Evaluating a semantic algebra on a wide-coverage grammar of English

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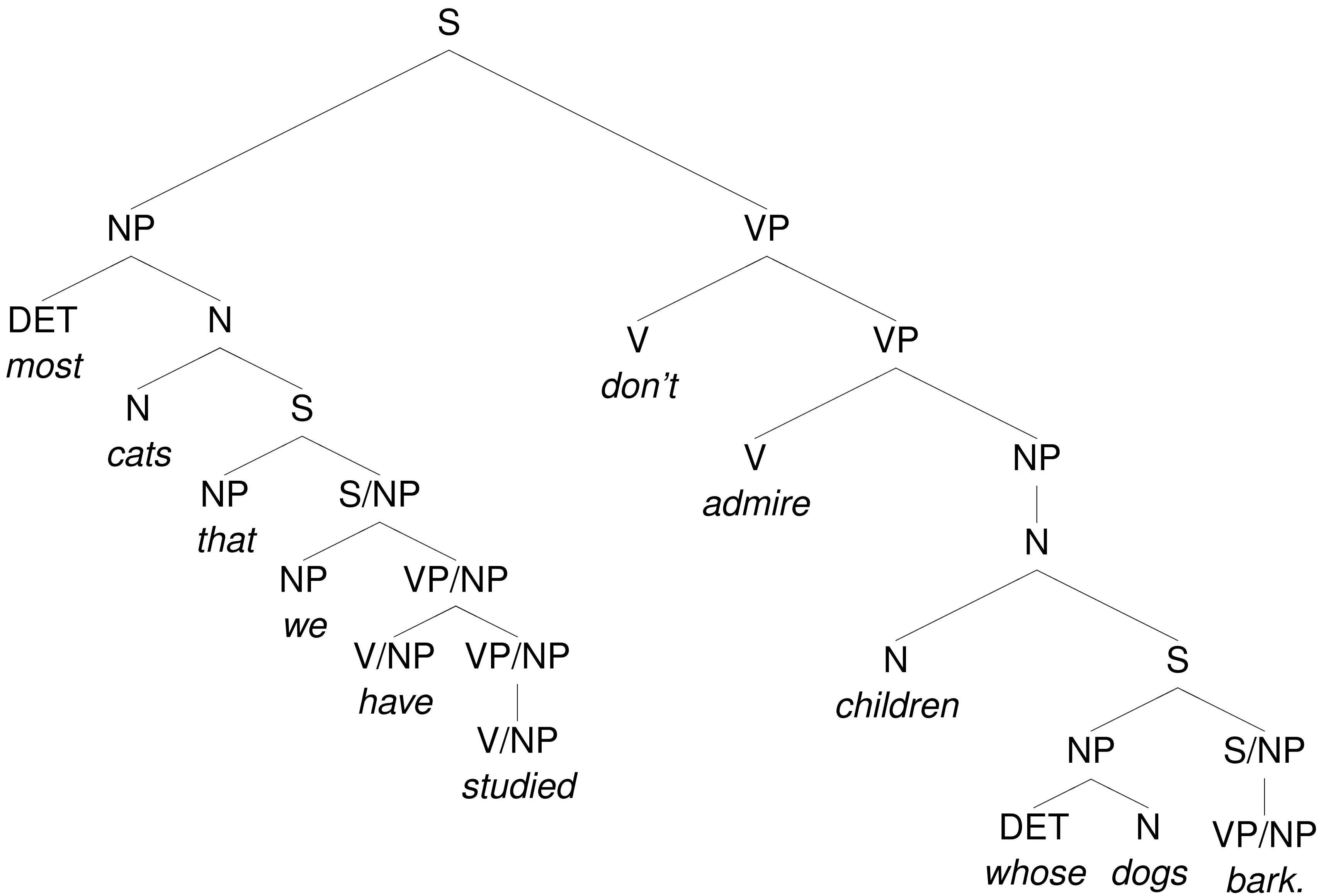
Desiderata for a linguistic theory

- General principles that hold true of human language
- Formal descriptive devices to make falsifiable predictions
- Cross-linguistic validity
- Simplicity

Overview of HPSG

- Linguistic objects can be described as attribute-value pairs
  (phonology), morphology, syntax, semantics, ...
- General principles constrain values for some attributes
  e.g. a phrase and its head daughter share certain values
- Most constraints are in the lexicon
- A small number of syntactic (phrase structure) rules suffice

A simple example



Minimal Recursion Semantics

Most cats that we have studied don't admire children whose dogs bark.

<h1,e2:prop:pres:indicative:-:-,
h3:_most_q(x4:3:pl:+, h5, h6),
h7:_cat_n_1(x4),
h8:pron(x9:1:pl),
h10:pronoun_q(x9, h11, h12),
h7:_study_v_1(e13:prop:pres:indicative:-:+, x9, x4),
h14:neg(e16, h15),
h17:_admire_v_1(e2, x4, x18:3:pl:+),
h19:udef_q(x18, h20, h21),
h22:_child_n_1(x18),
h23:def_explicit_q(x25:3:pl:+, h26, h24),
h22:poss(e27, x25, x18),
h28:_dog_n_1(x25),
h22:_bark_v_1(e29:prop:pres:indicative:-:-, x25),
h5 qeq h7, h11 qeq h8, h15 qeq h17, h20 qeq h22, h26 qeq h28>

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Another view: Semantic dependencies

Most cats that we have studied don't admire children whose dogs bark.

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x9:pronoun_q[]
e13:_study_v_1[ARG1 x9:pron, ARG2 x4:_cat_n_1]
e16:neg[ARG1 e2:_admire_v_1]
e2:_admire_v_1[ARG1 x4:_cat_n_1, ARG2 x18:_child_n_1]
x18:udef_q[]
x26:def_explicit_q[]
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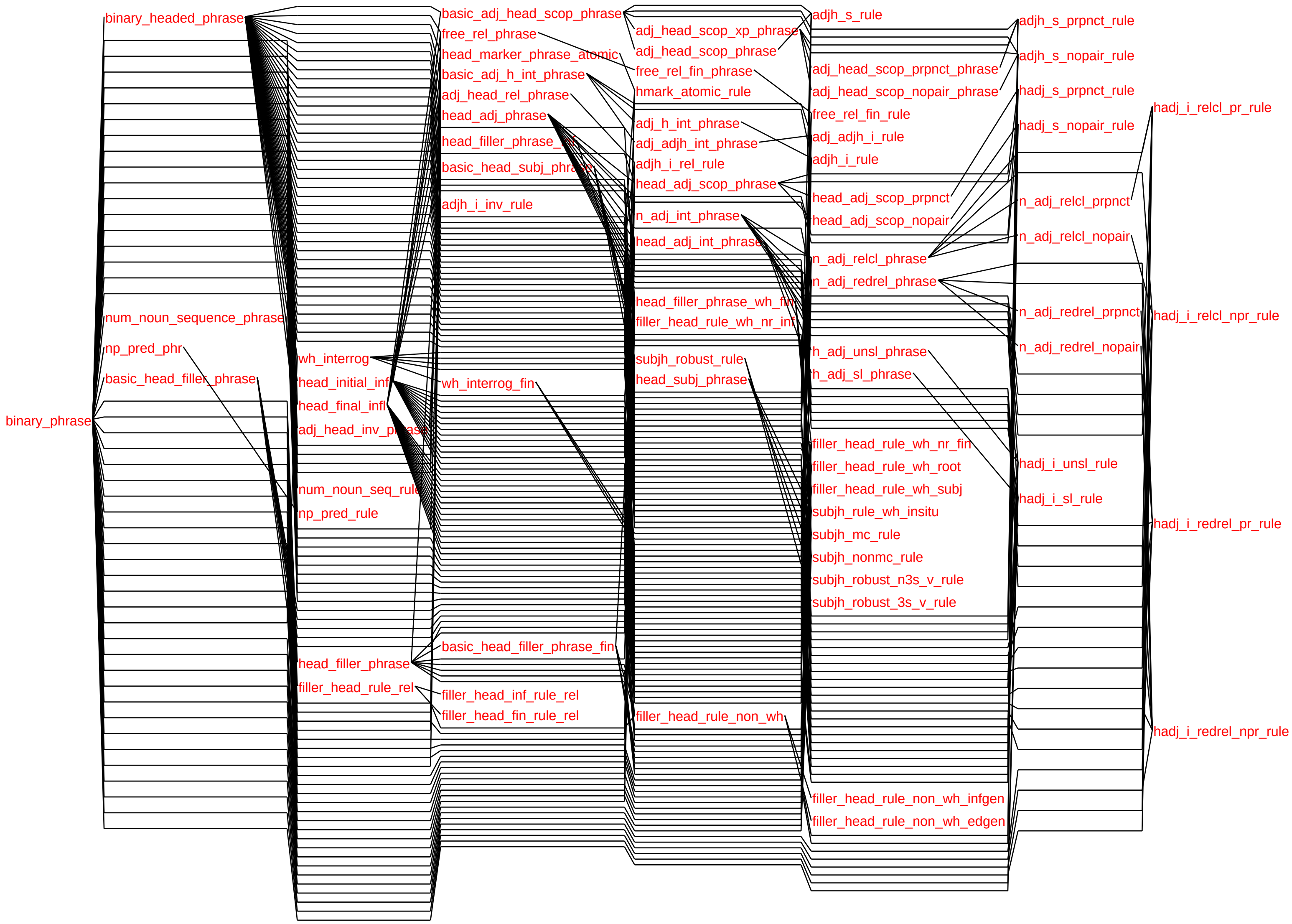
English Resource Grammar (ERG)

- 7000 types in multiple-inheritance monotonic hierarchy
- 1400 leaf lexical types
- 44,000 manually constructed lexemes
- 300 syntactic rules
- 100 morphological rules (inflection and derivation)
- Statistical parse selection model trained on 1.5 million word corpus
- Online demo: http://erg.delph-in.net

Standard HPSG Rules (Pollard & Sag 1994)

- Head-Subject
- Head-Complement
- Head-Specifier
- Head-Modifier
- Head-Marker
- Head-Filler
- Coordination

ERG syntactic rules (binary)



Semantics in feature structures

$$\begin{bmatrix} \text{ORTH} & \text{adore} \\ \text{HEAD} & \textit{verb} \\ \text{SUBJ} & \left\langle \begin{bmatrix} \text{HEAD} & \textit{noun} \\ \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{2} \end{bmatrix} \end{bmatrix} \right\rangle \\ \text{COMPS} & \left\langle \begin{bmatrix} \text{HEAD} & \textit{noun} \\ \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{3} \end{bmatrix} \end{bmatrix} \right\rangle \\ \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{1}\ \textit{event} \\ \text{RELS} & \left\langle \begin{bmatrix} \text{PRED} & \text{"adore\_v"} \\ \text{ARG0} & \boxed{1} \\ \text{ARG1} & \boxed{2} \\ \text{ARG2} & \boxed{3} \end{bmatrix} \right\rangle \\ \text{HCONS} & \langle\ \rangle \end{bmatrix} \end{bmatrix}$$

Semantics of sentences

The value of **CONT** for a sentence is a list of relations in the attribute **RELS**, with the arguments in those relations appropriately linked:

Kim adores snow

$$
\begin{bmatrix}
\text{HEAD} & \textit{verb} \\
\text{SUBJ} & \langle\ \rangle \\
\text{COMPS} & \langle\ \rangle \\
\text{CONT} & \begin{bmatrix}
\text{INDEX} & \boxed{1}\ \textit{event} \\
\text{RELS} & \left\langle \begin{bmatrix} \text{PRED} & \text{“adore\_v”} \\ \text{ARG0} & \boxed{1} \\ \text{ARG1} & \boxed{2} \\ \text{ARG2} & \boxed{3} \end{bmatrix}, \begin{bmatrix} \text{PRED} & \text{“Kim\_n”} \\ \text{ARG0} & \boxed{2} \end{bmatrix}, \begin{bmatrix} \text{PRED} & \text{“snow\_n”} \\ \text{ARG0} & \boxed{3} \end{bmatrix} \right\rangle \\
\text{HCONS} & \langle\ \rangle
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\end{bmatrix}
$$

Semantic composition for Minimal Recursion Semantics

- The **RELS** value of a phrase is the result of appending the **RELS** lists of its daughter(s), plus any from the construction itself.
- The **INDEX** value of a phrase is unified with the **INDEX** value of its semantic head daughter.

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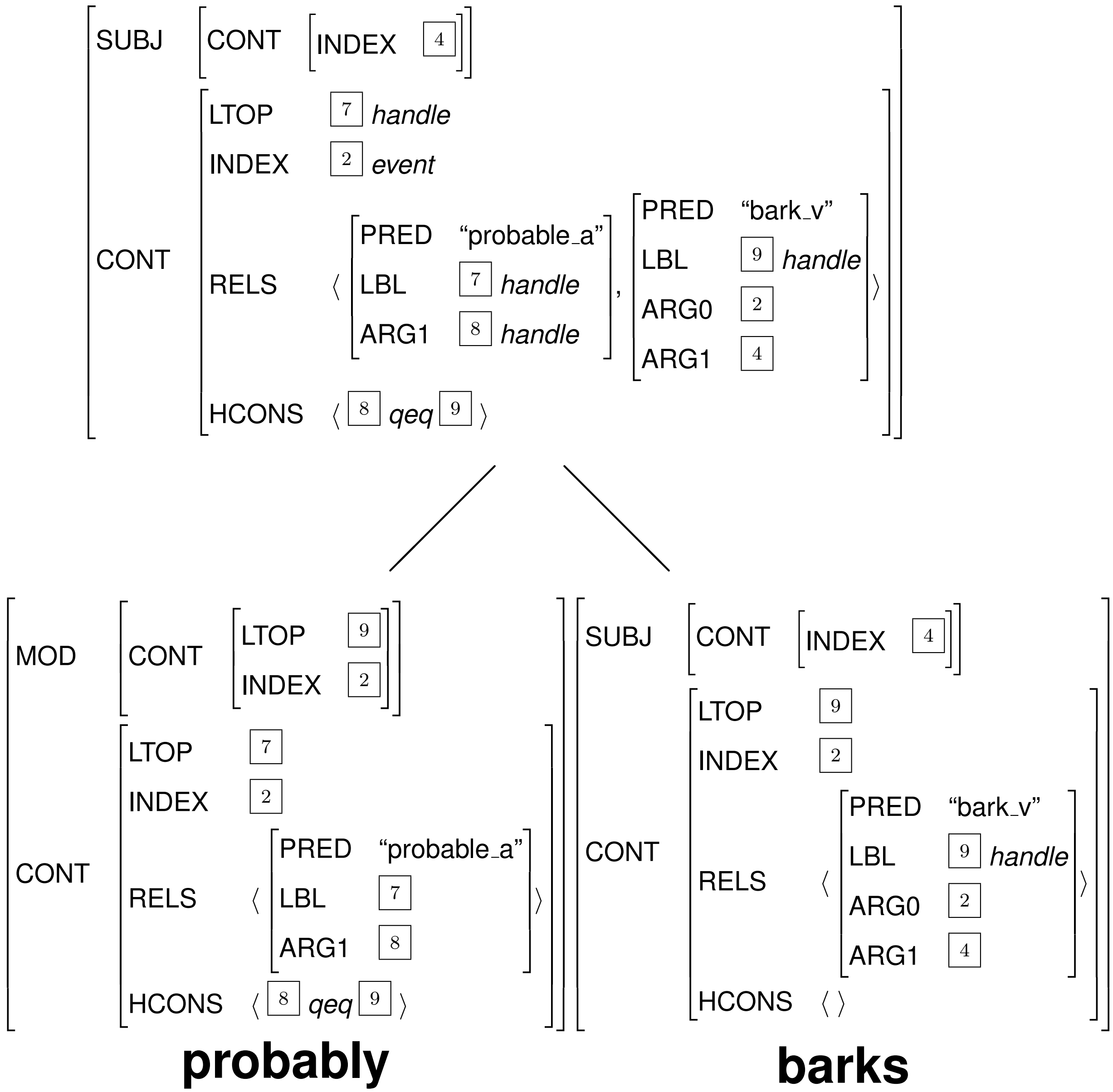
In addition, to accommodate scope underspecification:

- The **HCONS** value of a phrase is the result of appending the **HCONS** lists of its daughter(s), plus any from the construction itself.
- The **LTOP** value of a phrase is unified with the **LTOP** value of its semantic head daughter.

MRS Composition: “*probably barks*”



Linking semantic arguments

When heads select a complement or specifier, they constrain its **INDEX** value: a referential index for nouns, or an event variable for verbs.

$$
\begin{bmatrix}
\textit{trans-verb-lxm} & \\
\text{HEAD} & \textit{verb} \\
\text{SUBJ} & \left\langle \begin{bmatrix} \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{1} \end{bmatrix} \end{bmatrix} \right\rangle \\
\text{COMPS} & \left\langle \begin{bmatrix} \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{2} \end{bmatrix} \end{bmatrix} \right\rangle \\
\text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{3} \\ \text{RELS} & \left\langle \begin{bmatrix} \text{PRED} & \text{string} \\ \text{ARG0} & \boxed{3} \\ \text{ARG1} & \boxed{1} \\ \text{ARG2} & \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix}
\end{bmatrix}
$$

Scope in MRS

All angry dogs didn't bark.

$$\langle\, h_1,$$
$$\Big|\; h_4\text{:\_all\_q(ARG0 } x_5\text{, RSTR } h_6\text{, BODY \_\_)},$$
$$h_8\text{:\_angry\_a\_at(ARG0 } e_9\text{, ARG1 } x_5\text{, ARG2 \_\_)}, h_8\text{:\_dog\_n\_1(ARG0 } x_5\text{)},$$
$$h_2\text{:neg(ARG0 } e_{12}\text{, ARG1 } h_{11}\text{)}, h_{13}\text{:\_bark\_v\_1(ARG0 } e_3\text{, ARG1 } x_5\text{)} \;\Big|$$
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Scope Underspecification

- MRS: bag of tree fragments, with partial constraints on dominance
- Scopal $=_q$ handle constraints provide 'room' for quantifier insertion.

High-Level Goals in this Line of Work

Validate (and Refine) MRS Algebra (Copestake, et al. 2001)

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Enforce Separation of Church and State (at Scale)

- Syntax–semantics interface is mostly implicit in unification of signs;
- determine 'linguistic coverage' of MRS algebra relative to ERG rules.

Terminology to Talk about Meaning Construction

- Formally, an MRS is a triple $\langle T, P, C \rangle$: *top* handle, *predications*, *constraints*;
- composition through *MRS algebra terms* (MATs): five-tuple $\langle H, L, P, C, E \rangle$;

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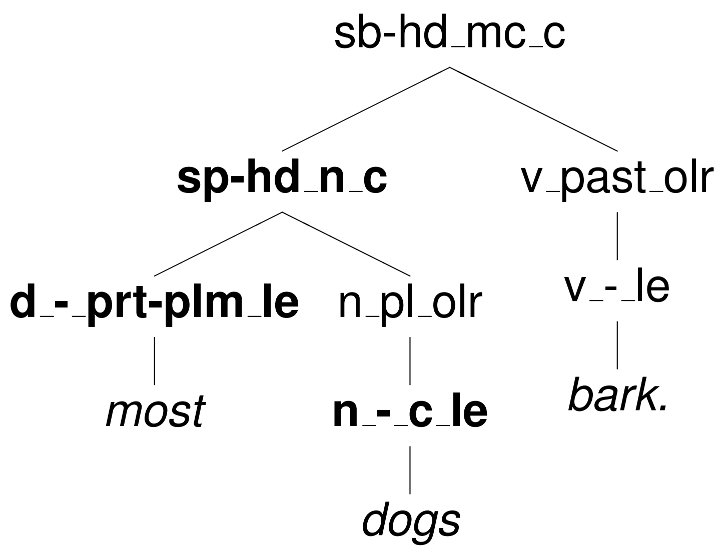
- (corresponds to lambda calculus: an argument hook 'plugs' a functor hole);
- *equalities* record variable 'unifications' from composition: β reduction.

A First Example of MATs Composition

Most dogs barked.



$$\langle\, h_1, \left|\, h_4{:}\_most\_q(x_5, h_6, \_\_), h_8{:}\_dog\_n\_1(x_5), h_2{:}\_bark\_v\_1(e_3, x_5) \,\right| \{\, h_6 =_q h_8, h_1 =_q h_2 \,\} \,\rangle$$

most

$$\langle \_\_, x_1, \_\_ \rangle$$
$$\{_{\text{SPEC}} \langle h_3, x_1, \_\_ \rangle \}$$
$$\left|\, h_0{:}\_most\_q(x_1, h_2, \_\_) \,\right|$$
$$\{\, h_2 =_q h_3 \,\}$$
$$\{\,\}$$

dogs

$$\langle h_4, x_5, \_\_ \rangle$$
$$\{\}$$
$$\left|\, h_4{:}\_dog\_n\_1(x_5) \,\right|$$
$$\{\,\}$$
$$\{\,\}$$

most dogs

$$\langle \_\_, x_1, \_\_ \rangle$$
$$\{\}$$
$$\left|\, h_0{:}\_most\_q(x_1, h_2, \_\_), h_4{:}\_dog\_n\_1(x_5) \,\right|$$
$$\{\, h_2 =_q h_3 \,\}$$
$$\{\, h_3 \equiv h_4, x_1 \equiv x_5 \,\}$$

A Composition Operation of Copestake, et al. (2001)

$$\langle H_f, L_f, P_f, C_f, E_f \rangle \bullet_{\mathsf{SPEC}} \langle H_a, L_a, P_a, C_a, E_a \rangle \rightarrow \langle H, L, P, C, E \rangle$$

Let $H_a = \langle \mathit{h}_a, \mathit{i}_a, \mathit{x}_a \rangle$ and $L' = {}_{\mathsf{SPEC}}\langle \mathit{h}_f, \mathit{i}_f, \mathit{x}_f \rangle \in L_F$:

$$H = H_f; L = L_f \setminus \{L'\} \cup L_a;$$

$$P = P_f \cup P_a; C = C_f \cup C_a;$$

$$E = E_f \cup E_a \cup \{\mathit{h}_f = \mathit{h}_a, \mathit{i}_f = \mathit{i}_a, \mathit{x}_f = \mathit{x}_a\}$$

Preliminary Reflections on MRS Algebra

A 'Straitjacket' for Sign-Based Composition

- Relatively simple framework with tightly constraining assumptions:
- accessibility: at most three 'pointers' into meaning fragments available;
- finiteness: fixed inventory of hole types, SPEC, SUBJ, COMPS, MOD, . . . ;
- uniformity: templatic form of composition operations, functor–argument;
- monotonicity: *set union* of holes, predications, constraints, and equalities.

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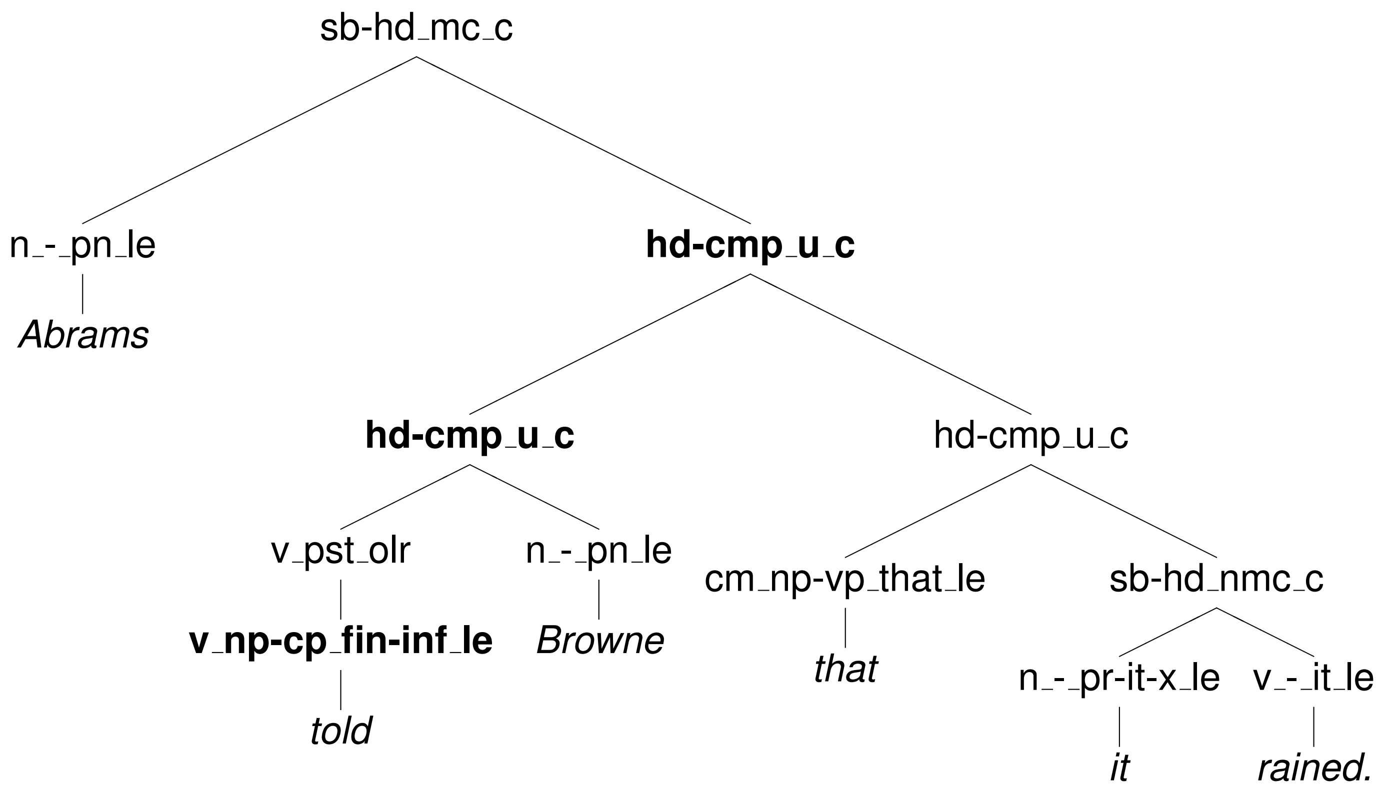
Assumptions about the Syntax–Semantics Interface

- Lexical entries provide initial MATs (need to deal with lexical ambiguity);
- each syntactic construction determines its operation;
- n-ary constructions (for $n > 2$) treated as sequence of operations;
- unary constructions treated as empty functor or argument MAT.

Non-Scopal vs. Scopal Complements



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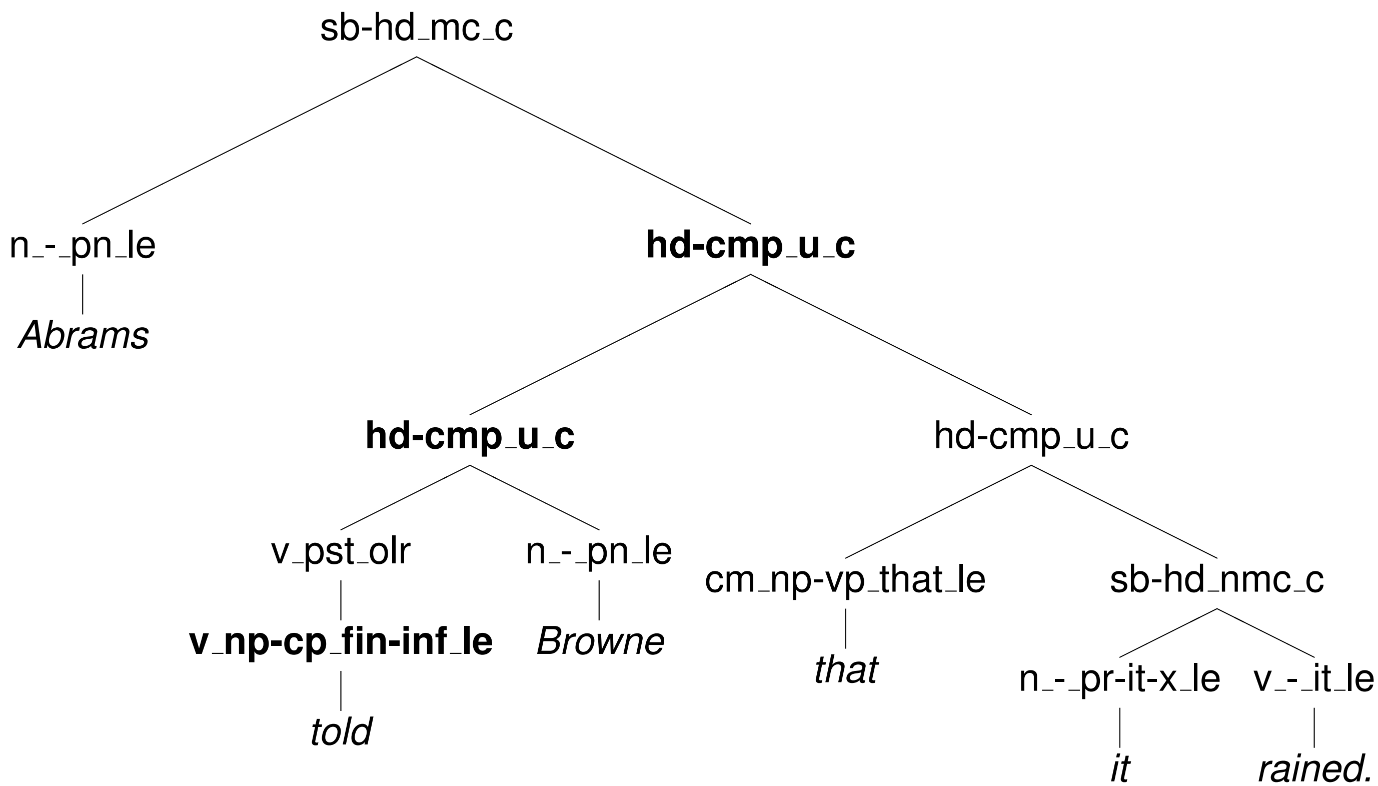


told

$\langle\, h_0,\ e_1,\ \_\_ \,\rangle$

$\left\{ \textsc{subj}\langle\, h_0,\ x_2,\ \_\_ \,\rangle,\ \textsc{comps}[\,\langle\, h_0,\ x_3,\ \_\_ \,\rangle, \langle\, h_5,\ \_\_,\ \_\_ \,\rangle] \right\}$

$\left|\ h_0\text{:\_tell\_v\_1}(e_1,\ x_2,\ x_3,\ h_4)\ \right|$

$\{\ h_4 =_q h_5\ \}$

$\{\ \}$

Browne

$\langle\, h_6,\ x_7,\ \_\_ \,\rangle$

$\{\}$

$\left|\ h_6\text{:named}(x_7,\ \textit{Browne})\ \right|$

$\{\ \}$

$\{\ \}$

that it rained

$\langle\, h_8,\ e_9,\ \_\_ \,\rangle$

$\{\}$

$\left|\ h_8\text{:\_rain\_v\_1}(e_9)\ \right|$

$\{\ \}$

$\{\ \}$

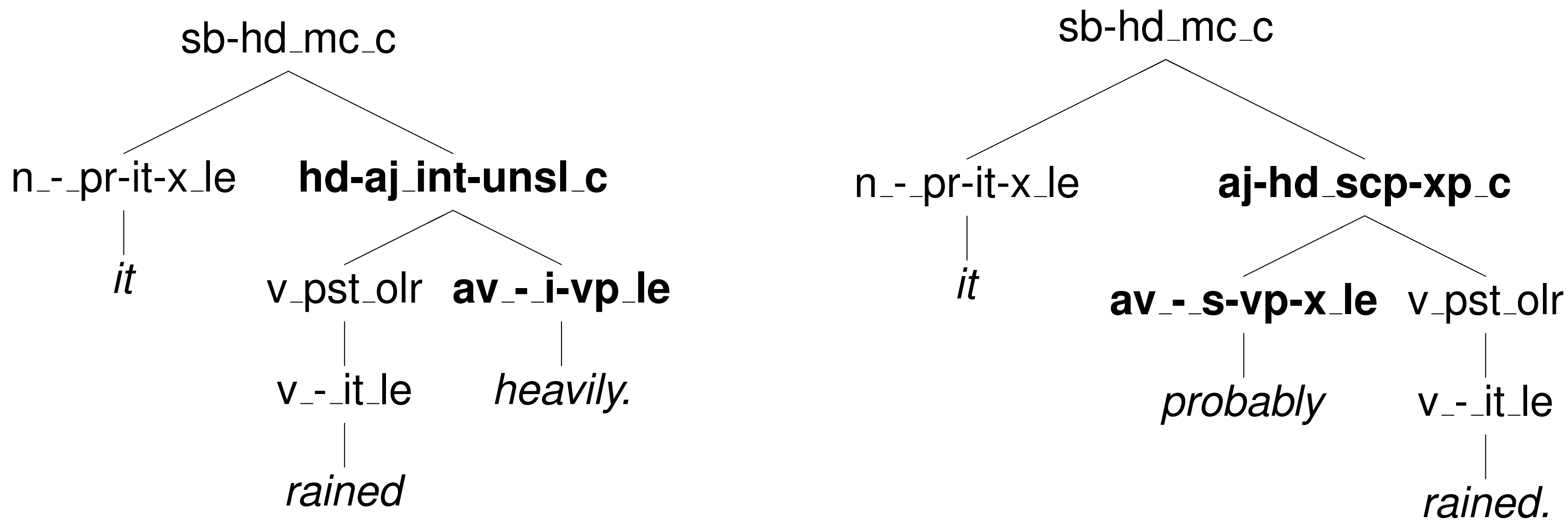
One Uniform $\bullet_{\text{COMPS}}$ Operation

Let $L' = [\,\langle\, h_l,\, i_l,\, x_l \,\rangle\,] \oplus L_g$:

$$\langle H_f, \{_{\text{COMPS}}\, L'\} \cup\; L_f, P_f, C_f, E_f \rangle \quad \bullet_{\text{COMPS}} \quad \langle H_a, L_a, P_a, C_a, E_a \rangle$$

$$\rightarrow \quad \langle H_f, \{_{\text{COMPS}}\, L_g\} \cup\; L_f \cup\; L_a, \ldots, \ldots \rangle$$

Restrictive vs. Scopal Modification



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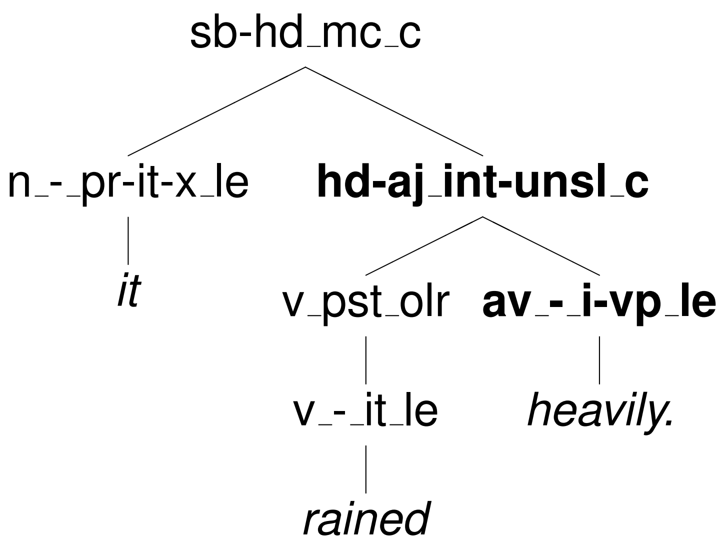
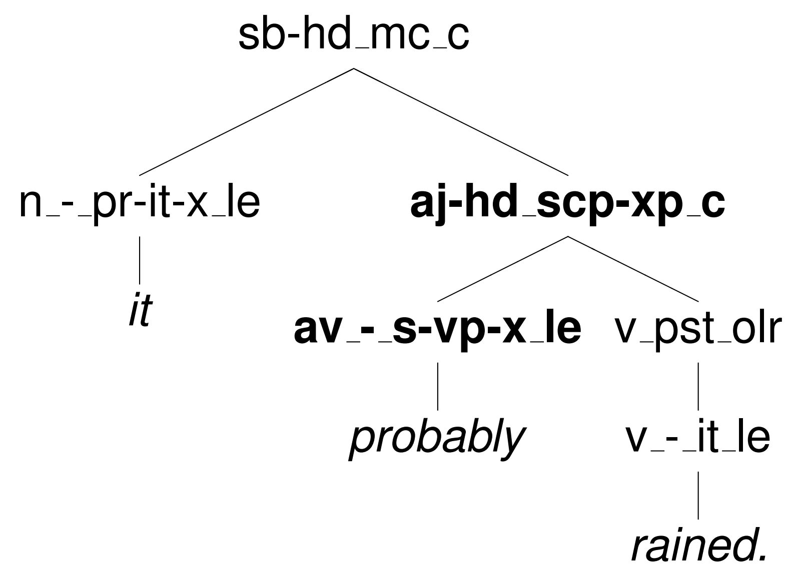




rained	*heavily*	*probably*
$\langle\, h_0,\, e_1,\, \_\_ \,\rangle$	$\langle\, h_2,\, e_3,\, \_\_ \,\rangle$	$\langle\, h_5,\, e_6,\, \_\_ \,\rangle$
$\{_{\text{SUBJ}}\langle \_\_, \_\_, \_\_ \rangle\}$	$\{_{\text{MOD}}\langle h_2,\, e_4,\, \_\_ \rangle\}$	$\{_{\text{MOD}}\langle h_8,\, \_\_,\, \_\_ \rangle\}$
$\lvert\, h_0\text{:\_rain\_v\_1}(e_1) \,\rvert$	$\lvert\, h_2\text{:\_heavy\_a\_1}(e_3,\, e_4) \,\rvert$	$\lvert\, h_5\text{:\_probable\_a\_1}(e_6,\, h_7) \,\rvert$
$\{\,\}$	$\{\,\}$	$\{\, h_7 =_q h_8 \,\}$
$\{\,\}$	$\{\,\}$	$\{\,\}$

One Uniform $\bullet_{\text{MOD}}$ Operation

Let $L' = {}_{\text{MOD}}\langle h_l, i_l, \_\rangle \in L_f$:

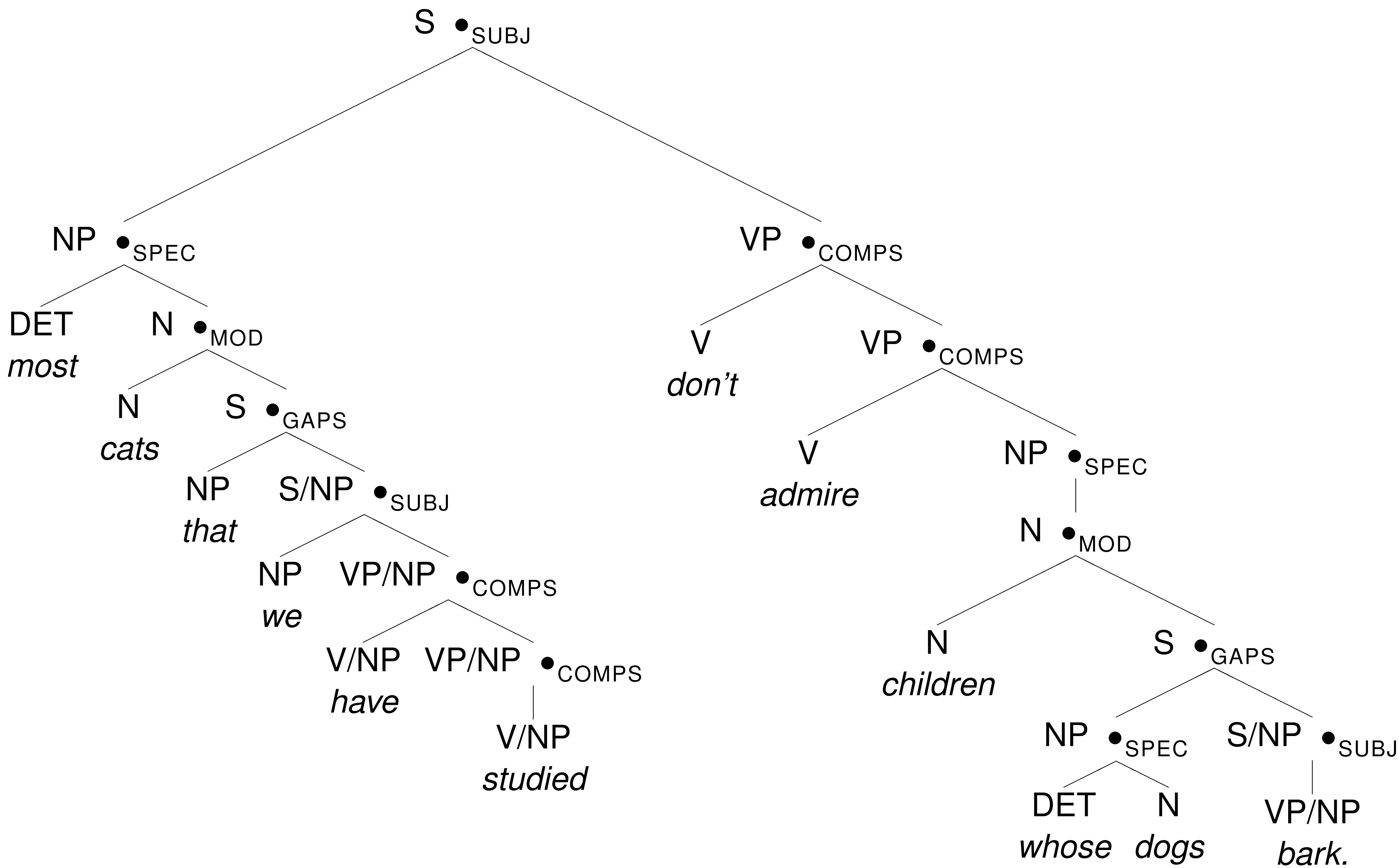
$$\langle\langle h_f, i_f, \_\rangle, L_f, P_f, C_f, E_f\rangle \quad \bullet_{\text{MOD}} \quad \langle\langle h_a, i_a, \_\rangle, L_a, P_a, C_a, E_a\rangle \quad \rightarrow$$

$$\langle\langle h_f, i_a, \_\rangle, L_f \setminus \{L'\} \cup L_a, P_f \cup P_a, C_f \cup C_a, E_f \cup E_a \cup \{h_l \equiv h_a, i_l \equiv i_a\}\rangle$$

Inventory of all operations to date

- SUBJ *cats sleep*
- COMPS *cats [chase mice]*
- SPEC *[most cats] sleep*
- MOD *cats [probably dream]*
- GAPS *what do cats chase?*
- CONJ *cats [sleep and dream]*

Our example, with algebra operations



Ongoing Work & Open Questions

- Evaluate proposal by Copestake et al. (2001) on full range of ERG analyses
  Auto-convert MRSs to MATs and use specialized grammar to check
- Determine degree of 'algebra compliance' in ERG: 45 %, 85 %, or 98 %?
- Continue tuning the ERG for better compliance

→ Non-trivial revisions and extensions to algebra are required

→ Core ideas of Copestake et al. remain intact

? What principles govern percolation of holes?

? How to compare to lambda calculus?