A modular theory of pronouns and binding

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LENLS 14, University of Tsukuba, Tokyo November 14, 2017

Overview

Today: a brief on the power of **abstraction** and **modularity** in semantic theorizing, with a focus on pronouns and the grammatical mechanisms for dealing with them.

Semanticists tend to respond to things beyond the Fregean pale by lexically and compositionally generalizing to the worst case. One-size-fits-all.

Functional programmers instead look for repeated patterns, and abstract those out as separate, modular pieces (functions). When we do semantics, this strategy has conceptual and especially empirical virtues.

The standard theory, and its discontents

A baseline semantic theory

Meanings are individuals, propositions, or functions from meanings to meanings:

$$\tau ::= e \mid t \mid \underbrace{\tau \rightarrow \tau}_{e \rightarrow t,\ (e \rightarrow t) \rightarrow t,\ \ldots}$$

Binary-branching nodes are interpreted via (type-driven) functional application:

$$[\![\alpha\ \beta]\!] := [\![\alpha]\!][\![\beta]\!] \text{ or } [\![\beta]\!][\![\alpha]\!], \text{ whichever is defined}$$

Pronouns and binding

This picture is awesome. But a lot of important stuff doesn't fit neatly in it.

Our focus today: (free and bound) *pronouns* — how are they valued, and what ramifications does the need to value them have for the rest of the grammar?

1. John saw her$_i$.
2. Every philosopher$_i$ thinks they$_i$'re a genius.

Standardly: extending the baseline theory with assignments

Denotations uniformly **depend on assignments** (ways of valuing free variables):

$$\tau_\circ ::= e \mid t \mid \tau_\circ \to \tau_\circ \qquad \tau ::= \underbrace{g \to \tau_\circ}_{g\to e\to t,\ g\to(e\to t)\to t,\ \ldots}$$

Interpret binary combination via **assignment-sensitive** functional application:

$$[\![\alpha\ \beta]\!] := \lambda g.[\![\alpha]\!]g([\![\beta]\!]g) \text{ or } [\![\beta]\!]g([\![\alpha]\!]g), \text{ whichever is defined}$$

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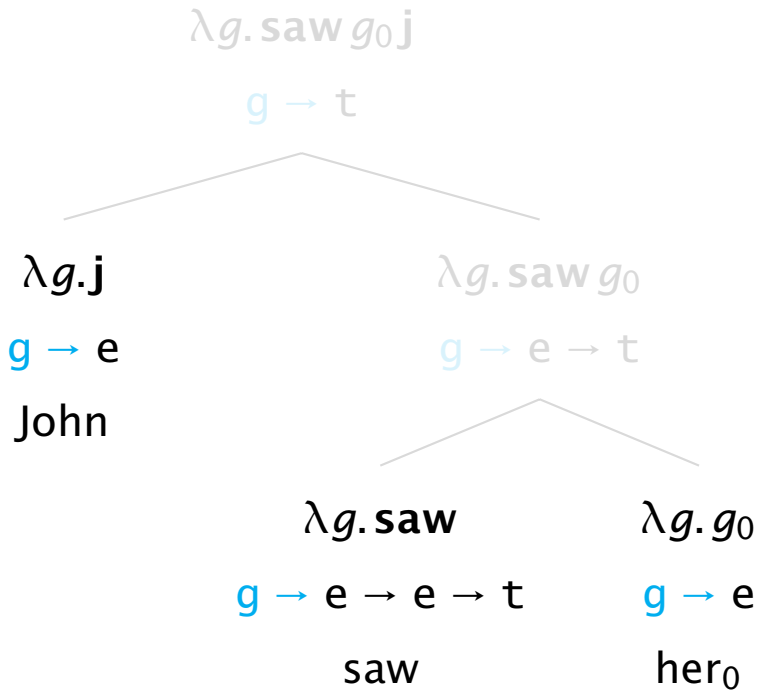

[Apply the result to a contextually furnished assignment to get a proposition.]

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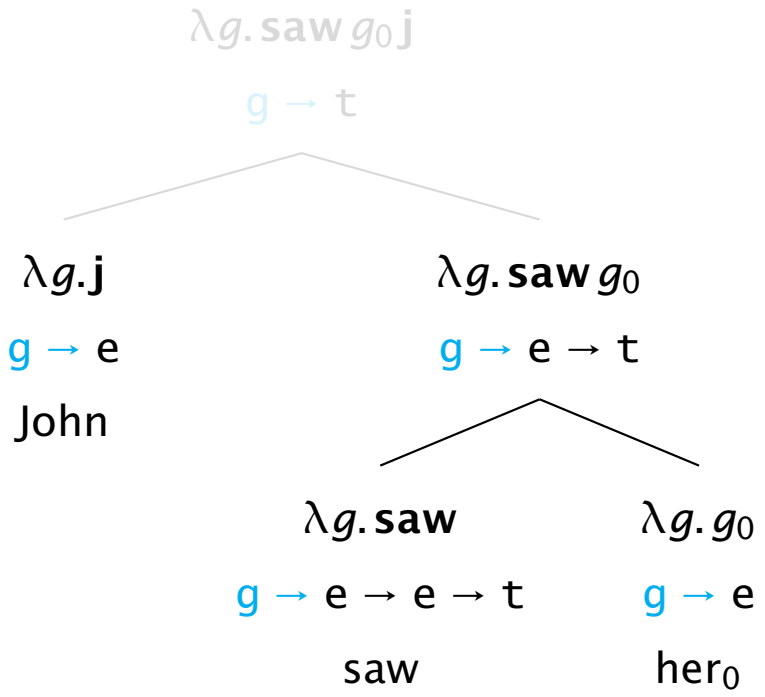

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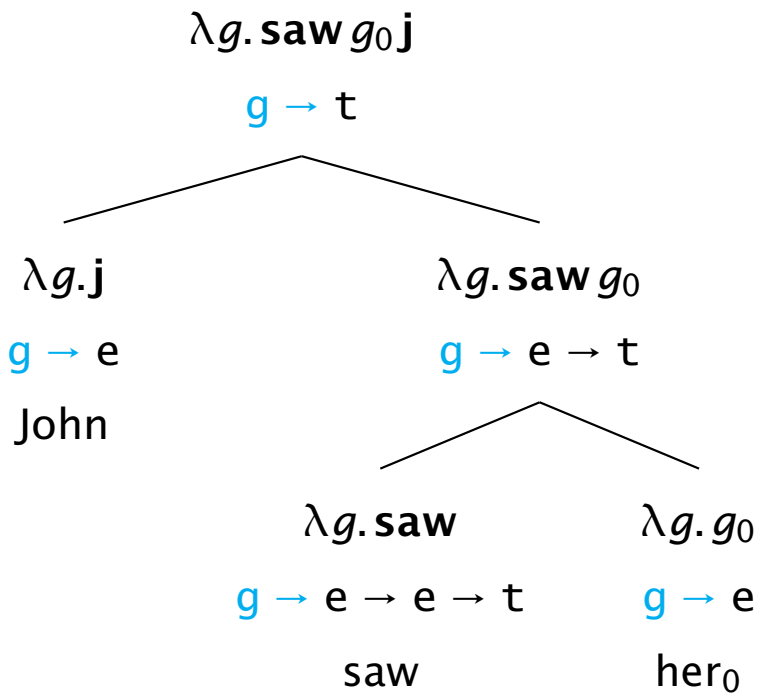

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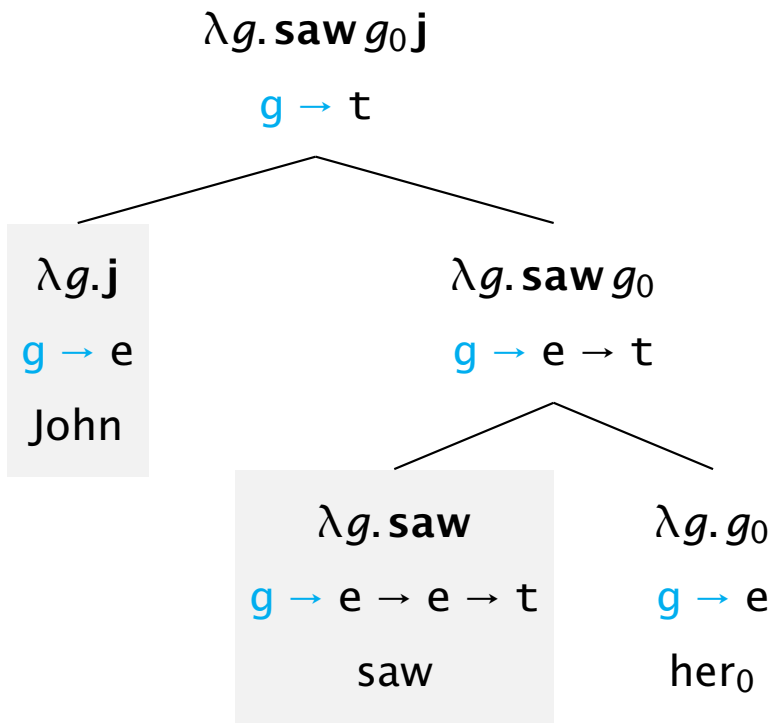
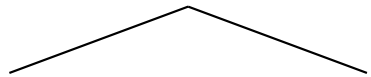
Complicating the lexicon: Nonprominals



Complicating the grammar: Abstraction

$$\lambda g.\, f\, g\, (\textbf{left}\, g_0) = \lambda g.\, \lambda x.\, \textbf{left}\, x$$

$g \rightarrow e \rightarrow t$



f	$\lambda g.\, \textbf{left}\, g_0$
$g \rightarrow t \rightarrow e \rightarrow t$	$g \rightarrow t$
Λ^0	t_0 left

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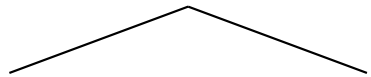

f	$\lambda g.\, \textbf{left}\, g_0$
$\mathtt{g} \to \mathtt{t} \to \mathtt{e} \to \mathtt{t}$	$\mathtt{g} \to \mathtt{t}$
Λ^0	$\mathtt{t}_0$ left

No f works in the general case...

The grammar wants to interpret both branches at *the same assignment*, but the right node must be interpreted at *a shifted assignment*:

$$\underbrace{[\![\Lambda^i\ \alpha]\!]}_{\text{extending } [\![\cdot]\!] \text{ with a syncategorematic rule}} := \lambda g.\lambda x.\, [\![\alpha]\!]\, g^{i \to x}$$

Under-generation: (binding) reconstruction

It is well known that (quantificational) binding does not require surface c-command (e.g., Sternefeld 1998, 2001, Barker 2012):

1. Which of their$_i$ relatives does everyone$_i$ like _?
2. His$_i$ mom, every boy$_i$ likes _.
3. Their advisor$_i$ seems to every Ph.D. student$_i$ _ to be a genius.
4. Unless he$_i$'s been a bandit, no man$_i$ can be an officer _.

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But Predicate Abstraction passes modified assignments *down the tree*, and so binding invariably requires (LF) c-command. Scoping the quantifier over the pronoun restores LF c-command, but should trigger a Weak Crossover violation:

5. *Who$_i$ does his$_i$ mother like _?
6. *His$_i$ superior reprimanded no officer$_i$.

Under-generation: paycheck pronouns

Simple pronouns anaphoric to expressions containing pronouns can receive "sloppy" readings (e.g., Cooper 1979, Engdahl 1986, Jacobson 2000):

1. John$_i$ deposited [his$_i$ paycheck]$_j$, but Bill$_k$ spent it$_j$.
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These are unaccounted for on the standard picture. There are two (related) issues:

a. The paycheck pronoun's meaning is different from the thing it's anaphoric to.

b. How does the $\__k$ "bind into" something with a different index?

Roadmap

The theoretical baggage associated with the standard account is straightforward and cheap to dispense with, via something called an **applicative functor**.

The empirical baggage seems to require an additional piece for dealing with *higher-order meanings*. This upgrades the applicative functor into a **monad**.

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- Time permitting, I'll deflate monads a bit, at least for pronouns. :)

Getting modular

Abstracting out and modularizing the standard account's key parts

In lieu of treating everything as trivially dependent on an assignment, invoke a function ρ which turns any x into a constant function from assignments into x:

$$\rho := \underbrace{\lambda x.\lambda g.x}_{a \to g \to a}$$

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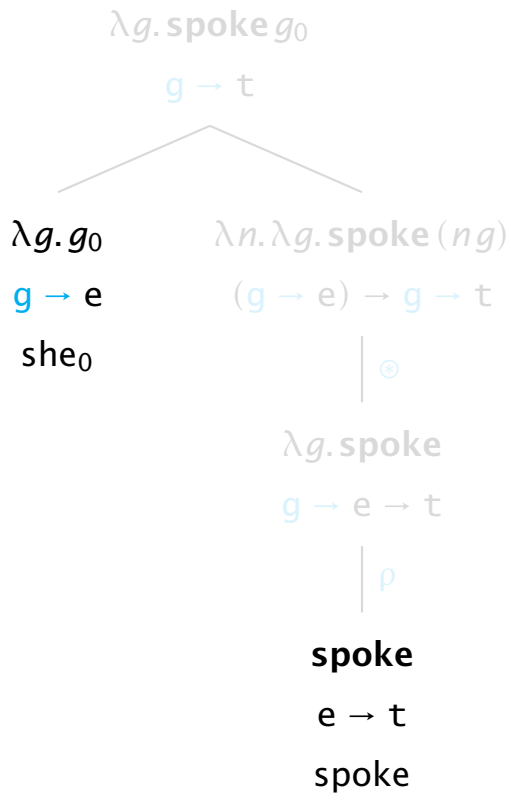
$$\rho := \underbrace{\lambda x.\lambda g.x}_{a \to \mathsf{g} \to a}$$

Instead of taking on $[\![\cdot]\!]$ wholesale, we'll help ourselves to a function $\circledast$ which allows us to perform assignment-friendly function application on demand:

$$\circledast := \underbrace{\lambda m.\lambda n.\lambda g.mg(ng)}_{(\mathsf{g} \to a \to b) \to (\mathsf{g} \to a) \to \mathsf{g} \to b}$$

Sample derivations



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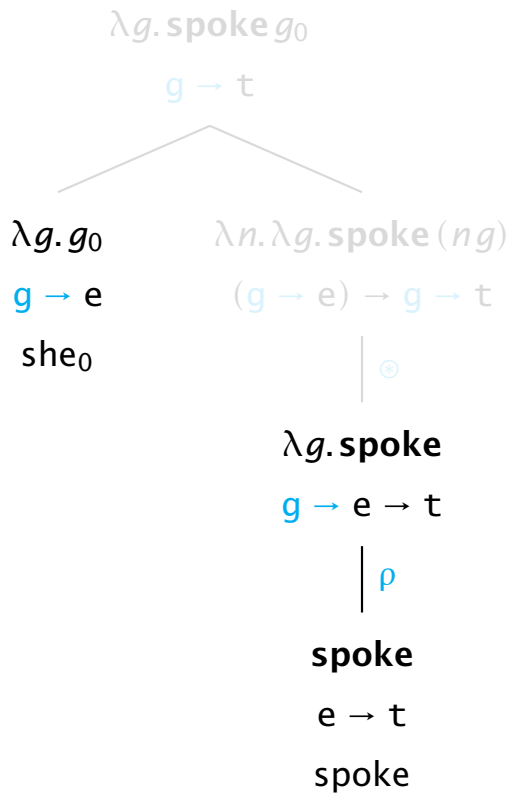

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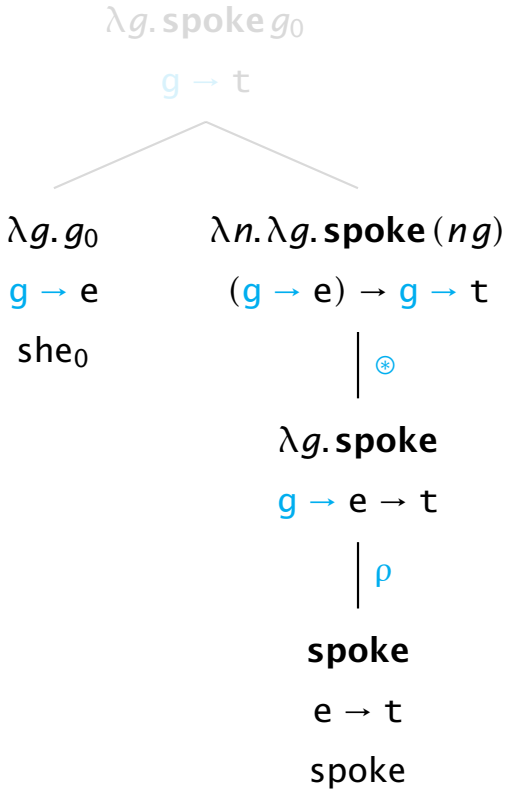

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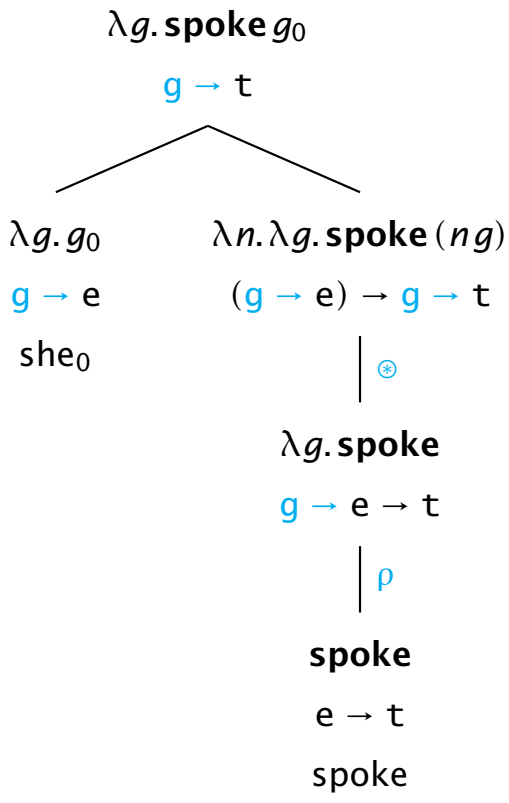

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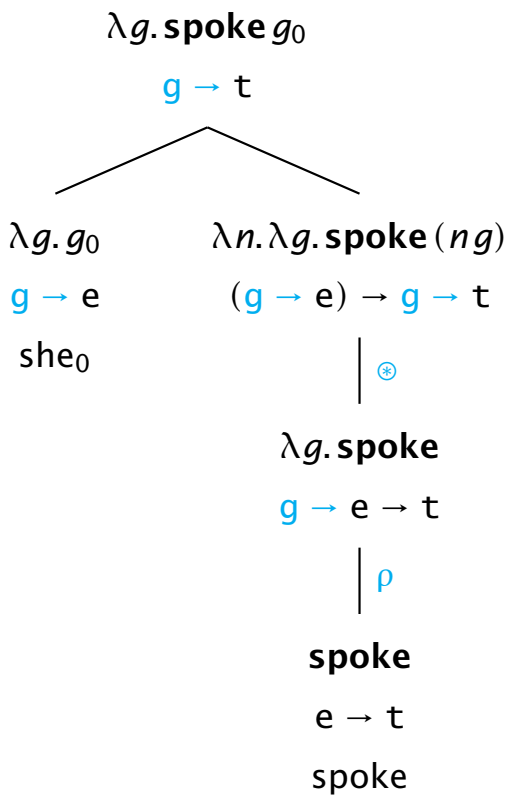

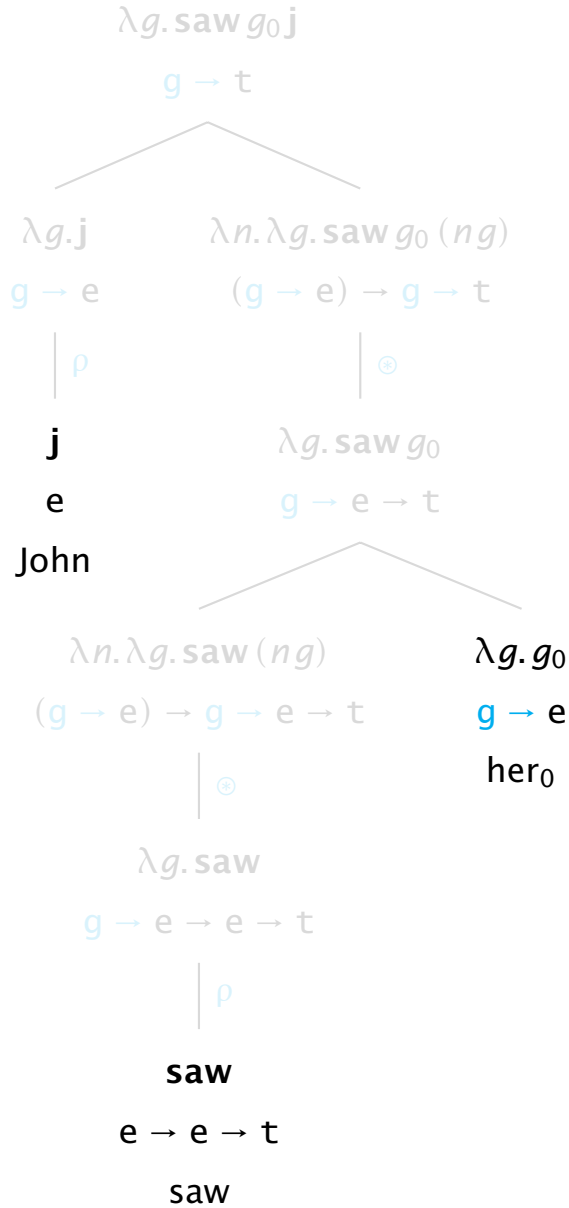

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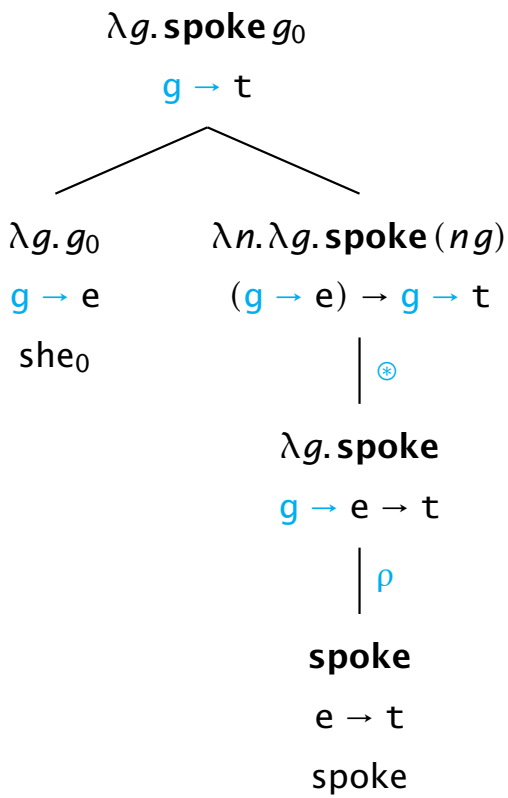

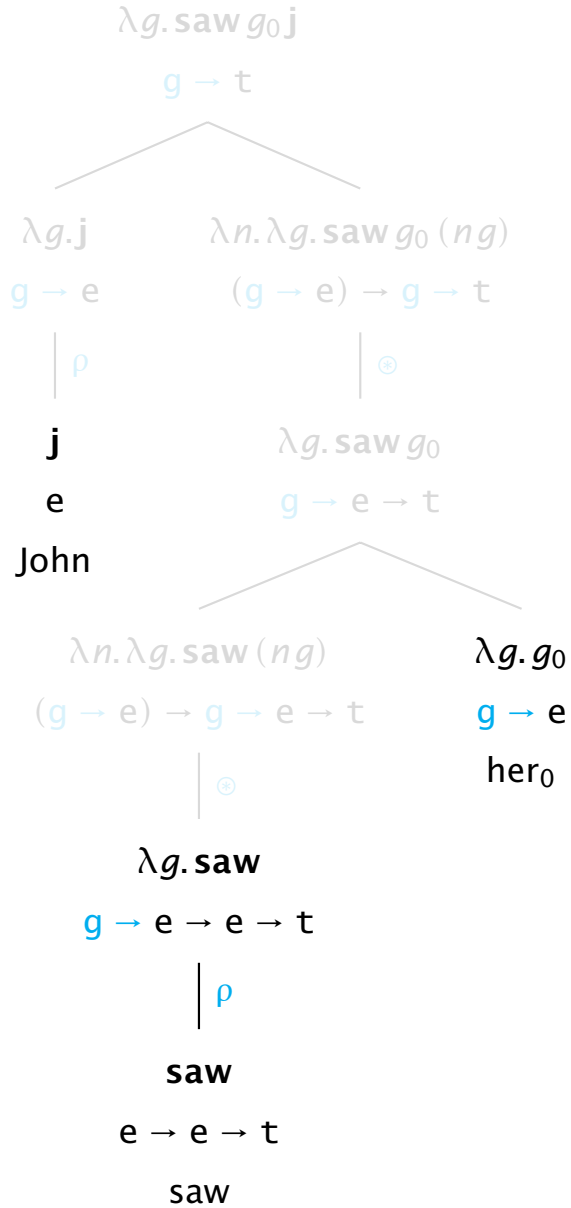

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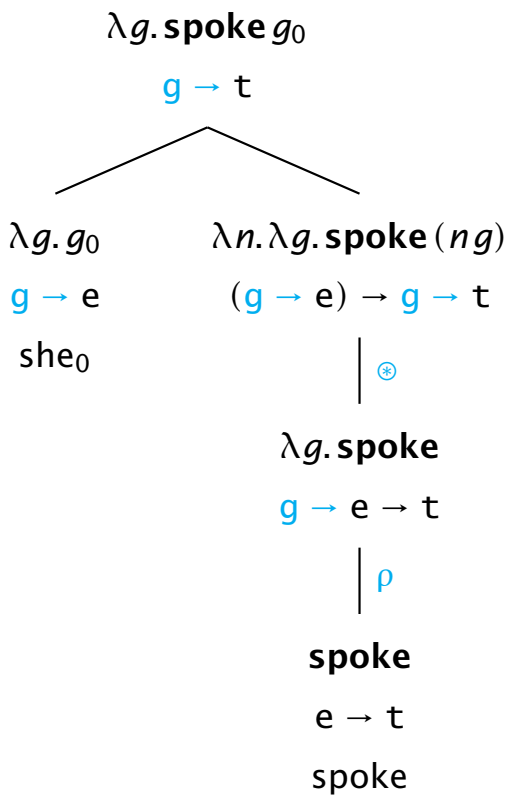

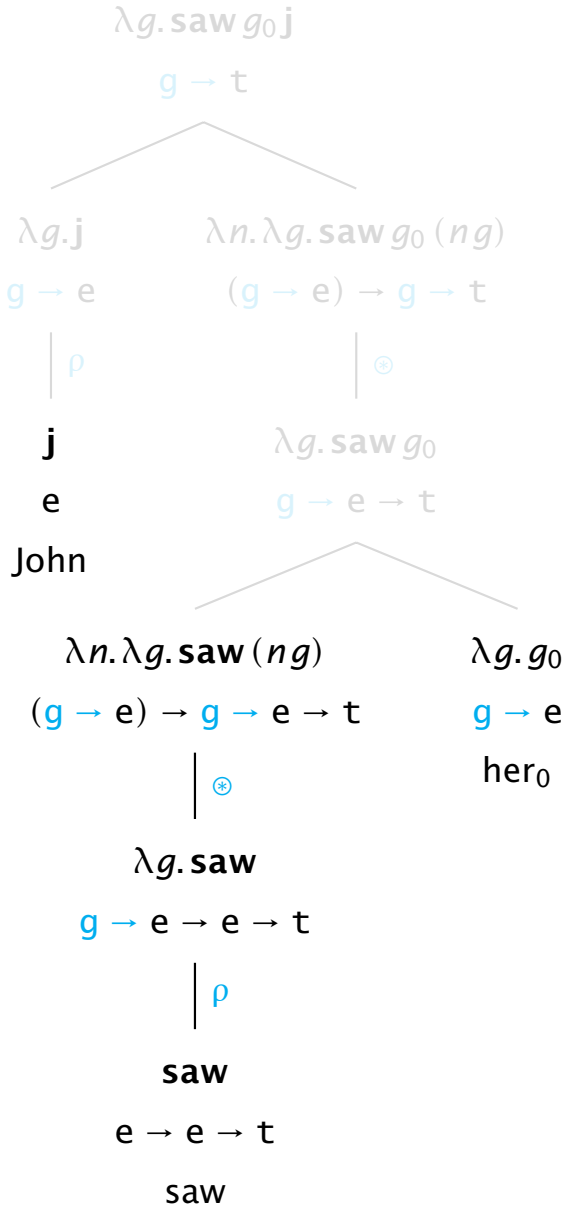

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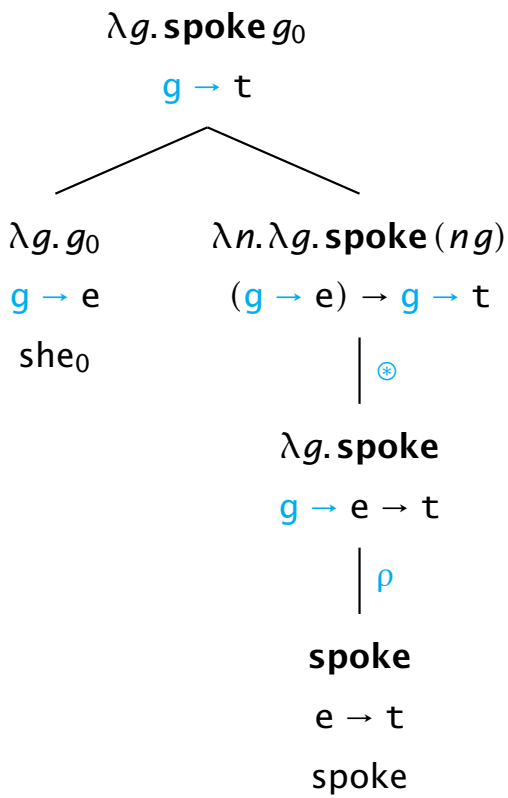

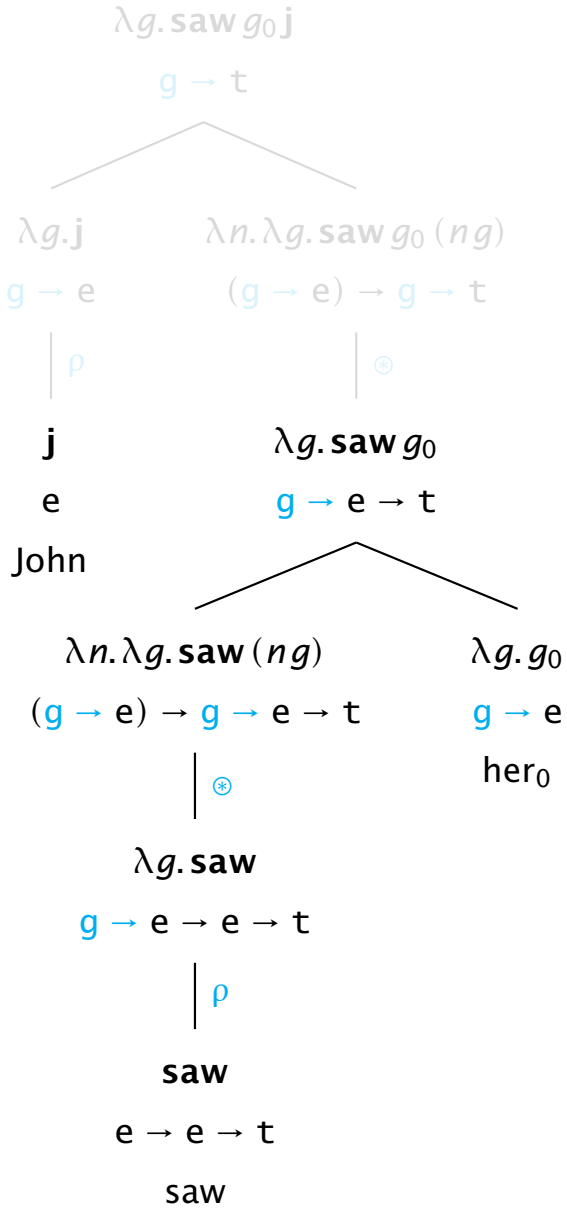

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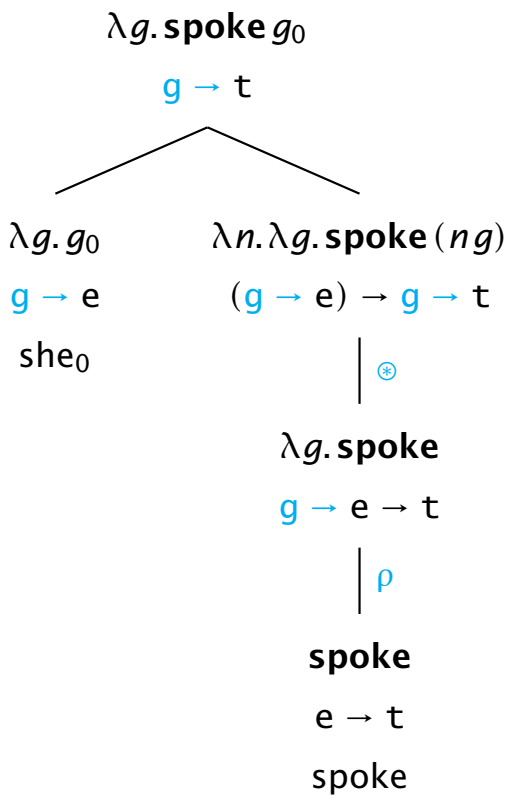

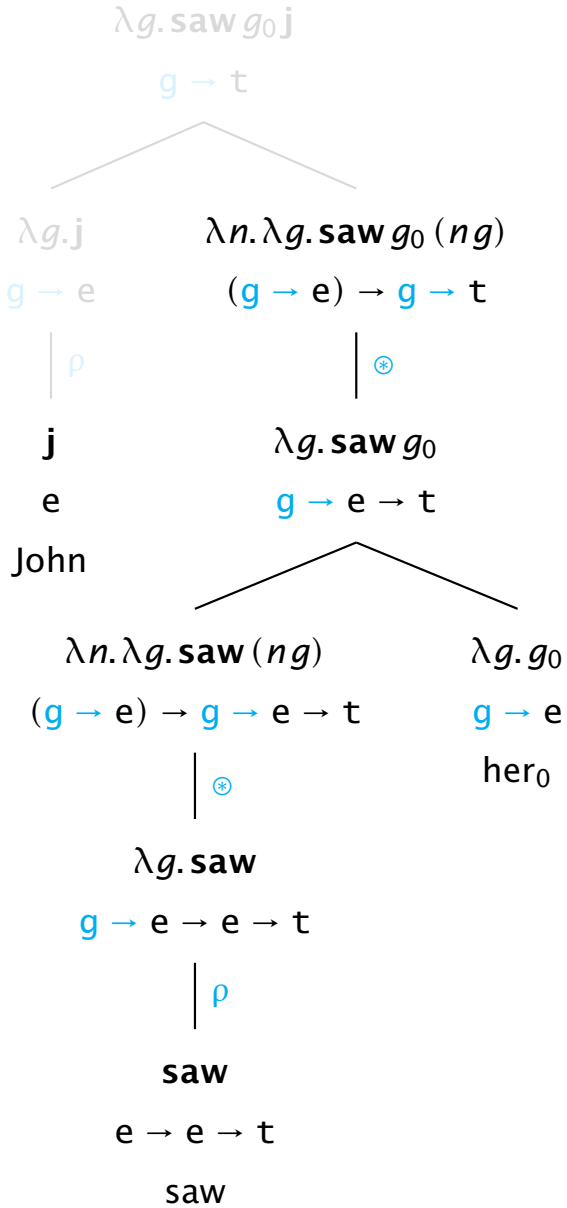

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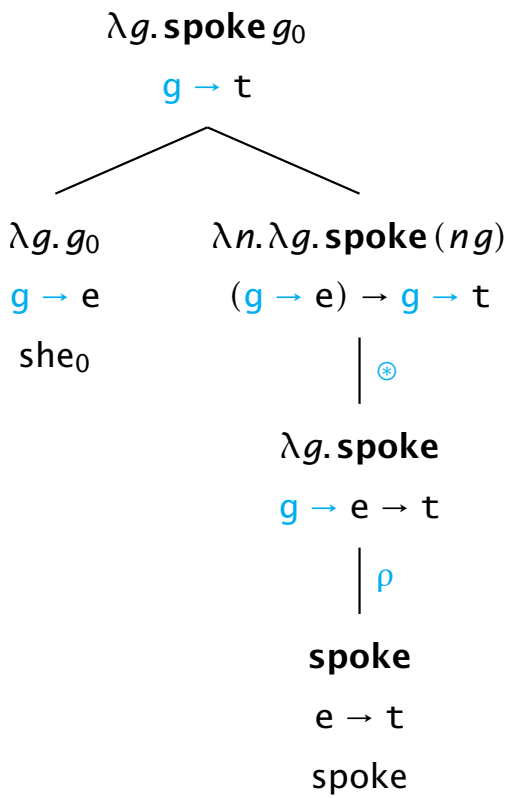

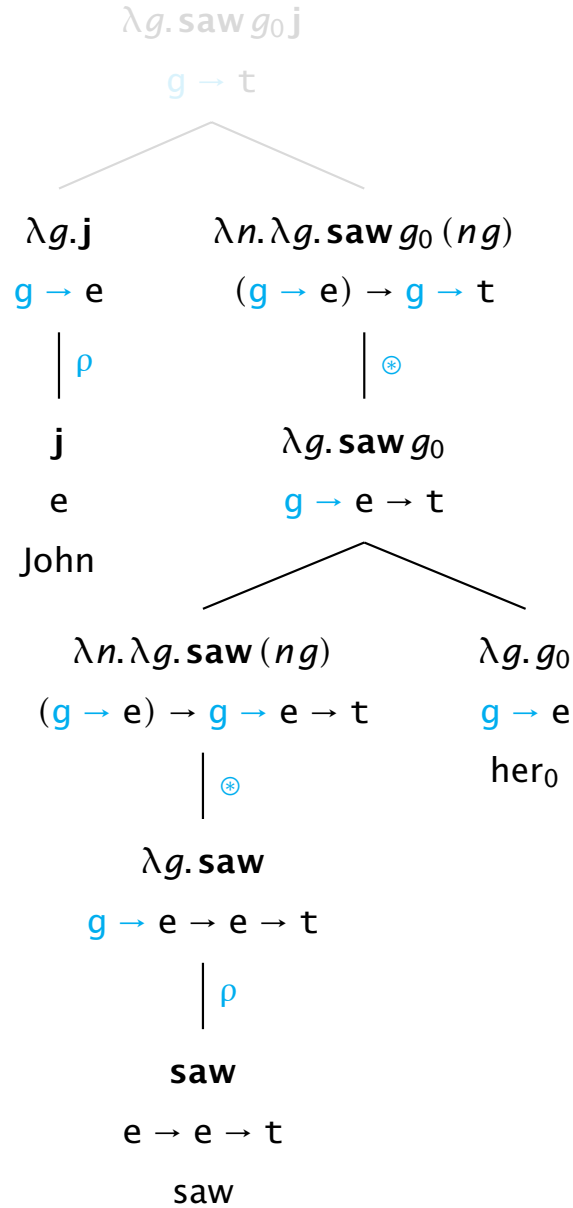

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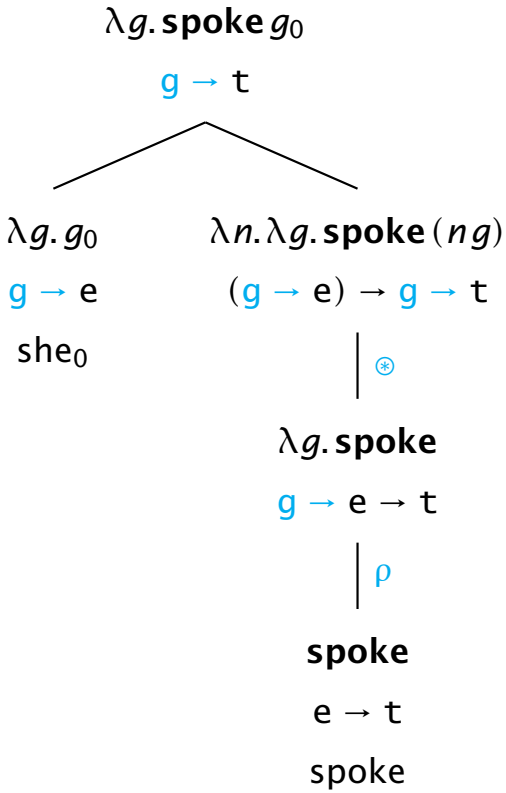

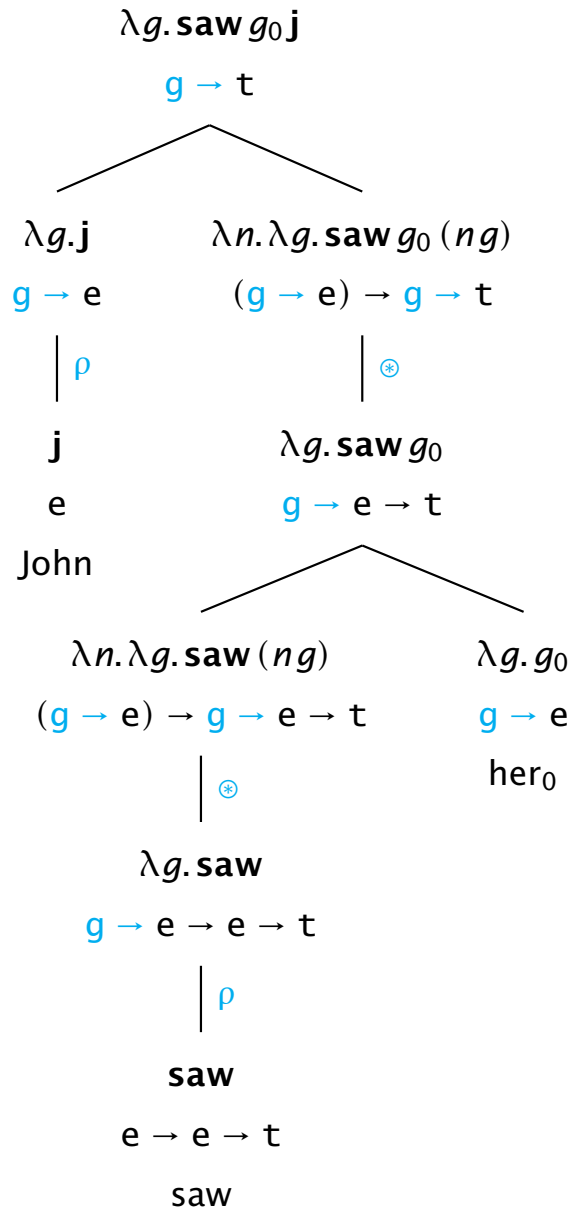

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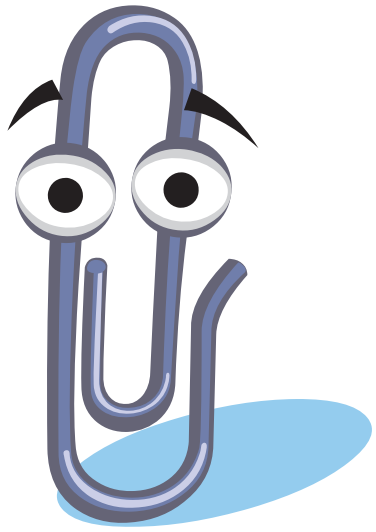

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Would you like help?

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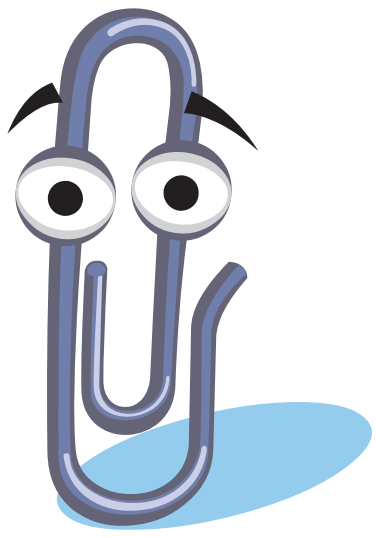

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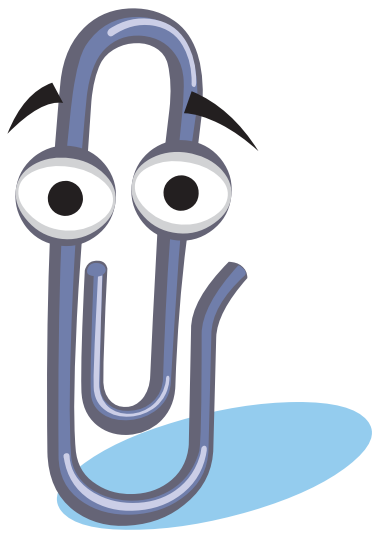

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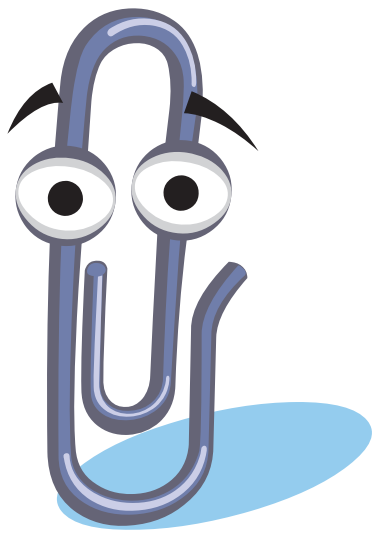

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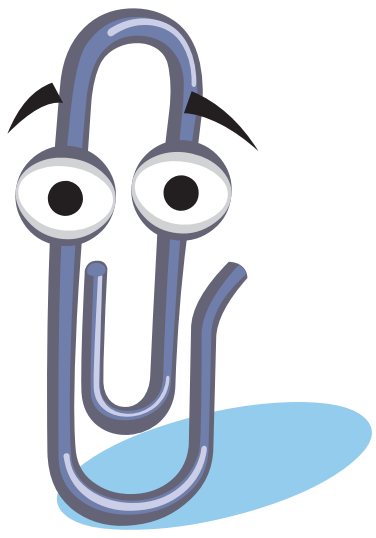

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Conceptual issues dissolved

First, ρ allows stuff that's not really assignment-dependent to be lexically so.

Second, because the grammar doesn't *insist on* composing meanings with $[\![\cdot]\!]$, abstraction can be defined directly (e.g., Sternefeld 1998, 2001, Kobele 2010):

$$\Lambda^i := \underbrace{\lambda f.\lambda g.\lambda x.f\, g^{i \to x}}_{(g \to a) \to g \to b \to a}$$

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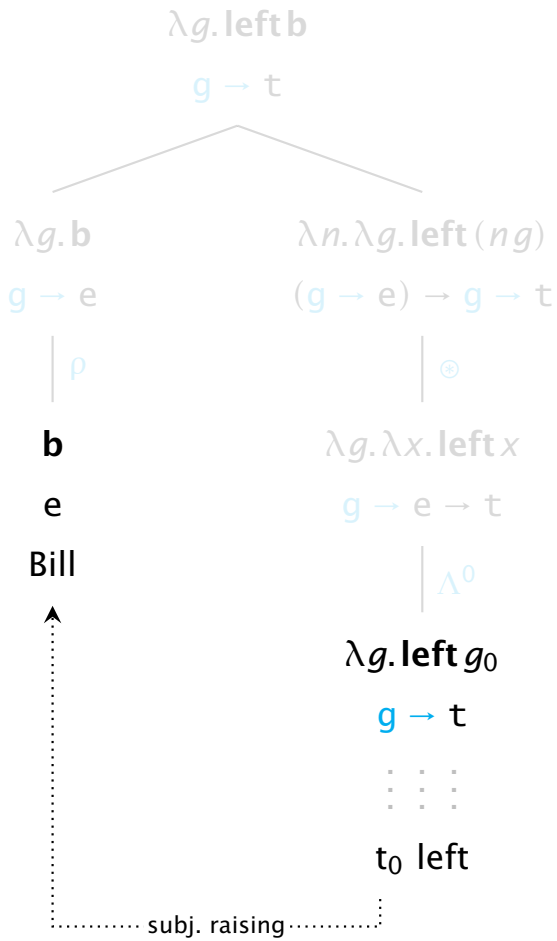

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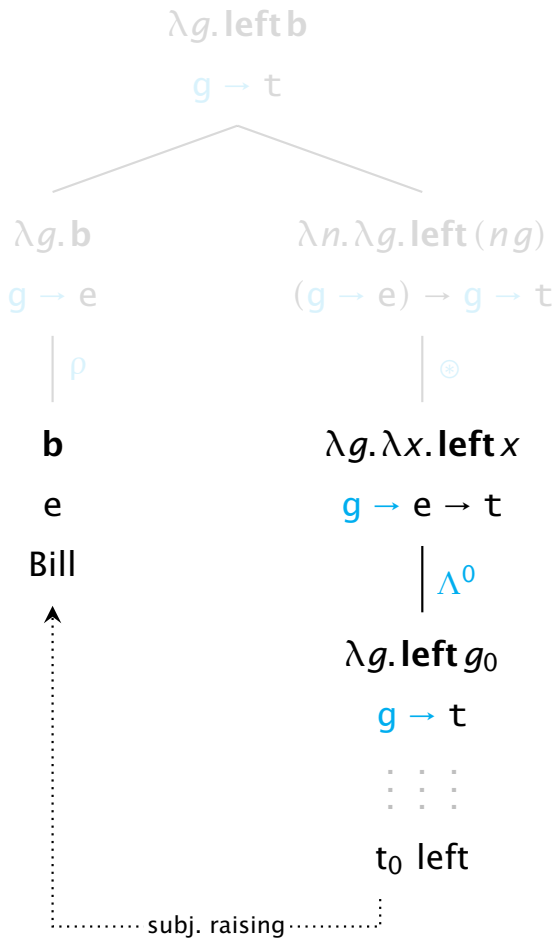

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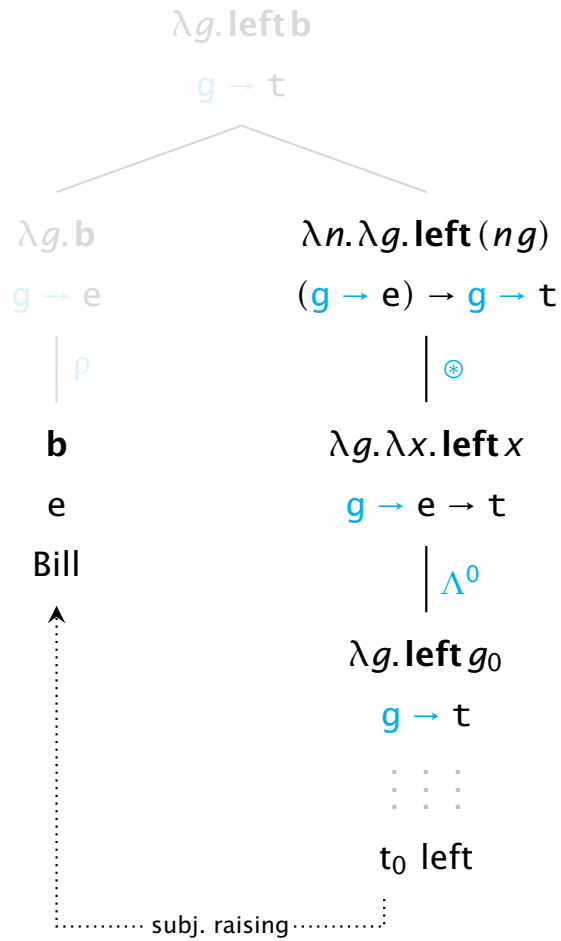

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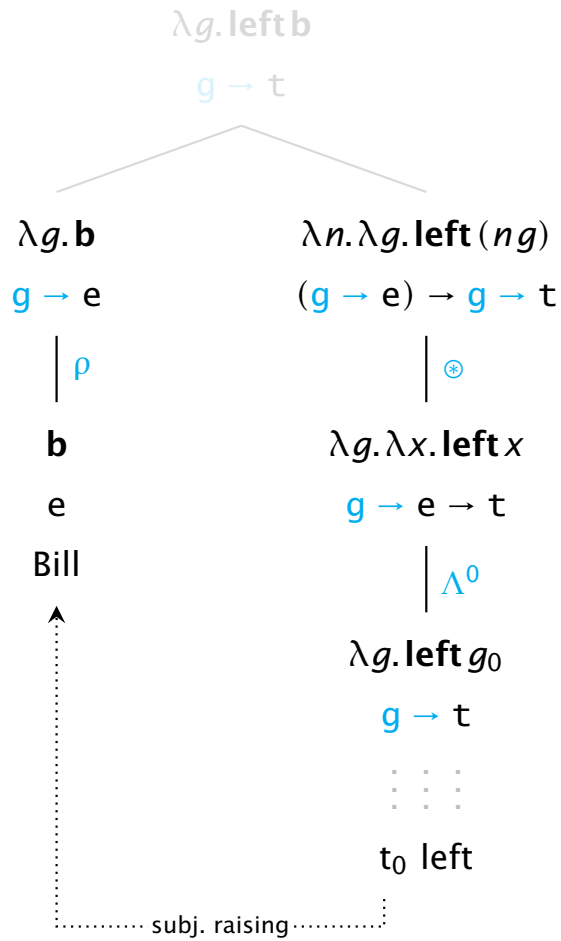

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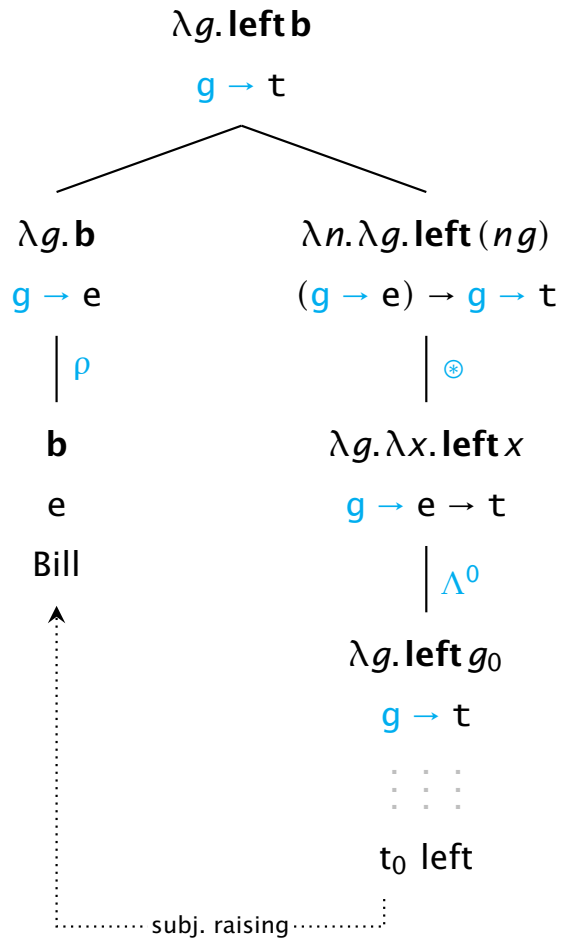


A familiar construct

When we abstract out ρ and $\circledast$ in this way, we're in the presence of something known to computer scientists and functional programmers as an **applicative functor** (McBride & Paterson 2008, Kiselyov 2015).

[You might also recognize ρ and $\circledast$ as the $\mathbb{K}$ and $\mathbb{S}$ combinators (Curry & Feys 1958).]

Applicative functors

An applicative functor is a type constructor F with two functions:

$$\rho :: a \to F\,a \qquad \circledast :: F\,(a \to b) \to F\,a \to F\,b$$

Satisfying a few laws:

Homomorphism

$$\rho\,f \circledast \rho\,x = \rho\,(f\,x)$$

Identity

$$\rho\,(\lambda x.\,x) \circledast v = v$$

Interchange

$$\rho\,(\lambda f.\,f\,x) \circledast u = u \circledast \rho\,x$$

Composition

$$\rho\,(\circ) \circledast u \circledast v \circledast w = u \circledast (v \circledast w)$$

Basically, these laws guarantee that $\circledast$ is a kind of fancy functional application, and that ρ is a trivial way to make something fancy.

Generality

Another example of an applicative functor, for sets:

$$\rho\, x := \{x\} \qquad m \circledast n := \{f\, x \mid f \in m, x \in n\}$$

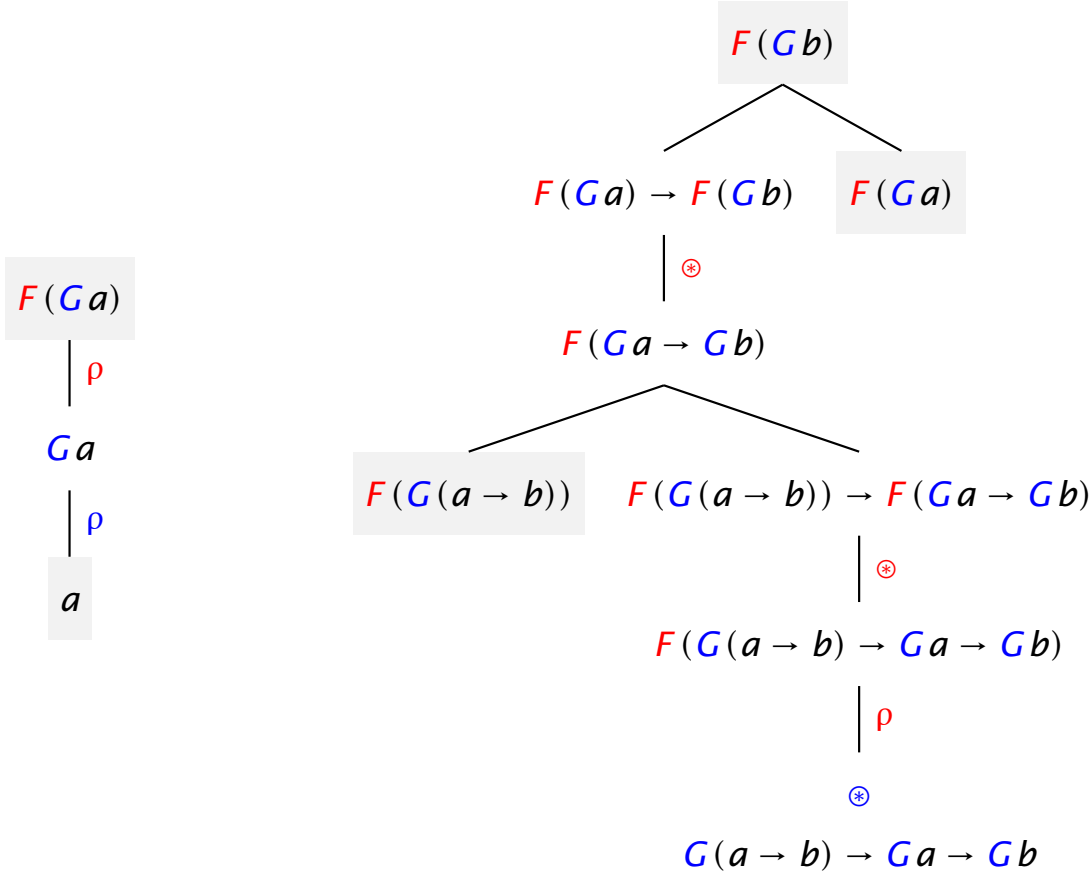
(See Charlow 2014, 2017 for more on this.)

The technique is super general, and can be fruitfully applied (inter alia) to dynamics, presupposition, supplementation, (association with) focus, and scope:

$$\rho\, x := \lambda k.\, k\, x \qquad m \circledast n := \lambda k.\, m\, (\lambda f.\, n\, (\lambda x.\, k\, (f\, x)))$$

(See Shan & Barker 2006, Barker & Shan 2008 for more on this.)

Applicative functors compose



Whenever you have two applicative functors, you're *guaranteed* to have two more!

Getting higher-order

To have and have not

Applicative functors dissolve the theoretical baggage associated with the standard account. *However*, it seems ρ and $\circledast$ are no help for reconstruction or paychecks (time permitting, I'll question this point at the end, but let's run with it for now).

Intuitively, both phenomena are *higher-order*: the referent anaphorically retrieved by the paycheck pronoun or the topicalized expression's trace is an 'intension', rather than an 'extension' (cf. Sternefeld 1998, 2001, Hardt 1999, Kennedy 2014).

1. John$_i$ deposited [his$_i$ paycheck]$_j$, but Bill$_k$ spent it$_j$.
2. [His$_i$ mom]$_j$, every boy$_i$ likes t$_j$.

Anaphora to intensions

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$$g \to g \to e$$

Going whole hog, pronouns have a generalized, recursive type:

$$\mathfrak{pro} ::= g \to e \mid \underbrace{g \to \mathfrak{pro}}_{g\to g\to e,\ g\to g\to g\to e,\ \ldots}$$

But, importantly, a unitary lexical semantics: $[\![\text{she}_0]\!] := \lambda g.\, g_0$.

μ for higher-order pronouns

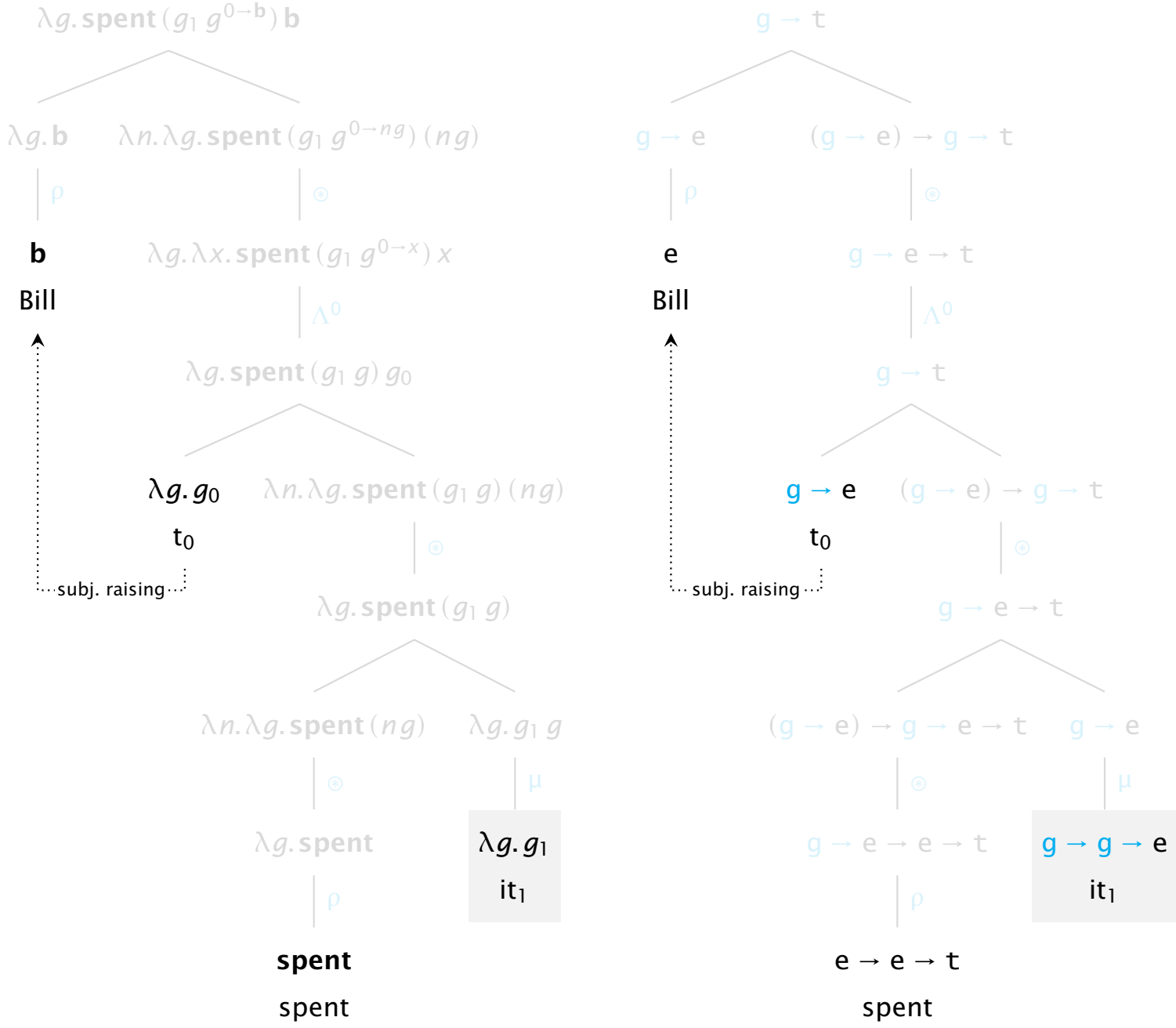
Higher-order pronoun meanings require a higher-order combinator:

$$\mu := \underbrace{\lambda m.\lambda g.\, m\, g\, g}_{(g \to g \to a) \to g \to a}$$

(Aka the $\mathbb{W}$ combinator from Combinatory Logic.)

μ takes an expression m that's anaphoric to an intension, and obtains an extension by evaluating the anaphorically retrieved intension $m\,g$ once more against g. In other words, it turns a higher-order pronoun meaning into a garden-variety one:

$$\mu\,(\underbrace{\lambda g.\, g_0}_{g \to g \to e}) = \underbrace{\lambda g.\, g_0\, g}_{g \to e}$$


λg. spent (g1 g^{0→b}) b
λg. b
λn. λg. spent (g1 g^{0→ng}) (ng)
ρ
⊛
b
Bill
λg. λx. spent (g1 g^{0→x}) x
Λ^0
λg. spent (g1 g) g0
λg. g0
t0
λn. λg. spent (g1 g) (ng)
subj. raising
⊛
λg. spent (g1 g)
λn. λg. spent (ng)
λg. g1 g
⊛
μ
λg. spent
λg. g1
it1
ρ
spent
spent
g → t
g → e
(g → e) → g → t
ρ
⊛
e
Bill
g → e → t
Λ^0
g → t
g → e
(g → e) → g → t
t0
⊛
subj. raising
g → e → t
(g → e) → g → e → t
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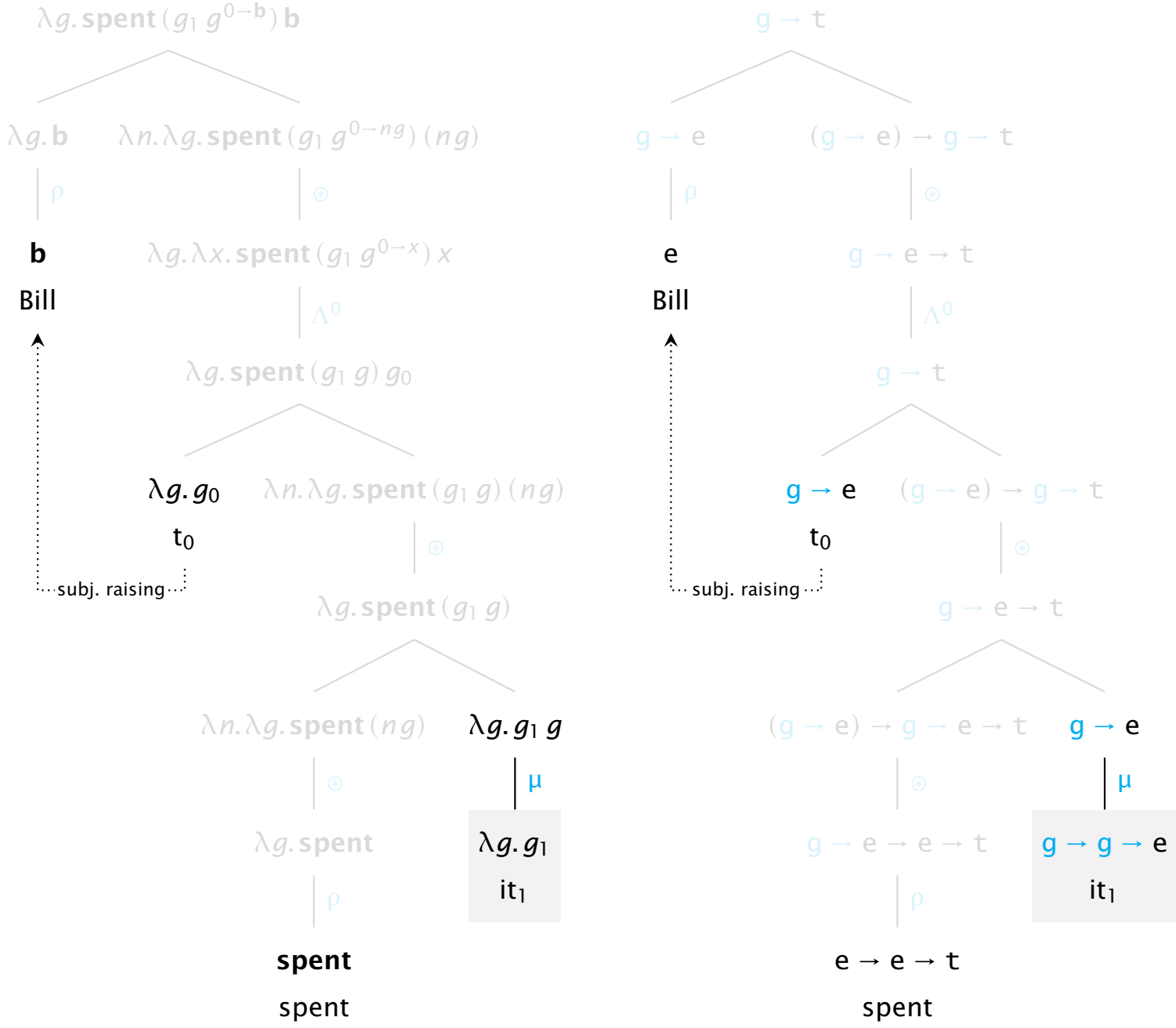
λg. spent (g1 g^0→b) b
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λg. λx. spent (g1 g^0→x) x
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subj. raising
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λg. spent (g1 g)
λn. λg. spent (ng)
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μ
λg. spent
λg. g1
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(g → e) → g → t
ρ
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g → e → t
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g → t
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(g → e) → g → t
subj. raising
⊛
g → e → t
(g → e) → g → e → t
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μ
g → e → e → t
g → g → e
it1
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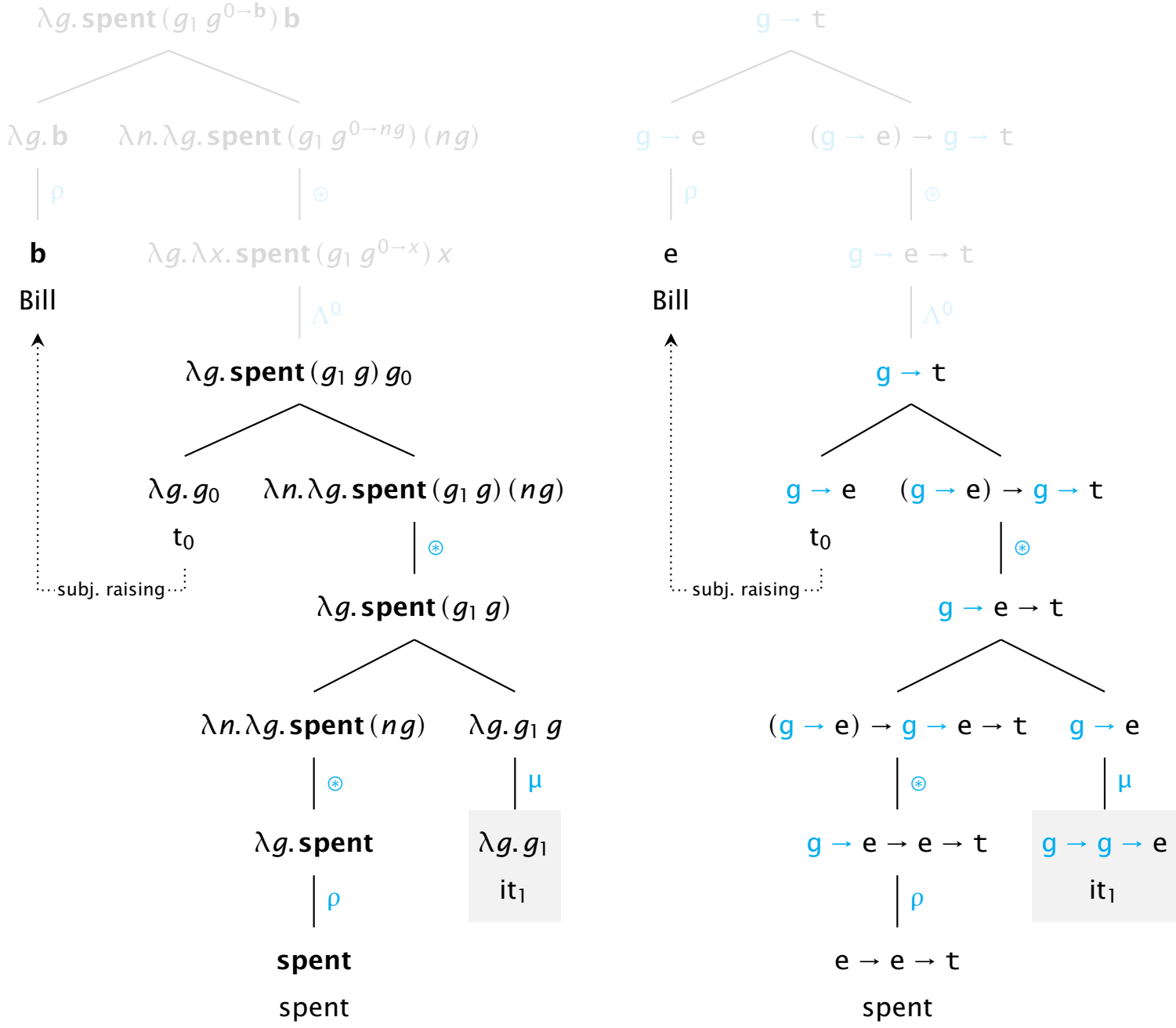
e → e → t
spent


λg. spent (g1 g0→b) b
λg. b
λn. λg. spent (g1 g0→ng) (ng)
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⊛
b
Bill
λg. λx. spent (g1 g0→x) x
Λ0
λg. spent (g1 g) g0
λg. g0
λn. λg. spent (g1 g) (ng)
t0
⊛
subj. raising
λg. spent (g1 g)
λn. λg. spent (ng)
λg. g1 g
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λg. g1
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⊛
subj. raising
g → e → t
(g → e) → g → e → t
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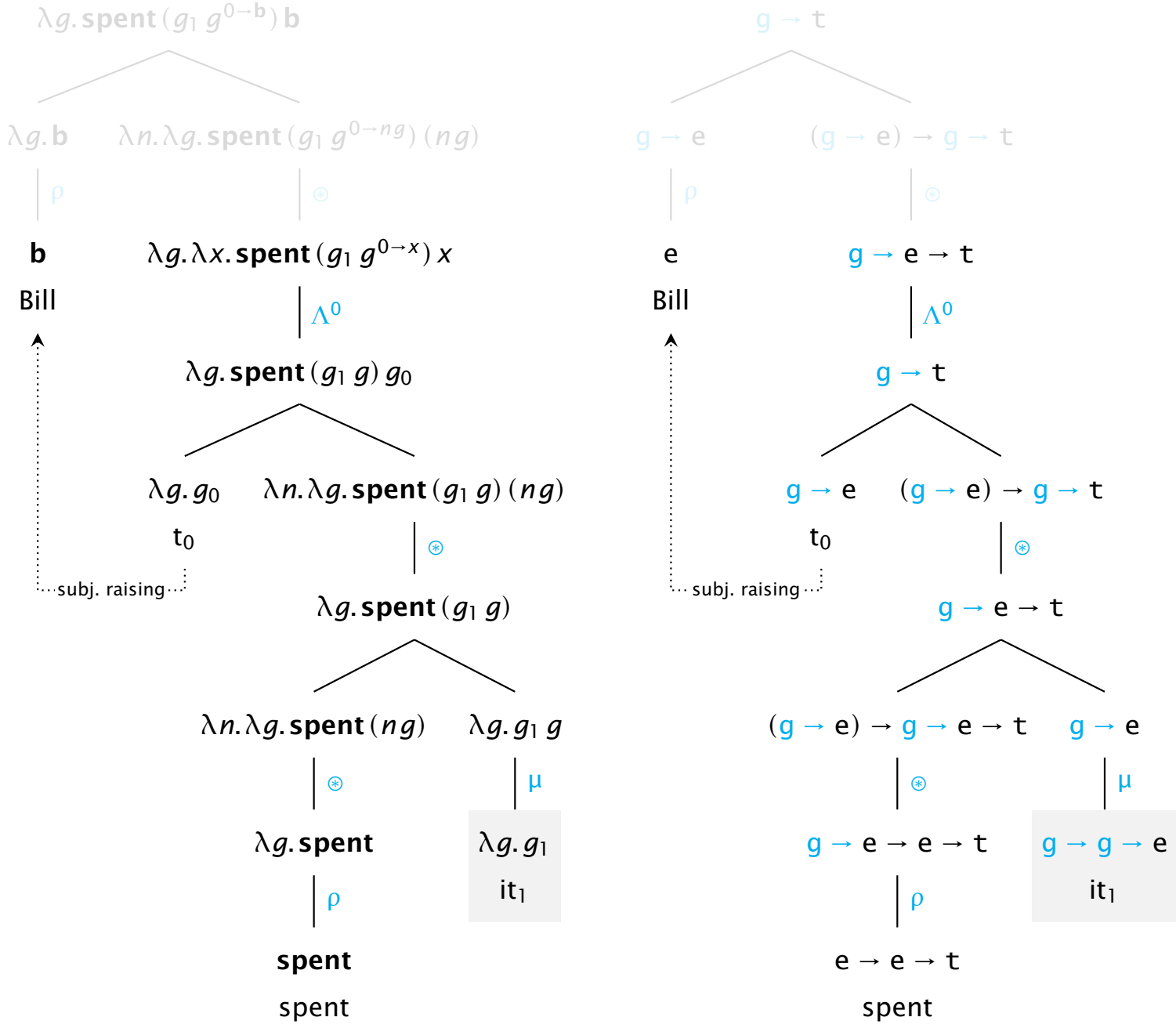
it1
ρ
e → e → t
spent


$\lambda g.\,\mathbf{spent}\,(g_1\,g^{0\to \mathbf{b}})\,\mathbf{b}$
$\lambda g.\,\mathbf{b}$
$\lambda n.\lambda g.\,\mathbf{spent}\,(g_1\,g^{0\to ng})\,(ng)$
ρ
$\circledast$
$\mathbf{b}$
Bill
$\lambda g.\lambda x.\,\mathbf{spent}\,(g_1\,g^{0\to x})\,x$
Λ^0
$\lambda g.\,\mathbf{spent}\,(g_1\,g)\,g_0$
$\lambda g.\,g_0$
t_0
$\lambda n.\lambda g.\,\mathbf{spent}\,(g_1\,g)\,(ng)$
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$\lambda g.\,\mathbf{spent}\,(g_1\,g)$
$\lambda n.\lambda g.\,\mathbf{spent}\,(ng)$
$\lambda g.\,g_1\,g$
μ
$\lambda g.\,\mathbf{spent}$
$\lambda g.\,g_1$
it_1
ρ
$\mathbf{spent}$
spent
$g \to t$
$g \to e$
$(g \to e) \to g \to t$
ρ
$\circledast$
e
Bill
$g \to e \to t$
Λ^0
$g \to t$
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subj. raising
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$g \to e \to t$
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$g \to e \to e \to t$
$g \to g \to e$
it_1
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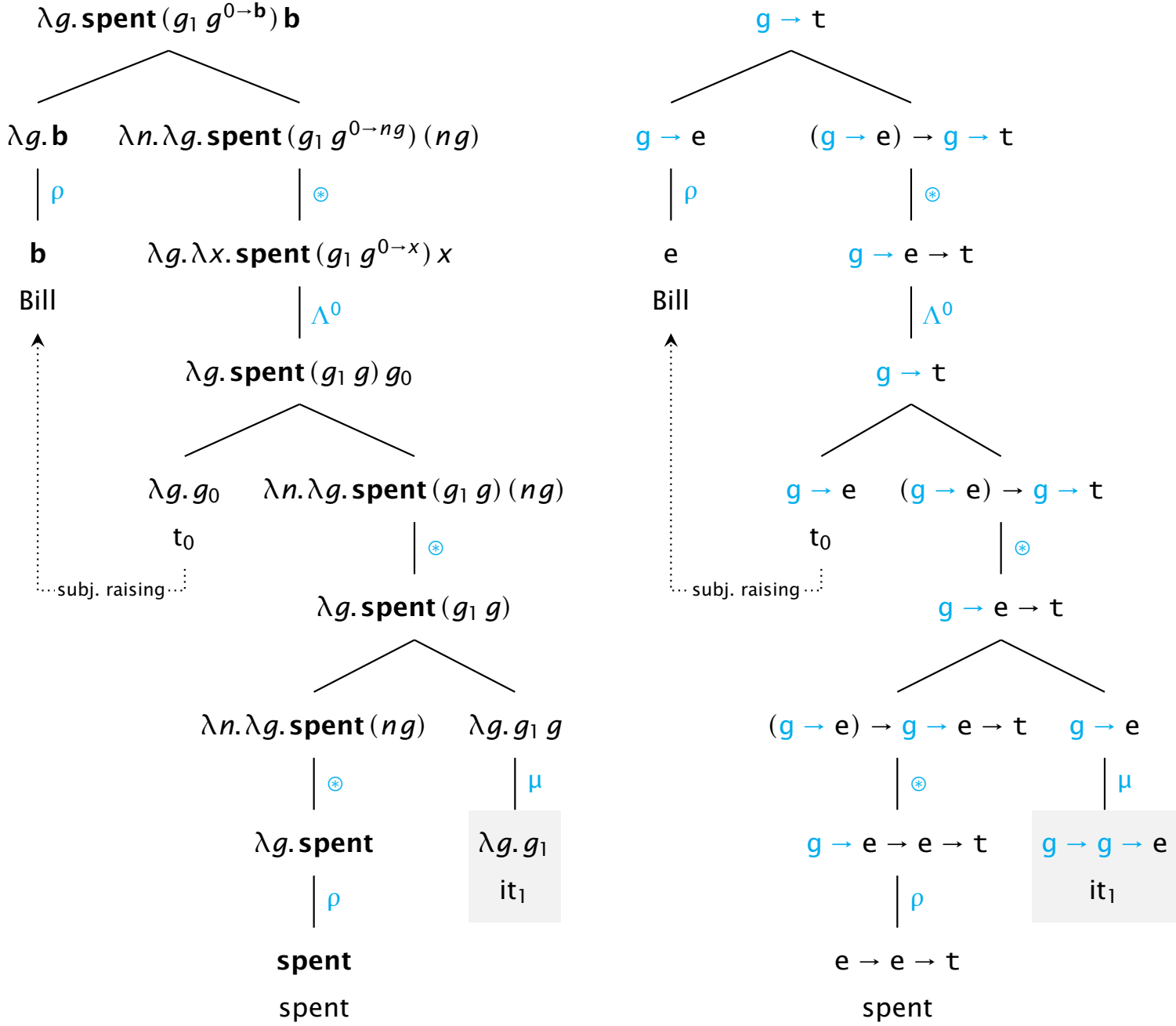
spent


λg. spent (g1 g^0→b) b
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(g → e) → g → e → t
g → e
⊛
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g → e → e → t
g → g → e
it1
ρ
e → e → t
spent

Taking stock

Aside from the type assigned to her_1 and the invocation of μ, this derivation is exactly the same as a normal case of pronominal binding.

The derived meaning is $\lambda g.\,\mathbf{spent}\,(g_1\;g^{0\to\mathbf{b}})\,\mathbf{b}$. If the incoming $\mathbf{g}$ assigns 1 to $\lambda g.\,\mathbf{paych}\,g_0$ (the intension of his_0 *paychech*), we're home free:

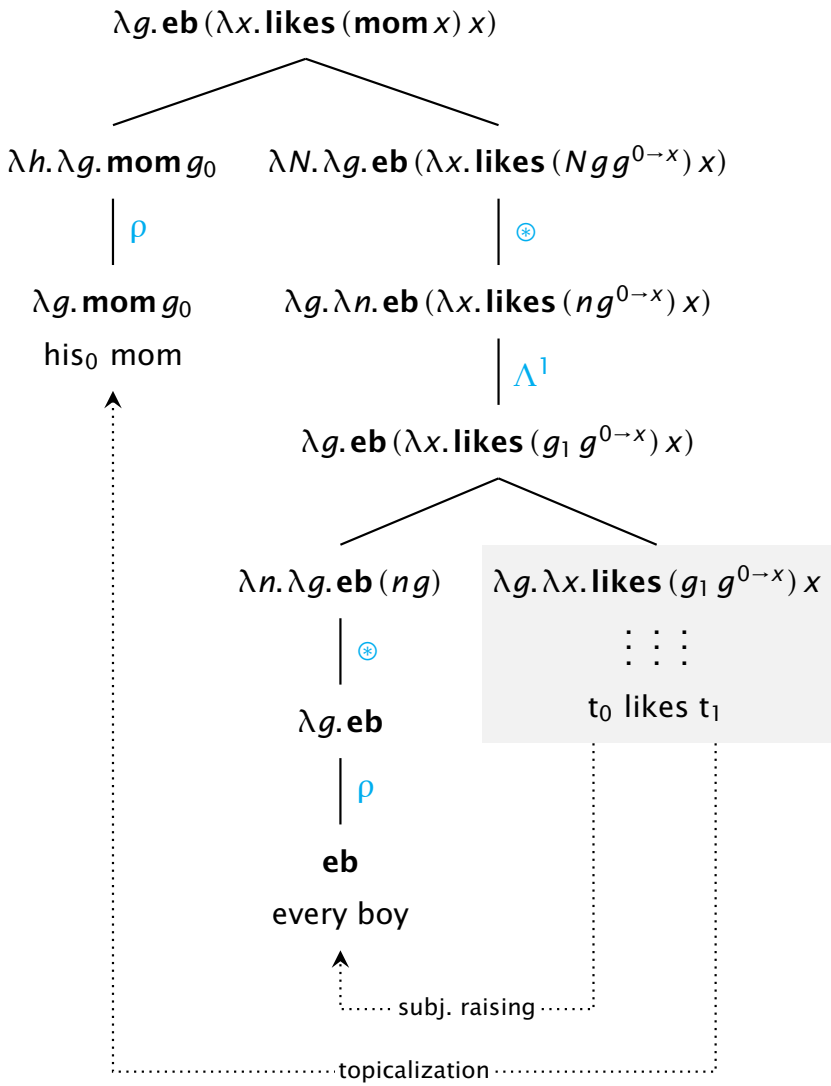
$$\begin{aligned}
(\lambda g.\,\mathbf{spent}\,(g_1\;g^{0\to\mathbf{b}})\,\mathbf{b})\,\mathbf{g} &= \mathbf{spent}\,(\mathbf{g}_1\;\mathbf{g}^{0\to\mathbf{b}})\,\mathbf{b} && \beta\\
&= \mathbf{spent}\,((\lambda g.\,\mathbf{paych}\,g_0)\,\mathbf{g}^{0\to\mathbf{b}})\,\mathbf{b} && \equiv\\
&= \mathbf{spent}\,(\mathbf{paych}\,(\mathbf{g}^{0\to\mathbf{b}})_0)\,\mathbf{b} && \beta\\
&= \mathbf{spent}\,(\mathbf{paych}\,\mathbf{b})\,\mathbf{b} && \equiv
\end{aligned}$$

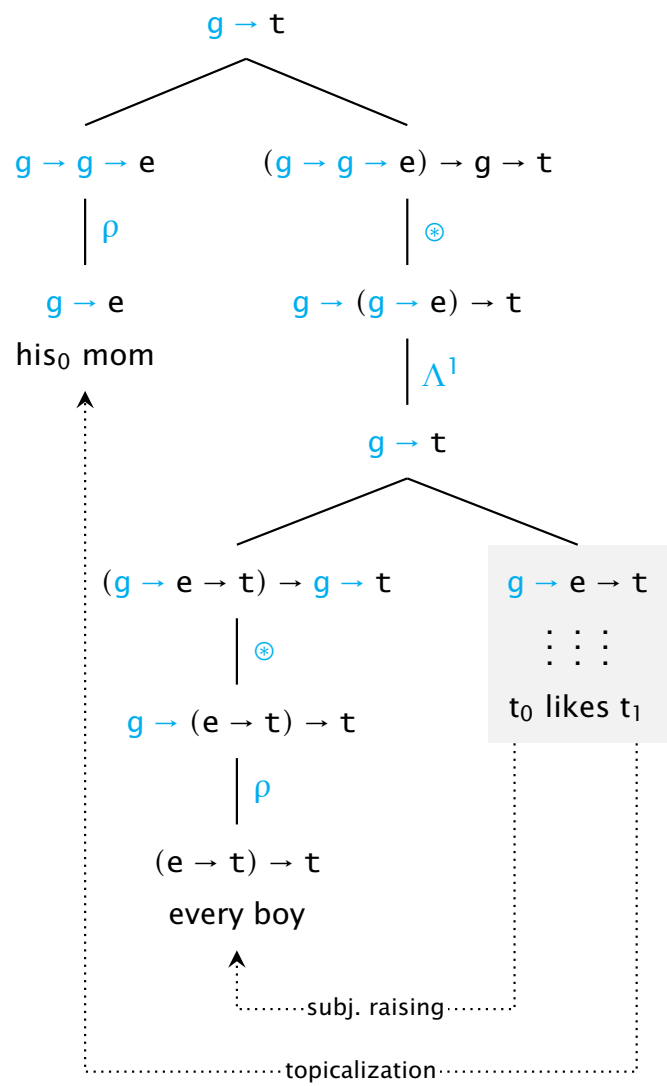
Reconstruction works the same

We can pull off a similar trick for reconstruction: treat the trace as higher-order, making it anaphoric to the *intension* of the topicalized expression.

1. [His$_i$ mom]$_j$, every boy$_i$ likes t$_j$.

Use μ to make sure everything fits together, and we're done.


λg.eb (λx.likes (mom x) x)
λh.λg.mom g0
λN.λg.eb (λx.likes (N g g0→x) x)
ρ
⊛
λg.mom g0
his0 mom
λg.λn.eb (λx.likes (n g0→x) x)
Λ1
λg.eb (λx.likes (g1 g0→x) x)
λn.λg.eb (n g)
λg.λx.likes (g1 g0→x) x
⊛
t0 likes t1
λg.eb
ρ
eb
every boy
subj. raising
topicalization


g → t
g → g → e
(g → g → e) → g → t
ρ
⊛
g → e
g → (g → e) → t
his0 mom
Λ1
g → t
(g → e → t) → g → t
g → e → t
⊛
t0 likes t1
g → (e → t) → t
ρ
(e → t) → t
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topicalization

Another familiar construct

Our grammatical interface for pronouns and binding has three pieces: ρ, $\circledast$, and μ.

ρ and $\circledast$ form an applicative functor. Do ρ, $\circledast$, and μ also correspond to something interesting?

Another familiar construct

Our grammatical interface for pronouns and binding has three pieces: ρ, $\circledast$, and μ.

ρ and $\circledast$ form an applicative functor. Do ρ, $\circledast$, and μ also correspond to something interesting? Yes, they're a **monad** (Moggi 1989, Wadler 1992, 1995, Shan 2002, Giorgolo & Asudeh 2012, Charlow 2014, 2017, . . .):

Associativity

$$\mu \circ \mu = \lambda m.\, \mu\,(\rho\,\mu \circledast m)$$

Identity

$$\mu \circ \rho = \lambda m.\, \mu\,(\rho\,\rho \circledast m) = \lambda m.\, m$$

Monads don't compose

There is an extremely sad fact about monads: unlike applicatives, they do not freely compose! If you have two monads, there is no guarantee you will have a third, and no general recipe for composing monads to yield new ones.

So applicatives are easy to work with in isolation. You can be confident that they will play nicely with other applicative things in your grammar. Monads, not so much.

> *The moral is this: if you have got an Applicative functor, that is good; if you have also got a Monad, that is even better! And the dual of the moral is this: if you need a Monad, that is fine; if you need only an Applicative functor, that is even better!*

(McBride & Paterson 2008: 8)

Variable-free semantics

Pronouns as identity maps

Jacobson proposes we stop thinking of pronouns as assignment-relative and index-oriented. Instead, she suggests we model pronouns as **identity functions**:

$$\textbf{she} := \underbrace{\lambda x.\, x}_{e \to e}$$

How should these compose with things like transitive verbs, which are looking for an individual, not a function from individuals to individuals?

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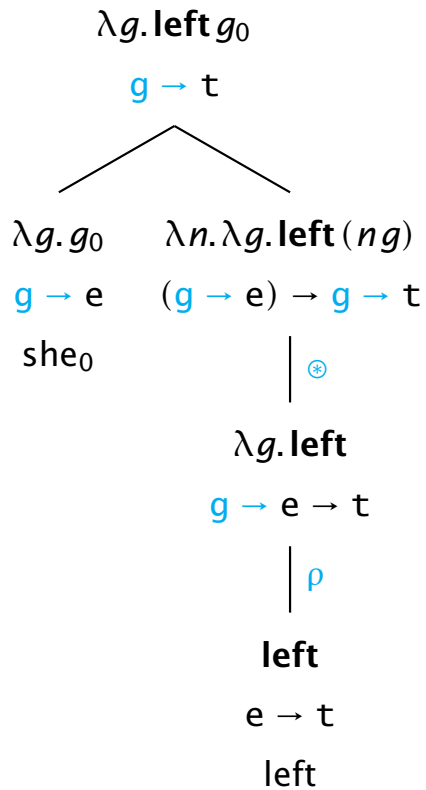
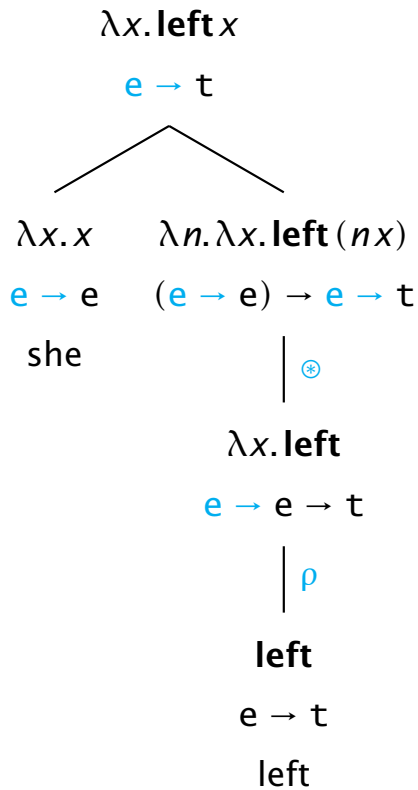
Of course, this is *exactly* the same problem that comes up when you introduce assignment-dependent meanings! And hence it admits the exact same solution.





In an important sense, then, the compositional apparatus underwriting variable-free composition is equivalent to that underwriting assignment-friendly composition!

Multiple pronouns

There is an important difference between assignments and individuals as reference-fixing devices. Assignments are data structures that can in principle value *every* free pronoun you need. But an individual can only value *co-valued* pronouns!

1. She saw her.

So a variable-free treatment of cases like these will inevitably give you something like the following (composition involves composing the applicative with *itself*):

$$\lambda x.\lambda y.\mathbf{saw}\, y\, x$$

Assignments, and “variables”, on demand

Witness the curry/uncurry isomorphisms:

$$\mathbf{curry}\, f := \lambda x.\lambda y.\, f\,(x, y) \qquad \mathbf{uncurry}\, f := \lambda(x, y).\, f\, x\, y$$

In other words, by (iteratively) uncurrying a variable-free proposition, you end up with a dependence on a sequence of things. Essentially, an assignment.

$$\mathbf{uncurry}\,(\lambda x.\lambda y.\,\mathbf{saw}\, y\, x) = \lambda(x, y).\,\mathbf{saw}\, y\, x = \lambda p.\,\mathbf{saw}\, p_1\, p_0$$

Obversely, by iteratively currying a sequence-dependent proposition, you end up with a higher-order function. Essentially, a variable-free meaning.

$$\mathbf{curry}\,(\lambda p.\,\mathbf{saw}\, p_1\, p_0) = \mathbf{curry}\,(\lambda(x, y).\,\mathbf{saw}\, y\, x) = \lambda x.\lambda y.\,\mathbf{saw}\, y\, x$$

Variable-free semantics?

So variable-free semantics (can) have the same combinatorics as the variable-full semantics. This is no great surprise: they're both about compositionally dealing with "incomplete" meanings.

Moreover, under the curry/uncurry isomorphisms, a variable-free proposition is equivalent (up to isomorphism) with an assignment-dependent proposition.

Let's call the whole thing off?

Back to applicatives

A bit o' type theory

What is the *type* of an assignment function?

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Muskens (1995) cautions against trying to pack too much into our assignments:

$$[\textbf{AX1}] \quad \forall g, n, x_\alpha : \exists h : h = g^{n \rightarrow x} \quad \text{for all } \alpha \in \Theta$$

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If, say, $g \rightarrow e \in \Theta$, this ends up paradoxical! **AX1** requires there to be as many assignments as there are functions from assignments to individuals: $|g| \geqslant |g \rightarrow e|$.

A hierarchy of assignments?

We might try parametrizing assignments by the types of things they harbor:

$$\mathsf{g}_a ::= \mathbb{N} \to a$$

(An a-assignment is a function from indices into inhabitants of a.)

This is no longer paradoxical: we have a hierarchy of assignments, much like we have a hierarchy of types.

This is *weird*

If $g_a ::= \mathbb{N} \to a$, what type is the blue part in the following?

1. . . . and $[_{VP}$ buy the couch$]_1$ she$_0$ did $[_{VP}\ t_1]$.

A couple of countervailing considerations:

a. There's a (free) pronoun, $\therefore g_e \to t$?

b. There's a (free) VP variable, $\therefore g_{e\to t} \to t$?

Splitting the difference: $g_e \to g_{e\to t} \to t$.

A non-problem

So is there a univocal type for propositions? If so, is every lexical entry specified relative to an infinite sequence of assignments, one per type in the inductive type hierarchy?

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So is there a univocal type for propositions? If so, is every lexical entry specified relative to an infinite sequence of assignments, one per type in the inductive type hierarchy? That seems bad.

But it is only bad if you're working in the old, one-size-fits-all paradigm.

Back to intensional pronouns (and traces)

With type-segregated assignment, we'll have the following for a paycheck pronoun or reconstruction-ready trace:

$$\lambda g.\, g_0 \equiv_\lambda \underbrace{\lambda g.\lambda h.\, g_0\, h}_{\mathsf{g}_{\mathsf{g}_\mathsf{e}\to\mathsf{e}}\to\mathsf{g}_\mathsf{e}\to\mathsf{e}}$$

This projects up into the following meaning for a paycheck sentence (composition here involves composing our old applicative with *itself*):

$$\underbrace{\lambda g.\lambda h.\, \mathbf{spent}\,(g_1\; h^{0\to\mathbf{b}})\,\mathbf{b}}_{\mathsf{g}_{\mathsf{g}_\mathsf{e}\to\mathsf{e}}\to\mathsf{g}_\mathsf{e}\to\mathsf{t}}$$

So our sentence depends on two assignments.

An applicative after all

The pressure to μ is the pressure to assign a uniform type to sentences. Things that depend on two assignments need to be turned into things that depend on just one, so that our sentence can depend on just one.

There are reasons to want that if you're working in the standard mold. There are no reasons to want that if your perspective on composition is more modular. And there are reasons to *disprefer* that if you're going variable-free.

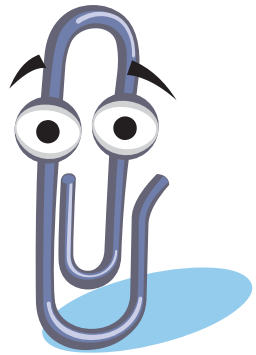
Remember the dual of the moral: if you need a Monad, that is fine; if you need only an Applicative functor, that is even better!

Concluding

Getting modular (either via applicative functors or monads) dissolves theoretical and empirical issues characteristic of one-size-fits-all approaches to composition.

Once we take a modular view on assignment-dependence, a strong parallel between variable-free and variable-full approaches comes into view.

Don’t tie your hands if you don’t have to.



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