Grammar Implementation with Lexicalized Tree Adjoining Grammars and Frame Semantics

Frame semantics

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University of Düsseldorf

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SFB 991

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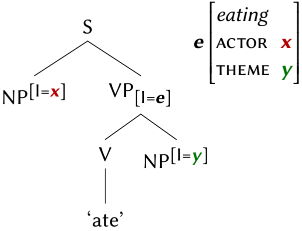
Reminder

(1) Adam ate an apple.



The overall story

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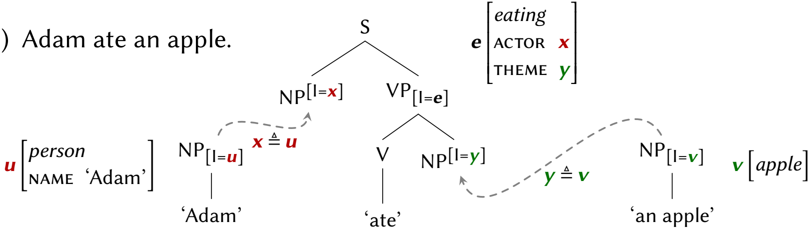

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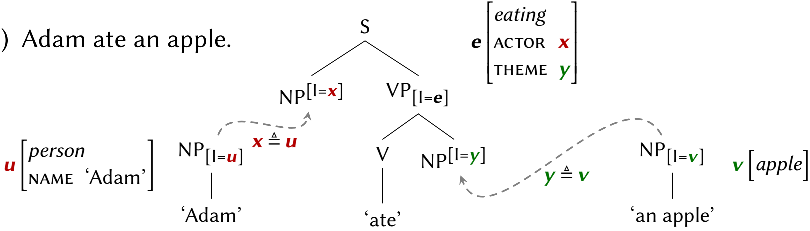

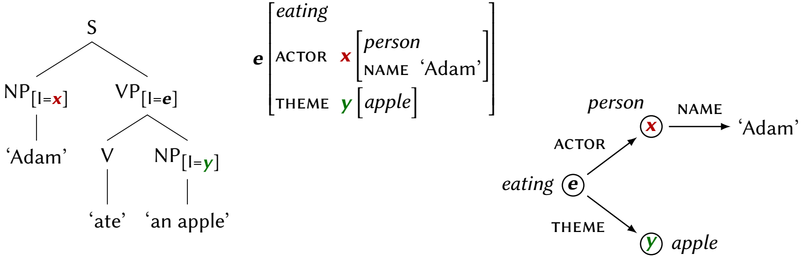

Outline of today's course

1. Introduction to frame semantics
   - Frames in the sense of Fillmore and Barsalou
   - Frames according to this course
2. Formalization of frames
   - Attribute-value descriptions and formulas
   - Formal definition of frames
   - Frames as models
   - Subsumption and unification
   - Attribute-value constraints
3. Further topics
   - Frames versus feature structures
   - Type constraints versus type hierarchy
4. Frame semantics: extensions
5. Summary and outlook

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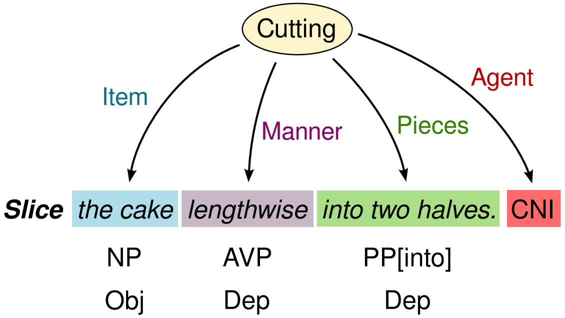
Frames according to Fillmore/FrameNet [framenet.icsi.berkeley.edu]

The 'Cutting' frame, annotated:



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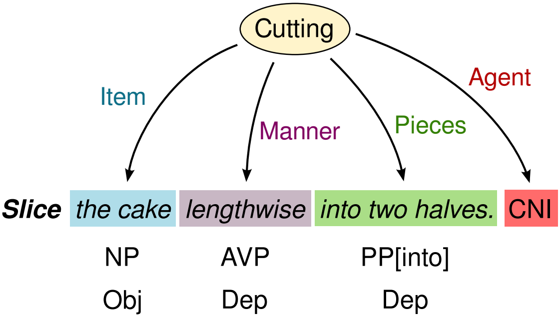


The FrameNet database:

- > 1200 frames
- > 13000 lexical units (= word senses)

Frames according to Fillmore/FrameNet [framenet.icsi.berkeley.edu]

Cutting frame

Definition: An [Agent] cuts an [Item] into [Pieces] using an [Instrument] (which may or may not be expressed).

Core frame elements:

Agent	The [Agent] is the person cutting the [Item] into [Pieces].
Item	The item which is being cut into [Pieces].
Pieces	The [Pieces] are the parts of the original [Item] which are the result of the slicing.

Non-core frame elements:

Instrument	The [Instrument] with which the [Item] is being cut into [Pieces].
Manner	[Manner] in which the [Item] is being cut into [Pieces].
Result	The [Result] of the [Item] being sliced into [Pieces]. (extrathematic)
In addition: Means, Purpose, Place, Time	

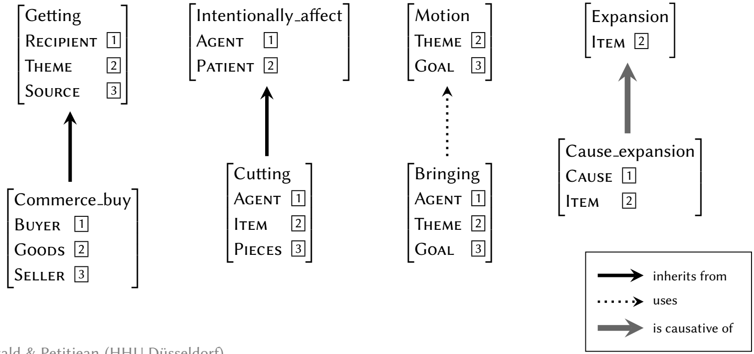
Lexical units: *carve*, *chop*, *cube*, *cut*, *dice*, *fillet*, *mince*, *pare*, *slice*

Frames according to Fillmore/FrameNet [framenet.icsi.berkeley.edu]

Frame-to-frame relations in FrameNet

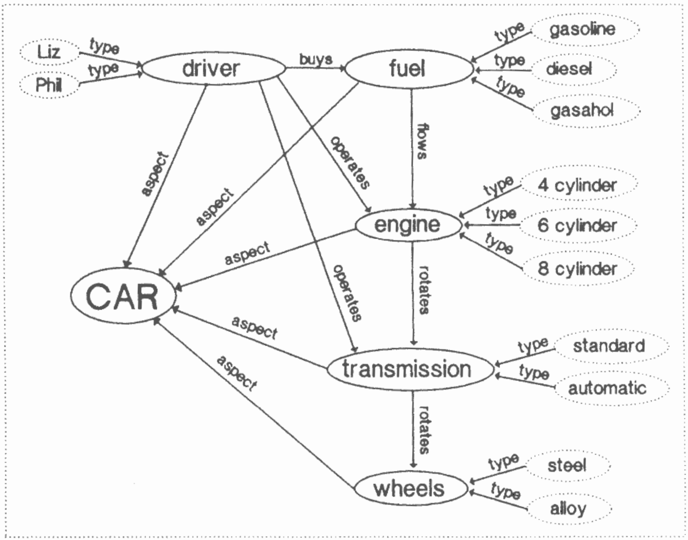
- Generalization relations: ‘inherits from’, ‘is perspective on’, ‘uses’
- Event structure relations: ‘is subframe of’, ‘precedes’
- Systematic relations: ‘is causative of’, ‘is inchoative of’

Examples



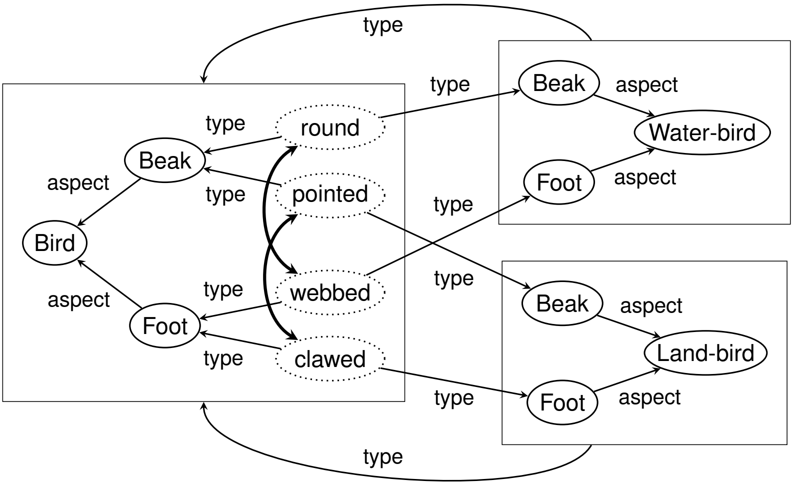
Frames according to Barsalou

[Barsalou 1992:30]



Frames according to Barsalou

[Gamerschlag et al. 2014:6]



Introduction to frame semantics

Frames according to this course [Kallmeyer/Osswald 2013; Osswald/Van Valin 2014]

- A representation format for **rich lexical** and **constructional content**.
- Can nicely capture **semantic composition** and **decomposition**.
- Can be formalized as **generalized feature structures** with **types**, **relations** and **node labels**.

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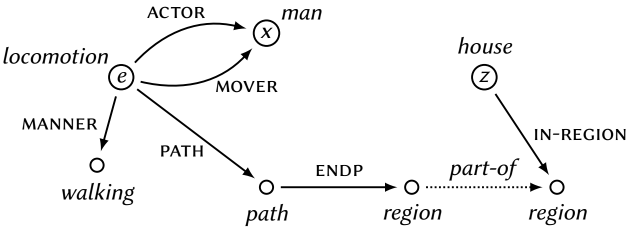
Basic assumptions

- **Attributes** (features, functional roles/relations) play a central role in the organization of semantic and conceptual knowledge and representation. [Barsalou 1992; Löbner 2014]
- Semantic components (participants, subevents) can be (recursively) addressed via **attributes** (from some "**base**" node).

  ⤳ inherently **structured representations** (models);
  composition by **unification** (under **constraints**)

Frames according to this course

Example



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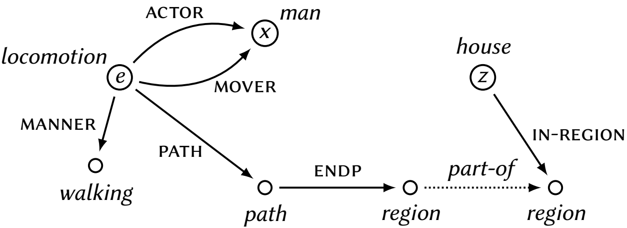
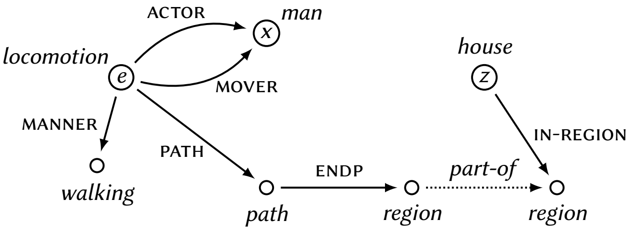


Ingredients

- Attributes (funct. relations): ACTOR, MOVER, PATH, MANNER, IN-REGION, …

Frames according to this course

Example



Ingredients

- Attributes (funct. relations): ACTOR, MOVER, PATH, MANNER, IN-REGION, …
- Type symbols: *locomotion*, *man*, *path*, *walking*, *region*, …

Frames according to this course

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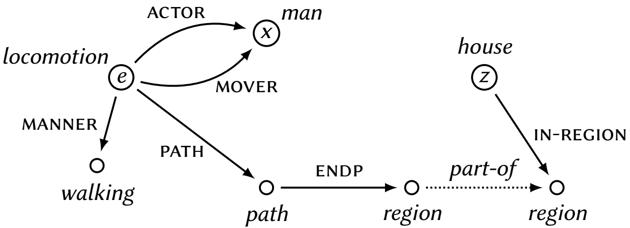

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- Proper relations: *part-of*

Frames according to this course

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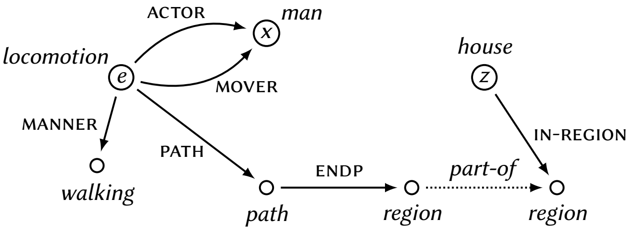

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Introduction to frame semantics

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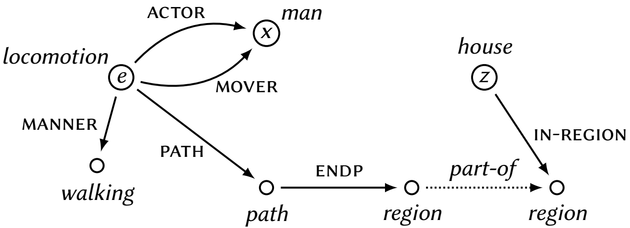

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Core property

- Every node is reachable from some labeled "base" node via attributes.

Example

(2) Anna ran

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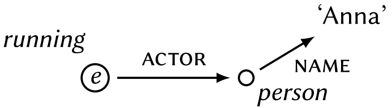
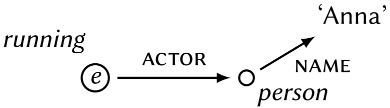


Example

(2) Anna ran to the station.



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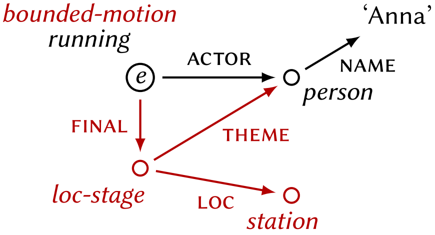

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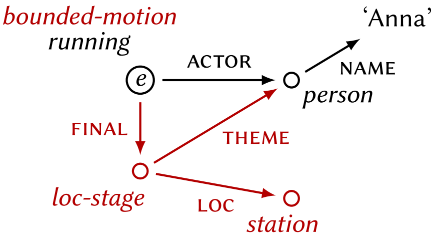

$$e \begin{bmatrix} \textit{running} \wedge \textit{bounded-motion} \\ \text{ACTOR} \; \boxed{1} \begin{bmatrix} \textit{person} \\ \text{NAME} \; \text{`Anna'} \end{bmatrix} \\ \text{FINAL} \; \begin{bmatrix} \textit{loc-stage} \\ \text{THEME} \; \boxed{1} \\ \text{LOC} \; [\textit{station}] \end{bmatrix} \end{bmatrix}$$

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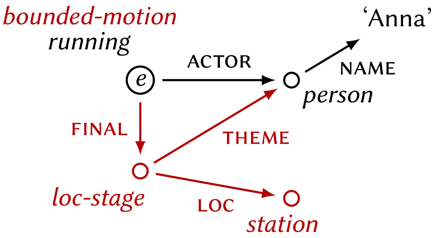

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Attribute-value logic

$$e \cdot (\textit{running} \wedge \textit{bounded-motion} \wedge \text{ACTOR} : (\textit{person} \wedge \text{NAME} \triangleq \text{`Anna'})$$
$$\text{ACTOR} \doteq \text{FINAL THEME} \wedge \text{FINAL} : (\textit{loc-stage} \wedge \text{LOC} : \textit{station}))$$

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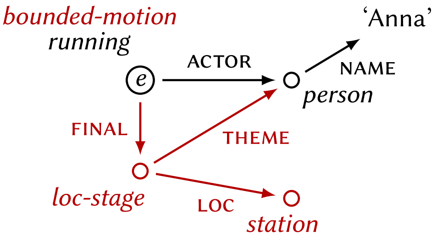

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Translation into first-order logic

$$\exists x \exists s \exists y (\textit{running}(e) \wedge \textit{bounded-motion}(e) \wedge \text{ACTOR}(e, x) \wedge \textit{person}(x) \wedge \text{NAME}(x, \text{`Anna'}) \\ \wedge \text{FINAL}(e, s) \wedge \textit{loc-stage}(s) \wedge \text{THEME}(s, x) \wedge \text{LOC}(s, y) \wedge \textit{station}(y))$$

Introduction to frame semantics

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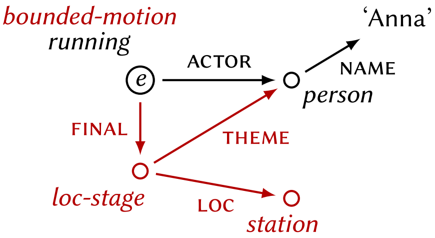

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Constraints

$$\textit{running} \Rrightarrow \textit{activity} \quad (\text{short for } \forall e(\textit{running}(e) \rightarrow \textit{activity}(e))),$$
$$\textit{loc-stage} \Rrightarrow \textsc{theme} : \top \wedge \textsc{loc} : \top, \quad \ldots$$

Example Lexical decomposition templates [Rappaport Hovav/Levin 1998]

(3) [[*x* ACT] CAUSE [BECOME [*y* *BROKEN*]]]

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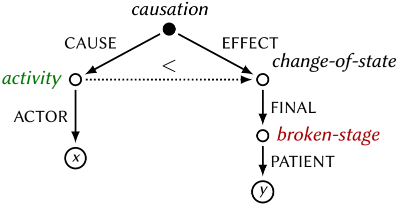

$$\begin{bmatrix} \textit{causation} & \\ \text{CAUSE} & \begin{bmatrix} \textit{activity} & \\ \text{EFFECTOR} & x \end{bmatrix} \\ \text{EFFECT} & \begin{bmatrix} \textit{change-of-state} & \\ \text{FINAL} & \begin{bmatrix} \textit{broke-stage} & \\ \text{PATIENT} & y \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

$\text{CAUSE} < \text{EFFECT}$

Description in attribute-value logic

$$\textit{causation} \wedge \text{CAUSE} : \textit{activity} \wedge \text{CAUSE ACTOR} \triangleq x$$
$$\wedge\ \text{EFFECT}\,(\textit{change-of-state} \wedge \text{FINAL} : (\textit{broken-stage} \wedge \text{PATIENT} \triangleq y))$$
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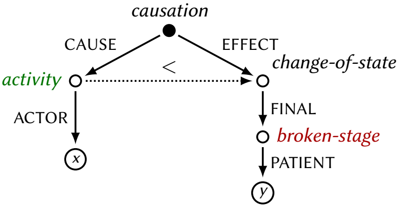

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Translation into first-order logic

$$\lambda e \exists e' \exists e'' \exists s (\textit{causation}(e) \wedge \text{CAUSE}(e, e') \wedge \text{EFFECT}(e, e'') \wedge e' < e'' \wedge$$
$$\textit{activity}(e') \wedge \text{ACTOR}(e', x) \wedge \textit{change-of-state}(e'') \wedge$$
$$\text{FINAL}(e'', s) \wedge \textit{broken-stage}(s) \wedge \text{PATIENT}(s, y))$$

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Attribute-value descriptions

Vocabulary / Signature

Attr	attributes (= dyadic functional relation symbols)		
Rel	(proper) relation symbols		
Type	type symbols (= monadic predicates)		
Nname	node names (“nominals”)	} Nlabel	node labels
Nvar	node variables		

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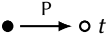
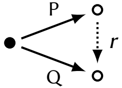
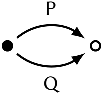
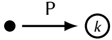
Primitive attribute-value descriptions (pAVDesc)

$$t \;\mid\; p:t \;\mid\; p \doteq q \;\mid\; [p_1, \ldots, p_n] : r \;\mid\; p \triangleq k$$

($t \in$ Type, $r \in$ Rel, $p, q, p_i \in \text{Attr}^*$, $k \in$ Nlabel)

Semantics

$\text{P} : t$		$\begin{bmatrix} \text{P} & [t] \end{bmatrix}$	$[\text{P}, \text{Q}] : r$		$\begin{bmatrix} \text{P} & \boxed{1} \\ \text{Q} & \boxed{2} \end{bmatrix}$ $r(\boxed{1}, \boxed{2})$
$\text{P} \doteq \text{Q}$		$\begin{bmatrix} \text{P} & \boxed{1} \\ \text{Q} & \boxed{1} \end{bmatrix}$	$\text{P} \triangleq k$		$\begin{bmatrix} \text{P} & k[\;] \end{bmatrix}$

Attribute-value formulas

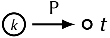
Primitive attribute-value formulas (pAVForm)

$$k \cdot p : t \;\mid\; k \cdot p \triangleq l \cdot q \;\mid\; \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$$

($t \in \text{Type}$, $r \in \text{Rel}$, $p, q, p_i \in \text{Attr}^*$, $k, l, k_i \in \text{Nlabel}$)

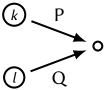
Semantics

$k \cdot \mathrm{P} : t$



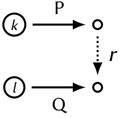
$k \begin{bmatrix} \mathrm{P} & [t] \end{bmatrix}$

$k \cdot \mathrm{P} \triangleq l \cdot \mathrm{Q}$



$k \begin{bmatrix} \mathrm{P} & \boxed{1} \end{bmatrix}$
$l \begin{bmatrix} \mathrm{Q} & \boxed{1} \end{bmatrix}$

$\langle k \cdot \mathrm{P}, l \cdot \mathrm{Q} \rangle : r$



$k \begin{bmatrix} \mathrm{P} & \boxed{1} \end{bmatrix}$
$l \begin{bmatrix} \mathrm{Q} & \boxed{2} \end{bmatrix}$
$r(\boxed{1}, \boxed{2})$

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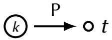
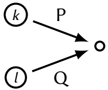
Semantics

$k \cdot \text{P} : t$



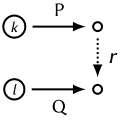
$k \left[\text{P} \; [t] \right]$

$k \cdot \text{P} \triangleq l \cdot \text{Q}$



$k \left[\text{P} \; \boxed{1} \right]$
$l \left[\text{Q} \; \boxed{1} \right]$

$\langle k \cdot \text{P}, l \cdot \text{Q} \rangle : r$



$k \left[\text{P} \; \boxed{1} \right]$
$l \left[\text{Q} \; \boxed{2} \right]$
$r(\boxed{1}, \boxed{2})$

Formal definitions (fairly standard)

Set/universe of “nodes” V

Attribute-value formulas

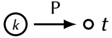
Primitive attribute-value formulas (pAVForm)

$$k \cdot p : t \;\mid\; k \cdot p \triangleq l \cdot q \;\mid\; \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$$

($t \in$ Type, $r \in$ Rel, $p, q, p_i \in$ Attr*, $k, l, k_i \in$ Nlabel)

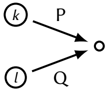
Semantics

$k \cdot \text{P} : t$



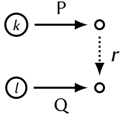
$k\begin{bmatrix}\text{P} & [t]\end{bmatrix}$

$k \cdot \text{P} \triangleq l \cdot \text{Q}$



$k\begin{bmatrix}\text{P} & \boxed{1}\end{bmatrix}$
$l\begin{bmatrix}\text{Q} & \boxed{1}\end{bmatrix}$

$\langle k \cdot \text{P}, l \cdot \text{Q} \rangle : r$



$k\begin{bmatrix}\text{P} & \boxed{1}\end{bmatrix}$
$l\begin{bmatrix}\text{Q} & \boxed{2}\end{bmatrix}$
$r(\boxed{1}, \boxed{2})$

Formal definitions (fairly standard)

Set/universe of "nodes"	V
Interpretation function	$\mathcal{I} : \text{Attr} \to [V \rightharpoonup V]$,

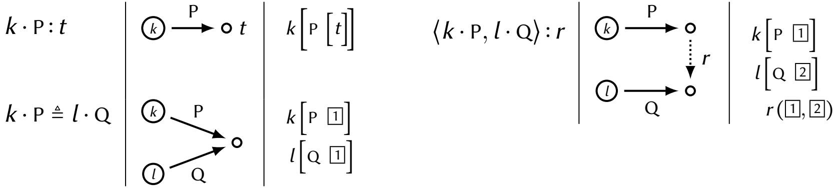
Attribute-value formulas

Primitive attribute-value formulas (pAVForm)

$$k \cdot p : t \;\mid\; k \cdot p \triangleq l \cdot q \;\mid\; \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$$

($t \in$ Type, $r \in$ Rel, $p, q, p_i \in \mathrm{Attr}^*$, $k, l, k_i \in$ Nlabel)

Semantics



Formal definitions (fairly standard)

Set/universe of "nodes"	V
Interpretation function	$\mathcal{I}$: Attr $\rightarrow [V \rightharpoonup V]$, Type $\rightarrow \wp(V)$,

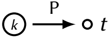
Primitive attribute-value formulas (pAVForm)

$$k \cdot p : t \mid k \cdot p \triangleq l \cdot q \mid \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$$

($t \in$ Type, $r \in$ Rel, $p, q, p_i \in$ Attr*, $k, l, k_i \in$ Nlabel)

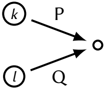
Semantics

$k \cdot \text{P} : t$



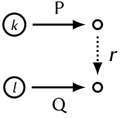
$k \left[\text{P} \left[t \right] \right]$

$k \cdot \text{P} \triangleq l \cdot \text{Q}$



$k \left[\text{P} \; \boxed{1} \right]$
$l \left[\text{Q} \; \boxed{1} \right]$

$\langle k \cdot \text{P}, l \cdot \text{Q} \rangle : r$



$k \left[\text{P} \; \boxed{1} \right]$
$l \left[\text{Q} \; \boxed{2} \right]$
$r(\boxed{1}, \boxed{2})$

Formal definitions (fairly standard)

Set/universe of "nodes"	V
Interpretation function	$\mathcal{I}$: Attr $\rightarrow [V \rightharpoonup V]$, Type $\rightarrow \wp(V)$,
	Rel $\rightarrow \bigcup_n \wp(V^n)$,

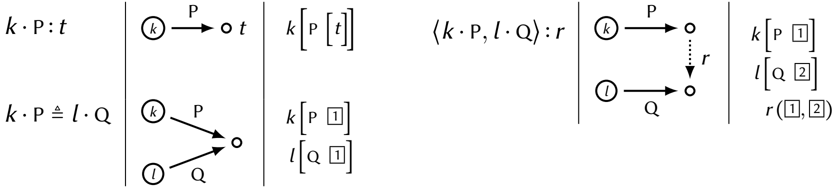
Attribute-value formulas

Primitive attribute-value formulas (pAVForm)

$$k \cdot p : t \;\mid\; k \cdot p \triangleq l \cdot q \;\mid\; \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$$

($t \in$ Type, $r \in$ Rel, $p, q, p_i \in$ Attr*, $k, l, k_i \in$ Nlabel)

Semantics



Formal definitions (fairly standard)

Set/universe of "nodes"	V
Interpretation function	$\mathcal{I}$: Attr $\to [V \rightharpoonup V]$, Type $\to \wp(V)$,
	Rel $\to \bigcup_n \wp(V^n)$, Nname $\to V$

Attribute-value formulas

Primitive attribute-value formulas (pAVForm)

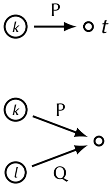
$$k \cdot p : t \;\mid\; k \cdot p \triangleq l \cdot q \;\mid\; \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$$

$(t \in \text{Type},\; r \in \text{Rel},\; p, q, p_i \in \text{Attr}^*,\; k, l, k_i \in \text{Nlabel})$

Semantics

$k \cdot \text{P} : t$

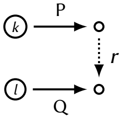
$k \cdot \text{P} \triangleq l \cdot \text{Q}$



$k \begin{bmatrix} \text{P} & [t] \end{bmatrix}$

$k \begin{bmatrix} \text{P} & \boxed{1} \end{bmatrix}$
$l \begin{bmatrix} \text{Q} & \boxed{1} \end{bmatrix}$

$\langle k \cdot \text{P}, l \cdot \text{Q} \rangle : r$



$k \begin{bmatrix} \text{P} & \boxed{1} \end{bmatrix}$
$l \begin{bmatrix} \text{Q} & \boxed{2} \end{bmatrix}$
$r(\boxed{1}, \boxed{2})$

Formal definitions (fairly standard)

Set/universe of "nodes"	V
Interpretation function	$\mathcal{I} : \text{Attr} \to [V \rightharpoonup V],\; \text{Type} \to \wp(V),$
	$\text{Rel} \to \bigcup_n \wp(V^n),\; \text{Nname} \to V$
(Partial) variable assignment	$g : \text{Nvar} \rightharpoonup V$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$\langle V, \mathcal{I}, g \rangle, v \vDash t$ iff $v \in \mathcal{I}(t)$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$\langle V, \mathcal{I}, g \rangle, v \vDash t$ iff $v \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g \rangle, v \vDash p : t$ iff $\mathcal{I}(p)(v) \in \mathcal{I}(t)$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

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$\langle V, \mathcal{I}, g\rangle, v \vDash t$ iff $v \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g\rangle, v \vDash p : t$ iff $\mathcal{I}(p)(v) \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g\rangle, v \vDash p \doteq q$ iff $\mathcal{I}(p)(v) = \mathcal{I}(q)(v)$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

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$\langle V, \mathcal{I}, g\rangle, v \vDash p : t$ iff $\mathcal{I}(p)(v) \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g\rangle, v \vDash p \doteq q$ iff $\mathcal{I}(p)(v) = \mathcal{I}(q)(v)$

$\langle V, \mathcal{I}, g\rangle, v \vDash [p_1, \ldots, p_n] : r$ iff $\langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v)\rangle \in \mathcal{I}(r)$

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$\langle V, \mathcal{I}, g \rangle, v \models t$ iff $v \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g \rangle, v \models p : t$ iff $\mathcal{I}(p)(v) \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g \rangle, v \models p \doteq q$ iff $\mathcal{I}(p)(v) = \mathcal{I}(q)(v)$

$\langle V, \mathcal{I}, g \rangle, v \models [p_1, \ldots, p_n] : r$ iff $\langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v) \rangle \in \mathcal{I}(r)$

$\langle V, \mathcal{I}, g \rangle, v \models p \triangleq k$ iff $\mathcal{I}(p)(v) = \mathcal{I}_g(k)$ ($k \in$ Nlabel)

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$\langle V, \mathcal{I}, g\rangle, v \vDash t$	iff $v \in \mathcal{I}(t)$
$\langle V, \mathcal{I}, g\rangle, v \vDash p : t$	iff $\mathcal{I}(p)(v) \in \mathcal{I}(t)$
$\langle V, \mathcal{I}, g\rangle, v \vDash p \doteq q$	iff $\mathcal{I}(p)(v) = \mathcal{I}(q)(v)$
$\langle V, \mathcal{I}, g\rangle, v \vDash [p_1, \ldots, p_n] : r$	iff $\langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v)\rangle \in \mathcal{I}(r)$
$\langle V, \mathcal{I}, g\rangle, v \vDash p \triangleq k$	iff $\mathcal{I}(p)(v) = \mathcal{I}_g(k)$ ($k \in$ Nlabel)

Satisfaction of primitive **formulas**

$\langle V, \mathcal{I}, g\rangle \vDash k \cdot p : t$ iff $\mathcal{I}(p)(\mathcal{I}_g(k)) \in \mathcal{I}(t)$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$$\begin{array}{ll}
\langle V, \mathcal{I}, g\rangle, v \vDash t & \text{iff } v \in \mathcal{I}(t) \\
\langle V, \mathcal{I}, g\rangle, v \vDash p : t & \text{iff } \mathcal{I}(p)(v) \in \mathcal{I}(t) \\
\langle V, \mathcal{I}, g\rangle, v \vDash p \doteq q & \text{iff } \mathcal{I}(p)(v) = \mathcal{I}(q)(v) \\
\langle V, \mathcal{I}, g\rangle, v \vDash [p_1, \ldots, p_n] : r & \text{iff } \langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v)\rangle \in \mathcal{I}(r) \\
\langle V, \mathcal{I}, g\rangle, v \vDash p \triangleq k & \text{iff } \mathcal{I}(p)(v) = \mathcal{I}_g(k) \quad (k \in \text{Nlabel})
\end{array}$$

Satisfaction of primitive **formulas**

$$\begin{array}{ll}
\langle V, \mathcal{I}, g\rangle \vDash k \cdot p : t & \text{iff } \mathcal{I}(p)(\mathcal{I}_g(k)) \in \mathcal{I}(t) \\
\langle V, \mathcal{I}, g\rangle \vDash k \cdot p \triangleq l \cdot q & \text{iff } \mathcal{I}(p)(\mathcal{I}_g(k)) = \mathcal{I}(q)(\mathcal{I}_g(l))
\end{array}$$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in \text{Nlabel}$ iff $\mathcal{I}(k) = v$ if $k \in \text{Nname}$ and
$g(k) = v$ if $k \in \text{Nvar}$ ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$$\begin{array}{ll}
\langle V, \mathcal{I}, g\rangle, v \models t & \text{iff } v \in \mathcal{I}(t) \\
\langle V, \mathcal{I}, g\rangle, v \models p : t & \text{iff } \mathcal{I}(p)(v) \in \mathcal{I}(t) \\
\langle V, \mathcal{I}, g\rangle, v \models p \doteq q & \text{iff } \mathcal{I}(p)(v) = \mathcal{I}(q)(v) \\
\langle V, \mathcal{I}, g\rangle, v \models [p_1, \ldots, p_n] : r & \text{iff } \langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v)\rangle \in \mathcal{I}(r) \\
\langle V, \mathcal{I}, g\rangle, v \models p \triangleq k & \text{iff } \mathcal{I}(p)(v) = \mathcal{I}_g(k) \quad (k \in \text{Nlabel})
\end{array}$$

Satisfaction of primitive **formulas**

$$\begin{array}{ll}
\langle V, \mathcal{I}, g\rangle \models k \cdot p : t & \text{iff } \mathcal{I}(p)(\mathcal{I}_g(k)) \in \mathcal{I}(t) \\
\langle V, \mathcal{I}, g\rangle \models k \cdot p \triangleq l \cdot q & \text{iff } \mathcal{I}(p)(\mathcal{I}_g(k)) = \mathcal{I}(q)(\mathcal{I}_g(l)) \\
\langle V, \mathcal{I}, g\rangle \models \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n\rangle : r & \text{iff } \langle \mathcal{I}(p_1)(\mathcal{I}_g(k_1)), \ldots, \mathcal{I}_g(p_n)(\mathcal{I}(k_n))\rangle \in \mathcal{I}(r)
\end{array}$$

Satisfaction of AV descriptions and formulas

Formal definitions (cont'd)

Abbreviation: $\mathcal{I}_g(k) = v$ for $k \in$ Nlabel iff $\mathcal{I}(k) = v$ if $k \in$ Nname and
$g(k) = v$ if $k \in$ Nvar ($g(k)$ defined)

Satisfaction of primitive **descriptions**

$\langle V, \mathcal{I}, g \rangle, v \vDash t$ iff $v \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g \rangle, v \vDash p : t$ iff $\mathcal{I}(p)(v) \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g \rangle, v \vDash p \doteq q$ iff $\mathcal{I}(p)(v) = \mathcal{I}(q)(v)$

$\langle V, \mathcal{I}, g \rangle, v \vDash [p_1, \ldots, p_n] : r$ iff $\langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v) \rangle \in \mathcal{I}(r)$

$\langle V, \mathcal{I}, g \rangle, v \vDash p \triangleq k$ iff $\mathcal{I}(p)(v) = \mathcal{I}_g(k)$ ($k \in$ Nlabel)

Satisfaction of primitive **formulas**

$\langle V, \mathcal{I}, g \rangle \vDash k \cdot p : t$ iff $\mathcal{I}(p)(\mathcal{I}_g(k)) \in \mathcal{I}(t)$

$\langle V, \mathcal{I}, g \rangle \vDash k \cdot p \triangleq l \cdot q$ iff $\mathcal{I}(p)(\mathcal{I}_g(k)) = \mathcal{I}(q)(\mathcal{I}_g(l))$

$\langle V, \mathcal{I}, g \rangle \vDash \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$ iff $\langle \mathcal{I}(p_1)(\mathcal{I}_g(k_1)), \ldots, \mathcal{I}_g(p_n)(\mathcal{I}(k_n)) \rangle \in \mathcal{I}(r)$

Satisfaction of **Boolean combinations** as usual.

Frames defined

Frame F over $\langle \text{Attr}, \text{Type}, \text{Rel}, \text{Nname}, \text{Nvar} \rangle$:

$F = \langle V, \mathcal{I}, g \rangle$, with V finite, such that every node $v \in V$ is reachable from some labeled node $w \in V$ via an attribute path,

Frames defined

Frame F over $\langle$Attr, Type, Rel, Nname, Nvar$\rangle$:

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(i) $w = \mathcal{I}_g(k)$ for some $k \in$ Nlabel (= Nname $\cup$ Nvar) and

(ii) $v = \mathcal{I}(p)(w)$ for some $p \in \text{Attr}^*$.

Frames defined

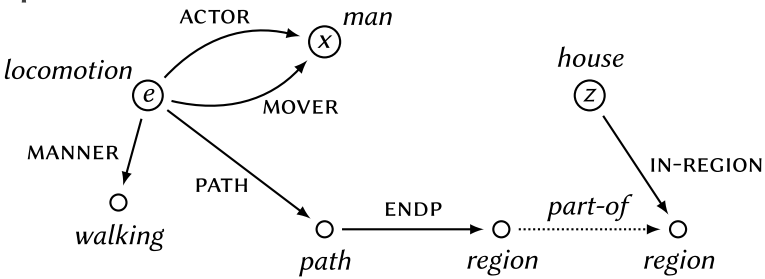
Frame F over $\langle$Attr, Type, Rel, Nname, Nvar$\rangle$:

$F = \langle V, \mathcal{I}, g \rangle$, with V finite, such that every node $v \in V$ is reachable from some labeled node $w \in V$ via an attribute path, i.e.,

(i) $w = \mathcal{I}_g(k)$ for some $k \in$ Nlabel (= Nname $\cup$ Nvar) and

(ii) $v = \mathcal{I}(p)(w)$ for some $p \in \text{Attr}^*$.

Example



Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

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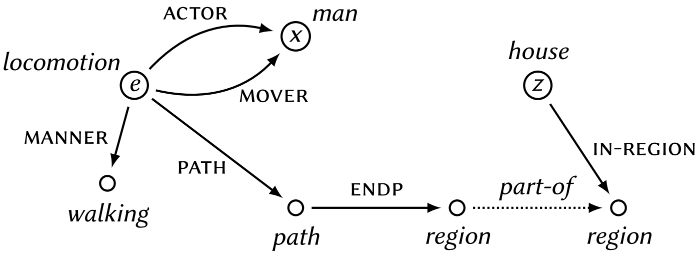
Example

F =



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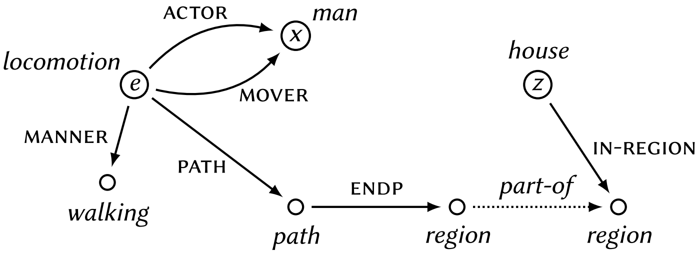
A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

Example

$F =$

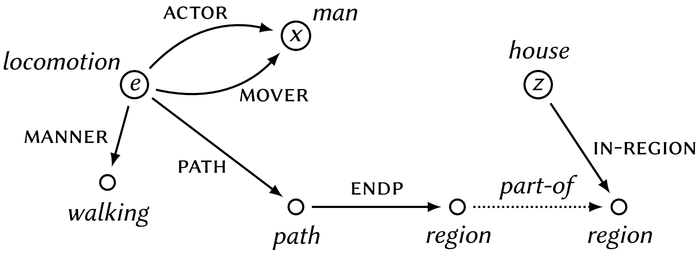


$F \vDash$

Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

Example

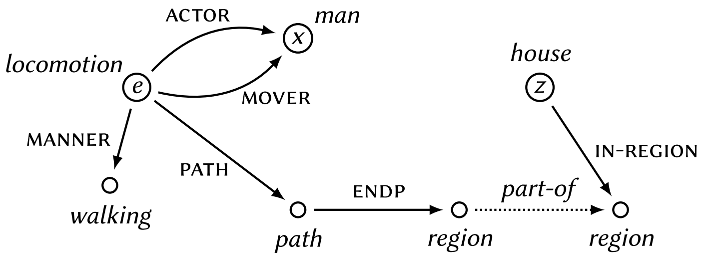
$F =$ 

$F \vDash e \cdot locomotion$

Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

Example

$F =$ 

$F \vDash e \cdot locomotion$

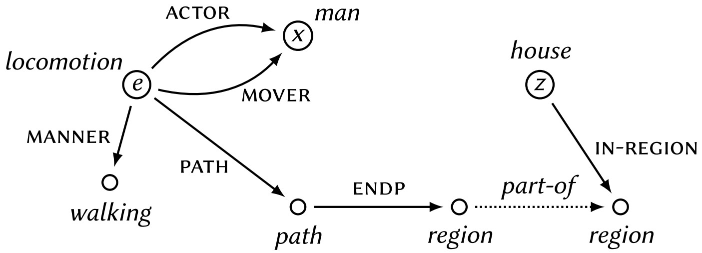
$F \vDash e \cdot (locomotion \wedge \text{ACTOR} : man)$

Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \models \phi$.

Example

$F =$



$F \models e \cdot \textit{locomotion}$

$F \models e \cdot (\textit{locomotion} \wedge \text{ACTOR} : \textit{man})$

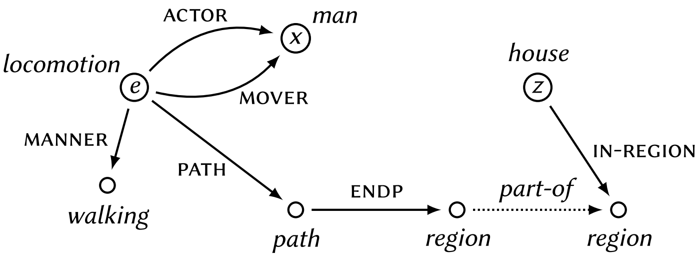
$F \models e \cdot (\textit{locomotion} \wedge \text{ACTOR} \triangleq x)$

Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

Example

$F =$



$F \vDash e \cdot \textit{locomotion}$

$F \vDash e \cdot (\textit{locomotion} \wedge \textsc{actor} : \textit{man})$

$F \vDash e \cdot (\textit{locomotion} \wedge \textsc{actor} \triangleq x)$

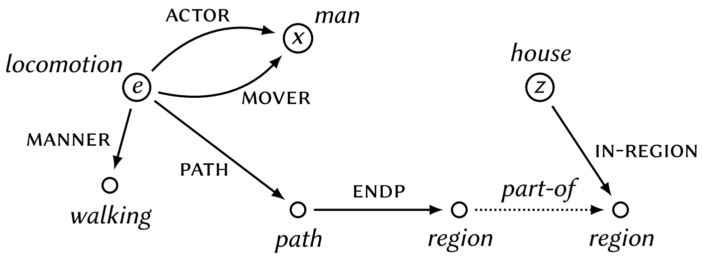
$F \vDash x \cdot \textit{man}$

Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

Example

$F =$



$F \vDash e \cdot locomotion$

$F \vDash e \cdot (locomotion \wedge \text{ACTOR} : man)$

$F \vDash e \cdot (locomotion \wedge \text{ACTOR} \triangleq x)$

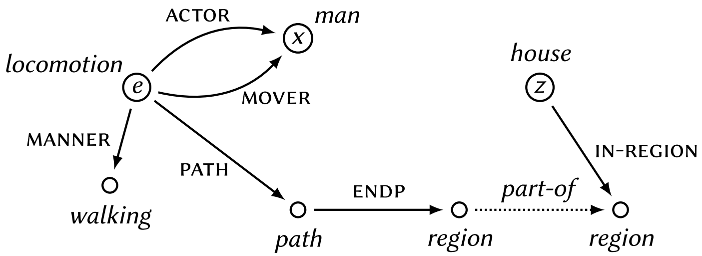
$F \vDash x \cdot man \wedge z \cdot house$

Frames as models of AV formulas

A frame $F = \langle V, \mathcal{I}, g \rangle$ is a **model** of an AV formula ϕ iff $F \vDash \phi$.

Example

F =



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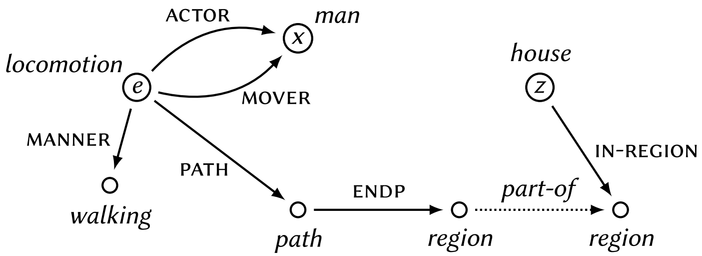

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$F \vDash \langle e \cdot \textsc{path endp}, z \cdot \textsc{in-region} \rangle : part\text{-}of$

Subsumption and unification

Subsumption

$F_1 = \langle V_1, \mathcal{I}_1, g_1 \rangle$ **subsumes** $F_2 = \langle V_2, \mathcal{I}_2, g_2 \rangle$ ($F_1 \sqsubseteq F_2$) iff there is a (necessarily unique) **morphism** $h : F_1 \to F_2$, i.e., a function $h : V_1 \to V_2$ such that

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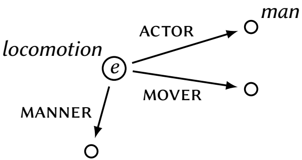

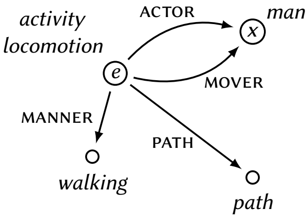

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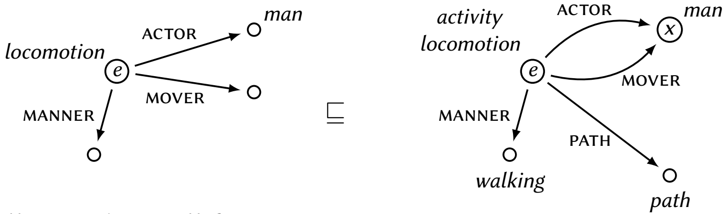

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Intuition

F_1 subsumes F_2 ($F_1 \sqsubseteq F_2$) iff F_2 is **at least as informative** as F_1.

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The worst case time-complexity of frame unification is almost linear in the number of nodes.

Frames as minimal models

Frames as minimal models of attribute-value formulas

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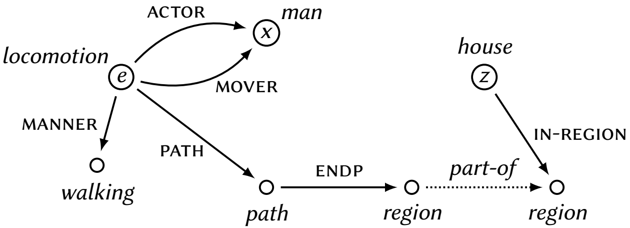

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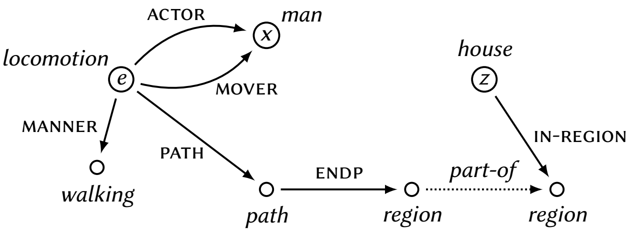

$$e \cdot (\textit{locomotion} \;\wedge\; \text{MANNER} : \textit{walking} \;\wedge\; \text{ACTOR} \triangleq x$$
$$\wedge\; \text{MOVER} \doteq \text{ACTOR} \;\wedge\; \text{PATH} : (\textit{path} \;\wedge\; \text{ENDP} : \textit{region}))$$
$$\wedge\; \langle e \cdot \text{PATH ENDP},\; z \cdot \text{IN-REGION} \rangle : \textit{part-of} \;\wedge\; x \cdot \textit{man}$$

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Constraints (general format) $\forall\phi,\ \phi \in \text{AVDesc}$

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Notation:

$\phi \Rrightarrow \psi$ for $\forall(\phi \rightarrow \psi)$

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$\textit{activity} \Rrightarrow \textit{event}$

$\textit{causation} \wedge \textit{activity} \Rrightarrow \bot$

$\text{AGENT} : \top \Rrightarrow \text{AGENT} \doteq \text{ACTOR}$

$\textit{activity} \Rrightarrow \text{ACTOR} : \top$

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activity $\Rrightarrow$ *event* (every activity is an event)

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activity $\Rrightarrow$ ACTOR : $\top$

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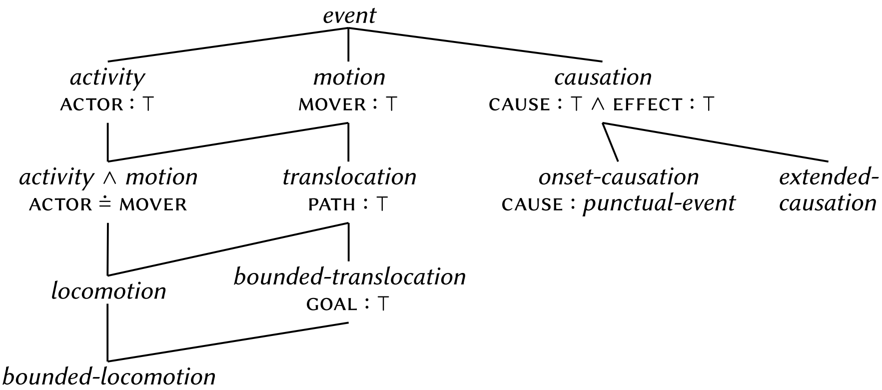
Attribute-value constraints

Graphical presentation of constraints



Caveat: Reading convention required!

Attribute-value constraints

Further examples [Babonnaud et al. 2016]

$book \Rrightarrow info\text{-}carrier$

Attribute-value constraints

Further examples

[Babonnaud et al. 2016]

book ⇛ *info-carrier*

book ● ⇝ *book*, *info-carrier* ●

Further examples [Babonnaud et al. 2016]

book $\Rightarrow$ *info-carrier*

book ● $\rightsquigarrow$ *book*, *info-carrier* ●

info-carrier $\Rightarrow$ *phys-obj* $\wedge$ CONTENT : *information*

Attribute-value constraints

Further examples

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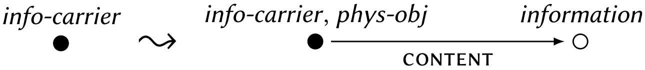

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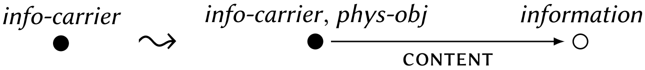

reading ⇛ PERC-COMP : *perception* ∧ MENT-COMP : *comprehension*
∧ [PERC-COMP, MENT-COMP] : *ordered-overlap*

Attribute-value constraints

Further examples

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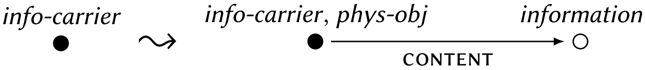
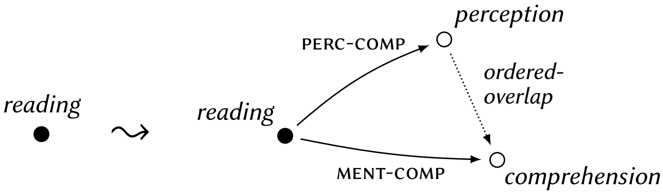


$$\mathit{reading} \Rrightarrow \textsc{perc-comp} : \mathit{perception} \wedge \textsc{ment-comp} : \mathit{comprehension}$$
$$\wedge \left[\textsc{perc-comp}, \textsc{ment-comp}\right] : \mathit{ordered\text{-}overlap}$$



Unification under constraints

Theorem (Frame unification under Horn constraints) [≈ Hegner 1994]

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Example

$$e \begin{bmatrix} \textit{eating} & \\ \textsc{actor} & x \\ \textsc{theme} & y \end{bmatrix} \sqcup \; u \begin{bmatrix} \textit{person} & \\ \textsc{name} & \text{‘Adam’} \end{bmatrix}$$

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A general view on semantic processing

Semantic processing as the **incremental construction** of **minimal** (**frame**) **models** (by unification under constraints) based on the input, the context, and background knowledge (lexicon, . . .).

Outline of today's course

1. Introduction to frame semantics
   - Frames in the sense of Fillmore and Barsalou
   - Frames according to this course
2. Formalization of frames
   - Attribute-value descriptions and formulas
   - Formal definition of frames
   - Frames as models
   - Subsumption and unification
   - Attribute-value constraints
3. Further topics
   - Frames versus feature structures
   - Type constraints versus type hierarchy
4. Frame semantics: extensions
5. Summary and outlook

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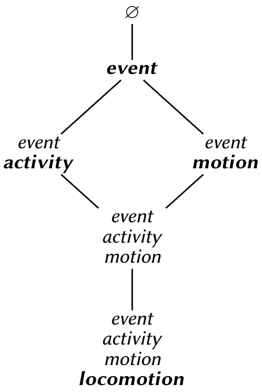

Outline of today's course

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3. Try to retain the idea of minimal model building and consider **frame types** as proper entities of the model/universe.

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Note: $\forall\phi\ \equiv\ \boldsymbol{\forall} x(x \cdot \phi),\quad \exists\phi\ \equiv\ \boldsymbol{\exists} x(x \cdot \phi)$ (with x not occurring in ϕ)

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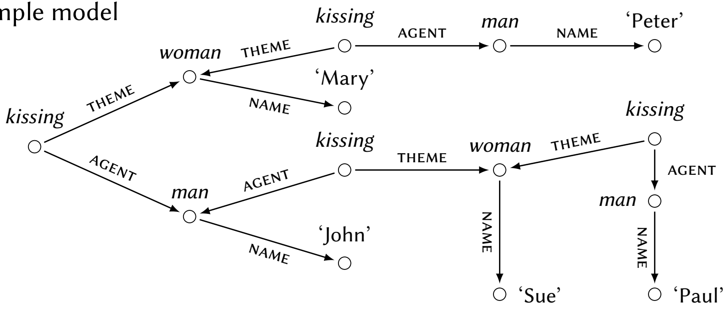

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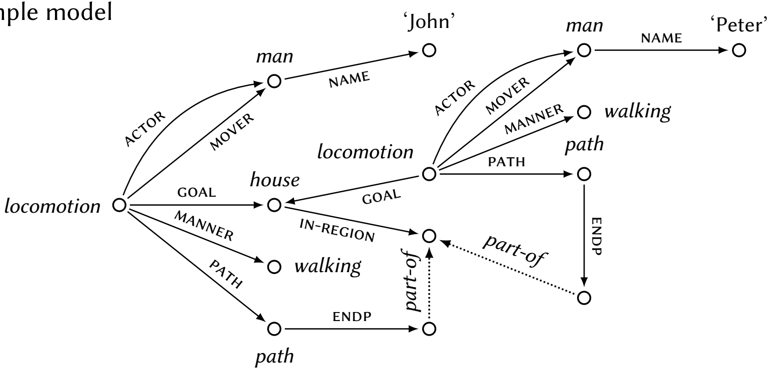

AV logic with quantifiers + underspecification ("hole semantics")

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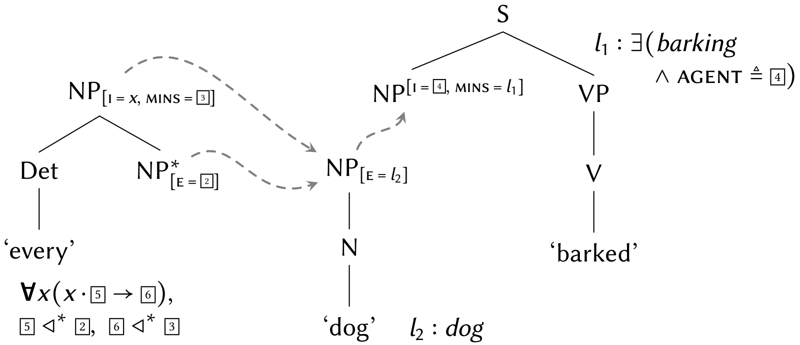

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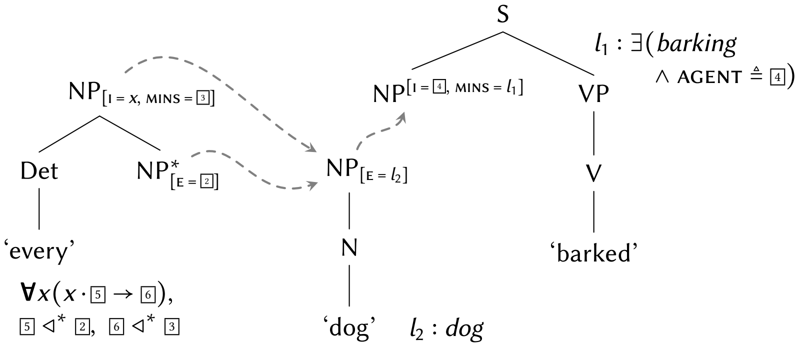

$\rightsquigarrow$ $\forall x(x \cdot \boxed{5} \rightarrow \boxed{6})$, $l_2 : dog$, $l_1 : \exists(barking \wedge \textsc{agent} \triangleq x)$, $\boxed{5} \lhd^* l_2$, $\boxed{6} \lhd^* l_1$

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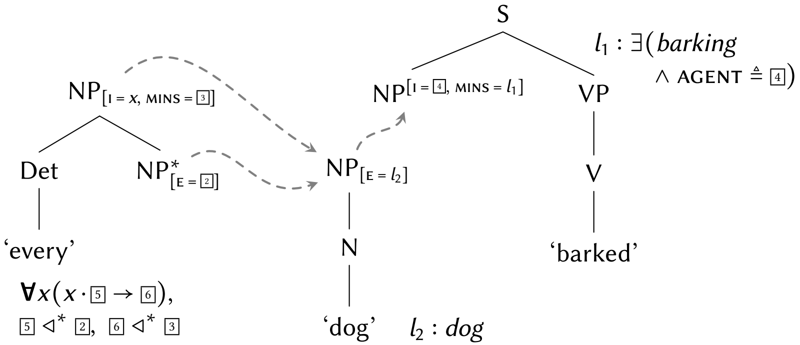

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Tomorrow

- Combining LTAG with frame semantics
- Elementary constructions as elementary trees with semantic frames
- Linguistic applications
- Looking ahead to the factorization of elementary constructions in the metagrammar.

References

Babonnaud, William, Laura Kallmeyer & Rainer Osswald. 2016. Polysemy and coercion – a frame-based approach using LTAG and Hybrid Logic. In Maxime Amblard, Philippe de Groote, Sylvain Pogodalla & Christian Retoré (eds.), **Logical Aspects of Computational Linguistics, 9th International Conference** Lecture Notes in Artificial Intelligence 10054, 18–33. Berlin: Springer.

Barsalou, Lawrence W. 1992. Frames, concepts, and conceptual fields. In Adrienne Lehrer & Eva Feder Kittay (eds.), **Frames, fields, and contrasts**, 21–74. Hillsdale, NJ: Lawrence Erlbaum Associates.

Carpenter, Bob. 1992. **The logic of typed feature structures** Cambridge Tracts in Theoretical Computer Science 32. Cambridge: Cambridge University Press.

Hegner, Stephen J. 1994. Properties of Horn clauses in feature-structure logic. In C. J. Rupp, Michael A. Rosner & Rod L. Johnson (eds.), **Constraints, language and computation**, 111–147. San Diego, CA: Academic Press.

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, .

Muskens, Rheinard. 2013. Data semantics and linguistic semantics. In Maria Aloni, Michael Franke & Floris Roelofsen (eds.), **The dynamic, inquisitive, and visionary life of ϕ, $?\phi$, and $\diamond\phi$. A festschrift for Jeroen Groenendijk, Martin Stokhof, and Frank Veltman**, 175–183.

Osswald, Rainer. 1999. Semantics for attribute-value theories. In Paul Dekker (ed.), **Proceedings of the twelfth amsterdam colloquium**, 199–204. Amsterdam: University of Amsterdam, ILLC.

References (cont.)

Osswald, Rainer & Robert D. Van Valin, Jr. 2014. FrameNet, frame structure, and the syntax-semantics interface. In Thomas Gamerschlag, Doris Gerland, Rainer Osswald & Wiebke Petersen (eds.), **Frames and concept types** (Studies in Linguistics and Philosophy 94), 125–156. Dordrecht: Springer.

Rappaport Hovav, Malka & Beth Levin. 1998. Building verb meanings. In Miriam Butt & Wilhelm Geuder (eds.), **The projection of arguments: Lexical and compositional factors**, 97–134. Stanford, CA: CSLI Publications.

Rounds, William C. 1997. Feature logics. In Johan van Benthem & Alice ter Meulen (eds.), **Handbook of logic and language**, 475–533. Amsterdam: North-Holland.