Semantic Modeling with Frames

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Introductory Course

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HEINRICH HEINE
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SFB 991

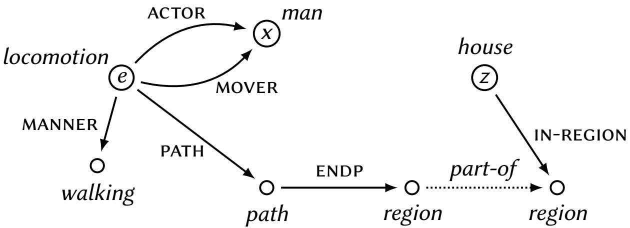
Part 2
Formal foundations

Topics

- Attribute-value descriptions and formulas
- Translation into predicate logic
- Formal definition of frames
- Frames as models
- Subsumption and unification
- Attribute-value constraints
- Frames versus feature structures
- Type constraints versus type hierarchy

Recap

Example



Ingredients

- Attributes (funct. relations): ACTOR, MOVER, PATH, MANNER, IN-REGION, …
- Type symbols: *locomotion*, *man*, *path*, *walking*, *region*, …
- Proper relation symbols: *part-of*
- Node labels (variables, constants): *e*, *x*, *z*

Core property

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

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			

Attribute-value descriptions

Vocabulary / Signature

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

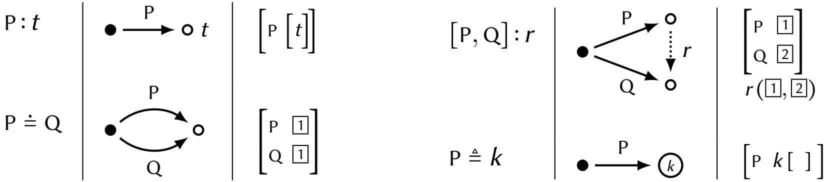
Nname, Nvar } Nlabel node labels

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



Translation into first-order predicate logic

Vocabulary / Signature

Attr	dyadic relation symbols (attributes)
Rel	relation symbols
Type	monadic predicates (type symbols)
Nname	constants (node names)
Nvar	variables

Important Functionality of attributes has to be enforced axiomatically!

Primitive attribute-value descriptions as predicates:

$p : t$	$\lambda x \exists y (p(x, y) \wedge t(y))$
$p \doteq q$	$\lambda x \exists y (p(x, y) \wedge q(x, y))$
$[p_1, \ldots, p_n] : r$	$\lambda x \exists y_1 \ldots \exists y_n (p_1(x, y_1) \wedge \cdots \wedge p_n(x, y_n) \wedge r(y_1, \ldots, y_n))$
$p \triangleq k$	$\lambda x (p(x, k))$

Attribute-value formulas

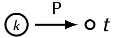
Primitive attribute-value formulas (pAVForm)

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

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

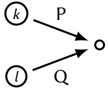
Semantics

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



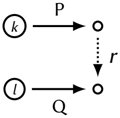
$k\left[\mathrm{P}\;\left[t\right]\right]$

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



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

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



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

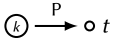
Primitive attribute-value formulas (pAVForm)

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

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

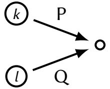
Semantics

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



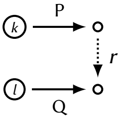
$k \Big[\mathrm{P}\ [t] \Big]$

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



$k \Big[\mathrm{P}\ \boxed{1} \Big]$
$l \Big[\mathrm{Q}\ \boxed{1} \Big]$

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



$k \Big[\mathrm{P}\ \boxed{1} \Big]$
$l \Big[\mathrm{Q}\ \boxed{2} \Big]$
$r(\boxed{1}, \boxed{2})$

Formal definitions (fairly standard)

Set/universe of "nodes" V

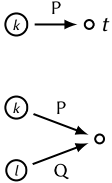
Primitive attribute-value formulas (pAVForm)

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

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

Semantics

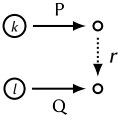
$k \cdot \mathrm{P} : t$ | $k \cdot \mathrm{P} \triangleq l \cdot \mathrm{Q}$



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

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

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



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

Formal definitions (fairly standard)

Set/universe of "nodes" V

Interpretation function $\mathcal{I} : \mathrm{Attr} \to [V \rightharpoonup V]$,

Attribute-value formulas

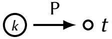
Primitive attribute-value formulas (pAVForm)

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

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

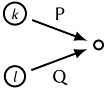
Semantics

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



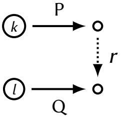
$k \left[\mathrm{P} \; \left[t \right] \right]$

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



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

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



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

Formal definitions (fairly standard)

Set/universe of "nodes" V

Interpretation function $\mathcal{I}$: Attr $\rightarrow [V \rightharpoonup V]$, Type $\rightarrow \wp(V)$,

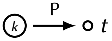
Primitive attribute-value formulas (pAVForm)

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

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

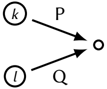
Semantics

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



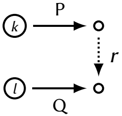
$k\left[\mathrm{P}\ \left[t\right]\right]$

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



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

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



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

Formal definitions (fairly standard)

Set/universe of "nodes" $\quad V$

Interpretation function $\quad \mathcal{I} : \mathrm{Attr} \to [V \rightharpoonup V], \ \ \mathrm{Type} \to \wp(V),$
$\quad \mathrm{Rel} \to \bigcup_n \wp(V^n),$

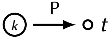
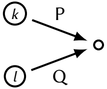
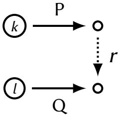
Attribute-value formulas

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, $p, q, p_i \in \text{Attr}^*$, $k, l, k_i \in$ Nlabel)

Semantics

$k \cdot \mathrm{P} : t$		$k\left[\mathrm{P}\ [t]\right]$
$k \cdot \mathrm{P} \triangleq l \cdot \mathrm{Q}$		$k\left[\mathrm{P}\ \boxed{1}\right]$ $l\left[\mathrm{Q}\ \boxed{1}\right]$
$\langle k \cdot \mathrm{P}, l \cdot \mathrm{Q} \rangle : r$		$k\left[\mathrm{P}\ \boxed{1}\right]$ $l\left[\mathrm{Q}\ \boxed{2}\right]$ $r(\boxed{1}, \boxed{2})$

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 $\to V$

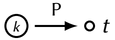
Primitive attribute-value formulas (pAVForm)

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

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

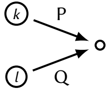
Semantics

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



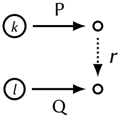
$k\left[\text{P}\left[t\right]\right]$

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



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

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



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

Formal definitions (fairly standard)

Set/universe of "nodes" V

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

(Partial) variable assignment g : 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**

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

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

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
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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 $\mathcal{I}(p)(v) = \mathcal{I}(q)(v)$

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
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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 $\langle \mathcal{I}(p_1)(v), \ldots, \mathcal{I}(p_n)(v) \rangle \in \mathcal{I}(r)$

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)

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**

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

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**

$\langle V, \mathcal{I}, g \rangle, v \models t$ 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 primitive **formulas**

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

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

$\langle V, \mathcal{I}, g \rangle \models \langle k_1 \cdot p_1, \ldots, k_n \cdot p_n \rangle : r$ 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 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**

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

Satisfaction of **Boolean combinations** as usual.

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,

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

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Frame F over ⟨Attr, Type, Rel, Nname, Nvar⟩:

$F = \langle V, \mathcal{I}, g \rangle$, 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.,

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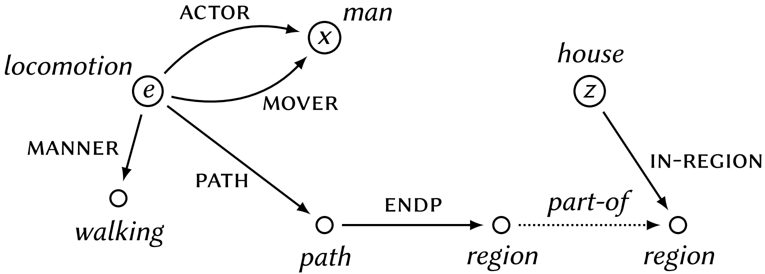
Example



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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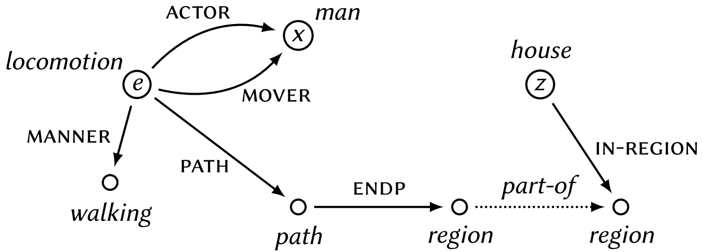

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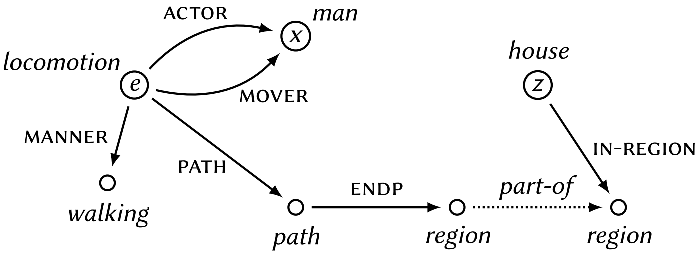

$F \vDash$

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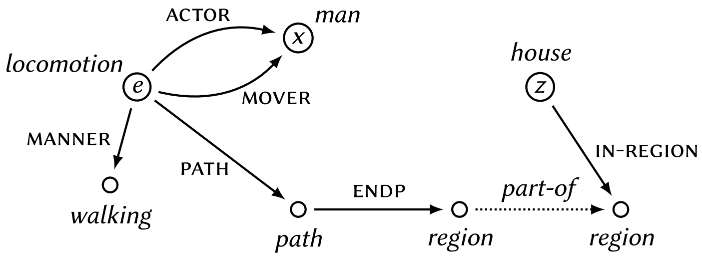
$F =$ 

$F \vDash e \cdot locomotion$

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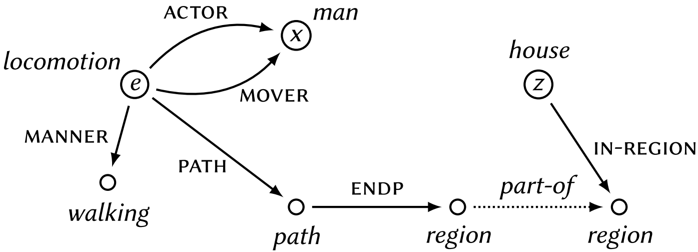

$F \vDash e \cdot locomotion$

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

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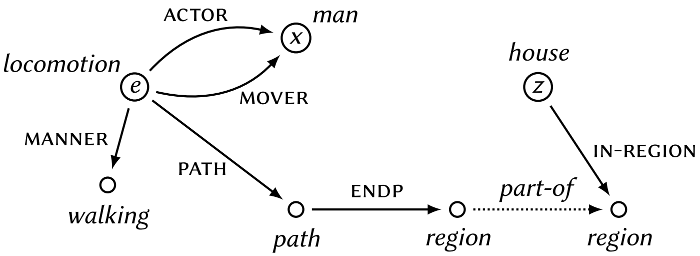

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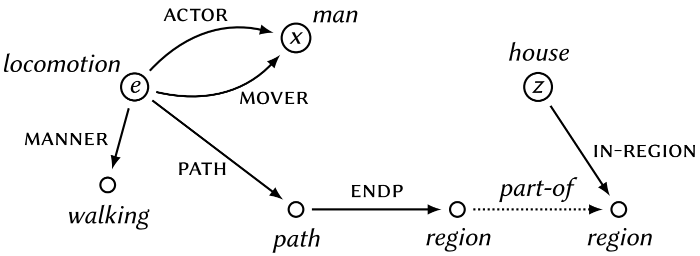

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$F \vDash x \cdot man$

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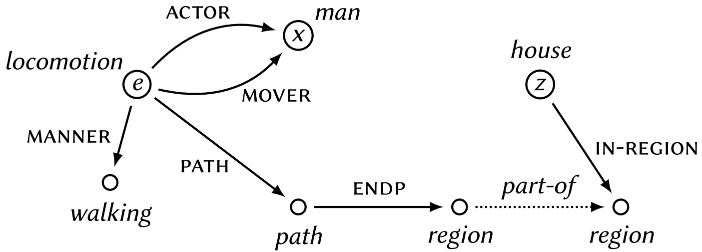
$F =$ 

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

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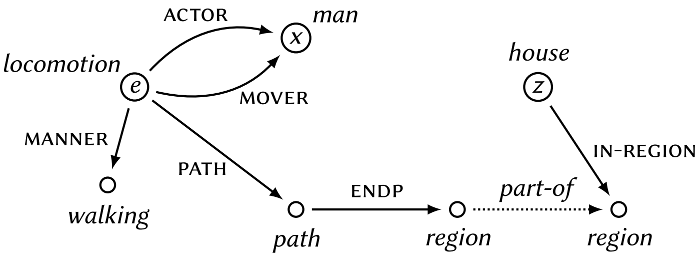

$F \vDash e \cdot \textit{locomotion}$

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

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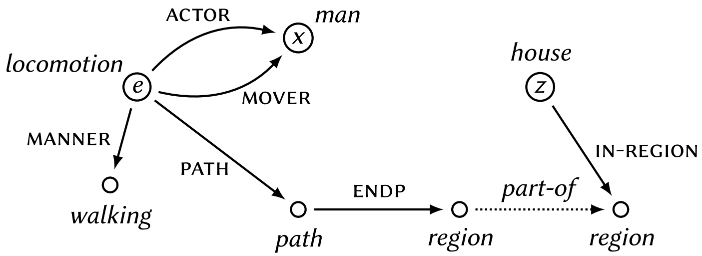
$F =$ 

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

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** $h : F_1 \rightarrow F_2$, i.e., a function $h : V_1 \rightarrow V_2$ such that

(i) $\mathcal{I}_2(f)(h(v)) = h(\mathcal{I}_1(f)(v))$, if $\mathcal{I}_1(f)(v)$ is defined, $f \in$ Attr, $v \in V_1$,

(ii) $h(\mathcal{I}_1(t)) \subseteq \mathcal{I}_2(t)$, for $t \in$ Type

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(iv) $h(\mathcal{I}_1(n)) = \mathcal{I}_2(n)$, for $n \in$ Nname

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Subsumption and unification

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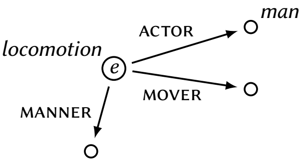

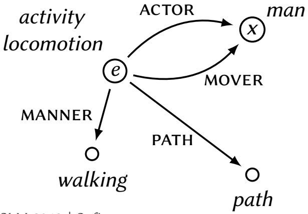

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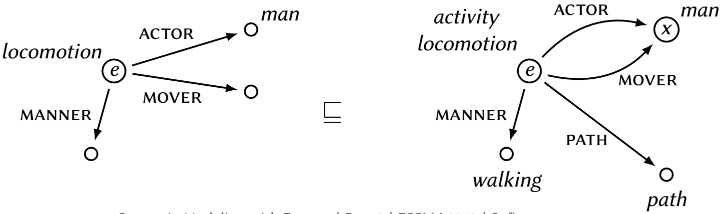

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Intuition

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

Subsumption and unification

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Unification

Least upper bound $F_1 \sqcup F_2$ of F_1 and F_2 w.r.t. subsumption (if existent).

Subsumption and unification

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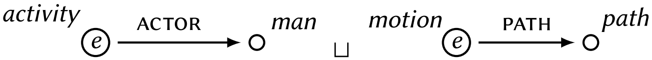
Theorem (Frame unification) [≈ Hegner 1994]

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

Subsumption and unification

Examples



Subsumption and unification

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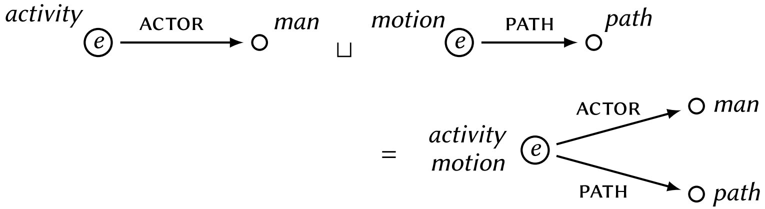

Subsumption and unification

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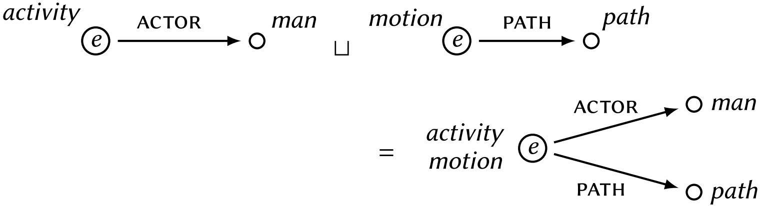

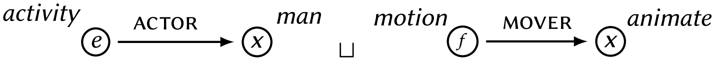

Subsumption and unification

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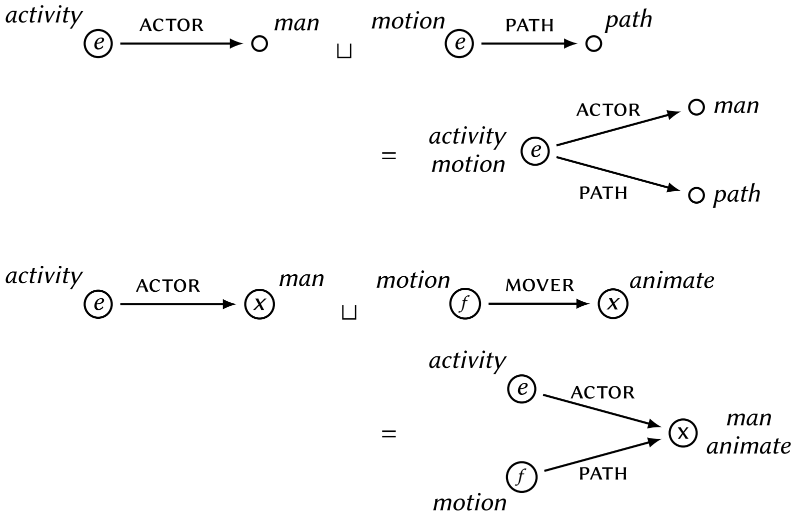

Frames as minimal models

Frames as minimal models of attribute-value formulas

(i) Every frame is the minimal model (w.r.t. subsumption) of a finite conjunction of primitive attribute-value formulas.

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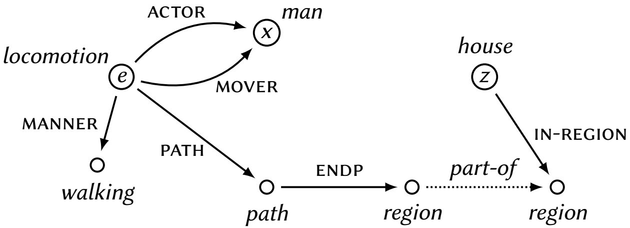

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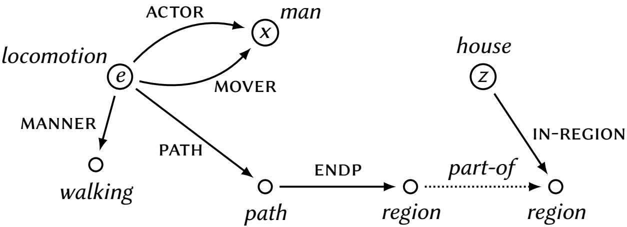

$$e \cdot (\mathit{locomotion} \;\wedge\; \textsc{manner} : \mathit{walking} \;\wedge\; \textsc{actor} \triangleq x$$
$$\wedge\; \textsc{mover} \doteq \textsc{actor} \;\wedge\; \textsc{path} : (\mathit{path} \;\wedge\; \textsc{endp} : \mathit{region}))$$
$$\wedge\; \langle e \cdot \textsc{path endp},\; z \cdot \textsc{in-region} \rangle : \mathit{part\text{-}of} \;\wedge\; x \cdot \mathit{man}$$

Attribute-value constraints

Constraints (general format) $\forall\phi$, with $\phi \in$ AVDesc

$\langle V, \mathcal{I}, g\rangle \vDash \forall\phi$ iff $\langle V, \mathcal{I}, g\rangle, v \vDash \phi$ for every $v \in V$

Notation:

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

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Horn constraints:

$\phi_1 \wedge \ldots \wedge \phi_n \Rrightarrow \psi \qquad (\phi_i \in \text{pAVDesc} \cup \{\top\},\ \psi \in \text{pAVDesc} \cup \{\bot\})$

Examples

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

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

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

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

$\textit{activity} \wedge \textit{motion} \Rrightarrow \text{ACTOR} \doteq \text{MOVER}$

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Examples

$\mathit{activity} \Rrightarrow \mathit{event}$ (every activity is an event)

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

$\textsc{agent} : \top \Rrightarrow \textsc{agent} \doteq \textsc{actor}$

$\mathit{activity} \Rrightarrow \textsc{actor} : \top$

$\mathit{activity} \wedge \mathit{motion} \Rrightarrow \textsc{actor} \doteq \textsc{mover}$

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Examples

$\textit{activity} \Rrightarrow \textit{event}$ (every activity is an event)

$\textit{causation} \wedge \textit{activity} \Rrightarrow \bot$ (there is nothing which is both a causation and an activity)

$\textsc{agent} : \top \Rrightarrow \textsc{agent} \doteq \textsc{actor}$

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$\textit{activity} \Rrightarrow \textit{event}$	(every activity is an event)
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$\text{AGENT} : \top \Rrightarrow \text{AGENT} \doteq \text{ACTOR}$	(every agent is also an actor)
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Attribute-value constraints

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

$\langle V, \mathcal{I}, g \rangle \vDash \forall\phi$ iff $\langle V, \mathcal{I}, g \rangle, v \vDash \phi$ for every $v \in V$

Notation:

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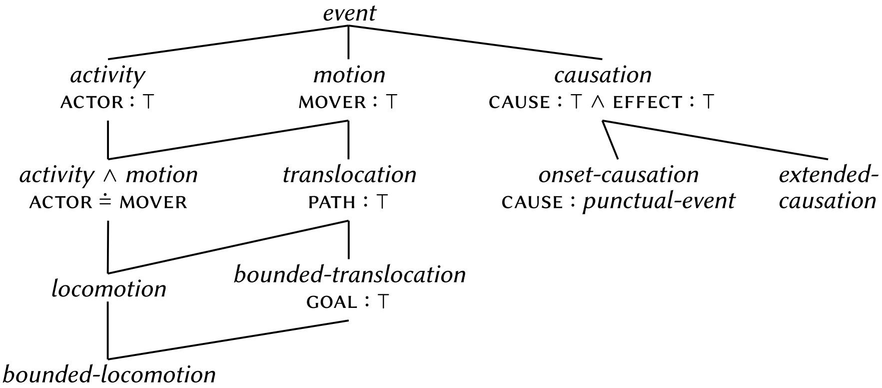
Attribute-value constraints

Possible graphical presentation of constraints



Caveat: Reading convention required !

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Proposition Given a frame F and a finite set of Horn formulas, then there is a unique least specific frame F' extending F that satisfies the given formulas (if satisfiable at all), and F' can be constructed in almost linear time.

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Theorem (Frame unification under Horn constraints) [≈ Hegner 1994]
The worst case time-complexity of frame unification under a finite set of Horn formulas is almost linear in the number of nodes.

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Digression: 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, …).

Frames versus feature structures

[→ Carpenter 1992, Rounds 1997, and many others]

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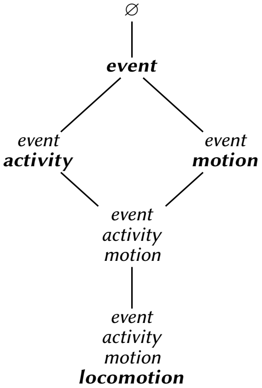

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Next topic

- Combining frame semantics with Lexicalized Tree Adjoining Grammars (LTAG)
- Elementary constructions as elementary trees with semantic frames
- Linguistic applications
- Brief outlook: factorization of elementary constructions in the metagrammar.