Polysemy and Coercion – A Frame-based Approach Using LTAG and Hybrid Logic

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Introduction

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Particularly challenging: **coercion** phenomena, where meaning "changes" in an apparently non-monotonic way, oftentimes explained with the presence of some operator that does not have a syntactic counterpart.

(1) a. Mary began the book.
    b. John left the party.
    c. Mary mastered the heavy book on magic.

Introduction

We propose to use **frames** as a way to represent rich lexical structures.

- Frames are a representation format of conceptual and lexical knowledge.
- They are commonly presented as semantic graphs with labelled nodes and edges where nodes correspond to entities (individuals, events, …) and edges to (functional or non-functional) relations between these entities.

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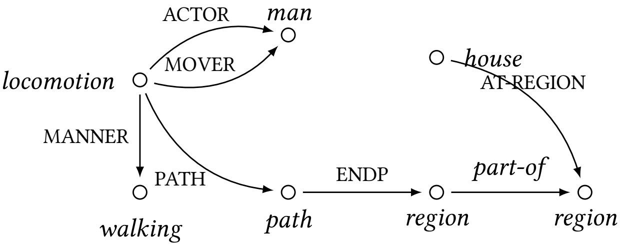

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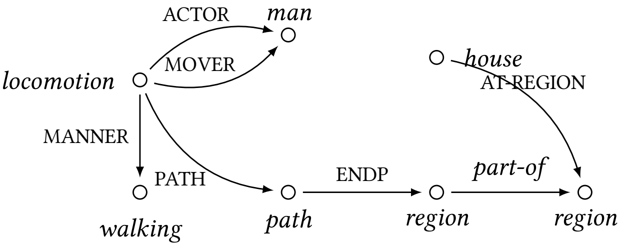

- Frames can be formalized as extended typed feature structures.

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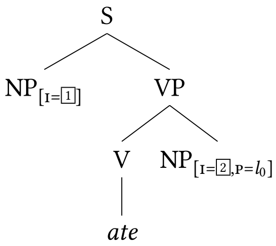

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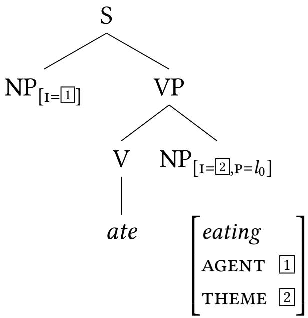

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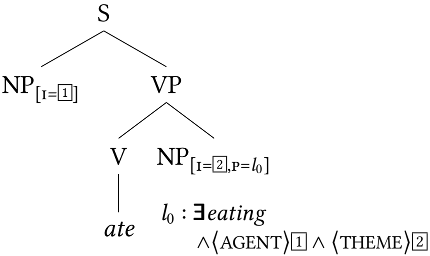

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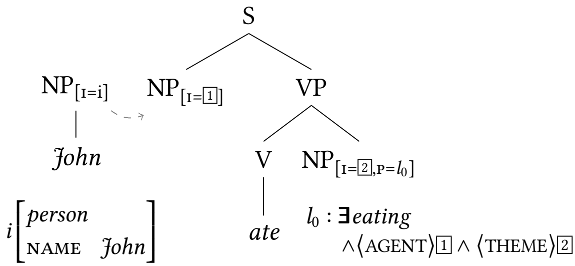

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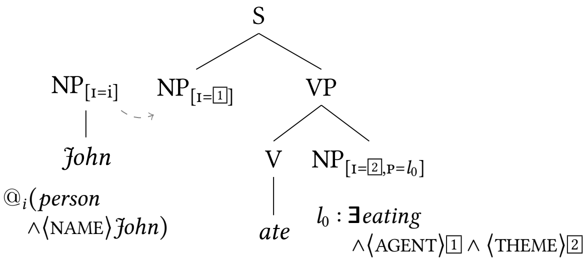

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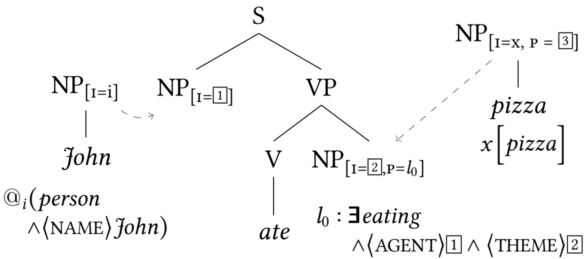

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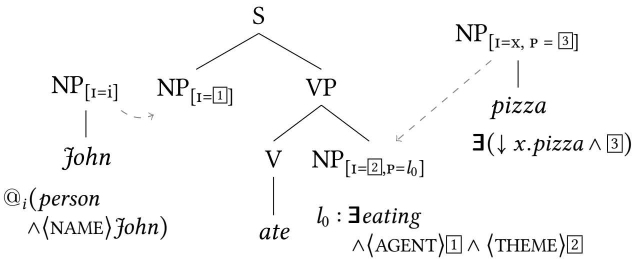
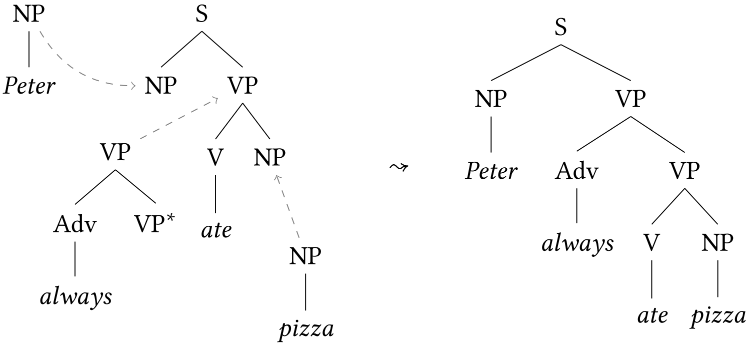


LTAG and frames

Lexicalized Tree Adjoining Grammar (LTAG, Joshi & Schabes (1997); Abeillé & Rambow (2000)):

- Finite set of **elementary trees**.
- Larger trees are derived via the tree composition operations **substitution** (replacing a leaf with a new tree) and **adjunction** (replacing an internal node with a new tree).



LTAG and frames

Syntax semantics interface (Kallmeyer & Osswald, 2013; Kallmeyer et al., 2016):

- Link a semantic representation to an entire elementary tree.
- Semantic representations: frames, expressed as typed feature structures, or rather HL formulas that describe frames.
- Interface features relate nodes in the syntactic tree to nodes in the frame graph.
- Model composition by unifications triggered by substitution and adjunction.

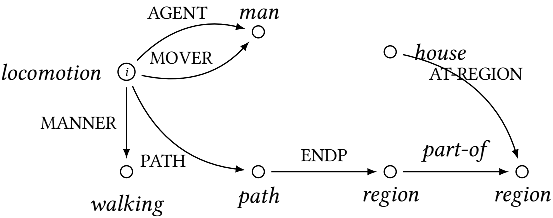
Hybrid logic for frames

Hybrid Logic is an extended version of *modal logic* (Blackburn et al., 2007)

- Modal logic has been proposed as a logic for feature structures (Blackburn, 1993).
- It supports the local perspective on graphs that we adopt when talking about frames: Formulas are evaluated in a specific node.
- Extensions of modal logic allow to incorporate the logical operators we need. This leads to *hybrid logic* (HL, Areces & ten Cate, 2007)

Hybrid logic for frames

Model $\mathcal{M}_1$:



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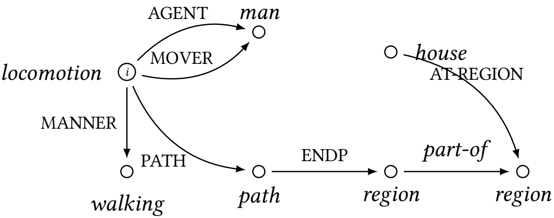

- *region* is true in the two nodes on the right at the bottom.
- $\langle\textsc{agent}\rangle$*man* is true at the *locomotion* node *i*.
- $locomotion \wedge \langle\textsc{manner}\rangle walking \wedge \langle\textsc{path}\rangle\langle\textsc{endp}\rangle\top$ is also true at the *locomotion* node *i*.

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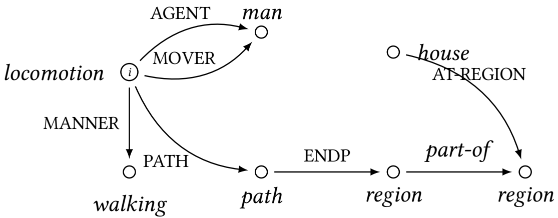

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HL extends this with

- the possibility to name nodes in order to go back to them without following a specific path;
- quantification over nodes.

Hybrid logic for frames

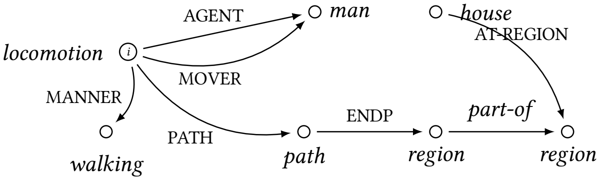
Given:

- Rel = Func ∪ PropRel (functional/non-functionsl relational symbols),
- Type (type symbols = propositional variables),
- Nom (nominals = node names), Nvar (node variables), Node := Nom ∪ Nvar.

$$\mathsf{Forms} ::= \top \mid p \mid n \mid \langle R \rangle \phi \mid \mathbf{\exists} \phi \mid @_n \phi \mid \downarrow x.\phi \mid \exists x.\phi \mid \neg \phi \mid \phi_1 \wedge \phi_2$$

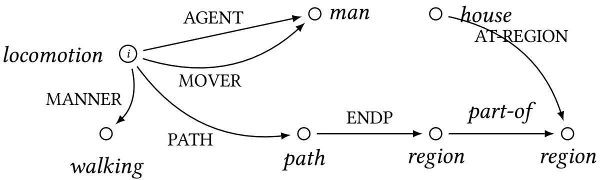
with $p \in \mathsf{Type}$, $n \in \mathsf{Node}$, $R \in \mathsf{Rel}$, $\phi, \phi_1, \phi_2 \in \mathsf{Forms}$.

Hybrid logic for frames



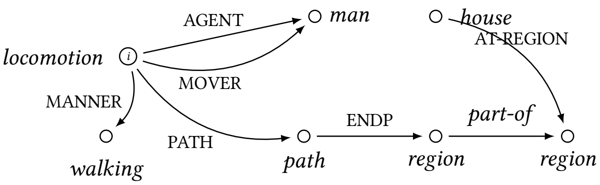
The truth of a formula is defined wrt. a specific node w of a model $\mathcal{M}$ and some assignment mapping Node to the nodes in $\mathcal{M}$. (For Nvar, this is g.)

Hybrid logic for frames



- $\exists\phi$ is true in w if there exists a w' in $\mathcal{M}$ that makes ϕ true.
  I.e., we move into some node in our frame and there ϕ is true.
  $\exists$*house* is true in any node in $\mathcal{M}_1$.

Hybrid logic for frames



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  As usual: $\forall\phi \equiv \neg\exists(\neg\phi)$
  $\forall(\mathit{path} \rightarrow \langle\textsc{endp}\rangle\top)$ is true in any node in $\mathcal{M}_1$.

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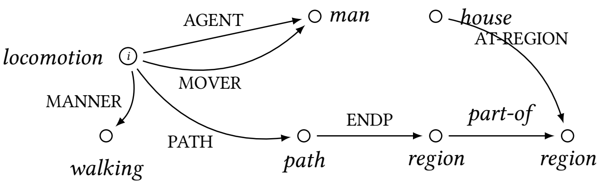

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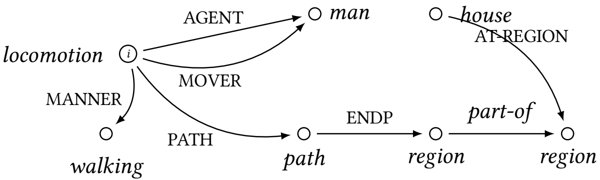
  $\forall(path \rightarrow \langle \text{ENDP} \rangle \top)$ is true in any node in $\mathcal{M}_1$.

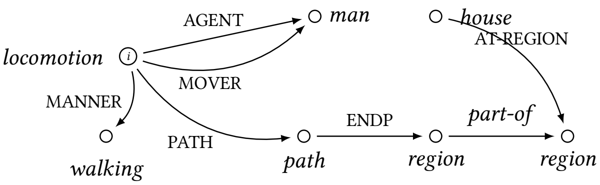
- $@_n\phi$ is true in w if ϕ is true in the node assigned to n.
  I.e., we move into the (unique) node named n and there, ϕ is true.
  $@_i locomotion$ is true in any node in $\mathcal{M}_1$.

Hybrid logic for frames



- $\downarrow x.\phi$ is true in w if ϕ is true in w under the assignment g^x_w. I.e., we call the node we are located at x, and then ϕ is true in that node.
  $\langle \text{PATH} \rangle \langle \text{ENDP} \rangle \langle \textit{part-of} \rangle \downarrow x.(\textit{region} \wedge \exists(\textit{house} \wedge \langle \text{AT-REGION} \rangle x))$
  is true in the *locomotion* node in $\mathcal{M}_1$.

Hybrid logic for frames



- $\exists x.\phi$ is true in w if there is a w' such that ϕ is true in w under an assignment $g^{x}_{w'}$.
  I.e., there is a node that we name x but for the evaluation of ϕ, we do not move to that node.
  $\exists x.\langle \textsc{path} \rangle \langle \textsc{endp} \rangle \langle \textit{part-of} \rangle (x \wedge \textit{region}) \wedge \boldsymbol{\exists}(\textit{house} \wedge \langle \textsc{at-region} \rangle x)$
  is true in the *locomotion* node in $\mathcal{M}_1$.

(2) a. The book is heavy. *phys-obj*

b. The book is interesting. *information*

book is inherently polysemous between a physical object reading and an information content reading (**dot object**, Pustejovsky, 1998).

Polysemy, dot objects and coercion

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- *read* allows for the direct selection of the dot object *book*, (3-a)
- It also enables coercion of its complement from the type *information*, (3-b), as well as the type *phys-obj*, (3-c).

Polysemy, dot objects and coercion

Semantics of the dot object *book*:

- General constraints from our frame signature:

(4) a. $\forall(\,book \rightarrow info\text{-}carrier\,)$

b. $\forall(\,info\text{-}carrier \rightarrow phys\text{-}obj \wedge \langle\textsc{content}\rangle information)$

- The lexical entry of *book* only specifies that the word contributes an element of type *book*.

With (4), we infer that the *book* node is also of types *info-carrier* (supertype of *book*) and *phys-obj* (supertype of *info-carrier*), and it has an attribute ⟨CONTENT⟩ with a value of type *information*.

Polysemy, dot objects and coercion

Semantics of *read* (inspired by Pustejovsky, 1998):

- *reading* can be decomposed into two subevents, the action of looking at a physical object (the **perception**) and the action of processing the provided information (the **comprehension**).

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- The two events are linked by a non-functional temporal relation *ordered-overlap*.

(5) $\forall(\textit{reading} \rightarrow \exists x.\langle\textsc{perc-comp}\rangle(\textit{perception} \wedge \langle \textit{ordered-overlap}\rangle x) \wedge \langle\textsc{ment-comp}\rangle(\textit{comprehension} \wedge x))$

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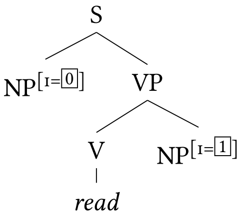
- The *perception* component has an attribute STIMULUS of type *phys-obj*, and the *comprehension* node has an attribute CONTENT which refers to the information that was read. This value is also the CONTENT of the STIMULUS node.
- The argument of *read* can provide either the stimulus of the perception (*phys-obj*) or its content.



$$
\begin{aligned}
\exists x.\exists y.\pmb{\exists}(\mathit{reading} \wedge \langle \textsc{agent} \rangle \boxed{0} \\
\wedge \langle \textsc{perc-comp} \rangle \langle \textsc{stimulus} \rangle x \\
\wedge \langle \textsc{ment-comp} \rangle \langle \textsc{content} \rangle y \\
\wedge @_x(\mathit{phys\text{-}obj} \wedge \langle \textsc{content} \rangle (\mathit{information} \wedge y)) \\
\wedge (\boxed{1} \leftrightarrow x \vee \boxed{1} \leftrightarrow y))
\end{aligned}
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Polysemy, dot objects and coercion

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\begin{aligned}
l_0 : \exists x.\exists y.\mathbf{\exists}(&\mathit{reading} \wedge \langle \textsc{agent} \rangle \boxed{0} \\
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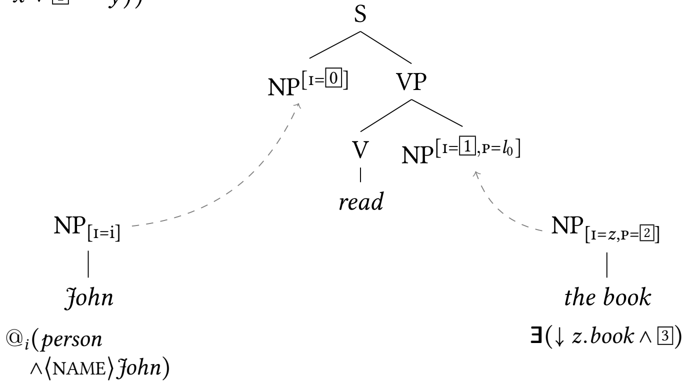

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\begin{aligned}
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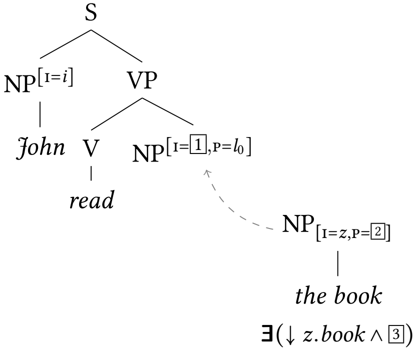
\end{aligned}
$$

$$
@_i(\mathit{person} \wedge \langle \textsc{name} \rangle \mathit{John})
$$



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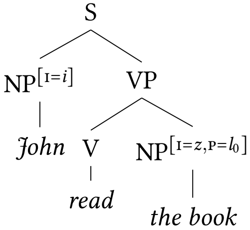
&\quad \wedge @_x(\mathit{phys\text{-}obj} \wedge \langle \textsc{content} \rangle (\mathit{information} \wedge y)) \\
&\quad \wedge (z \leftrightarrow x \vee z \leftrightarrow y)) \\
&@_i(\mathit{person} \wedge \langle \text{NAME} \rangle \mathit{John}) \\
&\boldsymbol{\exists}(\downarrow z.\mathit{book} \wedge l_0)
\end{aligned}
$$



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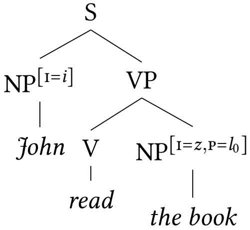
$x \leftrightarrow z$ because of the types



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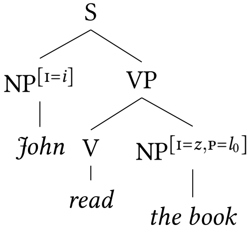

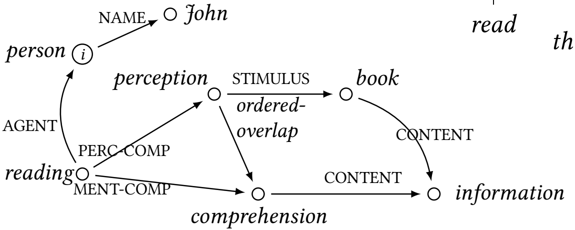

Polysemy, dot objects and coercion

(6) John read the story

- We have

(7) a. $\forall(\mathit{story} \rightarrow \mathit{information})$
b. $\forall(\mathit{phys\text{-}obj} \rightarrow \neg \mathit{information})$

- Therefore, when combining *story* as a direct object with the above tree-frame pair for *read*, we obtain $y \leftrightarrow z$.

Polysemy, dot objects and coercion

(6) John read the story

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- Therefore, when combining *story* as a direct object with the above tree-frame pair for *read*, we obtain $y \leftrightarrow z$.
- In addition, from the *reading* frame, we infer that there is a physical object that the story is written on and that John perceives this object while comprehending the story.
- In other words, the physical object is not contributed by the lexical entry of *story* but by coercion, which means in our case by unification and subsequent extension of frames.

Further examples of coercion

(8) John left the party.

leaving has a ⟨THEME⟩ attribute that is of type *location*. It is either the frame provided by the object NP or the value of the ⟨LOCATION⟩ attribute in that frame.

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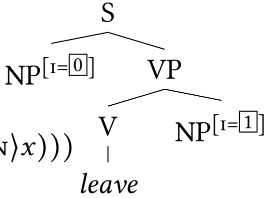
$$\exists x.\mathbf{\exists}(\mathit{leaving} \wedge \langle\text{AGENT}\rangle\boxed{0} \\ \wedge \langle\text{THEME}\rangle(\mathit{location} \wedge x) \\ \wedge (\boxed{1} \leftrightarrow x \vee @_{\boxed{1}}(\langle\text{LOCATION}\rangle x)))$$



Further examples of coercion

(9) Mary mastered the heavy book on magic.

Both *heavy* and *on magic* act as modifiers of *book*, but on its different components. The semantics of *on* (simplified here) allows for overwriting the *information* aspect of the modified noun.

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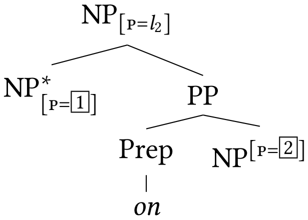
$$l_2 : \boxed{1} \wedge \exists x.(x \vee \langle \textsc{content} \rangle x) \wedge @_x(\textit{knowledge} \wedge \langle \textsc{topic} \rangle \boxed{2})$$



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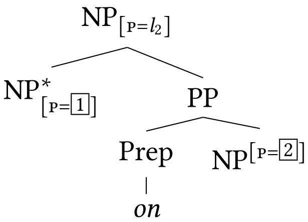

(10) $\forall(\mathit{knowledge} \rightarrow \mathit{information} \wedge \langle \textsc{topic} \rangle \top)$

Conclusion

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Conclusion

- Frames as semantic representations allow to describe rich semantic structures. The constraints arising from the frame signature can capture various generalizations.
- We use underspecified HL formulas in order to describe frames. HL allows in particular quantification over frame nodes and thereby also over subevents, which is important for characterizing rich event structures.
- This flexible architecture allows to account for polysemy and for different coercion phenomena in a monotonic and compositional way, without assuming any additional operators that are not related to syntactic structure and syntactic operations.

Thank you!

Abeillé, Anne & Owen Rambow. 2000. Tree Adjoining Grammar: An Overview. In Anne Abeillé & Owen Rambow (eds.), *Tree adjoining grammars: Formalisms, linguistic analysis and processing*, 1–68. CSLI.

Areces, Carlos & Balder ten Cate. 2007. Hybrid logics. In Blackburn et al. (2007) chap. 14, 821–868. doi:10.1016/S1570-2464(07)80017-6.

Blackburn, Patrick. 1993. Modal logic and attribute value structures. In Maarten de Rijke (ed.), *Diamonds and defaults*, 19–65. Kluwer, Dordrecht.

Blackburn, Patrick, Johan Van Benthem & Frank Wolter (eds.). 2007. *Handbook of modal logic*, vol. 3 Studies in Logic and Practical Reasoning. Elsevier.

Joshi, Aravind K. & Yves Schabes. 1997. Tree-Adjoining Grammars. In G. Rozenberg & A. Salomaa (eds.), *Handbook of formal languages*, 69–123. Berlin: Springer.

Kallmeyer, Laura & Rainer Osswald. 2013. Syntax-driven semantic frame composition in Lexicalized Tree Adjoining Grammars. *Journal of Language Modelling* 1(2). 267–330.

Kallmeyer, Laura, Rainer Osswald & Sylvain Pogodalla. 2016. *For*-adverbials and aspectual interpretation: An LTAG analysis using hybrid logic and frame semantics. In Christopher Piñón (ed.), *Empirical issues in syntax and semantics eiss*, vol. 11, .

Pustejovsky, James. 1998. The semantics of lexical underspecification. *Folia Linguistica* 32(3–4). 323–348.