Continuations for Comparatives*

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Abstract

I introduce Barker and Shan's (2014) project of finding natural language applications for continuations, walking the reader through the motivations and mechanics of said project, and then extend that project to another domain in which is it useful, namely comparatives. I examine the prevailing analyses of comparatives and then demonstrate how these analyses could be implemented in the continuations framework, comparing this version especially with that of Heim 2006. I then touch on some other issues surrounding comparatives—quantified comparative standards, Fleisher 2015 differentials, comparatives in other languages, ellipsis, and superlatives—and discuss how they impact (or don't) a continuations analysis of comparatives.

Contents

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1 Introduction

In this paper, I introduce the project of continuation semantics as carried out especially by Chris Barker and Chung-chieh Shan (2001, 2002, 2006, 2007, 2008, 2014, in various permutations), walking the reader through the motivations for the project as well as its formal implementations, presupposing no familiarity with continuations. After introducing continuations in the domain for which they were first introduced, quantifiers, I then extend this project to another domain, comparatives, which has been analyzed as sharing some of the properties of quantifiers. I present a survey of some of the data surrounding comparatives and the desiderata for analyses thereof, again presuming no expert knowledge of comparatives. After exploring comparatives in general, I review some of the most influential analyses thereof, including especially Heim 2000, 2006 and Schwarzschild and Wilkinson (2002) before illustrating how continuations can be used to provide an analysis of comparatives and discussing how that analysis overlaps with and/or diverges from existing accounts.

With the general picture of the core analysis in hand, I then explore some related issues, some of which have implications extending far beyond comparatives. I explore some of the thornier issues within the domain of comparatives, including the behavior of quantifier phrases within comparatives as well as some new issues surrounding differentials raised by Fleisher (2015). I also look at how comparative structures vary cross-linguistically, discussing how this variation bears on a continuation semantics account of comparatives. In addition, I consider some debates that extend beyond the study of comparatives proper, such as how superlative constructions are (or aren't) related to comparative constructions, as well as the status of comparative ellipsis, and reflect on how these debates influence the implementation of a continuation analysis for comparatives.

2 Background

2.1 Justifying the project

In the project of compositional semantics for natural language, the goal is for each word (or minimal part) to carry its own meaning, and for those meanings to combine in a predictable way—using a constrained set of operations—to produce the meaning of the sentence (or whole). In general, we take these meaning-combining operators (such as, most notably, function application) to be local—that is, effecting only adjacent parts—and to be conscious of the (semantic) types of the parts being combined. When adjacent parts don't have compatible types or when parts need to combine non-locally, then, this poses a difficulty to the project of compositional semanticists.

Perhaps the most famous example of this sort of difficulty is that of a quantifier in object position, as in (1).

(1) John saw everyone.

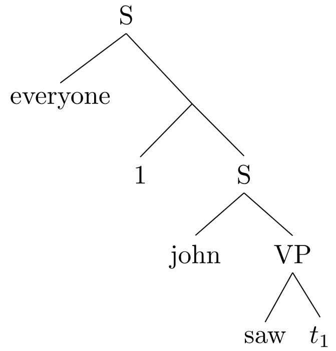
The verb *saw* is usually taken to be of type $< e, < e, t >>$, which we can understand as a function from individuals to properties, or as a function from individuals to a function from individuals to truth values, or as a function which takes an individual and returns a property, or perhaps most simply as a function which takes two individuals and returns a truth value. *john*, being an individual (type e), can combine nicely with *saw* (though as its second argument). The generalized quantifier *everyone*, however is not (usually taken to be)[1] an individual: it doesn't denote a (single) referent, and it isn't of type e but rather is (typically taken to be) of type $<< e, t >, t >$. This generalized quantifier (a function from properties to truth values) can't be the argument of *saw* (it not being type e), nor can it take *saw* as its argument (*saw* not being of type $< e, t >$). And thus the difficulty.

A common approach to this difficulty, as described by for instance Heim and Kratzer (1998), is to posit a movement[2] operation, **quantifier raising** (QR), which moves the type-mismatched *everyone* over the rest

[1] One might imagine an alternative strategy wherein *everyone* is taken to refer to the plural individual composed of the join of all (relevant) individuals in the (restricted) domain, but this approach runs into its own problems, and won't be discussed further here.

[2] As with all theories involving syntactic movement, this movement can be considered metaphorical for a number of different implementations. I won't discuss the different implementations further here.

of the sentence, leaving behind a trace of type e which can then be the first argument of *saw*, that trace being bound by an adjoined coindexed variable binder, which—after being combined via Predicate Abstraction to produce something of type $< e, t >$—can be the argument of the generalized quantifier. The final interpreted structure is illustrated in (2).

(2)


This movement is importantly *covert*: it occurs later in the derivation than the Surface Structure, and so has no phonological reflex (is unpronounced). The output of this post-surface movement for interpretation and type mismatch is called the **Logical Form** (LF).[3] This movement is also generally taken to be the same kind of movement as occurs earlier in the derivation, akin to *wh*-movement; this both constrains the movement, as whichever restrictions apply to *wh*-movement also apply to QR, and constrains the theory, not postulating an additional type of movement.[4]

There are some reasons to disprefer this approach, however. For decades, some linguists have been uneasy about positing post-surface syntactic movement (in particular, quantifier raising), as it has been considered both theoretically undesirable and empirically unsatisfactory (Williams 1986; Reinhart 1997; Chung 1998; Verkuyl 1999). Empirically, there are cases where QR overgenerates (e.g., object wide scope readings (Liu 1990; Ben-Shalom 1993)) as well as cases where in undergenerates (e.g., existential indefinites[5]). Theoretically speaking, positing QR also requires not just an additional mechanism, but an additional type of mechanism (namely, covert (LF) phrasal movement), which we should in general disprefer for reasons of economy (i.e., Occam's razor), but which has also been challenged as unnecessary and undesirable for the theory (Kayne 1998). QR certainly has explanatory power, but it's not a perfect solution.

An alternative approach to handling the problem of quantifier scope and quantifiers in object position involves being more flexible with types. One could posit lexically ambiguous entries for a quantifier like *everyone*, so that subject-position *everyone* would take an argument of type $< e, t >$ (the type of a VP, or a partly saturated transitive verb), but object-position *everyone* would take an argument of type $< e, < e, t >>$ (the type of an unsaturated transitive verb) (Hendriks 1987). Or, similarly, a verb like *saw* could be type-ambiguous (Montague 1973). Another flexible type approach involves not baking the type flexibility into lexical entries but instead postulating type-shifters as part of the interpretive apparatus; these type-shifters would allow otherwise-incompatible parts to change their types and then be able to combine in the regular fashion (Partee and Rooth 1983; Partee 1987)[6]. The continuations project that I will explore here takes this type-shifting approach.

[3] There has been significant debate in the literature about whether there is feature checking at LF and/or how it might differ from feature checking earlier in the derivation. This debate is important for any evaluation of the status of QR in the theory, but I won't go into them in depth here. For more, see Simpson 2000.

[4] Though, again, see the reference in footnote 3 for discussion on how the comparison between QR and *wh*-movement holds up.

[5] The scope of existential weak NPs is insensitive to islands, and its scope appears to be unbounded (Reinhart 1997; Surányi 2004)

[6] Partee and Rooth 1983 can be thought of as using a combination of these methods, as verbs have a minimal type but "higher-type homonyms" can be generated "only when needed for type coherence" by a lexical type-lifting process; this is a lexical process, not an interpretive one, but still allows for the as-needed creation of higher types.

2.2 Introducing continuations

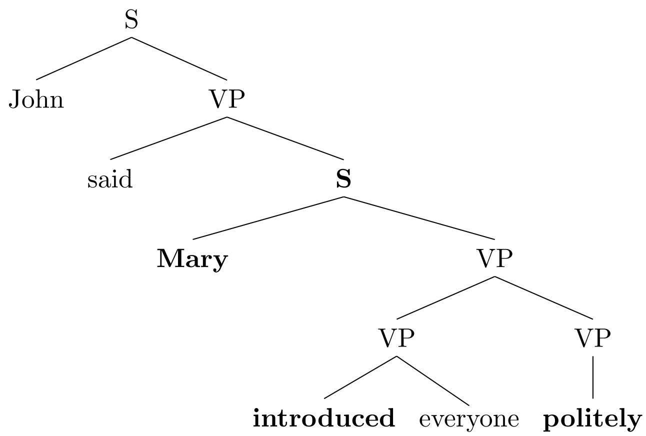
2.2.1 What's a continuation?

Put simply, a continuation is a part of the context surrounding an expression. (The word *continuation* is only meaningful relative to an expression.) For example, in the simple sentence (1), the continuation of the generalized quantifier *everyone* is *John saw* [ ]. In this simple example, the expression (*everyone*) occurs at the edge of its continuation, but that needn't be the case; discontinuous-looking contexts are also licit continuations, if they (with the bracketed expression) compose a complete structural unit.[7] To illustrate, the continuation of the generalized quantifier in (3a) is (3b), diagrammed structurally in (3c).

(3) a. John said Mary introduced everyone politely.

b. Mary introduced [ ] politely

c.



The discontinuous context in (3b), together with its missing bracketed material, makes up a single complete structure (the embedded S) in the sentence (3a), as diagrammed in (3c).

The reason we define this concept is because, according to the continuation hypothesis, these special kinds of contexts act as arguments for some expressions. Barker and Shan (2014, p. 1) define this hypothesis as in (4), arguing that "continuations are an essential component of a complete understanding of natural language meaning".

(4) **The continuation hypothesis**
Some natural language expressions denote functions on their continuations, i.e., functions that take their own semantic context as an argument.

Why should we accept continuations as units? As we've already seen, each constitutes a syntactic unit, albeit one missing a piece. They also can be understood as having a meaning contribution, namely the meaning of the entire clause with the bracketed expression abstracted. In (3a), for example, the meaning of the continuation in (3b) can be written as $\lambda x.\text{politely}(\text{introduce}(x, m))$: the property of being politely introduced by Mary. This is a property of individuals, something we'd normally classify as being of type $< e, t >$—but this continuation shouldn't have the same type as other things of type $< 3, t >$ (e.g., intransitive verbs)! The expression missing from a continuation isn't adjacent to it but within it! And, importantly, the continuation isn't the function taking an argument, but is itself the argument of its missing expression. We don't want the continuation in (3b), for instance, to be able to combine with an individual (of type e) via normal Function Application, nor will Function Application suffice to interpose the missing expression into the bracketed slot.

(5) a. * Mary introduced [ ] politely Bill.

b. * Mary introduced [ ] politely the students.

[7] This is a stronger restriction than that the parts be contiguous (as adjacent words might be structurally disjoint) but a looser restriction than constituency (which applies only to certain structural nodes, e.g. PP but not P′).

We need some new type structure to handle this distinction. Before I introduce it, however, two brief notes, one on formatting and presentation, and then one on attribution.

Through the course of their project of introducing continuations and their applications to natural language, Barker and Shan have used a variety of presentations. Barker 2001 used underlines for a continuized grammar, so a generalized quantifier like *everyone* has the semantic type $<< e, t >, t >$ and the syntactic category $\underline{\text{NP}}$: a continuized NP. Barker 2002 presents the same system using doubly curly braces for the continuized denotations of those same semantic types; a generalized quantifier has the continuized denotation $\{\{\text{NP}\}\}$. Shan and Barker 2006 incorporates this type-logical combinatory information into the semantic types, giving *everyone* a category label $t \,/\!\!/ (e \,\backslash\!\!\backslash t)$. By Barker 2007, this information was cast again as purely syntactic, with generalized quantifiers being of type $\text{S} \,/\!\!/ (\text{NP} \,\backslash\!\!\backslash \text{S})$. In Barker and Shan 2008, the authors introduced a new "'tower' notation" for continuations, writing the type of a generalized quantifier as $\frac{S \mid S}{DP}$. It's this same notation which they use in their 2014 book, which also features schematic diagrams ("tangram diagrams" featuring slotted triangles and other nesting shapes).

In this work, I'll be primarily working with the Shan and Barker 2006 $t \,/\!\!/ (e \,\backslash\!\!\backslash t)$ notation, though when initially introducing the framework I'll provide definitions across multiple presentation styles. I hope this will make the project clear, especially for those readers who might want to reference previous works which, as discussed, may use differing presentations. For the novel contribution on comparatives, though, I'll stick with the 2006 style. I do so not to make any strong statements about the interaction between syntax and semantics, but because (a) I simply find this presentation more appealing, and because (b) dealing in semantic type category labels allows me to discuss degrees (type d) and intervals (type D) without taking a stance on the syntax of Number/Numeral/Degree phrases.

And finally, before I continue introducing continuations as implemented by Barker and Shan, I should note that, as they take care to note in their (2014) book, Barker and Shan are by no means the first or only researchers working on continuations in natural language.

> "[W]e are by no means the first semanticists to make use of continuations. ... [We] argue that Montague's conception of DP meanings as generalized quantifiers is a form of continuation passing. Likewise, [] we consider the dynamic conception of meaning (on which a sentence is a context update function, as in, e.g., Groenendijk and Stokhof (1990)) as a different version of the same core idea of continuization. And yet again, we will suggest that Partee (1987)'s treatment of generalized coordination [], as well as Hendriks (1993)'s treatment of scope-taking [] also make implicit use of continuations.
>
> Nor are we the only researchers to study natural language semantics with explicit consideration of continuations. Around the same time we began our work, de Groote (2001) applied the λ_μ-calculus to natural language scope []. A few years later, de Groote (2006) gave a different continuation-based treatment of donkey anaphora []. Among the growing list of continuation-based analysis of natural language [] is Bernardi and Moortgat (2010)'s Lambek-Grishin calculus.
>
> In other words, this book is neither the first word nor the last word on continuations in natural language" (7f.)

It may not be the first nor the last word, but I will nevertheless be treating Barker and Shan 2014 as an exemplar of the project of using continuations to analyze natural language and its authors as champions (though not the sole champions) of this project. It's their work with which I'm most familiar, their framework(s) which I use and extend, and their parsers which (thanks to their generosity) have helped to test and verify this work.

2.2.2 New types

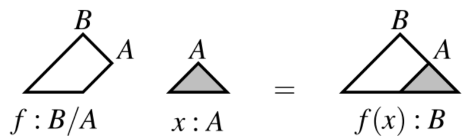
We turn now to the new types we'll need to introduce into our system in order to handle the new structures we've described above. Before we get too in-depth with these new types, though, let's start out on solid ground with something we're already familiar with.

			SYNTACTIC TYPE	MEANING	SEMANTIC TYPE	CCG SEM	CCG SYN	TOWER
(6)	**left**	intransitive verb	VP	$\lambda x.\text{left}(x)$	$< e, t >$	$e\backslash t$	DP\S	DP\S

The intransitive verb *left*, which we traditionally associate with the syntactic category VP and the Montagovian semantic type $< e, t > \equiv \texttt{e} \to \texttt{t}$, has the meaning $\lambda x.\text{left}(x)$: it's a function which takes an individual and returns true iff that individual left. Transposing that semantic type into a CCG-style framework (as in Shan and Barker 2006), *left* has the semantic type $e\backslash t$, and doing the same with the syntactic category (as in Barker 2007) gives us the syntactic type DP\S. And finally, in the tower notation, *left* has the same CCG syntactic type, and is quite uninteresting until it is modified to allow it to combine with other towers. We'll return to that shortly.

If you're not already familiar with the CCG notation, we can read $A\backslash B$ as a functor which, if combined with an argument of type A on its left, would form something of type B. So the semantic type $e\backslash t$ is that of a function looking for an individual (type e) on its left which returns a truth value (type t), and the syntactic category DP\S is one of a function looking for a determiner phrase on its left which returns a sentence. This schema is illustrated nicely in Barker and Shan's (2014) tangram diagrams:

(7)

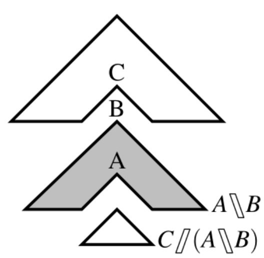


This CCG framework brings with it a toolbox of inferential rules which allow these types to combine in the ways we'd like, but importantly these combinatory rules expect functions and arguments to be adjacent to one another, not *inside* one another. So here's where new types are needed.

In addition to the slashes, which indicate left/right adjacency relations, we'll make use of fat slashes which will indicate containment relations. Read $A \backslash\!\!\backslash B$ as something that would be of type B if only it had something of type A inside of it (in a particular slot). (If it helps, you can think of these slashes as indicating up/down directionality.) Similarly, read $C /\!\!/ D$ as something that would be of type C if we could combine it with a D surrounding it. A continuation like those we've discussed above, then, will have a type that uses one of these fat slash types: the continuation in (3b), which would be of type t if only it had something of type e inside it, will be of type $e \backslash\!\!\backslash t$.

And, in keeping with the continuation hypothesis, this $e \backslash\!\!\backslash t$ continuation will be the argument of the functor inside of it. That functor, then, is something which wants a $e \backslash\!\!\backslash t$ surrounding it in order to form something of type t (the type of the full sentence in (3a)). The type of the scope-taking *everyone*, then, is $t /\!\!/ (e \backslash\!\!\backslash t)$: something that would form a type t if only it had a continuation of type $e \backslash\!\!\backslash t$ surrounding it. Let's illustrate this fat slash combination with another tangram diagram:

(8)



The shaded triangle is the continuation: it would be of type B if its type A slot were filled (and so it gets type $A \backslash\!\!\backslash B$). The small white triangle isn't missing any parts, but it wants to be surrounded by something of type $A \backslash\!\!\backslash B$. Upon doing so, it'll return something of type C, interacting with the rest of the sentence 'above'.[8]

With our familiarity with fat slashes, we can return to the presentations of a generalized quantifier like *everyone*:

			SYN TYPE	MEANING	SEM TYPE	CCG SEM	CCG SYN	TOWER
(9)	**everyone**	generalized quantifier	QP	$\lambda f.\forall x : f(x)$	$< et, t >$	$t /\!\!/ (e \backslash\!\!\backslash t)$	$S/\!\!/(DP\backslash\!\!\backslash S)$	$\dfrac{S \mid S}{DP}$

[8]In our *everyone* example, B and C are of the same type, t, so the upper white triangle is vacuous in the derivation. This needn't necessarily be the case, as we'll see later on in the paper.

The generalized quantifier *everyone*, which we traditionally associate with its own syntactic category (Quantifier Phrase) and the Montagovian semantic type $<< e,t >, t >$[9], has the meaning $\lambda f.\forall x : f(x)$: it's a function which takes a property and returns true iff all individuals (of some possibly-restricted domain) have that property.[10] Transposing that semantic type into our CCG-style framework, *everyone* has the semantic type $t \mathbin{/\!\!/} (e \mathbin{\backslash\!\!\backslash} t)$, described in detail above, or, in the Barker 2007 system, the equivalent syntactic type $S \mathbin{/\!\!/} (DP \mathbin{\backslash\!\!\backslash} S)$. And now that we have a lexical item that makes use of continuations (in that it takes a continuation as its argument), we can introduce the tower notation. Any syntactic category or semantic type of the form $C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B)$ can equivalently be written as $\frac{C \mid B}{A}$, and just as the fat slash notation can be 'read out' in the order middle>right>left, the tower notation can be 'read out' going counterclockwise starting from the bottom: this is something which acts locally as an A, takes scope at B, and returns something of type C. The tower notation for a generalized quantifier like *everyone*, then, using the notation from Barker and Shan 2008, 2014, is $\frac{S \mid S}{DP}$: it acts locally as a DP (appearing in the same place as a type e argument of a verb), takes scope at the level of the (possibly embedded) sentence, and returns a sentence.

To introduce just one more term, we can consider any structure of the type $C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B) \equiv \frac{C \mid B}{A}$ as being at a *continuation level*. This notion will be useful for two reasons. First, as continuations and continuation-sensitive structures interact with each other differently from normal Function Application (in a way that we'll define shortly), only things that are already at a continuation level can interact with one another. (Thus, having a term that allows us to differentiate between interaction classes will be helpful.) Second, because our new type structures operate on types, which are defined recursively, they can produce multiply embedded structures. In other words, there's nothing preventing the A in $C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B)$ from itself being of the form $C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B)$, producing a structure like $E \mathbin{/\!\!/} ((C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B)) \mathbin{\backslash\!\!\backslash} D)$. Or, equivalently, the tower structure $\frac{E \mid D}{\frac{C \mid B}{A}}$. This new structure is also at a continuation level; call it continuation level 2, as it has two sets of fat slashes or two tower levels. And of course this process can be iterated, producing interpretable types of any number of levels.[11]

2.2.3 Combining, lifting, and lowering

At this point we've added some additional types to our system—in either the fat slash or tower notation—, but they won't play nicely with the existing combinatory operations that CCG allows us. Function Application, for instance, schematized in (7), works with slashes, not fat slashes—and if it did, that'd negate the benefits of making a new type in the first place! What we need, then, are new operations that let these new types interact with our existing system. We'll need an operation that lets these new type structures combine with one another, as well as some operations that let them interact with our existing (normal slash) types.

First, let's tackle the most complex operation, the one which lets two of our new (fat slash or tower) structures combine with one another. Shan and Barker 2006 calls this operation "Scope", while Barker and Shan 2014 calls it simply "the combination schema", describing it as a "'/' variant"; for convenience and brevity, I'll adopt the name SCOPE. Like Function Application, SCOPE combines structures of different types, so long as those types stand in a certain relation to one another. For SCOPE to apply, the structures must meet three criteria:

(10) For two structures, Left & Right, to combine via the operation SCOPE,

a. both Left and Right must be at a continuation level,

b. the type at which Left takes scope must be the same type that Right returns

$$\left(\begin{array}{l} \text{in other words, to combine } C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B) + F \mathbin{/\!\!/} (D \mathbin{\backslash\!\!\backslash} E)\text{, it must be that } B = F \\ \text{or, equivalently, to combine } \frac{C \mid B}{A} + \frac{F \mid E}{D}\text{, it must be that } B = F \end{array} \right)$$

[9] $<< e,t >, t >$ is abbreviated to $< et, t >$ in (9) for space reasons; the two are equivalent.

[10] *everyone* in particular itself restricts the domain to individuals which also have the property of personhood. This particular restriction is not crucial here, and, as this entry is intended to provide a schema of generalized quantifiers writ large, is omitted here.

[11] How many levels are useful/needed for natural language is a separate question, one I'll not address here.

c. the local type of Left must be a function which takes the local type of Right as its argument

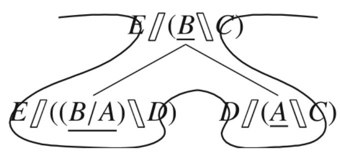
$$\left(\begin{array}{l}\text{in other words, to combine } C \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B) + F \mathbin{/\!\!/} (D \mathbin{\backslash\!\!\backslash} E),\ A \text{ must take } D \text{ as an argument} \\ \text{or, equivalently, to combine } \frac{C \mid B}{A} + \frac{F \mid E}{D},\ A \text{ must take } D \text{ as an argument}\end{array}\right)$$

If these conditions are met, SCOPE can apply. I'll briefly describe how, and then some diagrams will help to bring this all into focus.

When SCOPE combines two structures, the matching 'interior' scope types are removed (matching as per the condition in (10b)), the local types combine via normal Function Application (made possibly by the condition in (10c)), and the resulting structure is at the same continuation level as the lower of the two combinants.[12] Schematically, in the Shan and Barker 2006 notation:

$$\text{Scope} \quad ((E \mathbin{/\!\!/} (B \mathbin{\backslash\!\!\backslash} C))/(D \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} C)))/(E \mathbin{/\!\!/} ((B/A) \mathbin{\backslash\!\!\backslash} D))$$

$$\lambda L.\ \lambda R.\ \lambda \kappa.\ L\ (\lambda l.\ R(\lambda r.\ \kappa\ (lr)))$$

(11) 

(Shan and Barker 2006, (12))

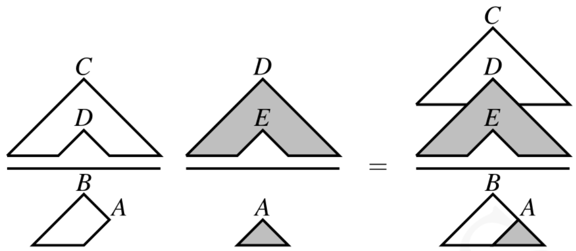
Looking at the curved line in the diagram, the innermost matching labels (the D's) are canceled out while the outermost labels (E and C) become the surrounding type labels of the output structure. Meanwhile, the local types (B/A and A) reduce to B via Function Application. (The type-logical and lambda calculus machinery necessary to make this combination are also provided above the diagram.) Equivalently, the same combinatory process in Barker and Shan 2014:

$$(12) \quad \left(\begin{array}{cc} \frac{C \mid D}{B/A} & \frac{D \mid E}{A} \\ \text{left.exp} & \text{right.exp} \\ \frac{g[\ ]}{f} & \frac{h[\ ]}{x} \end{array}\right) = \begin{array}{c} \frac{C \mid E}{B} \\ \text{left.exp right.exp} \\ \frac{g[h[\ ]]}{f(x)} \end{array} \qquad \text{(Barker and Shan 2014, (16))}$$

These entries are a little more complex than the abbreviated ones I gave above, but they're easy enough to parse: the top row contains the syntactic information (the towers introduced earlier), the middle row contains the phonological information (here, the labels "left" and "right"), and the bottom row the semantic information. First, let's focus on the towers on the top row. First, looking at the towers' 'top floors', note that the innermost labels already match, as per the condition in (10b), and that these Ds are not present in the output structure. The top-left type of the left combinant and the top-right type of the right combinant, meanwhile, end up as in their respective locations in the output structure. Second, looking at the syntactic towers' 'bottom floors', note the CCG-style Function Application as B/A and A combine to produce B as the local type in the output structure. At the same time, we can see Function Application occurring on the semantic row. The tower notation has separate semantic tiers for each syntactic tier, but note that both are combining via (left-to-right) Function Application: $g[]$ and $h[]$ combine to yield $g[h[]]$, and f and x combine to output $f(x)$.

Or, we can think about this diagrammatically:

[12] Just as a summand is a thing which is summed (e.g., in the expression $2 + 4 = 6$, 6 is the sum while 2 and 4 are the summands), I'm using the term *combinant* to mean a thing which is combined (in an underspecified way). Just as we could describe 2 and 4 as combining either by a summation procedure, or as the arguments of a summing function, we can describe the combination of our continuized structures in different (but equivalent) ways. In the Shan and Barker 2006 notation, SCOPE is an operator which takes two continuized structures as arguments; in the Barker and Shan 2014 notation, the continuized towers combine through an inferential process (just like '/' introduction or elimination). For brevity and to avoid biasing one metaphor over the other, I (re)introduce this term for which the OED lists mathematical uses from the 1800's.

(13) 

(Barker and Shan 2014, (17))

Above the line, we have the syntactic combination of slotted-triangles like we saw in (8). These combine as you might expect, the right fitting inside the left. Below the line, we see the same Function Application we saw in (7).

We have, then, an operation to combine two continuized structures. There is an equivalent paired operation for when the right combinant takes the left as its argument. In the Barker and Shan 2014 format this would be the "'\' variant"; in this variant, the third criterion for SCOPE to apply is reversed: the local type of the right combinant must be able to take the local type of the left as its argument. Though the order of the local types reverses, no changes are made to the ordering, interpretation, or reductions of the exterior fat slash/tower types. In the tangram diagram (13), the lower tier would be reversed, but the top would remain unchanged.

You might notice that this combination operation is sensitive to the linear order of its combinants—not of their local types, but of their continuation types; this is no accident. Nor is it an accident that Shan and Barker 2006 names this operation SCOPE. The way this operation works, the left combinant takes scope over the right, as is made apparent in the diagram in (13). What does it mean for one to scope over the other, beyond an ordering of tangrams? The operation's output has the return type of the left combinant's return type, regardless of whether the left or right combinant's local type was the function. This left-over-right bias is built into the system intentionally, as doing so addresses certain issues around crossover, superiority, and preferences for a surface order interpretation (e.g., for sentences with multiple quantifiers, as in (14)) (Shan and Barker 2006).

(14) Someone saw everyone.

This system includes a mechanism for deriving readings that don't cohere to the surface ordering: in (14), this means the interpretation with wide-scope *everyone*. Though the presentations look slightly different in the Shan and Barker 2006 and Barker and Shan 2014 notations, the key idea is that LIFT can create higher continuation level structures in two ways: LIFT can target either the entire structure (adding new fat slashes on the outside, or a new tower layer on top), or it can target just the local type (adding new fat slashes around that local type but inside the existing fat slashes, or a new tower layer in the *middle* of the tower). As Barker and Shan (2014, p. 44) put it: "After all, if you decide to add a new floor to a physical tower, there are two ways to go about it: either you add a new floor on the top of the old building (the original LIFT strategy), or you jack up an existing floor and build the new floor in the space in between. This second process is sometimes called 'roof lifting'." This alternative method allows for the generation of right-to-left scope interpretations, but doing so requires more rule applications: for *everyone* to take scope over *someone* in (14), *everyone* would have to be raised by this roof lifting LIFT before it could SCOPE over *someone*. The system still retains the left-to-right preference if we consider additional rule applications as having a processing cost.

We now have an operation for combining multiple structures at continuation levels. But, so far, the only words we've seen that make use of continuations are quantifiers, and even in a sentence like (14) with multiple quantifiers there are also non-quantifiers; so how do these new structures interact with words like *saw* (as in (14)) or *left* (as in (1))? For that, we'll need to be able to bring our familiar non-continuized types up to a continuation level, such that they can be combined by SCOPE. And for that, we'll need LIFT.

Barker and Shan's LIFT is a type-lifter, allowing a thing[13] of one type to combine with things it wouldn't otherwise be able to, but without changing the meaning it contributes. This sort of type-lifting isn't unique to the continuation project, and indeed there is an equivalent rule which does the same thing (type shift,

[13] I say "thing" here so as to avoid the assumption that only words have types and denotations. It may be the case that morphemes or phrases behave in this same way in some languages/constructions, the nuances of that argument being peripheral to the current project.

meaning left unchanged), only without lifting to a continuation level, given by Partee and Rooth (1983); Moortgat (1997); Partee (1987); Jacobson (1999); Steedman (2000), among others (Shan and Barker 2006, fn. 8). This new version differs only in that it lifts to a continuation level; see (15) for comparison.

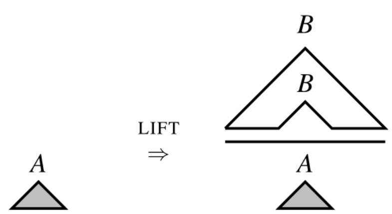
(15) Lift $(B/(A\backslash B))/A$ $\lambda x.\lambda F.F(x)$
LIFT[14] $(B \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} B))/A$ $\lambda x.\lambda F.F(x)$

(15) is in the Shan and Barker 2006 presentation style (note the fat slashes); we'll see the same operation in the tower presentation in a moment. Looking at (15) first, though, note that the only difference between the syntactic types is the kind of slash used in the output types. Type-logically, both are one-place functions that take something of type A and return that same A wrapped in surrounding slashes; for the classic treatment, thin slashes (turning e into $t/(e\backslash t)$), and for our new treatment, fat slashes (turning e into $t \mathbin{/\!\!/} (e \mathbin{\backslash\!\!\backslash} t)$). And their denotations are the same, in that both denote the identity function: they take an x (which is A), then take an F (of whatever type B is), and apply x to F in just the same way that they would be combined if their types allowed them to do so normally, that is, by Function Application.

Unsurprisingly, LIFT looks slightly different in each presentation style, but the idea is the same: syntactic type change paired with a semantic identity function. (16) is the tower notation schema for the LIFT operation:

(16) $$\begin{array}{c} A \\ \textit{phrase} \\ x \end{array} \overset{\text{LIFT}}{\Rightarrow} \begin{array}{c} \dfrac{B \mid B}{A} \\ \textit{phrase} \\ \dfrac{[\,]}{x} \end{array}$$ (Barker and Shan 2014, (18))

On the syntactic tier (above the word "phrase"), A remains the local type, but now takes scope at and returns something of type B. Semantically, the x is unchanged, only now it has a gap (the [ ], equivalent to the identity function) on its upper tier, which will be the function that takes x as its argument. And, schematically, we can see LIFT as in (17):

(17) 

(Barker and Shan 2014, (19))

Semantically (below the line), it still acts as an A. Syntactically, it's now a structure that wants to take a B inside of it and will then return a B.

Now that we have LIFT to bring our old types up to a continuation level,[15] we can use SCOPE to combine them with other continuized types. At the end of the derivation, though, we'll be left with something at a continuation level (as SCOPE's output is continuized). What we need, then, is an operator to return a continuized type to our more familiar types; this way we can be left with a simple type t for a sentence by the end of the derivation.[16] For this we'll introduce the complement to LIFT, namely LOWER.

Syntactically, LOWER takes a structure (at a continuation level) whose local type *and* the type at which it takes scope are *both* of type t, and then returns something of the return type of the original structure. In other words, LOWER allows the structure's 'takes scope at' type to actually do so, but we only allow this to happen with type t, assuming that this domain-closing is appropriate only at the level of a complete

[14]Shan and Barker 2006 calls the existing type-lifter "Lift", and the continuation type-lifter "Up". Barker and Shan 2014 calls the new type-lifter LIFT (leaving Lift as part of the inference procedure provided by CCG). I've mentioned them both, to illustrate their similarity (and in doing so to reduce the burden of new things added to the system), but will continue to use the name LIFT for simplicity's sake. The interaction between Shan and Barker 2006's Lift and Up will become important later on, but for now we can focus on understanding the role of LIFT in the system.

[15]LIFT can also be used to raise something at continuation level 1 to continuation level 2, and so forth.

[16]Or, as Shan and Barker (2006) put it, "[w]hat goes up must eventually come down". That line loses part of its charm, however, using the LIFT/LOWER naming scheme from Barker and Shan 2014 as opposed to Up/Down (Shan and Barker 2006).

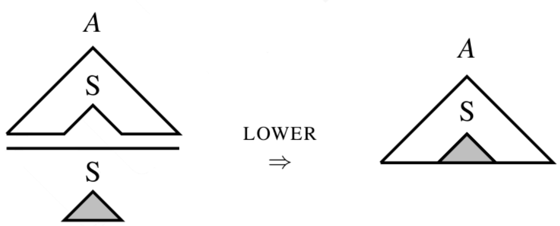
sentence.[17] This restriction also has consequences for explaining crossover effects (Shan and Barker 2006; Barker and Shan 2014). Semantically, it feeds the identity function as an argument to the meaning of the continuized structure. In the Shan and Barker 2006 notation, LOWER is a one-place function, taking the structure being lowered as its argument:

(18) LOWER $A/(A /\!\!/ (t \backslash\!\!\backslash t))$ $\lambda F.F(\lambda x.x)$

Syntactically, it takes something of type $(A /\!\!/ (t \backslash\!\!\backslash t))$ and returns its return type, A. And, exactly as described above, it applies this structure's denotation to the identity function. Or, in tower notation:

(19) $\dfrac{A \mid S}{S}$ *phrase* $\dfrac{f[\;]}{x}$ $\overset{\text{LOWER}}{\Rightarrow}$ A *phrase* $f[x]$ (Barker and Shan 2014, (21))

In this notation, we swap t out for S, but the operation is the same. Syntactically, we're left with an A, and semantically we apply the upper tier's identity function to the contents of its lower tier (x). To complete the set, we can consider LOWER in diagram form:

(20)


(Barker and Shan 2014, (22))

This illustration makes the 'lowering' nature of LOWER especially clear (even clearer than the two-story tower being reduced to one, as in (19)): the slotted triangle (representing the scope-taking structure) is lowered onto its own (shaded) 'meaning triangle' which it had been carrying around with it—provided, of course, that the types of the shaded triangle and the slot match.

Having definitions and diagrams is a good start, but it'll useful to see these new operations—SCOPE, LIFT, and LOWER—and our new continuized structures in action. Let's return to (1), repeated here for convenience, to look at an example derivation.

(1) John saw everyone.

First, let's look at a type tree derivation, using the Shan and Barker 2006 notation for compactness.

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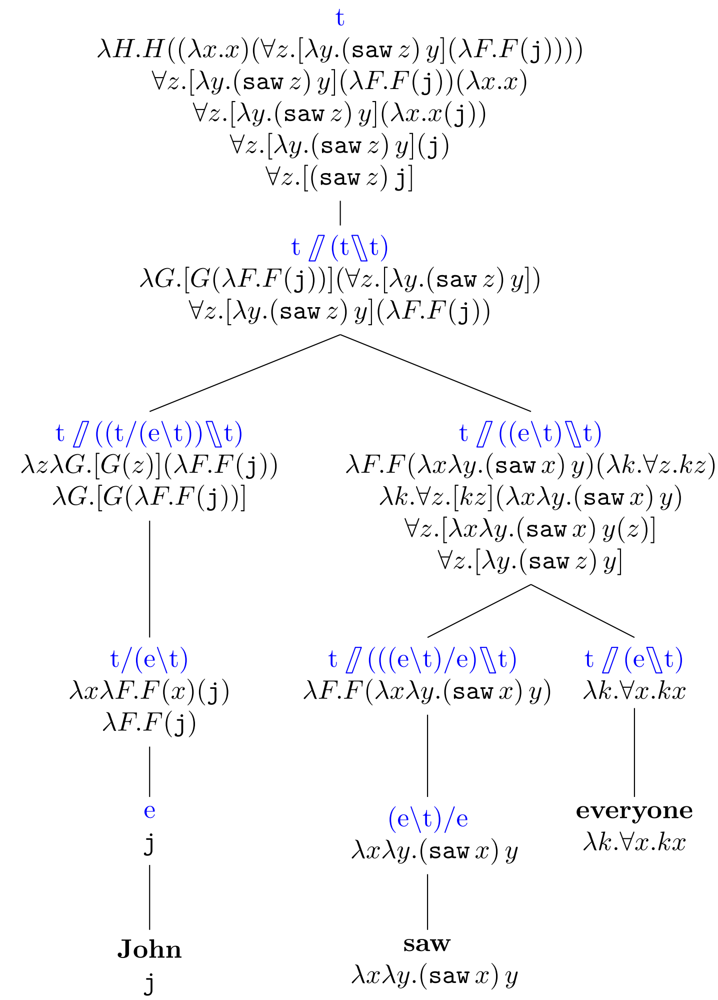
[17] The most common input to LOWER, being of type $t /\!\!/ (t \backslash\!\!\backslash t) \equiv \frac{S \mid S}{S}$, would also be able to take scope over a neighboring sentence in a semantics which allowed for such cross-sentential interaction, if LOWER simply didn't apply at the end of the sentence's derivation.
This isn't the only possible input to LOWER, however, whose definition is generalized over the return types of its inputs. As we'll see, this will be important later on in this project.

(21)



Each node in the tree in (21) has first its syntactic type (in blue, for easy spotting), and below it its semantic denotation (including step-by-step simplifications thereof). To understand this tree, let's read it from the bottom up, starting from the right. The generalized quantifier *everyone* is lexically of type $t /\!\!/ (e \backslash\!\!\backslash t)$, and the lexical type of the transitive verb *saw* is $(e\backslash t)/e$. These can't combine via Function Application, as neither takes the other as an argument, nor can they combine via SCOPE, because *saw* isn't at a continuation level. For them to combine, *saw* has to be LIFTed to a continuation level; this is the next label on the unary branch above *saw*, as it is raised by LIFT to type $t /\!\!/ (((e\backslash t)/e) \backslash\!\!\backslash t)$. In doing so, its denotation is changed as well, and the original denotation is now preceded by a $\lambda F.F$ identity function. Syntactically, it is now *saw*'s lexical type, now surrounded by a $t /\!\!/ (\_\_\_ \backslash\!\!\backslash t)$ continuation level 'wrapper'. This new type can now combine with *everyone* via SCOPE, as it meets the relevant conditions: both are continuation levels, the innermost continuation type labels are the same (*saw*'s scope-taking type and *everyone*'s return type—which is noncoincidentally now also *saw*'s return type), and the local type of *saw* can take the local type of *everyone* as its argument ($(e\backslash t)/e$ taking e). Now looking at the mother of the binary branch above *saw* and *everyone*, we get the output type of this occurrence of SCOPE: the output of the local type Function Application ($e\backslash t$), still at a continuation level whose labels are the outermost labels of its inputs (here, both are still t). And, semantically, the LIFTed verb's identity function takes *everyone*'s function as its argument, which in doing so nests *saw*'s core denotation within the scope of the universal quantifier.

This new type, $t /\!\!/ ((e\backslash t) \backslash\!\!\backslash t)$, is the type of the phrase *saw everyone*. The only other word for it to combine with, *John*, is of type e. These can't combine, either by Functional Application or by SCOPE, for the same reasons described above. To allow them to combine, we'll have to augment the type of *John* in two ways (and so in two steps). We need *John* to be at a continuation level, so we'll have to apply LIFT, but that alone would produce a structure of type $t /\!\!/ (e \backslash\!\!\backslash t)$, which still wouldn't be able to combine with the type of *saw everyone*! For SCOPE to apply, remember, the local type of the structure on the left must be able to take the local type of the structure on the right as its argument. So before applying our continuation type-shifting LIFT, we'll have to apply the traditional type-shifter Lift (e.g., Partee's (1987), which is built into the mechanics of our CCG type-logical system), which will turn *John*'s type e into type $t/(e\backslash t)$. This is the first label on the unary node above the lexical type of *John*. In doing so, the denotation of the Lifted *John* becomes an individual looking for a function to take it: $\lambda F.F(\mathtt{j})$. Only after Lift is applied is our new LIFT applied, surrounding $t/(e\backslash t)$ in a continuation wrapper, whose output—of type $t /\!\!/ ((t/(e\backslash t)) \backslash\!\!\backslash t)$—can then combine with *saw everyone* via SCOPE. Looking at the denotation of this LIFTed Lifted individual, we see another layer of identity functions making *John* into an omnivorous function, taking as its argument a function which would take a function to return those functions applied to *John*.

Looking at the topmost binary branch of (21), then, we see SCOPE combining the now-continuized types of *John* and *saw everyone*. SCOPE can apply because the innermost continuized labels are the same (they're both ts) and the local type of the structure on the left ($t/(e\backslash t)$) can take as its argument the local type of the structure on the right ($e\backslash t$). Semantically, SCOPE feeds the denotation of SAW EVERYONE to *John* as an argument, but that combination can only reduce so far (keeping in mind our left-to-right evaluation order). The output of that application of SCOPE, at the top of that topmost binary branch, is the output of that local Function Application surrounded by the outermost continuation types of its inputs' wrappers: $t /\!\!/ (t \backslash\!\!\backslash t)$. This is now the type of the entire sentence *John saw everyone*, but is still at a continuation level. Before we finish, then, we'll have to apply LOWER to return this to a non-continuation type. LOWER can apply because the local type and the scope-taking type are the same: both are ts.[18] LOWER, you'll recall, takes an $A /\!\!/ (t \backslash\!\!\backslash t)$ structure and returns an A, so LOWER will take the still-continuized type for *John saw everyone*, $t /\!\!/ (t \backslash\!\!\backslash t)$, and return a t: exactly what we'd like to have as the type for a full sentence. And, semantically, LOWER provides two more identity functions, allowing our previously incompatible terms to combine together. Because LOWER is "plugging a hole in a context" (Barker and Shan 2014, p. 16), as opposed to beta reduction, it can lead to variable capture, which is what allows j to end up inside the scope of the universal quantifier. Reducing the previously-*John* expression down to simply j in this way, by means of two identity functions, allows it to be taken as an argument by *saw* and thus gives us the truth conditions we want.

This type tree was in Shan and Barker 2006 notation, but of course the same could be done in Barker and Shan 2014 notation. *everyone*'s lexical type would be $\frac{S \mid S}{DP}$, just as it appears in (9). The lexical type of *saw* would be (DP\S)/DP, which would be LIFTed to $\frac{S \mid S}{(DP\backslash S)/DP}$ so that it could combine with *everyone* via SCOPE; the output of that combination would be a structure of category $\frac{S \mid S}{DP\backslash S}$. And, on the left side of the tree, *John* would be of category DP, Lifted to category S/(DP\S), then LIFTed to category $\frac{S \mid S}{S/(DP\backslash S)}$ before combining with *saw everyone* via SCOPE. This would return the continuized $\frac{S \mid S}{S}$, which would then be LOWERed to the simple familiar S.

And, for each type tree one could provide for this sort of derivation, there is an equivalent derivation-by-proof. Here is just one, an accompanying proof for the type-tree in (21), again in the Shan and Barker 2006 notation for compactness:

(22)

$$\frac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\text{john} \vdash \text{e} \qquad \text{t} \vdash \text{t}}{\text{john} \cdot \text{e}\backslash\text{t} \vdash \text{t}}\backslash L \qquad \text{e} \vdash \text{e}}{\text{john} \cdot ((\text{e}\backslash\text{t})/\text{e} \cdot \text{e}) \vdash \text{t}}/L}{\text{john} \cdot (\text{saw} \cdot \text{e}) \vdash \text{t}}\textsc{lex}}{\text{e} \circ \lambda x\ (\text{john} \cdot (\text{saw} \cdot x)) \vdash \text{t}}\equiv}{\lambda x\ (\text{john} \cdot (\text{saw} \cdot x\ )) \vdash \text{e}\backslash\!\!\backslash\text{t}}\backslash\!\!\backslash R \qquad \text{t} \vdash \text{t}}{\text{t} /\!\!/ (\text{e}\backslash\!\!\backslash\text{t}) \circ \lambda x\ (\text{john} \cdot (\text{saw} \cdot x)) \vdash \text{t}} /\!\!/ L}{\text{everyone} \circ \lambda x\ (\text{john} \cdot (\text{saw} \cdot x)) \vdash \text{t}}\textsc{lex}}{\text{john} \cdot (\text{saw} \cdot \text{everyone}) \vdash \text{t}}\equiv$$

[18] In fact, all of the types involved in this complex type structure match, but that's not a prerequisite for the application of this operation.

On can read this from the top down, where above each line is an axiom of the system (e.g., that *john* is of type e or that a t is of type t) or previously-derived conclusion, below the line is the conclusion, and to the right of the line is the rule used to derive that conclusion.[19] Alternatively, one can read it from the bottom up, where the bottom line is the sentence you want to derive, you move upwards replacing things with their lexical types and operating on those types until you're left with only axioms of the system. It's through this particular presentation (derivation-by-proof, as opposed to the type tree) that the scoping behavior is really apparent. For example, in the bottom two lines of the proof, reading upward, we can see *everyone* scope out of the sentence, leaving behind a lambda abstracted trace. Or, reading from the top down, if we look at the fourth and fifth lines of the proof we can see the type e object of *saw* scoping out, to later be built up into the generalized quantifier. An equivalent proof is equally possible in the tower notation, but I'll leave that to the interested reader; parallel tower proofs and subproofs are available in Barker and Shan 2014.

One final point worth noting about these new operations—especially LIFT[20]—is that they're available to the interpretive process at every step of the derivation. For some words, like quantifiers, these continuation types are lexically stipulated, but any word can, at any stage of the derivation, be type-shifted. This was already the case for our older CCG slash types (e.g., through Lift), but now applies to our continuation types (via LIFT) as well. And, just like non-continuation type-shifting, this can lead to many non-terminating (failed) derivations (where a word is LIFTed but fails to meet the prerequisites to SCOPE over something), as well as to some where words are vacuously LIFTed and LOWERed to no benefit.[21] The minimal derivation (for each possible truth-conditional interpretation), then, is the one we're interested in, and one could narrow it down to this quite easily with an economy restriction (e.g., a cost for each type-shifting operation). The any-time availability of these operations is not just a computational quirk; it has interpretive consequences, as well.

Thanks to the availability of Lift and LIFT, any LIFTed word can take scope at the level of the sentence in the just the same way that a quantifier can take scope (and indeed must). Looking at the bottom two lines of the proof in (22), for instance, note that it is logical equivalence, and not some particular feature of the quantifier, that allows *everyone* to take scope. The same could be done in this sentence frame by *John*, *the chair*, or any other thing of type e, and indeed the same is true of verbs, etc. Anything can take scope, if LIFTed to a continuation level in the right way. This might seem like an oversight—quantifiers take scope, not normal nouns and verbs!—but in fact it is intentional and useful. There are cases in natural language where we do want nouns to take scope, for instance indefinites (see Barker and Shan 2008 or Barker and Shan 2014, ch. 9 on indefinites and donkey anaphora).[22] Barker's (2007) analysis of parasitic scope using continuations also requires nouns to be able to take scope (e.g., *Everyone bought the same book* requires *book* to take scope for *same* to be parasitic to), and Barker and Shan 2014 tell a similar story for VP ellipsis which relies on wide-scoping non-elided verbs (under which the elided content takes parasitic scope). This new scope-taking mechanic, then, is available not just to lexically specified words but to any word, which is no mistake, but which instead allows for analyses of things like scoping indefinites and parasitic scope-takers.

So far, I've introduced the continuation hypothesis and the project of finding expressions in natural language which are sensitive to continuations, and introduced the definitions for the new types and new operations which we'll need to analyze and integrate continuation-sensitive structures with the rest of our semantics. In the process, I've also introduced two different notations for these new tools. We've also seen an in-depth example of how continuations can be used to model the scope-taking properties of generalized quantifiers, which does away with the need for QR while—thanks to a built-in preference for left-to-right evaluation—still explaining crossover and superiority phenomena (Shan and Barker 2006). With these tools in hand, we can turn to another domain which has often been analyzed as relying on QR and see how continuations can be useful there as well. That domain, of course, is that of comparatives.

[19] $\equiv$ means equivalence, LEX means lexical replacement/lookup, and a thin/fat slash with an L/R means a (fat)slash introduction rule (or, reading from the bottom up, an elimination rule).

[20] Or, in the proof presentation, fat slash introduction.

[21] In fact, there are an infinite number of such complete but vacuous derivations for any grammatical sentence, as the full sentence could be LIFTed and LOWERed any number of times.

[22] On most dynamic views, there are different kinds of scope-taking: indefinites take (logical) scope over the material that they c-command (at LF), while their binding domain (binding scope) is taken to be larger. In this system, in contrast, all scope-taking is handled by continuations. "A pronoun or other expression will be in the scope of a quantifier just in case it is part of the material that contributes to the the continuation that serves as the semantic argument of the quantifier" (Barker and Shan 2014, p 93).

3 Comparatives

For the remainder of the paper, I'll extend the continuation project as described above to another area which has traditionally been analyzed as involving LF movement, comparatives. Before we rush right into how continuations can be useful to an analysis of comparatives, it'll be useful to survey the territory into which we head. In this section, I'll introduce comparatives and some of the preliminary issues worth knowing about before we head into looking more closely at some traditional analyses and a new continuation analysis for comparatives. (Readers who are very familiar with the comparatives literature may skip ahead to §4.)

3.1 What's a comparative?

Comparative structures are ones which express a comparison in degree, quantity, or quality between two things. In English, comparatives come in a variety of forms, though most are marked with *more* or *-er* and *than*. Some examples of types of comparatives are:

(23) a. Mary is six inches taller than John.
 b. There are more passengers on the train than places to seat them.
 c. Arnold is a better bowler than Nathaniel will ever be.
 d. Mercy can write much faster than Percy can type.
 e. That carpet is more purple than blue.
 f. More people live in Chicago than in Boston.

In general, comparatives take two things and say that one exceeds the other in some way.[23] In the examples in (23), Mary's height exceeds John's (by (at least) six inches), the number of passengers on the train exceeds its seating capacity, Arnold's skill at bowling exceeds Nathaniel's (across time), Mercy's handwriting speed exceeds Percy's typing speed, the carpet's purpleness exceeds its blueness, and the population of Chicago exceeds that of Boston.

Comparatives are expressed in different structures cross-linguistically, with three major classes emerging in the literature. **Conjoined comparatives** express a comparison by means of two contrasting simple statements, akin to 'Mary is tall and John is not', sometimes involving negation or intensification to flag the contrast; this strategy is used in languages like Mian,[24] Itelmen,[25], and Mauwake,[26] about one of every four/five languages (Bobaljik 2012).[27] **Exceed comparatives** use a verb which means 'exceed'/'surpass', akin to 'Mary exceeds John in height'; this structure is used in languages like Amele,[28], Mandarin, and Tamashek,[29] and is about as common as the conjoined comparative (Stassen 2008; Bobaljik 2012). The remainder of the world's languages use a **standard comparative**[30] which involve a standard of comparison (marked by case or a particle), and sometimes marking on the predicate as well; this strategy is used by languages like English, Hebrew, and Japanese, and, as this is the class that involves scope-taking, will be the focus of the remainder of the paper.

We can contrast the broad class of comparatives with other comparing constructions, namely equatives (which say two things are equal in some respect, as in (24)) and superlatives (which say something is the most in some respect, as in (25)).

(24) a. Amanda has the same number of pets as Kelvin.
 b. Satoshi is as good a pianist as he is a violinist.

[23]Some comparatives express not that the subject exceeds, but is exceeded, namely those that make use of *less* and *fewer*. Following Bobaljik (2012), I'll take these to be the comparative plus negation. As such, they'll not differ in any important way from their non-negated counterparts; plus, succeeding with the positives is sufficient as a proof-of-concept for the expansion of continuations to comparatives. As such, I'll not consider them further. Though see §4.3 for effects of negation on the interpretation of some comparative structures.

[24]An Ok-Awyu language spoken in Papua New Guinea. Data from Fedden (2007), cited in Bobaljik 2012.

[25]A Chukotko-Kamchatkan language spoken in Eastern Russia. Data from Bobaljik (2000), cited in Bobaljik 2012.

[26]A Madang language spoken in Papua New Guinea. Data from Berghäll (2010), cited in Bobaljik 2012.

[27]Bobaljik (2012) also mentions that conjoined comparatives may be endangered; see his p. 19 fn. 11.

[28]A Madang language spoken in Papua New Guinea. Data from Roberts 1987, cited in Bobaljik 2012.

[29]A Berber language spoken in Mali. Data from Heath 2005, cited in Bobaljik 2012.

[30]So called because of their contents, not their prevalence.

(25) a. The tallest building in the US is One World Trade Center.
b. Chelsea is the most impressive painter in the class.

Comparatives relate two things, but that happens by way of four components which are worth distinguishing and labeling. In standard comparatives, the **subject** of the sentence and the **predicate** describing the subject (which is the dimension along which the subject is to be compared) are both straightforward. The thing against which the subject is compared is the **comparative standard**, and the amount that they differ by is the **differential**. In (23a), for example, the subject is Mary, the predicate (an adjective) is *tall* (describing height), the comparative standard is John,[31] and the differential is six inches. These four things are put together in a particular way, schematized in (26):

(26) Adjective(subject) $\geq$ comparative standard + differential

The comparative is true if the (maximum) degree to which the subject is predicate meets or exceeds the sum of the standard and the differential. In (23a), for example, the sentence is true if Mary's (maximum) height is greater than or equal to John's (maximum) height plus six inches, or, in other words, if Mary is six or more inches taller than John.

Why greater than or equal to, and not just equal to? In general, most analyses of comparatives assume that having a point on a scale entails all of the points lower on that scale, that the higher point is semantically stronger than the lower. In other words, they assume that (27a) and (28a) entail (27b) and (28b), respectively.

(27) a. Rick has three dogs.
b. Rick has two dogs.

(28) a. Five people each sang a song.
b. Four people each sang a song.

The (b) versions may not be the best descriptions of those events—in fact they won't be, as the (a) versions are more informative—but they can still be felicitous in certain contexts. For example, consider the context in (29):

> [Context: The ASPCA is giving out one free bag of dog food to everyone in Minneapolis who has two or more dogs, to help ease the burden of feeding more than one dog. Nicole is going door to door, finding out who qualifies. She knocks on Rick's door, and his roommate answers. After hearing about the giveaway, Rick's roommate answers:]

(29) Rick has two dogs.

In this context, Rick's roommate knows that Rick has exactly three dogs, but can still felicitously respond with (29) (which is identical to (27b)). He knows that Nicole only cares whether Rick has more than one dog; her behavior will be same no matter how many dogs Rick has, so longer as their number is greater than one. In some other context, (27b) might well *implicate* that Rick doesn't have more than two dogs—but that implicature is not an entailment, as we can see by its not arising in the context of (29). Similarly, we could construct a context wherein someone used (23a) to felicitously describe a world where Mary was in fact a foot taller than John. What we *can't* do, though, is construct a context wherein (23a) is used felicitously to describe a world where Mary is only three inches taller than John, is the same height as John, or is shorter than John. It truly is $\geq$, then, that we want in the scheme of (26) to describe the behavior of comparative constructions.

Even if it truly is $\geq$ that we want for to use to relate the comparands,[32] what about comparative structures that don't appear to have all of the elements of the schema in (26)? For example, most of the sentences in (23) don't seem to have differentials—and the one that does, (23a), could easily be grammatical if one were to omit the differential:

(30) Mary is taller than John.

[31] Actually, the comparative standard is John's height; I'll make this more precise shortly. For our first pass, though, calling John the comparative standard is sufficient to help us understand the label.

[32] *comparand* — n. a thing which is compared (e.g., in the expression $2+4>5$, $2+4$ and 5 are the comparands.)

And some of the sentences in (23) don't obviously have subjects and predicates to combine; (23b), for instance, seems to have a something acting like a subject (*passengers on the train*)[33], but no obvious predicate is being applied to them.[34] We'll address what's going on in examples without obvious subjects and predicates (like (23b) and (23f)) in §4.1, once we have the tools to do so. For now, though, let's briefly examine what's going on in an example like (30).

3.2 Contextual differentials

Some comparative structures, like (23a), have an explicit differential; that differential describes the (minimum)[35] degree of difference between the comparands. Others, like (30), don't. I'll argue now that in fact all comparatives have differentials, and that when they're not explicitly stated—as in (23)—they're given contextually.

It's clear that (30) is grammatical, and one can easily interpret its meaning even though no explicit differential is mentioned: Mary is taller than John, simple as that. Free of context, we can imagine whatever we like for the granularity of the comparison. In context, however, different meanings emerge.[36] Consider, first, the context of (31):

[Context: Jane and Karen have been assigned the task of lining up all of the students in the class by height. They begin with the tallest students, then proceed in descending order. Jane says, "Okay, Annie and Bill are up next," to which Karen replies, "No, wait. . .]

(31) Charlie is taller than Bill.

In this scenario, Charlie's being taller than Bill is relevant in that Charlie should be ordered before Alex, no matter how small the difference between them. Even a milimeter—-if one could perceive such a small height difference—would be enough to determine the students' relative ordering. In this context, it seems like the bare (differential-free) understanding of the comparative is warranted: any difference is enough to make the $>$ part of $\geq$ true. Contrast that with the same sentence in a different context, as in that of (32):

[Context: Jane and Karen have been assigned the task of grouping all of the students in the class by height. They group all of the short students together, then all of the medium students. Jane says, "Okay, Annie and Bill are up next," (thus grouping them together) to which Karen replies, "No, wait. . .]

(32) Charlie is taller than Bill.

Karen's response in this context is infelicitous or at least contextually inappropriate, as it seems that Karen has failed to identify the appropriate (unstated!) contextual differential. A reasonable rejoinder to Karen in this context would be something like *Yeah, but only by a quarter of an inch* or *Not by enough to matter*! We can see from this difference that, even with an unpronounced contextual differential, the same sentence can be interpreted as requiring different differentials in different contexts. So we should understand that all such sentences do indeed contain a contextual differential parameter.

That the normal schema uses $\geq$ is another argument for understanding a phonetically-null contextual differential in sentences like (30). If we were to maintain the same schema as in (26) but without a differential, we would expect a sentence like (30) to be true even when the comparands are the same height! And this is obviously unwanted behavior:

(33) # Mary is taller than John. In fact, they're the same height!

We don't want to just use the same $\geq$ schema but without a differential for those sentences without an explicit one. Alternatively, we could use separate schemas for comparatives with and without explicit differentials: those with explicit differentials would use $\geq$, and those without would use $>$. Doing so, however, would

[33]Or, if we take *there* to be an expletive subject, our problem is even more compounded. But, since *passengers on the train* seems to be the primary comparand, we might want to treat is as the subject, at least as the term is being used in the comparative schema in (26).

[34]*more* isn't an predicate, or least not a canonical one.

[35]See discussion in previous section. Even with an explicit differential, the difference between the comparands can be greater without making the utterance infelicitous (in certain contexts).

[36]If my analysis and the examples provided below aren't sufficient, see also discussion in Beck 2010.

require us to have two different comparative operators, depending on the presence or absence of an explicit differential. We can do away with this ambiguity of comparative operators if we understand the covert presence of a contextual differential where none appears explicitly. Any contextual differential which is non-zero—even if it's as small as a femtometer[37]—is enough to make a comparative sentence false for equal comparands, and in doing so make a discourse like (33) infelicitous.

This contextual differential could be implemented in a number of ways, including as a contextually-bound variable; the implementation is not of crucial importance to the computation of the comparative or the use of continuations, and so wont' be discussed further.

3.3 The structure(s) of comparatives

Standard comparatives have historically been divided into two classes. **Clausal comparatives** are those whose comparative standard contains a clausal structure (think CP). For example, some of the examples we saw earlier in (23) had what look like sentence structure in their comparative standards:

(23c) Arnold is a better bowler than [Nathaniel will ever be].

(23d) Mercy can write much faster than [Percy can type].

The standard in (23d) is itself a complete sentence, where the standard in (23c) appears to be derived from a full sentence (*Nathaniel will ever be a bowler*)—though some work is necessary to explain the presence of the NPI *ever*—but it clearly includes a subject, modal, and verb, indicative of a sentence-like structure. In contrast, **phrasal comparatives** are those whose comparative standard appears to contain a smaller structure (e.g., a DP or PP).[38] Returning again to our examples in (23):

(23a) Mary is six inches taller than [John].

(23b) There are more passengers on the train than [places to seat them].

(23e) That carpet is more purple than [blue].

(23f) More people live in Chicago than [in Boston].

There has been significant debate in the literature about whether these actually represent distinct classes, derived through distinct processes, or whether phrasal comparatives are just significantly reduced clausal comparatives—and how languages are the same or different in forming these classes (Hazout 1995; Pancheva 2006; Merchant 2009; Bhatt and Takahashi 2011, among many others). If there are two classes, they might not both be is use in all languages, and if that's the case, they might be completely independent, or there might be an implicational relationship between them. There is also some variation among things called phrasal comparatives, which might give rise to more than two classes(Beck et al. 2012).

For the present project, I'll be focusing on clausal comparatives, those which clearly have internal structure (and whose structure has proven of interest to analyses of comparatives). If it turns out that phrasal comparatives are best analyzed as themselves clausal, then this work will be sufficient. If not, this work will still serve as a sufficient proof of concept for the usefulness of continuations in addressing (some) comparatives, with the hope that only minor modifications will be necessary to accommodate the process which accounts for phrasal comparatives.

One might also divide comparatives into classes based on the comparative morpheme being used: English uses both *-er* and *more* to indicate comparatives. Some languages have a similar morphemes which 'share the load' of handling comparatives, while other languages have just a single comparative morpheme. There has been much discussion in the literature on the differences between synthetic comparatives (those that use *-er*) and analytic ones (those that use *more*), including their distribution (both in the lexicon and across different Englishes) (Dixon 2005; Mondorf 2002, 2009a,b). For now, I'll presume that this difference is not a semantic one, and that the contribution of the comparative is the same regardless of whether *-er* or *more* is used.

[37]Or pick your favorite small unit.

[38]The unfortunate fact that the names "clausal" and "phrasal" are both similar and not well-defining of their respective extensions is well-known and much-lamented in the literature, but those are the names that have been used and used long enough to have cemented their place in the discussion. As such, I'll stick with them here, rather than introducing my own terminology, especially as the typologizing of comparatives won't be central here.

There are other structural differences one can identify among comparatives, even within the class of clausal comparatives, for instance. Not all comparatives have the same exact structure, as we saw from the variety of examples in (23). An example like (23f) clearly has two things being compared—the populations of Chicago and Boston—but it isn't obvious that they have a subject and predicate to be composed in the same way as was schematized in (26) for structures like that of (23a). The difference between these structures isn't as large as one might think, however, and in fact that distance will be further closed by some work we'll do in §4.1. For now, though, we'll table these other structural differences.

3.4 Ellipsis

As is probably clear from the brief introduction to clausal comparatives above, comparatives are often analyzed as involving **ellipsis**. The exact mechanism for the reduction of the content in the comparative standard is the topic of significant debate in the literature, such that this type of reduction is given its own name: comparative deletion, or comparative ellipsis. The assumption is that, at least for clausal comparatives, the complete form being interpreted for the sentences in (34) is that of (34c).

(34) a. Mary is (six inches) taller than Bill.[39]
b. Mary is (six inches) taller than Bill is.
c. Mary is (six inches) taller than Bill is tall.

The sentence in (34c) is a bit odd, and under most contexts we'd never say such a thing—we'd usually omit that last adjective—, most likely because of some phonological constraints against short-term repetition (at least when the semantic content is so easily retrievable). But we can see that the predicate within the comparative standard is actually there when the two predicates are not the same:

(35) Mary is (six inches) taller than Bill is wide.

In a sentence like (35), eliding the last predicate (*wide*) changes the meaning of the sentence: leaving out *wide* would make the sentence identical to (34b), which we'd interpret as meaning the same thing as (34c), filling in the blank with *tall*. Thsi is reason to believe, then, that the meaning of the repeated predicate *tall* is (interpreted as being) present, just as it is in (34c).

Beginning our analysis of a sentence like (34a) or (34b) as having the same logical form as (34c) might be useful, but it also undermines one of the possible end-goals of this project. This project can be viewed as arguing for the existence of continuation-sensitive material in natural language, but it can also be viewed as (perhaps implicitly) arguing against the need for post-surface syntactic movement (LF movement), and in doing do contributes to the argument against the need for LF altogether. LF movement isn't the only thing which makes use of LF in current semantic theories (e.g., exhaustivity operators[40]), but doing away with the need for LF movement would still move toward that goal.[41]

For this reason, even though the bulk of this paper will focus on 'full' sentences that look like (35), we'll not make the assumption that this content is simply provided at LF. If we wanted to do so, we'd be fine: the implementation provided here would serve as a template, and any elided comparative structures would simply reconstruct that material (through whichever method one prefers), with the derivation proceeding from there as described here (in §4.1). In §4.6, I'll consider an analysis of comparative ellipsis which makes use of continuations, following the analysis of verb phrase ellipsis (VPE) sketched in Barker and Shan 2014, Part II.

[39]This form looks, at least on the surface, like a phrasal comparative (with a DP) and not like a clausal comparative. Under some analyses, however, as discussed briefly in the §3.3, at least some comparatives that look like this are in fact themselves reduced clausal comparatives. For that reason, I include (34a) on this list. This won't be a crucial part of the analysis in §4, just a question of the range of the data accounted for.

[40]We need LF for such operators which are phonologically null and whose syntactic presence (in the surface form) is not apparent. Covert material which is phonologically null but whose presence is felt at the surface level (e.g., null determiners, whose 'presence' blocks other material) does not necessitate an LF, even though it is covert.

[41]This is not to assume or assert that everyone shares this goal. but for those who do, doing away with LF movement is one piece of the puzzle, and continuations are one way to handle that piece.

3.5 Degrees, intervals, & quantification

One last thing worth discussing relates to the ontology of comparatives. I said earlier that comparatives relate the "degree, quantity, or quality" of two comparands, but what exactly are those things, and how are they handled by our semantic system? We can divide the space of possibilities in (at least) two ways. First, as I foreshadowed in §2.2.1, one can analyze the dimension(s) on which comparatives do their comparing as involving degrees and intervals. Second, we can divide analyses of these constructions into ones that involve quantification and those that do not. There has been significant debate in the literature about both of these issues, and we'll briefly introduce each in turn.

We can think of comparatives as comparing **degrees** (type d), points on an ordered scale. Under such analyses, they do so by virtue of the semantics of the (gradable) adjectives that they are built from, those adjectives picking out a scale (Cresswell 1976; Bierwisch 1989; Kennedy 1999).[42] In this sense, comparatives are often called degree constructions, in that they can be thought to relate different degrees. Some other examples of degree constructions (and their labels) from Schwarzschild 2008, p. 313:

(36) a. A is AS high now as it was last night. EQUATIVE
b. A is TOO high to reach. EXCESSIVE
c. A is the MOST expensive one. SUPERLATIVE
d. A is high ENOUGH to see.
e. A is SO expensive that Bill can't afford it.
f. A is LESS taut than B is.

We can think of (36a) as relating the degree of A's height now to the degree of A's height last night, and we can think of (36b) as relating the degree of A's height to the (maximal) degree that the speaker can reach.

Alternatively, we can think of adjectives as introducing **intervals**—sets of contiguous degrees—(type D) over which they're true. The upper limit of that interval would be the degree we'd otherwise assign in the degree approach. This effectively boils the down-scale entailment discussed in §3.1 into the value actually denoted by the adjective. Arguments for this sort of approach, as exemplified by those presented by Schwarzschild and Wilkinson (2002), stem primarily from comparatives with quantificational comparative standards, which we'll return to in §4.2. The intervals can be encoded directly into the lexical entry of gradable adjectives (as in Beck 2010), or derived from a degree (e.g., with Heim's (2006) point-to-interval operator).

But how are these degrees or intervals to be treated? We can think of the degree/interval as a free variable introduced by the adjective, to be bound by the an operator or by context in simple sentences like *John is tall*. This is the **quantificational** approach: the operators introduce some quantifier ($\exists$ or $\forall$) which bind the degree/interval variable. In our case, this means treating the comparative operator as a quantificational structure (Cresswell 1976; Heim 2000). The assumption, here, is that the comparative operator and the *than* clause (containing the comparative standard) form a constituent at LF (Bresnan 1973; Lechner 1999 but see Lerner and Pinkal 1995; Kennedy 1999 for criticism of this assumption.) Alternatively, one can treat the degree as being introduced as something other than a free variable to be bound. Kennedy (1999), for instance, treats gradable adjectives as measure functions, functions from individuals to degrees; this introduces a degree as the output of a function which is sensitive both to a contextually specified scale and to the individual being described. Because this is not quantificational, it doesn't lead to the same consequences for, among other things, interaction with other scope-taking operators.

These different approaches have consequences for analyses of the syntax and semantics of comparatives, as we'll see in §4.2, and also for related phenomena like superlatives (which we'll return to in §4.4). Many researchers working on these issues try to provide a unified analysis, wherein all degree constructions are either quantificational or non-quantificational; some, though, argue that different degree constructions need different semantic approaches (for instance, Stateva 2002). Ultimately, I hope to show that the analysis provided here is compatible with both degree and interval approaches: regardless of their lexical meaning, they take scope—at least under quantificational analyses—in interesting ways, which is where continuations come in.

[42] Or, in some analyses, possibly one of multiple scales (Sassoon 2013).

4 Continuations for Comparatives

Now that we have a sense of the continuation hypothesis and what continuations are, as well as some of the basic issues surrounding comparatives, we can start to put the two of them together. For this section, I'll be introducing continuations to the analysis of comparatives, and I'll be doing so by means of comparison with a traditional quantificational account, namely that of Heim (2000, 2006). This account is by no means the only account of comparatives, of course (see §3.5 for some examples of alternative theories), but it is a good example of a popular account, and one which relies on LF movement.[43] Starting with a single example and then increasing in difficulty, I'll introduce the traditional account and then explain the corresponding moves we'll have to make to account for the same data in a continuations analysis.

4.1 Core example

For our base example, consider (35), repeated here for convenience:[44]

(37) Mary is six inches taller than Bill is wide.

While (37) doesn't appear to be as basic an example as a sentence like (34a) or (34b), it allows us to table certain questions of contextually-provided information (§3.2) and elided content (§3.4) for the interim.

At the end of the day, for the sentence in (37), Heim's (2000) account gives an LF and truth conditions as in (38):

(38) a. $[6''$ -er than $[wh_1$ Bill is t_1 wide$]]_2$ Mary is t_2 tall

b. $\textsc{max}(\texttt{height}(m)) \geq \textsc{max}(\texttt{width}(b)) + 6''$

The logical form in (38a) involves two LF movements:[45] one of the comparative standard, and one within the comparative standard (which I'm referring to functionally, but which Heim calls the *than* clause). We'll look at each one in turn, introducing the continuation analysis additions as we go. I'll show that, using a continuation analysis of the comparative construction, we can derive the same truth conditions for (37) as Heim does (in 38b) without the need for any movement.

4.1.1 Movement of the comparative standard

Adjectives, as discussed earlier, are assumed to (obligatorily) take a degree (of type d)[46] to their left—and then return a property, the set of individuals (type et) that are that degree tall.[47] This applies to absolute adjectives with both explicit and implicit degree phrases (DegPs).[48]

(39) a. John is tall.

[43] For an argument in support of Heim 2006 over competing accounts of Beck 2010 and Alrenga and Kennedy 2014, see Fleisher 2015.

[44] The original example (35) noted the optionality of the differential; for convenience, we'll use an explicit differential in our further examples. Heim 2000 only briefly discusses differentials, and Heim 2006 doesn't even do that, leaving Fleisher (2015) to deduce how they fit into Heim's system; we'll return to the role of differentials in §4.3—for now, the location of the differential isn't our main focus. For a reminder of what is going on when the differential isn't explicitly provided, see §3.2.

[45] Heim (2006) adds a third movement; we'll return to this in §4.2.

[46] As discussed in §3.5, some analyses have intervals baked into the lexical entries. For simplicity, though, I'll refer to this argument as a degree until it becomes important to make the distinction between them, at which point I'll note that divergence.

[47] This then includes individuals taller than that degree; see §3.1.

[48] In the quantificational view, adjectives introduce a free (degree) variable which is bound quantificationally. Non-quantificational accounts, too, though, associate a degree with the adjective (to make up the extended adjectival projection), even in absolute constructions like *Mary is tall* which don't have an overt degree phrase. In an account like that of Kennedy (1999), for example, (following Abney (1987)) all of the following constructions involve a Degree Phrase which denotes a comparison:

(i) Mary is tall.

(ii) Mary is $5'$ tall.

(iii) Mary is taller than Bill.

In Kennedy's (1999) analysis, these sentences all make use of a degree relation between a "reference value" (the height of the subject) and the value of the comparative standard. In (ii) and (iii), that standard is specified, but in (i) it is contextually resolved via a "standard-identification" function which picks out a relevant comparison class (as introduced by Siegel 1976; Klein 1982).

b. John is **d** tall.
c. John is six feet tall.

The bare absolute adjective in (39a) is understood as having a contextually-supplied DegP, as in (39b), while the DegP in (39c) is explicit. To keep this parallel—and in so doing require only one denotation for each adjective—Heim (2000, 2006) treats adjectives in comparative constructions the same way. Comparatives, after all, involve a degree-denoting piece: the comparative standard (the *than* clause). The comparative standard, then, being a DegP, should be in the same location, giving a sentence like (40a) a form like (40b).

(40) a. John is taller than six feet.
b. John is [-er than six feet] tall.

This way, the denotation of the adjective *tall* remains the same: it takes a DegP (of type d) on its left; this one just happens to be a little bit more complex than the DegPs in (39a) and (39c).

To be more precise, Heim (2000) has the form in (40b) not as the LF of (39c), but as the nearly-surface form: as she puts it, "In those cases where [the comparative standard] is superficially discontinuous, we can attribute this to an (obligatory) superficial extraposition process which does not feed LF." (In an endnote, she then explains why extraposition is probably not the right analysis.) Either way, the important thing to note is that under this analysis the degree-denoting comparative standard is interpreted pre-adjectivally, in parallel with other degree phrases. This comparative standard, though, is of type $<< d, t >, t >$ for Heim (2000, 2006), so the entire *than* phrase must move from this (pre-surface structure) pre-adjectival position:

> "Being of type <dt,t>, these complex DegPs cannot be interpreted *in situ*, but must move for interpretability to a position above the adjective's subject (not necessarily above the surface subject, if there are lower covert subjects). The movement leaves a trace of type d and creates a λ-abstract of type <d,t>, which makes a suitable argument to the DegP." (Heim 2000, p. 42)

It's also worth noting here that Heim treats *-er* as the morpheme containing the comparative operator, with *than* being a semantically-vacuous phonological reflex on the comparative standard's DegP. (Some others treat *than* as the meaningful morpheme, with *-er* as a reflex.) Because this choice carries with neither assumptions nor consequences which bear on the move to a continuation analysis, I'll not question it here.[49]

In the framework we're using (introduced in §2), we can retain a single unified denotation form for adjectives without needing to posit movement (either pre-surface or post-surface). The comparative operator (*-er*) combines with the predicate before the predicate takes any arguments, and the comparative operator can introduce arguments internally within its denotation to the meaning of a predicate in whichever order it likes; nothing has to move for "interpretability" (type reasons). Our comparative operator, then, we can define as:

```
(("erthan" ((d\(e\t)) \ ((d\(e\t)) / d) )) (^ A (^ d (^ D (^ e (max A e >= d + D ))))))
```

This is our (new) lexical entry for the comparative operator in the parser associated with the Shan and Barker 2006 system. On the left is the phonological form (the PF or "spellout" of the morpheme),[50] followed by the syntactic type (again, in the Shan and Barker 2006 system these are semantic types (e, t, and d) along with slashes) and then on the right the semantic denotation (with ^ standing in for λ). So, reading through the syntactic type, we can see that `erthan` first takes an adjective (of type *det*, represented as `(d\(e\t))`) on its left, then combines with a degree (of type d) on its right—this will be the comparative standard—,

[49] There are some contexts where *than* is not adjacent to *-er/more*, as in (23c), (23e), and (23f); this choice may make different predictions in those cases. In the examples we'll start with here, however, *-er* and *than* will always be adjacent, and so the choice is unimportant.

If one wanted to have a full implementation which handled *-er* and *than* distinctly—which makes sense, as they show up in different syntactic positions, and not always adjacent to one another—we could give *-er* the same meaningful denotation for the comparative morpheme we're about to assign, and for *than* we'd have to introduce a dummy type. As discussed here, *than* takes things of type d, and those same type d things are fed into the comparative morpheme as arguments, but we don't want *than* to attach to just any degree phrase (outside of a comparative, for instance) or to stack, so an identity function won't work. Instead, we'd want *than* to take degree phrases (d), returning a dummy phrase (d_2) which is the type taken by the comparative morpheme. *than* itself, then, would have a semantics like $\lambda d \lambda k.d$, taking a degree phrase, whose k wrapper would be throws away upon being taken as an argument by the comparative morpheme.

[50] In the formalism I name the operator `erthan` as the choice of morphemes is unimportant; see previous body paragraph. One could just as easily assign this denotation to just *-er*, with *than* semantically vacuous (the identity function).

returning something also of type *det*, effectively standing in place of the original adjective. It then goes on to take on its left a degree (the differential) and individual that the adjective would have, before returning a truth-evaluable statement (of type t). The output expression in the semantic denotation should look familiar: it's an encoding of the comparative schema in (26). The (maximum) degree to the subject has on the scale denoted by the adjective is compared to the sum of the comparative standard and the differential.

Following Heim (2000, p. 42), the comparative returns a statement which includes the **maximum** operator, as defined in (41).

(41) $\max(\mathrm{P}) := \iota \mathrm{d}.\mathrm{P}(\mathrm{d}) = 1 \& \ \forall \mathrm{d}'[\mathrm{P}(\mathrm{d}') = 1 \rightarrow \mathrm{d}' \leq \mathrm{d}]$ Heim 2000, (6)

max returns the maximum degree from some scale of degrees; this is intended to account for the entailment of scales that we discussed in (3.1), namely the notion that if John is six feet tall, then he's also five feet tall, and four feet tall, etc. When we're comparing the relative degrees of individuals, we don't want to just compare any two degrees that are true of them—if John is exactly six feet tall and Mary is exactly five feet tall, then, given this property of scales, it's true that John is two feet tall and that Mary is three feet tall. But if we compare those particular values, we'll wrongly conclude that Mary is taller than John! Even though the scale of height has this property, it'd be false to say that Mary is taller than John, so it must be that we're not comparing just any values but the maximum values of each person's height; for this reason we need the **max** operator.

With this comparative operator (and Heim's **max** operator), the system can easily handle the comparative standard's being located to the right of the adjective as opposed to the left, and can do so without needing an additional form for adjectives in comparative constructions. We can see just this part in action if we look at the derivation of a comparative even simpler than (37), something like (42a):

(42) a. John is one inch taller than six feet.

b. MAX $\{d : \mathrm{tall}(\mathrm{john}, d)\} \geq 6' + 1''$ (cf. Heim 2000, (7))

$= \texttt{height}(\texttt{j}) \geq 6' + 1''$

Given the comparative schema given in (26), we should expect (42a) to have truth conditions matching the expression in (42b). And indeed we get just this sort of result: a full derivation for (42a) using the Shan and Barker 2006 system's parser is in Figure 1.

```
edge       : 235 john is oneinch tall erthan sixfeet   (0 6)   t
semantics  : (max (^ d (^ x (height x >= d))) j >= sixfeet + oneinch)
proofnet   : ((1 . t) (john (2 . e)) (is (((2 . e) \ (1 . t)) / ((3 . e) \ (4 . t))))
(oneinch d) (tall (d \ ((5 . e) \ (6 . t)))) (erthan ((d \ ((5 . e) \ (6 . t))) \ ((d \ ((3
. e) \ (4 . t))) / d))) (sixfeet d))
derivation: ((L john) (is ((L oneinch) ((tall erthan) sixfeet))))

john is oneinch tall erthan sixfeet t = (max (^ d (^ x (height x >= d))) j >= sixfeet +
oneinch)
  john (1 / (e \ 1)) = (^ f (f j))
    L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
    john e = j
  is oneinch tall erthan sixfeet (e \ t) = (^ e (max (^ d (^ x (height x >= d))) e >=
  sixfeet + oneinch))
    is ((e \ t) / (e \ t)) = (^ k k)
    oneinch tall erthan sixfeet (e \ t) = (^ e (max (^ d (^ x (height x >= d))) e >=
    sixfeet + oneinch))
      oneinch (1 / (d \ 1)) = (^ f (f oneinch))
        L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
        oneinch d = oneinch
      tall erthan sixfeet (d \ (e \ t)) = (^ D (^ e (max (^ d (^ x (height x >= d))) e >=
      sixfeet + D)))
        tall erthan ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >= d))) e
       >= d + D))))
          tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
          erthan ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e >= d
          + D)))))
        sixfeet d = sixfeet
```

Figure 1: A derivation of *John is one inch taller than six feet.*

There are some comments worth making about this derivation, but first, let me explain what we're looking at here. The first line, labeled "edge", has the input string, namely the sentence in (42a), as well as its length (4 words) and its output type (t). Line 2, labeled "semantics", has the truth conditions of the sentence. (I'll comment on the contents of this line in a moment.) Line 3, "proofnet", describes the internal workings of the parser, whose inner-workings are not crucial to understand right now. On line 4, "derivation", however, we can see the derivation which leads to this parse. The parentheses indicate order of operations, the order in which Function Application has taken place. In this line, `L` is Lift (as described in §2.2.3).

Below that is the derivation itself, step by step. The first line on which any lexical item appears is its 'leaf node', and that line lists (from left to right) its phonological form, syntactic type, and semantic denotation. Looking at the line 9, for instance, we can see the introduction of *John* into the derivation. The phonological form is `john`, its type is e, and its denotation is the individual (abbreviated as) `j`. Here I recommend reading from the bottom up, just as one might with a derivation tree. In this particular one, we see the comparative combine with the predicate (*tall*), then the comparative standard (six feet),[51] then the differential (one inch), and finally the subject (John).

The astute reader may have noticed that the truth conditions listed on line 2 don't match exactly with the expression in (42b) that we were hoping for. This is a side effect of using **max** in this parser, which doesn't allow for denotations to contain operators, as opposed to on paper.[52] Because of our normal interpretation of points on scales (e.g., heights) and the behavior of **max** (which was created to capture that interpretation), the maximum degree of someone's height is equivalent to that person's height (in the normal way we talk about height). What it means for John to be six feet tall is for the maximum degree of heights that are true of him to be the degree 'six feet'.[53] What we need is a version of **max** (here called $\max_2$) which has access to the adjective's measure function such that **max** can get inside the abstraction over individuals.[54] This would allow us to reduce an expression like (43a) to (43c).

(43) a. $\max_2(\lambda d \lambda x.\text{height}(x) \geq d)$
b. $\lambda x.\max(\lambda d.\text{height}(x) \geq d)$
c. $\lambda x.\text{height}(x)$

This exact procedure is used in papers on these constructions (e.g., Fleisher 2015), and it simplifies things significantly. Unfortunately, I don't have the coding skills to have added this sort of substitution principle to the Shan and Barker 2006 parser, so the semantics I'm left with at the end of the derivation in Figure 1 is not full simplified. On paper, however, we could simplify it fully:

(44) $\max(\lambda d \lambda x.[\text{height}(x) \geq d])(j) \geq 6' + 1''$
$= \lambda x.[\text{height}(x)](j) \geq 6' + 1''$
$= \text{height}(j) \geq 6' + 1''$

And this fully simplified expression is, of course, what we were looking for as in (42b).

Now we've got a comparative operator, Heim's maximum operator (and the means to simplify it), which is enough to handle the placement of the comparative standard in an example like (40a) without needing the sort of movement in (40b). The only other thing we'll need to handle (40a) is a contextual variable to take the place of the covert differential that must be there (as argued for in §3.2). We can call it `d`, and if its semantics—the contextual differential it picks out—is handled by an assignment function (or something akin to one), then we can handle examples like (40a).

[51] Represented here as a single lexical entry, `sixfeet`, just to keep the derivation short. Another grammar which separates numerals (like *six*) and measure terms (like *feet*) exists for any interested readers. That distinction, however, makes no difference to the computation of the comparative other than to lead to somewhat longer derivations, and so I've simplified things for the purposes of this project.

[52] Or in a parser augmented with provisions made specifically to handle **max**, which neither the Shan and Barker 2006 parser nor the Barker and Shan 2014 parser handles in the way described here.

[53] It's also true that someone who is six feet tall is also five feet tall, as we've now discussed several times, but in most contexts an utterance of *John is six feet tall* is understood as meaning that John is exactly six feet tall (and no taller). I'll not discuss the question of the status of scalar implicatures here.

[54] My thanks to Nick Fleisher for pointing this out.

4.1.2 Movement within the comparative standard

A sentence like (37)—repeated here for convenience—, unlike (40a), also needs an additional movement under Heim; Heim's (2000; 2006) analysis.

(37) Mary is six inches taller than Bill is wide.

To understand why, it'll be useful to take a moment to look at comparative standards as a class. Comparative standards appear to be able to take a number of different forms, even in a single construction, like that of (37).

(45) a. Mary is taller than [six feet].
b. Mary is taller than [John].
c. Mary is taller than [Bill is (tall)].

Looking at the sentences in (45), we see a variety of things in the *than* phrase: we see what looks like a DegP in (45a), what looks like a DP in (45b), and what looks like a CP in (45c).[55] If we consider the bracketed material in these sentences to be so varied, we're mising an important generalization about these comparative standards. In fact, all of these denote a degree, something of type d. And note further that the sentence-like structure is not truly a full sentence of type t; it's not just any such sentence that can fit in this position, and this structure cannot contain an explicit degree in the pre-adjectival position where one would otherwise put a degree:

(46) * John is taller than Mary is five feet tall.

What is needed, then, is a way to interpret a structure like [*Bill is tall*] as itself a degree-denoting phrase.

In the classical account, the degree-ness of these CP-like clauses (and the infelicity of explicit degrees in them) is handled via *wh-* movement. As Heim (2000, p. 51) puts it:

> "Following standard practice, I take *than*-clauses to be derived by *wh*-movement of a covert operator from the degree-argument position of an adjective. The trace is interpreted as a variable over degrees. The *wh*-clause as a whole may be treated in analogy with a free relative, as a definite description of a maximal degree.
>
> (39) $[\![\textit{wh}_1 \textit{ the bed is } t_1 \textit{long}]\!]$ = max{ d: long(the bed,d)} "

Under Heim's analysis, it's this *wh*-movement which allows us to interpret the CP-like structure as a degree, and it's the presence of the trace of the covert operator which blocks sentences like (46).

Because our aim is to account for comparatives without this sort of movement, we need to account for the degree-type nature of the standard, even when it appears to be sentence-like. And, as this is precisely the part of the derivation that under Heim; Heim's (2000; 2006) account requires *wh*-movement—the same sort of movement which is theorized to account for quantifier raising for scope at LF—, it's this part that we can account for using continuations. Just as quantifiers made use of continuation-sensitive material which has some local type but which took scope at some other type, we'll want something similar for the comparative standards within comparative structures.

To fill this need, I introduce a new covert operator for the pre-adjectival position of comparative standards, just the same place as Heim's *wh-* trace. Because it's in this pre-adjectival position, its local type should be d. What we need it to do, however, is to allow us to interpret the sentence-looking comparative standard as a degree. Translating this need into our continuation type language, our new operator will take scope over the entire comparative standard (the *than* phrase) which is of type t, but it will return something of type d, allowing us to interpret the standard as denoting a degree. Its definition, then, looks like this:

```
((”?d” (d // (d \\ t))) (^ k (max k)))
```

I named the operator `?d` so as to invoke the idea of 'the issue of d': the (unknown) answer to the question *How d is x?*—in our example (37), the degree of Bill's width (which is unspecified in the comparative). Reading through the lexical entry, it's phonologically null (but has a name for the parser's sake), and it has

[55]See §3.3 for a discussion about whether these things are in fact of comparable types.

the syntactic type $d \mathbin{/\!\!/} (d \mathbin{\backslash\!\!\backslash} t)$ (read the double slashes as fat slashes): its local type is d, it takes scope at t, and its return type is d.[56]

Let's try to understand what's really going on here. Within our (often-elided) comparative standard, we have a nearly-complete sentence: *Bill is* [ ] *wide*. It would be a full sentence (of type t) except that it's missing a degree phrase (of type d) somewhere specific inside of it. In Barker and Shan 2014 terms, this nuclear scope, the sentence without the missing scope-taker, is the continuation, and is of type $d \mathbin{\backslash\!\!\backslash} t$: a t missing a d inside it. This continuation is the argument of our scope taker—our new operator—which should return a degree, something of type d, so its type is $(d \mathbin{/\!\!/} (d \mathbin{\backslash\!\!\backslash} t))$: an expression which needs a continuation of type $d \mathbin{\backslash\!\!\backslash} t$ surrounding it in order to return a d.

Being of type $(d \mathbin{/\!\!/} (d \mathbin{\backslash\!\!\backslash} t))$, the degree-scoping operator is lexically continuation-sensitive (and at continuation level 1). Unlike the generalized quantifiers we'd seen earlier (type $t \mathbin{/\!\!/} (e \mathbin{\backslash\!\!\backslash} t)$), this operator's scope-taking input type (t) does not match its output type (d). This is still kosher in the world of continuations, following Wadler 1994, p. 47: "there is no reason why the type p of a composable continuation need be the same as the type o returned by the entire computation". This type mismatch does, however, require more power than either the Continuation monad or continuation-passing in a dynamic semantic system can deliver, as discussed in Barker and Shan 2014, §18.4.

Turning back to the lexical entry, we can see that semantically, `?d` is a **max**-imized identity function: it passes the content up, but embeds that content under a **max** operator. This allows us to interpret the comparative standard in (37) not just as any old degree of Bill's width, but the maximal degree of Bill's width—in common parlance, Bill's width.

In action, the comparative standard from our example (37), *Bill is wide*, as represented in (47), returns the correct semantics for the embedded degree-denoting sentence-like phrase.

(47) a. ...[Bill is wide].

b. `Bill is ?d wide`

The comparative standard will have the derivation tree as in (48), and the full parser derivation in Figure 2.

[56] Or, in tower notation, `?d` has the syntactic type $\frac{Deg \mid S}{Deg}$.

(48)

- d
  $\lambda G.[G(\lambda z.z)](\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d)(\lambda F.F(\texttt{b})))$
  $(\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d)(\lambda F.F(\texttt{b})))(\lambda z.z)$
  $\lambda x.[\texttt{width}(x)](\texttt{b})$
  $\texttt{width}(\texttt{b})$
  - d $/\!\!/$(t $\backslash\!\!\backslash$ t)
    $\lambda G.[G(\lambda F.F(\texttt{b}))](\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d))$
    $\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d)(\lambda F.F(\texttt{b}))$
    - d $/\!\!/$ ((t/(e\t)) $\backslash\!\!\backslash$ d)
      $\lambda z\lambda G.[G(z)](\lambda F.F(\texttt{b}))$
      $\lambda G.[G(\lambda F.F(\texttt{b}))]$
      - t/(e\t)
        $\lambda x\lambda F.F(x)(\texttt{b})$
        $\lambda F.F(\texttt{b})$
        - e
          $\texttt{b}$
          - **Bill**
            $\texttt{b}$
    - d $/\!\!/$((e\t) $\backslash\!\!\backslash$ t)
      $\lambda P.[P](\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d))$
      $\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d)$
      - d $/\!\!/$(((e\t)/(e\t)) $\backslash\!\!\backslash$ d)
        $\lambda P.P$
        - (e\t)/(e\t)
          - **is**
            $\lambda P.P$
      - d $/\!\!/$((e\t) $\backslash\!\!\backslash$ t)
        $\lambda F.[F(\lambda d\lambda x.\texttt{width}(x) \geq d)](\lambda k.\textsc{max}(k))$
        $\lambda k.[\textsc{max}(k)](\lambda d\lambda x.\texttt{width}(x) \geq d)$
        $\textsc{max}(\lambda d\lambda x.\texttt{width}(x) \geq d)$
        - d $/\!\!/$(d $\backslash\!\!\backslash$ t)
          - **?d**
            $\lambda k.\textsc{max}(k)$
        - t $/\!\!/$((d\(e\t)) $\backslash\!\!\backslash$ t)
          $\lambda z\lambda F.[F(z)](\lambda d\lambda x.\texttt{width}(x) \geq d)$
          $\lambda F.[F(\lambda d\lambda x.\texttt{width}(x) \geq d)]$
          - d\(e\t)
            - **wide**
              $\lambda d\lambda x.\texttt{width}(x) \geq d$

```
1  edge       : 164 bill is ?d wide       (0 4)    d
2  semantics  : (max(^ r (width b >= r)))
3  proofnet   : (d (bill (1 . e)) (is (((1 . e) \ (2 . t)) / ((3 . e) \ (4 . t)))) (?d (d // (d
   \\ (5 . t)))) (wide (d \ ((3 . e) \ (4 . t)))))
4  derivation: (D ((S (U (L bill))) ((S (U is)) ((S ((S (U L)) ?d)) (U wide)))))
5
6  bill is ?d wide d = (max(^ r (width b >= r)))
7    D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
8     bill is ?d wide (d // (t \\ t)) = (^ c (max(^ r (c (width b >= r)))))
9       bill ((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r b))))))
10        S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
          (^ l (R (^ r (c (l r)))))))))
11        bill (1 // ((2 / (e \ 2)) \\ 1)) = (^ f (f (^ f (f b))))
12          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
13          bill (1 / (e \ 1)) = (^ f (f b))
14            L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
15            bill e = b
16      is ?d wide (d // ((e \ t) \\ t)) = (^ c (max(^ r (c (^ x (width x >= r))))))
17        is ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c r)))))
18          S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
            (^ l (R (^ r (c (l r)))))))))
19          is (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
20            U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
21            is ((e \ t) / (e \ t)) = (^ k k)
22        ?d wide (d // ((e \ t) \\ t)) = (^ c (max(^ r (c (^ x (width x >= r))))))
23          ?d ((d // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c (max(^ r (R (^ r1 (c (r1
            r))))))))
24            S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c
            (L (^ l (R (^ r (c (l r)))))))))
25            ?d (d // ((1 / (d \ 1)) \\ t)) = (^ c (max(^ r (c (^ f (f r))))))
26              RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^
                f (f r)))))))
27                S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R
                (^ c (L (^ l (R (^ r (c (l r)))))))))
28                RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
29                  U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
30                  L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
31              ?d (d // (d \\ t)) = (^ k (max k))
32          wide (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ d (^ x (width x >= d)))))
33            U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
34            wide (d \ (e \ t)) = (^ d (^ x (width x >= d)))
```

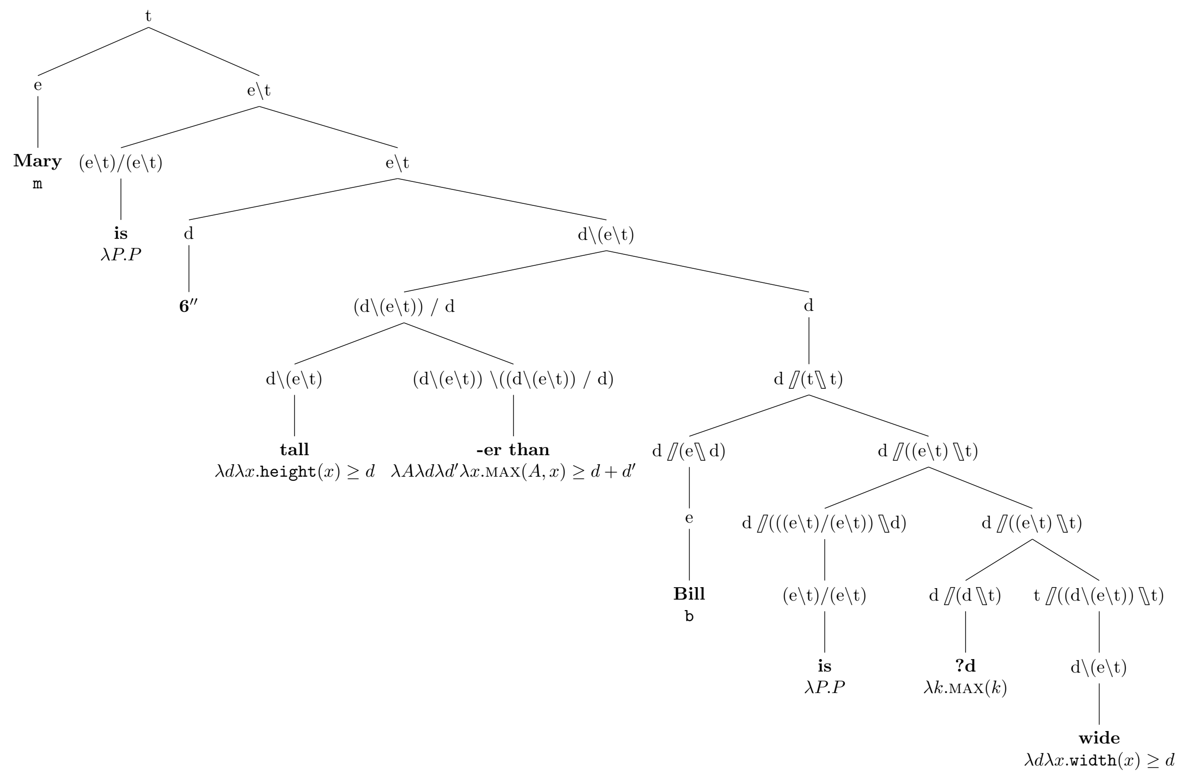
Figure 2: A derivation of the embedded DegP *Mary is tall*.

We can walk through Figure 2 just as we did Figure 1, which lines up with the derivation tree above. Line 1 lists the input string (the embedded sentence-like comparative standard), the number of words (4) and the output type (d). Line 2 has the semantic denotation of the entire clause, and here, too, we can see that it could be further simplified, just as I illustrated for the previous derivation in (44): $\max(\lambda r.\text{width}(\texttt{b}) \geq r)$ reduces to width(b). In line 4, we now see L (Lift) joined by U, which represents our LIFT operation, S (SCOPE), and D (LOWER). Note that *Bill* has to be targeted by both Lift and LIFT (in that order) in order to be combined via SCOPE with the continuized *is* `?d` *wide* in just the same way as *John* had to be Lifted and LIFTed in order to combine with the continuized *saw everyone* in (21); we can see this in lines 11–14 in Figure 2 and in the derivation tree in (48) on the left-most branch.

One interesting difference between this derivation and the one we saw for the generalized quantifier in §2 is that here we see LIFT applying a scope-type other than t. In the derivation tree, we can see both *Bill* and *is* LIFTed with a $d /\!\!/ (\_\_\_ \backslash\!\!\backslash\, d)$ continuation level 'wrapper' (whose tower equivalent would be $\frac{Deg\,|\,Deg}{A}$ instead of $\frac{S\,|\,S}{A}$). (This process is somewhat harder to point out in the parser derivation, wherein numbers are used for the variables over types for the definitions of LIFT, LOWER, etc.)

With this in hand, we can now turn to the full derivation of our core example (37). The sentence will have a type tree as in (49):

(49)



Making the entire derivation tree in this format would be quite crowded and hard to read. (All of the interesting stuff in the tree derivation happens within the scope of the continuation, anyway, all of which is provided in the tree in (48).) Instead, we can see the whole process in the parser's derivation in Figure (3).

For our core example sentence (37), then, we can derive the same truth conditions as Heim's (2000) in (38b) without needing either *wh-* movement within the comparative standard or type-mismatch movement of the entire comparative standard to widest scope. Instead of the LF as in (38a) (repeated here), we end up with the much simpler interpretation form in (50).

(38a) [6″ -er than [wh_1 Bill is t_1 wide]]$_2$ Mary is t_2 tall — HEIM 2000

(50) Mary is 6″ tall -er than Bill is `?d` wide — CONTINUATION ANALYSIS

This continuation-analysis form, which is not coincidentally quite close to the surface form, differs from the surface form only in the presence of our new scoping operator which, though covert, seems to block the presence of explicit degree phrases. And, building on the work of Shan and Barker 2006, we can do so in a way that also has further explanatory power regarding preferences for left-to-right interpretation (but without sacrificing the ability to derive ambiguous alternative readings).

Before we tackle a more complicated example, a brief aside so that I can make good on a promise I made earlier. Now that we've introduced `?d` and seen it in action, we can return to my earlier claim about how the various forms that comparatives can take (as in (23)) are not as distinct as they might seem. Take (23f), for example, repeated here for convenience:

(23f) More people live in Chicago than in Boston.

How are we to interpret this structure? There's no obvious subject or predicate to fit into the comparative schema laid out in (26)! What we do have, however, are some clauses that look quite sentence-like: [*people live in Chicago*] and what I take to be a semi-elided form of [*people live in Boston*]. And now we know what do with things that look like sentences but are degree-denoting! And as further evidence that these clauses operate like the comparative standard in (37), note that just like we saw in (46), (23f doesn't seem to be able to take explicit degrees:

(51) a. * More people live in Chicago than 4.5 million live in Boston.

b. * More 9.5 million people live in Chicago than live in Boston.

c. 5 million more people live in Chicago than in Boston

Of course (51c) is grammatical, but there the number 5 million is serving not as a precisification of Chicago's population, but instead as the (now-explicit) differential between the values of [*d people live in Chicago*] and [*d people live in Boston*].

So, using our new `?d` continuation-sensitive scoping operator, we can close the distance among the various forms that comparatives can take. In just the same way that we interpret *Bill is wide*—the comparative standard in 37—as $\lambda d.\texttt{width}(\texttt{b}, d)$, the (maximum) degree to which Bill is wide, we interpret the first comparand of (23f), *people live in Chicago* as $\lambda d.d\texttt{people-live-in}(c)$, the (maximum) number of people who live in Chicago. The only difference is that to analyze (23f) we'll need two occurrences of `?d`, one for each degree-denoting sentence-like clause. And, as we saw in (51c), this form too allows for the inclusion of explicit differentials. This implies that we can use an only slightly-tweaked (26) schema to account for both forms, differing only in whether the subject is introduced with a subject and predicate or within a degree-denoting `?d` phrase.

```
edge       : 535 mary is sixinches tall erthan bill is ?d wide        (0 9)    t
semantics : (max (^ d (^ x (height x >= d))) m >= (max (^ r (width b >= r))) + sixinches)
proofnet   : ((1 . t) (mary (2 . e)) (is (((2 . e) \ (1 . t)) / ((3 . e) \ (4 . t))))
(sixinches d) (tall (d \ ((5 . e) \ (6 . t)))) (erthan ((d \ ((5 . e) \ (6 . t))) \ ((d \
((3 . e) \ (4 . t))) / d))) (bill (7 . e)) (is (((7 . e) \ (8 . t)) / ((9 . e) \ (10 .
t)))) (?d (d // (d \\ (11 . t)))) (wide (d \ ((9 . e) \ (10 . t)))))
derivation: ((L mary) (is ((L sixinches) ((tall erthan) (D ((S (U (L bill))) ((S (U is))
((S ((S (U L)) ?d)) (U wide)))))))))

mary is sixinches tall erthan bill is ?d wide t = (max (^ d (^ x (height x >= d))) m >=
(max (^ r (width b >= r))) + sixinches)
 mary (1 / (e \ 1)) = (^ f (f m))
  L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
  mary e = m
 is sixinches tall erthan bill is ?d wide (e \ t) = (^ e (max (^ d (^ x (height x >= d)))
 e >= (max (^ r (width b >= r))) + sixinches))
  is ((e \ t) / (e \ t)) = (^ k k)
  sixinches tall erthan bill is ?d wide (e \ t) = (^ e (max (^ d (^ x (height x >= d))) e
  >= (max (^ r (width b >= r))) + sixinches))
   sixinches (1 / (d \ 1)) = (^ f (f sixinches))
    L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
    sixinches d = sixinches
   tall erthan bill is ?d wide (d \ (e \ t)) = (^ D (^ e (max (^ d (^ x (height x >=
   d))) e >= (max (^ r (width b >= r))) + D)))
    tall erthan ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >= d))) e
    >= d + D))))
     tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
     erthan ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e >= d
     + D)))))
    bill is ?d wide d = (max (^ r (width b >= r)))
     D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
     bill is ?d wide (d // (t \\ t)) = (^ c (max (^ r (c (width b >= r)))))
      bill ((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r b))))))
       S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R
       (^ c (L (^ l (R (^ r (c (l r)))))))))
       bill (1 // ((2 / (e \ 2)) \\ 1)) = (^ f (f (^ f (f b))))
        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
        bill (1 / (e \ 1)) = (^ f (f b))
         L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
         bill e = b
      is ?d wide (d // ((e \ t) \\ t)) = (^ c (max (^ r (c (^ x (width x >= r))))))
       is ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c
       r)))))
        S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R
        (^ c (L (^ l (R (^ r (c (l r)))))))))
        is (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
         U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
         is ((e \ t) / (e \ t)) = (^ k k)
       ?d wide (d // ((e \ t) \\ t)) = (^ c (max (^ r (c (^ x (width x >= r))))))
        ?d ((d // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c (max (^ r (R (^ r1
        (c (r1 r))))))))
         S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^
         R (^ c (L (^ l (R (^ r (c (l r)))))))))
         ?d (d // ((1 / (d \ 1)) \\ t)) = (^ c (max (^ r (c (^ f (f r))))))
          RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^
          r (c (^ f (f r)))))))
           S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^
           L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
           RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
            U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
            L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
          ?d (d // (d \\ t)) = (^ k (max k))
        wide (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ d (^ x (width x >= d)))))
         U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
         wide (d \ (e \ t)) = (^ d (^ x (width x >= d)))
```

Figure 3: A derivation of *Mary is six inches taller than Bill is wide.*

4.2 Quantificational comparative standards

The analysis of comparatives met a considerable challenge when attempting to account for sentences with quantificational comparative standards—that is, comparative standards which include a quantified element—such as (52).

(52) Mary is 6″ taller than every boy is.

Why should this sort of sentence pose a challenge? First, there is a question of types: The comparative standard in (40a), *six feet*, is plainly a degree, of type *d*, and I've argued (following the prevailing opinion in the literature) that the standard *Bill is wide*, as in (37), should also be interpreted as degree-denoting. But how can the comparative standard of (52)—presuming it's [*every boy is* [] *tall*]—be understood as a degree? Unless all of the boys are the exact same height, presumably that standard should denote a set of degrees (or perhaps a plurality of degrees, or some other complex type), or at least not a simple type *d*.

Second, putting type issues aside, there is an issue of scope-taking. Under quantificational theories (like that of Heim (2000, 2006)), both the comparative standard and the *wh* variable-over-degrees within the comparative standard move at LF. And, as is known, sentences with multiple quantificational elements should exhibit scope ambiguity, with multiple possible scopal configurations of those quantificational elements. For instance, recall that (14) has two possible interpretations:[57]

(14) Someone saw everyone.

1. For every x (in some salient set of people), there is some person y such that y saw x. $\forall > \exists$
2. There is one person x such that x saw everyone (in some salient set of people). $\exists > \forall$

In a sentence like (14), then, with multiple quantificational elements (the quantifier *every* and the quantificationally-bound degree denoted by the comparative standard), we should expect there to be multiple possible scopal orderings and thus multiple possible interpretations.

For the sentence in (52), however, there is only one interpretation available. This (single) available interpretation is clear: for each boy (in the salient set of boys), Mary is taller than that boy. In other words, Mary is taller than the tallest boy (and every other boy as well). This is the wide-scope universal reading.

(52) Mary is 6″ taller than every boy is.

1. For every boy x, Mary is taller than the height d of x. $\forall > -er$[58]
2. Mary is taller than d, where d is the height that every boy has. $*-er > \forall$

The other interpretation that we might have otherwise predicted is a bit trickier, but one can imagine it: there is some height d such that every boy has that height—such that that height is true of the entire set of boys. Remembering the way these scales are understood to work,[59] the only (maximal) height that could fit that criterion is the (maximal) height of the *shortest* boy. The tallest height that all of the boys share is the highest height of the shortest boy, making this interpretation of (52) equivalent to that of *Mary is 6″ taller than the shortest boy*, which has much weaker truth conditions. Following Fleisher (2015), I'll call this a MIN reading, as opposed to the MAX reading we seem to obligatorily get in this case.

To explain this behavior, we need to explain the exceptional wide-scope of the universal quantifier, provide another mechanism for comparative scope-taking, or do something else. Schwarzschild and Wilkinson (2002) argued forcefully that these sorts of sentences are problematic, showing additionally that there was similarly problematic behavior of other elements in *than* clauses—such as verbs as modals—which aren't usually considered to undergo LF movement, which nevertheless get wide scope readings. Schwarzschild and Wilkinson (2002) proposed that rather than degrees, gradable adjectives denote relations between individuals and *intervals*; compare (53a) and (53b).

(53) a. $[\![\text{tall}]\!] = \lambda d_d \lambda x_e.\text{height}(x) \geq d$ DEGREE

[57] I order them in this way to set up a parallel with the comparative example. For more on why the wide-scope existential interpretation for (14) seems easier to get, see the earlier discussion of the left-to-right evaluation order built into the Shan and Barker 2006 system.

[58] The comparative isn't actually the thing scoping, but this makes for a shorter more parallel schema than any other possible label.

[59] If I'm six feet tall, I'm also five feet tall, etc.

b. $[\![\text{tall}]\!] = \lambda D_{<d,t>} \lambda x_e.\text{height}(x) \in D$ INTERVAL

In the degree semantics we were using above, an adjective denotes the $\geq$ relation between an individual and the degree they hold on a scale. On an interval semantics, an adjective denotes the relationship between an individual and a set of degrees.[60] This allows the *than* clause in (52) to pick out not a particular degree of height that all boys have, but instead to pick out an interval that contains all of their (maximum) heights. If Mary's height exceeds this interval (or, really, if the interval denoted by Mary's height *contains* this boys'-height interval), then she must be taller than every boy, including the tallest boy—which gives us the MAX reading we want.

In response to the arguments presented in Schwarzschild and Wilkinson 2002, as well as some other data about modals, Heim (2006) introduces a new scope-taking operator to her system: Π, a "point-to-interval" ("p-i") operator.[61] Π turns degree predicates into generalized quantifiers over degrees: interval predicates. Importantly to Heim's analysis, though, "the Π-phrase, being a generalized quantifier over degrees, could move up and be interpretable in higher positions", allowing it to take non-local scope; this, in turn, allows Heim to account for scopal ambiguities that arise with modals within *than* clauses. A comparative standard like (54a) is analyzed as having an LF as (54b) derived in (54c), interpreted as (54d), and the same for (55).

(54) a. [Bill is   wide] (cf. Heim 2006, (41))

b. $wh\, \lambda 1\, [\, [\, \Pi\, t_1\,] \lambda 2\, [\text{ Bill is } t_2 \text{ wide}\,]\,]$

c. [Bill is Π *wh* wide]

$[\, \Pi\, wh\,] \lambda 2\, [\, \text{Bill is } t_2 \text{ wide}\,]$

$wh\, \lambda 1\, [\, [\, \Pi\, t_1\,] \lambda 2\, [\text{ Bill is } t_2 \text{ wide}\,]\,]$

d. $\lambda P_{<d,t>}.\text{Bill's width} \in P$

(55) a. [every boy is   tall]

b. $wh\, \lambda 1 [\text{every boy } \lambda 2\, [\, [\, \Pi\, t_1\,] \lambda 3\, [\, t_2 \text{ is } t_3 \text{ tall}\,]\,]\,]$

c. [every boy is Π *wh* tall]
$[\, \Pi\, wh\,] \lambda 3\, [\, \text{every boy is } t_3 \text{ tall}\,]$
$\text{every boy } \lambda 2\, [\, [\, \Pi\, wh\,] \lambda 3\, [\, t_2 \text{ is } t_3 \text{ tall}\,]\,]$
$wh\, \lambda 1 [\text{every boy } \lambda 2\, [\, [\, \Pi\, t_1\,] \lambda 3\, [\, t_2 \text{ is } t_3 \text{ tall}\,]\,]\,]$

d. $\lambda D.\forall x[\, \text{girl}(x) \rightarrow \text{height}(x) \in D\,]$

In (55b), the quantifier *every* has wider scope than Π, which gives the MAX reading for (52). When Π scopes above a comparative-standard-internal quantifier, though, we get the MIN reading.

Whether one prefers handling quantificational comparative standards by moving entirely to intervals (à la Schwarzschild and Wilkinson 2002) or by raising degrees to intervals when necessary (e.g., through the Π operator, à la Heim 2006),[62] the same can be accomplished in a continuations analysis which handles this scope-taking without movement.

[60] Schwarzschild and Wilkinson (2002) constrain this set to be contiguous: an interval. Heim (2006) doesn't impose this constraint:

> "The difference between Schwarzschild & Wilkinson's semantics and the one I use here is just that their adjective-denotations impose a further condition on their arguments: these can't be arbitrary sets of points on the degree scale, but must be intervals (i.e., sets which satisfy the condition that for any two points they contain they also contain all points in between). The result of trying to apply an adjective to a non-interval set of degrees would presumably be undefined. As it turns out, in the actual examples which I will analyze or discuss below, the sets that adjectives apply to always happen to be intervals. So I might as well have adopted the interval-based entries of Schwarzschild & Wilkinson, but then again, I have no specific motivation to." (p. 6)

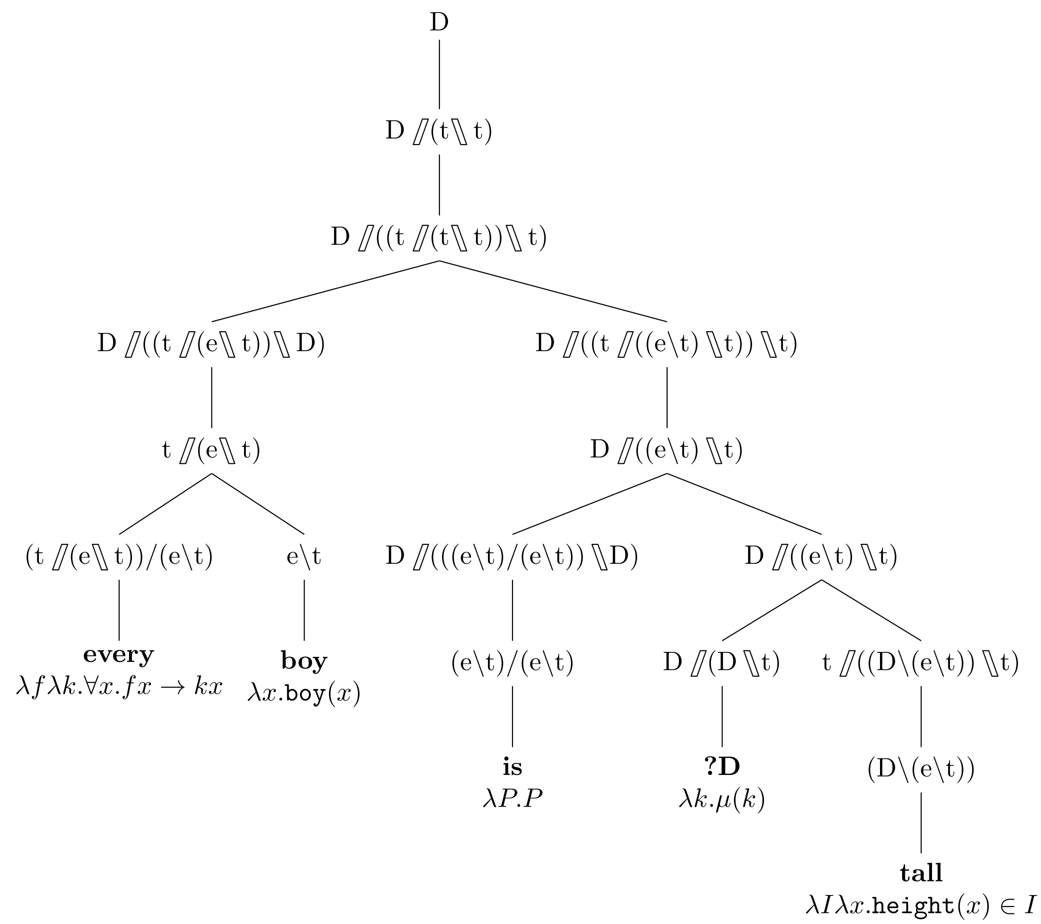
[61] Heim attributes the idea for this operator and its name to Schwarzschild 2004.

[62] Fleisher (2015) calls both Schwarzschild and Wilkinson (2002) and Heim (2006) "entanglement theories", as the degrees associated with the comparative standard (e.g., *every boy* or *exactly five boys*) are "distributed over the matrix degree relation" and so are part of the interpretation of the matrix comparison relation. These theories, in which the comparative standard is entangled with the matrix relation, stand in contrast to those in which the degrees within comparative standards remain there: "encapsulation theories". Despite their different implementations, then, Schwarzschild and Wilkinson 2002 and Heim 2006 are not very different, something that Heim herself muses about:

> "The remarkable degree to which our analysis predicts S&W's data invites the question of how it relates to the analysis that these authors themselves develop. Is it perhaps the same analysis or a notational variant of it? A superficial reading of their paper certainly does not convey this impression. . . . Nevertheless, the predictions of

Accommodating the Schwarzschild and Wilkinson 2002 analysis requires changing the denotations for gradable adjectives to replace entries that denote degrees (as we saw in (53a)) with those that denote intervals (as in (53b)), as well as replacing the comparative operator and maximality operator with equivalents that deal with intervals as opposed to degrees (for both, see (Schwarzschild and Wilkinson 2002), p. 23). Even in this analysis, though, the comparative standard in the *than* clause still involves abstraction (now over intervals), as we still need to interpret *every boy is tall* not as a denoting a truth value but as denoting an interval (the interval containing the heights of every boy). We can use the what is basically the same `?d` operator defined above, albeit now with Schwarzschild and Wilkinson's (2002) μ maximality operator as opposed to Heim's (2000) **max** (and perhaps it'd be more fitting to call it `?D`), and end up with a derivation of the comparative standard not dissimilar to the one we saw in (48):

(56)



The type tree in (56) is just like that of (48), only now with D (the type of an interval, a set of degrees) and with the modified lexical entries for `?D` and *wide*.

To accommodate Heim's (2006) analysis, we need only introduce a weaker version of the Π operator, one which simply raises predicates of degrees to predicates of sets of degrees (intervals). The extra mobility of Π is unnecessary under a continuation implementation: both quantifiers and our new quantifiers-over-degrees take scope via the same mechanism—continuations—and so can interact freely without additional mechanisms. (The derivation for this Heim 2006 compatible version is identical to that of (48) with the addition of an *in situ* degree-to-interval operator.) The interpretive system has free access to LIFT, which as we've seen can allow different elements to scope over one another, not just those elements which encode continuation-sensitivity lexically. There is a preference order for such scope-taking, but this order is not fixed. Two continuation-level functions can combine in either order (the right over the left only if the right is

the two theories systematically coincide, and with certain auxiliary assumptions, this is provably so." (p. 10) at a higher continuation level). Unfortunately, this strength is also a weakness, one shared by Heim's (2006) account.

The important remaining caveat in the Heim 2006 account is that it relies upon an additional constraint on the scopal possibilities of Π. As Heim puts it,

> "To prevent massive overgeneration of unattested readings, we must make sure that Π never moves over a DP-quantifier, an adverb of quantification, or for that matter, an epistemic modal or attitude verb. Nor must any DP-quantifier be allowed to reconstruct down into its scope. Its capacity for scoping over other material must be severely constrained." (Heim 2006, p. 16)

Without such a constraint, for instance, the flexibility available to the system in the relative orderings of the quantifier and the quantifier-over-degrees in a sentence like (52) allows for both the licit wide-scope universal interpretation and the wide-scope degree interpretation which is unattested—see the appendix for their full derivations, too large to include here.[63]

Takahashi (2006) named this constraint the **Heim-Kennedy constraint**,[64] and its scope,[65] limits, and motivations (including attempts to reduce it to a general economy principle) have been much discussed in the literature (Takahashi 2006; Lassiter 2012; Mayr and Spector 2012; Fleisher 2013, among others). As understood by Alrenga and Kennedy (2014, p. 26), the constraint stipulates that "If the scope of a quantificational DP contains the trace of a DegP, it also contains that DegP itself." This constraint is sufficient to rule out a number of unattested scope combinations that the theory allows to be generated, but it is quite stipulative, in that it is a constraint on a particular type of phrase (not heads in general, or functional projections in general), and it remains unclear why it should be that a degree phrase and a quantificational DP should have to stand in this particular relation to one another.

We can capture the Heim-Kennedy constraint within the continuations framework by imposing a restriction on the combinatory possibilities of the SCOPE operation. This means adding another clause to the criteria listed in (10) (back in §2.2.3), disallowing the case where Left (the left combinant) is DegP and Right (the right combinant) is a quantified DP.[66] This new criterion would be the only to make reference in its formulation to the character of the combinants over which SCOPE operates: the other criteria care about the relations between the combinants (identity and function-argument compatibility, to be exact), but they don't make reference to the specific types of those combinants. If the expansion of restrictive power this requires is worrisome, that's the same worry about the stipulative nature of the Heim-Kennedy constraint in general. The type-sensitive nature of this restriction, however, may not be unique to the Heim-Kennedy constraint, in that there may be other phenomena which require SCOPE to be sensitive to particular phrase types, as Charlow (2015) has argued for the wide scoping of indefinites.

The elimination or at least explanation of this constraint continues to elude the field.[67] In the meantime, we can represent it formally within the continuation semantics framework.

4.3 Fleisher (2015) differentials

All of the differentials we've discussed this far have been simple degree phrases, whether explicitly or contextually provided. Fleisher (2015) notes some other classes of differentials, largely overlooked in the literature, which contribute to different interpretations of comparative sentences. We've already seen the typical MAX reading, as well as the perhaps-odd but logically derivable MIN reading (§4.2). With differentials other than the simple upward entailing ones we've been examining, he argues, we get different readings:

(57) a. UE differential → MAX reading:
John is (more than six inches) taller than every girl is. Fleisher's (2015) (3)

[63] These derivations don't include the Π operator; these derivations are lengthy enough as is, and the focus is the different scope orders generated by the theory (here, by the parser).

[64] After Heim (2000) called it "Kennedy's generalization".

[65] Pardon the pun.

[66] It's not clear whether either implicational statement of this restriction ("If Left is DegP, Right must not be a quantified DP", and its converse) are meaningfully different here from each other or from the stricter "Disallow the combination wherein Left is DegP and Right is a quantified DP"; they should be logically equivalent, but the different formulations may have implementational differences for the particular parser.

[67] I had hoped that the move to continuations would have provided a neat solution to this problem, or avoided it entirely, but unfortunately I am forced to rely upon this constraint just as Heim is.

b. DE differential → MIN-&-MAX reading:
   John is less than six inches taller than every girl is.

c. Non-monotone differential → MIN=MAX reading:
   John is exactly six inches taller than every girl is.

The differentials we've been dealing with, he points out, are all upward entailing: the contextual differential in *John is taller than every girl is* is interpreted identically to the explicit one in *John is more than six inches taller than every girl is.* In both cases, there is some granularity of comparison, provided by the differential, and any height value above that increment makes the sentence true. With a downward entailing differential like *less than*, the truth-making heights that John can have are constrained by both a floor (he must be taller than the tallest girl) and a ceiling (he can be no more than 6″ taller than the shortest girl).[68] And with a non-monotone differential like *exactly*, the comparative forces us to interpret the heights of the all of the girls as being the same; the tallest girl and the shortest girl are the same height, so Fleisher (2015) calls this reading the MIX=MAX reading.

With this data in hand, Fleisher (2015) compares a variety of analyses of comparisons to see which can account for these sorts of differentials and the interpretations they lead to. He concludes that encapsulation theories like Beck 2010; Alrenga and Kennedy 2014 "can sometimes be tweaked so as to derive the MIN=MAX reading", but that those tweaks "do not successfully generalize to DE differentials; such theories simply cannot derive the observed MIX-&-MAX reading" (p. 4). Entanglement theories, in contrast, do derive the full paradigm of interpretations, Fleisher argues.

Schwarzschild and Wilkinson (2002) handles these interpretations "in a natural way" without requiring any modifications; Fleisher (2015) only makes some syntactic choices which Schwarzschild and Wilkinson are agnostic about (but which they suggest as possible implementations). Considering that this theory requires no further modifications, and given that I've already shown how we can implement a Schwarzschild and Wilkinson 2002 style analysis in a continuation framework above (as in 56), I've nothing interesting left to say about handling these differentials in a Schwarzschild and Wilkinson 2002 analysis.

Heim 2006, which Fleisher (2015) also classifies as an entanglement theory, can also be made to derive the full paradigm of interpretations illustrated in (57). To do so, Fleisher argues for treating "the differential as another degree-type argument of the comparative morpheme *er*"—which we've already been doing, as in (26) and our lexical entry for `erthan` in §4.1.1; Heim 2006, p. 14 omits the differential in the definition of the comparative morpheme. Moreover, under this analysis, being a movement analysis, "differential phrases like *exactly six inches* are generalized quantifiers over degrees and must raise from this degree argument position to take scope." The only way in this theory to treat *exactly six inches* as a degree is via movement, in just the same way that an object-position quantifier must move up so that its trace can be interpreted as a variable over individuals. This sort of movement-for-type-compatibility is exactly the sort of thing we can handle with continuations.

First, we add lexical entries for the differential-modifying elements *exactly*, *less than*, and *more than*, with the understanding that the interpretation of differentials with implicit such elements should be interpreted as though they included an explicit *exactly or more than.* These lexical entries are straightforward: these elements take a degree and return a property of degrees, an interval.

```
(("exactly" ((d \ t) / d)) (^ d (^ k (k = d))))
(("less than" ((d \ t) / d)) (^ d (^ k (k < d))))
(("more than" ((d \ t) / d)) (^ d (^ k (k > d))))
```

After taking its degree argument, *exactly* returns true if its input is equal to that initial degree; *less than* requires that it be less, and *more than* behaves just as straightforwardly.

For these differentials to interact with their immediate context, we'll need to introduce another continuation-sensitive operator. (We could have instead encoded this continuation-sensitivity into *exactly*, etc., directly, but that type-lifting isn't necessary in all non-comparative contexts, and seems non-basic. Including it there, then, would require ambiguous lexical entries for these elements.) This operator allows the property-of-degrees to interact locally with the comparative operator which takes it as an argument (as per Fleisher's

[68]The naming can be slightly confusing here, in that it's actually the floor, the lowest-allowable value for John's height, which is contributed by the MAX reading part of this interpretation, as it is contributed by the height of the tallest girl (who has the maximum degree of height contributed by the set of girls). Meanwhile the ceiling, the highest-allowable value for John's height, is contributed by the MIN reading, as it is provided by reference to the shortest girl (the minimum of the set).

(2015) suggestion and our (26)), so its local type is d, just like the other degree-scoping operator we introduced in §4.1.

```
((”?d2” ( (d \ t) \ ( t // (d \\ t) ))) (ˆ k k))
```

We can think of this operator, `?d2`, as cousin to our previous operator for the comparative standard, `?d`. This differential scoping operator takes as its argument the interval specified within the differential, and then returns a continuation-sensitive operator, one whose local type is d—such that it can act as the local argument of the comparative morpheme *-er*. This operator takes scope at t, the level of the sentence, only now there is no sentence lower than the matrix sentence for it to LOWER prior to the end of the derivation, and after taking scope returns a truth-evaluable statement (also of type t), namely a modified version of the relation contributed by the comparative operator. Semantically, this operator is just the identity function, passing the interval contributed by the differential up the derivation. This arrangement allows the restriction imposed by the differential to take matrix scope, and in doing so to interact with the rest of the sentence such that all of the degrees associated with the comparative standard (even if quantified) bear the relationship to the subject specified by the differential.

Derivations with these Fleisher 2015 differentials can be found in the appendix.[69]

4.4 Superlatives and the Containment Hypothesis

Though it doesn't directly bear on the analysis of the scopal behavior of comparatives in the same way that Fleisher's (2015) discussion of differentials did, the question of how superlatives are best analyzed is worth discussing here as well. While comparatives and superlatives don't do exactly the same thing, they are related constructions (at least functionally): recall Schwarzschild's list of degree constructions in (36). Where comparatives relate two things,[70] superlatives pick out one thing as having the highest degree (on some scale) relative to some group.

Why should this other degree construction bear on our analysis of comparatives at all? The most often given answer is that we should hope for some parallels among the different degree constructions, be it structural, semantic, or otherwise. And indeed there have been attempts in the literature to establish such parallels, including Heim 2000. A more recent and much stronger reason to look at the connection between the comparative and the superlative comes from Bobaljik (2012), who, after conducting a typology of the morphological forms that comparatives and superlatives take, concludes that the two are more closely related than is popularly thought. He argues for the Containment Hypothesis, as stated in (58), the view that the superlative contains a nested comparative.

(58) **The Containment Hypothesis**
The representation of the superlative properly contains that of the comparative (in all languages that have a morphological superlative).

Under this view, instead of giving both comparatives and superlatives a structure like (59), as is widely done (Heim 2000; Hackl 2009; Gajewski 2010), Bobaljik argues for the structure in (60).

(59) [[ADJECTIVE] DEGREE] — Bobaljik 2012 (47)
  a. [[ADJECTIVE] COMPARATIVE/-ER] — Bobaljik 2012 (46a)
  b. [[ADJECTIVE] SUPERLATIVE/-EST] — Bobaljik 2012 (46b)

(60) [[[ADJECTIVE] COMPARATIVE] SUPERLATIVE] — Bobaljik 2012 (7a)

Stateva (2002) argues against this sort of view, positing two *-er* morphemes, one of which, present in comparatives, is quantificational, while the other (her *-ER*), present in superlatives, is non-quantificational.

[69] I was unable to get the parser to produce derivations for sentences with both Fleisher differentials *and* comparative standards that included any scope-taking. This wasn't due to a conflict of denotations—the parser didn't complete with no results, as it does for sentences with no good parses—but due to memory limits on the server I was using. The parse for the simple comparative standard *six feet* provided in the appendix required over 4,000 edges (where most of the parses shown above took only a few hundred); apparently throwing in the complexity from scope-taking within the comparative standards was too much to handle. That said, combining these things works on paper, and they work in smaller chunks as well, all of which are now represented here.

[70] Two individuals, at least—where one or both of those individuals can be plural individuals—, plus a differential.

Not only does the superlative not contain the comparative, but they end up being derived by different processes. Bobaljik (2012) doesn't consider Stateva's (2002) objections unsurmountable, and points to some distributional facts (e.g., the unavailability of an explicit *than* clause) to indicate that there may be more going on than Stateva (2002) notes.

Turning to those facts, we can see quite quickly that the superlative doesn't work quite the same way that the comparative does.

(61) a. John is (the) tallest.
b. John is (the) tallest boy in the class.
c. * John is (the) tallest than the other boys in the class.
d. John is (by {far|10″}) the tallest boy in the class (by {far|10″}).
e. * John is (6′) the (6′) tallest boy in the class (6′).

The superlative can appear unadorned, as in (61a). It can also appear with explicit reference to the class against which the subject is being compared, as in (61b), but this reference class can't be introduced in a *than* clause the way a comparative's standard is (as illustrated in (61c)). Similarly, a superlative construction can include the amount by which the subject exceeds the reference class (on the relevant scale denoted by the adjective), but that amount is provided in a *by* phrase (as in (61d)) and cannot be given bare in the way the comparative construction's differential is given, as shown in (61e)—even in the pre-adjectival position. (The superlative's differential is contextually provided when not given explicitly, just as it is for the comparative.)

That the superlative seems not to handle a comparative standard or differential in the way the comparative does—with a locally-typed phrase needing to take scope at some other type—is good evidence that the continuation-analysis won't provide anything especially insightful to our understanding of the superlative, nor will the superlative pose any significant challenge to the continuation project (or at least no more than it poses to the general investigation of the syntax and semantics of superlatives). The continuations framework introduced here could handle any definition of the superlative operator which would be sufficient for Bobaljik (2012): there's nothing to prevent the superlative operator from taking the [[ADJECTIVE] COMPARATIVE] complex as an argument and modifying or passing along some or all of the denotation of that complex.

For just one treatment compatible with the rest of the denotations given here, consider a denotation for a word like *tallest* as in (62):

(62) $[\![\text{tallest}]\!] = \lambda Y_{<e,t>} \lambda x. \forall y \in Y \,|\, \text{height}(x) \geq \text{height}(y)$

In this denotation, *tallest* takes a predicate (e.g., the one denoted by *boy in the class*) and then an individual (e.g., John), and returns true if the height of that individual is greater than or equal to the height of every (other) individual that makes that predicate true; this analysis would also carry the presupposition that $x \in Y$—in (61b), that John is himself a boy in the class—but I omit this presupposition for brevity. To achieve this end result, the denotation for the superlative morpheme must take not just the complex [[ADJECTIVE] COMPARATIVE] as an argument (as Bobaljik suggests), but both the comparative morpheme and the adjective as arguments in order to allow the adjective to be repeated. This is still in line with the Containment Hypothesis, as the superlative requires the presence of the comparative in order to function—it just has to take the comparative morpheme as an argument before the comparative takes the adjective as an argument. Consider the denotations in (63) and (64):[71]

(63) $[\![\text{-er}]\!] = \lambda A_{<det>} \lambda d \lambda d' \lambda x. \, \text{MAX}(A(x)) \geq d + d'$

(64) $[\![\text{-est}]\!] = \lambda C_{<(det)ddet>} \lambda A_{<det>} \lambda Y_{<e,t>} \lambda x. \forall y \in Y \,|\, C(A)(\text{MAX}(A(y)))(d_{\text{context}})(x)$

The comparative morpheme is as described and shown earlier. The superlative, however, is new. It first takes the comparative morpheme, then the adjective, and then the reference set (over which we're quantifying) and the subject. This denotation allows the superlative to introduce the quantification but leaves the comparison (the introduction of $\geq$) to the comparative morpheme. It feeds the variable y (quantifying over the reference set) along with the adjective to the comparative standard's place in the comparative morpheme, and fills the differential place with a free variable to be bound by context (or a *by-phrase*). To see this in action, see the derivation in (65), omitting type-label subscripts for compactness:

[71] I call these *-er* and *-est* in keeping with the examples in (61), but these could be just as easily labeled COMP and SUPER.

(65) $$\begin{aligned}&[\![-est]\!]\,([\![-er]\!])([\![tall]\!])\\
&= \lambda C \lambda A \lambda Y \lambda x.\, \forall y \in Y |\, C(A)(\textsc{max}(A(y)))(d_c)(x)\ (\lambda A' \lambda d \lambda d' \lambda x'.\, \textsc{max}(A'(x')) \geq d + d')\ ([\![tall]\!])\\
&= \lambda A \lambda Y \lambda x.\, \forall y \in Y |\ [\lambda A' \lambda d \lambda d' \lambda x'.\, \textsc{max}(A'(x')) \geq d + d']\,(A)(\textsc{max}(A(y)))(d_c)(x)\ ([\![tall]\!])\\
&= \lambda A \lambda Y \lambda x.\, \forall y \in Y |\ [\lambda d \lambda d' \lambda x'.\, \textsc{max}(A(x')) \geq d + d']\,(\textsc{max}(A(y)))(d_c)(x)\ ([\![tall]\!])\\
&= \lambda A \lambda Y \lambda x.\, \forall y \in Y |\ [\lambda d' \lambda x'.\, \textsc{max}(A(x')) \geq (\textsc{max}(A(y))) + d']\,(d_c)(x)\ ([\![tall]\!])\\
&= \lambda A \lambda Y \lambda x.\, \forall y \in Y |\ [\lambda x'.\, \textsc{max}(A(x')) \geq (\textsc{max}(A(y))) + d_c]\,(x)\ ([\![tall]\!])\\
&= \lambda A \lambda Y \lambda x.\, \forall y \in Y |\ \textsc{max}(A(x)) \geq (\textsc{max}(A(y))) + d_c\ ([\![tall]\!])\\
&= \lambda Y \lambda x.\, \forall y \in Y |\ \textsc{max}([\![tall]\!]\,(x)) \geq (\textsc{max}([\![tall]\!]\,(y))) + d_c\\
&= \lambda Y \lambda x.\, \forall y \in Y |\ \text{height}(x) \geq (\text{height}(y)) + d_c\end{aligned}$$

This is exactly the result we wanted, as in (62), plus the explicit term for the contextual differential parameter (which, again, can also be filled in via a *by*-phrase). There are surely other analyses of the superlative which are compatible with the continuations framework presented here, but this is one, and one which is compatible with the Containment Hypothesis.

4.5 Cross-linguistic variation

The examples we've looked at so far have been in English, but even within the class of standard comparatives there are different structures. How applicable is this analysis? Can continuations be used to account for comparatives in, say, Hebrew or Japanese? In investigating them, we'll discover that there is indeed a good deal of cross-linguistic variability, even with those languages that use standard comparatives, in how comparatives are formed and how they behave. I'll show, though, that none of this variation is problematic for a the continuations project.

In Hebrew, the comparative standard is marked with locative case (∼ 'from') and the predicate is only optionally modified (analytically, not synthetically):

(66) *Dan gavoha (yoter) mi-Meri.*
Dan tall more from-Mary
'Dan is taller than Mary.' Bobaljik 2012 (24)

The example in (66) might be better considered a phrasal comparative than a clausal one, as the copula is (optionally) acceptable between Dan and the adjective, but not following Mary.

(67) *Dan (hu) gavoha (yoter) mi-Meri (*hi).*
Dan COP.MASC tall more from-Mary COP.FEM
'Dan is taller than Mary.'

There are other comparative structures in Hebrew which are easier to interpret as being clausal, however. Hazout (1995) discusses both "*aSer*-comparatives"[72] (those which use a particle meaning roughly 'that/which') and "*ma*-comparatives" (those which add the *wh*-form meaning 'what' in front of a dependent version of that same complementizer). In both forms, the comparative standard is marked with the same locative preposition (which is morphologically attached to the following word/particle), in front of either *aSer* or *ma Se*, respectively.

(68) *Dan axal yoter tapuxim [mi-aSer Dina axla bananot].*
Dan ate more apples from-that Dina ate bananas
'Dan ate more apples than Dina did bananas.' Hazout 1995 (4)

(69) *Dan axal yoter tapuxim mi [ma Se Dina axla bananot].*
Dan ate more apples from what that Dina ate bananas
'Dan ate more apples than Dina did bananas.' Hazout 1995 (38)

Both of these types of Hebrew comparative structures exhibit comparative deletion similar to what we saw in §3.4, and, just as in English, elided content is interpreted as identical with an earlier antecedent:

[72] In IPA, /aʃɛˈʁ/. For continuity, though, I'll use Hazout's (1995) notation throughout. The example sentences' brackets, too, are directly from Hazout 1995. Importantly, the locative particle *mi-* 'from' is morphologically attached to the following particle; there is no difference in the (in)dependence/attachment of this particle between (68) and (69).

(70) *Dan axal yoter tapuxim [mi-aSer Dina axla].*
Dan ate more apples from-that Dina ate
'Dan ate more apples than Dina did.' Hazout 1995 (5)

(71) *Dan axal yoter tapuxim mi [ma Se Dina axla].*
Dan ate more apples from what that Dina ate
'Dan ate more apples than Dina did.' Hazout 1995 (39)

In both (70) and (71), the number of apples Dan has eaten is compared to the number of apples Dina did—it cannot be the number of bananas, as in (68) and (69). Hazout (1995) argues that *aSer* and *ma* comparatives are structurally different, pointing to some different ellipsis behavior of the two types, in that leaving only the direct object is allowable with *aSer*, as in (72), but is not with *ma*, as in (73).

(72) *Dan axal yoter tapuxim [mi-aSer bananot].*
Dan ate more apples from-that bananas
'Dan ate more apples than (he did) bananas.' Hazout 1995 (35a)

(73) ** Dan axal yoter tapuxim mi [ma Se bananot].*
Dan ate more apples from what that bananas
intended: 'Dan ate more apples than Dina did bananas.' Hazout 1995 (40)

It strikes me, however, that (72) could well be analyzed as a phrasal comparative, however—there's no content that forces us to understand it as a CP[73]—, and we shouldn't expect there to be any phrasal comparatives involving *ma*, as *ma* explicitly takes the DegP argument position of the (possibly elided) predicate, and there would be no such position in a phrasal comparative! The very existence of such a position would make it clausal, at which point eliding the comparative standard's subject and predicate—but leaving the direct object—becomes a question of gapping, not VPE.

Regardless of the resolution of this point, we can use continuations to model the behavior of Hebrew just as we did for English. The interpretation of a sentence-like comparative standard like *Dina axla bananot* in (68)/(69) as denoting a degree will work just as it did in English, through the application of the `?d` operator. In the *ma* structures, we can even think of *ma* as an overt instance of `?d`, as the only missing element from the embedded CP (the equivalent of a *than* clause) is the degree term, in these examples the number of bananas that Dina ate. The difference between *aSer* and *ma* comparatives, under this view, is that the `?d` operator is overt in the *ma* comparatives, being pronounced as the *wh* word, which then has to move up to the specifier of the embedded CP for *wh* reasons.[74] *aSer* comparatives use the same operator—they must, being interpreted as degree-denoting—but covertly, with no phonological reflex (except for realizing the complementizer as the independent *aSer* as opposed to the dependent *Se-*).

We turn now to Japanese, which famously leaves *wh* words in situ (though they, like other words, can be moved for topicalization) (Bayer 1996). Japanese comparatives leave the predicate unmarked (not even optionally marking them, as in Hebrew), with overt marking only on the standard.

(74) *Sally-wa Bill-yori kaikoi.*
Sally-TOP Bill-from smart
'Sally is smarter than Bill.' Bobaljik 2012 (25), citing Beck, Oda, and Sugisaki 2004

The comparative standard is marked with *yori* 'from' (or *yori-mo*, with the same meaning), followed optionally by *motto* (often glossed as 'more')[75] and the subject can optionally be marked with *no hoo-ga* 'X's side' (when it is not topicalized, as the subject in (74) is). Additionally, the order of these two is flexible, so long as the predicate is sentence-final.

[73]The presence of *aSer*, which acts also as a complementizer, might make us think that this standard is a full CP; but there more-clearly-phrasal equivalent of (72), whose standard is simply *mi-bananot* ('from bananas'), is illicit. It may be that *aSer* is required in cases like this where the predicate is a VP (including a direct object) as opposed to a bare adjective.

[74]This is movement, yes, but the same kind of pre-surface movement we get for other *wh* words. The continuation analysis doesn't aim to get rid of all *wh*-movement—in fact, there are mechanisms built in, which I didn't demonstrate here, for pre-surface *wh*-movement—it only provides an alternative to post-surface movements, LF movements. *ma* appears in the surface form, and so can move following those procedures.

[75]This leads some to assume that *motto* is the comparative morpheme, understood as being covertly present when omitted. Oda (2008), though, argues that gradable adjectives are inherently comparative in Japanese.

(75) *Bill-yori Sally-no-hoo-ga kaikoi.*
Bill-from Sally-GEN-side smart
'Sally is smarter than bill.'

This pattern is sufficient for comparing DPs, including quantified DPs.[76]

(76) *John-wa juugyoo-no-onna-no-ko-yori se-ga takai.*
john-TOP class-GEN-woman-GEN-child-from height-NOM tall
'John is taller than every girl in the class.'[77]

Oda (2008) classifies these as phrasal comparatives, with what he calls clausal comparatives having a comparative standard which is more complex:

(77) *Mary-wa [John-ga kaita (no) yori(mo)] (motto) takusan-no ronbun-o kaita.*
Mary-TOP [John-NOM wrote (NO) from] (more) many-GEN paper-ACC wrote
'Mary wrote more papers than John did.' Oda 2008 (19)

The particle *no*, which Oda (2008) calls a "nationalizer", is a complementizer (Suzuki 2000), and though Oda puts it in parentheses, he also mentions that there is high variability, and that some speakers prefer it to be present in these constructions. (He also provides an example where it is obligatory.) This comparative standard, as Beck, Oda, and Sugisaki (2004) point out, is interpreted as a relative clause: 'As for Mary, she wrote more papers than those that John wrote.' This construction can include quantified standards as well:

(78) *John-wa [dare-ga katta (no) yori]-mo takai hon-o katta.*[78]
john-TOP [who-NOM bought (NO) from]-MO expensive book-ACC bought
'John bought a more expensive book than anyone did.' Oda 2008, p. 100, (iii)

There are interesting differences between Japanese and English comparatives, which have led to significant debate in the literature (Beck et al. 2004; Kennedy 2005; Oda 2008). For example, Japanese disallows comparatives of degrees across different scales, as in (79), but allows comparatives of numbers of different things, as in (80); English allows both.

(79) * *Kono tana-wa [ano doa-ga hiroi yori(mo)] (motto) takai.*
this shelf-TOP [that door-NOM wide from] (more) tall
intended: 'This shelf is taller than that door is wide.' Oda 2008 (22)

(80) *John-wa [Mary-ga simbun-o yonda yori(mo)] (motto) takusanno ronbun-o yonda.*
John-top [Mary-nom newspaper-acc read from] (more) many paper-acc read
'John read more papers than Mary read newspapers.' Oda 2008 (23)

Furthermore, where English allows for scope ambiguity with modals, Japanese does not. Take the famous example from Heim 2000, (28), for instance:

(81) a. (This draft is 10 pages.) The paper is required to be exactly 5 pages longer than that.
b. required [[exactly 5 pp. -er than that] the paper be t long]
$\forall w \in \text{Acc} : \max\{d : \text{long}_w(p, d) = 15\text{pages}\}$
c. [exactly 5 pp. -er than that] [required [the paper be t long]]
$\max\{d : \forall w \in \text{Acc} : \text{long}_w(p, d) = 15\text{pages}\}$

[76] This is also probably the same pattern which describes the comparison of multiple full propositions (e.g., 'John's eating apples is better than Mary's eating bananas'). These comparatives follow the same pattern—which Oda (2008) calls phrasal, not clausal—even though we might not initially react to these as being phrasal. Importantly in these full proposition comparatives, each proposition is complete; for part of one to be elided requires the kind of comparative we're about to see, with *no*.

[77] This can also mean 'a girl in the class', 'some girl in the class', 'all the girls in the class', etc.

[78] Oda (2008) actually has this sentence-final verb as *kaita* 'wrote', not *katta* 'bought', but this is likely just a typo. In that case, the gloss would be 'John wrote a book more expensive than (one that) anyone bought.'

This English sentence allows for two readings: In the wide scope modal reading, in all acceptable worlds the length of the paper is exactly 15 pages. In the wide scope comparative reading, the maximum length of the paper in all worlds where it is acceptable is 15 pages—in other words, it is 15 *or more* pages long (the shortest acceptable one is 15 pages). This is the equivalent of the (unavailable) reading for (52) which makes reference to the height that all the boys share (i.e., the height of the shortest boy). Japanese lacks this reading:

(82) *Sono ronbun-wa sore yori(mo) tyoodo 5 peeji nagaku-nakerebanaranai.*
that paper-TOP that from exactly 5 pages long-be_required
'That paper must be exactly 15 pages long.' Beck et al. 2004, p. 331

This Japanese version of Heim's example can only be understood with the wide scope modal reading: the paper must be exactly 15 pages long (and no longer). Beck et al. (2004) and Oda (2008) conclude that there is no movement of degrees in Japanese.

Given these differences, Beck et al. (2004) conclude that degree abstraction is parametrized: there is a language-by-language setting for the syntactic availability of bound degree variables, the Degree Abstraction Parameter; they also posit that languages like English have comparatives which are compositional (making use of explicit comparative content) whereas languages like Japanese have comparatives which are contextual (making use of contextually-provided information). Kennedy (2005) disagrees, arguing that it comes down to types: complex standards in Japanese are (only) type *e*, whereas complex standards in English are (potentially) type *d*. Or, as Oda (2008, p. 49) puts it, "By Kennedy's generalization, the behaviors of Japanese comparatives can be regarded as phrasal comparatives that are widely observed cross-linguistically"; Oda then goes on to provide examples of the phrasal/clausal distinction across languages, including data from Hankamer 1973 and Kennedy 2005.[79]

If in fact, as Kennedy (2005)'s analysis puts it, all comparatives in Japanese are phrasal (because all comparative standards are type *e*), then the analysis described herein has no bearing on Japanese. This implementation focuses on the type-lifting and scope-taking behaviors of comparative standards, how we interpret sentence-looking structures as degree-denoting, and their scopal interactions with other scope-takers. But if Japanese comparative standards don't denote degrees and don't ever take scope, then they can be implemented without continuations. This isn't to say that Japanese presents a counterargument to the utility of continuations in the analysis of natural language, though. If continuation-sensitivity is a feature that grammars can make use of, the fact that Japanese happens not to is not an argument that no languages do, in just the same way that Japanese's not making use of *wh*-raising doesn't constitute an argument against the existence of *wh*-raising as a property of languages in general. It *does* invalidate the stronger claim that continuations are used in *every* language—a claim that neither Barker and Shan (2014) nor I have made.

4.6 Ellipsis revisited

Throughout this paper, I've begun my derivations with fully spelled-out comparative standards, even though (as we've seen) they can come in a number of shapes. As discussed in §3.4, ellipsis ("comparative ellipsis") seems to play a part in the story of comparative structures; my taking the fully spelled-out versions as given amounts to assuming a "reconstructed" logical form, which cheapens the prospects of this project. What can be done about this?

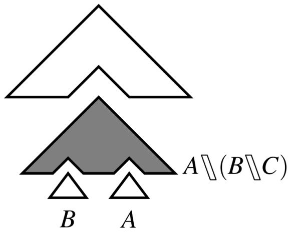
Barker and Shan 2014 describes a single project, but discusses two different frameworks in which one could compute continuations and continuation-sensitive material. Part I of the book deals with a formalism based in combinatory categorial grammar, one which handles binding via a $\triangleright$ operator. Part II introduces an alternative formalism rooted in type-logical grammar (Lambek 1958; Moortgat 1997), one which allows elements to be sensitive not only to their immediately surrounding contexts but also the contexts of their contexts.[80] This change[81] allows, in particular, interactions with continuations which contain multiple

[79] Oda (2008) prefers Beck et al.'s (2004) approach, as Kennedy's (2005) doesn't cover matrix clause movement behavior, where Beck et al.'s has more prediction power (e.g., for the lack of wide scope comparative reading).

[80] Another immediately apparent difference, other than the absence of $\triangleright$, is that LIFT and LOWER are theorems, not operations, in the Lambek-style formalism.

[81] As discussed in Barker and Shan's (2014) Afterword, however, the two formalisms are compatible with only a minor change, allowing the parasitic scope-taking formalism to retain the benefits of the left-to-right evaluation demonstrated in Shan and

missing pieces, multiple points of discontinuity, as schematized in (83).

(83) 

(Barker and Shan 2014, (243))

The ability to deal with such multiple discontinuity structures is what enables Barker and Shan to present a general story about parasitic scope-taking (following and building on Barker 2007), which among other things allows for an analysis of pronominal binding, and building on that, verb phrase ellipsis. Introducing a duplicator combinator[82] allows us to denote particular relationships (e.g., identity) between the fillers of a multiply-discontinuous continuation. What this means is that, in the same way that in the internal reading of *Every boy said he left* the pronoun *he* takes parasitic scope under the wide-scope *everyone* (and in doing so becomes 'captured', coreferential with it), Barker and Shan (2014) can analyze a VPEGAP[83] operator as taking parasitic scope under the wide-scoping main verb, which by doing so becomes a 'copy' of that verb.

This seems like an excellent step forward; surely we can use this for comparatives as well! If pronouns like *he* are of type $(DP \mathbin{\backslash\!\!\backslash} S) \mathbin{/\!\!/} (DP \mathbin{\backslash\!\!\backslash} (DP \mathbin{\backslash\!\!\backslash} S))$ (which Barker and Shan abbreviate to DP^{DP})[84]—anaphora to a continuation—and the type of the VPEGAP operator is VP^{VP}[85], then we could use a similar A^A operation to have the elided adjectival content from the comparative standard copy the matrix predicate.

There are some reasons to think, however, that there shouldn't be such a close identity between comparative ellipsis and VP ellipsis. As Kennedy (1999) points out, comparative deletion seems to exhibit a strictly local dependency that VPE does not.

(84) The table is wider than this rug is, but this rug is longer than the desk is. ✓ *the desk is long*
\# *the desk is wide*

(85) Marcus read every book I did, and I bought every book Charles did. ✓ *every book Charles bought*
✓ *every book Charles read*

The VPE example in (85) has two possible interpretations due to ambiguity over the resolution of the elided VP. In the local (narrow) reading, wherein the closest verb (*bought*) is interpreted as the antecedent of the elided VP, the speaker bought every book Charles bought. In the non-local (wide) reading, the further verb (*read*) plays that role, and the speaker is understood as having bought every book Charles read. Both readings are available. In the comparative deletion case in (84), however, only the local reading is available: we understand the final adjective applying to the desk as being the local *long*, and the reading wherein it is understood as *wide* seems unavailable. (For more examples, including some where comparatives *do* show ambiguity, but still differently than VPE, see Kennedy 1999; Hendriks 1999.) We might want different mechanisms, then, to explain comparative deletion and VPE; there are some reasons to think that comparative deletion is sensitive to discourse parallelism, pragmatic considerations, and other non-syntactic factors (Hendriks and de Hoop 1998). Were the thinking to go the other way, however, and comparative deletion were to be considered similar to VPE, then the Lambek-style formalism in Part II of Barker and Shan 2014 could handle it. As far as formalizing the non-VPE-style comparative deletion within a continuation analysis, I have nothing to add here.

5 Conclusion

In this paper, I have adopted and introduced the work on continuations in natural language by Barker and Shan and extended their project to comparatives, which have often been analyzed as involving post-surface

Barker 2006.

[82] $\lambda k \lambda x.kxx$

[83] Verb phrase ellipsis gap.

[84] The general schema is $A^B \equiv (B \mathbin{\backslash\!\!\backslash} S) \mathbin{/\!\!/} (A \mathbin{\backslash\!\!\backslash} (B \mathbin{\backslash\!\!\backslash} S))$ (Barker and Shan 2014, (246)), though in these examples $A = B$.

[85] Where VP abbreviates $DP \backslash S$.

movement to LF for type-interpretability reasons. I've shown that the formalism described by Barker and Shan is capable of handling the difficulties posed by comparatives when supplemented by a few continuation-sensitive operators which I introduced. This is the case whether one prefers a theory of comparatives that is quantificational (Heim 2000, 2006) or not (Schwarzschild and Wilkinson 2002), based on intervals or degrees, as demonstrated here. I've shown that a continuation-analysis implementation can also handle the non-upward entailing differentials highlighted by Fleisher (2015). I've also highlighted some other ongoing debates in the comparatives literature, such as the nature of comparative deletion and the comparative's relation to the superlative, and while I wasn't able to solve them, at least shown that a continuation analysis can handle the currently-visible possible outcomes of those debates. I've also explored the structures of standard comparatives in two non-English languages, Hebrew and Japanese, showing how their variations in comparative constructions make use of continuations (or don't, but don't pose challenges to this project in not doing so).

Appendix

A derivation of the unattested wide-scope degree interpretation of *Mary is six inches taller than every boy is tall*

```
edge      : 639 mary is sixinches tall erthan every boy is ?d tall   (0 10)  t
semantics : (max (^ d (^ x (height x >= d))) m >= (max (^ r (forall z ((^ x (boy x)) z -->
(^ r1 (height r1 >= r)) z)))) + sixinches)
proofnet  : ((1 . t) (mary (2 . e)) (is (((2 . e) \ (1 . t)) / ((3 . e) \ (4 . t))))
(sixinches d) (tall (d \ ((5 . e) \ (6 . t)))) (erthan ((d \ ((5 . e) \ (6 . t))) \ ((d \
((3 . e) \ (4 . t))) / d))) (every (((7 . t) // ((8 . e) \\ (9 . t))) / ((10 . e) \ (11 .
t)))) (boy ((10 . e) \ (11 . t))) (is (((8 . e) \ (12 . t)) / ((13 . e) \ (14 . t)))) (?d
(d // (d \\ (15 . t)))) (tall (d \ ((13 . e) \ (14 . t)))))
derivation: ((L mary) (is ((L sixinches) ((tall erthan) (D ((S (U D)) ((S (U (S ((S (U L))
(every boy))))) ((S (U (S (U is)))) ((S (U U)) ((S ((S (U L)) ?d)) (U tall)))))))))))

mary is sixinches tall erthan every boy is ?d tall t = (max (^ d (^ x (height x >= d))) m
>= (max (^ r (forall z ((^ x (boy x)) z --> (^ r1 (height r1 >= r)) z)))) + sixinches)
  mary (1 / (e \ 1)) = (^ f (f m))
    L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
    mary e = m
  is sixinches tall erthan every boy is ?d tall (e \ t) = (^ e (max (^ d (^ x (height x >=
  d))) e >= (max (^ r (forall z ((^ x (boy x)) z --> (^ r1 (height r1 >= r)) z)))) +
  sixinches))
    is ((e \ t) / (e \ t)) = (^ k k)
    sixinches tall erthan every boy is ?d tall (e \ t) = (^ e (max (^ d (^ x (height x >=
    d))) e >= (max (^ r (forall z ((^ x (boy x)) z --> (^ r1 (height r1 >= r)) z)))) +
    sixinches))
      sixinches (1 / (d \ 1)) = (^ f (f sixinches))
        L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
        sixinches d = sixinches
      tall erthan every boy is ?d tall (d \ (e \ t)) = (^ D (^ e (max (^ d (^ x (height x
      >= d))) e >= (max (^ r (forall z ((^ x (boy x)) z --> (^ r1 (height r1 >= r)) z)))) +
      D)))
        tall erthan ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >= d))) e
        >= d + D))))
          tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
          erthan ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e >= d
          + D)))))
        every boy is ?d tall d = (max (^ r (forall z ((^ x (boy x)) z --> (^ r1 (height r1
        >= r)) z))))
          D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
          every boy is ?d tall (d // (t \\ t)) = (^ c (max (^ r (c (forall z ((^ x (boy x))
          z --> (^ r1 (height r1 >= r)) z))))))
            RULE ((1 // (2 \\ 3)) / (1 // ((2 // (t \\ t)) \\ 3))) = (^ R (^ c (R (^ r (c
            (r (^ x x)))))))
              S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R
              (^ c (L (^ l (R (^ r (c (l r)))))))))
              RULE (1 // ((2 / (2 // (t \\ t))) \\ 1)) = (^ f (f (^ k (k (^ x x)))))
                U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
```

```
  D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
every boy is ?d tall (d // ((t // (t \\ t)) \\ t)) = (^ c (max (^ r (c (^ c (forall z ((^ x (boy x)) z --> (^ r1 (c (height r1 >= r))) z)))))))
 every boy ((1 // ((t // (2 \\ 3)) \\ 4)) / (1 // ((t // ((e \ 2) \\ 3)) \\ 4))) = (^ R (^ c (R (^ r (c (^ c (forall z ((^ x (boy x)) z --> (^ r1 (r (^ r2 (c (r2 r1))))) z))))))))
  S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
  every boy (1 // (((t // (2 \\ 3)) / (t // ((e \ 2) \\ 3))) \\ 1)) = (^ f (f (^ R (^ c (forall z ((^ x (boy x)) z --> (^ r (R (^ r1 (c (r1 r))))) z))))))
   U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
   every boy ((t // (1 \\ 2)) / (t // ((e \ 1) \\ 2))) = (^ R (^ c (forall z ((^ x (boy x)) z --> (^ r (R (^ r1 (c (r1 r))))) z))))
    S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
    every boy (t // ((1 / (e \ 1)) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ f (f r)))) z)))
     RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^ f (f r)))))))
      S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
      RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
       U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
       L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
     every boy (t // (e \\ t)) = (^ k (forall z ((^ x (boy x)) z --> k z)))
      every ((t // (e \\ t)) / (e \ t)) = (^ x (^ k (forall z (x z --> k z))))
      boy (e \ t) = (^ x (boy x))
 is ?d tall (d // ((1 // ((e \ t) \\ 1)) \\ t)) = (^ c (max (^ r (c (^ c (c (^ x (height x >= r))))))))
  is ((1 // ((2 // ((e \ t) \\ 3)) \\ 4)) / (1 // ((2 // ((e \ t) \\ 3)) \\ 4))) = (^ R (^ c (R (^ r (c (^ c (r (^ r (c r)))))))))
   S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
   is (1 // (((2 // ((e \ t) \\ 3)) / (2 // ((e \ t) \\ 3))) \\ 1)) = (^ f (f (^ R (^ c (R (^ r (c r)))))))
    U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
    is ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c r)))))
     S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
     is (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
      U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
      is ((e \ t) / (e \ t)) = (^ k k)
  ?d tall (d // ((1 // ((e \ t) \\ 1)) \\ t)) = (^ c (max (^ r (c (^ f (f (^ x (height x >= r))))))))
   RULE ((1 // ((2 // (3 \\ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^ f (f r)))))))
    S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
    RULE (1 // (((2 // (3 \\ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
     U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
     U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
   ?d tall (d // ((e \ t) \\ t)) = (^ c (max (^ r (c (^ x (height x >= r))))))
    ?d ((d // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c (max (^ r (R (^ r1 (c (r1 r))))))))
     S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
     ?d (d // ((1 / (d \ 1)) \\ t)) = (^ c (max (^ r (c (^ f (f r))))))
      RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^ f (f r)))))))
       S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
       RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
        L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
```

```
                  ?d (d // (d \\ t)) = (^ k (max k))
               tall (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ d (^ x (height x >= d)))))
                U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
```

A derivation of the attested wide-scope universal interpretation of *Mary is six inches taller than every boy is tall*

```
edge      : 647 mary is sixinches tall erthan every boy is ?d tall   (0 10)  t
semantics : (forall z ((^ x (boy x)) z --> (^ r (max (^ d (^ x (height x >= d))) m >= (max (^ r1 (height r >= r1))) + sixinches)) z))
proofnet  : ((1 . t) (mary (2 . e)) (is (((2 . e) \ (3 . t)) / ((4 . e) \ (5 . t)))) (sixinches d) (tall (d \ ((6 . e) \ (7 . t)))) (erthan 2 ((d \ ((6 . e) \ (7 . t))) \ ((d \ ((4 . e) \ (5 . t))) / d))) (every (((1 . t) // ((8 . e) \\ (9 . t))) / ((10 . e) \ (11 . t)))) (boy ((10 . e) \ (11 . t))) (is (((8 . e) \ (12 . t)) / ((13 . e) \ (14 . t)))) (?d (d // (d \\ (15 . t)))) (tall (d \ ((13 . e) \ (14 . t)))))
derivation: (D ((S (U (L mary))) ((S (U is)) ((S (U (L sixinches))) ((S (U (tall erthan))) ((S (U D)) ((S ((S (U S)) ((S (U U)) ((S (U L)) (every boy))))) ((S (U (S (U is)))) (U ((S ((S (U L)) ?d)) (U tall))))))))))))

mary is sixinches tall erthan every boy is ?d tall t = (forall z ((^ x (boy x)) z --> (^ r (max (^ d (^ x (height x >= d))) m >= (max (^ r1 (height r >= r1))) + sixinches)) z))
 D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
  mary is sixinches tall erthan every boy is ?d tall (t // (t \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (max (^ d (^ x (height x >= d))) m >= (max (^ r1 (height r >= r1))) + sixinches))) z)))
   mary ((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r m))))))
    S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
    mary (1 // ((2 / (e \ 2)) \\ 1)) = (^ f (f (^ f (f m))))
     U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
     mary (1 / (e \ 1)) = (^ f (f m))
      L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
      mary e = m
   is sixinches tall erthan every boy is ?d tall (t // ((e \ t) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ e (max (^ d (^ x (height x >= d))) e >= (max (^ r1 (height r >= r1))) + sixinches)))) z)))
    is ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c r)))))
     S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
     is (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
      U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
      is ((e \ t) / (e \ t)) = (^ k k)
    sixinches tall erthan every boy is ?d tall (t // ((e \ t) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ e (max (^ d (^ x (height x >= d))) e >= (max (^ r1 (height r >= r1))) + sixinches)))) z)))
     sixinches ((1 // (2 \\ 3)) / (1 // ((d \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r sixinches))))))
      S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
      sixinches (1 // ((2 / (d \ 2)) \\ 1)) = (^ f (f (^ f (f sixinches))))
       U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
       sixinches (1 / (d \ 1)) = (^ f (f sixinches))
        L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
        sixinches d = sixinches
     tall erthan every boy is ?d tall (t // ((d \ (e \ t)) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ D (^ e (max (^ d (^ x (height x >= d))) e >= (max (^ r1 (height r >= r1))) + D))))) z)))
      tall erthan ((1 // ((d \ (e \ t)) \\ 2)) / (1 // (d \\ 2))) = (^ R (^ c (R (^ r (c (^ D (^ e (max (^ d (^ x (height x >= d))) e >= r + D))))))))
       S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
```

```
33      tall erthan (1 // (((d \ (e \ t)) / d) \\ 1)) = (^ f (f (^ d (^ D (^ e (max (^ d (^ x (height x >= d))) e >= d + D))))))
34        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
35        tall erthan ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >= d))) e >= d + D))))
36          tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
37          erthan ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e >= d + D)))))
38    every boy is ?d tall (t // (d \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (max (^ r1 (height r >= r1))))) z)))
39      RULE ((1 // (2 \\ 3)) / (1 // ((2 // (t \\ t)) \\ 3))) = (^ R (^ c (R (^ r (c (r (^ x x)))))))
40        S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
41        RULE (1 // ((2 / (2 // (t \\ t))) \\ 1)) = (^ f (f (^ k (k (^ x x)))))
42          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
43          D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
44      every boy is ?d tall (t // ((d // (t \\ t)) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ c (max (^ r1 (c (height r >= r1))))))) z)))
45        every boy ((t // ((1 // (2 \\ 3)) \\ 4)) / (t // ((1 // ((e \ 2) \\ 3)) \\ 4))) = (^ R (^ c (forall z ((^ x (boy x)) z --> (^ r (R (^ r1 (c (^ c (r1 (^ r1 (c (r1 r))))))))) z))))
46          S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
47          every boy (t // (((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ R (^ c (R (^ r1 (c (r1 r)))))))) z)))
48            RULE ((1 // (((2 // (3 \\ 4)) / (5 // (6 \\ 4))) \\ 7)) / (1 // ((2 // ((3 / 6) \\ 5)) \\ 7))) = (^ R (^ c (R (^ r (c (^ R (^ c (r (^ l (R (^ r (c (l r)))))))))))))
49              S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
50              RULE (1 // ((((2 // (3 \\ 4)) / (5 // (6 \\ 4))) / (2 // ((3 / 6) \\ 5))) \\ 1)) = (^ f (f (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))))
51                U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
52                S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
53            every boy (t // ((1 // ((2 / (e \ 2)) \\ 1)) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ f (f (^ f (f r)))))) z)))
54              RULE ((1 // ((2 // (3 \\ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^ f (f r)))))))
55                S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
56                RULE (1 // (((2 // (3 \\ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
57                  U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
58                  U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
59              every boy (t // ((1 / (e \ 1)) \\ t)) = (^ c (forall z ((^ x (boy x)) z --> (^ r (c (^ f (f r)))) z)))
60                RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^ f (f r)))))))
61                  S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
62                  RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
63                    U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
64                    L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
65                every boy (t // (e \\ t)) = (^ k (forall z ((^ x (boy x)) z --> k z)))
66                  every ((t // (e \\ t)) / (e \ t)) = (^ x (^ k (forall z (x z --> k z))))
67                  boy (e \ t) = (^ x (boy x))
68        is ?d tall (1 // ((d // ((e \ t) \\ t)) \\ 1)) = (^ c (c (^ c (max (^ r (c (^ x (height x >= r))))))))
69          is ((1 // ((2 // ((e \ t) \\ 3)) \\ 4)) / (1 // ((2 // ((e \ t) \\ 3)) \\ 4))) = (^ R (^ c (R (^ r (c (^ c (r (^ r (c r))))
```

```
                                              )))))
                          S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^
                          R (^ c (L (^ l (R (^ r (c (l r)))))))))
                          is (1 // (((2 // ((e \ t) \\ 3)) / (2 // ((e \ t) \\ 3))) \\ 1)) = (^ f
                          (f (^ R (^ c (R (^ r (c r)))))))
                            U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                            is ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r
                            (c r)))))
                              S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^
                              L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
                              is (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
                                U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                                is ((e \ t) / (e \ t)) = (^ k k)
                        ?d tall (1 // ((d // ((e \ t) \\ t)) \\ 1)) = (^ f (f (^ c (max (^ r (c (^
                        x (height x >= r))))))))
                          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                          ?d tall (d // ((e \ t) \\ t)) = (^ c (max (^ r (c (^ x (height x >=
                          r))))))
                            ?d ((d // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c (max (^ r (R
                            (^ r1 (c (r1 r))))))))
                              S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^
                              L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
                              ?d (d // ((1 / (d \ 1)) \\ t)) = (^ c (max (^ r (c (^ f (f r))))))
                                RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R
                                (^ r (c (^ f (f r)))))))
                                  S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) =
                                  (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
                                  RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f
                                  x)))))
                                    U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                                    L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
                                ?d (d // (d \\ t)) = (^ k (max k))
                            tall (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ d (^ x (height x >= d)))))
                              U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                              tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
```

A derivation of *John is exactly one inch taller than six feet*

```
edge       : 4133 john iss exactly oneinch ?d2 tall erthan2 sixfeet      (0 8)   t
semantics  : ((^ r (max (^ d (^ x (height x >= d))) j >= sixfeet + r)) = oneinch)
proofnet   : ((1 . t) (john (2 . e)) (iss (((2 . e) \ (3 . t)) / ((4 . e) \ (5 . t))))
(exactly ((d \ (6 . t)) / d)) (oneinch d) (?d2 ((d \ (6 . t)) \ ((1 . t) // (d \\ (7 .
t))))) (tall (d \ ((8 . e) \ (9 . t)))) (erthan2 ((d \ ((8 . e) \ (9 . t))) \ ((d \ ((4 .
e) \ (5 . t))) / d))) (sixfeet d))
derivation: (D ((S (U (L john))) ((S (U iss)) ((S ((S (U L)) ((exactly oneinch) ?d2))) (U
((tall erthan2) sixfeet))))))

john iss exactly oneinch ?d2 tall erthan2 sixfeet t = ((^ r (max (^ d (^ x (height x >=
d))) j >= sixfeet + r)) = oneinch)
  D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
  john iss exactly oneinch ?d2 tall erthan2 sixfeet (t // (t \\ t)) = (^ c ((^ r (c (max (^
  d (^ x (height x >= d))) j >= sixfeet + r))) = oneinch))
    john ((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r j))))))
      S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
      (^ l (R (^ r (c (l r)))))))))
      john (1 // ((2 / (e \ 2)) \\ 1)) = (^ f (f (^ f (f j))))
        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
        john (1 / (e \ 1)) = (^ f (f j))
          L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
          john e = j
    iss exactly oneinch ?d2 tall erthan2 sixfeet (t // ((e \ t) \\ t)) = (^ c ((^ r (c (^ e
    (max (^ d (^ x (height x >= d))) e >= sixfeet + r)))) = oneinch))
      iss ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c r)))))
        S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
        (^ l (R (^ r (c (l r)))))))))
        iss (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
```

```
          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
          iss ((e \ t) / (e \ t)) = (^ k k)
      exactly oneinch ?d2 tall erthan2 sixfeet (t // ((e \ t) \\ t)) = (^ c ((^ r (c (^ e
      (max (^ d (^ x (height x >= d))) e >= sixfeet + r)))) = oneinch))
        exactly oneinch ?d2 ((t // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c ((^ r (R
        (^ r1 (c (r1 r))))) = oneinch)))
          S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c
          (L (^ l (R (^ r (c (l r)))))))))
          exactly oneinch ?d2 (t // ((1 / (d \ 1)) \\ t)) = (^ c ((^ r (c (^ f (f r)))) =
          oneinch))
            RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^
            f (f r)))))))
              S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R
              (^ c (L (^ l (R (^ r (c (l r)))))))))
              RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
                U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
            exactly oneinch ?d2 (t // (d \\ t)) = (^ k (k = oneinch))
              exactly oneinch (d \ t) = (^ k (k = oneinch))
                exactly ((d \ t) / d) = (^ d (^ k (k = d)))
                oneinch d = oneinch
              ?d2 ((d \ t) \ (t // (d \\ t))) = (^ k k)
        tall erthan2 sixfeet (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ D (^ e (max (^ d (^ x
        (height x >= d))) e >= sixfeet + D)))))
          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
          tall erthan2 sixfeet (d \ (e \ t)) = (^ D (^ e (max (^ d (^ x (height x >= d))) e
          >= sixfeet + D)))
            tall erthan2 ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >=
            d))) e >= d + D))))
              tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
              erthan2 ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e
              >= d + D)))))
            sixfeet d = sixfeet
```

A derivation of *John is less than one inch taller than six feet*

```
edge      : 4133 john iss lessthan oneinch ?d2 tall erthan2 sixfeet    (0 8)   t
semantics : ((^ r (max (^ d (^ x (height x >= d))) j >= sixfeet + r)) < oneinch)
proofnet  : ((1 . t) (john (2 . e)) (iss (((2 . e) \ (3 . t)) / ((4 . e) \ (5 . t))))
(lessthan ((d \ (6 . t)) / d)) (oneinch d) (?d2 ((d \ (6 . t)) \ ((1 . t) // (d \\ (7 .
t))))) (tall (d \ ((8 . e) \ (9 . t)))) (erthan2 ((d \ ((8 . e) \ (9 . t))) \ ((d \ ((4 .
e) \ (5 . t))) / d))) (sixfeet d))
derivation: (D ((S (U (L john))) ((S (U iss)) ((S ((S (U L)) ((lessthan oneinch) ?d2))) (U
((tall erthan2) sixfeet))))))

john iss lessthan oneinch ?d2 tall erthan2 sixfeet t = ((^ r (max (^ d (^ x (height x >=
d))) j >= sixfeet + r)) < oneinch)
  D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
  john iss lessthan oneinch ?d2 tall erthan2 sixfeet (t // (t \\ t)) = (^ c ((^ r (c (max
  (^ d (^ x (height x >= d))) j >= sixfeet + r))) < oneinch))
    john ((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r j))))))
      S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
      (^ l (R (^ r (c (l r)))))))))
      john (1 // ((2 / (e \ 2)) \\ 1)) = (^ f (f (^ f (f j))))
        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
        john (1 / (e \ 1)) = (^ f (f j))
          L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
          john e = j
    iss lessthan oneinch ?d2 tall erthan2 sixfeet (t // ((e \ t) \\ t)) = (^ c ((^ r (c (^
    e (max (^ d (^ x (height x >= d))) e >= sixfeet + r)))) < oneinch))
      iss ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c r)))))
        S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
        (^ l (R (^ r (c (l r)))))))))
        iss (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
          iss ((e \ t) / (e \ t)) = (^ k k)
```

```
      lessthan oneinch ?d2 tall erthan2 sixfeet (t // ((e \ t) \\ t)) = (^ c ((^ r (c (^ e
      (max (^ d (^ x (height x >= d))) e >= sixfeet + r)))) < oneinch))
        lessthan oneinch ?d2 ((t // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c ((^ r (R
        (^ r1 (c (r1 r))))) < oneinch)))
          S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c
          (L (^ l (R (^ r (c (l r)))))))))
          lessthan oneinch ?d2 (t // ((1 / (d \ 1)) \\ t)) = (^ c ((^ r (c (^ f (f r)))) <
          oneinch))
            RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^
            f (f r)))))))
              S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R
              (^ c (L (^ l (R (^ r (c (l r)))))))))
              RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (^ x (^ f (f x)))))
                U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
                L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
            lessthan oneinch ?d2 (t // (d \\ t)) = (^ k (k < oneinch))
              lessthan oneinch (d \ t) = (^ k (k < oneinch))
                lessthan ((d \ t) / d) = (^ d (^ k (k < d)))
                oneinch d = oneinch
              ?d2 ((d \ t) \ (t // (d \\ t))) = (^ k k)
        tall erthan2 sixfeet (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ D (^ e (max (^ d (^ x
        (height x >= d))) e >= sixfeet + D)))))
          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
          tall erthan2 sixfeet (d \ (e \ t)) = (^ D (^ e (max (^ d (^ x (height x >= d))) e
          >= sixfeet + D)))
            tall erthan2 ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >=
            d))) e >= d + D))))
              tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
              erthan2 ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e
              >= d + D)))))
            sixfeet d = sixfeet
```

A derivation of *John is more than one inch taller than six feet*

```
edge      : 4133 john iss morethan oneinch ?d2 tall erthan2 sixfeet     (0 8)    t
semantics : ((^ r (max (^ d (^ x (height x >= d))) j >= sixfeet + r)) > oneinch)
proofnet  : ((1 . t) (john (2 . e)) (iss (((2 . e) \ (3 . t)) / ((4 . e) \ (5 . t))))
(morethan ((d \ (6 . t)) / d)) (oneinch d) (?d2 ((d \ (6 . t)) \ ((1 . t) // (d \\ (7 .
t))))) (tall (d \ ((8 . e) \ (9 . t)))) (erthan2 ((d \ ((8 . e) \ (9 . t))) \ ((d \ ((4 .
e) \ (5 . t))) / d))) (sixfeet d))
derivation: (D ((S (U (L john))) ((S (U iss)) ((S ((S (U L)) ((morethan oneinch) ?d2))) (U
((tall erthan2) sixfeet))))))

john iss morethan oneinch ?d2 tall erthan2 sixfeet t = ((^ r (max (^ d (^ x (height x >=
d))) j >= sixfeet + r)) > oneinch)
  D (1 / (1 // (t \\ t))) = (^ k (k (^ x x)))
  john iss morethan oneinch ?d2 tall erthan2 sixfeet (t // (t \\ t)) = (^ c ((^ r (c (max
  (^ d (^ x (height x >= d))) j >= sixfeet + r))) > oneinch))
    john ((1 // (2 \\ 3)) / (1 // ((e \ 2) \\ 3))) = (^ R (^ c (R (^ r (c (r j))))))
      S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
      (^ l (R (^ r (c (l r)))))))))
      john (1 // ((2 / (e \ 2)) \\ 1)) = (^ f (f (^ f (f j))))
        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
        john (1 / (e \ 1)) = (^ f (f j))
          L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
          john e = j
    iss morethan oneinch ?d2 tall erthan2 sixfeet (t // ((e \ t) \\ t)) = (^ c ((^ r (c (^
    e (max (^ d (^ x (height x >= d))) e >= sixfeet + r)))) > oneinch))
      iss ((1 // ((e \ t) \\ 2)) / (1 // ((e \ t) \\ 2))) = (^ R (^ c (R (^ r (c r)))))
        S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L
        (^ l (R (^ r (c (l r)))))))))
        iss (1 // (((e \ t) / (e \ t)) \\ 1)) = (^ f (f (^ k k)))
          U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
          iss ((e \ t) / (e \ t)) = (^ k k)
      morethan oneinch ?d2 tall erthan2 sixfeet (t // ((e \ t) \\ t)) = (^ c ((^ r (c (^ e
      (max (^ d (^ x (height x >= d))) e >= sixfeet + r)))) > oneinch))
```

```
morethan oneinch ?d2 ((t // (1 \\ 2)) / (t // ((d \ 1) \\ 2))) = (^ R (^ c ((^ r (R (^ r1 (c (r1 r))))) > oneinch)))
  S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
  morethan oneinch ?d2 (t // ((1 / (d \ 1)) \\ t)) = (^ c ((^ r (c (^ f (f r)))) > oneinch))
    RULE ((1 // ((2 / (3 \ 2)) \\ 4)) / (1 // (3 \\ 4))) = (^ R (^ c (R (^ r (c (^ f (f r)))))))
      S (((4 // (2 \\ 5)) / (3 // (1 \\ 5))) / (4 // ((2 / 1) \\ 3))) = (^ L (^ R (^ c (L (^ l (R (^ r (c (l r)))))))))
      RULE (1 // (((2 / (3 \ 2)) / 3) \\ 1)) = (^ f (f (f (^ x (^ f (f x))))))
        U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
        L ((2 / (1 \ 2)) / 1) = (^ x (^ f (f x)))
    morethan oneinch ?d2 (t // (d \\ t)) = (^ k (k > oneinch))
      morethan oneinch (d \ t) = (^ k (k > oneinch))
        morethan ((d \ t) / d) = (^ d (^ k (k > d)))
        oneinch d = oneinch
      ?d2 ((d \ t) \ (t // (d \\ t))) = (^ k k)
tall erthan2 sixfeet (1 // ((d \ (e \ t)) \\ 1)) = (^ f (f (^ D (^ e (max (^ d (^ x (height x >= d))) e >= sixfeet + D)))))
  U ((2 // (1 \\ 2)) / 1) = (^ x (^ f (f x)))
  tall erthan2 sixfeet (d \ (e \ t)) = (^ D (^ e (max (^ d (^ x (height x >= d))) e >= sixfeet + D)))
    tall erthan2 ((d \ (e \ t)) / d) = (^ d (^ D (^ e (max (^ d (^ x (height x >= d))) e >= d + D))))
      tall (d \ (e \ t)) = (^ d (^ x (height x >= d)))
      erthan2 ((d \ (e \ t)) \ ((d \ (e \ t)) / d)) = (^ A (^ d (^ D (^ e (max A e >= d + D)))))
    sixfeet d = sixfeet
```

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