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Holes in Meaning Construction with Minimal Recursion Semantics

Stephan Oepen & Dan Flickinger

Universitetet i Oslo, Stanford University, and
Center for Advanced Study at the
Norwegian Academy of Science and Letters

oe@ifi.uio.no, danf@stanford.edu

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Holes in Meaning Construction with Minimal Recursion Semantics

‘Empirical ERG Research’

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Holes in Meaning Construction with Minimal Recursion Semantics

Lollies & Lambdas → Hooks & Holes

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Background: Wide-Coverage Grammar Engineering

Deep Linguistic Processing with HPSG (`www.delph-in.net`)

- Practical and re-usable HPSG implementations; ongoing since 1990s;
- Typed feature structure formalism: [Carpenter, 92], [Copestake, 92];
- phrase structure rules with complex categories (feature structures);
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LinGO English Resource Grammar (ERG; `lingo.stanford.edu`)

- Comprehensive: ~9000 types; 84 lexical and 222 grammar rules (1214);
- hand-built lexicon of 39,000 lemmas; 1,100 types; some 10,000 verbs;
- coverage ~80 – 95% across domains: Wikipedia, GENIA, WSJ, et al.

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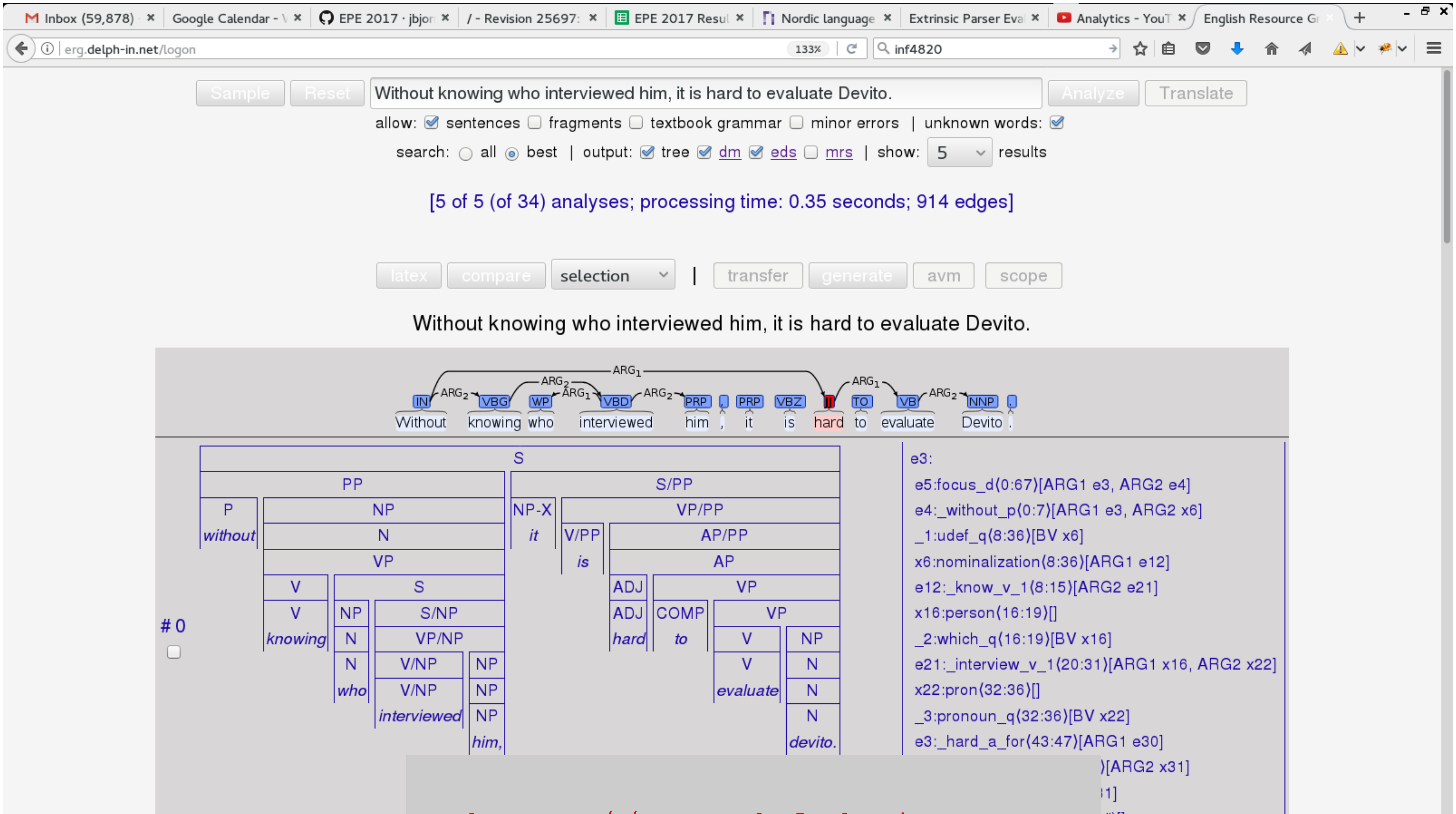
Long-term joint effort with (among others):

Emily M. Bender, Ann Copestake,
John Carroll, Woodley Packard,
Ivan A. Sag, Hans Uszkoreit, and more.

Go Play Yourselves (Tonight): The ERG On-Line



http://erg.delph-in.net

Parsing into Logical-Form Meaning Representation

Minimal Recursion Semantics (Copestake, et al. 2005)

- Abstract representation of grammatically determined *sentence meaning*;
- underspecification of quantifier scope (and finer-grained word senses);
- mono-stratal, sign-based design: syntax and semantics via *unification*;

$\rightarrow$ syntactic derivation and meaning representation correspond *one-to-one*.

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But this theory would not work.

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But this theory would not work.

MRS Fundamentals by Example (1/3)

All angry dogs didn't bark.

$$\langle\, h_1,\ \left|\begin{array}{l} h_4\text{:\_all\_q}(\text{ARG0 } x_5,\ \text{RSTR } h_6,\ \text{BODY } \_\_),\\ h_8\text{:\_angry\_a\_at}(\text{ARG0 } e_9,\ \text{ARG1 } x_5,\ \text{ARG2 } \_\_),\ h_8\text{:\_dog\_n\_1}(\text{ARG0 } x_5),\\ h_2\text{:neg}(\text{ARG0 } e_{12},\ \text{ARG1 } h_{11}),\ h_{13}\text{:\_bark\_v\_1}(\text{ARG0 } e_3,\ \text{ARG1 } x_5)\end{array}\right|\ \{\, h_1 =_q h_2,\ h_6 =_q h_8,\ h_{11} =_q h_{13} \,\}\,\rangle$$

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$$\forall x_5 : \mathrm{angry'}(x_5) \wedge \mathrm{dog'}(x_5) \rightarrow \neg\, \mathrm{bark'}(e_3, x_5)$$

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Scope Underspecification 101

- MRS as collection of tree fragments, with partial constraints on dominance;
- scopal $=_q$ handle constraints provide candidate 'room' for quantifier insertion.

MRS Fundamentals by Example (2/3)

Abrams told Browne that it rained.

$$\langle\, h_1,$$
$$\left|\begin{array}{l} h_2\text{:named}(x_6, \textit{Abrams}), h_2\text{:named}(x_{10}, \textit{Browne}), \\ h_2\text{:\_tell\_v\_1}(e_3, x_6, x_{10}, h_9), h_{15}\text{:\_rain\_v\_1}(e_{16}) \end{array}\right|$$
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Two Basic Types of Semantic Arguments

- Individuals, e.g. nominal complements: logical conjunction, equate handles;
- propositions, e.g. clausal complements: scopally subordinate, introduce $=_q$.
- when (and if) mapped to logical form, the handle meta-variables disappear.

MRS Fundamentals by Example (3/3)

It rained heavily.

$$\left\langle\, h_1,\ \left|\begin{array}{l} h_2\text{:\_rain\_v\_1}(e_3), \\ h_2\text{:\_heavy\_a\_1}(e_4,\, e_3) \end{array}\right|\ \{\, h_1 =_q h_2 \,\}\,\right\rangle$$

It probably rained.

$$\left\langle\, h_1,\ \left|\begin{array}{l} h_2\text{:\_probable\_a\_1}(e_4,\, h_5), \\ h_6\text{:\_rain\_v\_1}(e_3) \end{array}\right|\ \{\, h_1 =_q h_2,\, h_5 =_q h_6 \,\}\,\right\rangle$$

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Most angry dogs are fierce.

$$\langle\, h_1,\, e_3,\ \left|\begin{array}{l} h_4\text{:\_most\_q}(x_5,\, h_6,\, \_\_), \\ h_8\text{:\_angry\_a\_at}(e_9,\, x_5,\, \_\_),\, h_8\text{:\_dog\_n\_1}(x_5), \\ h_2\text{:\_fierce\_a\_1}(e_3,\, x_5) \end{array}\right|\ \{\, h_1 =_q h_2,\, h_6 =_q h_8 \,\}\,\rangle$$

$$\text{most' } x_5 : \text{angry'}(x_5) \wedge \text{dog'}(x_5) \; ; \; \text{fierce'}(e_3, x_5)$$

High-Level Goals in this Line of Work

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

- Earlier proposal for (ERG-style) constrained composition of MRS fragments;
- only spelled out for small selection of simple examples; no implementation.

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- Syntax–semantics interface is mostly implicit in unification of HPSG signs;
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Transfer Semantic Lexicon to Dependency-Based Syntax

- Explicit, formal, and 'lean' syntax–semantics interface should be portable;

? leverage wealth of fine-grained lexical information in ERG with UD syntax.

Terminology to Talk about Meaning Construction

Operationalizing MRS Composition

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

HOOK
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| ELEMENTARY PREDICATIONS |
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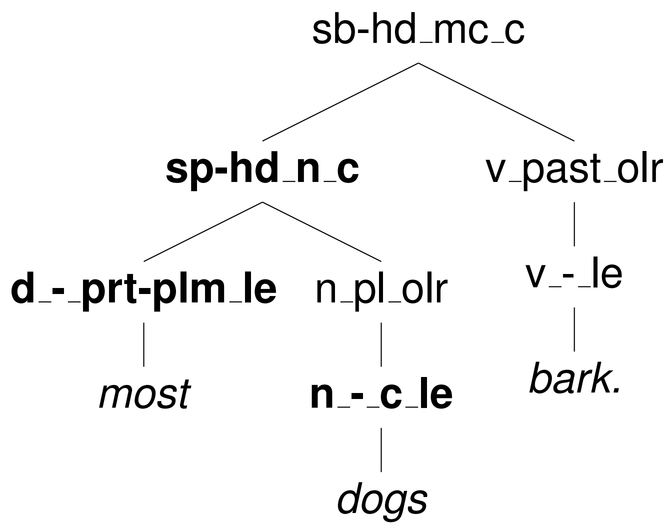
- correspondence to lambda calculus: an argument hook 'plugs' a functor hole;
- set of *equalities* records variable 'unifications' from composition: β reduction.

A First Example of MATs Composition

Most dogs barked.



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most	*dogs*	*most dogs*
$\langle\ \_\_,\ x_1,\ \_\_\ \rangle$	$\langle\ h_4,\ x_5,\ \_\_\ \rangle$	$\langle\ \_\_,\ x_1,\ \_\_\ \rangle$
$\{_{\text{SPEC}}\langle\ h_3,\ x_1,\ \_\_\ \rangle\}$	$\{\}$	$\{\}$
$\mid h_0\text{:\_most\_q}(x_1,\ h_2,\ \_\_)\mid$	$\mid h_4\text{:\_dog\_n\_1}(x_5)\mid$	$\mid h_0\text{:\_most\_q}(x_1,\ h_2,\ \_\_),\ h_4\text{:\_dog\_n\_1}(x_5)\mid$
$\{\ h_2 =_q h_3\ \}$	$\{\ \}$	$\{\ h_2 =_q h_3\ \}$
$\{\ \}$	$\{\ \}$	$\{\ h_3 \equiv h_4,\ x_1 \equiv x_5\ \}$

A First Example of MATs Composition

Composition Operations of Copestake, et al. (2001):

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

Let $H_a = \langle h_a, i_a, x_a \rangle$ and $L' = {}_{\text{SPEC}}\langle h_f, i_f, x_f \rangle \in L_F$:

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

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

$$E = E_f \cup E_a \cup \{h_f = h_a, i_f = i_a, x_f = x_a\}$$

most	*dogs*	*most dogs*
$\langle \_, x_1, \_ \rangle$	$\langle h_4, x_5, \_ \rangle$	$\langle \_, x_1, \_ \rangle$
$\{{}_{\text{SPEC}}\langle h_3, x_1, \_ \rangle\}$	$\{\}$	$\{\}$
$\vert h_0$:_most_q$(x_1, h_2, _) \vert$	$\vert h_4$:_dog_n_1$(x_5) \vert$	$\vert h_0$:_most_q$(x_1, h_2, _)$, h_4:_dog_n_1$(x_5) \vert$
$\{ h_2 =_q h_3 \}$	$\{ \}$	$\{ h_2 =_q h_3 \}$
$\{ \}$	$\{ \}$	$\{ h_3 \equiv h_4, x_1 \equiv x_5 \}$

Preliminary Reflections on MRS Algebra

A 'Straitjacket' for Sign-Based Composition

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

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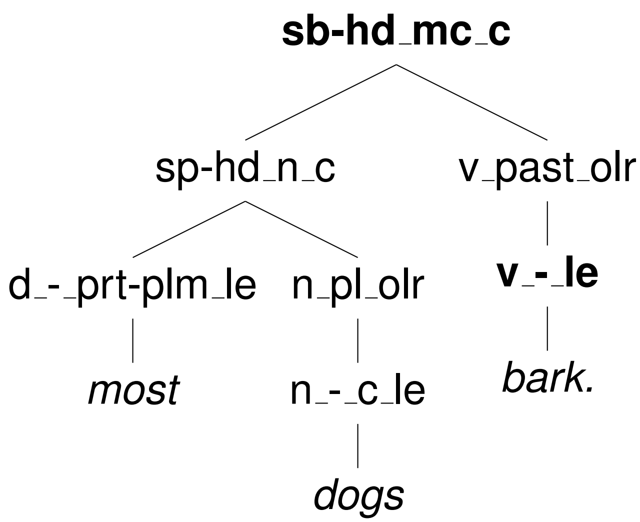
- uniformity: templatic form of all composition operations, functor–argument;
- monotonicity: *set union* of holes, predications, constraints, and equalities.

Assumptions about Syntax–Semantics Interface

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

Rounding up Our First Example

Most dogs barked.



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

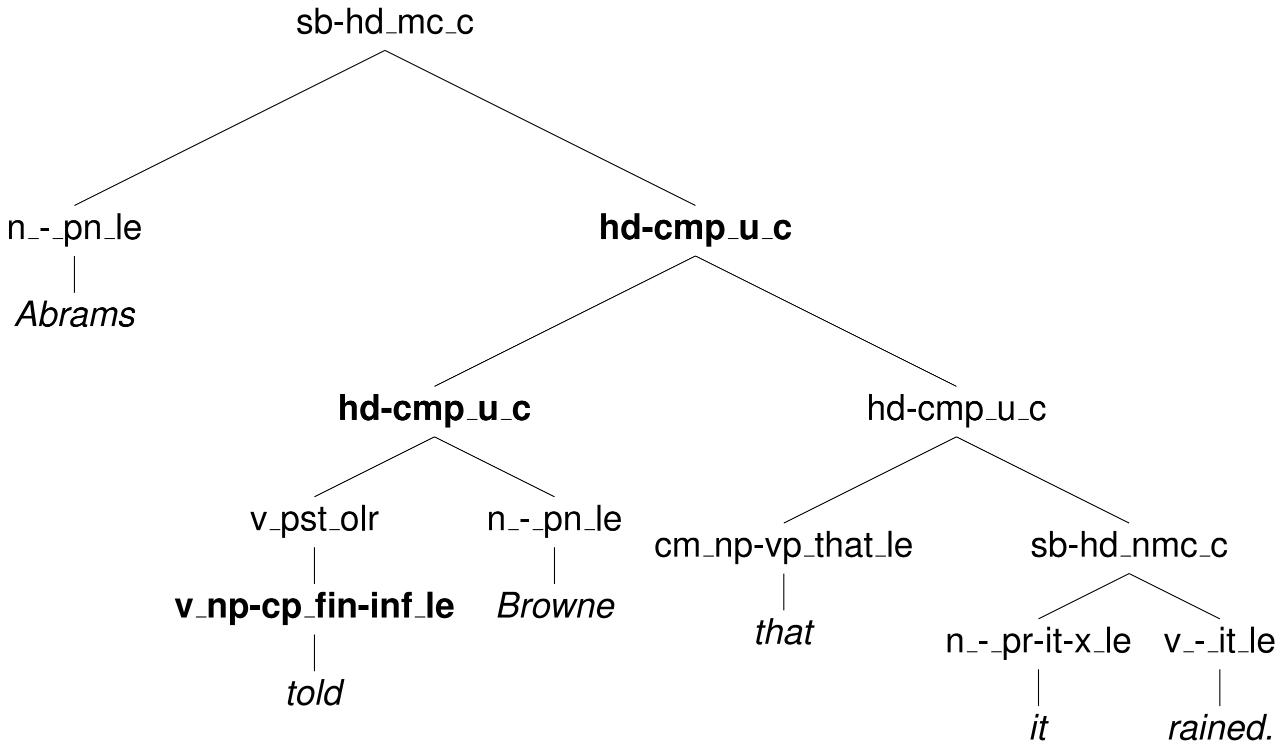
most dogs

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

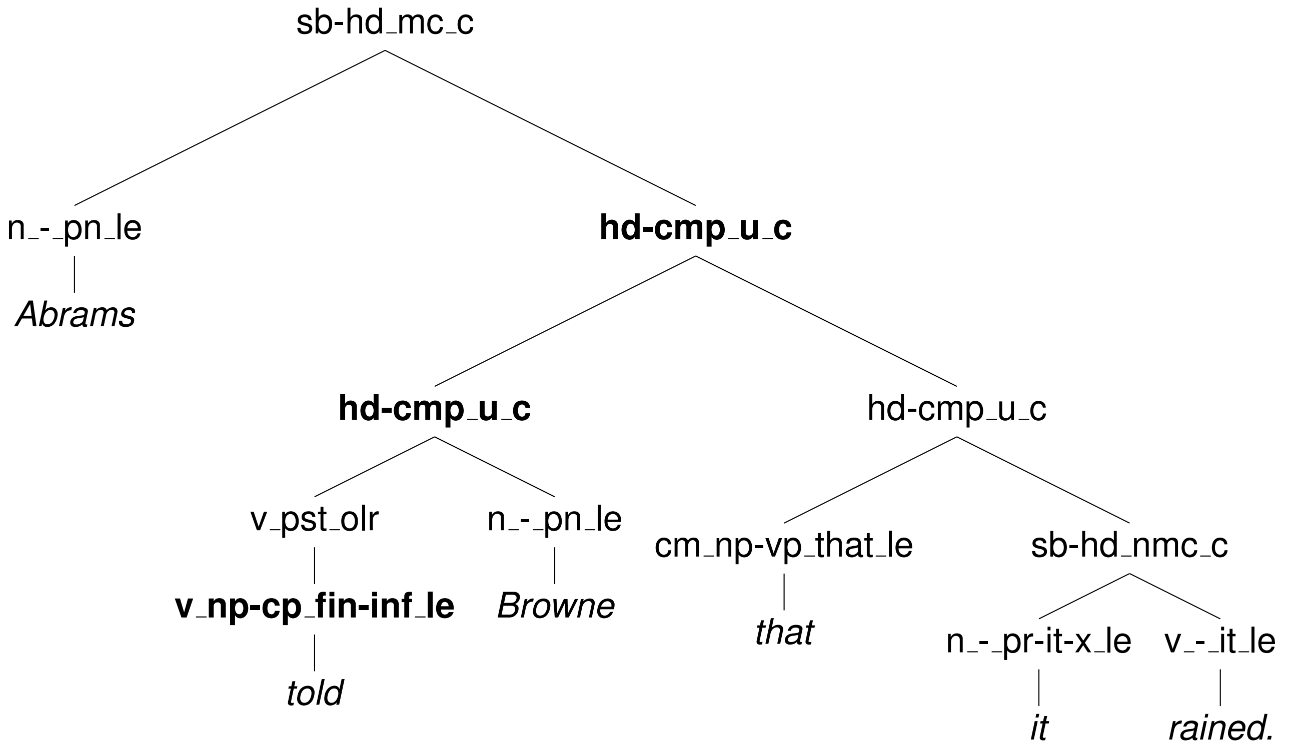
barked

$$\langle\ h_6,\ e_7,\ x_8\ \rangle$$
$$\{_{\text{SUBJ}}\langle\ h_6,\ x_8,\ \_\ \rangle\}$$
$$\left|\ h_6\text{:\_bark\_v\_1}(e_7,\ x_8)\ \right|$$
$$\{\ \}$$
$$\{\ \}$$

Non-Scopal vs. Scopal Complements



Non-Scopal vs. Scopal Complements



told

$$\langle\, h_0,\, e_1,\, \_\, \rangle$$
$$\left\{ \begin{array}{l} \text{SUBJ}\langle\, h_0,\, x_2,\, \_\, \rangle, \\ \text{COMPS}[\, \langle\, h_0,\, x_3,\, \_\, \rangle, \langle\, h_5,\, \_,\, \_\, \rangle\,] \end{array} \right\}$$
$$\left|\, h_0\text{:\_tell\_v\_1}(e_1,\, x_2,\, x_3,\, h_4)\, \right|$$
$$\{\, h_4 =_q h_5\, \}$$
$$\{\,\}$$

Browne

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

that it rained

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

Non-Scopal vs. Scopal Complements

sb-hd_mc_c

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

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

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

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

told

that

n_-_pr-it-x_le v_-_it_le

it rained.

told

$\langle\, h_0,\ e_1,\ \_\,\rangle$
$\left\{ \begin{array}{l} _{\text{SUBJ}}\langle\, h_0,\ x_2,\ \_\,\rangle, \\ _{\text{COMPS}}[\,\langle\, h_0,\ x_3,\ \_\,\rangle, \langle\, h_5,\ \_,\ \_\,\rangle\,] \end{array} \right\}$
$\left|\ h_0\text{:\_tell\_v\_1}(e_1,\ x_2,\ x_3,\ h_4)\ \right|$
$\{\ h_4 =_q h_5\ \}$
$\{\ \}$

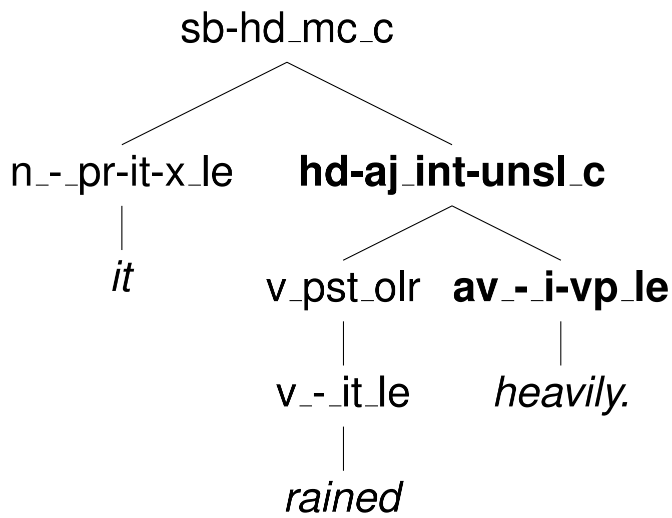
Browne

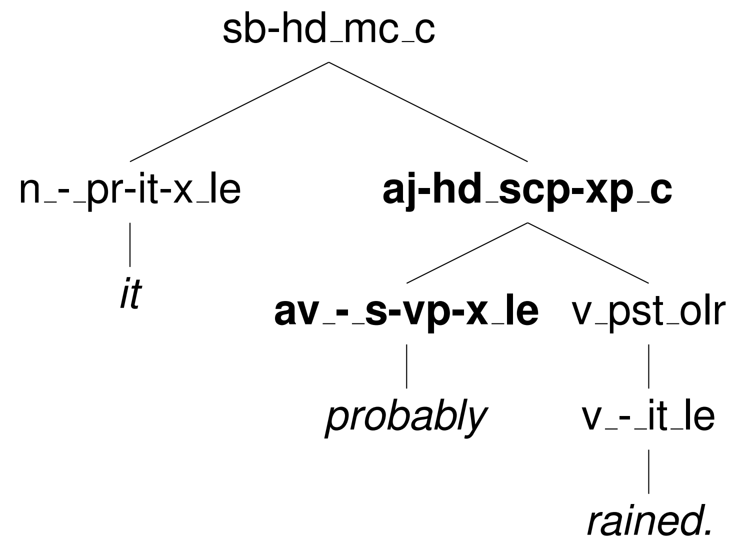
$\langle\, h_6,\ x_7,\ \_\,\rangle$
$\{\}$
$\left|\ h_6\text{:named}(x_7,\ \textit{Browne})\ \right|$
$\{\ \}$
$\{\ \}$

that it rained

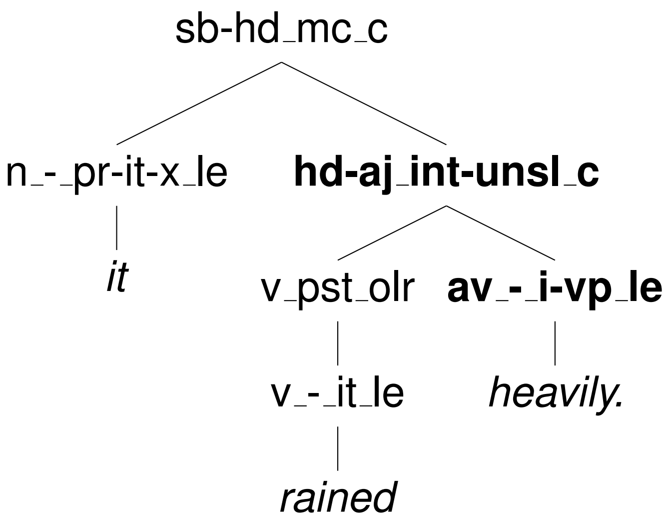
$\langle\, h_8,\ e_9,\ \_\,\rangle$
$\{\}$
$\left|\ h_8\text{:\_rain\_v\_1}(e_9)\ \right|$
$\{\ \}$
$\{\ \}$

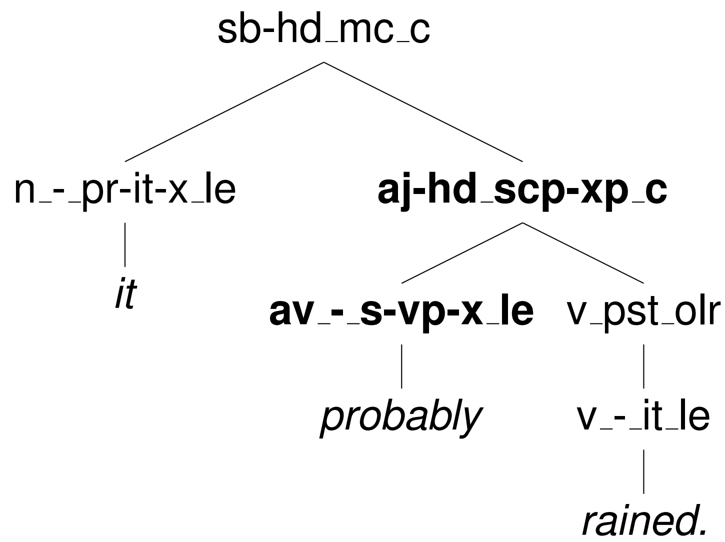
Restrictive vs. Scopal Modification





Restrictive vs. Scopal Modification





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

Restrictive vs. Scopal Modification

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

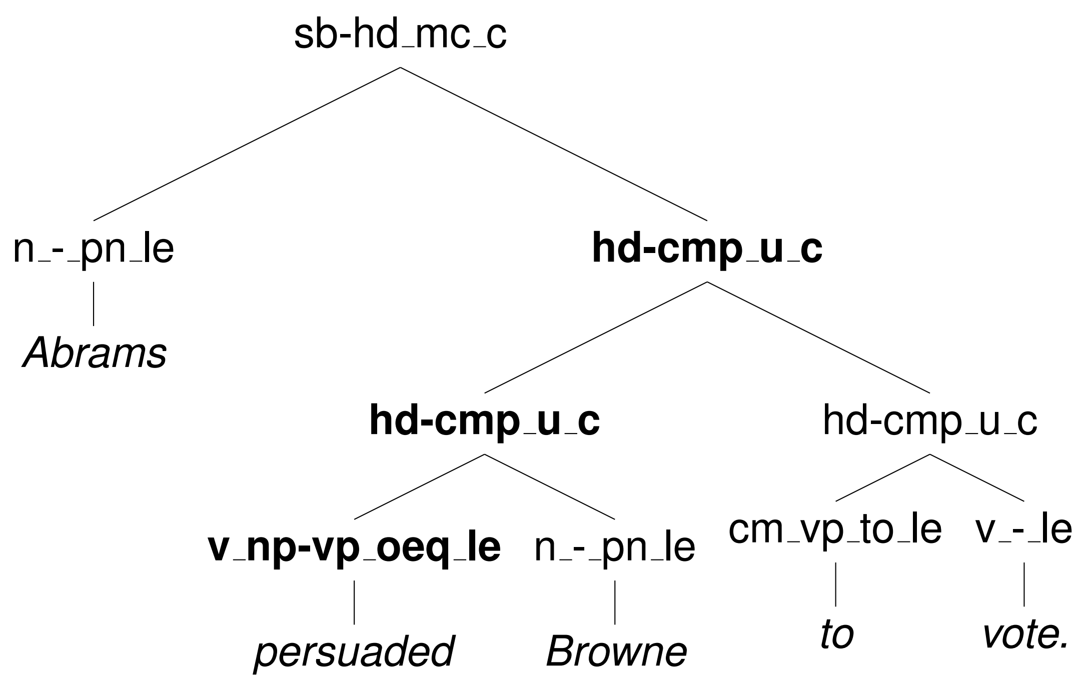
Let $L' = {}_{\text{MOD}}\langle h_l, i_l, \_ \rangle \in L_f$:

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

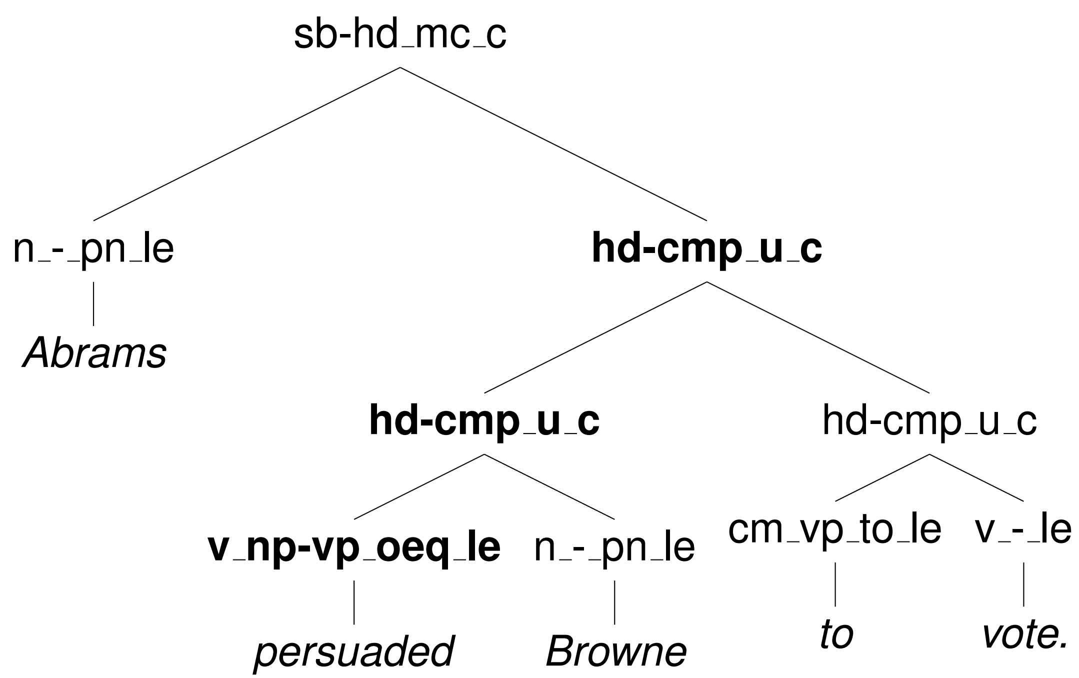
$$\langle\langle h_f, i_a, \_ \rangle, L_f \setminus \{L'\} \cup L_a, P_f \cup P_a, C_f \cup C_a, E_f \cup E_a \cup \{h_l \equiv h_a, i_l \equiv i_a\}\rangle$$

rained	*heavily*	*probably*
$\langle h_0, e_1, \_ \rangle$	$\langle h_2, e_3, \_ \rangle$	$\langle h_5, e_6, \_ \rangle$
$\{{}_{\text{SUBJ}}\langle \_, \_, \_ \rangle\}$	$\{{}_{\text{MOD}}\langle h_2, e_4, \_ \rangle\}$	$\{{}_{\text{MOD}}\langle h_8, \_, \_ \rangle\}$
$\mid h_0$:_rain_v_1$(e_1) \mid$	$\mid h_2$:_heavy_a_1$(e_3, e_4) \mid$	$\mid h_5$:_probable_a_1$(e_6, h_7) \mid$
$\{\}$	$\{\}$	$\{ h_7 =_q h_8 \}$
$\{\}$	$\{\}$	$\{\}$

Control and Raising (and Predicatives)



Control and Raising (and Predicatives)



persuaded

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

$\{_{\text{SUBJ}}\langle\, h_0,\, x_2,\, \_ \,\rangle,\, _{\text{COMPS}}[\,\langle\, h_0,\, x_3,\, \_ \,\rangle, \langle\, h_5,\, \_,\, \_ \,\rangle\,]\}$

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

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

$\{\,\}$

to vote

$\langle\, h_6,\, e_7,\, x_8 \,\rangle$

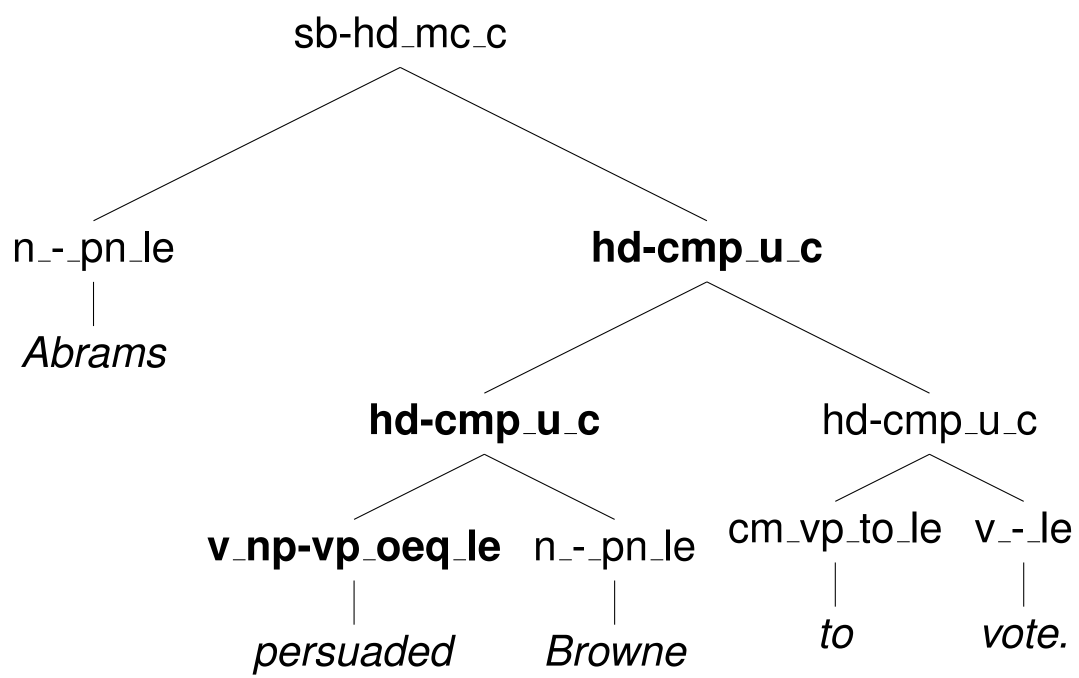
$\{_{\text{SUBJ}}\langle\, h_6,\, x_8,\, \_ \,\rangle\}$

$\left|\, h_6\text{:\_vote\_v\_1}(e_7,\, x_8) \,\right|$

$\{\,\}$

$\{\,\}$

Control and Raising (and Predicatives)



persuaded

$$\langle\, h_0,\ e_1,\ \_\ \rangle$$
$$\{_{\text{SUBJ}}\langle\, h_0,\ x_2,\ \_\ \rangle,\ _{\text{COMPS}}[\,\langle\, h_0,\ x_3,\ \_\ \rangle,\ \langle\, h_5,\ \_,\ x_3\ \rangle\,]\}$$
$$\left|\ h_0{:}\_\text{persuade\_v\_of}(e_1,\ x_2,\ x_3,\ h_4)\ \right|$$
$$\{\ h_4 =_q h_5\ \}$$
$$\{\ \}$$

to vote

$$\langle\, h_6,\ e_7,\ x_8\ \rangle$$
$$\{_{\text{SUBJ}}\langle\, h_6,\ x_8,\ \_\ \rangle\}$$
$$\left|\ h_6{:}\_\text{vote\_v\_1}(e_7,\ x_8)\ \right|$$
$$\{\ \}$$
$$\{\ \}$$

Control and Raising (and Predicatives)

External Arguments

- Third hook component enables control of various ‘open’ complements;
- subject vs. object control vs. raising is a lexical property of functors;
- extends to different kinds of predicative constructions, e.g.

The books are in the box.

She considers him childish.

She placed the books in the box.

persuaded

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

$\{_{\text{SUBJ}}\langle\, h_0,\, x_2,\, \_\, \rangle,\, _{\text{COMPS}}[\, \langle\, h_0,\, x_3,\, \_\, \rangle, \langle\, h_5,\, \_,\, x_3\, \rangle\,]\}$

$|\; h_0\text{:\_persuade\_v\_of}(e_1,\, x_2,\, x_3,\, h_4)\; |$

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

$\{\,\}$

to vote

$\langle\, h_6,\, e_7,\, x_8\, \rangle$

$\{_{\text{SUBJ}}\langle\, h_6,\, x_8,\, \_\, \rangle\}$

$|\; h_6\text{:\_vote\_v\_1}(e_7,\, x_8)\; |$

$\{\,\}$

$\{\,\}$

Control and Raising (and Predicatives)

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- Third hook component enables control of various ‘open’ complements;
- subject vs. object control vs. raising is a lexical property of functors;
- extends to different kinds of predicative constructions, e.g.

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She placed the books in the box.

persuaded

$\langle h_0, e_1, \_ \rangle$
$\{_{\text{SUBJ}}\langle h_0, x_2, \_ \rangle, _{\text{COMPS}}[\langle h_0, x_3, \_ \rangle, \langle h_5, \_, x_3 \rangle]\}$
$| h_0\text{:\_persuade\_v\_of}(e_1, x_2, x_3, h_4) |$
$\{ h_4 =_q h_5 \}$
$\{ \}$

to vote

$\langle h_6, e_7, x_8 \rangle$
$\{_{\text{SUBJ}}\langle h_6, x_8, \_ \rangle\}$
$| h_6\text{:\_vote\_v\_1}(e_7, x_8) |$
$\{ \}$
$\{ \}$

Control and Raising (and Predicatives)

sb-hd_mc_c

Refinement of $\bullet_{\text{COMPS}}$ Operation:

Let $L' = \_\langle h_l, i_l, x_l \rangle \in L_f,\ x_l \equiv i_a \in E$:

$$L = L_f \setminus \{L'\} \cup L_a \setminus \{l \mid l = \langle \_, i_a, \_ \rangle\}$$

v_np-vp_oeq_le n_-_pn_le cm_vp_to_le v_-_le

persuaded *Browne* *to* *vote.*

persuaded

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

$\{_{\text{SUBJ}}\langle h_0, x_2, \_ \rangle, {}_{\text{COMPS}}[\langle h_0, x_3, \_ \rangle, \langle h_5, \_, x_3 \rangle]\}$

$|\ h_0\text{:\_persuade\_v\_of}(e_1, x_2, x_3, h_4)\ |$

$\{ h_4 =_q h_5 \}$

$\{ \}$

to vote

$\langle h_6, e_7, x_8 \rangle$

$\{_{\text{SUBJ}}\langle h_6, x_8, \_ \rangle\}$

$|\ h_6\text{:\_vote\_v\_1}(e_7, x_8)\ |$

$\{ \}$

$\{ \}$

Control and Raising (and Predicatives)

sb-hd_mc_c

Refinement of $\bullet_{\text{COMPS}}$ Operation:

Let $L' = \_\langle h_l, i_l, x_l \rangle \in L_f,\ x_l \equiv i_a \in E$:

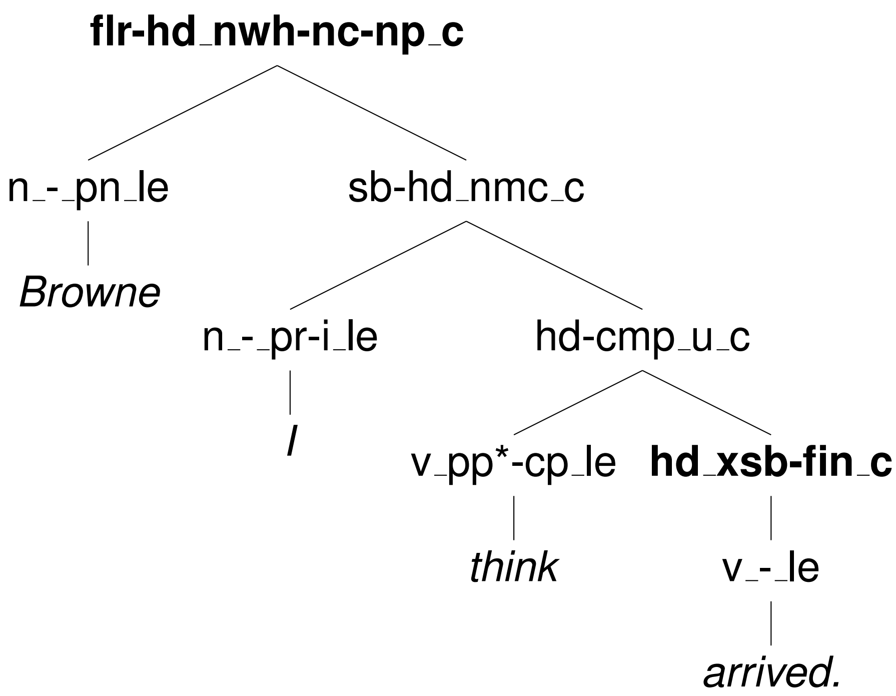
$$L = L_f \setminus \{L'\} \cup L_a \setminus \{l \mid l = \langle \_, i_a, \_ \rangle\}$$

$\rightarrow$ Controlling external argument (kind of) 'plugs' a hole;

need to refine other composition operations accordingly.

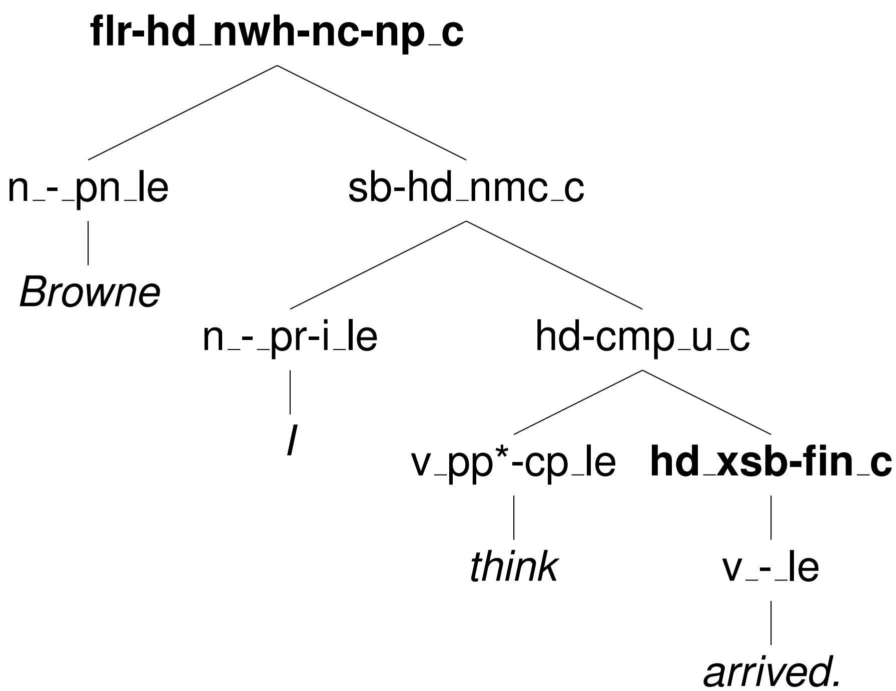
persuaded	*to vote*
$\langle h_0, e_1, \_ \rangle$	$\langle h_6, e_7, x_8 \rangle$
$\{_{\text{SUBJ}}\langle h_0, x_2, \_ \rangle, _{\text{COMPS}}[\langle h_0, x_3, \_ \rangle, \langle h_5, \_, x_3 \rangle]\}$	$\{_{\text{SUBJ}}\langle h_6, x_8, \_ \rangle\}$
$\mid h_0$:_persuade_v_of$(e_1, x_2, x_3, h_4) \mid$	$\mid h_6$:_vote_v_1$(e_7, x_8) \mid$
$\{ h_4 =_q h_5 \}$	$\{\}$
$\{\}$	$\{\}$

Relative Clauses Feed on Extraction



$$\langle\ h_1,\ \left|\begin{array}{l} h_2\text{:pron}(x_{11}), \\ h_2\text{:\_think\_v\_1}(e_3, x_{11}, h_{16}), \\ h_{17}\text{:named}(x_4, \textit{Browne}), \\ h_{17}\text{:\_arrive\_v\_1}(e_{18}, x_4) \end{array}\right|\ \{\ h_1 =_q h_2, h_{16} =_q h_{17}\ \}\ \rangle$$

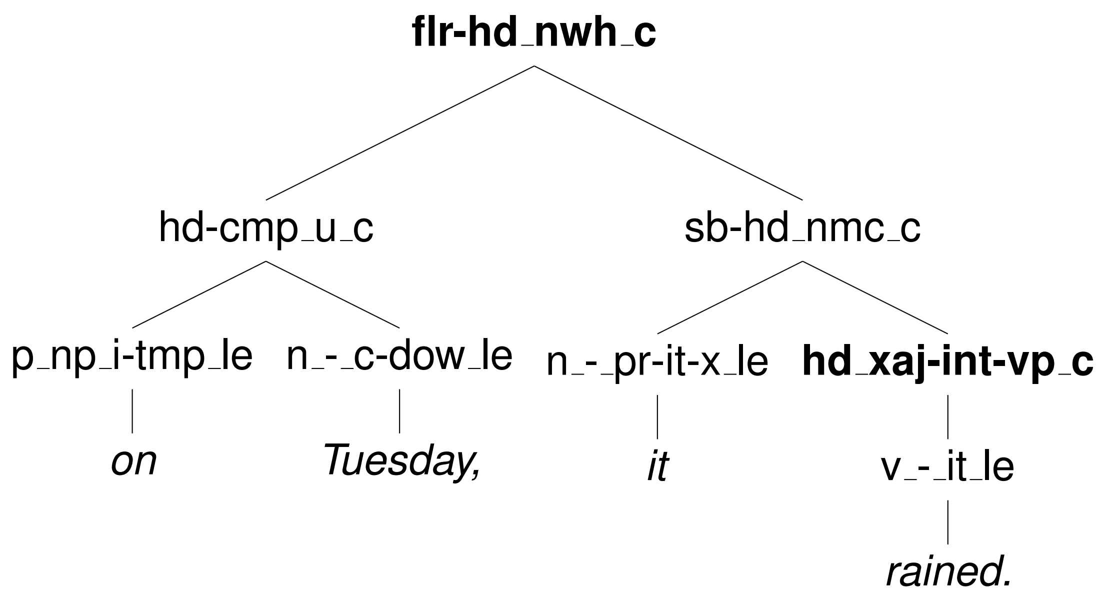
Relative Clauses Feed on Extraction



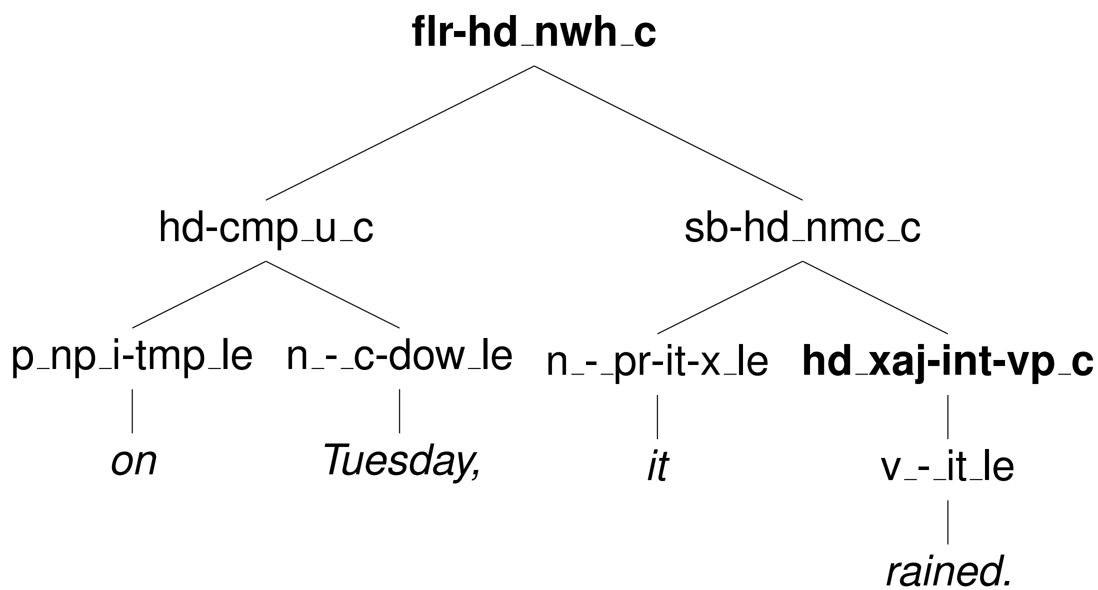
$$\langle\, h_1,\ \{ h_2\text{:pron}(x_{11}),\ h_2\text{:\_think\_v\_1}(e_3, x_{11}, h_{16}),\ h_{17}\text{:named}(x_4, \textit{Browne}),\ h_{17}\text{:\_arrive\_v\_1}(e_{18}, x_4) \},\ \{ h_1 =_q h_2,\ h_{16} =_q h_{17} \} \,\rangle$$

arrived		XSB *empty argument*		*arrived*
$\langle h_0, e_1, x_2 \rangle$		$\langle h_3, x_4, \_ \rangle$		$\langle h_0, e_1, x_2 \rangle$
$\{_{\text{SUBJ}} \langle h_0, x_2, \_ \rangle \}$		$\{_{\text{GAPS}} [\langle h_3, x_4, \_ \rangle] \}$		$\{_{\text{GAPS}} [\langle h_3, x_4, \_ \rangle] \}$
$\mid h_0\text{:\_arrive\_v\_1}(e_1, x_2) \mid$	$\bullet_{\text{SUBJ}}$	$\mid\ \mid$	$\rightarrow$	$\mid h_0\text{:\_arrive\_v\_1}(e_1, x_2) \mid$
$\{\}$		$\{\}$		$\{\}$
$\{\}$		$\{\}$		$\{ h_0 \equiv h_3,\ x_2 \equiv x_4 \}$

Modifiers Can be Extracted Too (Of Course)



Modifiers Can be Extracted Too (Of Course)

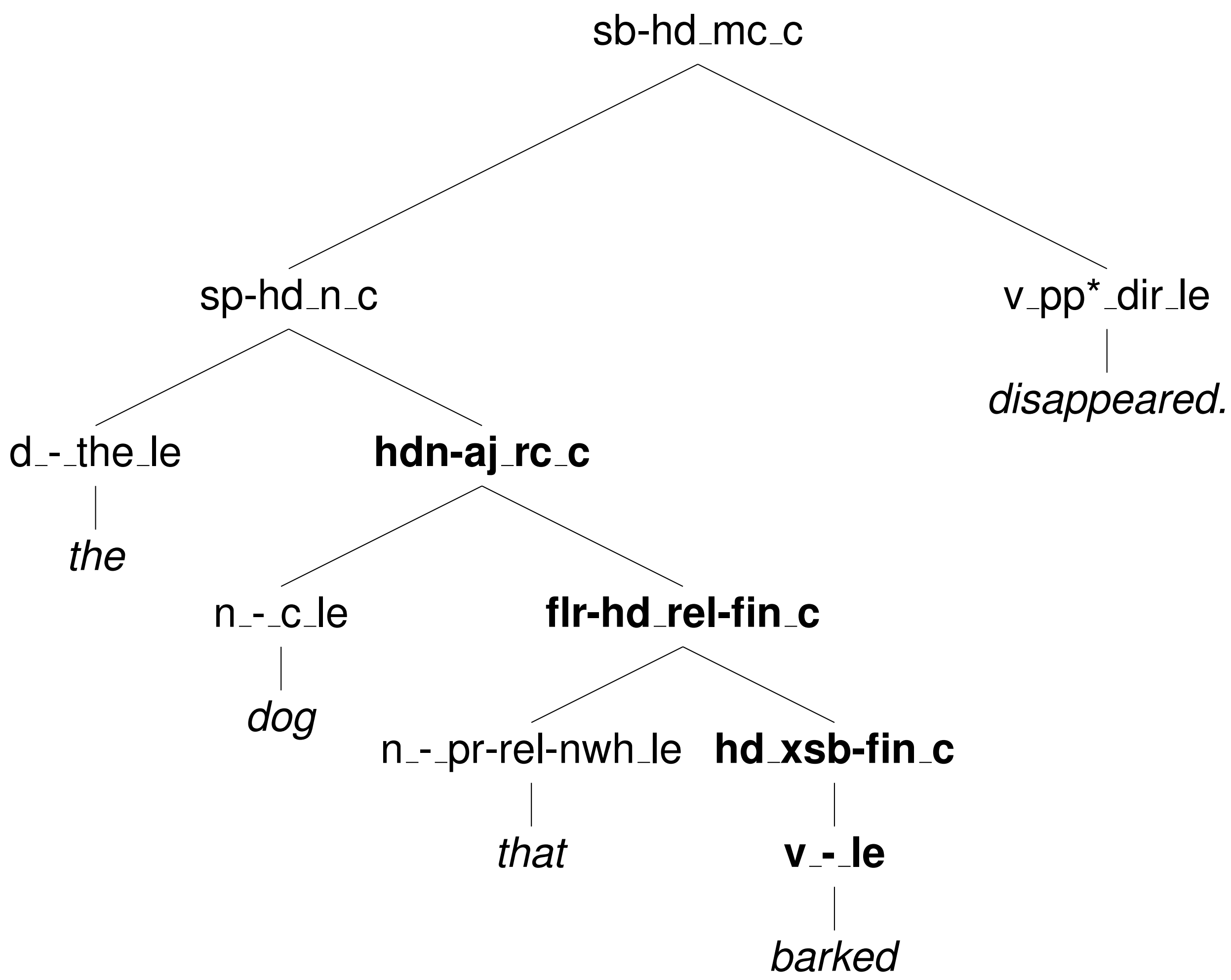


XAJ *empty functor*

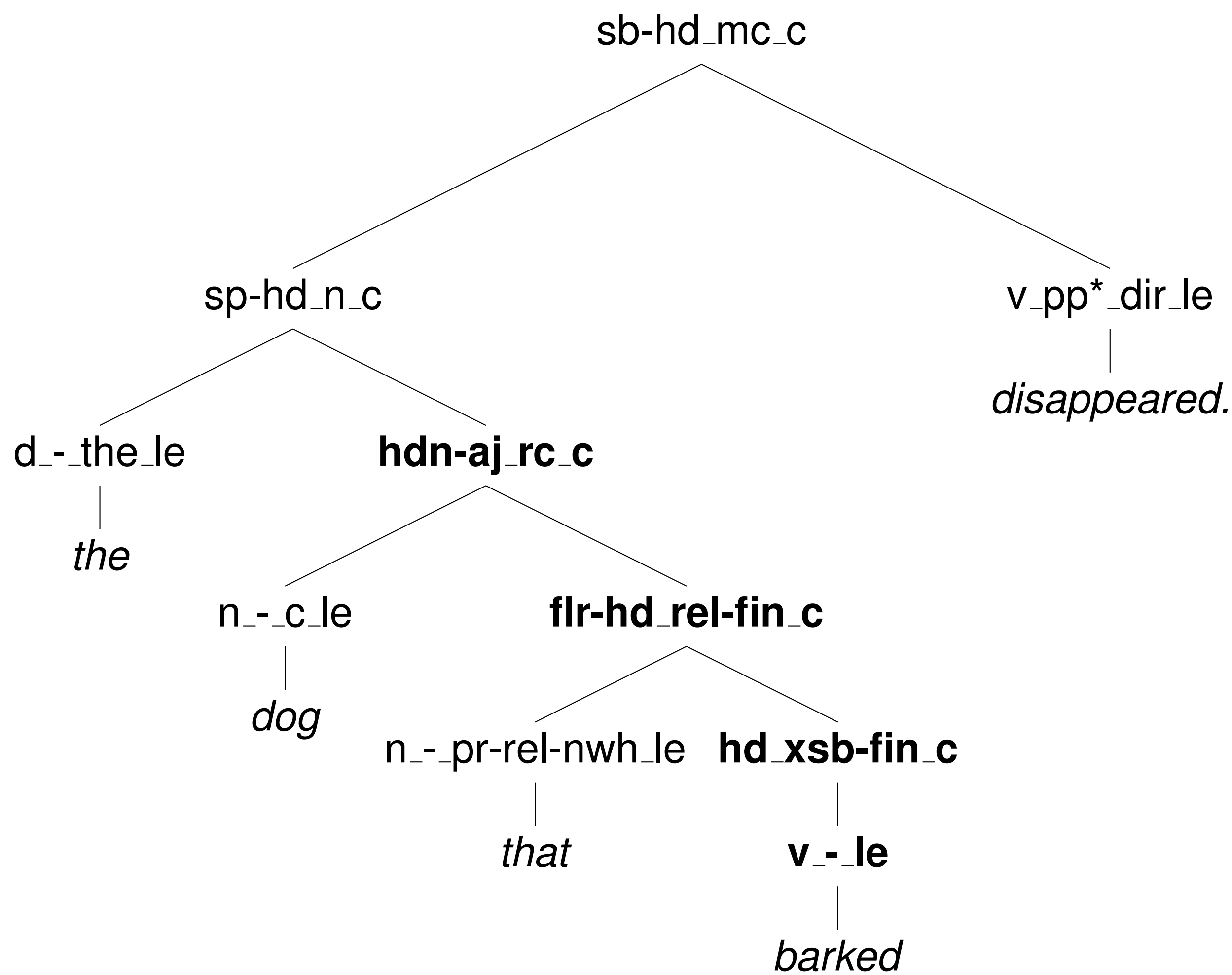
$\langle\, h_0,\ e_1,\ x_2 \,\rangle$
$\{_{\text{GAPS}}[\,\langle\, h_0,\ e_1,\ x_2 \,\rangle\,],\ _{\text{MOD}}\langle\, h_0,\ e_1,\ x_2 \,\rangle\}$
$|\ |$
$\{\,\}$
$\{\,\}$

$\langle\, h_2,$
$\big|\ h_3\text{:\_rain\_v\_1}(e_3),$
$h_3\text{:\_on\_p\_temp}(e_4,\ e_3,\ x_6),\ h_3\text{:dofw}(x_6,\ \textit{Tue})\ \big|$
$\{\, h_2 =_q h_3 \,\}\,\rangle$

Putting Things Together: Relative Clauses



Putting Things Together: Relative Clauses



$$\langle\, h_1,\; \big|\, h_4{:}\_\text{the\_q}(x_6, h_7, \_), h_8{:}\_\text{dog\_n\_1}(x_6), h_8{:}\_\text{bark\_v\_1}(e_9, x_6), h_2{:}\_\text{disappear\_v\_1}(e_3, x_6) \,\big|,\; \{\, h_1 =_q h_2, h_7 =_q h_8 \,\} \,\rangle$$

Putting Things Together: Relative Clauses

dog

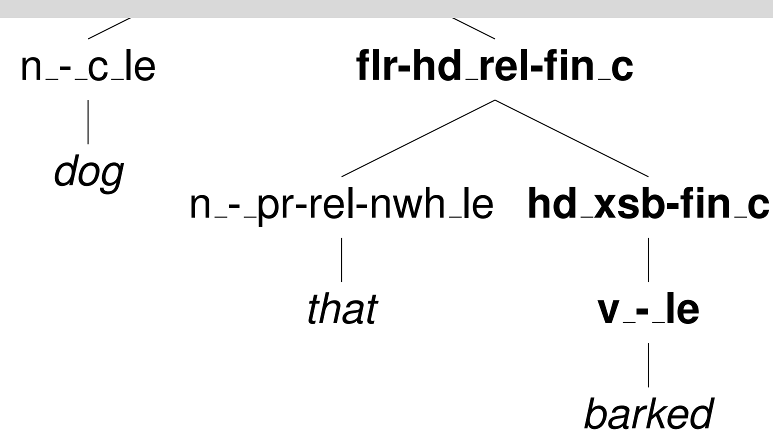
$\langle\, h_0,\, x_1,\, \_\_ \,\rangle$
$\{\}$
$\big|\, h_0{:}\_\text{dog\_n\_1}(x_1) \,\big|$
$\{\,\}$
$\{\,\}$

barked XSB

$\langle\, h_4,\, e_5,\, \_\_ \,\rangle$
$\{_{\text{GAPS}}[\,\langle\, h_4,\, x_6,\, \_\_ \,\rangle\,]\}$
$\big|\, h_4{:}\_\text{bark\_v\_1}(e_5,\, x_6) \,\big|$
$\{\,\}$
$\{\,\}$

that

$\langle\, h_2,\, x_3,\, \_\_ \,\rangle$
$\{_{\text{MOD}}\langle\, h_2,\, x_3,\, \_\_ \,\rangle\}$
$\big|\,\big|$
$\{\,\}$
$\{\,\}$



$\langle\, h_1,$
$\big|\, h_4{:}\_\text{the\_q}(x_6,\, h_7,\, \_\_),\, h_8{:}\_\text{dog\_n\_1}(x_6),\, h_8{:}\_\text{bark\_v\_1}(e_9,\, x_6),\, h_2{:}\_\text{disappear\_v\_1}(e_3,\, x_6) \,\big|$
$\{\, h_1 =_q h_2,\, h_7 =_q h_8 \,\}\,\rangle$

Putting Things Together: Relative Clauses

sb-hd-mc_c

dog	*barked* XSB	*that*
$\langle\, h_0,\, x_1,\, \_\, \rangle$	$\langle\, h_4,\, e_5,\, \_\, \rangle$	$\langle\, h_2,\, x_3,\, \_\, \rangle$
$\{\}$	$\{_{\text{GAPS}}[\langle\, h_4,\, x_6,\, \_\, \rangle]\}$	$\{_{\text{MOD}}\langle\, h_2,\, x_3,\, \_\, \rangle\}$
$\vert\, h_0\text{:\_dog\_n\_1}(x_1)\,\vert$	$\vert\, h_4\text{:\_bark\_v\_1}(e_5,\, x_6)\,\vert$	$\vert\,\vert$
$\{\,\}$	$\{\,\}$	$\{\,\}$
$\{\,\}$	$\{\,\}$	$\{\,\}$

→ Generalizes without revisions to empty relativizer and modifier gaps;

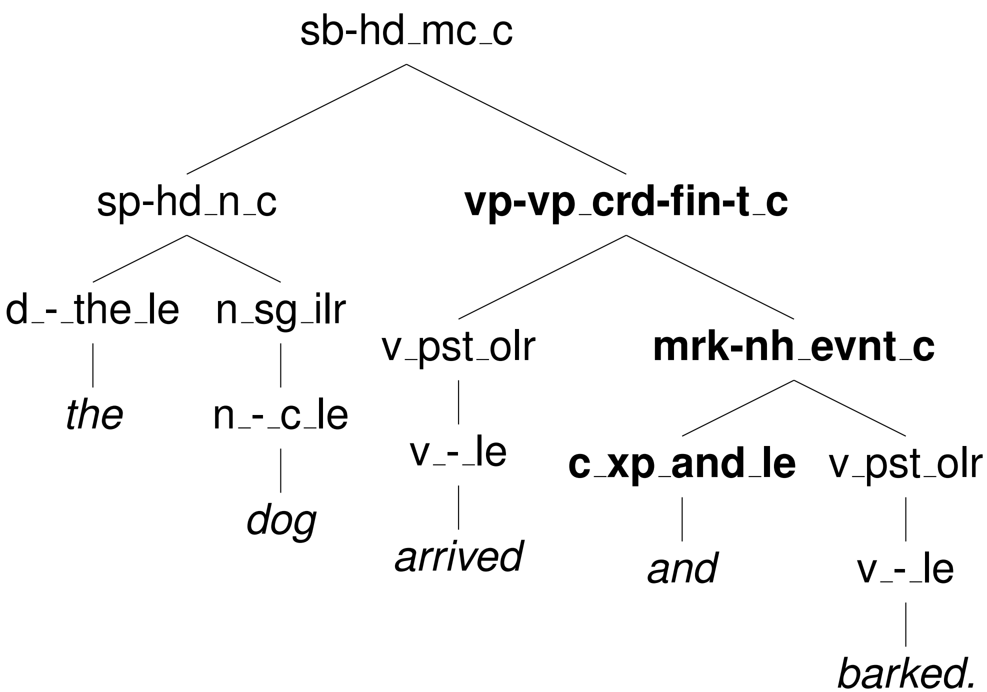
→ plays nicely with unbounded depedencies, i.e. intervening clauses:

The dog on which I think you depend barked.

- well-chartered territory: clear benefits of close alignment with syntax.

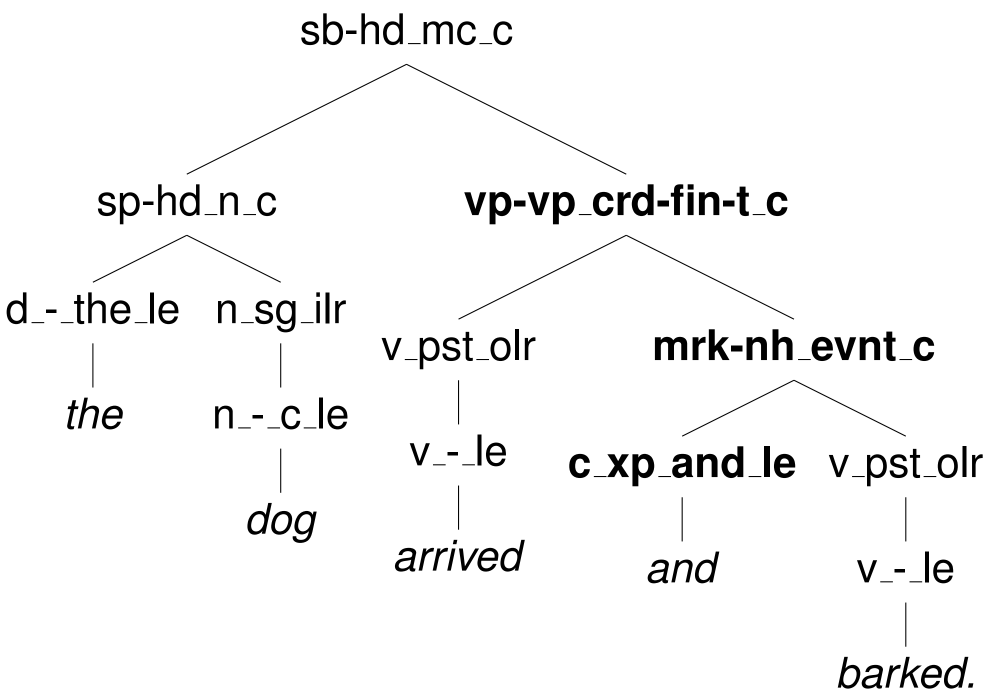
$\vert\, h_4\text{:\_the\_q}(x_6,\, h_7,\, \_),\, h_8\text{:\_dog\_n\_1}(x_6),\, h_8\text{:\_bark\_v\_1}(e_9,\, x_6),\, h_2\text{:\_disappear\_v\_1}(e_3,\, x_6)\,\vert$
$\{\, h_1 =_q h_2,\, h_7 =_q h_8 \,\}\,\rangle$

Basics of Constituent Coordination



$$\left\langle\, h_1,\; \left| \begin{array}{l} h_{11}\text{:\_the\_q}(x_6, h_{13}, \_\_), h_{14}\text{:\_dog\_n\_1}(x_6), \\ h_2\text{:\_and\_c}(e_1, e_3, e_4), h_2\text{:\_arrive\_v\_1}(e_3, x_6), h_2\text{:\_bark\_v\_1}(e_4, x_6) \end{array} \right| \; \{\, h_1 =_q h_2, h_{13} =_q h_{14} \,\} \,\right\rangle$$

Basics of Constituent Coordination



and

$\langle\, h_0,\, i_1,\, \_\_ \,\rangle$

$\{_{\text{CONJ}}[\,\langle\, h_0,\, i_2,\, \_\_ \,\rangle \langle\, h_0,\, i_3,\, \_\_ \,\rangle\,]\}$

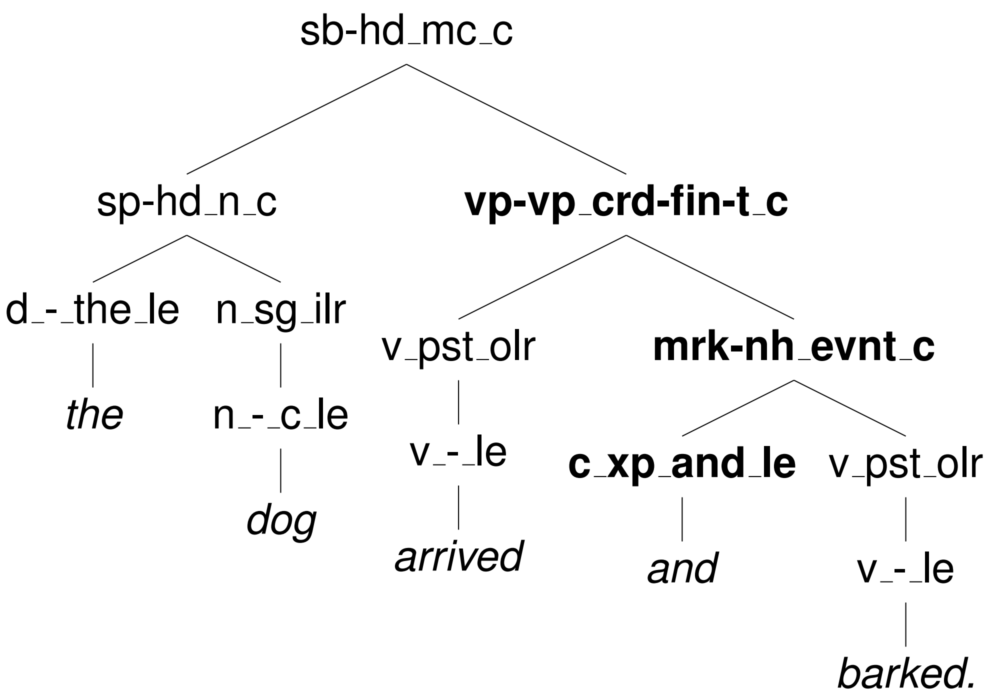
$\left|\, h_0\text{:\_and\_c}(i_1,\, i_2,\, i_3) \,\right|$

$\{\,\}$

$\{\,\}$

$$\langle\, h_1,\ \left|\begin{array}{l} h_{11}\text{:\_the\_q}(x_6,\, h_{13},\, \_\_),\, h_{14}\text{:\_dog\_n\_1}(x_6), \\ h_2\text{:\_and\_c}(e_1,\, e_3,\, e_4),\, h_2\text{:\_arrive\_v\_1}(e_3,\, x_6),\, h_2\text{:\_bark\_v\_1}(e_4,\, x_6) \end{array}\right|\ \{\, h_1 =_q h_2,\, h_{13} =_q h_{14} \,\}\,\rangle$$

Basics of Constituent Coordination



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$\{\, \}$
$\{\, \}$

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$$\{\, h_1 =_q h_2,\, h_{13} =_q h_{14} \,\}\,\rangle$$

→ Set union $P_f \cup P_a$ needs to ‘unify’ SUBJ holes from both verb phrases.

Basics of Constituent Coordination

Interaction with Different Scopal Contexts

The dog arrived and didn't bark.

$\rightarrow$ equate index and external argument variables from both holes, attach to 'current' scope context: conjoin with conjunction.

barked.

$$\langle\, h_1,\ \left|\begin{array}{l} h_{11}\text{:\_the\_q}(x_6,\ h_{13},\ \_\_),\ h_{14}\text{:\_dog\_n\_1}(x_6), \\ h_2\text{:\_and\_c}(e_1,\ e_3,\ e_4),\ h_2\text{:\_arrive\_v\_1}(e_3,\ x_6),\ h_2\text{:\_bark\_v\_1}(e_4,\ x_6) \end{array}\right|\ \{\, h_1 =_q h_2,\ h_{13} =_q h_{14} \,\}\,\rangle$$

$\rightarrow$ Set union $P_f \cup P_a$ needs to 'unify' SUBJ holes from both verb phrases.

Basics of Constituent Coordination

sb-hd_mc_c

Interaction with Different Scopal Contexts

The dog arrived and didn't bark.

$\rightarrow$ equate index and external argument variables from both holes, attach to 'current' scope context: conjoin with conjunction.

arrived *and* v_-_le

Appears to generalize well to argument and modifier coordination.

h_2:_and_c(e_1, e_3, e_4), h_2:_arrive_v_1(e_3, x_6), h_2:_bark_v_1(e_4, x_6)

$\{ h_1 =_q h_2, h_{13} =_q h_{14} \} \rangle$

$\rightarrow$ Set union $P_f \cup P_a$ needs to 'unify' SUBJ holes from both verb phrases.

Ongoing Work & Open Questions

Rationalizing Broad-Coverage Meaning Construction in ERG

- Evaluate proposal by Copestake, et al. (2001) on broad range of analyses;
- determine degree of ‘algebra compliance’ in ERG: is it 45 %, 85 %, or 98 %?

→ non-trivial revisions and extensions to algebra required; core ideas intact;

→ could offer some guidance on design choices in ERG (syntactic) analyses;

? What principles govern percolation of holes? Compare to lambda calculus?

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Adaptation to Other Frameworks, e.g. Universal Dependencies

? How much and what kinds of syntactic 'signals' required for composition?

- automatically extract semantic lexicon of initial MATs from ERG (underway);
- dependency types map onto operations; obliqueness hierarchy for $\bullet_{\text{COMPS}}$;
- (maybe non-deterministic) graph rewriting and/or enhanced dependencies.

Syntactic Relations

	Nominal	Clause	Modifier Word	Function Word
Core Predicate Dep	nsubj obj iobj	csubj ccomp xcomp		
Non-Core Predicate Dep	obl vocative expl dislocated	advcl	advmod* discourse	aux cop mark
Nominal Dep	nmod appos nummod	acl	amod	det clf case
Coordination	**MWE**	**Loose**	**Special**	**Other**
conj cc	fixed flat compound	parataxis list	orphan goeswith reparandum	punct root dep

(Courtesy of the Chief Cat Herder)

Transfer to Universal Dependencies

Candidate Mappings

$\text{NSUBJ} \mid \text{CSUBJ} \rightarrow \bullet_{\text{SUBJ}}$

$\text{ADVMOD}^{-1} \mid \text{AMOD}^{-1} \mid \text{NMOD}^{-1} \rightarrow \bullet_{\text{MOD}}$

Core Predicate Dep	nsubj obj iobj	csubj ccomp xcomp		
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Candidate Obliqueness Hierarchy

$$\text{OBJ} \prec \text{IOBJ} \prec \text{OBL} \prec \text{XCOMP} \prec \text{CCOMP} \rightarrow \bullet_{\text{COMPS}}$$

Core Predicate Dep	nsubj obj	csubj ccomp		
	dislocated			
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	dislocated			
	nmod			det

Candidate Lexical Entries

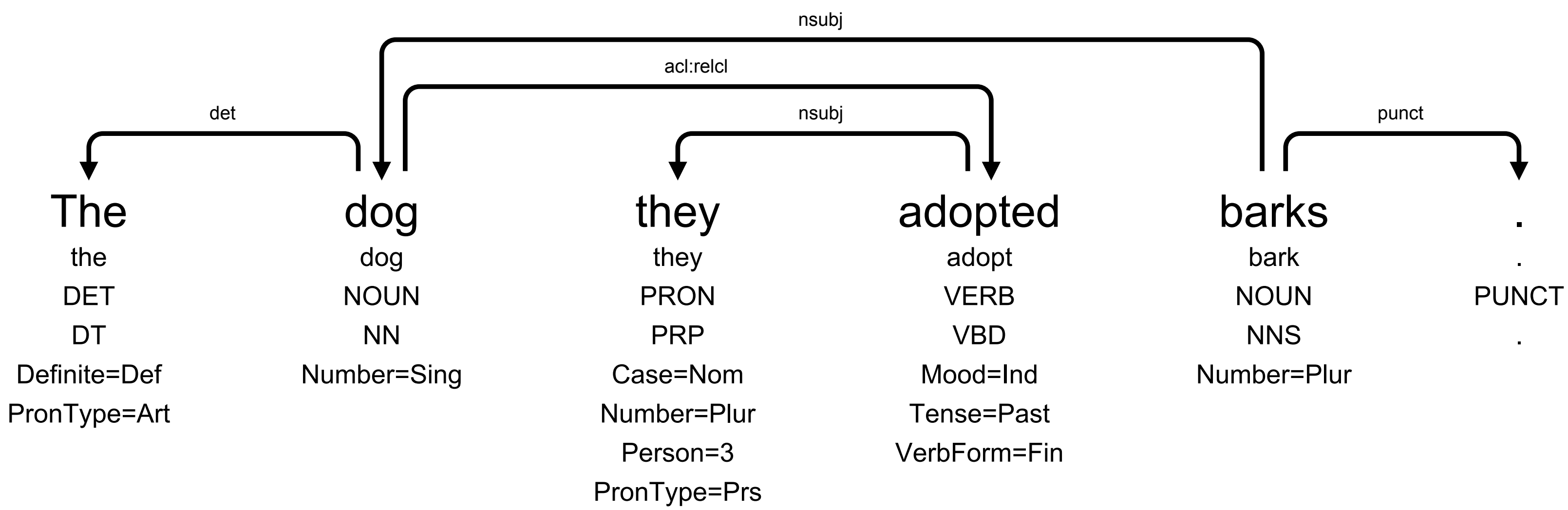
$$\textit{give}_1 : \text{COMPS}\ [\text{NP}, \text{NP}] \qquad \textit{give}_2 : \text{COMPS}\ [\text{NP}, \text{PP}_{to}]$$

$$\textit{apologize} : \text{COMPS}\ [\text{PP}_{to}, \text{PP}_{for}]$$

$$\textit{bet} : \text{COMPS}\ [\text{NP}, \text{NP}, \text{CP}_{that}]$$

(Courtesy of the Chief Cat Herder)

Transfer to Universal Dependencies



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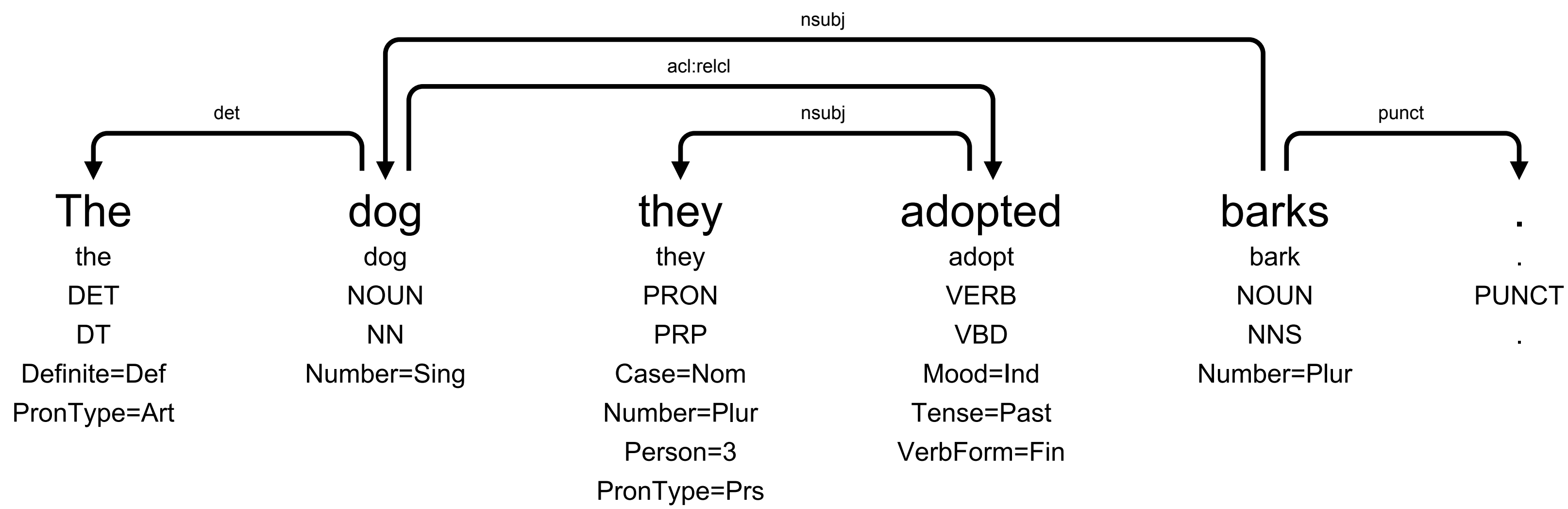

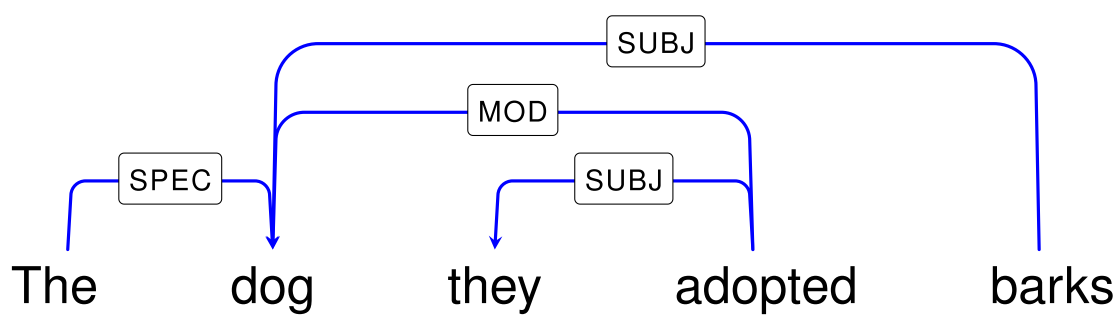

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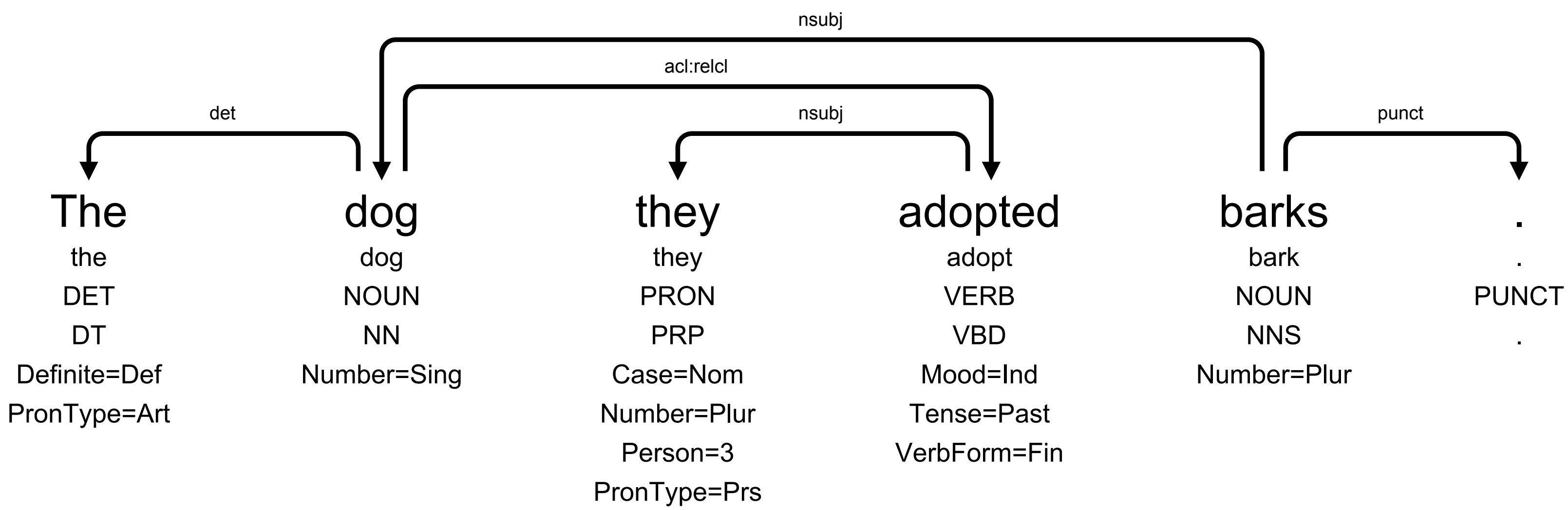
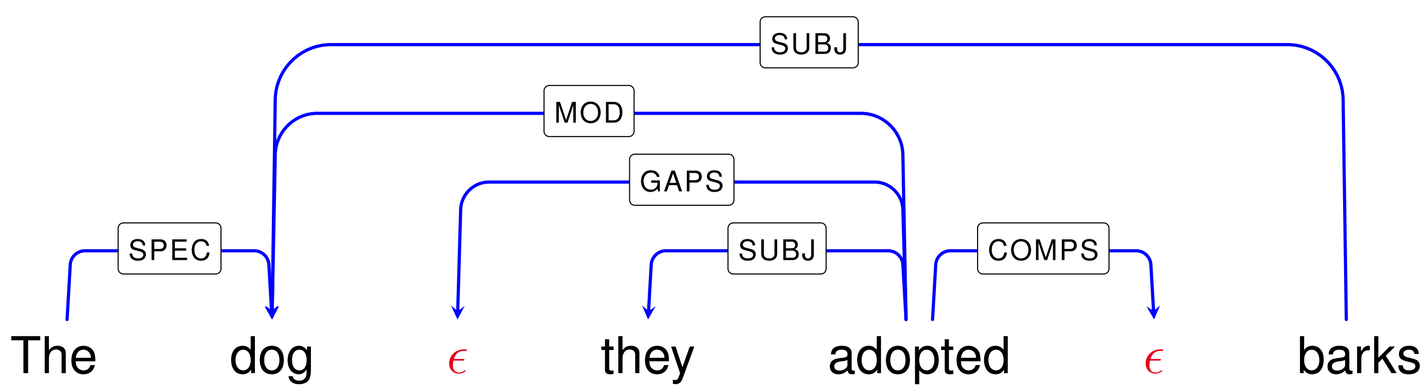
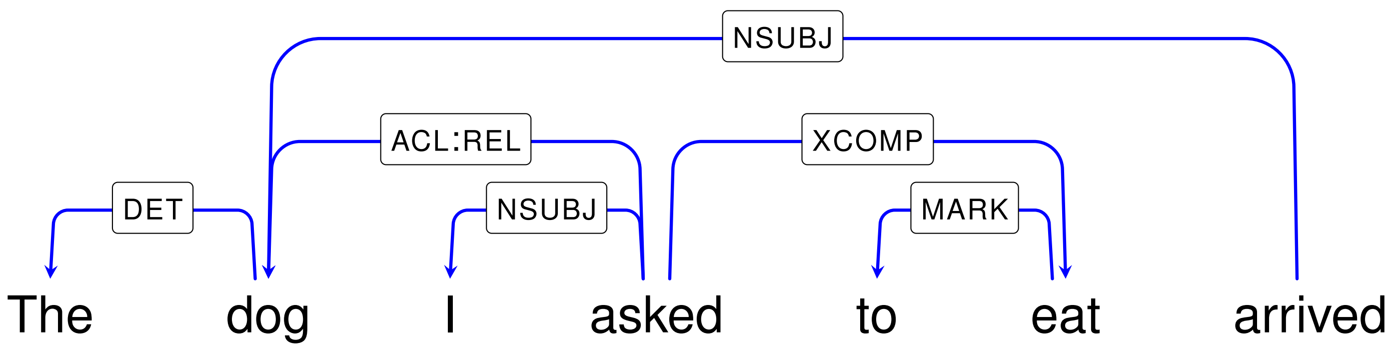




Missing Syntactic Information in Basic Tree



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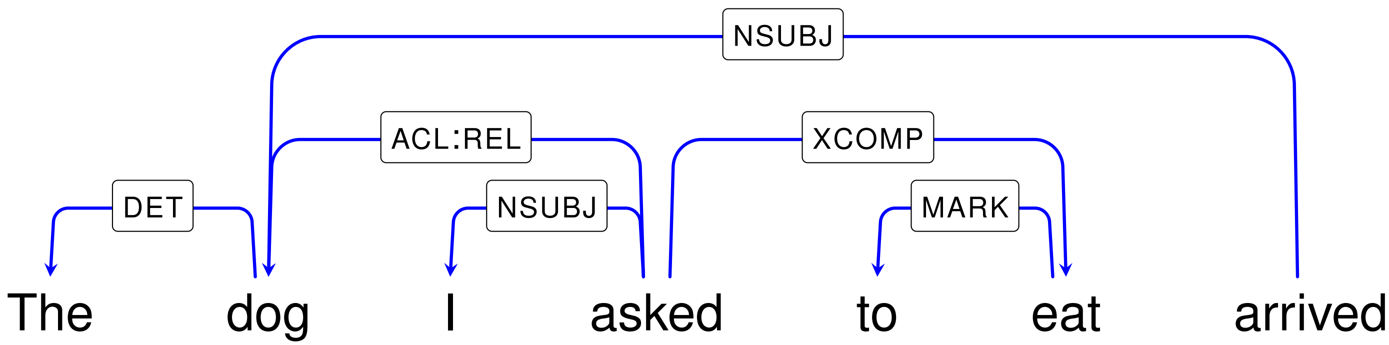
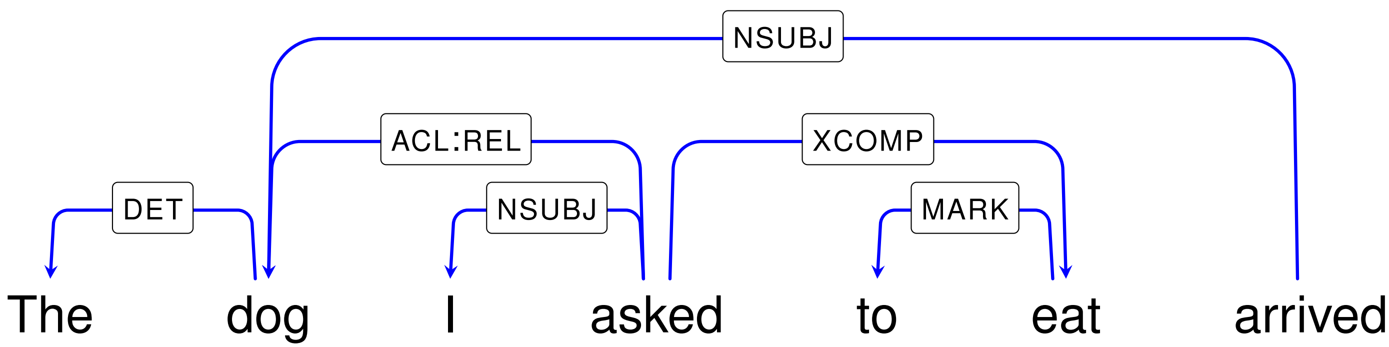


Abrams ate. *Abrams ate cake.*

Abrams asked to resign. *Abrams asked Browne to resign.*

Missing Syntactic Information in Basic Tree



Abrams ate. *Abrams ate cake.*

Abrams asked to resign. *Abrams asked Browne to resign.*

$$eat_1 : \text{SUBJ}\langle \_, \_, \_ \rangle; \text{COMPS}[\,]$$

$$eat_2 : \text{SUBJ}\langle \_, \_, \_ \rangle; \text{COMPS}\left[\langle \_, \_, \_ \rangle^{\text{NP}} \right]$$

$$ask_1 : \text{SUBJ}\langle \_, x_0, \_ \rangle; \text{COMPS}\left[\langle \_, \_, x_0 \rangle^{\text{VP}_{to}} \right]$$

$$ask_2 : \text{SUBJ}\langle \_, x_0, \_ \rangle; \text{COMPS}\left[\langle \_, x_1, \_ \rangle^{\text{NP}}, \langle \_, \_, x_1 \rangle^{\text{VP}_{to}} \right]$$