Remarks on MCFGs in the Light of Minimalist Grammars

October 6, 2010

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Outline of the talk

- Introduction.
  - Minimalist grammars.
  - Implementation of two locality conditions.
  - Relation to multiple context-free grammars.
- Monadic branching multiple context-free grammars.
- Concluding remarks.

Introduction

- Minimalist grammars (MGs) (Stabler 1997, 1999) provide an attempt at a rigorous algebraic formalization (of some) of the perspectives adopted in the minimalist branch of generative grammar.

  MGs in that format constitute a mildly context-sensitive grammar (MSCG) formalism in the sense of Joshi 1985 (Michaelis 2001a,b).

- Two crucial features of MGs helped achieving this result:
  - the resource sensitivity (encoded in the checking mechanism),
  - the implementation of the shortest move condition (SMC).

Minimalist grammars

- Work on MGs defined in this sense can, thus, be seen as having led to a realignment of “grammars found ‘useful’ by linguists” and formal complexity theory.

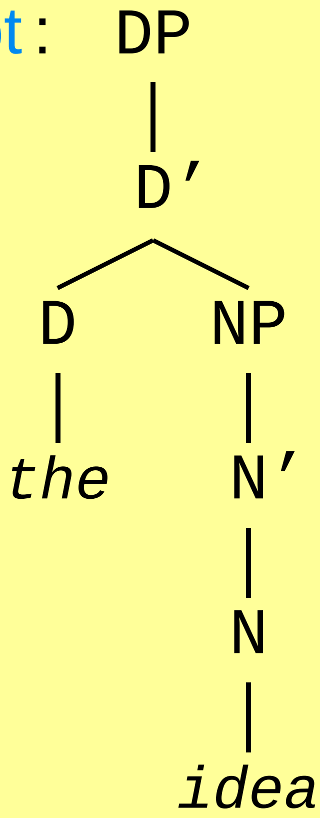
Minimalist grammars

- In fact, MGs are capable of integrating (if needed) a variety of (arguably) “odd” items from the syntactician’s toolbox such as:

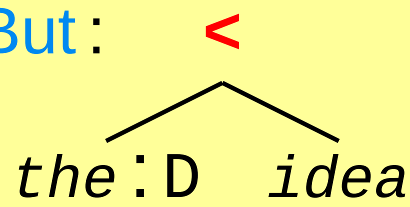
  - head movement (Stabler 1997, 2001)
  - (strict) remnant movement (Stabler 1997, 1999)
  - affix hopping (Stabler 2001)
  - adjunction and scrambling (Frey & Gärtner 2002)
  - late adjunction and extraposition (Gärtner & Michaelis 2008)
  - copy-movement (Kobele 2006)
  - relativized minimality (Stabler 2011)

- The objects generated by an MG — minimalist expressions.

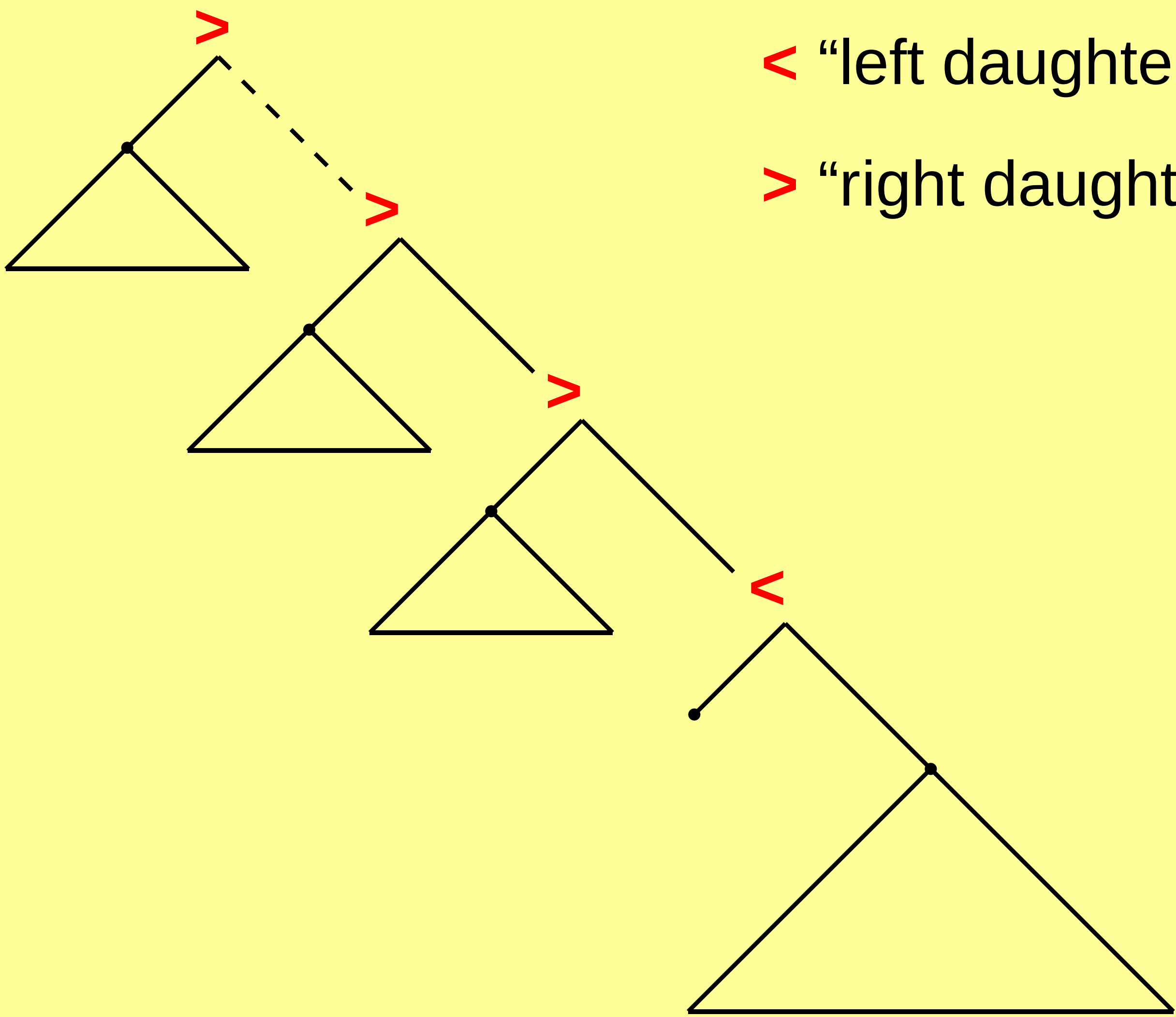
Not:



But:



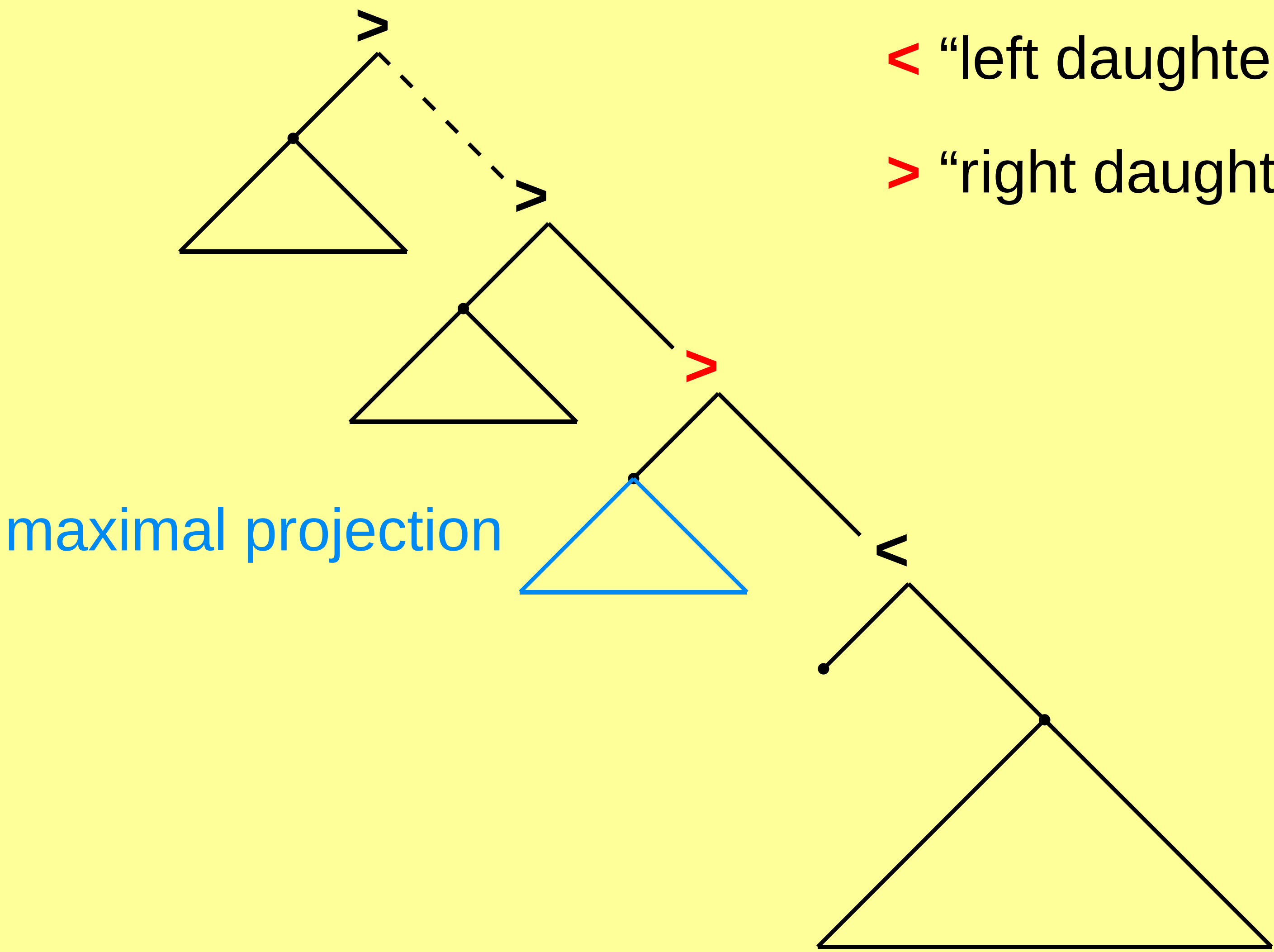
< “points towards” the projecting daughter, and, thus, “towards” the head of the phrase.



< “left daughter projects”

> “right daughter projects”

- non-leaf-labels [projection]



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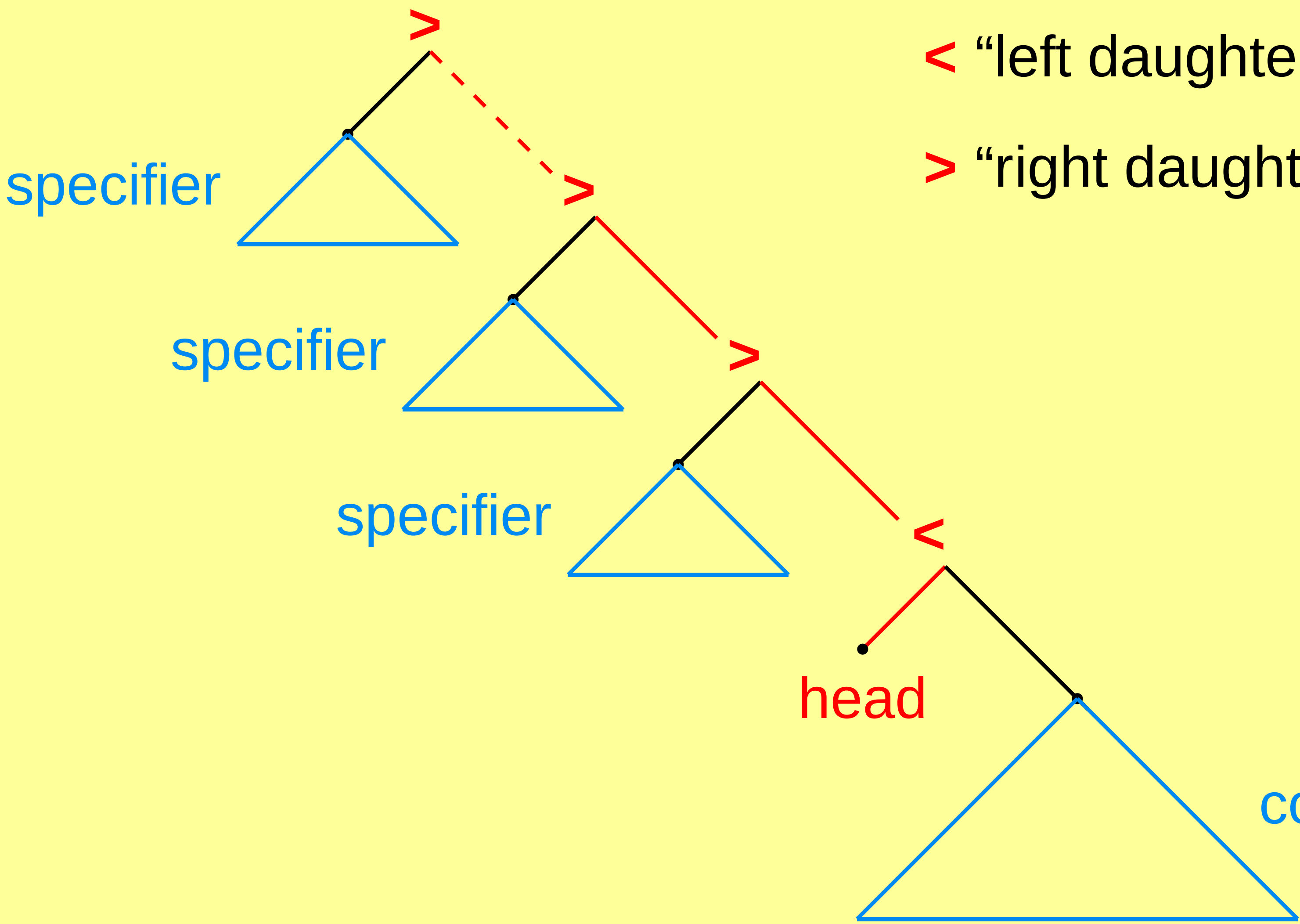

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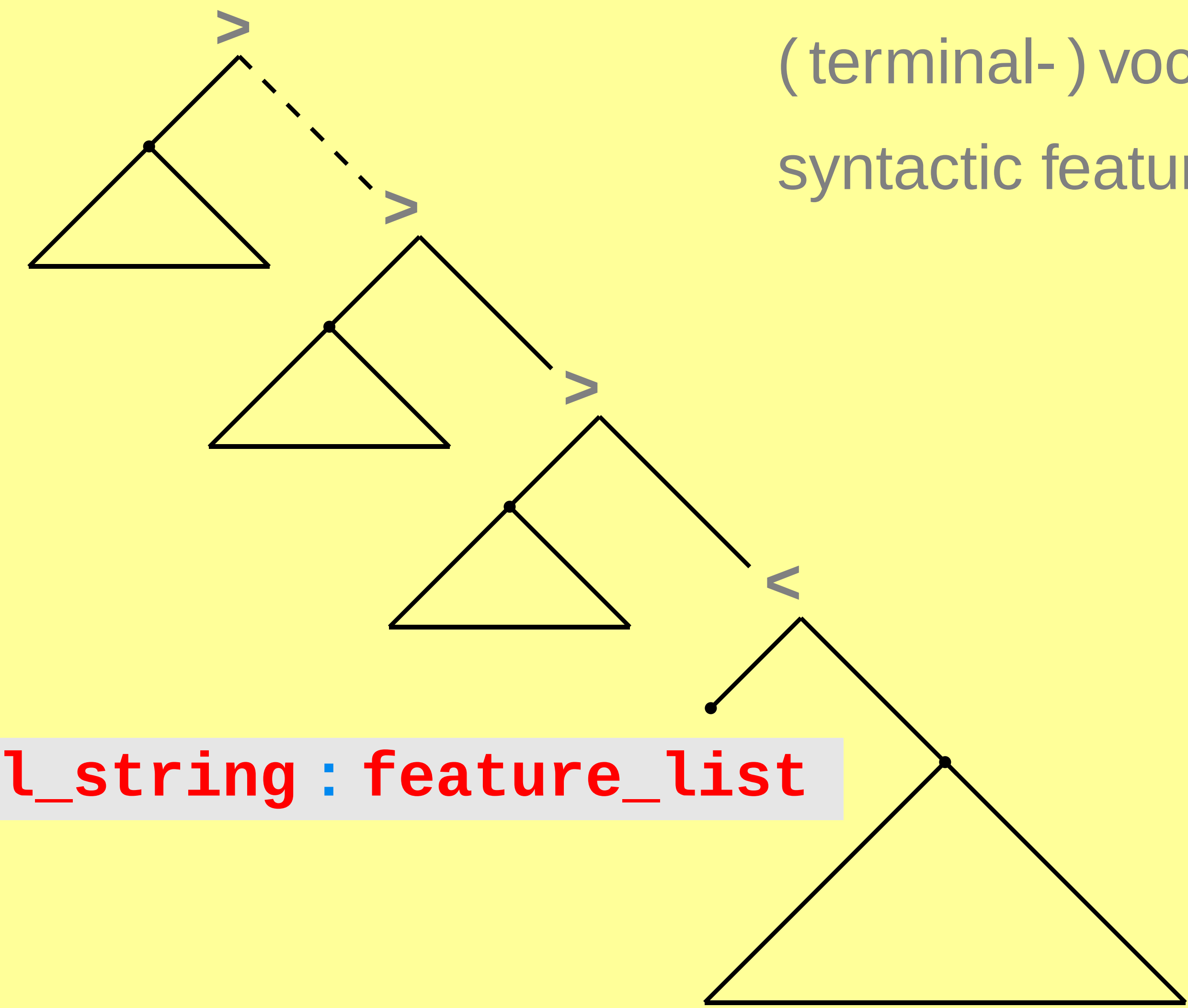


(terminal-) vocabulary

syntactic features

terminal_string : feature_list

- leaf-labels

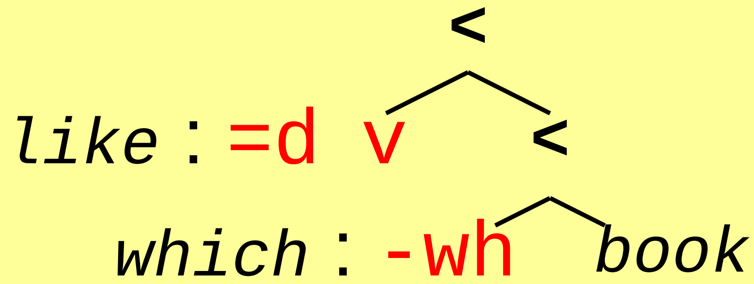
- There are different types of syntactic features.

(basic) categories:	`x, y, z, ...`
m(erge)-selectors:	`=x, =y, =z, ...`
m(ove)-licensees:	`-x, -y, -z, ...`
m(ove)-licensors:	`+x, +y, +z, ...`

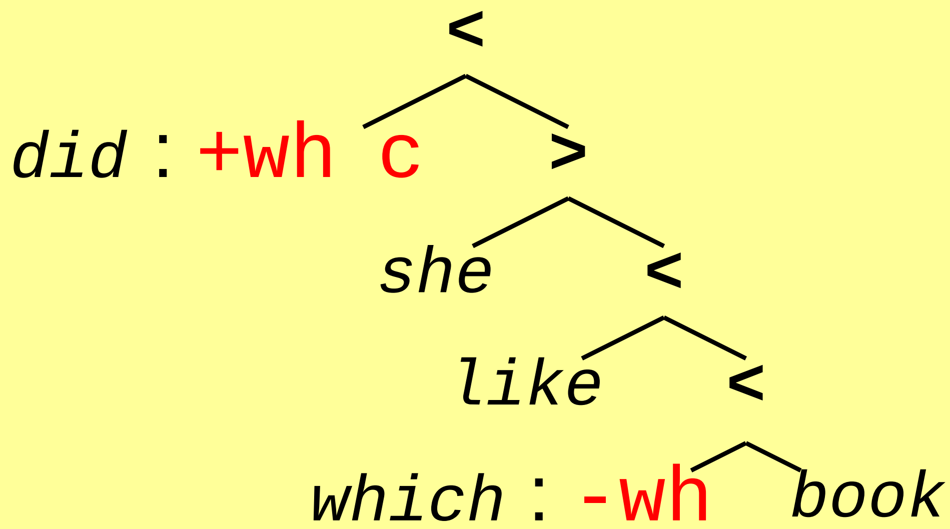
...

Minimalist expresssions (examples)

like :: =d =d v



she :: d



Building minimalist expressions

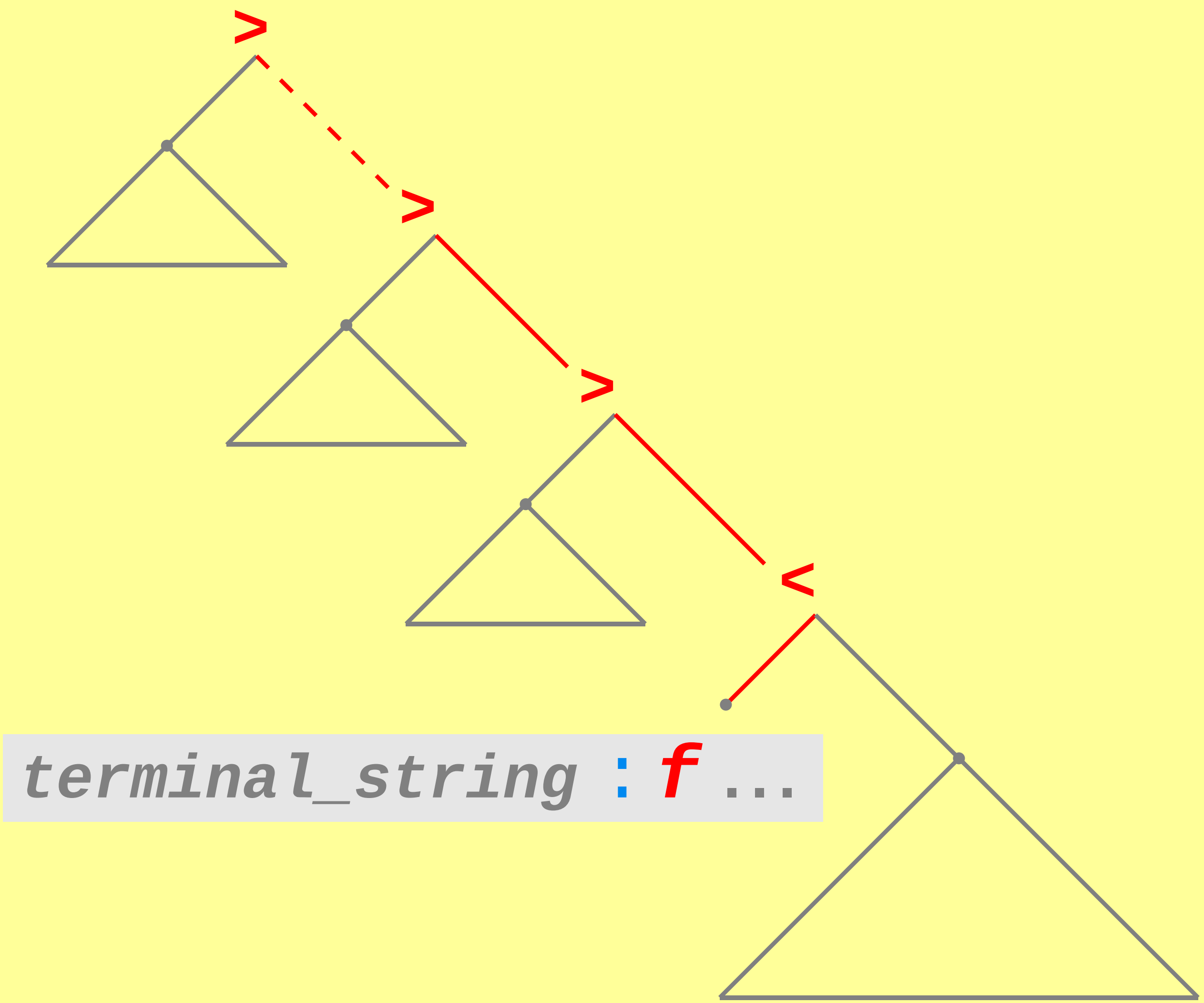
- Starting from a finite set of simple expressions (a lexicon),
  minimalist expressions can be built up recursively

  – by applying structure building functions
    checking off instances of syntactic features “from left to right,”

    where, after having applied a structure building function, the triggering feature instances are canceled.

- Different types of syntactic features trigger
  different structure building functions.

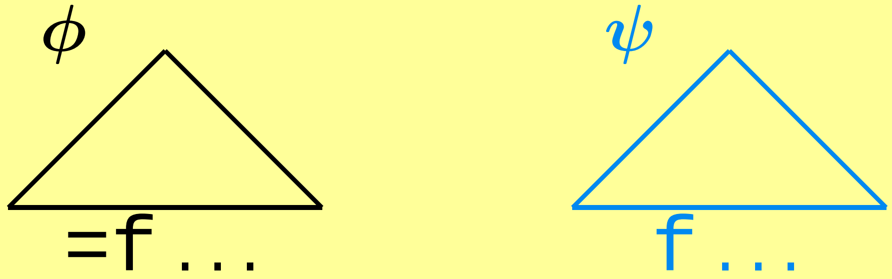
“ Displaying feature *f* ”



head-label is of the form `terminal_string : f ...`

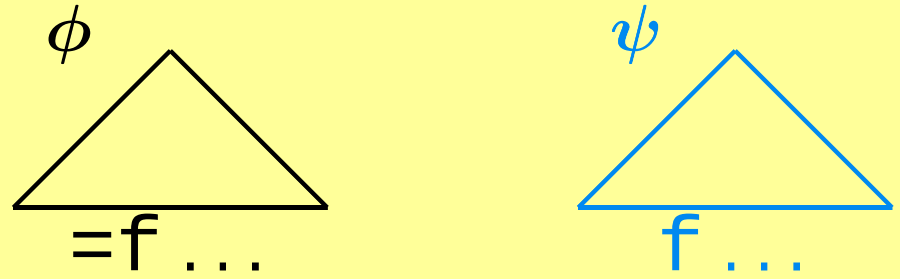
Structure building functions

$$\text{merge} : \text{Trees} \times \text{Trees} \xrightarrow{\text{part}} \text{Trees}$$



Structure building functions

merge : Trees × Trees $\xrightarrow{\text{part}}$ Trees



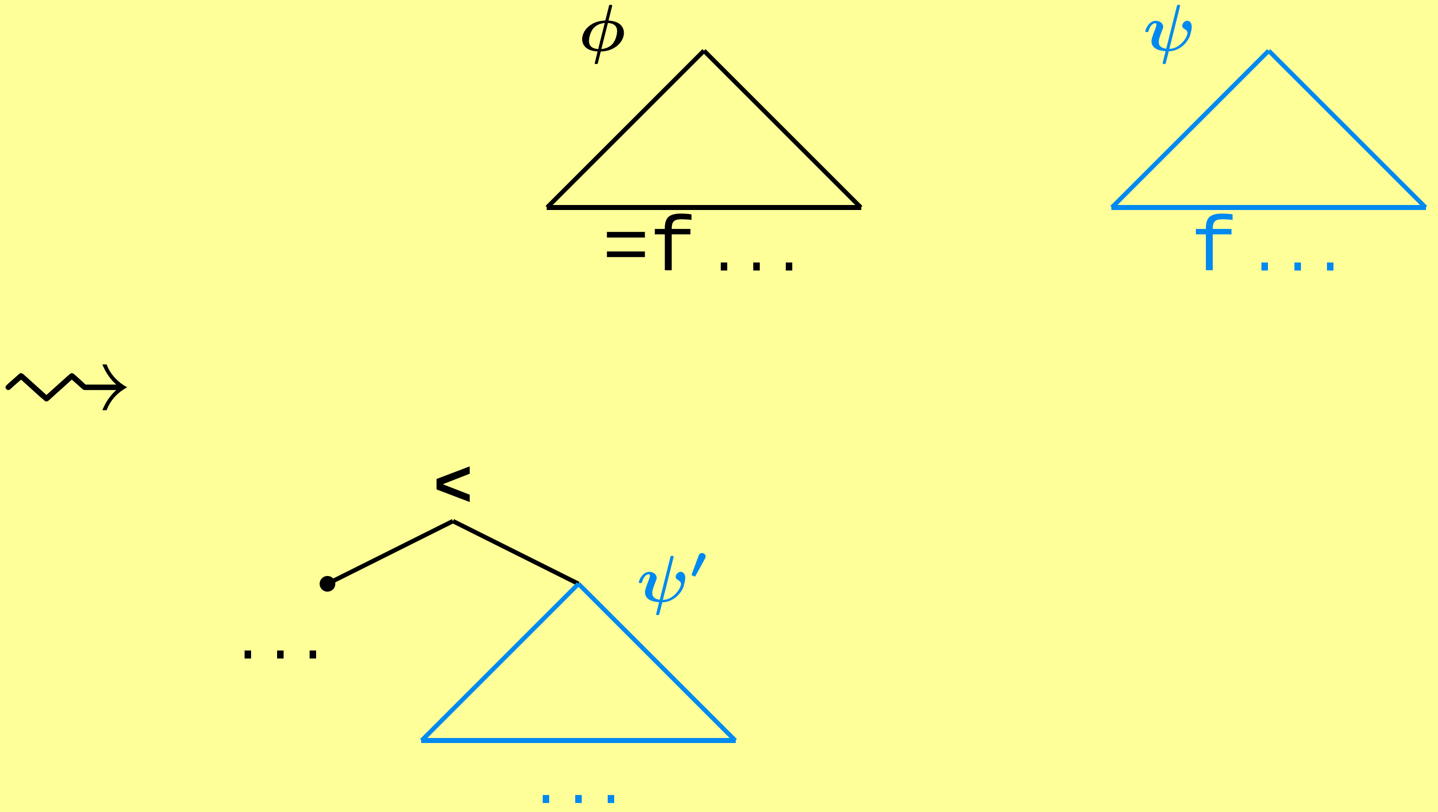
$\rightsquigarrow$

selecting ϕ simple

selecting ϕ complex

Structure building functions

$$\text{merge} : \text{Trees} \times \text{Trees} \xrightarrow{\text{part}} \text{Trees}$$



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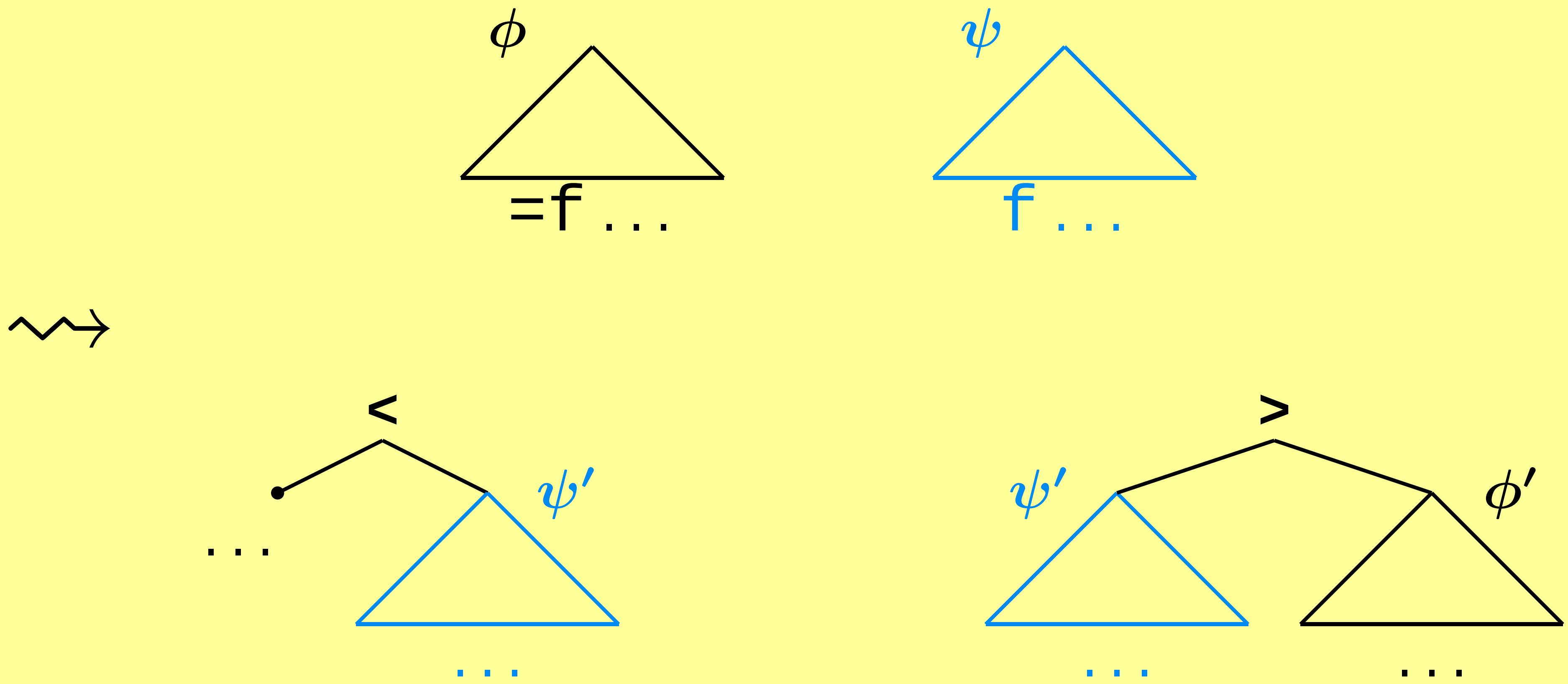


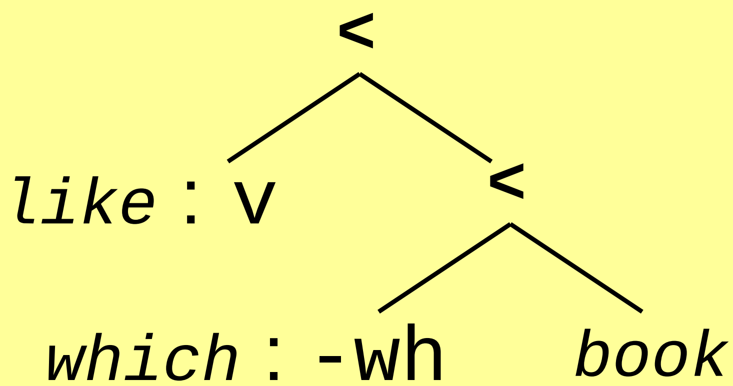
selecting ϕ simple

selecting ϕ complex

merge

selecting tree is simple

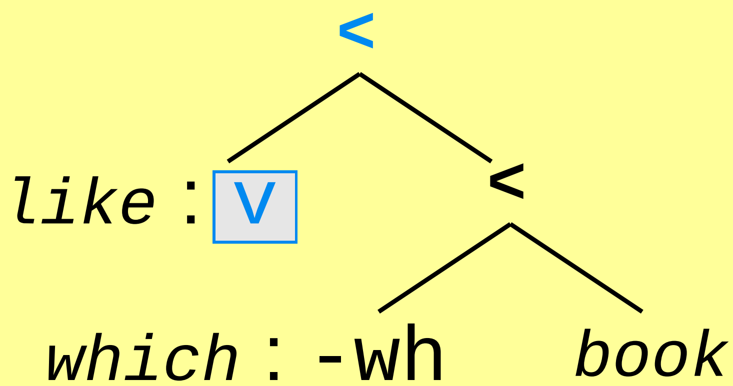
∅ :: =v =d i

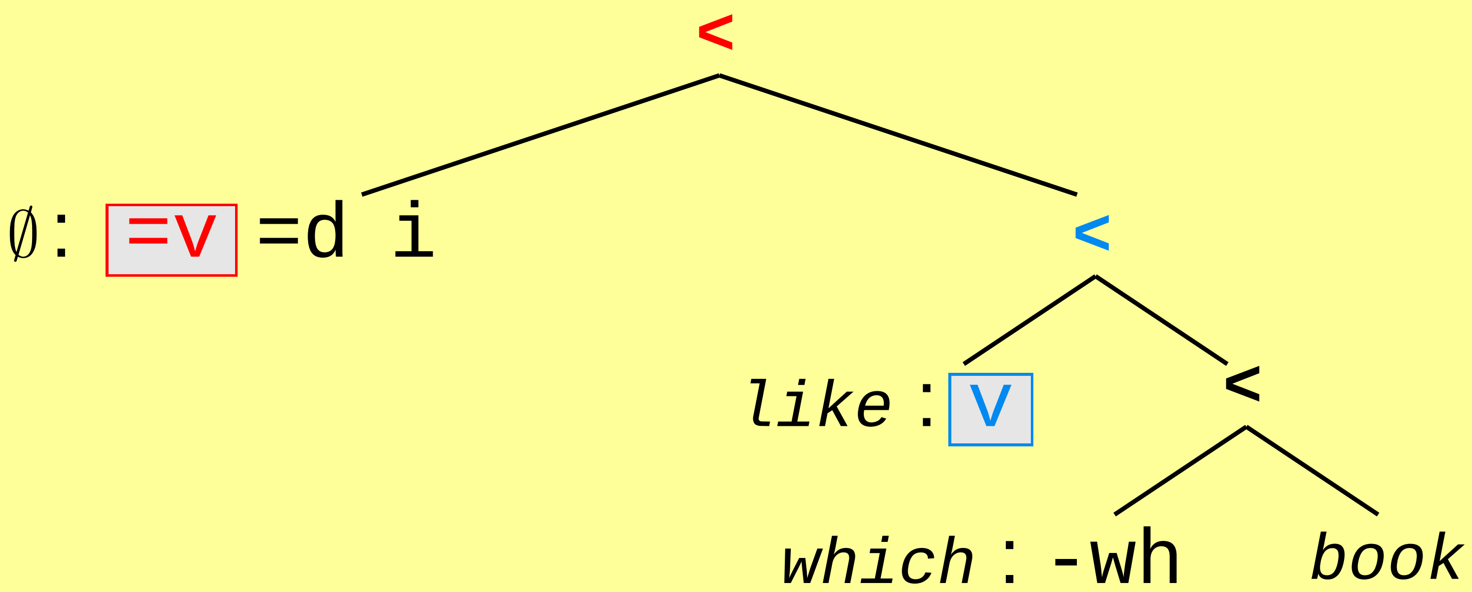


merge

selecting tree is simple

$\emptyset$ :: =v =d i

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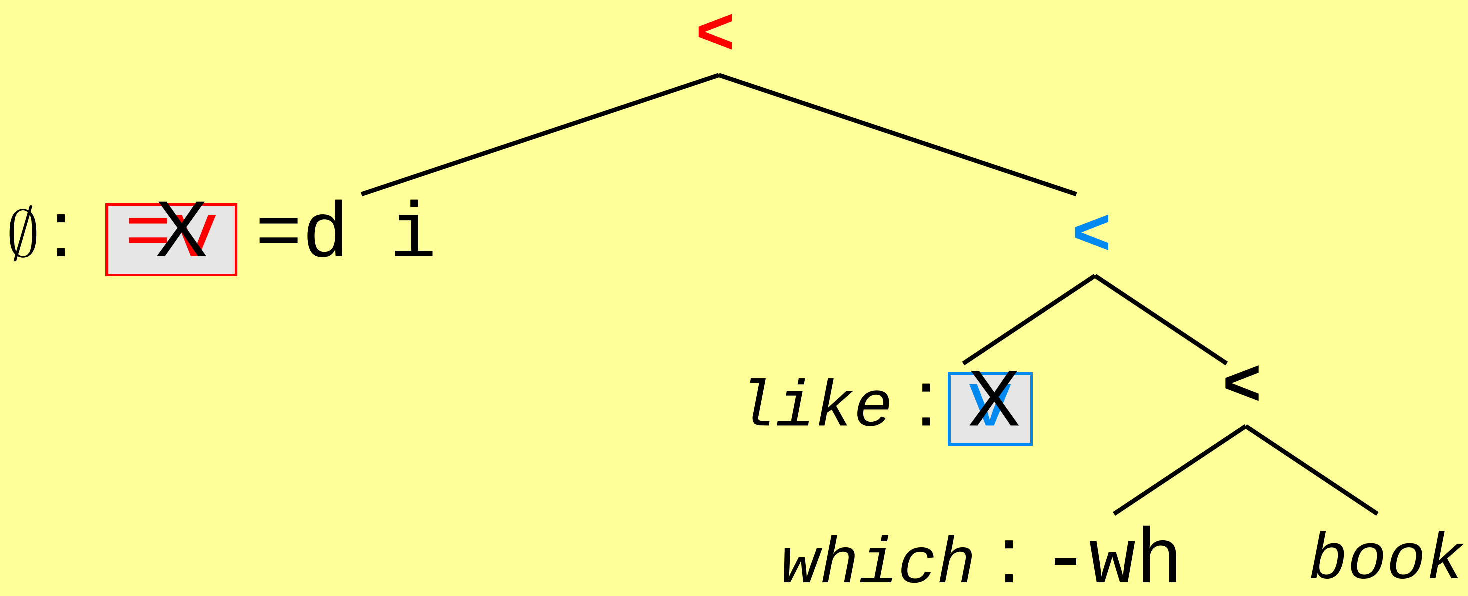
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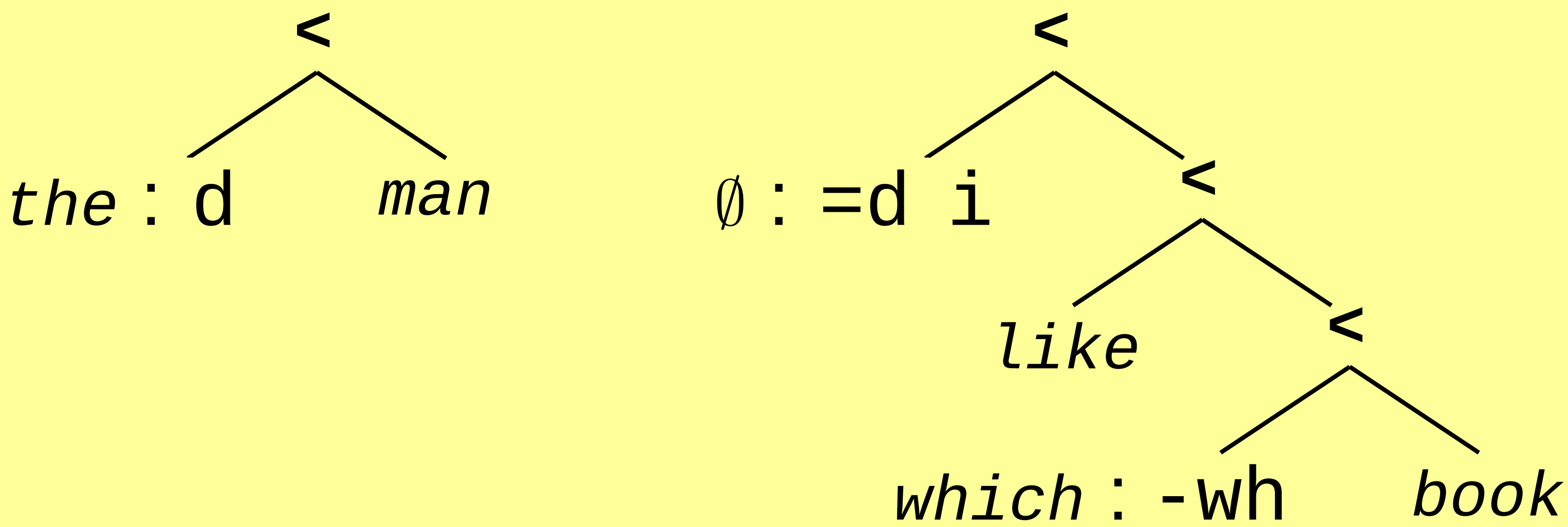
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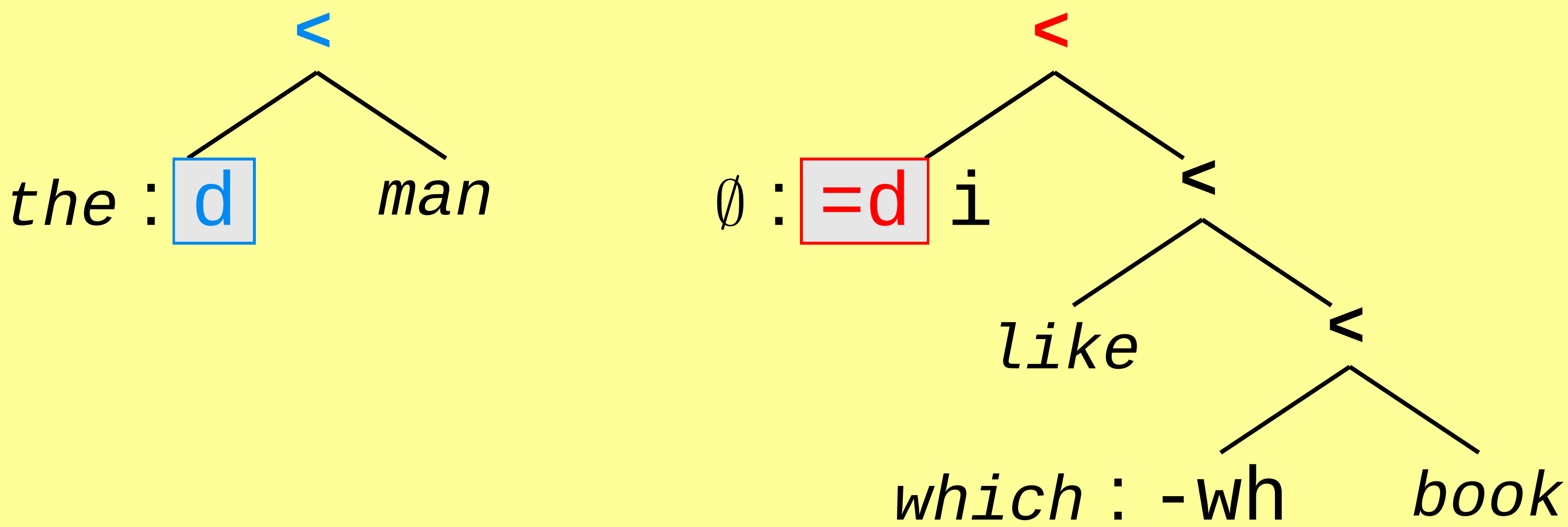
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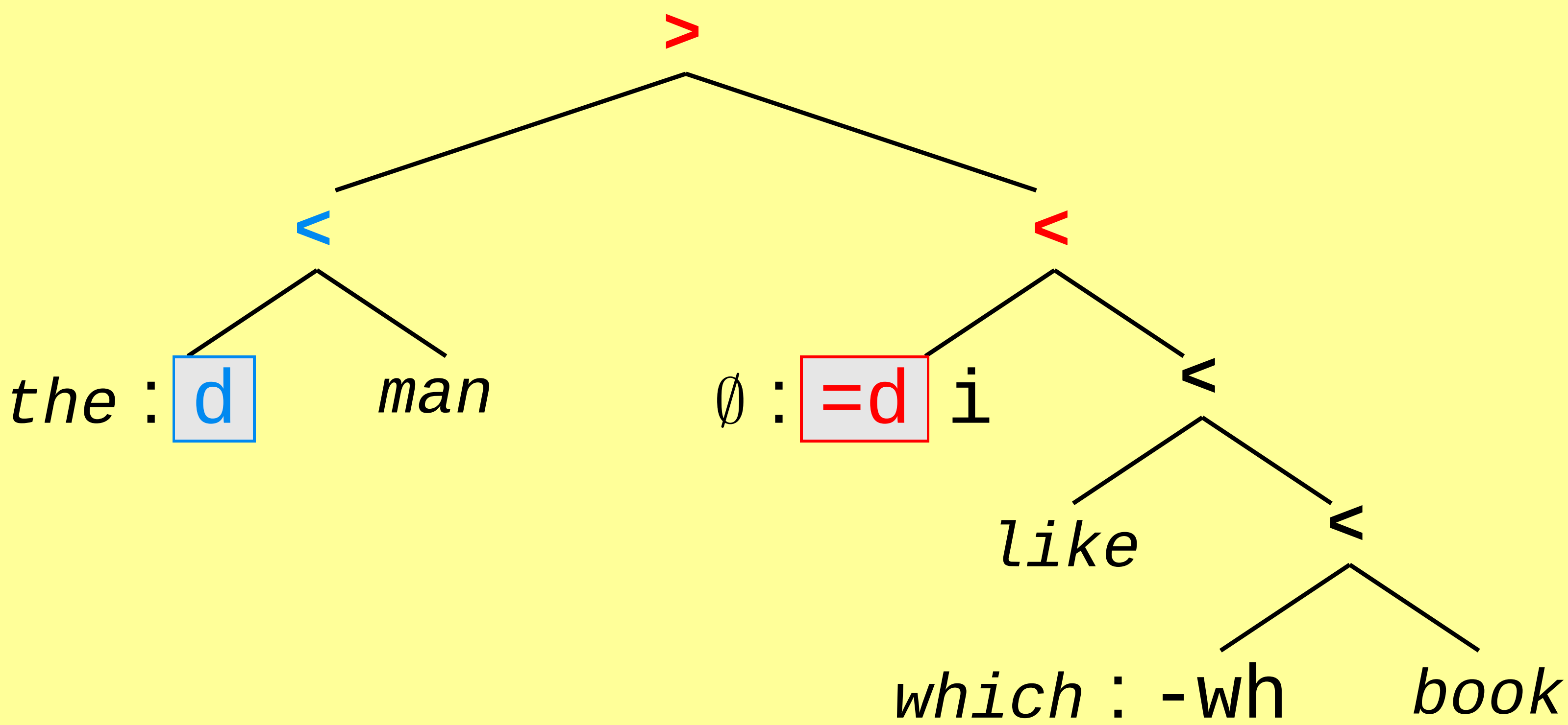
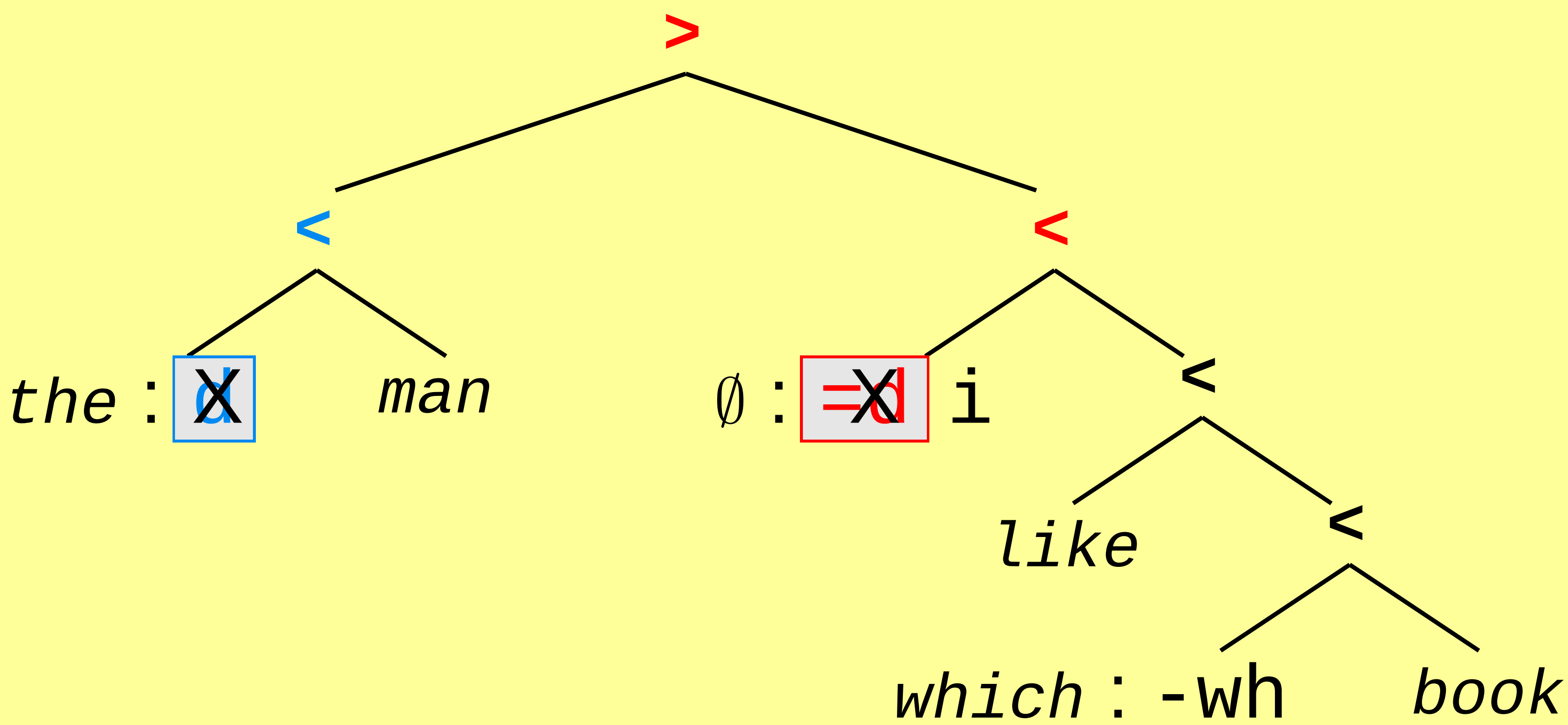
selecting tree is complex

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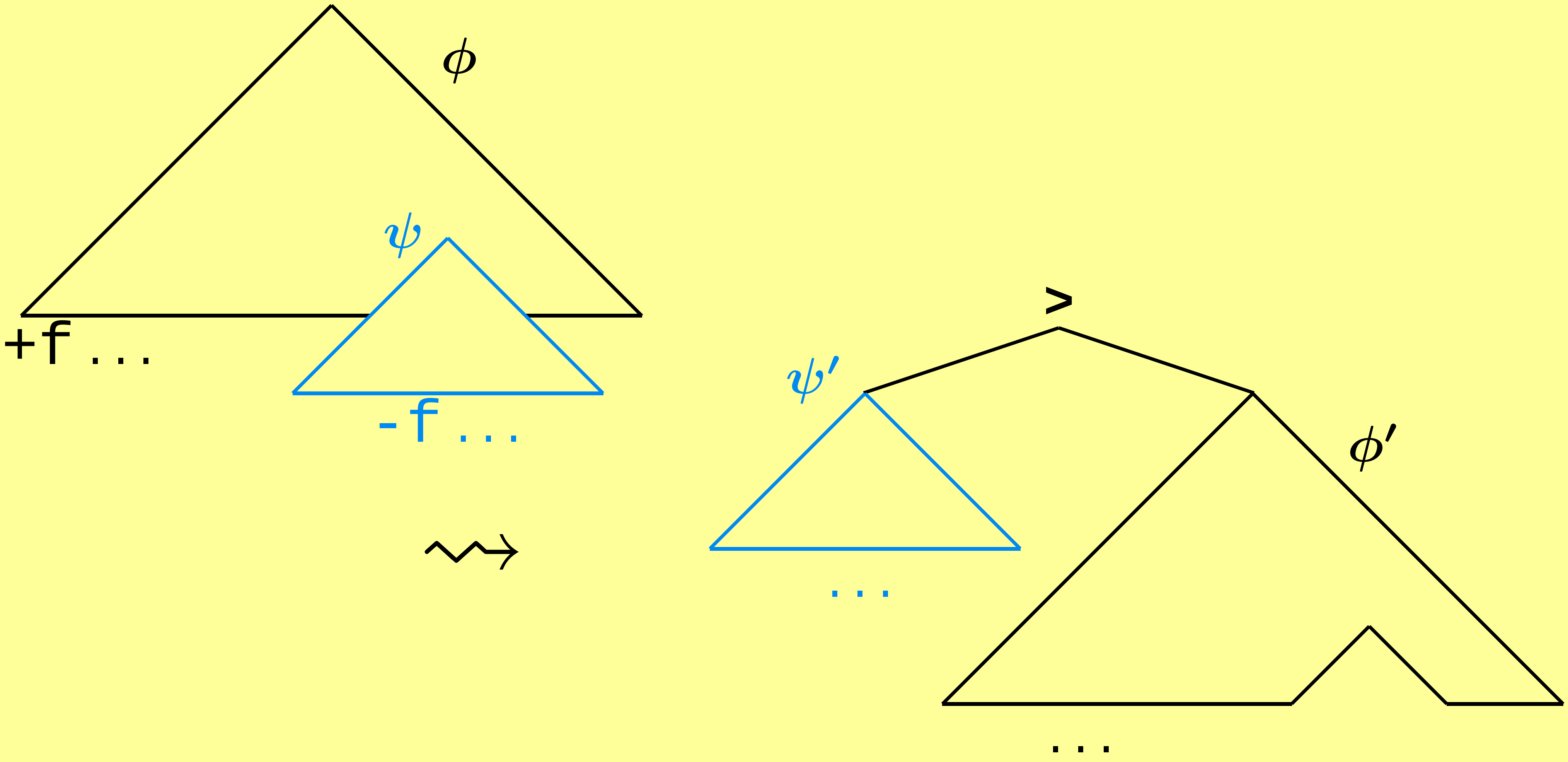
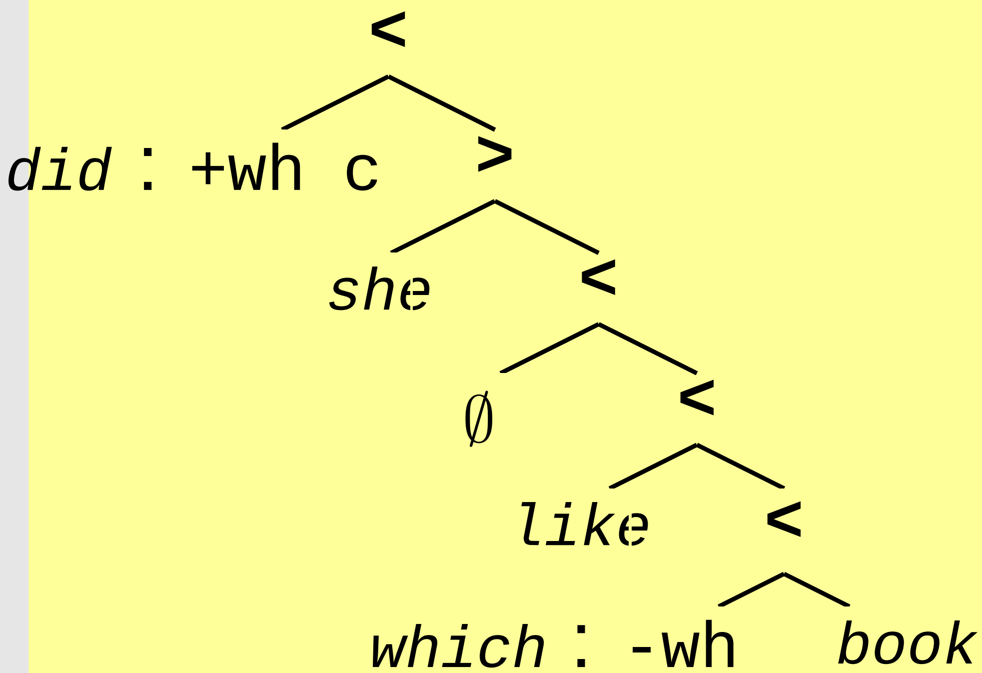
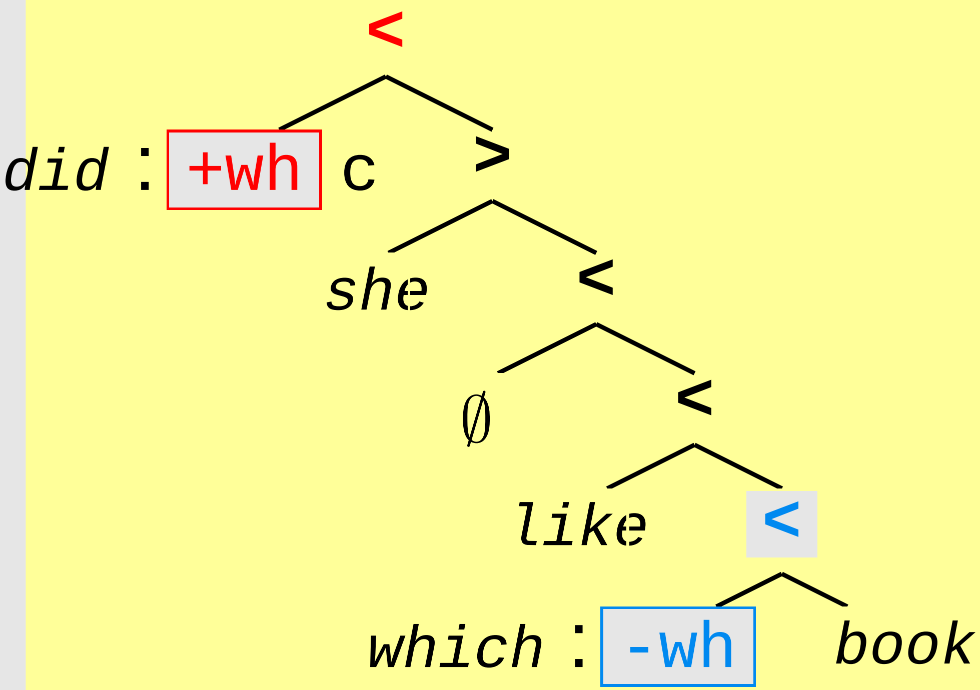
move : Trees $\xrightarrow{\text{part}}$ Trees



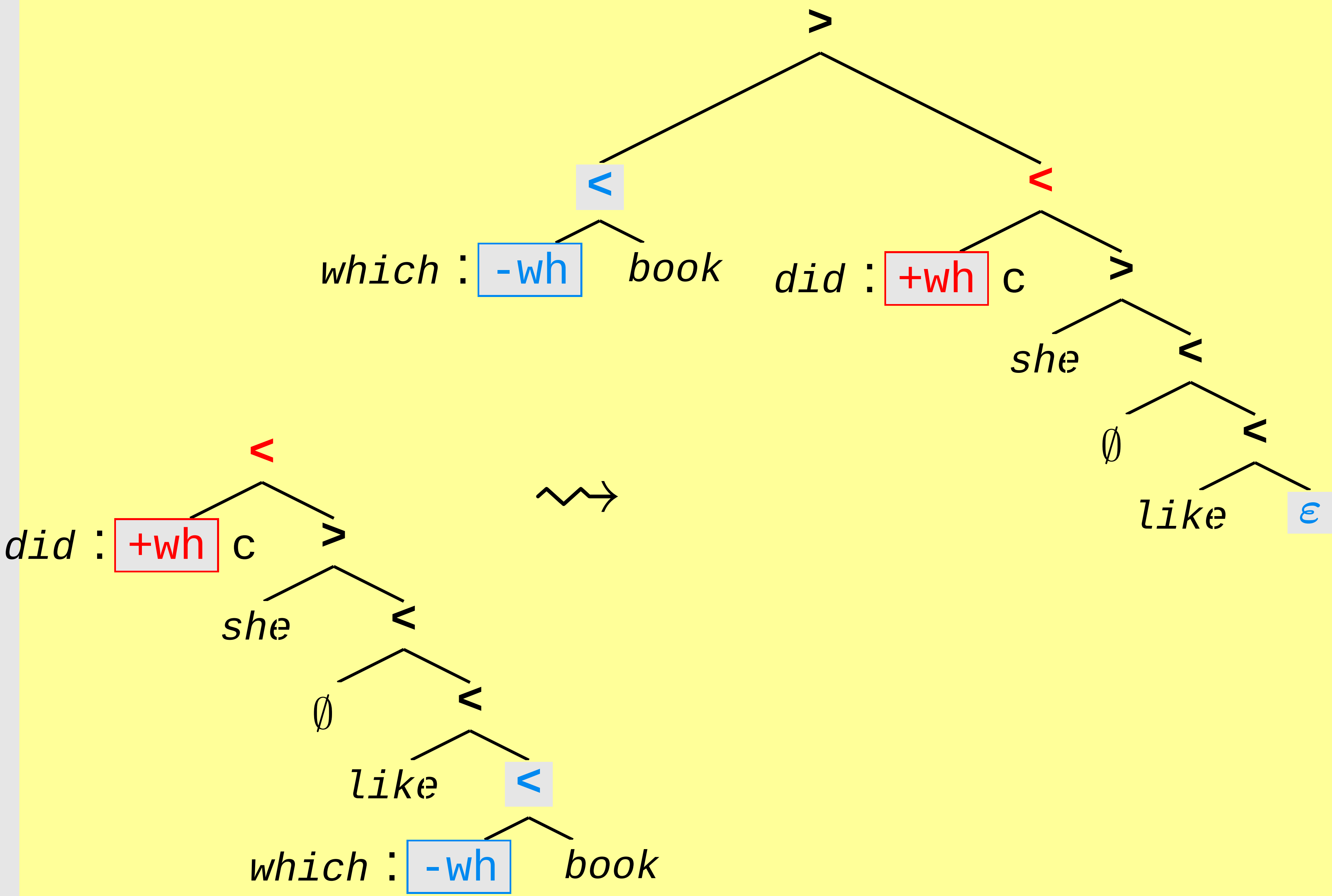
move



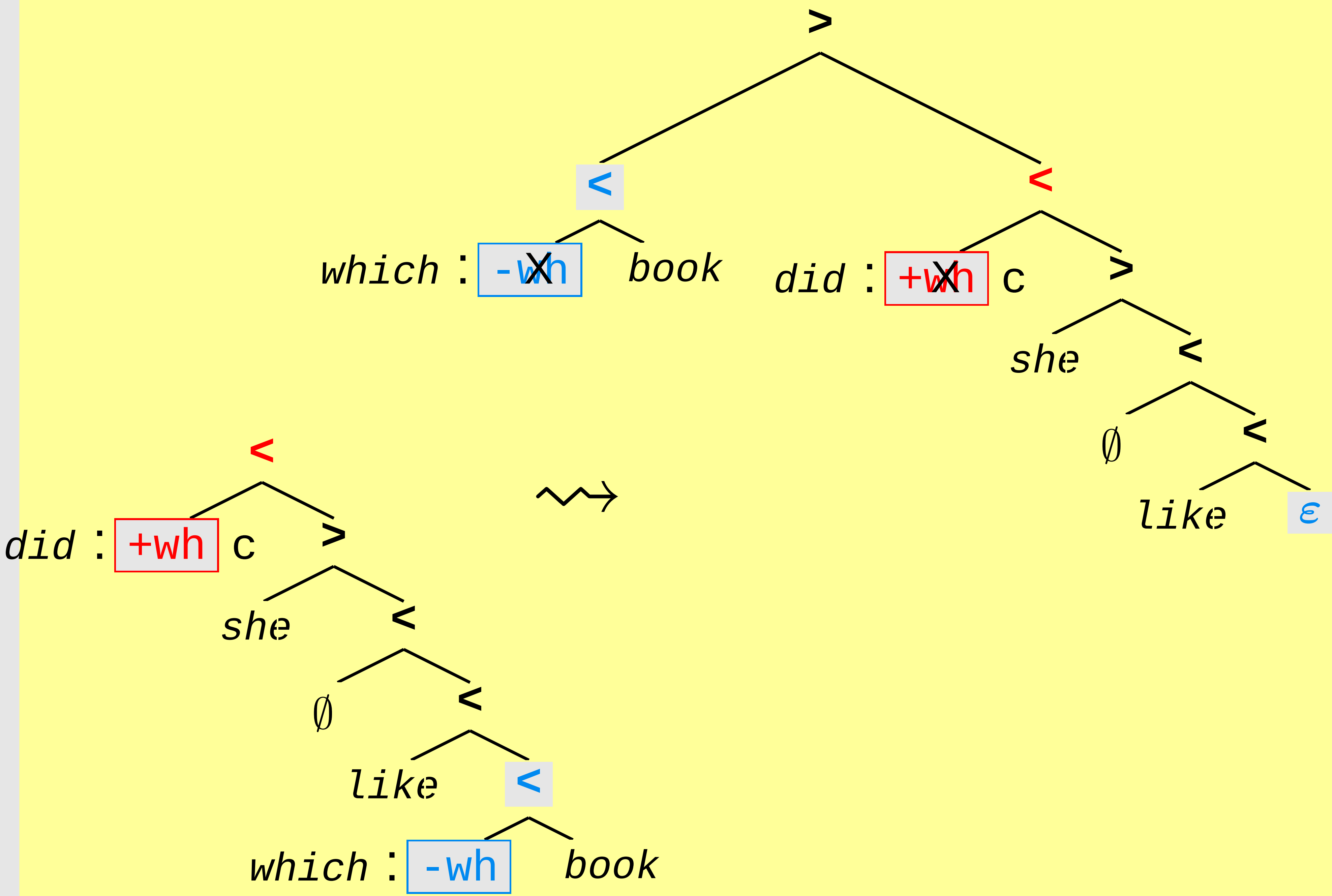
move



move



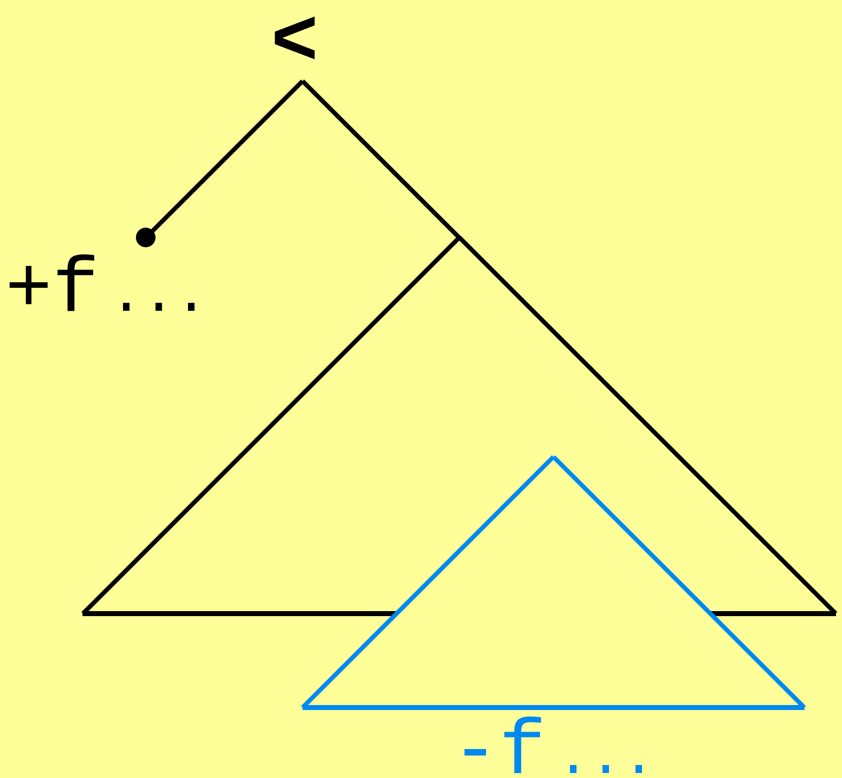
move



Shortest movement condition (SMC) (Stabler 1997, 1999)

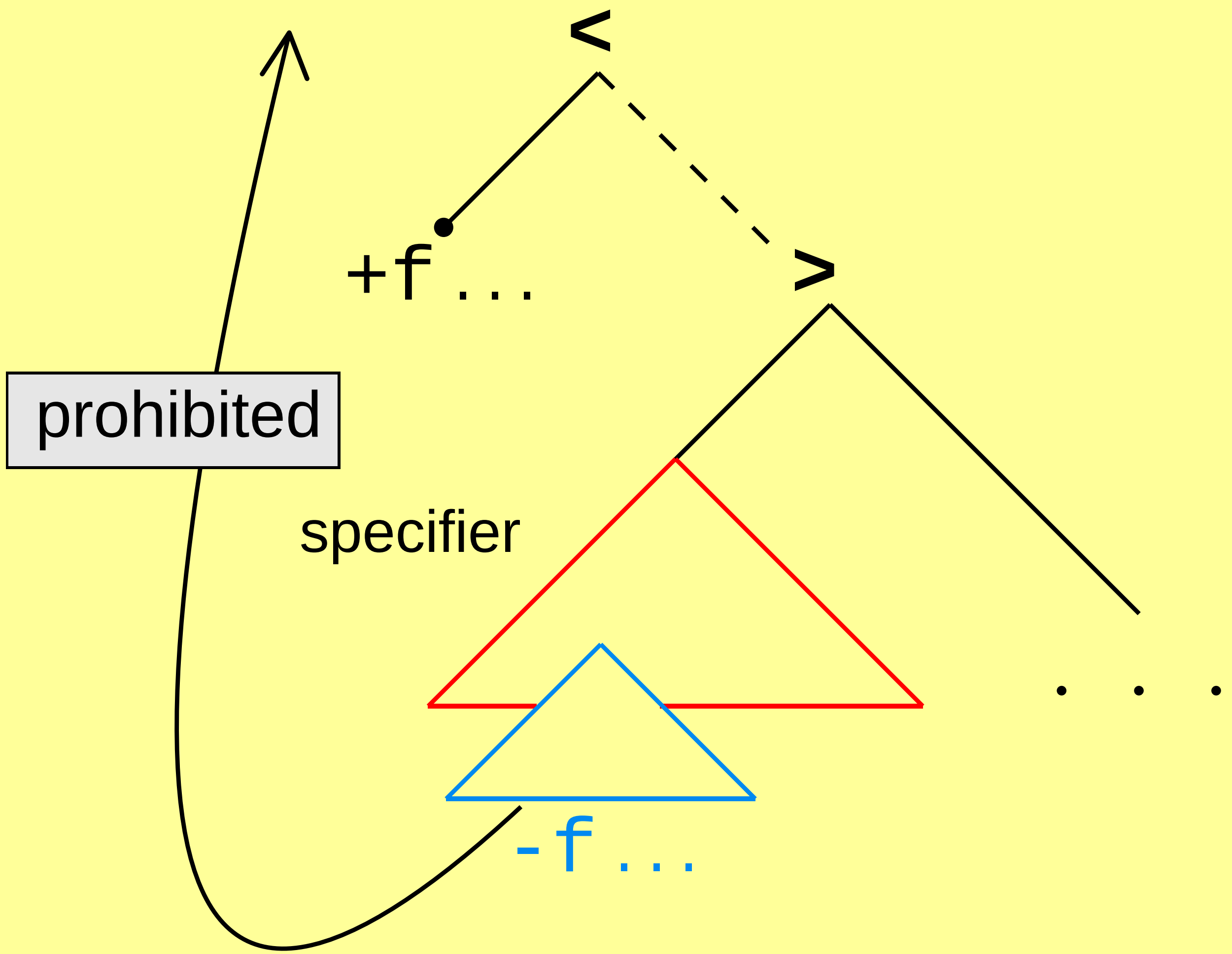
- The number of competing licensee features triggering a movement is (finitely) bounded by n.

  In the strictest version $n = 1$, i.e., there is at most one maximal projection displaying a matching licensee feature:



Specifier island condition (SPIC) (Stabler 1999)

- Proper “extraction” from specifiers is blocked.



Minimalist grammars

$$G = \langle \text{Feat}, \text{Lex}, \Omega, \text{c} \rangle$$

- $\text{Feat} = \text{Syn} \cup \text{Terminals}$ [features]

  $\text{Syn} = \text{Base} \cup \text{Select} \cup \text{Licensees} \cup \text{Licensors} \cup \ldots$

  x =x -x +x

- Lex a finite set of simple expressions [lexicon]
- $\Omega = \{\text{merge}, \text{move}, \ldots\}$ [structure building functions]
- $\text{c} \in \text{Base}$ [distinguished category]

The **closure** of G, CL(G) $:\Longleftrightarrow$

closure of the lexicon under finite applications of the functions in Ω.

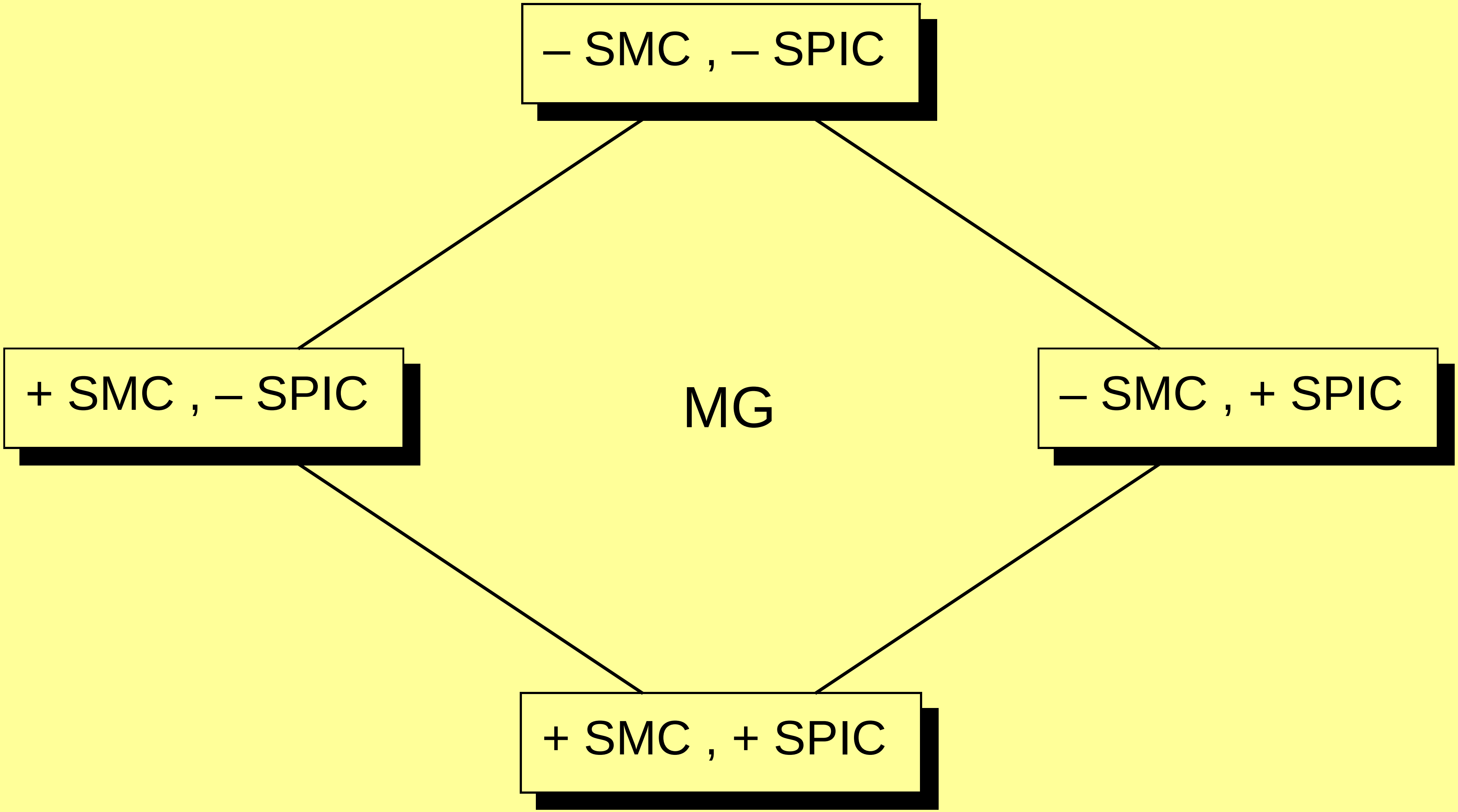
The **tree language** of G, T(G) $:\Longleftrightarrow$

trees in CL(G) with no unchecked syntactic features, but exactly one unchecked instance of category c within the head-label.

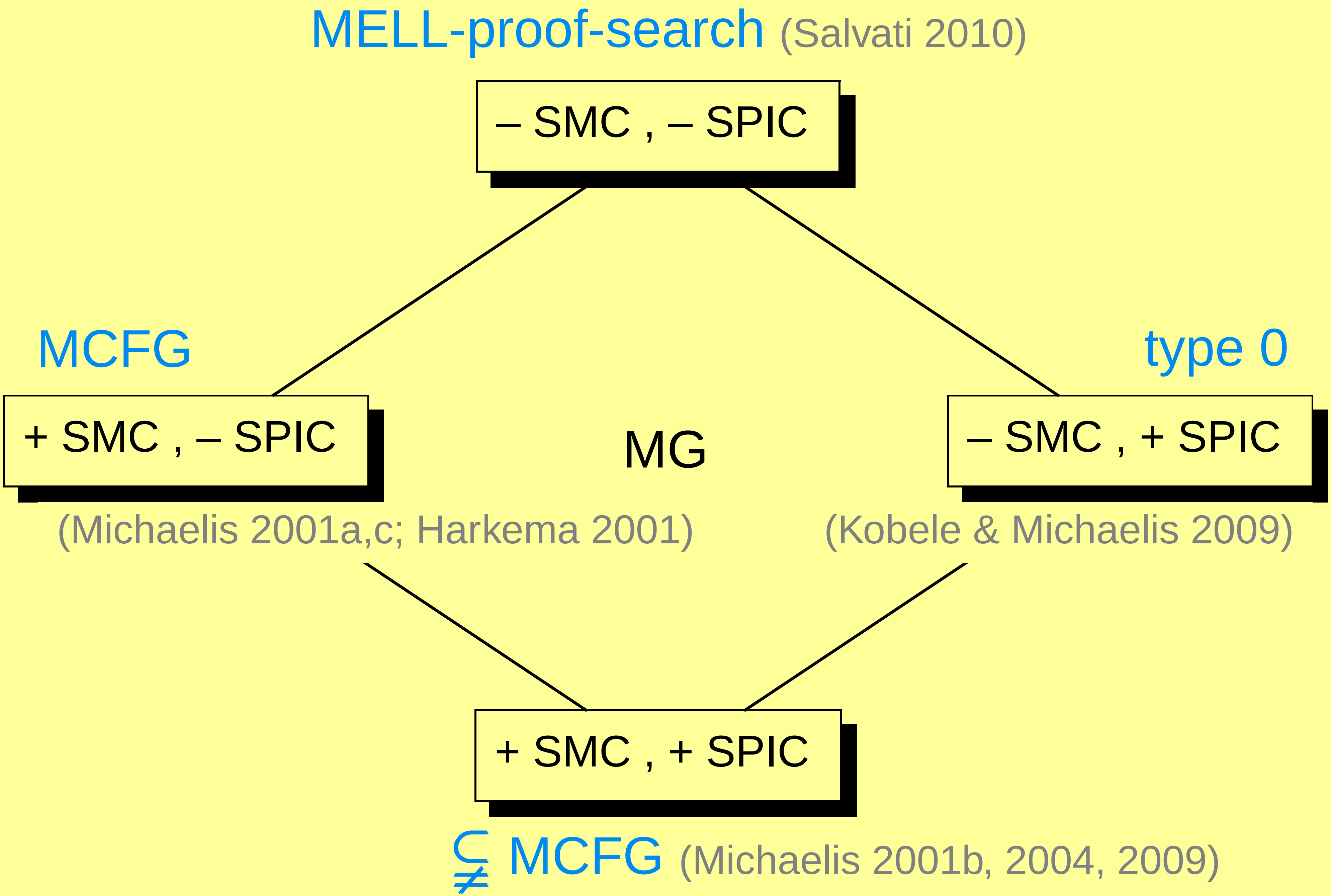
The **string language** of G, L(G) $:\Longleftrightarrow$

(terminal) yields of the trees in T(G).

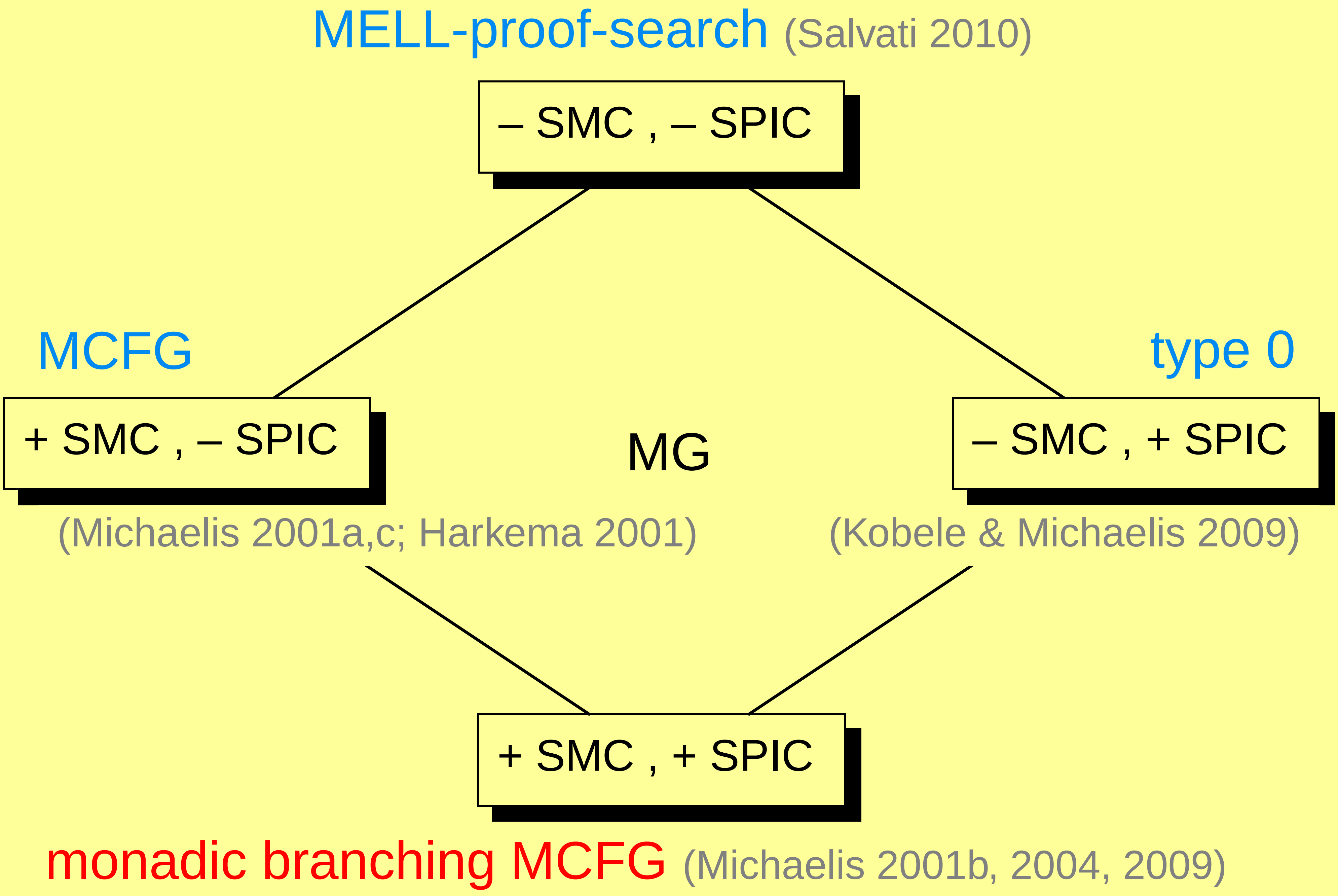
SMC and SPIC — restricting the move-operator domain



SMC and SPIC — restricting the move-operator domain



SMC and SPIC — restricting the move-operator domain



An MCFG, G, is an m-MCFG(f)

iff G it has dimension m and rank f. The language derived by G, L(G), is an m-MCFL(f).

- m-MCFL(f), likewise, denotes the class of all m-MCFL(f)s.

$$\text{m-MCFL} = \bigcup_{f \geq 1} \text{m-MCFL}(f)$$

$$\text{MCFL}(f) = \bigcup_{m \geq 1} \text{m-MCFL}(f)$$

$$\text{MCFL} = \bigcup_{m \geq 1} \text{m-MCFL}$$

- Subscript $\_\_\__{wn}$ indicates well-nestedness.

(Restricted) MCFG-normal form

Proposition: MCFL $=$ MCFL(2) .

An MCFG, G, is an MCFG_{mb}, or, monadic branching

iff G is of rank 2, and each binary rule is of the form:

$$A(\alpha_1, \ldots, \alpha_k) \leftarrow B(x), C(y_1, \ldots, y_n)$$

Proposition: $\text{m-MCFL}_{mb} = \text{m-MCFL}_{wn,mb}$ for each $m \geq 1$.

— Transform a given MCFG_{mb} into its non-permuting “closure” —

Corollary: $\text{MCFL}_{mb} \subseteq \text{MCFL}_{wn}$.

MCFG_{mb}-normal form

An MCFG_{mb} $G = \langle N, \Sigma, P, S \rangle$ is in MCFG_{mb}-NF

iff each rule is of one of the forms (i)–(iv):

(i) $A(x, y_1, y_2, \ldots, y_n) \longleftarrow B(x), C(y_1, y_2, \ldots, y_n)$

(ii) $A(x y_1, y_2, \ldots, y_n) \longleftarrow B(x), C(y_1, y_2, \ldots, y_n)$

(iii) $A(y_{n+1} y_1, y_2, \ldots, y_n) \longleftarrow B(y_1, \ldots, y_n, y_{n+1})$

(iv) $A(w) \longleftarrow \quad [w \in \Sigma^*]$

MCFG_{mb}-normal form

An MCFG_{mb} $G = \langle N, \Sigma, P, S \rangle$ is in MCFG_{mb}-NF

iff each rule is of one of the forms (i)–(iv):

(i) $A(\, x \,, y_1 \,, y_2 \,, \ldots, y_n \,) \longleftarrow B(\, x \,), C(\, y_1 \,, y_2 \,, \ldots, y_n \,)$

(ii) $A(\, x\, y_1 \,, y_2 \,, \ldots \,, y_n \,) \longleftarrow B(\, x \,), C(\, y_1 \,, y_2 \,, \ldots \,, y_n \,)$

(iii) $A(\, y_{n+1}\, y_1 \,, y_2 \,, \ldots \,, y_n \,) \longleftarrow B(\, y_1 \,, \ldots \,, y_n \,, y_{n+1} \,)$

(iv) $A(\, w \,) \longleftarrow \qquad \left[\, w \in \Sigma^* \,\right]$

Proposition: $\text{MCFL}_{\text{mb}} = \text{MCFL}_{\text{mb}}\text{-NF}\,.$

Proposition:

m-MCFL$_{mb}$ is a substitution-closed full AFL for each $m \geq 1$.

Proof (sketch):

a) REG $\subseteq$ CFL $=$ 1-MCFL(2) $=$ 1-MCFL$_{mb}$ $\subseteq$ m-MCFL$_{mb}$.

b) Closure under substitution is also straightforward.

c) Closure under intersection with regular sets follows from the proof of Theorem 3.9 in Seki et al. 1991:

Construction of MCFG G' such that $L(G') = L(G) \cap R$ for given MCFG G and regular set R.

G' is an m-MCFG$_{mb}$ in case G is an m-MCFG$_{mb}$.

AFL properties

Proposition:

The class of all m-$MCFL_{mb}$ is a strictly increasing hierarchy .

Proof: Basically Seki et al. 1991 again .

$$\{a_1^k \ldots a_{2m}^k \mid k \geq 0\} \in \text{m-}MCFL_{mb}$$

$$\{a_1^k \ldots a_{2m+2}^k \mid k \geq 0\} \notin \text{m-}MCFL_{mb}$$

Corollary:

The class $MCFL_{mb}$ is not a principle AFL .

Embedding within MCFL(1) and MCFL_{wn}

Recall that

$$\mathrm{MCFL}_{mb} \subseteq \mathrm{MCFL}_{wn} .$$

Clearly we have

$$\mathrm{MCFL}(1) \subseteq \mathrm{MCFL}_{mb} ,$$

but also

$$\mathrm{MCFL}(1) \subsetneq \mathrm{MCFL}_{mb} ,$$

because of

- $\mathrm{MCFL}(1) = \mathrm{ET0L}_{FIN} \subsetneq \mathrm{EDT0L}$,
- $\mathrm{CFL} = \text{1-}\mathrm{MCFL}(2) \subseteq \mathrm{MCFL}_{mb}$, and
- $\mathrm{CFL} - \mathrm{EDT0L} \neq \emptyset$.

The copying theorem in Kanazawa & Salvati 2010 does not help seperating $MCFL_{mb}$ from $MCFL_{wn}$, but a variation of it does so .

Theorem [copying theorem , Kanazawa & Salvati 2010]

For $L = \{ w\#w \mid w \in L_0 \}$, (i) and (ii) are equivalent :

(i) $L \in MCFL_{wn}$.

(ii) $L \in MCFL(1)$.

Theorem [reversal copying theorem]

For $L = \{ w\#w^R \mid w \in L_0 \}$, (i)–(iii) are equivalent :

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(i) $L \in MCFL_{mb}$.

(ii) $L \in MCFL(1)$.

(iii) $L_0 \in MCFL(1)$.

Towards $MCFL_{mb} \subsetneqq MCFL_{wn}$

<u>Theorem</u> [reversal copying theorem revisited]

For $L = \{ w \# w^R \mid w \in L_0 \}$, (i') implies (ii'):

(i') $L \in$ m-$MCFL_{mb}$.

(ii') $L \in$ m+1-MCFL(1) and $L_0 \in$ m-MCFL(1) .

Towards $MCFL_{mb} \subsetneq MCFL_{wn}$

<u>Theorem</u> [reversal copying theorem revisited]

For $L = \{ w\#w^R \mid w \in L_0 \}$, (i') implies (ii') :

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<u>Theorem</u> ["seperation"]

For each $L_0 \in$ CFL , $L = \{w\#w^R \mid w \in L_0\} \in$ 2-$MCFL_{wn}$.

<u>Corollary</u> : $MCFL_{mb} \subsetneq MCFL_{wn}$

Towards $MCFL_{mb} \subsetneq MCFL_{wn}$

Theorem [reversal copying theorem revisited]

For $L = \{ w\#w^R \mid w \in L_0 \}$, (i') implies (ii'):

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Theorem ["seperation"]

For each $L_0 \in$ CFL, $L = \{w\#w^R \mid w \in L_0\} \in$ 2-$MCFL_{wn}$.

Corollary: $MCFL_{mb} \subsetneq MCFL_{wn}$

Proof of corollary: Let $L_0 \in$ CFL – MCFL(1). Then

$L = \{w\#w^R \mid w \in L_0\} \in$ 2-$MCFL_{wn}$ – $MCFL_{mb}$ by theorems above.

Towards $MCFL_{mb} \subsetneq MCFL_{wn}$

Theorem [reversal copying theorem revisited]

For $L = \{ w\#w^R \mid w \in L_0 \}$, (i') implies (ii') :

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Towards $MCFL_{mb} \subsetneq MCFL_{wn}$

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For each $L_0 \in$ CFL , $L = \{w\#w^R \mid w \in L_0\} \in$ 2-$MCFL_{wn}$.

Corollary : $MCFL_{mb} \subsetneq MCFL_{wn}$

Question :

1-$MCFL_{mb}$ = 1-$MCFL_{wn}$. [Obvious]

m-$MCFL_{mb} \subsetneq$ m-$MCFL_{wn}$ for each $m > 1$. [Open]

Towards $\mathrm{MCFL}_{mb} \subsetneq \mathrm{MCFL}_{wn}$

Theorem [reversal copying theorem revisited]

For $L = \{ w \# w^R \mid w \in L_0 \}$, (i') implies (ii') :

(i') $L \in$ m-MCFL_{mb} .

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Theorem [reversal copying theorem revisited]

For $L = \{ w \# w^R \mid w \in L_0 \}$, (i') implies (ii') :

(i') $L \in$ m-MCFL_{mb} .

(ii') $L \in$ m+1 -MCFL(1)

Theorem [reversal copying theorem revisited]

For $L = \{ w\#w^R \mid w \in L_0 \}$, (i’) implies (ii’) :

(i’) $L \in$ m-$\mathrm{MCFL_{mb}}$.

(ii’) $L \in$ m+1 -MCFL(1)

Proof (sketch) : $G = \langle N, \Sigma, P, S \rangle$ an m-$\mathrm{MCFG_{mb}}$ with $L(G) = L$.

Theorem [reversal copying theorem revisited]

For $L = \{ w \# w^R \mid w \in L_0 \}$, (i') implies (ii'):

(i') $L \in$ m-$MCFL_{mb}$.

(ii') $L \in$ m+1 -MCFL(1)

Proof (sketch): $G = \langle N, \Sigma, P, S \rangle$ an m-$MCFG_{mb}$ with $L(G) = L$.

W.l.o.g. each $p \in P$ is non-deleting , and

each $A \in N$ is useful and derives an infinite subset of $(\Sigma^*)^{arity(A)}$.

$L = \{ w\#w^R \mid w \in L_0 \} \in MCFL_{mb}$

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Suppose that

$$p\,T_1 T_2 : A(v_1, \ldots, v_k) \vdash_G T : S(w\#w^R)$$

T, T_1, T_2 derivation trees over P, v_i, $w \in \Sigma^*$, $p \in P$ with

$$p = A(\alpha_1, \ldots, \alpha_k) \leftarrow B(x), C(y_1, \ldots, y_n)$$

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$$p = A(\alpha_1, \ldots, \alpha_k) \leftarrow B(x), C(y_1, \ldots, y_n)$$

Then

$$\vdash_G T_1 : B(u) \quad \text{and} \quad \vdash_G T_2 : C(u_1, \ldots, u_n)$$

for some $u, u_1, \ldots, u_n \in \Sigma^* \{ \varepsilon, \# \} \Sigma^*$.

$L = \{ w \# w^R \mid w \in L_0 \} \in MCFL_{mb}$

Proof (sketch): $G = \langle N, \Sigma, P, S \rangle$ an m-MCFG$_{mb}$ with $L(G) = L$.

$p\, T_1 T_2 : A(v_1, \ldots, v_k) \vdash_G T : S(w \# w^R)$ implies

$\vdash_G T_1 : B(u)$ and $\vdash_G T_2 : C(u_1, \ldots, u_n)$

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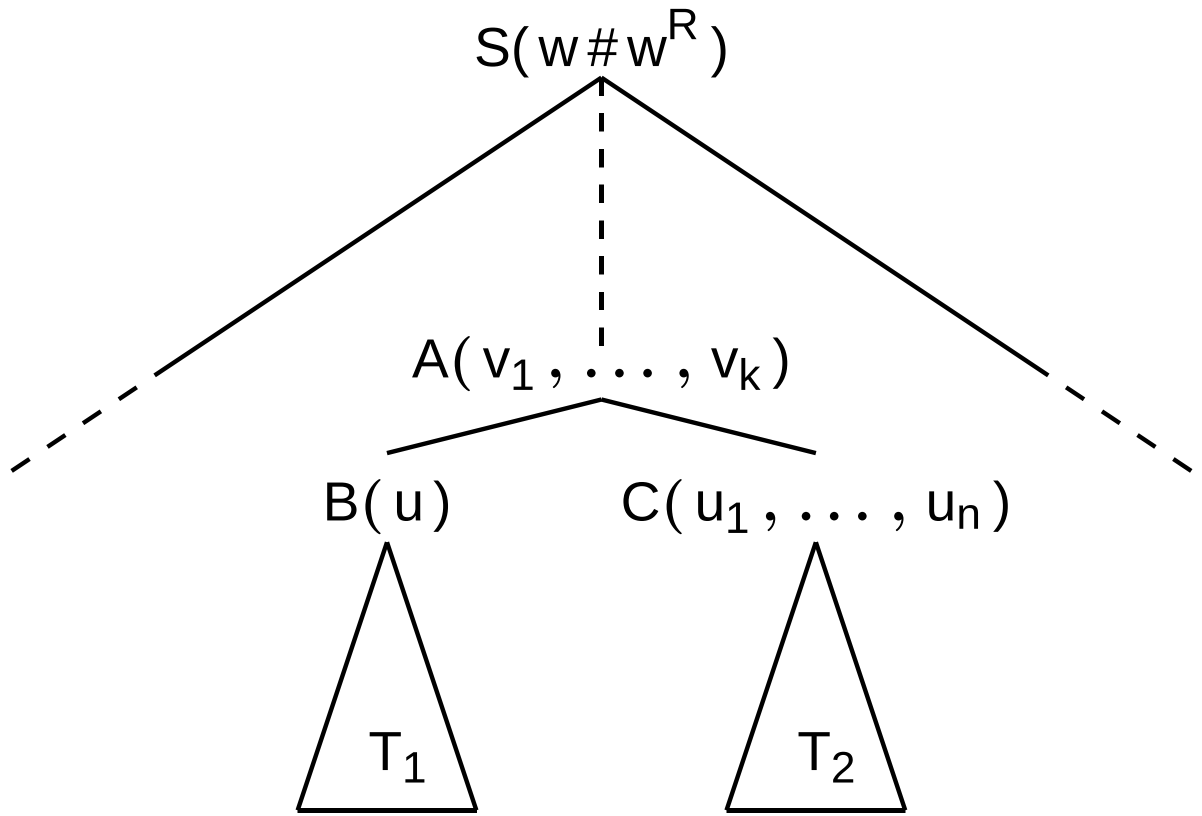

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Suppose that $u \in \Sigma^*$. Then w.l.o.g.

$$\vdash_G S\left(w_1\, u\, w_2 \,\#\, (w_1\, u\, w_2)^R \right) \qquad w = w_1\, u\, w_2$$

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but also

$$\vdash_G S\Big(w_1\, u'\, w_2 \# (w_1 u w_2)^R\Big) \qquad \text{if } \vdash_G B(u')$$

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Contradiction , since B derives an infinite subset of Σ^* by choice of G .

$L = \{ w\#w^R \mid w \in L_0 \} \in MCFL_{mb}$

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Suppose that $u \in \Sigma^*$.

Contradiction

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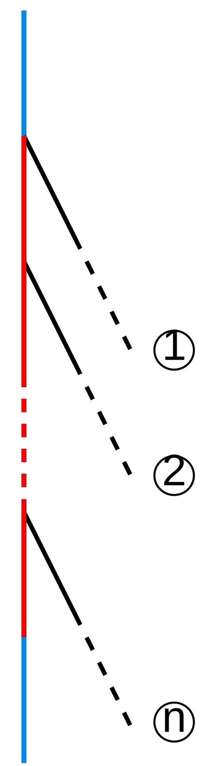

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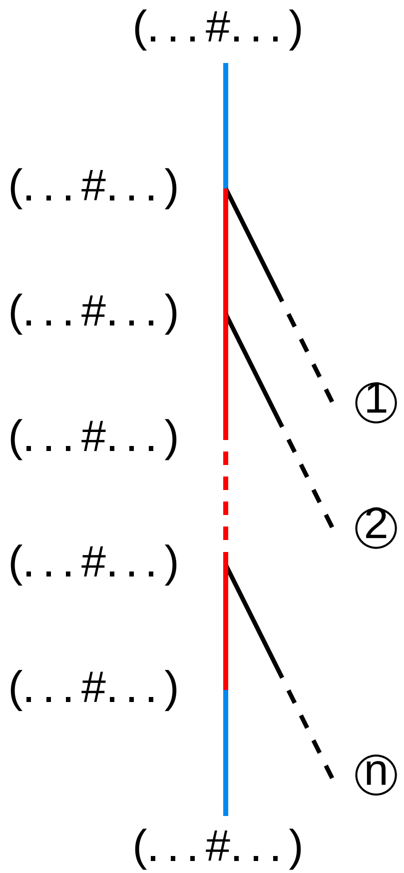

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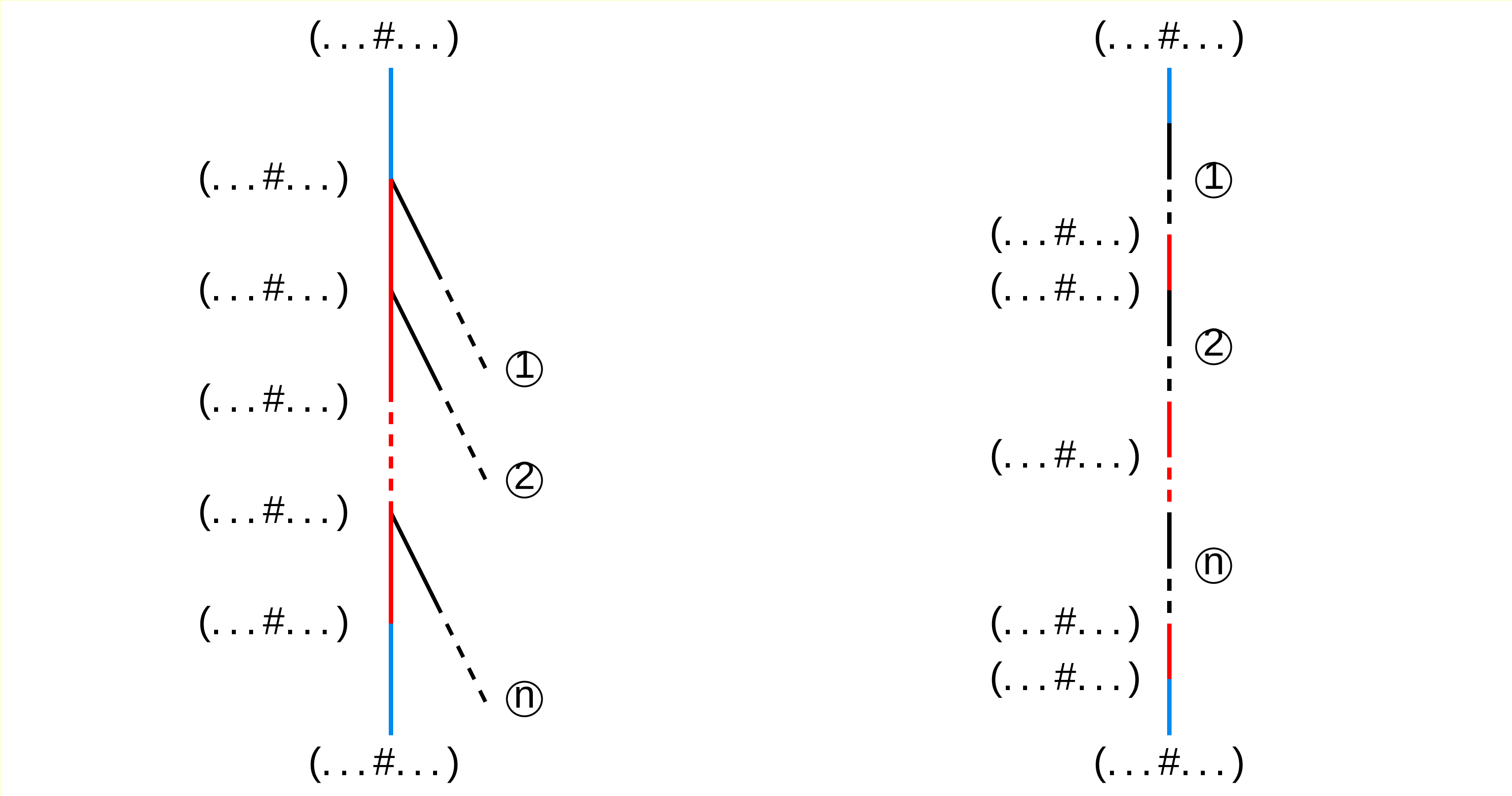

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Define $G' = \langle N', \Sigma, P', S \rangle \in$ m+1-MCFG(1) with $L(G') = L$.

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$$N' = N \cup \{ [A/B] \mid A, B \in N \}.$$

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For binary branching $p \in P$,

$$p = A(\alpha_1, \ldots, \alpha_k) \leftarrow B(x), C(y_1, \ldots, y_n) \notin P'$$

$$p' = A(\alpha_1, \ldots, \alpha_k) \leftarrow [C/B](x, y_1, \ldots, y_n) \in P'$$

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$$p = A(\alpha_1, \ldots, \alpha_k) \leftarrow C(y_1, \ldots, y_n) \in P'$$

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For terminating $p \in P$ and $B \in N$,

$$p \ = A(w_1, \ldots, w_k) \leftarrow \quad \in P'$$

$$p' = [A/B](x, w_1, \ldots, w_k) \leftarrow B(x) \in P'$$

□

MCFG_{mb}-normal form

An MCFG_{mb} $G = \langle N, \Sigma, P, S \rangle$ is in MCFG_{mb}-NF

iff each rule is of one of the forms (i)–(iv):

(i) $A(x, y_1, y_2, \ldots, y_n) \longleftarrow B(x), C(y_1, y_2, \ldots, y_n)$

(ii) $A(x y_1, y_2, \ldots, y_n) \longleftarrow B(x), C(y_1, y_2, \ldots, y_n)$

(iii) $A(y_{n+1} y_1, y_2, \ldots, y_n) \longleftarrow B(y_1, \ldots, y_n, y_{n+1})$

(iv) $A(w) \longleftarrow$ $\left[w \in \Sigma^* \right]$

MCFG(2) —> MG-normal forms

- Michaelis 2001c
- Michaelis 2004

$$A(\alpha_1, \ldots, \alpha_m) \leftarrow B(x_1, \ldots, x_k), C(y_1, \ldots, y_n)$$ (Michaelis 2001c)

$A(\alpha_1, \ldots, \alpha_m) \longleftarrow B(x_1, \ldots, x_k), C(y_1, \ldots, y_n)$ (Michaelis 2001c)

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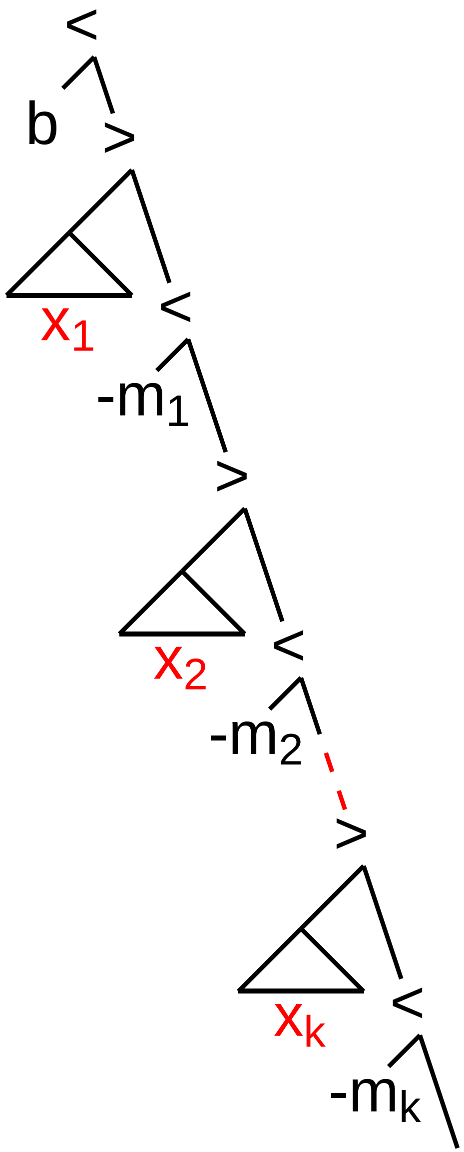

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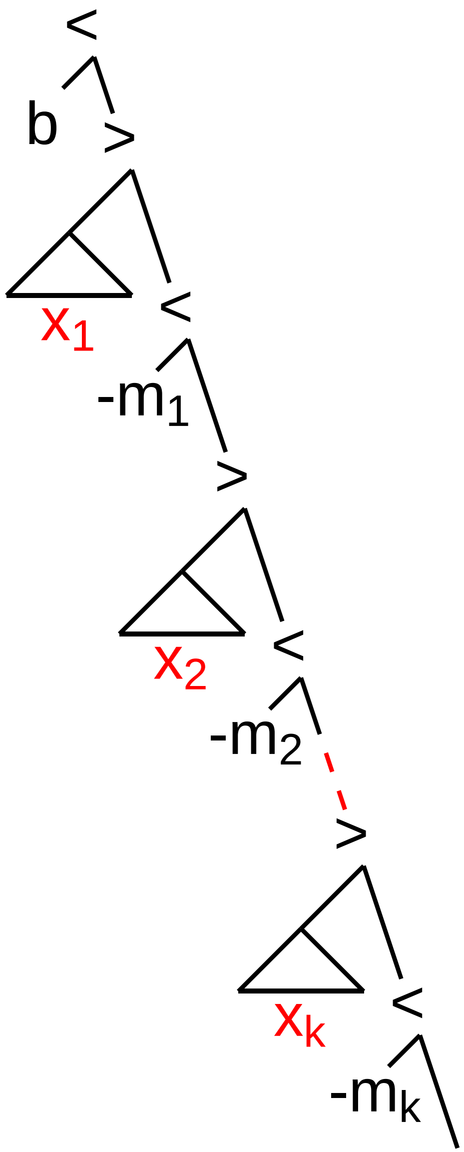

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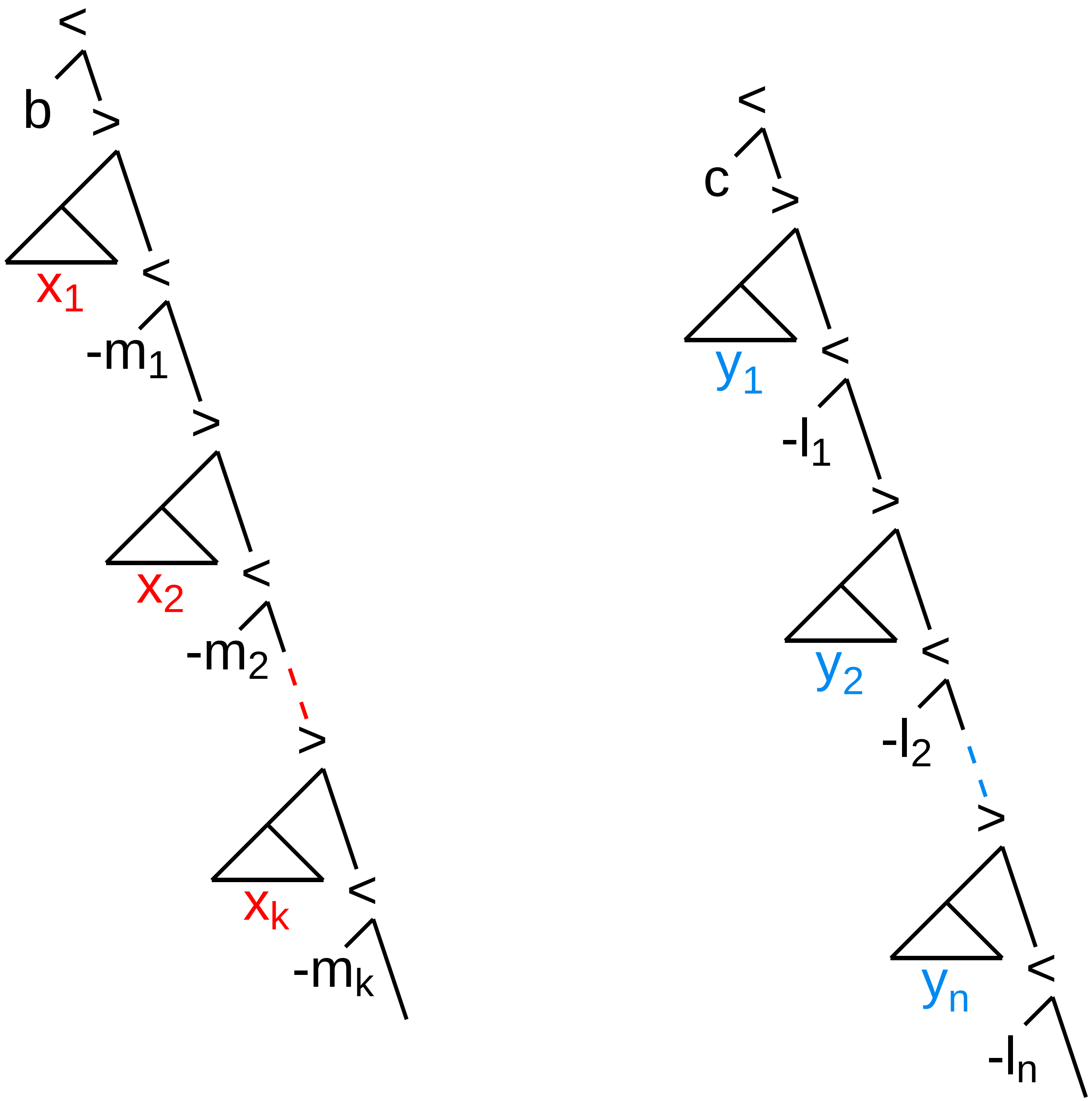

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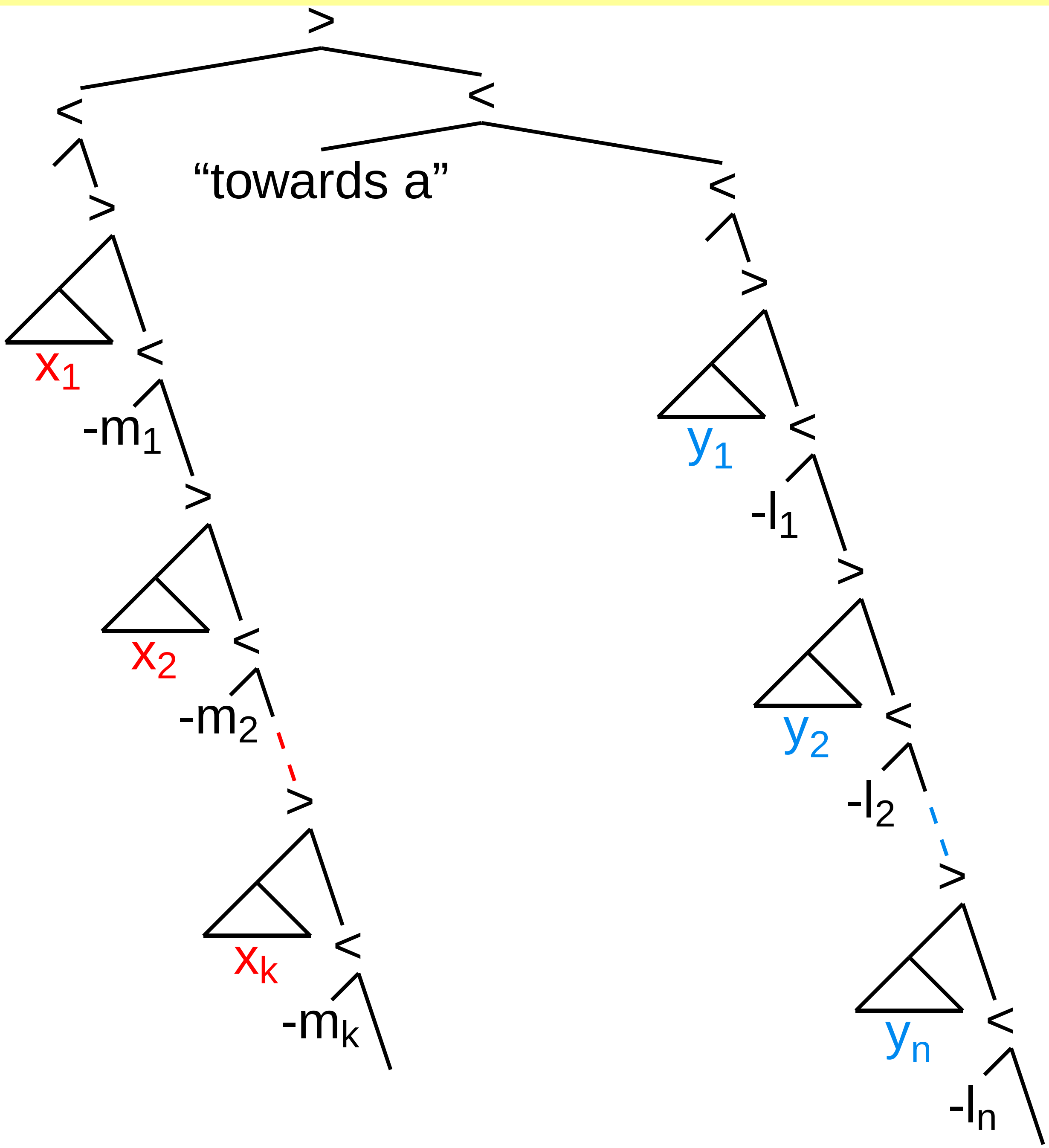
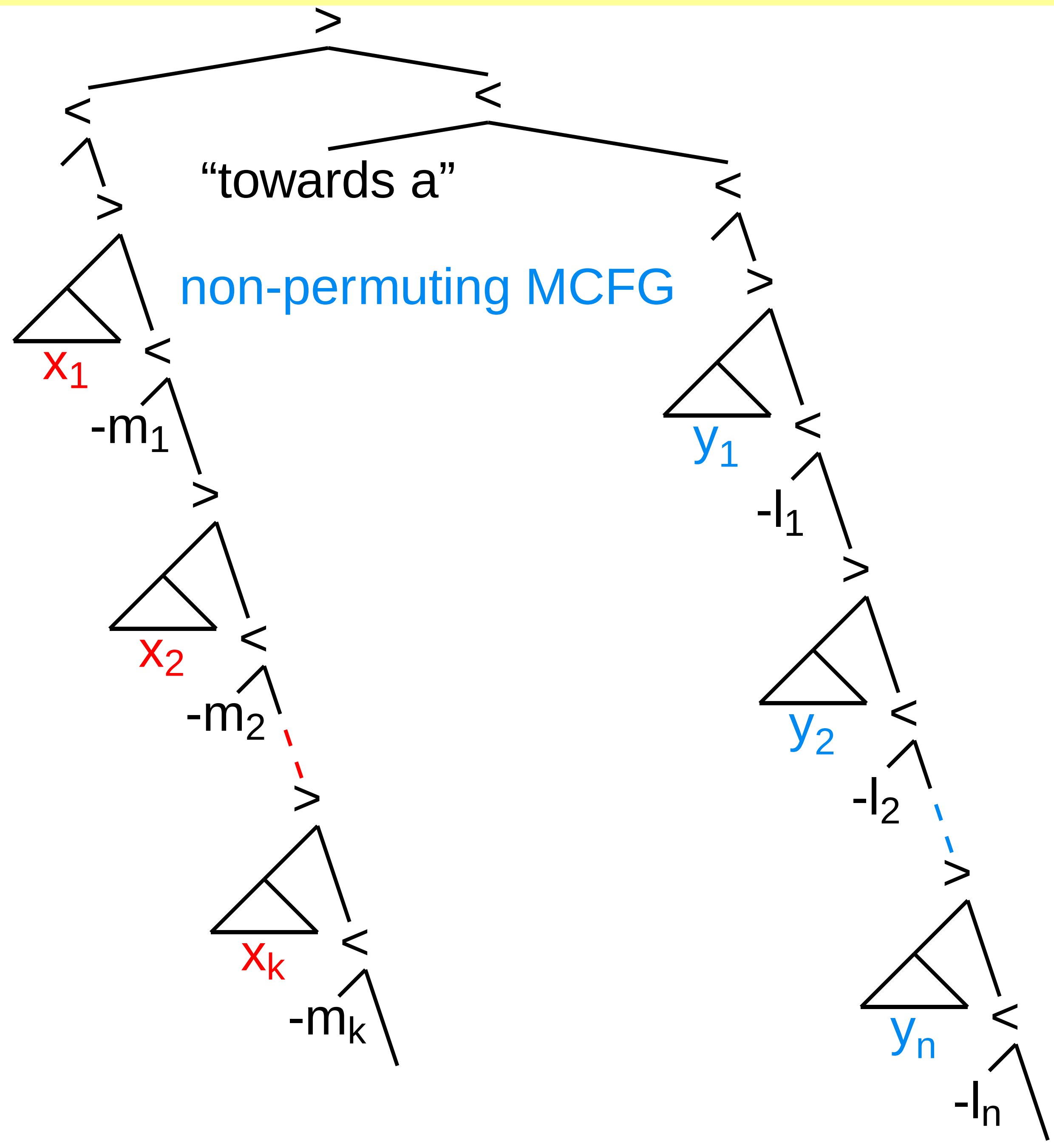
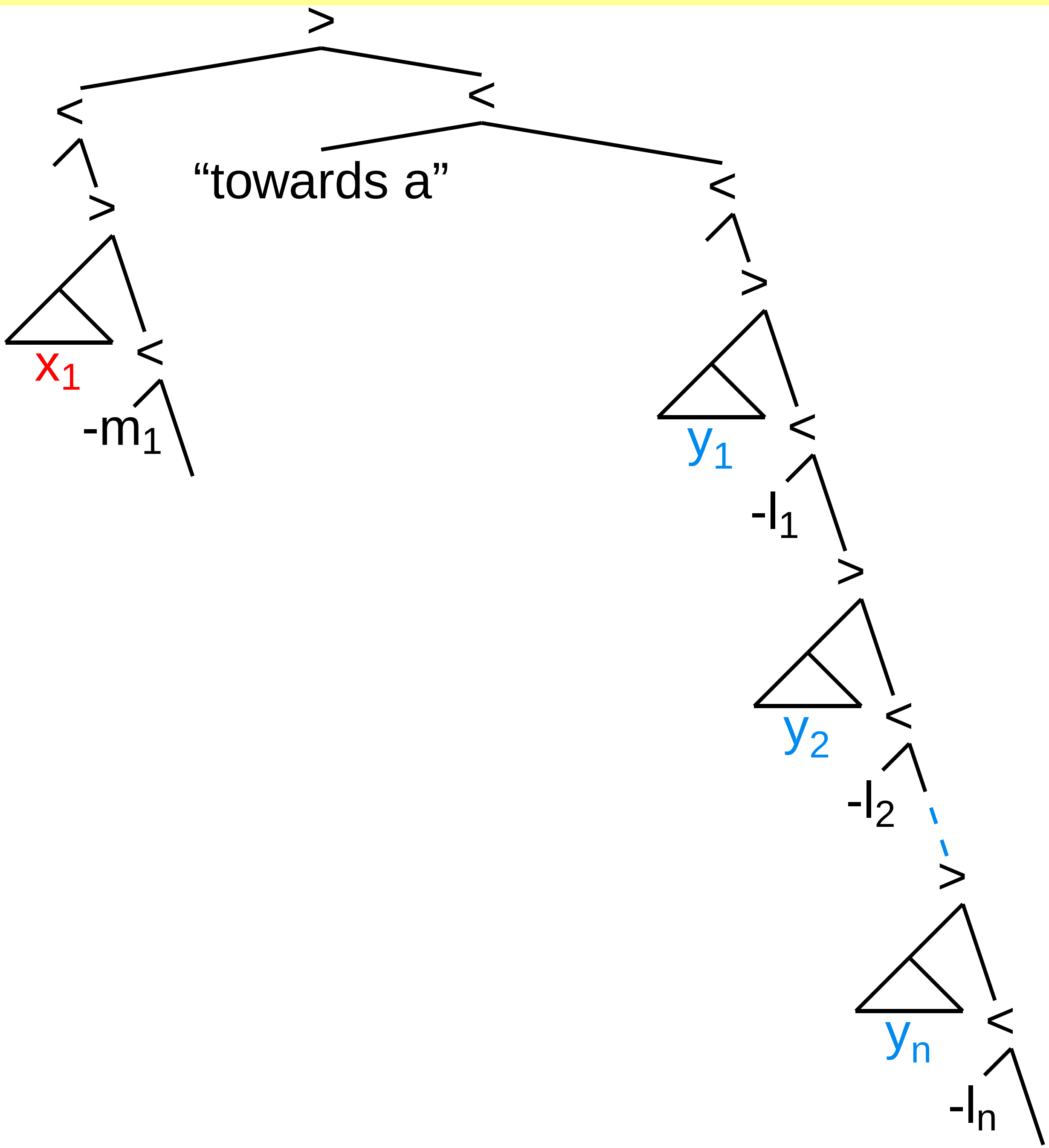


$A(\alpha_1, \ldots, \alpha_m) \leftarrow B(x_1, \ldots, x_k), C(y_1, \ldots, y_n)$ (Michaelis 2001c)



$$A(\alpha_1, \ldots, \alpha_m) \leftarrow B(x_1)\ C(y_1, \ldots, y_n)$$ (Michaelis 2001c)



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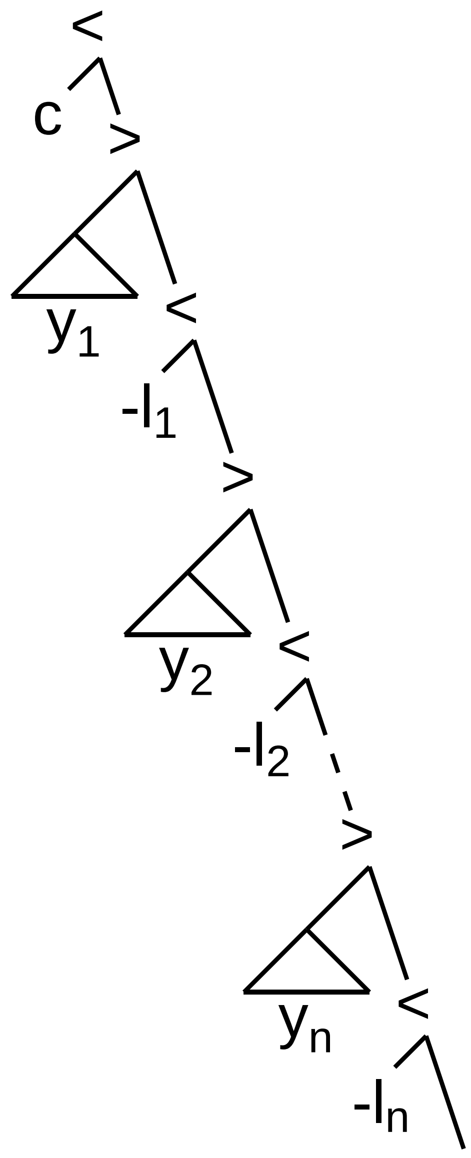

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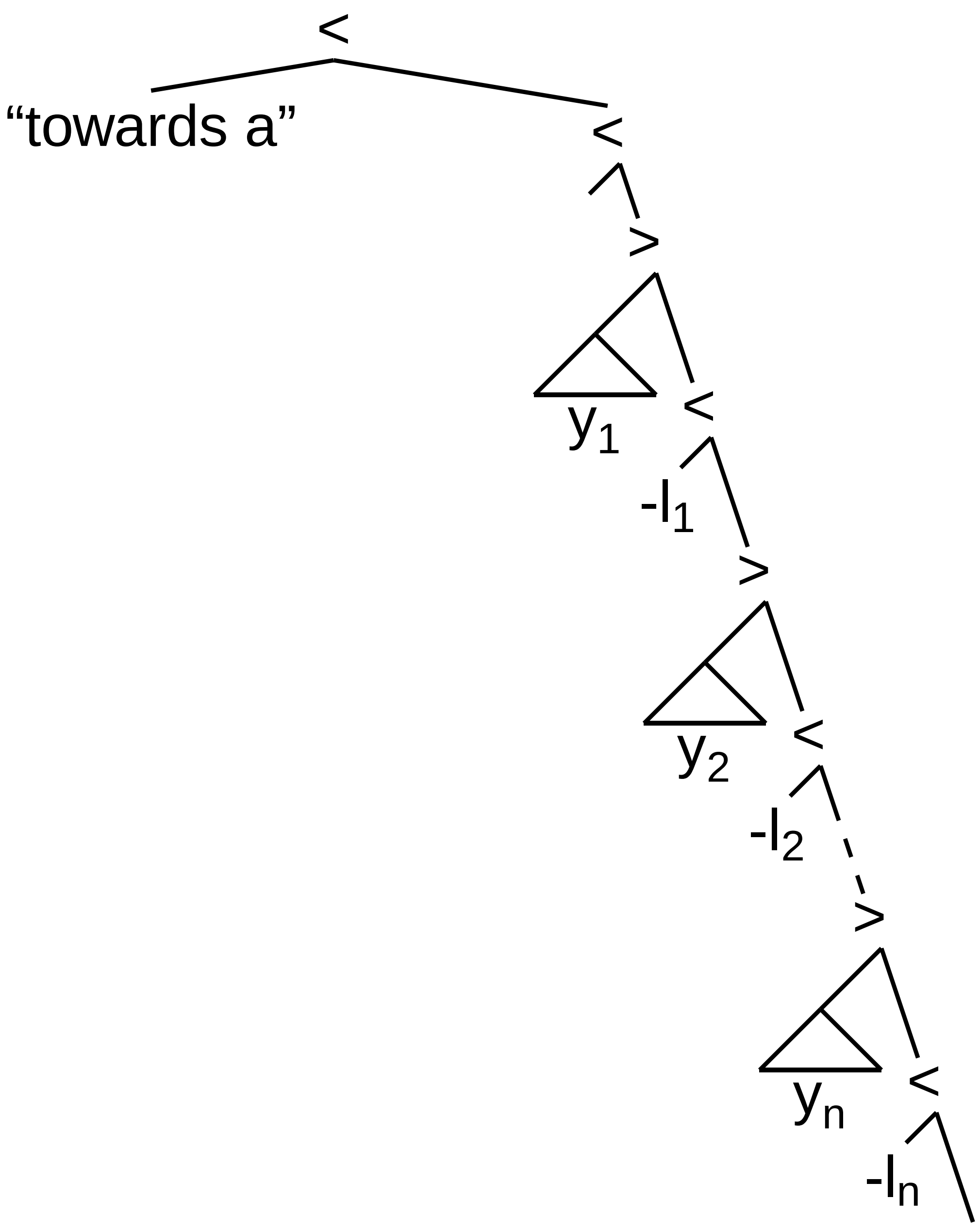

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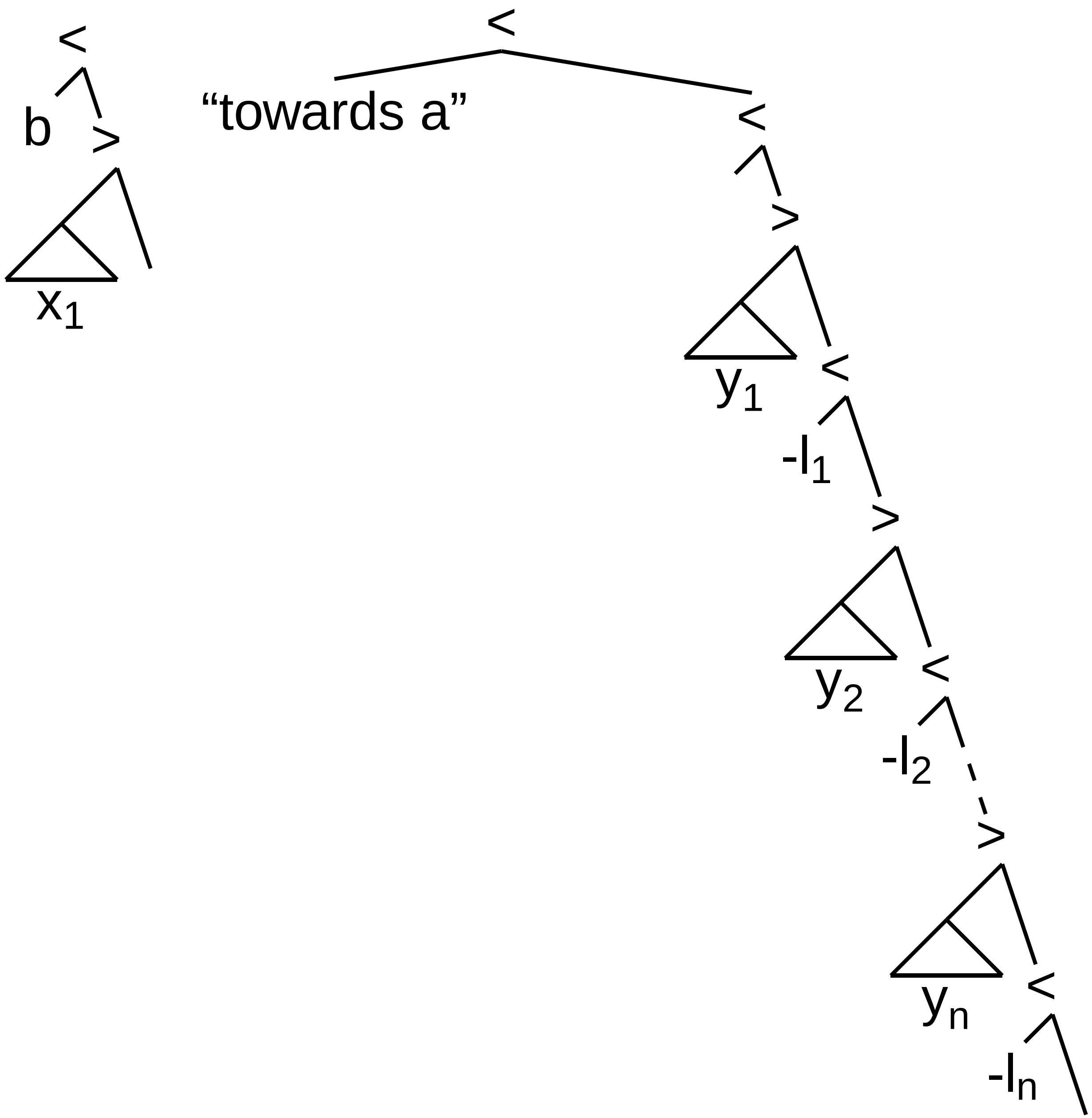
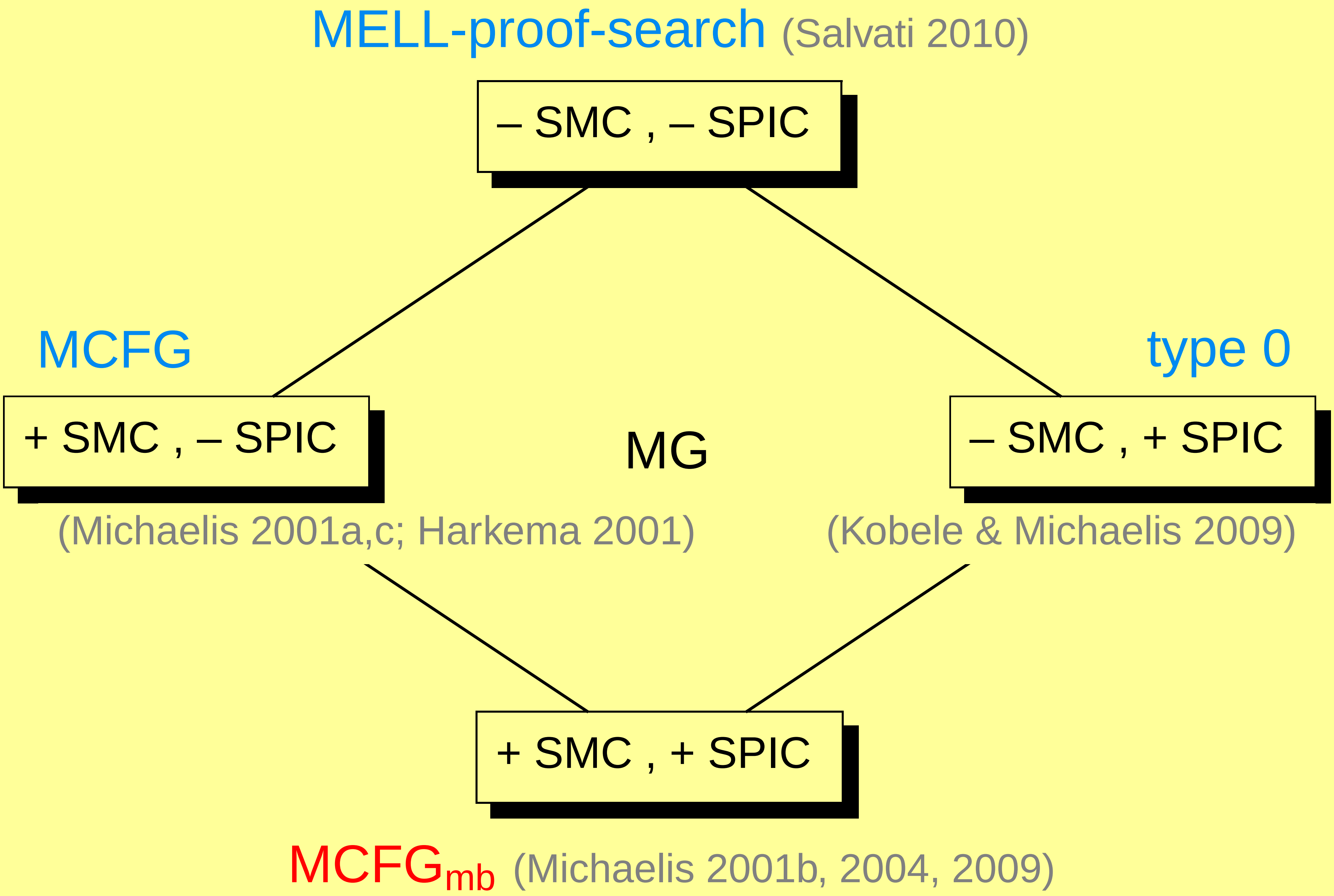


Concluding remarks



Concluding remarks

- $\mathrm{MCFL}_{mb} \subsetneq \mathrm{MCFL}_{wn} \subsetneq \mathrm{MCFL}$.

- The class of all m-MCFL_{mb} constitutes a strictly increasing hierarchy of substitution-closed full AFLs.

- Kanazawa & Salvati 2010 :
  Because of their limited copying power MCFL_{wn} may offer a “more fruitful approach” to natural language syntax than MCFL .

- SPIC seems to be a “canonical” restriction in MG-terms.

  What does MCFL-well-nestedness in its full version mean in MG-terms? Is there a canonical MG-formulation of it?

Thank you!

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