Sharpening the empirical claims of generative syntax through formalization

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Part 2

Minimalist Grammars

Outline

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Wait a minute!

"I thought the whole point was deciding between candidate sets of primitive derivational operations! Isn't it begging the question to set everything in stone at the beginning like this?"

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> “I thought the whole point was deciding between candidate sets of primitive derivational operations! Isn’t it begging the question to set everything in stone at the beginning like this?”

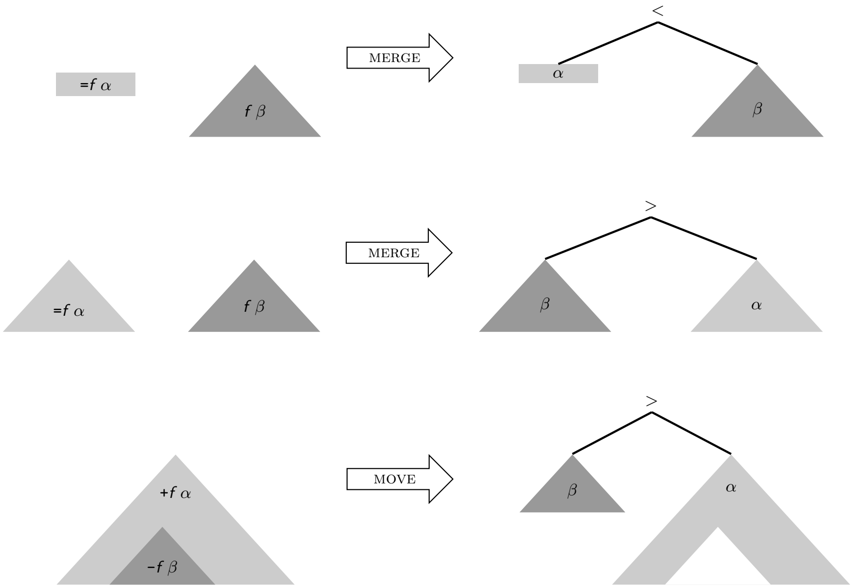
- We’re not setting this in stone — we will look at alternatives.
- But we need a concrete starting point so that we can make the differences concrete.
- What’s coming up is meant as a relatively neutral/“mainstream” starting point.

Minimalist Grammars

Defining a grammar in the MG formalism is defining a set *Lex* of lexical items

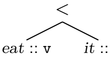
- A lexical item is a string with a sequence of features.
  e.g. *like* :: `=d =d v`, *mary* :: `d`, *who* :: `d -wh`
- Generates the closure of the $Lex \subset Expr$ under two derivational operations:
  - MERGE : $Expr \times Expr \xrightarrow{\text{partial}} Expr$
  - MOVE : $Expr \xrightarrow{\text{partial}} Expr$
- Each feature encodes a requirement that must be met by applying a particular derivational operation.
  - MERGE checks `=f` and `f`
  - MOVE checks `+f` and `-f`
- A derived expression is complete when it has only a single feature remaining unchecked.

Merge and move

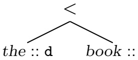


Examples

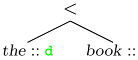
$\textsc{merge}\,(\textit{eat} :: \texttt{=d v}, \textit{it} :: \texttt{d}) =$



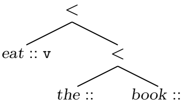
$\textsc{merge}\,(\textit{the} :: \texttt{=n d}, \textit{book} :: \texttt{n}) =$



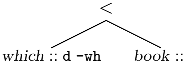
$\textsc{merge}\,(\textit{eat} :: \texttt{=d v},$



$) =$



$\textsc{merge}\,(\textit{which} :: \texttt{=n d -wh}, \textit{book} :: \texttt{n}) =$



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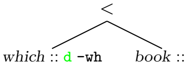

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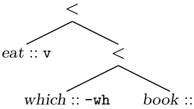
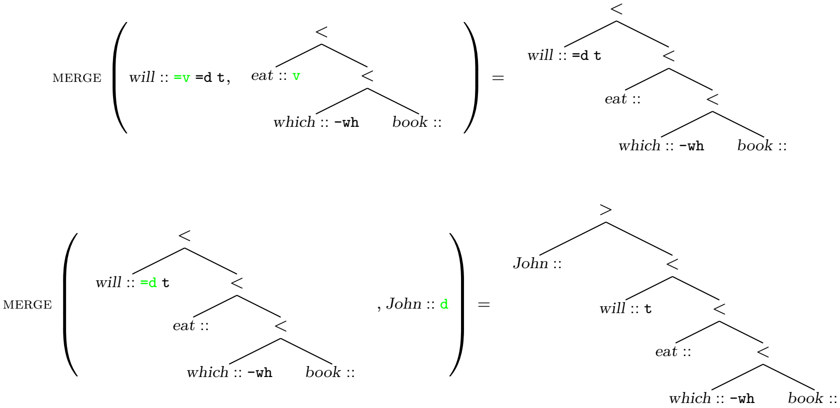


Examples


MERGE
will :: =v =d t,
<
eat :: v
<
which :: -wh
book ::
=
<
will :: =d t
<
eat ::
<
which :: -wh
book ::
MERGE
<
will :: =d t
<
eat ::
<
which :: -wh
book ::
, John :: d
=
>
John ::
<
will :: t
<
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<
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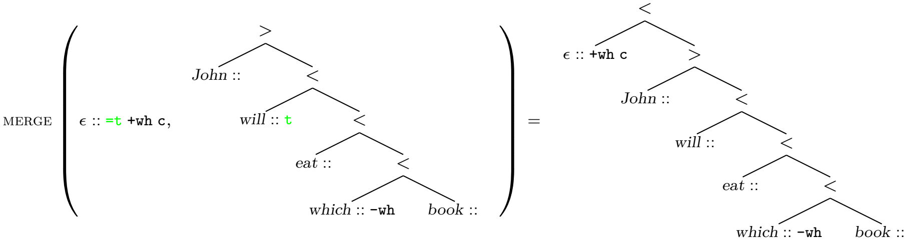
book ::

Examples


MERGE
ϵ :: =t +wh c,
>
John ::
<
will :: t
<
eat ::
<
which :: -wh
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=
<
ϵ :: +wh c
>
John ::
<
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<
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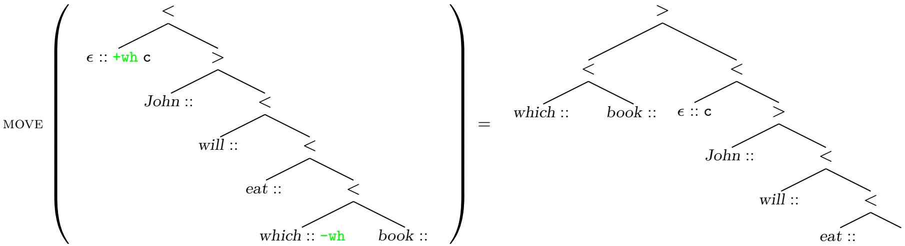
MOVE
<
ϵ :: +wh c
>
John ::
<
will ::
<
eat ::
<
which :: -wh
book ::
=
>
<
which ::
book ::
<
ϵ :: c
>
John ::
<
will ::
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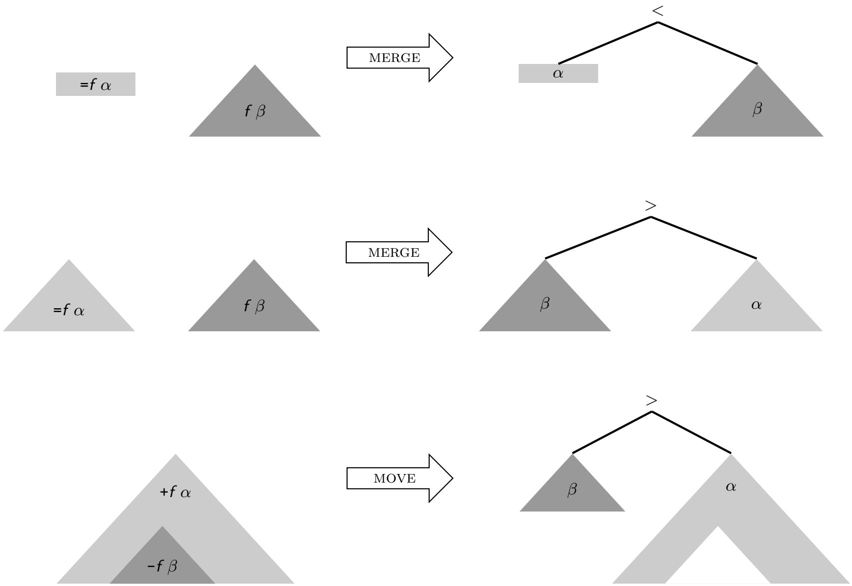
Merge and move



Definitions

$$\textsc{merge}\Big(e_1[\text{=}f\ \alpha], e_2[f\ \beta]\Big) = \begin{cases} [_< \ e_1[\alpha]\ e_2[\beta]] & \text{if } e_1[\text{=}f\ \alpha] \in Lex \\ [_> \ e_2[\beta]\ e_1[\alpha]] & \text{otherwise} \end{cases}$$

$$\textsc{move}\Big(e_1[\text{+}f\ \alpha]\Big) = [_> \ e_2[\beta]\ e_1'[\alpha]]$$

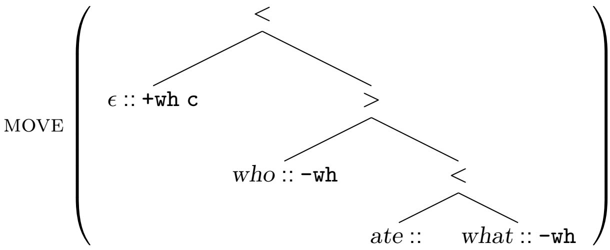
where $e_2[\text{-}f\ \beta]$ is a unique subtree of $e_1[\text{+}f\ \alpha]$

and e_1' is like e_1 but with $e_2[\text{-}f\ \beta]$ replaced by an empty leaf node

Shortest Move Constraint

How do we know which subtree should be displaced when we apply MOVE?

By stipulation, there can only ever be one candidate. This is the Shortest Move Constraint (SMC).



is **undefined**

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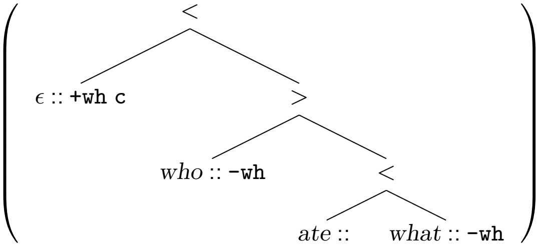
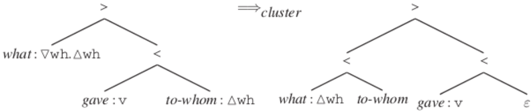
MOVE



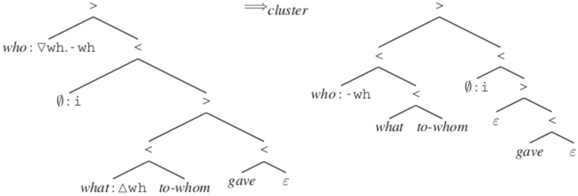
is **undefined**

Q: Multiple wh-movement?
A: Clustering!

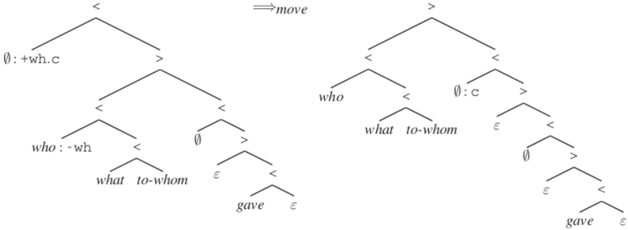
(7) a.



b.



c.



(Gärtner and Michaelis 2010)

Notation

=d v or =dp vp?

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Categorial grammar:

- Primitive symbols for "complete" things, e.g. S, NP
- Derived symbols for "incomplete" things, e.g. S\NP
- Lexical category can specify "what's missing"

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Traditional X-bar theory:

- Primitive symbols for “incomplete” things, e.g. V, T
- Derived symbols for “complete” things, e.g. VP, TP ($= V'', T''$)
- Separate subcategorization info specifies “what’s missing”

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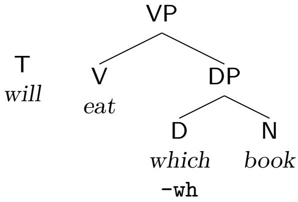
MGs:

- Primitive symbols for "complete" things, like CG
- So `t` means "a complete projection of T", not "a T head"

Notation comparison



	Conventional notation
‘eat which book’ is a VP	VP label on root
‘which book’ must move	`-wh` on ‘which’
‘will’ combines with a VP	implicit

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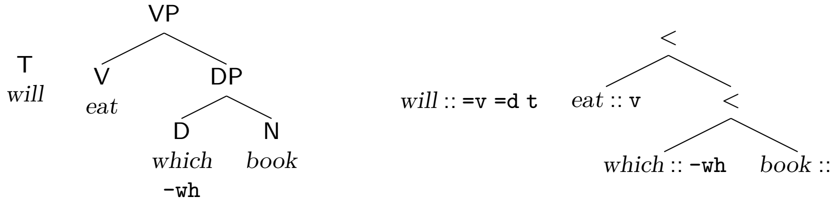

	Conventional notation	MG notation
'eat which book' is a VP	VP label on root	`v` on 'eat'
'which book' must move	`-wh` on 'which'	`-wh` on 'which'
'will' combines with a VP	implicit	`=v` on 'will'

Outline

A Minimalist Grammar

cake :: `d`	*what* :: `d -wh`
John :: `d -k`	*who* :: `d -k -wh`
eat :: `=d =d v`	ϵ :: `=t +wh c`
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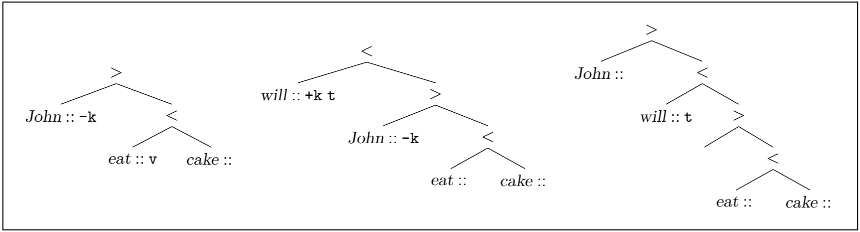

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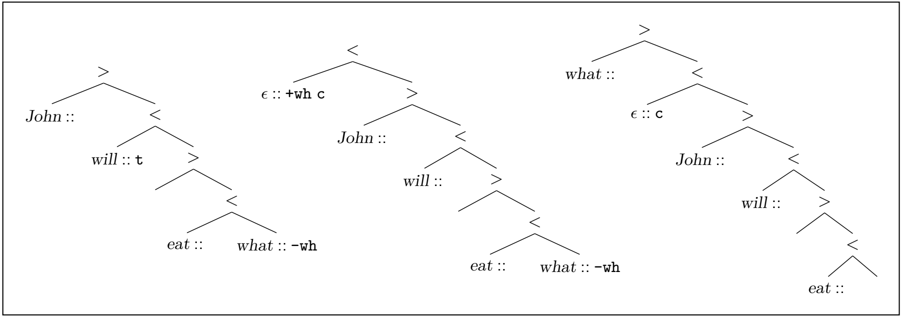
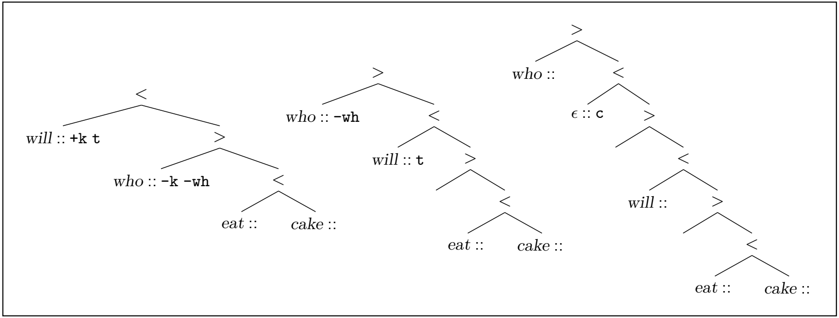


A Minimalist Grammar

$\mathit{cake} :: \mathtt{d}$	$\mathit{what} :: \mathtt{d}\ \mathtt{-wh}$
$\mathit{John} :: \mathtt{d}\ \mathtt{-k}$	$\mathit{who} :: \mathtt{d}\ \mathtt{-k}\ \mathtt{-wh}$
$\mathit{eat} :: \mathtt{=d}\ \mathtt{=d}\ \mathtt{v}$	$\epsilon :: \mathtt{=t}\ \mathtt{+wh}\ \mathtt{c}$
$\mathit{will} :: \mathtt{=v}\ \mathtt{+k}\ \mathtt{t}$	$\epsilon :: \mathtt{=t}\ \mathtt{c}$



A Minimalist Grammar . . . which overgenerates

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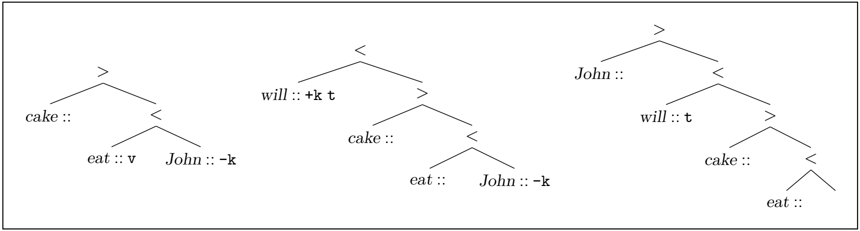

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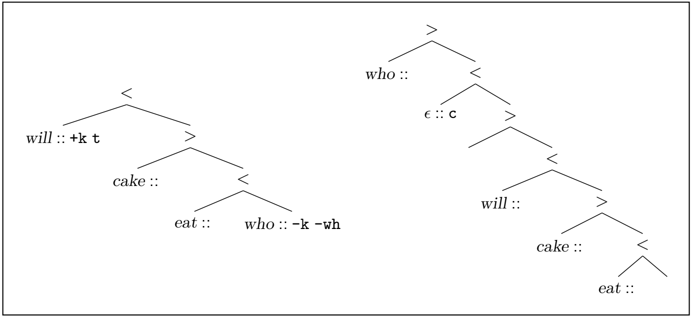

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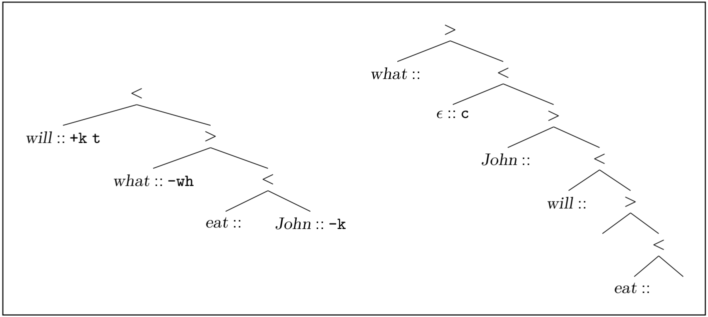

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John will eat cake	*John will cake eat*
what John will eat	*what John will eat*
who will eat cake	*who will cake eat*

A Minimalist Grammar . . . which overgenerates

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S	$\rightarrow$	NP VP	VP	$\rightarrow$	V NP
NP	$\rightarrow$	*John*	VP	$\rightarrow$	*runs*
NP	$\rightarrow$	*Mary*	VP	$\rightarrow$	*walks*
			V	$\rightarrow$	*loves*

John runs	*Mary runs*
John walks	*Mary walks*
John loves John	*Mary loves John*
John loves Mary	*Mary loves Mary*

First solution: covert movement/agree

cake :: `d -k`	*what* :: `d -k -wh`
John :: `d -k`	*who* :: `d -k -wh`
eat :: `=d +k̄ =d v`	ϵ :: `=t +wh c`
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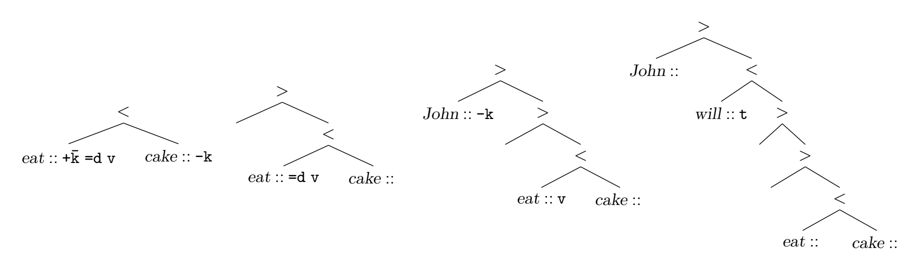

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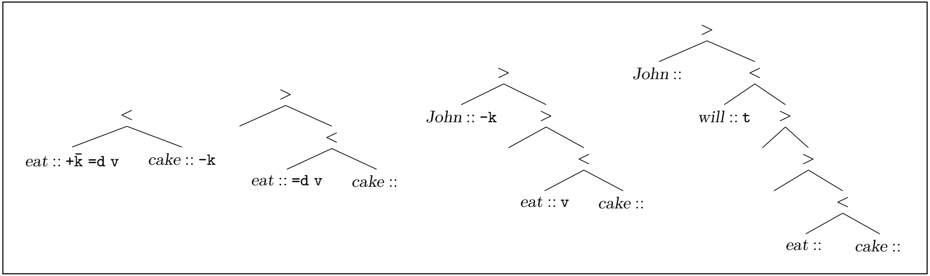

Note order of features on *eat*!

Second solution

Separate `d` into `subj` and `obj`

cake :: `obj`	*what* :: `obj -wh`
John :: `subj -k`	*who* :: `subj -k -wh`
eat :: `=obj =subj v`	ϵ :: `=t +wh c`
will :: `=v +k t`	ϵ :: `=t c`

Problem "solved":

John will eat cake
what John will eat
who will eat cake

Outline

Adding embedded clauses

cake :: `obj`	*what* :: `obj -wh`	*think* :: `=c =subj v`
John :: `subj -k`	*who* :: `subj -k -wh`	*ask* :: `=q =subj v`
eat :: `=obj =subj v`	ϵ :: `=t +wh q`	*Mary* :: `subj -k`
will :: `=v +k t`	ϵ :: `=t c`	

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John :: `subj -k`	*who* :: `subj -k -wh`	*ask* :: `=q =subj v`
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will :: `=v +k t`	ϵ :: `=t c`	

John will eat cake	*Mary will think John will eat cake*	...
what John will eat	*what Mary will think John will eat*	...
who will eat cake	*who Mary will think will eat cake*	...

Adding embedded clauses

cake :: obj	*what* :: obj -wh	*think* :: =c =subj v
John :: subj -k	*who* :: subj -k -wh	*ask* :: =q =subj v
eat :: =obj =subj v	ϵ :: =t +wh q	*Mary* :: subj -k
will :: =v +k t	ϵ :: =t c	

John will eat cake	*Mary will think John will eat cake*	. . .
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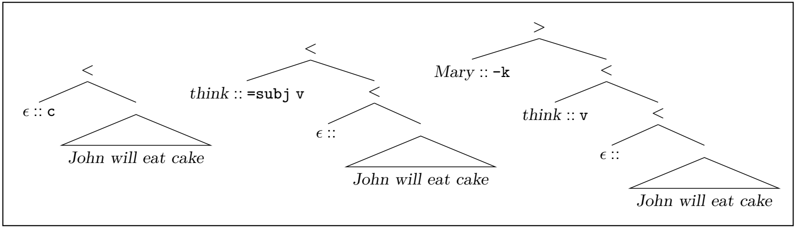
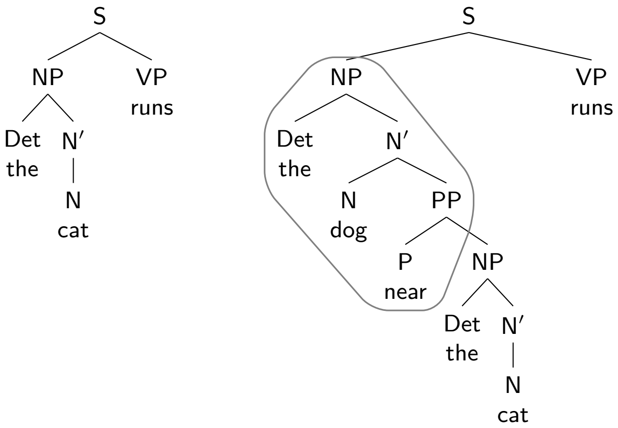


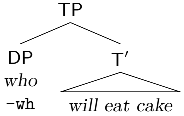
Reminder: "Loops" in a CFG

S	$\rightarrow$	NP VP	VP	$\rightarrow$	*runs*
NP	$\rightarrow$	Det N′	Det	$\rightarrow$	*the*
N′	$\rightarrow$	N	N	$\rightarrow$	*dog*
N′	$\rightarrow$	N PP	N	$\rightarrow$	*cat*
PP	$\rightarrow$	P NP	P	$\rightarrow$	*near*

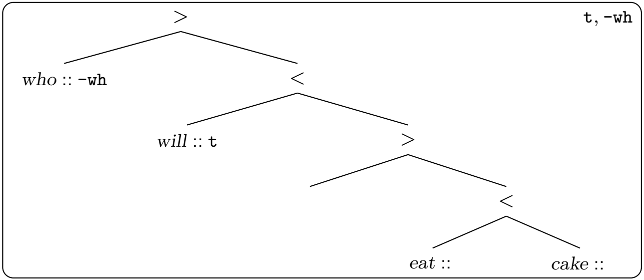


Which extensions create “loops”?

Starting point:



A simple, non-looping completion



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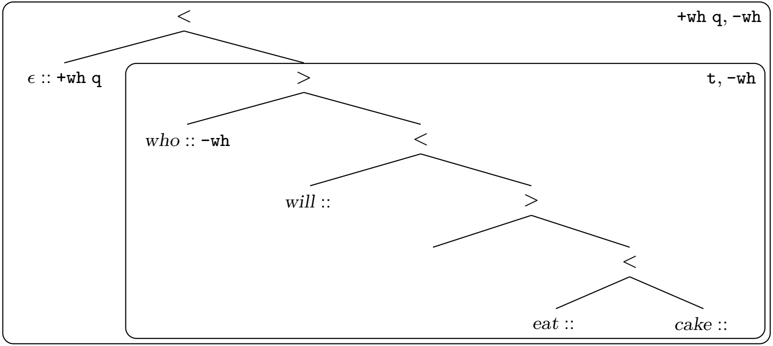

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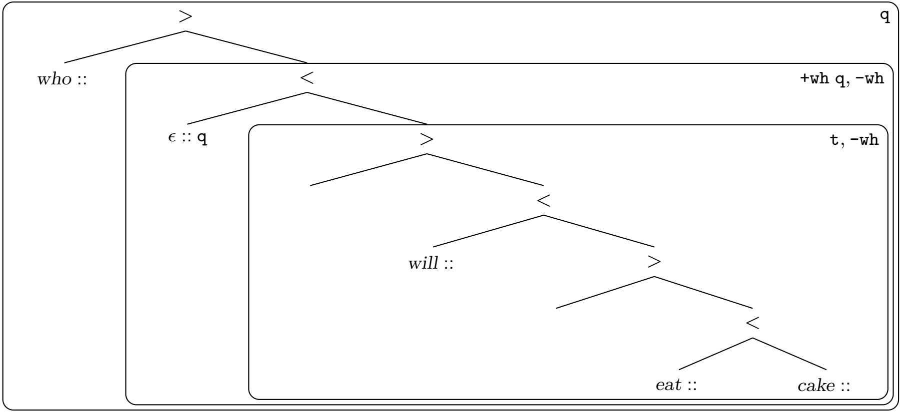

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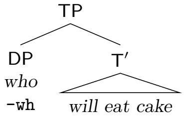

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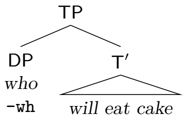
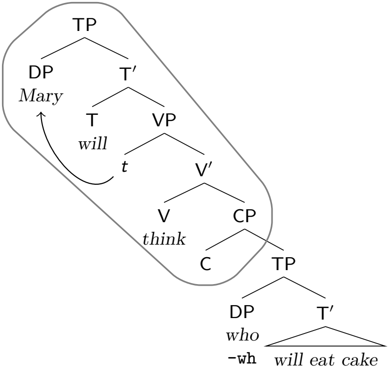
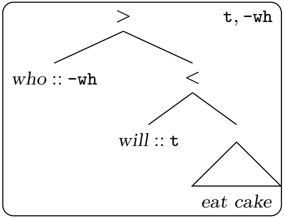
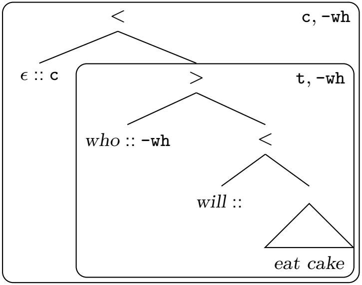




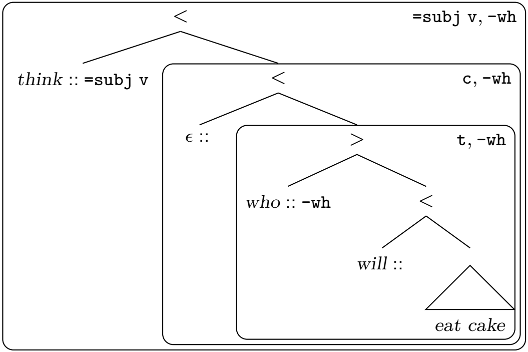
Extending with *Mary will think . . .*



Extending with *Mary will think* . . .



Extending with *Mary will think …*



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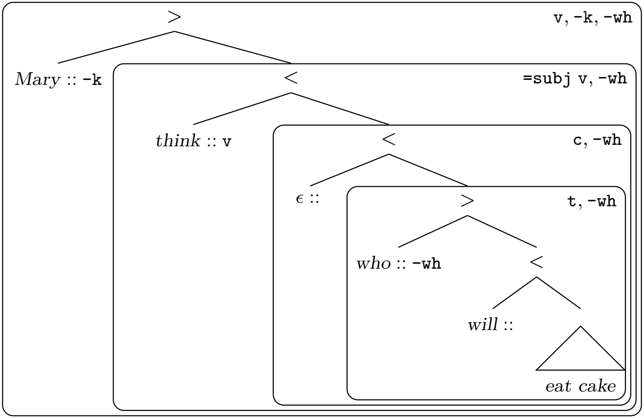

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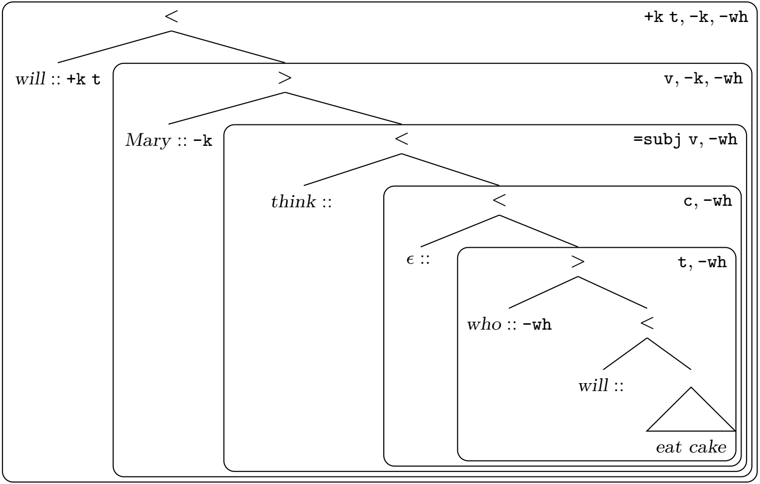

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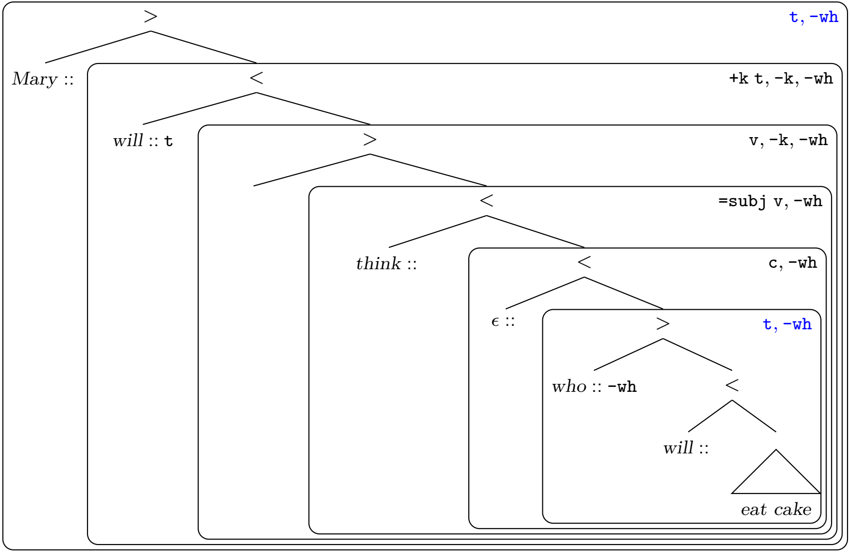
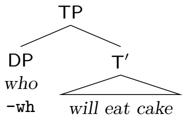
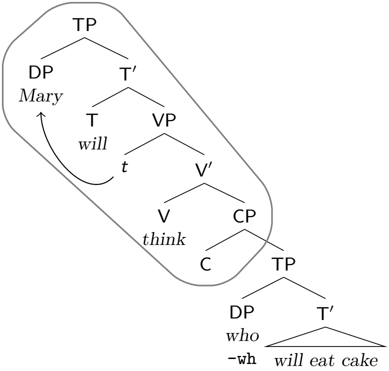


Which extensions create "loops"?

Starting point:





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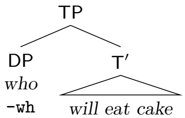

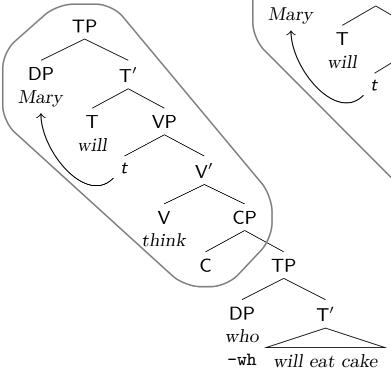

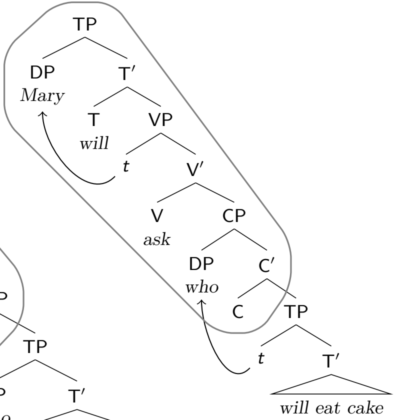

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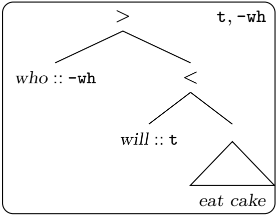

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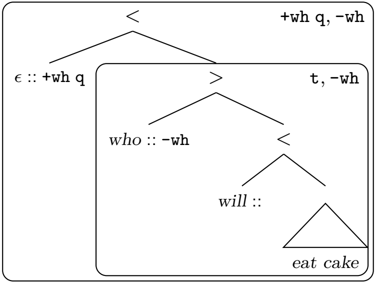

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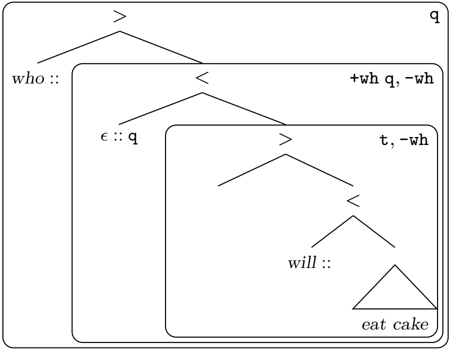

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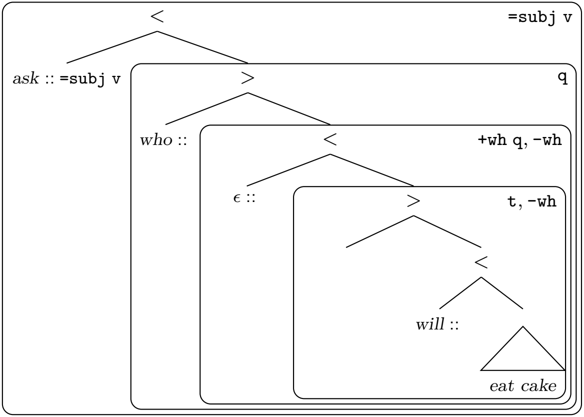

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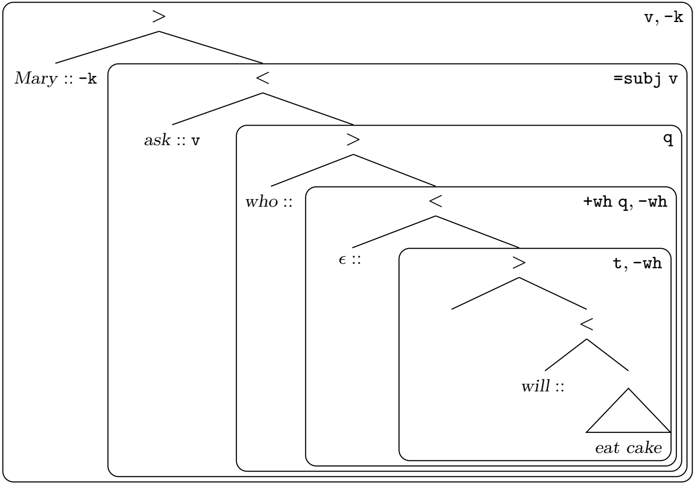

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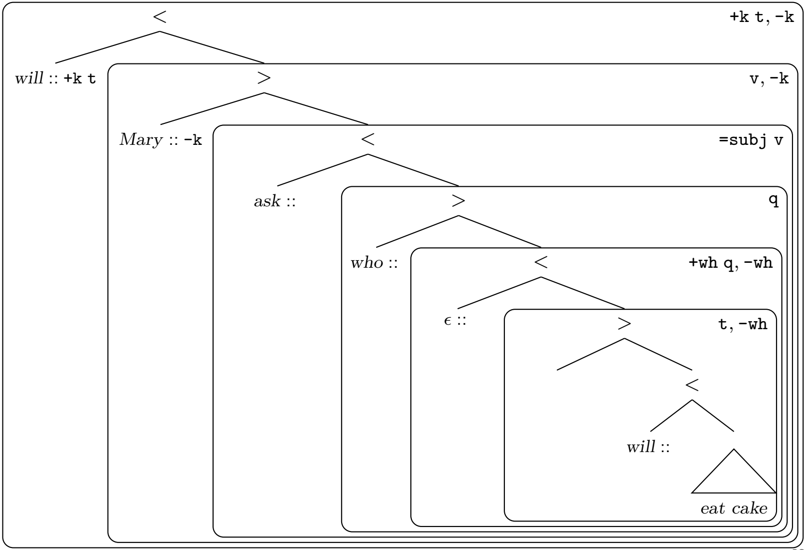

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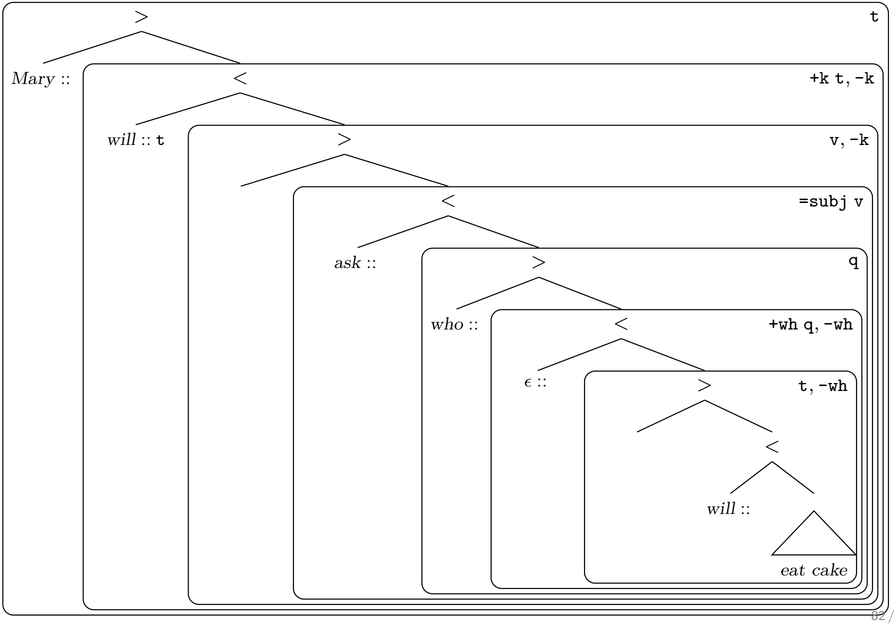

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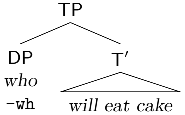

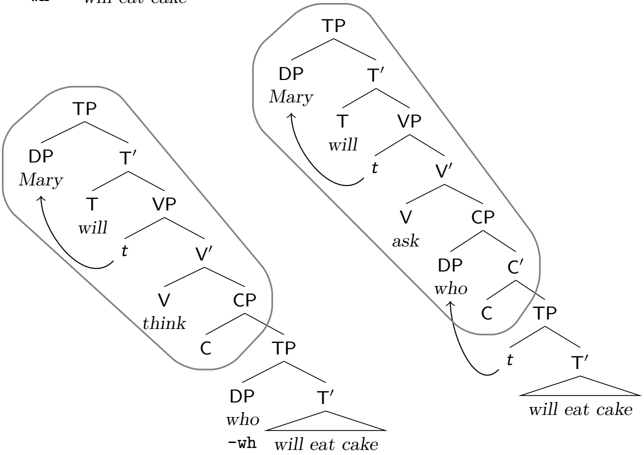

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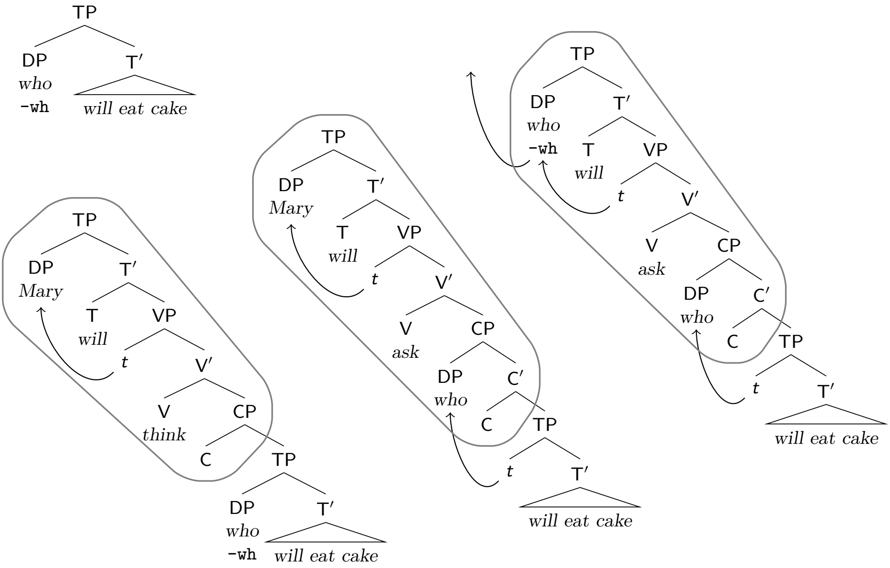

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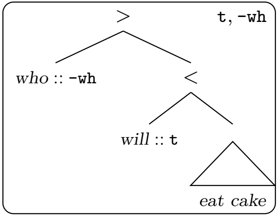

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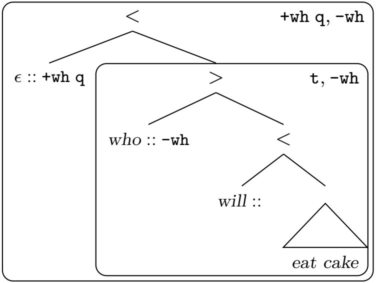

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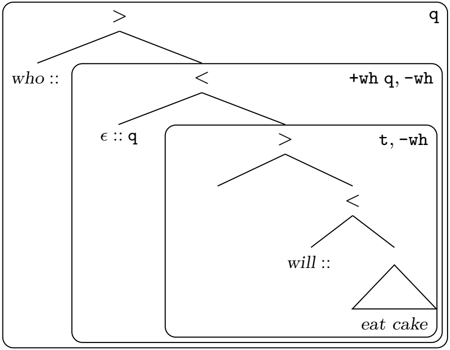

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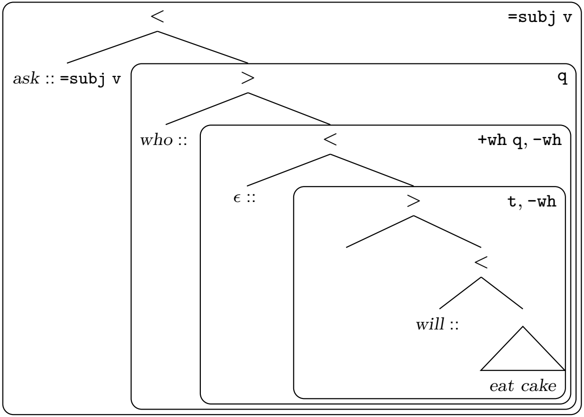

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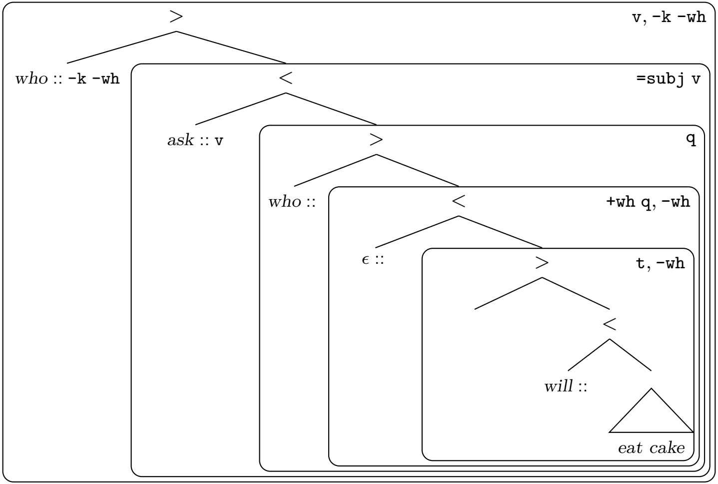

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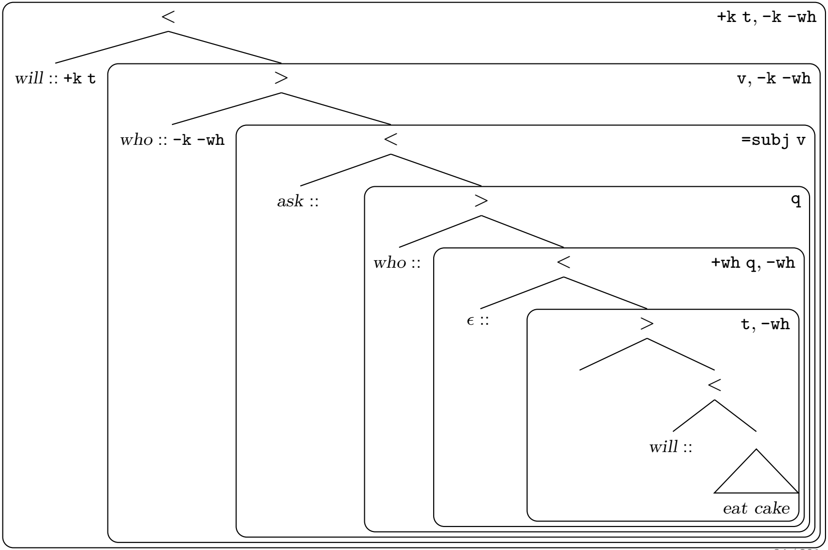

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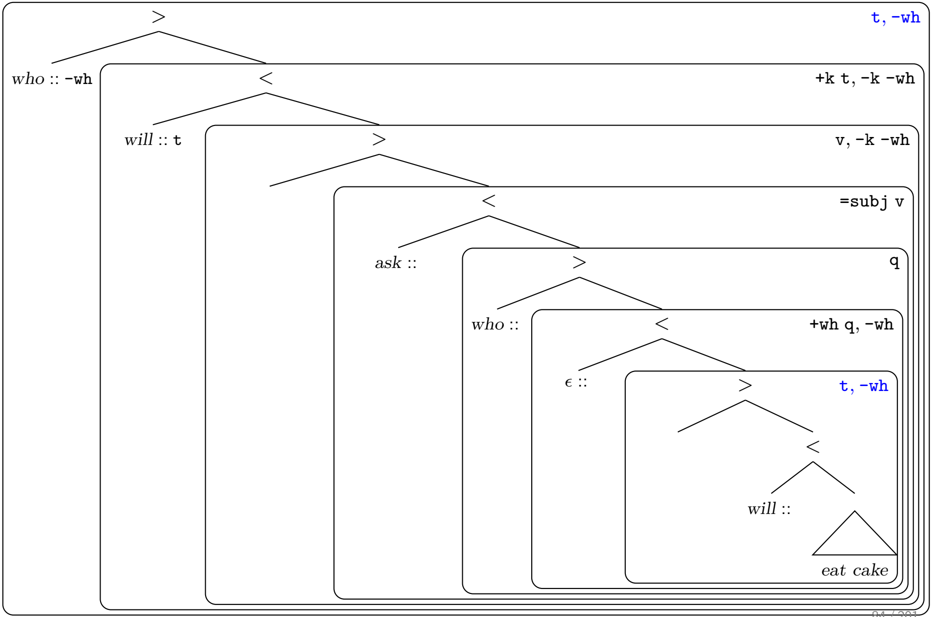

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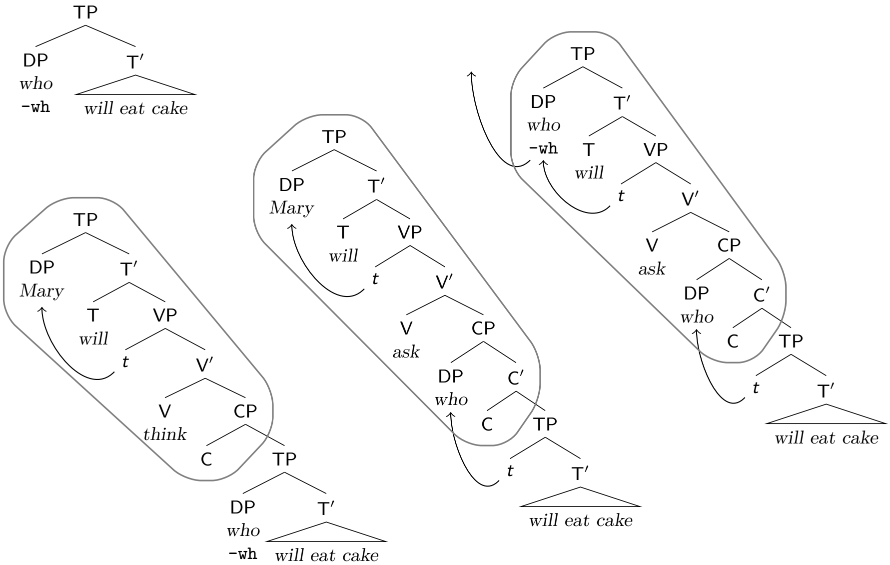
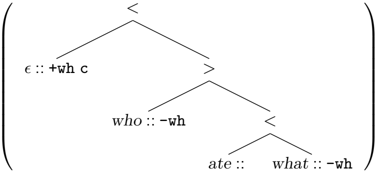


Importance of the SMC

The SMC ensures that there is a finite number of types (that we care about).

Recall: MOVE 

is **undefined**

(Michaelis 2001)

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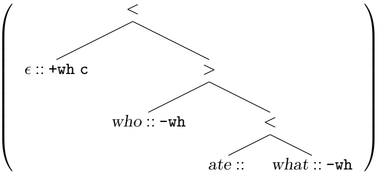
Recall: MOVE 

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- So MOVE cannot be applied to expressions of type $\langle \texttt{+wh c}, \texttt{-wh}, \texttt{-wh} \rangle$.

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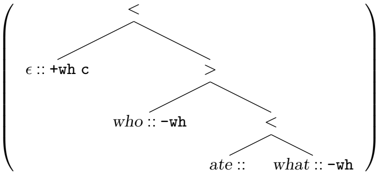

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- So MOVE cannot be applied to expressions of type ⟨+wh c, -wh, -wh⟩.
- Nor to expressions of type ⟨+wh c, -wh -k, -wh⟩.
- These are “dead end” types.

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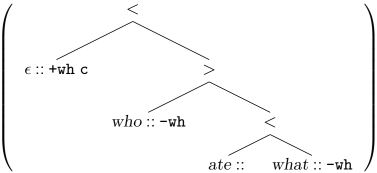

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- Nor to expressions of type ⟨+wh c, -wh -k, -wh⟩.
- These are "dead end" types.
- An expression of type ⟨t, -wh -k, -wh⟩ can be the input to MERGE.

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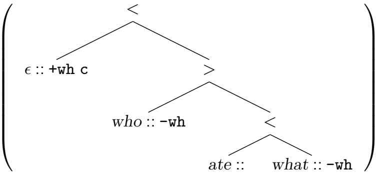

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- An expression of type $\langle$t, -wh -k, -wh$\rangle$ can be the input to MERGE.
- But such types are also bound to lead to dead ends.

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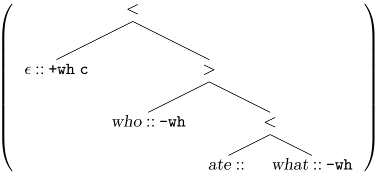

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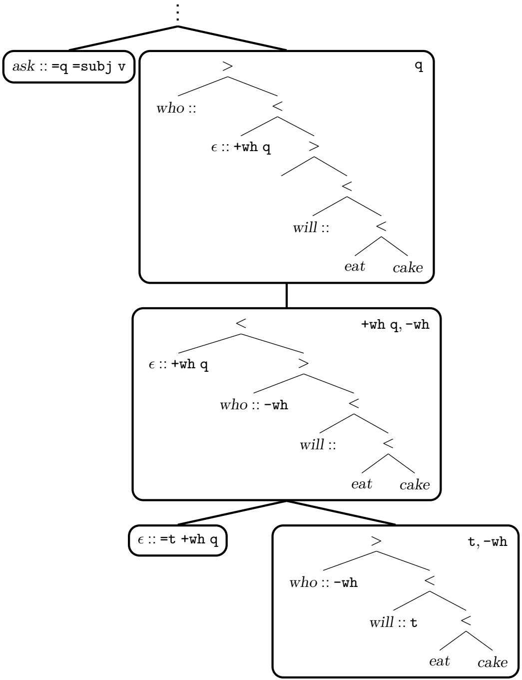
- These are "dead end" types.

- An expression of type $\langle$t, -wh -k, -wh$\rangle$ can be the input to MERGE.
- But such types are also bound to lead to dead ends.

So any type of the form $\langle \alpha, \ldots, \texttt{-f}\alpha_i, \ldots, \texttt{-f}\alpha_j, \ldots \rangle$ is not **useful**.
Thus there are only a finite number of useful types.

(Michaelis 2001)

Outline

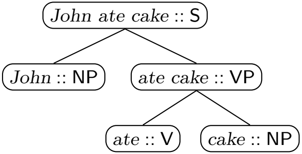

⋮
ask :: =q =subj v
>
q
who ::
<
ϵ :: +wh q
>
<
will ::
<
eat
cake
<
+wh q, -wh
ϵ :: +wh q
>
who :: -wh
<
will ::
<
eat
cake
ϵ :: =t +wh q
>
t, -wh
who :: -wh
<
will :: t
<
eat
cake

A possible concern

Question

“But hasn’t our eventual derived expression lost the information that ‘cake’ is a DP?”

Derivations



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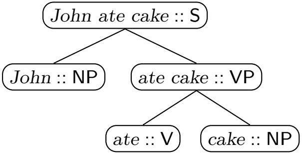
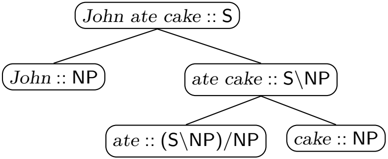


$$\dfrac{\mathit{John} :: \mathsf{NP} \qquad \dfrac{\mathit{ate} :: (\mathsf{S}\backslash\mathsf{NP})/\mathsf{NP} \qquad \mathit{cake} :: \mathsf{NP}}{\mathit{ate\ cake} :: \mathsf{S}\backslash\mathsf{NP}}}{\mathit{John\ ate\ cake} :: \mathsf{S}}$$



A possible concern

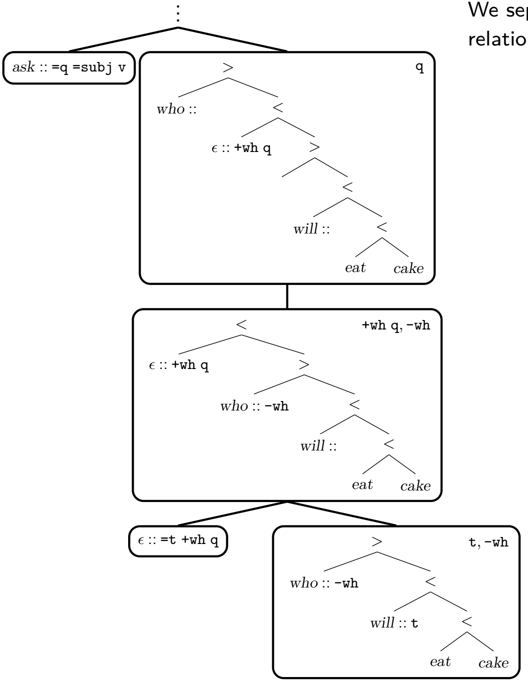
Question

"But hasn't our eventual derived expression lost the information that 'cake' is a DP?"

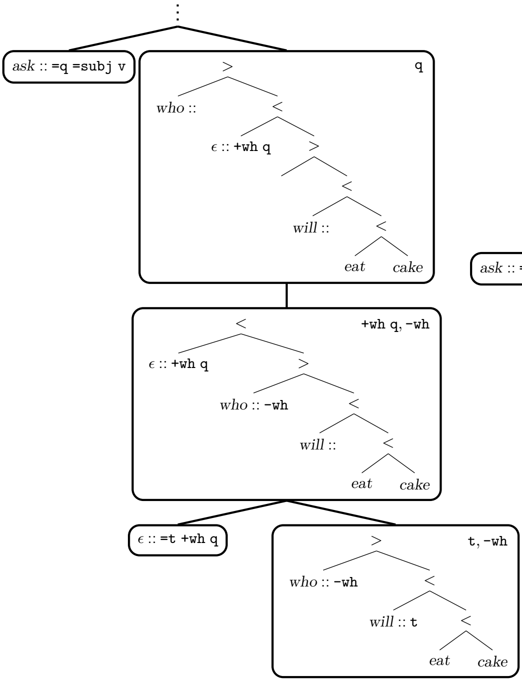
Answer

Yes, but only in the same way that $\mathit{John\ ate\ cake}$ :: S has also lost this information.

The point is not that we can look at the whole derivation to retrieve that information, the point is that the information has already done its job.



We separate the derivational precedence relation from the part-whole relation


ask :: =q =subj v
>
q
who ::
<
ϵ :: +wh q
>
<
will ::
<
eat
cake
<
+wh q, -wh
ϵ :: +wh q
>
who :: -wh
<
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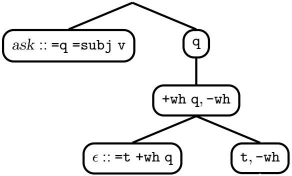
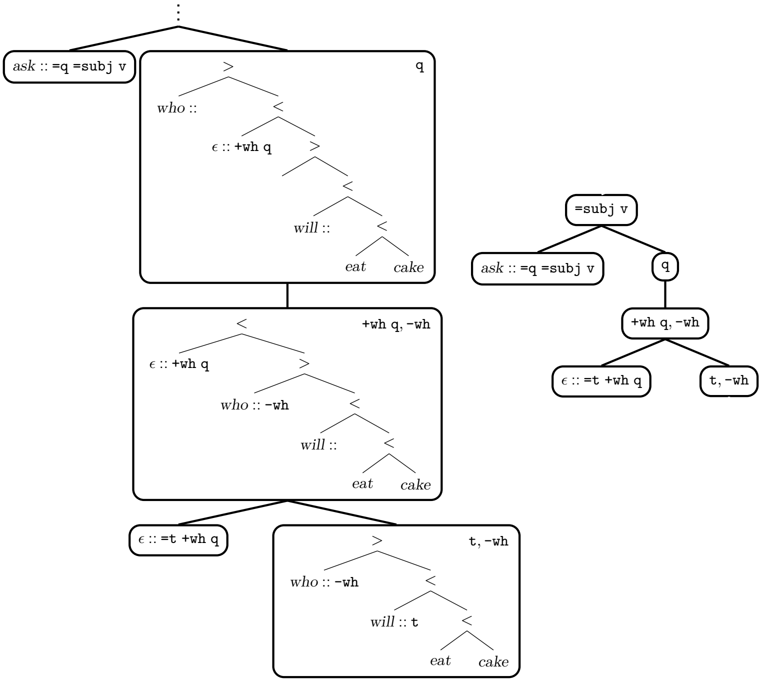
<
eat
cake
ϵ :: =t +wh q
>
t, -wh
who :: -wh
<
will :: t
<
eat
cake


ask :: =q =subj v
q
+wh q, -wh
ϵ :: =t +wh q
t, -wh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ϵ :: +wh q
who :: -wh
will ::
eat
cake
ϵ :: =t +wh q
t, -wh
who :: -wh
will :: t
eat
cake
=subj v
ask :: =q =subj v
q
+wh q, -wh
ϵ :: =t +wh q
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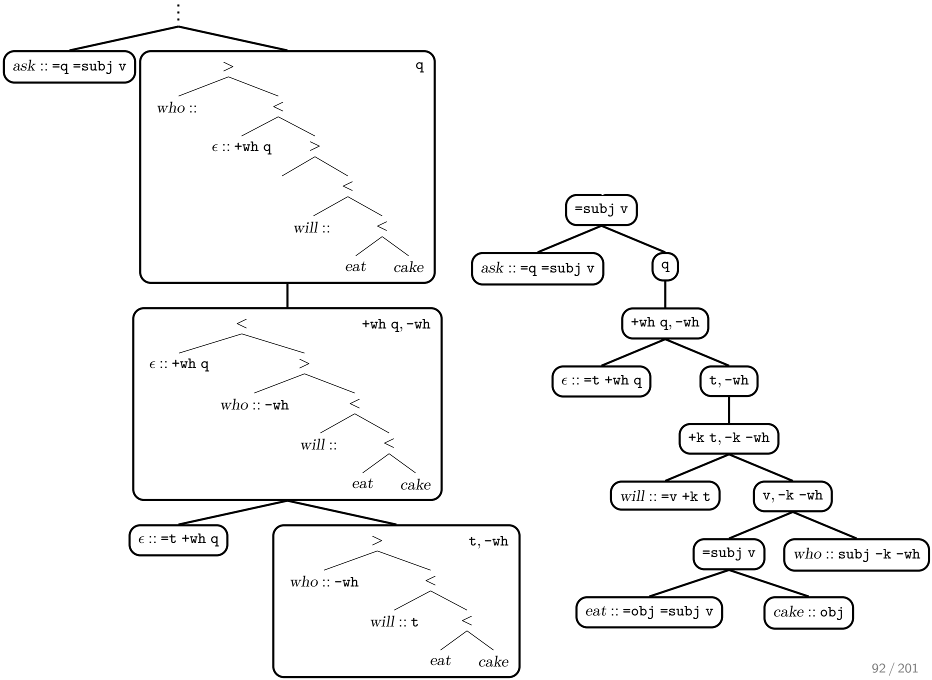
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ϵ :: =t +wh q
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t, -wh
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<
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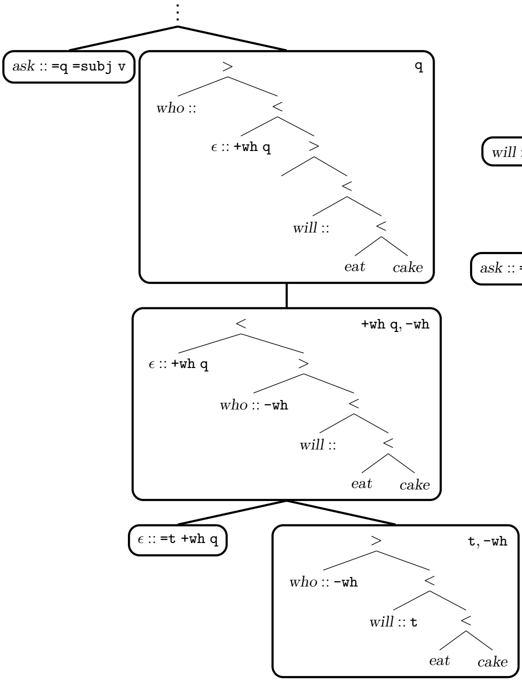
cake
=subj v
ask :: =q =subj v
q
+wh q, -wh
ϵ :: =t +wh q
t, -wh
+k t, -k -wh
will :: =v +k t
v, -k -wh
=subj v
who :: subj -k -wh
eat :: =obj =subj v
cake :: obj



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ϵ :: =t +wh q
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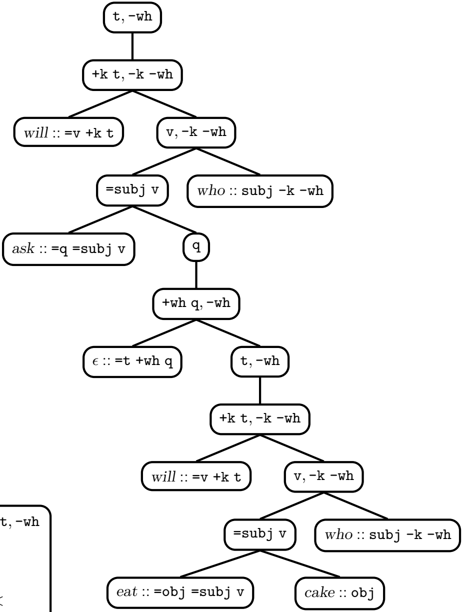

t, -wh
+k t, -k -wh
will :: =v +k t
v, -k -wh
=subj v
who :: subj -k -wh
ask :: =q =subj v
q
+wh q, -wh
ϵ :: =t +wh q
t, -wh
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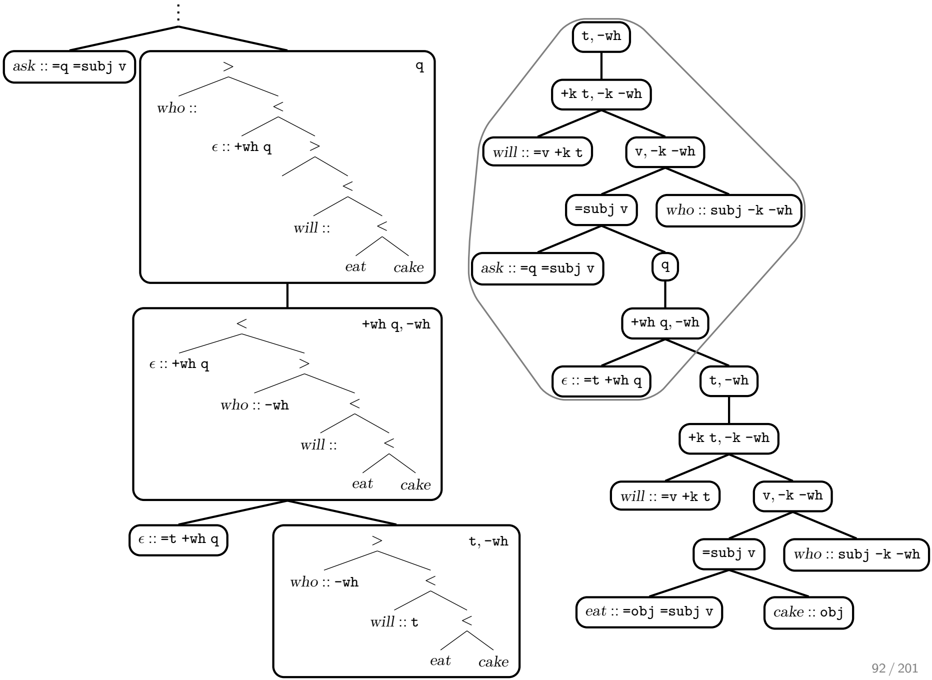
v, -k -wh
=subj v
who :: subj -k -wh
eat :: =obj =subj v
cake :: obj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t, -wh
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will :: t
eat
cake
t, -wh
+k t, -k -wh
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v, -k -wh
=subj v
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v, -k -wh
=subj v
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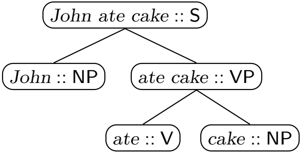
eat :: =obj =subj v
cake :: obj

Labeling of internal nodes



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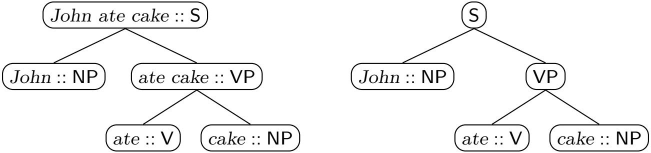

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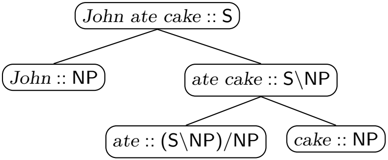

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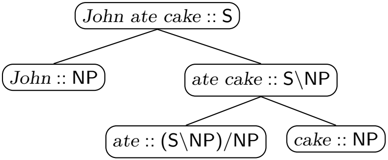

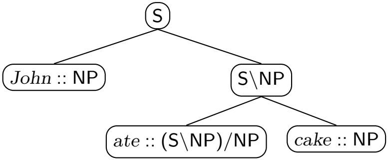

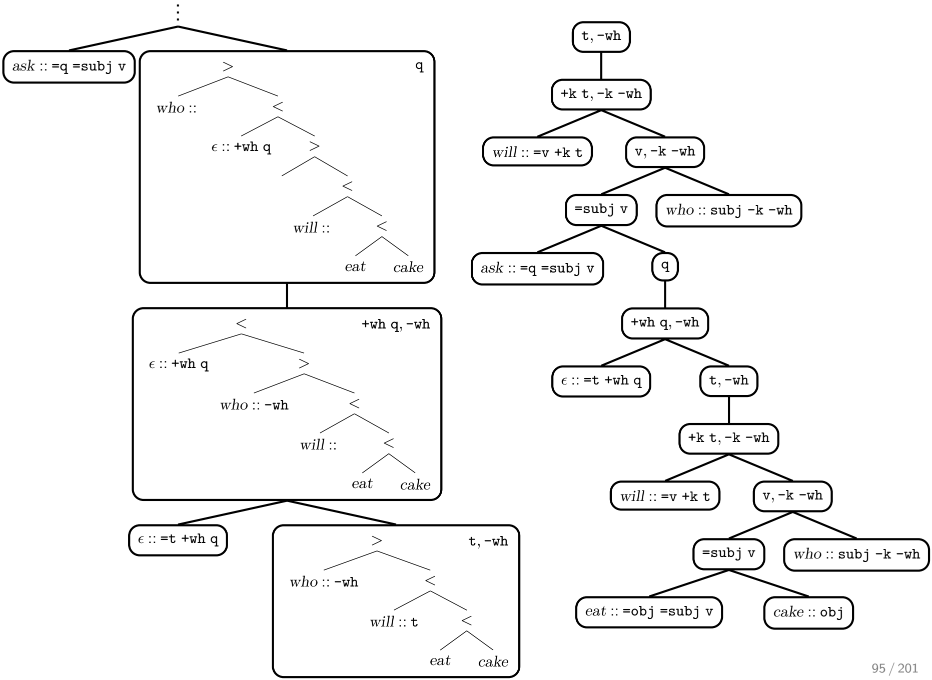
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who :: -wh
will :: t
eat
cake
t, -wh
+k t, -k -wh
will :: =v +k t
v, -k -wh
=subj v
who :: subj -k -wh
ask :: =q =subj v
q
+wh q, -wh
ϵ :: =t +wh q
t, -wh
+k t, -k -wh
will :: =v +k t
v, -k -wh
=subj v
who :: subj -k -wh
eat :: =obj =subj v
cake :: obj

Context-free structure

$$
\begin{aligned}
\langle \texttt{=subj v} \rangle &\rightarrow \langle \texttt{=q =subj v} \rangle \quad \langle \texttt{q} \rangle \\
\langle \texttt{q} \rangle &\rightarrow \langle \texttt{+wh q}, \texttt{-wh} \rangle \\
\langle \texttt{+wh q}, \texttt{-wh} \rangle &\rightarrow \langle \texttt{=t +wh q} \rangle \quad \langle \texttt{t}, \texttt{-wh} \rangle
\end{aligned}
$$

Context-free structure

$$
\begin{array}{rcll}
\langle \texttt{=subj v} \rangle & \rightarrow & \langle \texttt{=q =subj v} \rangle & \langle \texttt{q} \rangle \\
\langle \texttt{q} \rangle & \rightarrow & \langle \texttt{+wh q}, \texttt{-wh} \rangle & \\
\langle \texttt{+wh q}, \texttt{-wh} \rangle & \rightarrow & \langle \texttt{=t +wh q} \rangle & \langle \texttt{t}, \texttt{-wh} \rangle
\end{array}
$$

General schemas for MERGE steps (approximate):

$$
\begin{array}{rcll}
\langle \gamma, \alpha_1, \dots, \alpha_j, \beta_1, \dots, \beta_k \rangle & \rightarrow & \langle \texttt{=f}\gamma, \alpha_1, \dots, \alpha_j \rangle & \langle \texttt{f}, \beta_1, \dots, \beta_k \rangle \\
\langle \gamma, \alpha_1, \dots, \alpha_j, \delta, \beta_1, \dots, \beta_k \rangle & \rightarrow & \langle \texttt{=f}\gamma, \alpha_1, \dots, \alpha_j \rangle & \langle \texttt{f}\delta, \beta_1, \dots, \beta_k \rangle
\end{array}
$$

General schemas for MOVE steps (approximate):

$$
\begin{array}{rcl}
\langle \gamma, \alpha_1, \dots, \alpha_{i-1}, \alpha_{i+1}, \dots, \alpha_k \rangle & \rightarrow & \langle \texttt{+f}\gamma, \alpha_1, \dots, \alpha_{i-1}, \texttt{-f}, \alpha_{i+1}, \dots, \alpha_k \rangle \\
\langle \gamma, \alpha_1, \dots, \alpha_{i-1}, \delta, \alpha_{i+1}, \dots, \alpha_k \rangle & \rightarrow & \langle \texttt{+f}\gamma, \alpha_1, \dots, \alpha_{i-1}, \texttt{-f}\delta, \alpha_{i+1}, \dots, \alpha_k \rangle
\end{array}
$$

Context-free structure

$$\begin{array}{rcll} \langle \texttt{=subj v} \rangle & \rightarrow & \langle \texttt{=q =subj v} \rangle & \langle \texttt{q} \rangle \\ \langle \texttt{q} \rangle & \rightarrow & \langle \texttt{+wh q}, \texttt{-wh} \rangle & \\ \langle \texttt{+wh q}, \texttt{-wh} \rangle & \rightarrow & \langle \texttt{=t +wh q} \rangle & \langle \texttt{t}, \texttt{-wh} \rangle \end{array}$$

General schemas for MERGE steps (approximate):

$$\begin{array}{rcll} \langle \gamma, \alpha_1, \dots, \alpha_j, \beta_1, \dots, \beta_k \rangle & \rightarrow & \langle \texttt{=f}\gamma, \alpha_1, \dots, \alpha_j \rangle & \langle \texttt{f}, \beta_1, \dots, \beta_k \rangle \\ \langle \gamma, \alpha_1, \dots, \alpha_j, \delta, \beta_1, \dots, \beta_k \rangle & \rightarrow & \langle \texttt{=f}\gamma, \alpha_1, \dots, \alpha_j \rangle & \langle \texttt{f}\delta, \beta_1, \dots, \beta_k \rangle \end{array}$$

General schemas for MOVE steps (approximate):

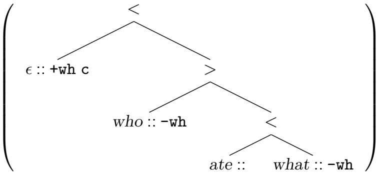
$$\begin{array}{rcl} \langle \gamma, \alpha_1, \dots, \alpha_{i-1}, \alpha_{i+1}, \dots, \alpha_k \rangle & \rightarrow & \langle \texttt{+f}\gamma, \alpha_1, \dots, \alpha_{i-1}, \texttt{-f}, \alpha_{i+1}, \dots, \alpha_k \rangle \\ \langle \gamma, \alpha_1, \dots, \alpha_{i-1}, \delta, \alpha_{i+1}, \dots, \alpha_k \rangle & \rightarrow & \langle \texttt{+f}\gamma, \alpha_1, \dots, \alpha_{i-1}, \texttt{-f}\delta, \alpha_{i+1}, \dots, \alpha_k \rangle \end{array}$$

- MOVE steps **change** something without **combining** it with anything
- Compare with unary CFG rules, or type-raising in CCG, or ...

Importance of the SMC

The SMC ensures that there is a finite number of types (that we care about).

Recall: MOVE



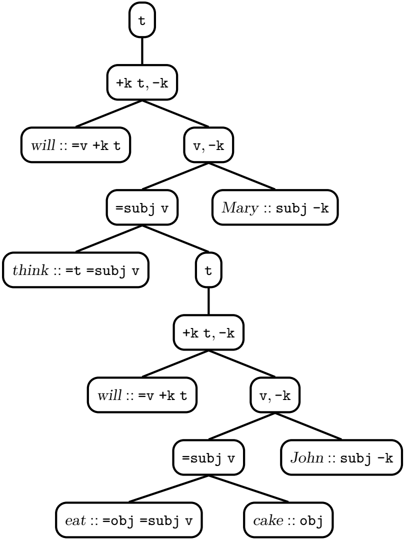
is **undefined**

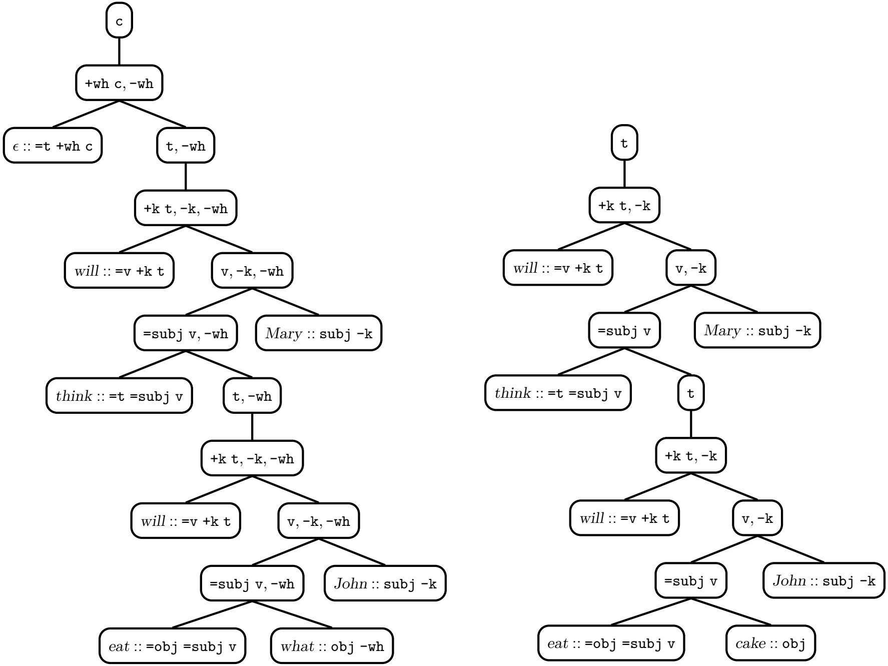
- So MOVE cannot be applied to expressions of type $\langle$+wh c, -wh, -wh$\rangle$.
- Nor to expressions of type $\langle$+wh c, -wh -k, -wh$\rangle$.
- These are "dead end" types.

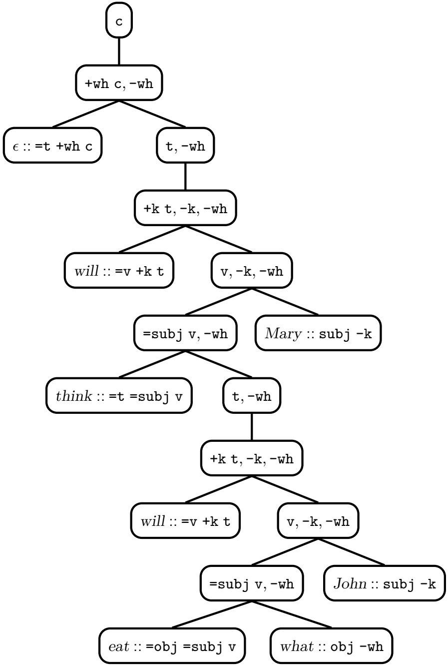
- An expression of type $\langle$t, -wh -k, -wh$\rangle$ can be the input to MERGE.
- But such types are also bound to lead to dead ends.

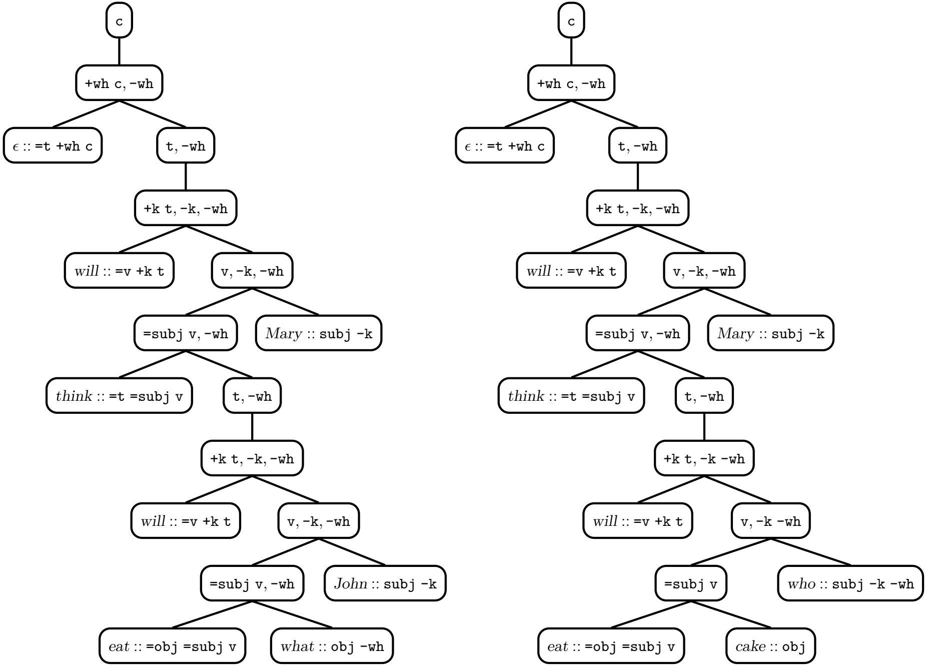
So any type of the form $\langle\alpha, \ldots, \texttt{-f}\alpha_i, \ldots, \texttt{-f}\alpha_j, \ldots\rangle$ is not **useful**.
Thus there are only a finite number of useful types.

(Michaelis 2001)


t
+k t, -k
will :: =v +k t
v, -k
=subj v
Mary :: subj -k
think :: =t =subj v
t
+k t, -k
will :: =v +k t
v, -k
=subj v
John :: subj -k
eat :: =obj =subj v
cake :: obj


c
+wh c, -wh
ϵ :: =t +wh c
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
Mary :: subj -k
think :: =t =subj v
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
John :: subj -k
eat :: =obj =subj v
what :: obj -wh
t
+k t, -k
will :: =v +k t
v, -k
=subj v
Mary :: subj -k
think :: =t =subj v
t
+k t, -k
will :: =v +k t
v, -k
=subj v
John :: subj -k
eat :: =obj =subj v
cake :: obj


c
+wh c, -wh
ϵ :: =t +wh c
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
Mary :: subj -k
think :: =t =subj v
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
John :: subj -k
eat :: =obj =subj v
what :: obj -wh


c
+wh c, -wh
ϵ :: =t +wh c
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
Mary :: subj -k
think :: =t =subj v
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
John :: subj -k
eat :: =obj =subj v
what :: obj -wh
c
+wh c, -wh
ϵ :: =t +wh c
t, -wh
+k t, -k, -wh
will :: =v +k t
v, -k, -wh
=subj v, -wh
Mary :: subj -k
think :: =t =subj v
t, -wh
+k t, -k -wh
will :: =v +k t
v, -k -wh
=subj v
who :: subj -k -wh
eat :: =obj =subj v
cake :: obj

Part 1: Grammars and cognitive hypotheses

- What is a grammar?
- What can grammars do?
- Concrete illustration of a target: Surprisal

Parts 2–4: Assembling the pieces

- Minimalist Grammars (MGs)
- MGs and MCFGs
- Probabilities on MGs

Part 5: Learning and wrap-up

- Something slightly different: Learning model
- Recap and open questions

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