Split and compose:
Deriving long-distance dependencies in a continuation-based grammar

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Overview The *continuation-based grammar* (Barker & Shan, 2014), which provides an appealing account of scope and binding without employing the notion of c-command, is known to struggle to capture the weak crossover effect in long-distance dependencies (Leong & Erlewine, 2019). To address this issue, we introduce a new combinatory rule SPLIT into the continuation-based grammar. This rule, together with the mechanism of *function composition* (Steedman, 2000), allows the scope of a *wh*-phrase to be appropriately reconstructed to its original position, correctly predicting the behavior of binding in long-distance dependencies.

Background Bound variable anaphora is an essential domain of inquiry in the study of the syntax-semantics interface. While binding is conventionally assumed to require the binder to c-command the pronoun from an A-position (Reinhart, 1983), this view has been challenged by counterexamples such as (1a) (binding out of a possessor) and (1b) (binding out of a VP) (Barker, 2012).

(1) a. [Every$_i$ girl's mother] praised her$_i$. b. We [sell no$_i$ wine] before its$_i$ time.

Against this backdrop, Barker and Shan (henceforth B&S) developed a categorial grammatical framework which derives binding via the left-to-right composition of quantifier scope. Their central assumption is that scope-taking expressions denote functions over their *continuation* (i.e., their surrounding content). Correspondingly, a scope-taker has a syntactic category of the form $C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B)$, where $Y \mathbin{\backslash\!\!\backslash} X$ (resp. $X \mathbin{/\!\!/} Y$) refers to expressions that return X when given Y inside (resp. outside). Intuitively, this complex category indicates that the scope-taker is locally A, takes scope over B, and results in C given its continuation. The behavior of these scope-taker categories is defined by the rules shown in Figure 1, where we use the *tower notation*, which separates the scope-level information above the line.

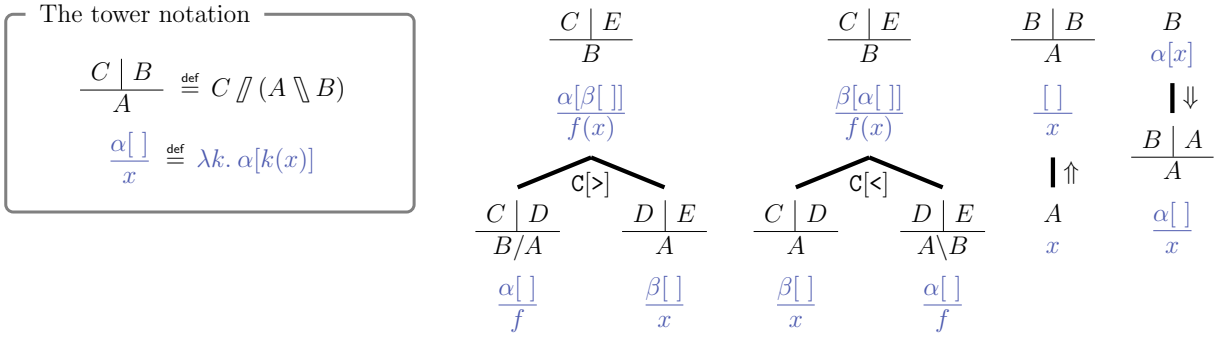
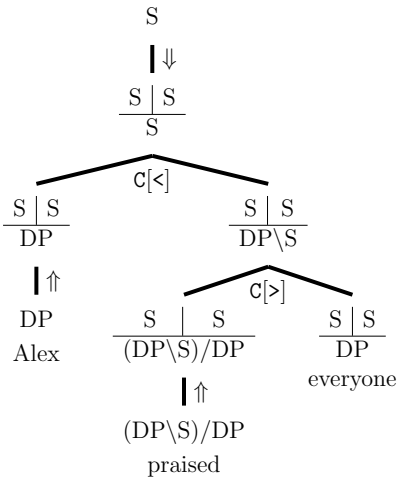


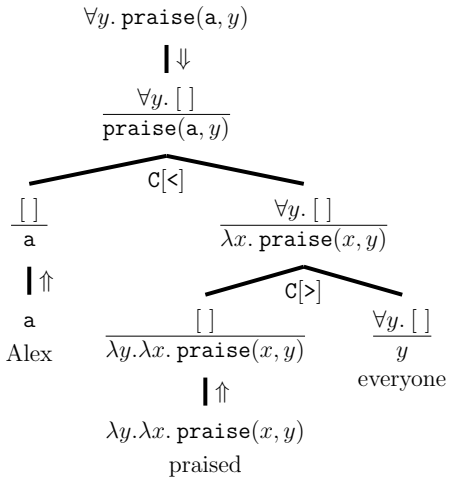
Figure 1: Basic combinatory rules

To illustrate their usage, consider the sentence *Alex praised everyone*. We show its derivation in (2), separating the syntactic categories and the denotations for readability. Here, we first apply LIFT ⇑ to the non-scope-takers (*Alex* and *praised*). Then, we successively apply the "continuized" function application (C[>] and C[<]), which composes scope *from left to right*, regardless of the direction of the function application done at the bottom level. At the root of the tree, we complete the derivation by collapsing the tower with LOWER ⇓.

(2) a.

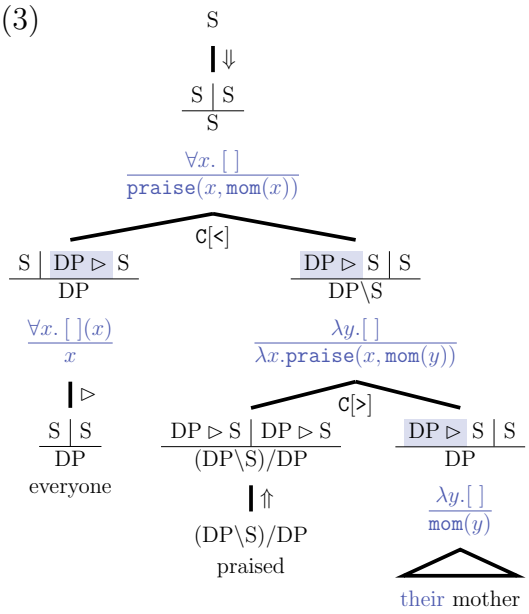


b.



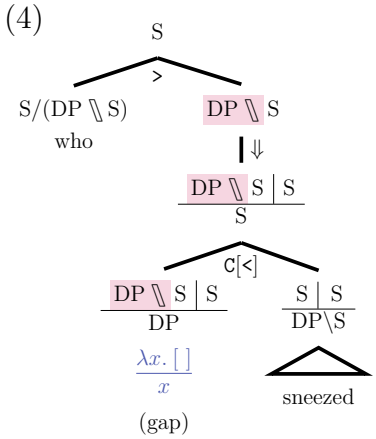
Turning to binding, B&S posit that expressions containing an unbound pronoun have a distinguished category DP ▷ A and denote a function from entities (Jacobson, 1999). Consider (3) for example. Crucially, *their mother* is treated as a scope-taker, with DP ▷ placed on the scope level. On the side of the subject, we apply a unary rule BIND ▷ that makes a scope-taker require an unbound pronoun on its right. At the root of the tree, these two occurrences of DP ▷ cancel each other. Semantically, this amounts to saturating λy with the variable x bound by the quantifier, which yields the desired bound-variable interpretation. Remarkably, this scope-based analysis of binding can immediately capture the problematic cases like (1a) and (1b), since, in these cases too, the quantifier takes scope over the pronoun.

(3)



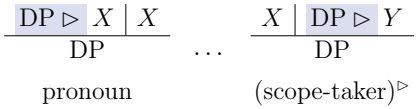
B&S extend this account to cases where a *wh*-phrase binds a pronoun (e.g., *Who$_i$ praised their$_i$ mother?*), by stipulating a covert operator for the gap. As depicted in (4), a gap introduces the category DP ⧹ S (i.e., a sentence missing a DP inside), which serves as the argument of the *wh*-phrase. Since gaps take scope like quantifiers, a *wh*-phrase can bind a pronoun via the gap: we can construct a derivation parallel to (3) by applying ▷ to the gap.

(4)



Finally, their linear order-based account can be applied to the *weak crossover* effect (Postal, 1971), exemplified by (5). The crossover cases have a common configuration, schematized on the right, where the pronoun precedes the scope-taker (e.g., quantifiers, gaps). The account correctly blocks binding since the scope-level composition proceeds from left to right.

(5) a. ?* Their$_i$ mother praised everyone$_i$.
b. ?* Whom$_i$ did their$_i$ mother praise __?



In this way, B&S's framework provides a promising account of binding based on the left-to-right composition of scope, which is made possible by the notion of continuations.

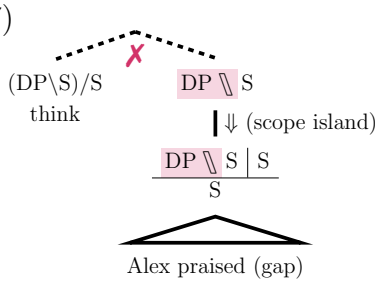
Problem However, this framework faces a serious issue in handling long-distance dependencies.

(6) Whom does Kim think [Alex praised __]?

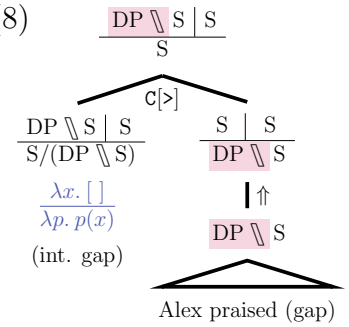
We show an attempted derivation of (6) in (7). Once we derive the finite clause, which is a scope island, we need to apply ⇓ to prevent further scope-taking (Charlow, 2014). Then, there is no way to compose the resultant DP \ S with the complement-taking verb *think*.

As a possible remedy, Leong and Erlewine (2019) posited an *intermediate gap* at the edge of the finite clause (as an analogue of successive cyclic movement), which "re-lifts" DP \ as shown in (8), allowing us to derive (6). However, this revision incorrectly permits binding in (9), an instance of weak crossover. This is because, since the intermediate gap precedes the pronoun, *whom* can bind the pronoun via the intermediate gap, as depicted on the right of (9).

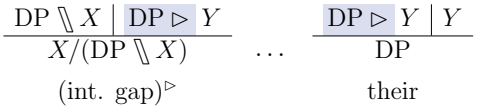
(7)



(8)



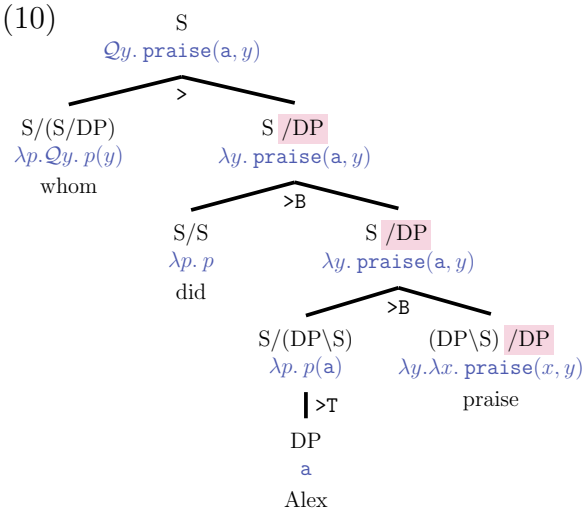
(9) ?* Whom$_i$ does Kim think __ [their$_i$ mother praised __]?



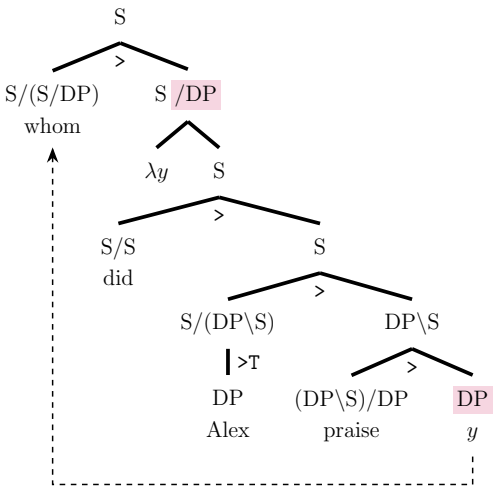
Leong and Erlewine (2019) argued that the core of the issue is that B&S's framework establishes *wh*-dependencies with the same mechanism as scope-taking, which must be blocked by finite clause boundaries. In light of this, they left the analysis of long-distance dependencies as an open problem for the continuation-based grammar.

Proposal (split and compose) To address this issue, we adopt a *gap-free* analysis of long-distance dependencies (Steedman, 2000). The main component of this approach is the combinatory rule of *function composition*, which links two function categories together. To illustrate, consider (10). Here, the subject DP undergoes *type-raising*, which turns A into $X/(A\backslash X)$ (as with LIFT). Then, the resultant category S/(DP\S) can compose into the transitive verb via the forward function composition >B, yielding S /DP (i.e., a sentence missing its object). By repeating this process, we can inherit up the missing argument /DP, until it is finally fed by *whom*. More intuitively, we can metaphorically describe the object DP as moved up to a higher position, as in (11) (although no syntactic movement is involved in reality).

(10)



(11) Movement-like description of (10)



Next, to make this gap-free analysis compatible with the continuation-based grammar, we propose a unary rule SPLIT, which is shown in Figure 2. Formally, this is the *partially applied* version of the continuized function application: as shown in (12), C[>] is equivalent to applying $\Upsilon_>$ to the left argument and combining it with the right using > (the same holds for C[<]). In effect, the rule splits a tower with a slash and creates a function from a tower to another. This resultant function semantically composes the two scopes $\alpha[\ ]$ and $\beta[\ ]$ according to the directionality of the slash. Namely, if the argument A is expected on the right (resp. left), then its scope $\beta[\ ]$ is placed inside (resp. outside) $\alpha[\ ]$. In this way, SPLIT is faithful to the left-to-right composition of scope in the continuation-based grammar.

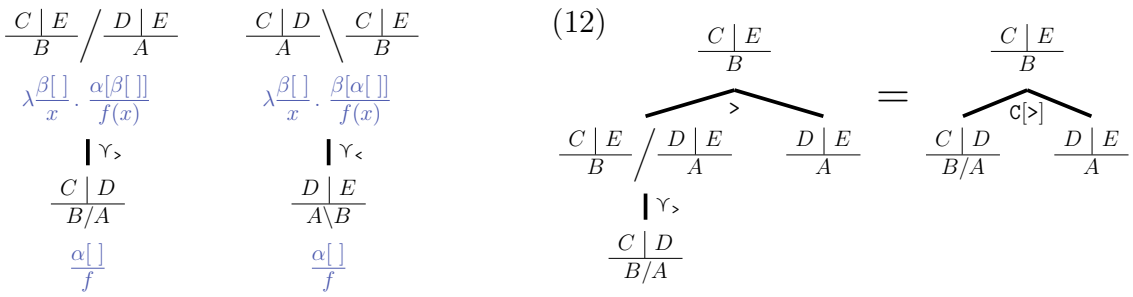


Figure 2: SPLIT (proposal)

We further assume the auxiliary rules in Figure 3. The first one PROLIFT, which was proposed by Leong and Erlewine (2019), lifts $A\triangleright$ from the bottom level to the continuation level (while we can eschew this additional rule with the monadic formulation of B&S's framework (Charlow, 2014; Bumford & Charlow, 2022), we leave the details for future work). In addition, we introduce, for each unary rule U, its variant $U_{>\mathtt{B}}$ that applies U to the result of a function category ($U_{<\mathtt{B}}$ is similarly defined). We note that the rule can be derived by composing U and the input with >B or <B.

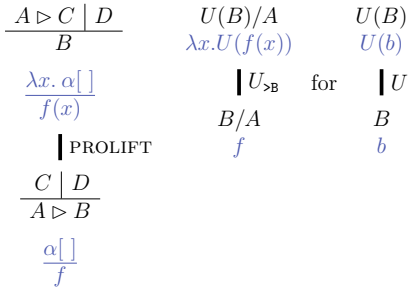
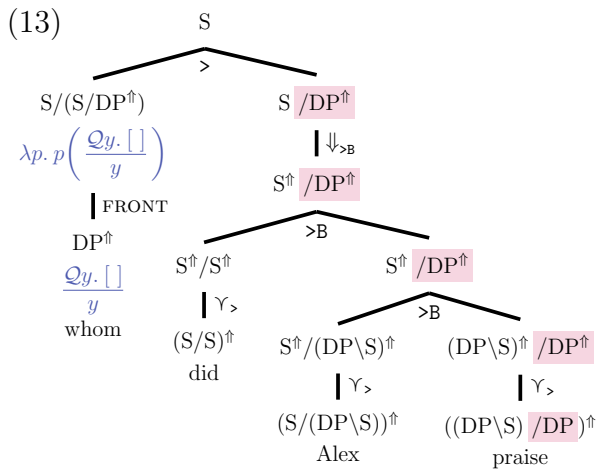
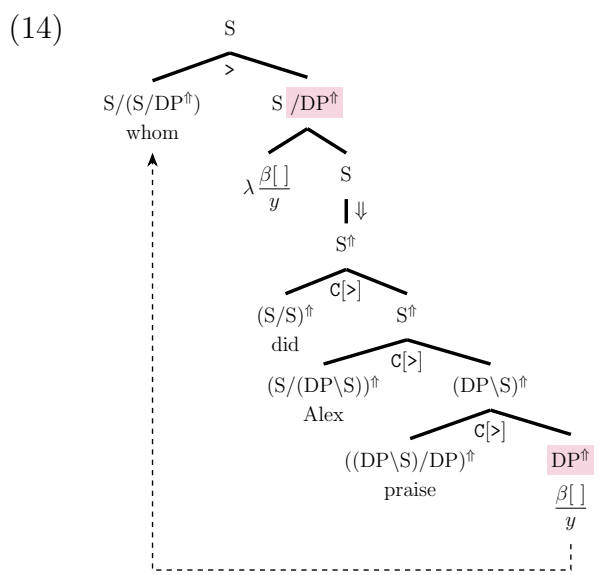


Figure 3: Auxiliary rules

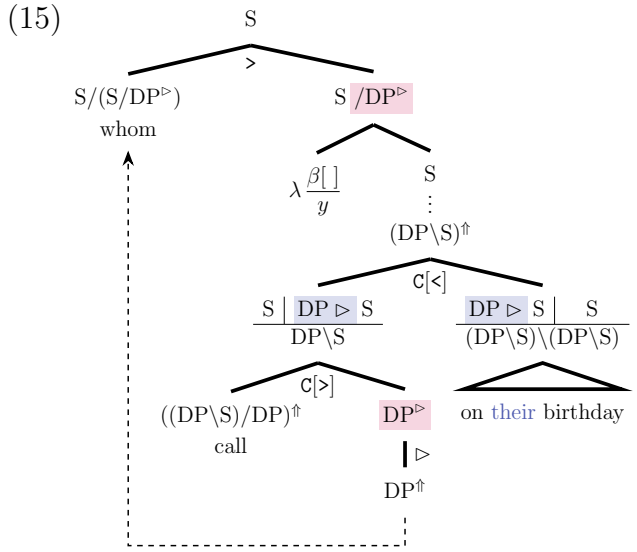
Let us now see how SPLIT interacts with function composition. Consider the derivation (13) of *Whom did Alex praise?*, where we write $A^{\Uparrow}$ for the lifted A (i.e., $S /\!\!/ (A \setminus\!\!\setminus S)$). Crucially, by applying SPLIT to the lifted constituents, we can compose them with >B, as we did in (10). Again, we can give a more intuitive picture with a movement-like description in (14). As we can see, the derivation proceeds as if *whom* were in the object position as a scope taker $\mathrm{DP}^{\Uparrow}$. In other words, the scope of $\mathcal{Q}y$ is reconstructed into the position where $\beta[\ ]$ appears.



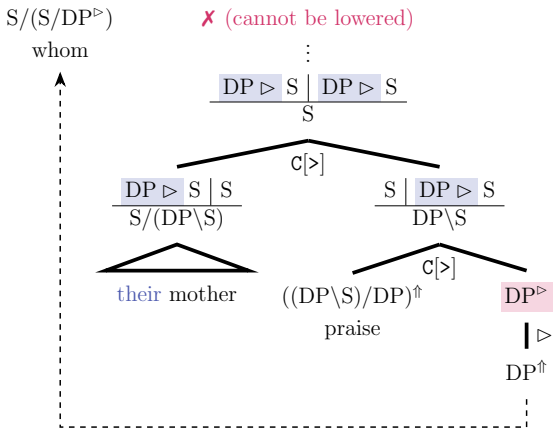


Account This split-and-compose approach derives binding in a way similar to B&S's framework. For instance, consider the acceptable case *Whom$_i$ did Alex call on their$_i$ birthday?*, where the pronoun appears after the object position. In this case, we can split the transitive verb to expect a binder $S /\!\!/ (DP \setminus\!\!\setminus (DP \triangleright S))$ on its right (we abbreviate this category as $DP^{\triangleright}$), which allows binding as illustrated in (15). In contrast, in the crossover cases like (5b), the trace cannot bind the pronoun due to the left-to-right nature of the scope-level composition (see (16)). Hence, we correctly predict the weak crossover effect in (5b).

(15)



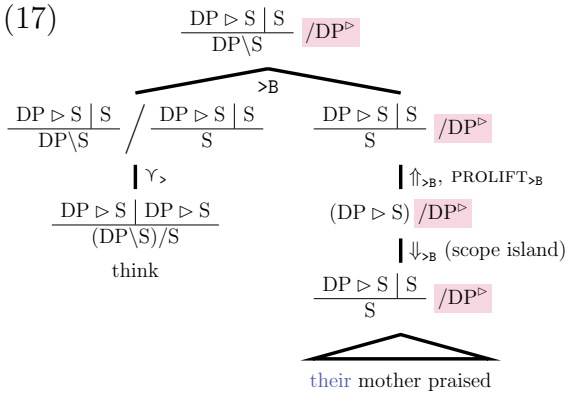
(16)



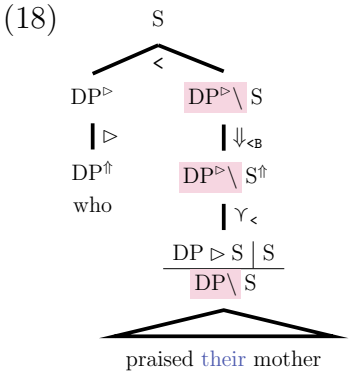
A significant advantage of this account is that function composition can be applied even over clausal boundaries, which immediately yields long-distance *wh*-dependencies. The details are shown in (17). We first apply $\Downarrow_{>B}$ to the embedded clause (as it is a scope island), but we can restore DP $\triangleright$ back to the scopal level with $\Uparrow_{>B}$ and PROLIFT$_{>B}$. After splitting the complement-taking verb *think*, we can compose it into the embedded clause. Notably, since we do not posit any intermediate gaps, there is no chance for the pronoun *their* to be bound, as in (16). Therefore, we correctly block binding in (9), for exactly the same reason as in the non-embedded case (5b).

Finally, we briefly consider subject extraction. Consider the derivation (18) for *Who praised their mother?*. After $\Upsilon_<$ is applied to the VP *praised their mother*, the constituent expects a binder $DP^{\triangleright}$ to its left. This can be filled by the subject *who*, yielding the desired bound interpretation.

(17)



(18)



Summary Although B&S's continuation-based theory of binding is promising for its left-to-right composition of scope, it cannot adequately handle long-distance *wh*-dependencies because of its treatment of gaps as scope-takers, whose effects cannot go beyond finite clause boundaries. To resolve this problem, we proposed SPLIT, which allows scope-takers to be combined via function composition, thereby providing a gap-free analysis of *wh*-reconstruction. Since function composition, unlike scope-taking, can cross finite clause boundaries, this approach successfully derives the weak crossover effect even in long-distance *wh*-dependencies.

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