respect]?
b. Which woman [that he loves] [does John respect]?

On Jacobson's account, the (appearance of a) bound reading for (7a) arises by application of **m** to *that he loves*, where **m**(*that he loves*) $= \lambda f \forall x.\mathbf{loves}(fx)x$ (see the discussion in Jacobson (2003) after her example (28)). This shift allows *that he loves* to denote a set of functions suitable for intersecting with the set of functions denoted by (the functional reading of) *does every man respect*. But the fact that *every man* is quantificational plays no role in constructing the functional reading: all that is required is application of **z** to *respect*. Consequently, *does John respect* will also have a functional interpretation, namely, $\lambda f.\mathbf{respects}(f\,\mathbf{j})\,\mathbf{j}$. The prediction is that (7b) should have an analysis such that *his mother* is a true answer only if every man loves his mother. But (7b) has no such reading.

Evidently, **m** should not be allowed to apply freely, but needs to be triggered by the presence of some overt quantifier elsewhere in the sentence. The main claim of the apparent-binding approach is that there is no formal link between the quantifier and the pronoun it seems to bind; but what examples like (7) show is that eliminating the formal link gives rise to spurious readings. Because our account does not rely on the **m** operator, these spurious readings do not arise.

Undergeneration: outbound binding. A third empirical problem involves cases in which the fronted *wh*-phrase contains a quantifier, rather than a pronoun.

(8) a. [Which of every applicant$_i$'s scores] did someone forget to record in his$_i$ file? (Engdahl)

b. ...we summarize [what part of each model$_i$] is critical for producing its$_i$ fundamental behavior

c. We're trying to find out [which aspect of each wine$_i$] has the strongest effect on its$_i$ quality.

I will call examples like (8), in which it is a quantifier that needs to be reconstructed, **outbound binding**. Outbound binding is unexpected on the apparent-binding account. The problem is that there is no obvious way to shift *of every applicant's scores* to a set of functions. The reason is that there is no gap or pronoun to get the functional interpretation started, as there was in the relative clause case, so **m** does not apply. I return to outbound binding in section 6.3 below.

***How-many* questions**. Finally, the extension of the analysis in Jacobson (2003) sketched above does not give an appropriate semantics for other types of questions:

(9) How many [relatives of his] [does every man love]?

Assume the men are John and Bill, who each love their parents, and no one else. Then **m**(*relatives of his*) will yield the following set of functions:

$$\begin{array}{ll} f_1(\mathbf{j}) = \mathbf{mom}(\mathbf{j}) & f_1(\mathbf{b}) = \mathbf{mom}(\mathbf{b}) \\ f_2(\mathbf{j}) = \mathbf{mom}(\mathbf{j}) & f_2(\mathbf{b}) = \mathbf{dad}(\mathbf{b}) \\ f_3(\mathbf{j}) = \mathbf{dad}(\mathbf{j}) & f_3(\mathbf{b}) = \mathbf{mom}(\mathbf{b}) \\ f_4(\mathbf{j}) = \mathbf{dad}(\mathbf{j}) & f_4(\mathbf{b}) = \mathbf{dad}(\mathbf{b}) \end{array}$$

Since there are four functions, the simple-minded version of *how many* will incorrectly predict that *four* ought to be a true answer in the situation described. (The situation is more complex if we allow non-atomic entities in the range of the functions, but the answers still come out wrong.)

The problem is that we don't want a count of functions, we want a function from individuals to counts: for each individual x, the number of x's relatives that are loved by x.

Interestingly, there is an apparent-binding analysis that constructs exactly the right sort of function. Winter (2004) approach is dual to Jacobson's: Jacobson starts with the functional meaning that her theory assigns to the relative clause and shifts the nominal head (via her **m**) so that it matches in type. Winter shifts instead the functional relative clause meaning (via his operator **RG**) into a function from individuals to sets (for instance, mapping each man onto the set of things he loves). As far as I can see, however, Winter's analysis shares (some version of) the other three empirical challenges with Jacobson's account.

These four empirical issues (the plumber problem, spurious readings, outbound binding, and *how-many* questions) motivate considering an alternative analysis of reconstruction. We provide such an account below, without needing an operator like **m** or **RG** (nor any operator specific to handling reconstruction). The result will be an analysis on which the apparent binding between the quantifier and the pronoun is genuine binding.

0.2.3 Semantic reconstruction

Several authors have suggested that reconstruction is primarily semantic in nature rather than syntactic. Versions of this idea are due to Cresti (1995:85), Rullman (1995:174), and Sternefeld (1998). There is a relevant discussion in Romero (1998:82); von Stechow (1998) traces the idea back to a 1979 Bennet paper (no longer available from IULC), and relates it to the notion of dynamic binding as discussed, e.g., in Chierchia (1992). The basic idea is that syntactic displacement and its reconstruction is the same sort of syntactic reconstruction that characterizes beta-reduction in the lambda-calculus.

(10) a. Himself, everyone loves _.
b. $(\lambda x \forall y.\mathbf{loves}\, y\, x)(\text{himself}_y)$
c. $\forall y.\mathbf{loves}\, y\, \text{himself}_y$

This example, and (11) below, are adapted from Sternefeld (1998). Though only marginally grammatical in English, translations of (10a) are better in other languages, including German.

Asserting a semantic equivalence between (10b) and (10c) captures the relationship between the surface position of the displaced constituent and its role in the semantic interpretation. Unfortunately, the reduction is not valid, since the variable y associated with *himself* comes to be bound by *everyone*. To see that this is not valid, note that (10b) is α-equivalent (and thus semantically equivalent) to $(\lambda x.\forall z.\mathbf{loves}\, z\, x)(\text{himself}_y)$, which does not lead to the desired result.

Sternefeld shows how a more sophisticated approach can provide the desired effect without violating any of the rules of the lambda calculus.

(11) a. $\lambda g.(\lambda Y.\forall x.\mathbf{loves}\,(Y\, g[x/1])\, x)\,\boxed{(\lambda g.g(1))}$
b. $\lambda g.\forall x.\mathbf{loves}\,(g[x/1](1))\, x$

Sternefeld assumes that sentences denote sets of assignment functions (as in many dynamic frameworks). If pronouns can denote functions from assignment functions to entities, as in the boxed expression $\lambda g.g(1)$, then the computation of (11b) from (11a) is perfectly valid according to the rules of the lambda calculus. Sternefeld calls denotations such as $\lambda g.g(1)$ 'pseudo variables', precisely because they are able to evade the normal rules of variable capture.

The way that pseudo-variables achieve delayed evaluation is by separating the process of evaluating a variable into two stages: in the first (outermost) stage, compute the appropriate assignment function. In the second, later (innermost) stage, apply the assignment function to the variable (index). Thus at the expense of adding a layer of indirection to the interpretation of (only some!) pronouns, we have a strategy for handling reconstruction semantically rather than syntactically.

The problem is that giving pseudo-variables free rein would provide a way for quantifiers to bind any pronoun that they take scope over. In other words, the difference between reconstruction situations in which binding is ok, and (for example) weak crossover situations in which binding is not ok, would become a matter of stipulation governing access to pseudo-variables. In addition, it is not clear how Sternefeld's analysis could be extended to cover outbound anaphora.

0.2.4 The continuation-based approach

Unlike the syntactic account, the system in Shan and Barker (2006) is directly compositional: it does not rely on movement, or copying, or any sort of LF. However, unlike Jacobson's functionalist account, we do not have any trouble ignoring kittens, nor do we generate the spurious readings due to overapplication of **m**. We do correctly generate outbound readings, and *how-many* questions do not pose any problem. In addition, on our direct compositional account, there is a bone fide binding relationship between the quantifier and the pronoun.

Like Sternefeld, we achieve delayed evaluation by assigning some uses of pronouns to categories with higher semantic types. Unlike Sternefeld, the availability of these more complex categories arises from type-shifting operators that are independently motivated in order to handle simple quantificational and binding, without any stipulation specific to reconstruction.

0.3 A general theory of scope and binding

This section presents the theory of scope and binding developed in Shan and Barker (2006). This theory was constructed without any consideration of either weak crossover or reconstruction examples. Nevertheless, we shall see that it automatically accounts for weak crossover contrasts like that in (1) as well as a range of reconstruction examples like that in (2).

The grammar is an ordinary combinatory categorial grammar in the style of Szabolcsi (e.g., 1992), Jacobson (e.g., 1999), Steedman (e.g., 2000), and others. As usual, for any categories A and B, the **default mode** of combination provides categories 'A/B' (an A missing a B to its right) and 'B\A' (an A missing a B to its left).

(12) Syntax Semantics

$$\mathrm{A}/\mathbf{B} \quad \mathbf{B} \Rightarrow \mathrm{A} \qquad f \quad x \Rightarrow fx$$

$$\mathbf{B} \quad \mathbf{B}\backslash\mathrm{A} \Rightarrow \mathrm{A} \qquad x \quad f \Rightarrow fx$$

As usual, syntactic combination is a cancellation operation in which the bolded occurrences of the category B must match. The corresponding semantic operation is functional application, where the expression in the slashed category denotes a function f and the expression in the category B denotes an argument x.

In addition to the default mode, there is a second mode of combination. For any categories A and B, the **continuation mode** provides additional categories ‘A⫽B’ (an A missing a B where the B surrounds the A) and ‘B⑊A’ (an A missing a B somewhere inside of it).[1]

As a matter of notation, instead of using the ordinary (‘linear’) form of a category such as C⫽(A⑊B), I will usually display the category in the form of a *tower*, thus: $\frac{\mathrm{C} \mid \mathrm{B}}{\mathrm{A}}$. At times below, however, I will revert to the linear notation according to the needs of the discussion at hand. In tandem on the semantics side, I define the stacked expression $\frac{g[\ ]}{x}$ to be notation for the linear algebraic expression $\lambda\kappa.g(\kappa x)$.

One advantage of the tower notation is that it reveals how combination in the presence of continuations is a form of cancellation:

(13) Syntax Semantics

$$\frac{\mathrm{C} \mid \mathbf{D}}{\mathrm{A}/\mathbf{B}} \quad \frac{\mathbf{D} \mid \mathrm{E}}{\mathbf{B}} \Rightarrow \frac{\mathrm{C} \mid \mathrm{E}}{\mathrm{A}} \qquad \frac{g[\ ]}{f} \quad \frac{h[\ ]}{x} \Rightarrow \frac{g[h[\ ]]}{fx}$$

$$\frac{\mathrm{C} \mid \mathbf{D}}{\mathbf{B}} \quad \frac{\mathbf{D} \mid \mathrm{E}}{\mathbf{B}\backslash\mathrm{A}} \Rightarrow \frac{\mathrm{C} \mid \mathrm{E}}{\mathrm{A}} \qquad \frac{g[\ ]}{x} \quad \frac{h[\ ]}{f} \Rightarrow \frac{g[h[\ ]]}{fx}$$

Once again, bolded categories must match in order to cancel. In the corresponding semantic operation, ‘$g[\ ]$’ is an expression g containing a

[1] Any category of the form B⑊A is a CONTINUATION; see Barker 2002 for motivation for the relevance of continuations in natural language semantics. Emmon Bach tells me that he used a double slash with a somewhat similar meaning, but he couldn’t remember where, and I haven’t been able to track down this use. Barker and Shan (2006) discuss the continuation mode within the framework of multi-modal Type Logical Grammar.

distinguished position somewhere within it, such that $g[x]$ is g with x inserted into that distinguished position.[2]

0.3.1 Quantification and scope

We will need two type-shifting operators to provide a general scope-taking mechanism: Lift and Lower.

Lift is an essential type-shifting operator familiar from Partee and Rooth (1983) and much subsequent work. (Indeed, Sternefeld's pseudo-variables are nothing more than Lifted variables.)

$$\text{Lift: } \boxed{\text{A}{:}x \Rightarrow \frac{\text{X} \mid \text{X}}{\text{A}} : \frac{[\;]}{x}}$$

This rule says that if some expression is a member of category A and has semantic value x, then that expression is also a member of the category $\frac{\text{X} \mid \text{X}}{\text{A}}$ (in linear notation, $\text{X}/\!\!/(\text{A}\backslash\!\!\backslash\text{X})$) with semantic value $\frac{[\;]}{x}$ (in linear notation, $\lambda\kappa.\kappa x$).

Just as in Partee and Rooth, Lift allows expressions without any quantificational force of their own to participate in derivations with proper quantifiers. For instance, given lexical entries as follows,

(14) a. someone $\frac{\text{S} \mid \text{S}}{\text{NP}} : \frac{\exists x[\;]}{x}$

b. everyone $\frac{\text{S} \mid \text{S}}{\text{NP}} : \frac{\forall y[\;]}{y}$

c. loves (NP\S)/NP: **loves**

In the presence of Lift, we have the following derivation:

[2] Bracket notation is not commonly encountered in linguistics discussions, but is standard in theoretical computer science, especially in discussions of the lambda calculus (see, e.g., Barendregt 1984). Crucially, unlike β-reduction, this substitution operation is variable-capturing. For instance, if $g[\;]$ is $\lambda x.\mathbf{loves}\,\_\,\mathbf{j}$, where _ marks the distinguished position within $g[\;]$, then $g[x]$ is $\lambda x.\mathbf{loves}\,x\,\mathbf{j}$, in which x is bound by the lambda. I use bracket notation purely as a notational convenience; in particular, despite the discussion of semantic reconstruction above, the variable-capturing nature of the brackets plays no essential role in providing an interpretation for reconstruction examples. After all, these brackets are entirely dispensable: Shan and Barker (2006) present an equivalent grammar using the linear notation exclusively.

$$\frac{\mathrm{S}_3 \,|\, \mathrm{S}_2}{\underset{\text{someone}}{\mathrm{NP}_2}} \left(\frac{\mathrm{S}_2 \,|\, \mathrm{S}_1}{\underset{\text{loves}}{(\mathrm{NP}_2\backslash \mathrm{S}_0)/\mathrm{NP}_1}} \; \frac{\mathrm{S}_1 \,|\, \mathrm{S}_4}{\underset{\text{everyone}}{\mathrm{NP}_1}} \right) = \frac{\mathrm{S}_3 \,|\, \mathrm{S}_4}{\underset{\text{someone loves everyone}}{\mathrm{S}_0}}$$

Only for these first few derivations, I decorate category symbols with subscripts to help the reader figure out what cancels with what. Here, *loves* undergoes Lift with X = S. It combines first with *everyone*, at which point the NP_1's cancel and the S_1's cancel. When the verb phrase combines with the subject, the NP_2's and the S_2's cancel, producing the result on the right hand side of the equal sign.

The semantic calculation proceeds in parallel.

$$\frac{\exists x[\,]}{x} \left(\frac{[\,]}{\mathbf{loves}} \quad \frac{\forall y[\,]}{y} \right) = \frac{\exists x(\forall y[\,])}{\mathbf{loves}\, y\, x}$$

Since the final value contains an unresolved instance of [ ], we need an operator that is the dual of Lift in order to complete the derivation:

$$\text{Lower: } \boxed{\frac{\mathrm{X} \,|\, \mathbf{S}}{\mathbf{S}} : \frac{g[\,]}{x} \Rightarrow \mathrm{X}{:}g[x]}$$

Unlike (13) above, Lower is a cancellation operation in which an S below the line cancels with the right top corner S (the two bolded S's in the diagram). In addition to its usefulness in various linguistic analyses (notably including Partee 1987), Lower is characteristic of continuation analyses (Plotkin 1975, Barker 2002, Shan and Barker 2006, etc.) as well as other types of dynamic systems (e.g., Chierchia 1985, as discussed in Barker 2002:236).

Once we have Lower, the derivation of *Someone loves everyone* continues as follows:

$$\frac{\mathrm{S}_3 \,|\, \mathrm{S}_4}{\mathrm{S}_0} : \frac{\exists x(\forall y[\,])}{\mathbf{loves}\, y\, x} \overset{\text{Lower}}{\Rightarrow} \mathrm{S}_3 : \exists x(\forall y(\mathbf{loves}\, y\, x))$$

S_0 cancels with S_4, and the two-level denotation collapses to a single level.

0.3.2 Inverse scope and multiple continuation levels

In the derivation just above, the quantifiers take scope corresponding to their linear order. Arriving at the inverse scoping requires a second continuation layer.

At this point I must say a word about combining towers. In our system, any combination rule gives rise to another combination rule that operates under an extra continuation level. More precisely, any rule

$$A_1 \cdots A_n \Rightarrow B$$

gives rise to a rule

$$\frac{X_0 \mid X_1}{A_1} \cdots \frac{X_{n-1} \mid X_n}{A_n} \Rightarrow \frac{X_0 \mid X_n}{B}.$$

This is fairly intuitive in practice. For example, choosing $n = 2$, this is how the ordinary function application rules in (12) give rise to the continuation-aware function application rules in (13). Similarly, choosing $n = 1$, the ordinary Lift rule above gives rise to the following continuation-aware Lift rule:

$$\frac{\mathrm{X} \mid \mathrm{X}}{\mathrm{A}} : \frac{f[\ ]}{x} \quad \text{gives rise to} \quad \frac{\dfrac{\mathrm{X} \mid \mathrm{X}}{\mathrm{Y} \mid \mathrm{Y}}}{\mathrm{A}} : \frac{\dfrac{f[\ ]}{[\ ]}}{x}$$

This derived Lift applies to the lexical entry for *everyone* given above in (14):

$$\frac{\mathrm{S}_1 \mid \mathrm{S}_1}{\mathrm{NP}} : \frac{\forall y[\ ]}{y} \overset{\text{Lift}}{\Rightarrow} \frac{\dfrac{\mathrm{S}_1 \mid \mathrm{S}_1}{\mathrm{S}_2 \mid \mathrm{S}_2}}{\mathrm{NP}} : \frac{\dfrac{\forall y[\ ]}{[\ ]}}{y}$$

We now have a derivation for inverse scope as follows:

$$\underset{\text{someone}}{\frac{\dfrac{\cdots}{\mathrm{S} \mid \mathrm{S}}}{\mathrm{NP}}} \left(\underset{\text{loves}}{\frac{\dfrac{\cdots}{\cdots}}{(\mathrm{NP}\backslash\mathrm{S})/\mathrm{NP}}} \quad \underset{\text{everyone}}{\frac{\dfrac{\mathrm{S} \mid \mathrm{S}}{\mathrm{S} \mid \mathrm{S}}}{\mathrm{NP}}} \right) = \underset{\text{someone loves everyone}}{\frac{\dfrac{\mathrm{S} \mid \mathrm{S}_2}{\mathrm{S}_2 \mid \mathrm{S}_1}}{\mathrm{S}_1}}$$

The derivation finishes by applying Lower twice: first to cancel the S_1's, and then to cancel the S_2's. The parallel semantic calculation shows how higher levels take scope over lower levels:

$$\frac{\dfrac{\cdots}{\exists x[\ ]}}{x} \left(\frac{\dfrac{\cdots}{\cdots}}{\mathbf{loves}} \quad \frac{\dfrac{\forall y[\ ]}{\cdots}}{y} \right) = \frac{\dfrac{\forall y[\ ]}{\exists x[\ ]}}{\mathbf{loves}\, y\, x} \overset{\substack{\text{Lower} \\ \text{(twice)}}}{\Rightarrow} \forall y(\exists x(\mathbf{loves}\, y\, x))$$

The generalization is that higher levels take scope over lower levels (by virtue of the interpretation of the tower notation), and within a single level, elements on the left take scope over elements on the right (by virtue of the details of combination given in (13)).

In addition to accounting for inverse scope, higher continuation levels will be crucial in the explanation of reconstruction.

Combination, Lift and Lower provide a general mechanism for scope-taking. We will need only two additional operators to account for reconstruction. The first governs binding, and the second characterizes fronted *wh*-constructions.

0.3.3 Binding

Let NP⊳S be the category of clauses containing a bindable NP position somewhere within them. In general, inserting a pronoun into an expression that would otherwise be in some arbitrary category X creates an expression in category NP⊳X:

$$\text{his} \quad \frac{\mathrm{NP}\triangleright\mathrm{X} \mid \mathrm{X}}{\mathrm{NP}} : \frac{\lambda z[\ ]}{z}$$

Note that pronouns have a non-trivial effect at the first continuation level (i.e., above the horizontal line). That amounts to claiming that (unlike Jacobson's treatment) pronouns are quite literally scope-taking elements. Pronouns, then, are expressions that turn whatever contains them into something containing a bindable NP. Dowty (2007) also argues that pronouns are scope-takers, though his proposal is not compatible with our assumption that pronouns are also identity maps. Claiming that pronouns are identity maps is an assumption that we share with Jacobson, and that is crucial to our analysis in this paper.

So pronouns create expressions that can be bound into. The other half of establishing a binding relationship is accomplished via the following type-shifting operator:

$$\text{Bind:} \ \boxed{\frac{\mathrm{A} \mid \mathrm{B}}{\mathrm{NP}} : \frac{f[\ ]}{x} \quad \Rightarrow \quad \frac{\mathrm{A} \mid \mathrm{NP}\triangleright\mathrm{B}}{\mathrm{NP}} : \frac{f([\ ]x)}{x}}$$

This scheme says that any NP taking scope over an expression of category B can bind some NP within that B. The semantics copies the denotation of the NP (the x at the lower level) to serve as the value of the bound NP (the x at the higher level).

The binder and the bound pronoun find each other via cancellation:

$$\begin{array}{c} \frac{\mathrm{S} \mid \mathrm{NP}\triangleright\mathrm{S}}{\mathrm{NP}} \\ \text{everyone} \end{array} \begin{array}{c} \frac{\quad}{(\mathrm{NP}\backslash\mathrm{S})/\mathrm{NP}} \\ \text{loves} \end{array} \left(\begin{array}{c} \frac{\mathrm{NP}\triangleright\mathrm{S} \mid \mathrm{S}}{\mathrm{NP}} \\ \text{his} \end{array} \begin{array}{c} \frac{\quad}{\mathrm{NP}\backslash\mathrm{NP}} \\ \text{mother} \end{array} \right)$$

The idea is that the binding dependency created by the pronoun cancels with the binding value provided by the subject NP.[3]

[3]Some technical details: *everyone* has undergone the Bind operator, *loves* under-

$$\frac{\forall y([\;]\,y)}{y}\;\frac{\quad}{\textbf{loves}}\left(\frac{\lambda z[\;]}{z}\;\frac{\quad}{\textbf{mom}}\right) = \frac{\forall y.(\lambda z[\;])\,y}{\textbf{loves}\,(\textbf{mom}\,z)\,y}$$

Lower

$$\Rightarrow\quad \forall y.(\lambda z.\textbf{loves}\,(\textbf{mom}\,z)\,y)\,y = \forall y.\textbf{loves}\,(\textbf{mom}\,y)\,y$$

In the semantics, the variable provided by the quantifier ends up binding the argument position of the relational noun *mother*, as desired.

0.3.4 Weak crossover

Remarkably, given this basic account of scope and binding, a wide range of weak crossover cases fall out for free.

$$\frac{\mathrm{NP}\rhd\mathrm{S} \mid \mathrm{S}}{\mathrm{NP}}\;\frac{\quad}{\mathrm{NP\backslash NP}}\;\frac{\quad}{\mathrm{(NP\backslash S)/NP}}\;\frac{\mathrm{S} \mid \mathrm{NP}\rhd\mathrm{S}}{\mathrm{NP}}$$

his mother loves everyone

In this derivation, cancellation proceeds without a hitch. The result, however, does not match the input schema of the Lower type-shifter (which requires S above the line, not NP$\rhd$S). As a result, the expression cannot be collapsed into a final value. Intuitively, the reason is that the pronoun and the quantifier are facing away from each other, and neither is aware of the other: at the end of the derivation, the pronoun is still seeking a binder, and the quantifier is still waiting for something to bind.

Shan and Barker (2006) provide a more detailed discussion of the explanation for weak crossover, along with a wide range of examples.

0.4 Questions

In order to treat the reconstruction examples of interest such as (2), which have fronted *wh* phrases, it remains only to extend the grammar to handle *wh*-questions. The strategy will be to use a single lexical entry for both in-situ *wh*-questions and fronted *wh*-questions. Let an expression in category A?B be some expression in category B within which an element of category A has been questioned.

$$\text{who}\quad \frac{\mathrm{NP?X} \mid \mathrm{X}}{\mathrm{NP}} : \frac{\textbf{who}(\lambda z[\;])}{z}$$

goes Lift with X=NP$\rhd$S, the lexical category of the pronoun has been instantiated with X=S, and *mother* must undergoes Lift with X=S.

The structure of this lexical entry resembles that of a pronoun, except that in place of the syntactic connective $\rhd$ there is ?. I can illustrate how this lexical entry works by pretending that English has in-situ *wh*-questions (somewhat marginally available as an echo question):

$$
\begin{array}{ccc}
\overline{\quad\mathrm{NP}\quad} & \overline{\quad(\mathrm{NP}\backslash \mathrm{S})/\mathrm{NP}\quad} & \dfrac{\mathrm{NP?S} \mid \mathrm{S}}{\mathrm{NP}} \\
\text{John} & \text{loves} & \text{who}
\end{array}
\quad
\begin{array}{c}\text{Lower}\\ \Rightarrow\end{array}
\quad
\mathrm{NP?S}\text{: } \mathbf{who}(\lambda z.\mathbf{loves}\, z\, \mathbf{j})
$$

Depending on your favorite semantics for questions (which I leave open; see also section 5 below), this could be glossed as 'Please identify a person z such that John loves z'.

Our fourth and final type-shifting operator allows *wh*-phrases to occur at the front of a sentence:

$$\text{Front: } \boxed{(\mathrm{X?Y})\sslash \mathrm{Z}{:}f \Rightarrow (\mathrm{X?Y})/\mathrm{Z}{:}f}$$

This operator takes an in-situ *wh*-phrase with category $(\mathrm{X?Y})\sslash\mathrm{Z}$, and modifies it in the tiniest way possible: by replacing $\sslash$ with /, with no change whatsoever in the semantics. For instance, we might have

$$
\begin{array}{ccc}
(\mathrm{NP?S})\sslash(\mathrm{NP}\bbslash \mathrm{S}) & \text{Front} & (\mathrm{NP?S})/(\mathrm{NP}\bbslash \mathrm{S}) \\
\text{who} & \Rightarrow & \text{who}
\end{array}
$$

This one syntactic change accounts for the difference between in-situ word order and fronted word order. Here's how: the continuation mode $\sslash$ allows an in-situ element such as a quantifier or a *wh*-word to combine with a larger phrase that encloses it, as we have seen above; the default mode /, of course, only allows an element to combine with a phrase that linearly follows it. The net result is that after shifting with the Front operator, a *wh*-phrase that originally (i.e., lexically) expected to be embedded in-situ within a larger expression now expects to find its semantic context packaged as a gap-containing phrase to its right.

Crucially, the Front operator does not affect the semantics of the *wh*-phrase at all. Because the expression with which the *wh*-phrase combines has the same syntactic category and the same semantic value regardless of whether the *wh*-phrase is in-situ or has been fronted (in the example below, for instance, the syntactic category the *wh*-phrase combines with is $\mathrm{NP}\bbslash\mathrm{S}$ either way), the semantic value of the complete question does not differ when the *wh*-phrase is in-situ or fronted. As a consequence, if a pronoun could have been bound if the *wh*-phrase were in-situ, it can likewise be bound when the *wh*-phrase has been fronted.

Before we can complete our analysis of simple sentences with fronted *wh*-phrases, we need only provide an analysis of the *wh*-gap:

$$\_ \qquad \mathrm{X}/\!\!/\mathrm{X}{:}\lambda x.x$$

This analysis says that silence (i.e., '_') is the sort of expression that, when combined with an expression X containing it, forms an expression of category X. In other words, just like multiplying in arithmetic by $\frac{\mathrm{X}}{\mathrm{X}}$, combining an expression with a gap constitutes the identity function.

Since X can be any arbitrary category, there are many ways to instantiate a gap, and we will exploit this flexibility below. One of the simplest useful NP gaps instantiates X as NP\\S:

$$\_ \qquad (\mathrm{NP}\backslash\!\!\backslash\mathrm{S})/\!\!/(\mathrm{NP}\backslash\!\!\backslash\mathrm{S}) = \frac{\mathrm{NP}\backslash\!\!\backslash\mathrm{S} \mid \mathrm{S}}{\mathrm{NP}}$$

We have given the gap both in linear notation, to show that it is a legitimate instantiation of the general gap scheme, and the equivalent tower notation for use in the derivation of the expression *does John love _*:

$$\begin{array}{ccccc} \overline{\mathrm{S/S}} & \overline{\mathrm{NP}} & \overline{(\mathrm{NP}\backslash\mathrm{S})/\mathrm{NP}} & \dfrac{\mathrm{NP}\backslash\!\!\backslash\mathrm{S} \mid \mathrm{S}}{\mathrm{NP}} & = \dfrac{\mathrm{NP}\backslash\!\!\backslash\mathrm{S} \mid \mathrm{S}}{\mathrm{S}} \\ \text{does} & \text{John} & \text{love} & \_ & \text{does John love \_} \end{array}$$

$$\begin{array}{cc} \text{Lower} & \mathrm{NP}\backslash\!\!\backslash\mathrm{S} \\ \Rightarrow & \text{does John love \_} \end{array}$$

This, of course, is just a question body, the gapped clause following the *wh*-word. The question body combines with *who* (which has undergone the Front operator):

$$\begin{array}{c} (\mathrm{NP?S})/(\mathrm{NP}\backslash\!\!\backslash\mathrm{S}) \\ \text{who} \end{array} \left(\begin{array}{c} \mathrm{NP}\backslash\!\!\backslash\mathrm{S} \\ \text{does John love \_} \end{array} \right) = \begin{array}{c} \mathrm{NP?S} \\ \text{who does John love \_?} \end{array}$$

The system guarantees that the semantics of the fronted question will be identical to the semantics of the in-situ version derived above, i.e., **who**($\lambda z.$**loves** z **j**).

The four type-shifters introduced above were motivated only by the most basic considerations of providing an analysis of scope, binding, and question formation: Lift, Lower, Bind, and Front. None of these operators were complicated in any way in anticipation of handling either weak crossover or reconstruction. Nevertheless, the system described above automatically accounts for a wide range of weak crossover examples, and, as we will see, reconstruction examples.

0.5 Functional questions

Since we claim (in common with Engdahl and many others) that reconstruction examples and functional questions arise through the same mechanisms, we must explain how functional questions work.

(15) Q. Who does everyone love _?
A1. the Queen
A2. his mother

As is well known, the question in (15) has at least two sorts of answers. The first is closely parallel to the analysis given above, in which there is a single individual loved by everyone. A suitable answer for this interpretation would be (A1).

On the functional interpretation, there will be a potentially different loved person for each choice of lover. A suitable answer for this interpretation would be (A2): the person that each person x loves is x's mother. We will develop an account of this functional reading in some detail here, since many details of the analysis will be directly relevant for the analysis of reconstruction below.

0.5.1 Complex pronoun meanings as predicate modifiers

Before discussing functional questions, it will be helpful to discuss functional answers first. The classic answer to a functional question, of course, has the same category as a plain pronoun:

$$\begin{array}{cccc} \dfrac{\mathrm{NP}\rhd\mathrm{S} \;\big|\; \mathrm{S}}{\mathrm{NP}} & \dfrac{\phantom{\mathrm{NP}\backslash\mathrm{NP}}}{\mathrm{NP}\backslash\mathrm{NP}} & = & \dfrac{\mathrm{NP}\rhd\mathrm{S} \;\big|\; \mathrm{S}}{\mathrm{NP}} \\ \text{her} & \text{mother} & & \text{her mother} \end{array}$$

The claim is that *her* and *her mother* have the same category. We can call *her mother* a complex pronoun, in the same spirit that, e.g., *those men* counts as a complex demonstrative. That means that pronouns and complex pronouns should have equivalent syntactic distributions, and they should make interchangeable (but not semantically equivalent) contributions to the truth conditions of the larger expression. (See, e.g., Jacobson 1999 for motivation and discussion.)

Semantically, a pronoun adds a functional dependence to whatever expression contains it. If *John saw Mary* denotes a truth value, then *John saw her* denotes a function from individuals to truth values. As explained above, this is accomplished by instantiating the lexical category of *her* as $(\mathrm{NP}\rhd\mathrm{S})/\!\!/(\mathrm{NP}\backslash\!\!\backslash\mathrm{S})$: a function from meanings of type $\langle \mathtt{e}, \mathtt{t}\rangle$ to meanings of type $\langle \mathtt{e}, \mathtt{t}\rangle$. But of course $\langle \mathtt{e}, \mathtt{t}\rangle$ is also the type of a nominal or other one-place predicate. Thus another valid perspective on the meaning of a pronoun is that it is a predicate modifier: it takes a predicate as argument and returns a modified predicate. Ignoring gender presuppositions, the specific function denoted by a pronoun is the identity function. But the complex expression *her mother* contributes content beyond the identity function. More specifically, given a predicate P as argument, the function denoted by *her mother* will return the composition of P with the **mother** function. For example, if *John saw her* denotes the function mapping each individual x to the proposition that John saw x, *John saw her mother* denotes the function from individuals x to the proposition that John saw x's mother.

0.5.2 Functional readings

Allowing gaps, *wh*-words, and pronouns to schematize over an infinite class of identity types provides considerable flexibility. Among the advantages of this flexibility is that it predicts not only functional readings, but, as we will see shortly, reconstruction examples.

In relying on functional gaps in this way, our account resembles the functionalist tradition of Engdahl (1986), Chierchia (1993), Jacobson (1999), and others. As Szabolcsi (1997) points out, one distinctive feature of this style of analysis is that the *wh*-phrase always takes wide scope over any (non-*wh*) quantificational element. But as she notes (p. 318), this does not limit the contribution of the quantifier to the semantics of the interrogative in certain important ways. In particular, it is possible to implement variations on Karttunen's or Groenendijk and Stokhof's semantics for a variety of question types. Therefore I leave the semantics of questions unanalyzed in this paper: since the choice of question semantics is independent of the phenomena we analyze here, the reader is free to supply their favorite conception of question meaning.[4]

Here is an instantiation of the schema for *who*, along with its corresponding gap, that will give rise to a simple functional reading of (15). Let 'pn' abbreviate the category of a simple pronoun, i.e., $(\mathrm{NP}\triangleright\mathrm{S})/\!\!/(\mathrm{NP}\backslash\!\!\backslash\mathrm{S})$.

$$\begin{array}{ll} \text{who} & (\text{pn}?\text{S}) /\!\!/ (\text{pn}\backslash\!\!\backslash\text{S}) \\ \text{\_} & (\text{pn}\backslash\!\!\backslash\text{S}) /\!\!/ (\text{pn}\backslash\!\!\backslash\text{S}) \end{array}$$

Unpacking this instantiation of the gap, we have

[4]Szabolcsi, along with Beghelli (1997), goes on to criticize Chierchia's account in particular as failing to make sufficiently fine-grained empirical distinctions. We will have nothing to say on this occasion about most of the intricate facts presented there, including contrasting availability of functional and pair-list readings for *what* and *who* versus *which*, matrix versus embedded interrogatives, *every* versus *each*, etc.

$$(\mathrm{pn}\backslash\!\!\backslash \mathrm{S}) \mathbin{/\!\!/} (\mathrm{pn}\backslash\!\!\backslash \mathrm{S}) = \frac{\mathrm{pn}\backslash\!\!\backslash \mathrm{S} \mid \mathrm{S}}{\mathrm{pn}} = \frac{\begin{array}{c|c} \mathrm{pn}\backslash\!\!\backslash \mathrm{S} & \mathrm{S} \\ \hline \mathrm{NP}\triangleright\mathrm{S} & \mathrm{S} \end{array}}{\mathrm{NP}}$$

The first step just converts from linear notation to tower notation, and the right hand side merely expands the abbreviation of the lower occurrence of 'pn'.

This instantiation of the gap enables the following analysis of the question body (i.e., *does everyone love* _). (This exact partial derivation will form part of the analysis of some of the reconstruction examples discussed below in the next section.)

$$\begin{array}{cccc} \dfrac{\overline{}}{\begin{array}{c|c} \mathrm{S} & \mathrm{NP}\triangleright\mathrm{S} \end{array}} & \dfrac{\overline{}}{} & \begin{array}{c|c} \mathrm{pn}\backslash\!\!\backslash \mathrm{S} & \mathrm{S} \\ \hline \mathrm{NP}\triangleright\mathrm{S} & \mathrm{S} \end{array} & \begin{array}{c|c} \mathrm{pn}\backslash\!\!\backslash \mathrm{S} & \mathrm{S} \\ \hline \mathrm{S} & \mathrm{S} \end{array} \\ \hline \mathrm{NP} & (\mathrm{NP}\backslash\mathrm{S})/\mathrm{NP} & \mathrm{NP} & \mathrm{S} \\ \text{everyone} & \text{love} & \text{--} \quad = & \end{array}$$

In effect, the quantifier binds a virtual pronoun within the gap position.

$$\begin{array}{ccccc} \dfrac{\overline{}}{\forall y([\,]\,y)} & \dfrac{\overline{}}{} & \dfrac{\lambda\mathcal{P}[\,]}{\mathcal{P}(\lambda w[\,])} & = & \dfrac{\lambda\mathcal{P}[\,]}{\forall y.\mathcal{P}(\lambda w[\,])\,y} \\ \hline y & \mathbf{love} & w & & \mathbf{love}\,w\,y \end{array}$$

The semantic value of the gap looks complicated, but it is just an elaborate version of the identity function.[5]

We finish the derivation of this expression by applying the Lower operator twice:

$$\frac{\begin{array}{c|c} \mathrm{pn}\backslash\!\!\backslash \mathrm{S} & \mathrm{S} \\ \hline \mathrm{S} & \mathrm{S} \end{array}}{\mathrm{S}} \quad \overset{\text{Lower (twice)}}{\Rightarrow} \quad \mathrm{pn}\backslash\!\!\backslash \mathrm{S} : \lambda\mathcal{P}(\forall y.\mathcal{P}(\lambda w.\mathbf{love}\,w\,y)\,y)$$

Finally, the question-fronting operator applies to the instantiation of the lexical category of *who*:

$$(\mathrm{pn?S}) \mathbin{/\!\!/} (\mathrm{pn}\backslash\!\!\backslash \mathrm{S}) \quad \overset{\text{Front}}{\Rightarrow} \quad (\mathrm{pn?S})/(\mathrm{pn}\backslash\!\!\backslash \mathrm{S})$$

[5] It is easier to see this if we convert from the tower notation into linear notation: $\lambda\gamma\lambda\mathcal{P}.\gamma(\lambda\kappa(\mathcal{P}(\lambda w.\kappa w)))$ To see that it is indeed an identity function, note that $\lambda w.\kappa w$ is η-equivalent to κ, $\lambda\kappa(\mathcal{P}\kappa)$ is η-equivalent to $\mathcal{P}$, and $\lambda\gamma\lambda\mathcal{P}.\gamma\mathcal{P}$ is easily recognizable as the identity function.

which enables it it combine with the lowered question body just given to

produce a question of category pn?S (i.e., a clause in which a pronoun has been questioned. The semantic value is simply the function denoted by *who* applied to the value of the question body:

$$\mathbf{who}(\lambda\mathcal{P}(\forall y.\mathcal{P}(\lambda w.\mathbf{love}\, w\, y)\, y))$$

which can be paraphrased as 'for which pronoun meaning $\mathcal{P}$ is it true

that everyone loves $\mathcal{P}$?' If the answer is the (complex) pronoun *his mother*, the prediction is that this will be a true answer only if inserting the answer into gap position expresses a true claim, i.e., only if it is true that everyone loves his mother.

Note that in any successful derivation of a fronted *wh*-phrase, the instantiation of the gap and of the *wh*-word must complement each other, in the sense that whatever the gap requires for completion (here, the pn part of pn\\S) must be exactly what the *wh*-phrase is questioning (here, the pn part of pn?S). In other words, the gap stands in the place the *wh*-phrase would have occupied if it were in-situ, and (metaphorically) transmits access to the gap position to the fronted *wh*-phrase.

0.6 Deriving reconstruction

We are now in a position to consider our core reconstruction case.

(16) Which relative of his does everyone love _?

We have already analyzed the question body, which receives the same functional analysis given above. Now we derive the fronted *wh*-phrase:

$$\begin{array}{ccccc}
\begin{array}{c|c} \text{(NP/N)?S} & \text{S} \\ \hline \multicolumn{2}{c}{\cdots} \end{array} & & & & \begin{array}{c|c} \text{(NP/N)?S} & \text{S} \\ \hline \text{NP}\rhd\text{S} & \text{S} \end{array} \\
\hline & \hline & \begin{array}{c|c} \text{NP}\rhd\text{S} & \text{S} \end{array} & & \hline \\
\hline & & \hline & & \\
\text{NP/N} & \text{N/NP} & \text{NP} & & \text{NP} \\
\text{which} & \text{relative-of} & \text{his} & = & \text{which rel of his}
\end{array}$$

The *wh*-word has undergone Lift. Because this *wh*-phrase will occur in fronted position, we now apply the Front operator. Using the 'pn' abbreviation, we have

$$\begin{array}{ccc}
\text{((NP/N)?S)} \mathbin{/\!\!/} (\text{pn}\backslash\!\!\backslash\text{S}) & \text{Front} & \text{((NP/N)?S)} / (\text{pn}\backslash\!\!\backslash\text{S}) \\
\text{which relative of his} & \Rightarrow & \text{which relative of his}
\end{array}$$

On the semantic side, we have

$$\frac{\dfrac{\textbf{which}(\lambda f[\,])}{\rule{5em}{0.4pt}}}{f} \quad \frac{\dfrac{\rule{3em}{0.4pt}}{\rule{3em}{0.4pt}}}{\textbf{rel}} \quad \frac{\dfrac{\rule{3em}{0.4pt}}{\lambda z[\,]}}{z} = \frac{\dfrac{\textbf{which}(\lambda f[\,])}{\lambda z[\,]}}{f(\textbf{rel}\, z)}$$

The Front operator does not affect the semantics of the *wh*-phrase. In linear notation:

$$\lambda\gamma.\textbf{which}(\lambda f.\gamma(\lambda\kappa\lambda z.\kappa(f(\textbf{rel}\, z))))$$

Putting the pieces together:

$$\begin{array}{c}((\text{NP/N})?\text{S})\ /\ (\text{pn}\backslash\!\!\backslash\text{S}) \\ \text{which relative of his}\end{array} \left(\begin{array}{c}\text{pn}\backslash\!\!\backslash\text{S} \\ \text{does everyone love \_\_}\end{array}\right):$$

$$(\lambda\gamma.\textbf{which}(\lambda f.\gamma(\lambda\kappa\lambda z.\kappa(f(\textbf{rel}\, z)))))\Big(\lambda\mathcal{P}(\forall y.\mathcal{P}(\lambda w(\textbf{love}\, w\, y))\, y)\Big)$$
$$= (\text{NP/N})?\text{S} : \textbf{which}(\lambda f \forall y.\textbf{love}(f(\textbf{rel}\, y))\, y)$$

A paraphrase of this denotation could be 'For which choice function f does every person y love $f(y$'s relatives)?' A suitable answer for this interpretation would be *the tallest*. This is a reconstruction interpretation on which the quantifier *everyone* binds the pronoun in the fronted *wh*-phrase. Moreover, unlike on the apparent-binding approach, this is genuine (not merely apparent) binding.

0.6.1 Reconstruction with functional answers

At this point, I have made good on my promise to show how a suitable theory of quantification and binding could automatically generate a reconstruction example involving displaced binding. However, the most natural reading of the question is one on which an appropriate answer might be *his mother*. Therefore we will go on to show how the same fundamental analysis automatically generates this interpretation as well. The details will be more complicated, but will involve no new techniques or assumptions.

The functional answer is a reading on which the answer depends not only on a specific set of relatives, but also on the identity of the person whose relatives we're considering. For example, on this doubly-dependent reading, the value could be different for Mary versus Bob even if they are siblings and have the same set of relatives.

Accommodating this reading involves exploiting the assumption that *wh*-words, like pronouns and gaps, can take on any identity type. The derivation of the fronted *wh*-phrase begins exactly as above, except that we start with $\dfrac{(\text{pn}/\text{N})?\text{S} \mid \text{S}}{\text{pn}/\text{N}}$ as the initial category for *which*, instead of $\dfrac{(\text{NP}/\text{N})?\text{S} \mid \text{S}}{\text{NP}/\text{N}}$. Thus:

$$\begin{array}{ccccc}
\dfrac{(\text{pn}/\text{N})?\text{S} \mid \text{S}}{\dfrac{\cdots}{\text{pn}/\text{N}}} & \dfrac{}{\text{N}/\text{NP}} & \dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\text{NP}} & & \dfrac{(\text{pn}/\text{N})?\text{S} \mid \text{S}}{\dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\text{pn}}} \\
\text{which} & \text{relative-of} & \text{his} & = &
\end{array}$$

Recalling that 'pn' abbreviates $\dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\text{NP}}$, let 'ppn' abbreviate $\dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\text{NP}}}$. Then we have

$$\begin{array}{ccc}
(\text{pn}/\text{N})?\text{S} \,/\!\!/\, (\text{ppn}\backslash\!\!\backslash\text{S}) & \text{Front} & (\text{pn}/\text{N})?\text{S} \,/\, (\text{ppn}\backslash\!\!\backslash\text{S}) \\
\text{which relative of his} & \Rightarrow & \text{which relative of his}
\end{array}$$

Semantically, this gives us $\lambda\gamma.\mathbf{which}(\lambda\mathcal{F}.\gamma(\lambda\kappa\lambda x.\kappa(\mathcal{F}(\mathbf{rel}\,x))))$, where $\mathcal{F}$ is a variable over meanings in category pn/N (functions from nominal meanings to generalized pronoun meanings).

Since the analysis of the fronted *wh*-phrase is more complicated, the analysis of the question body must be correspondingly elaborated. Ignoring *does*, we have

$$\begin{array}{ccc}
\dfrac{\text{S} \mid \text{NP}\rhd\text{S}}{\dfrac{\text{S} \mid \text{NP}\rhd\text{S}}{\text{NP}}} & \dfrac{}{(\text{NP}\backslash\text{S})/\text{NP}} & \dfrac{\text{ppn}\backslash\!\!\backslash\text{S} \mid \text{S}}{\dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\dfrac{\text{NP}\rhd\text{S} \mid \text{S}}{\text{NP}}}} \\
\text{everyone} & \text{love} & \text{--}
\end{array}$$

In this case, the quantifier *everyone* binds twice (here is the type-shifting recipe for computing the category of *everyone*: Bind, then Lift, then Bind). It binds once for the reconstructed pronoun, and once for the virtual pronoun contributed by the *wh*-word. Once we combine and lower three times, the question body has category ppn$\backslash\!\!\backslash$S, which combines with the fronted *wh*-phrase.

The semantics of the question body:

$$\cfrac{\cfrac{\cfrac{}{\forall x.[\,]x}}{\cfrac{[\,]x}{x}} \quad \cfrac{\cfrac{}{}}{\cfrac{}{\mathbf{love}}} \quad \cfrac{\lambda g[\,]}{\cfrac{g(\lambda f[\,])}{\cfrac{f(\lambda y[\,])}{y}}}}{} = \cfrac{\lambda g[\,]}{\cfrac{\forall x.g(\lambda f[\,])\,x}{\cfrac{f(\lambda y[\,])\,x}{\mathbf{love}\,y\,x}}}$$

Combining the fronted *wh*-phrase with the question body:

$$(\lambda\gamma.\mathbf{which}(\lambda\mathcal{F}.\gamma(\lambda\kappa\lambda x.\kappa(\mathcal{F}(\mathbf{rel}\,x))))) \Big(\lambda g\forall x.g(\lambda f.f(\lambda y.\mathbf{love}\,y\,x)\,x)\,x\Big)$$
$$= \mathbf{which}(\lambda\mathcal{F}\forall x.\mathcal{F}(\mathbf{rel}\,x)(\lambda y.\mathbf{love}\,y\,x)\,x)$$

This meaning is asking for a function $\mathcal{F}$ which, given some set of relatives, returns a pronoun function $\mathcal{P}$ such that x loves $\mathcal{P}$.

Degenerate answers and pair-list answers. A completely general answer will designate a potentially different loved relative for each individual: "Choosing among the set of John's relatives, John loves his mother; choosing among the set of Bill's relatives, Bill loves is his father; ...", and the analysis just given provides enough resolving power to accommodate fully general answers. But *his mother* is not such a fully general answer. How then does it come to be suitable as a reply to (2)?

If it happens that the that the correct pronoun function is constant for all of the relevant individuals, then the simpler functional answer *his mother* can be used, in which case the intended meaning is that for each individual x, the relative of x that x loves is x's mother. In other words, I am suggesting that answers often waste some of the resolving power available to them. In many situations, the only answers interesting enough to give are ones that are systematic in this fashion, what are often called "natural" functions in the literature.

Thus in this paper we are following the general strategy of Engdahl, Chierchia and others in assuming that functional readings are just a special case of fully general pair-list readings. This is more for the sake of expository simplicity than because of any deeply-set views; see Sharvit (1999) for arguments that this strategy may not be adequate.

0.6.2 *How-many* questions

Now I return briefly to *how many* questions. For the purposes of this paper, I will assume that *how many* is syntactically equivalent to *which*, predicting that they will have the same range of derivations. For instance, based on the analysis of the *which* question just given, we will have

(17) a. How many relatives of his does everyone love _?
b. **how-many** $(\lambda\mathcal{F}\forall x.\mathcal{F}(\mathbf{rel}\,x)(\lambda y.\mathbf{love}\,y\,x)\,x)$

The complete answer will be a function $\mathcal{F}$ associating individuals x with numbers d in such a way that given the set of x's relatives, $\mathcal{F}$ returns a pronoun meaning such that x loves d-many of those relatives. The important point here is that the derivation provides exactly the information that the denotation of *how many* will need: an individual, a set, and a property that reveals which members of the set need to be counted.

0.6.3 Outbound binding

We have seen that a pronoun within a fronted constituent has a semantic effect as if it had been reconstructed into the gap position. It is perfectly possible for the fronted phrase to contain a quantificational NP instead of a pronoun, in which case the quantifier will take scope as if it had been reconstructed into the gap position. In particular, it is possible for such a quantifier to bind any pronoun that could have been bound from the gap position.

(18) Which relative of everyone$_i$ _ loves him$_i$ (the most)?

We instantiate the gap with X = (S⫽(NP⑊(NP▷S)))⑊S, and the rest of the derivation resembles the derivation for (16). The question body (_ *loves him*) will expect as its argument a quantificational NP that is ready to bind a pronoun (i.e., an argument of category $\frac{\mathrm{S} \mid \mathrm{NP}\triangleright\mathrm{S}}{\mathrm{NP}}$). As long as *everyone* undergoes the Bind operator before combining with the rest of the fronted *wh*-phrase, this is exactly what the fronted *wh*-phrase delivers. The reduced semantic value of the complete derivation is $\mathbf{which}(\lambda f\forall x.\mathbf{loves}\,x(f(\mathbf{rel}\,x)))$, in which the universal quantifier introduced by *everyone* clearly binds the variable introduced by the pronoun, as desired.

0.6.4 Interaction with crossover

The analysis correctly predicts that semantic reconstruction of fronted *wh*-phrases will obey weak crossover constraints on the interaction of the gap position with potential binders:

(19) a. Which woman that _ loves him$_i$ (do you think) every man$_i$ invited _?
b.*Which woman that he$_i$ loves _ (do you think) _ invited every man$_i$?

See Shan and Barker (2006: 123-4) for a derivation and discussion of a similar contrast involving *whose* instead of *which*.

0.7 Conclusion: reconstruction as delayed evaluation

The derivations above follow from unconstrained application of four general, independently motivated type-shifters (Lift, Lower, Bind, and Front), given suitably general lexical entries for *wh* words, pronouns, and gaps. The essential insight is the simple idea (championed by Jacobson) that pronouns, *wh*-words, and gaps all denote identity functions, combined with the idea that these items are scope-taking elements, as in recent work of Dowty. Because the identity function can be instantiated in various ways, gaps can in effect contain virtual pronouns. This makes it possible for a quantifier to bind into the gap, which in turn enables a (suitably instantiated) *wh*-phrase to accept a functional answer. When the fronted *wh*-phrase contains quantifiers or bindable pronouns, the fronting mechanism guarantees that these elements will behave semantically as if they had been interpreted in the gap position. Thus the system automatically provides reconstruction effects without movement or copying, without stipulating pseudo-variables, without stipulating a special functionalization operator such as Jacobson's **m**—indeed, without any special stipulation at all. The result is a directly compositional account that handles weak crossover and reconstruction, and on which the appearance of quantificational binding in reconstruction examples is in fact genuine binding brought about by delayed evaluation.

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