Semantic Modeling with Frames

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ESSLLI 2018

Introductory Course

Sofia University

06. 08. – 10. 08. 2018

HEINRICH HEINE
UNIVERSITÄT DÜSSELDORF

SFB 991

Part 1

History, motivation, overview

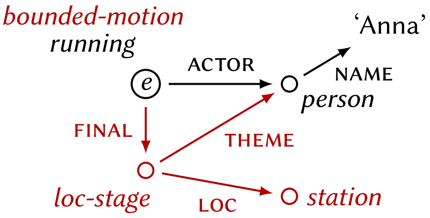
What this course is about

Overall goal

- A proposal of doing formal cognitive semantics by means of frame-based representations

A simple illustration

(1) Anna ran to the station.



Issues

- Formal definition, relation to more standard logical approaches
- Compositional derivation at the syntax-semantics interface
- Application to a wide range of semantic phenomena

Course overview

- Frames in semantics, cognitive science and AI (Fillmore, Barsalou, Minsky, …) — frames as a tool for doing formal cognitive semantics
- Basic definitions of frames and frame descriptions (model, satisfaction, …) — subsumption and unification — relation to first order predicate logic
- Frame semantics + Lexicalized Tree Adjoining Grammars as a model of the syntax-semantics interface — applications to a number of constructions
- Possible extensions of the basic formal framework (collections, quantification, …).
- Further applications: polysemy and coercion phenomena — semantic shifts — dynamics of events and interpretations

Frames in Artificial Intelligence

M. Minsky (1974): *A Framework for Representing Knowledge*

> "A **frame** is a data-structure for representing a stereotyped situation, like being in a certain kind of living room, or going to a child's birthday party. Attached to each frame are several kinds of information. Some of this information is about how to use the frame. Some is about what one can expect to happen next. Some is about what to do if these expectations are not confirmed."

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"We can think of a frame as a **network of nodes and relations**. The "top levels" of a frame are fixed, and represent things that are always true about the supposed situation. The lower levels have many terminals – "slots" that must be filled by specific instances or data."

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M. Minsky (1986): *The Society of Mind*

"The essay [entitled "A Framework for Representing Knowledge"] influenced the next decade of research on Artificial Intelligence, despite the fact that most readers complained that **its explanations were too vague**."

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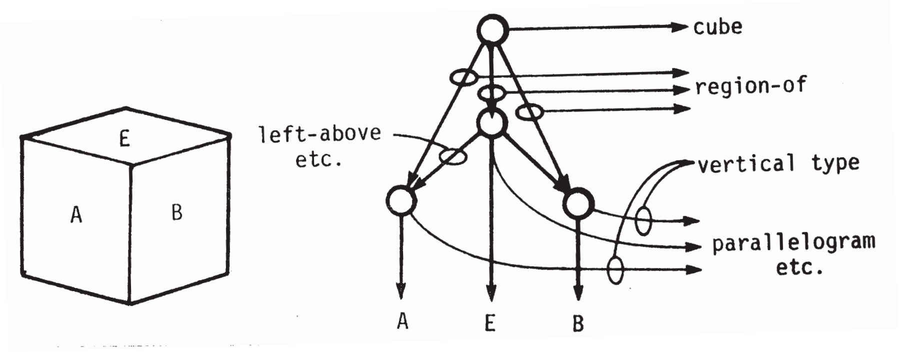
M. Minsky (1974): *A Framework for Representing Knowledge*

Example

"A simplified frame-system to represent the perspective appearances of a cube"



Frames in Artificial Intelligence

Representation frameworks (*inter alia*)

- FRL (Frame Representation Language; Roberts & Goldstein 1977)
- KL-ONE (Brachman & Schmolze 1985; developed since ≈ 1977)
- F-Logic (Frame Logic; Kifer, Lausen & Wu 1995)
- Description Logics, Feature Logics, …

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$$\mathit{barking} \sqsubseteq \exists\, \mathit{actor} \,.\, \mathit{canine} \qquad \text{(Description Logics)}$$

$$\forall e(\mathit{barking}(e) \rightarrow \exists x(\mathit{actor}(e,x) \wedge \mathit{canine}(x)) \qquad \text{(FOPL)}$$

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Every barking has a canine actor. || An/the actor of a barking is canine.

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Example

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$\forall e(barking(e) \rightarrow \exists x(actor(e, x) \wedge canine(x)))$ (FOPL)

Every barking has a canine actor. || An/the actor of a barking is canine.

$barking \Rrightarrow \textsc{actor} : canine$ (Feature Logics)

$canine \Rrightarrow \neg\, feline$

FrameNet frames

Frames according to C. Fillmore (C. Fillmore 1982: *Frame semantics*)

"**Frame semantics** comes out of traditions of **empirical semantics** rather than formal semantics. […]
A frame semantics outlook is **not** (or is not necessarily) **incompatible with** work and results in **formal semantics**; but it differs importantly from formal semantics in emphasizing the continuities between language and experience."
[Fillmore 1982: 111]

"The word **frame** in this context is used to refer to a **schematic representation of speakers' knowledge** of the situations or states of affair that underlie the **meanings of lexical items**." [Fillmore 2007: 130]

"In Frame Semantics, the meaning dimension is expressed in terms of the **cognitive structures** (**frames**) that shape speakers' understanding of linguistic expressions." [Fillmore/Baker 2010: 317]

FrameNet frames

The FrameNet project

[framenet.icsi.berkeley.edu]

"The FrameNet project is dedicated to producing **valency descriptions** of **frame-bearing lexical units** (LUs), in both **semantic** and **syntactic** terms,

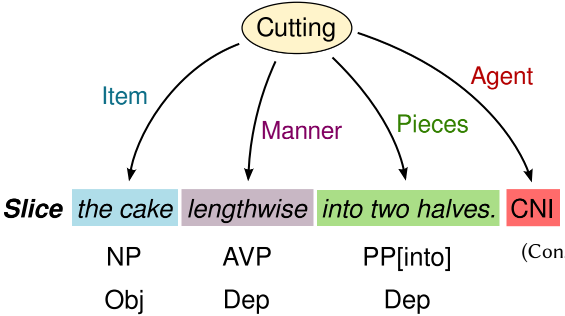
and it bases this work on **attestations of word usage** taken from a very large digital **corpus**.

The semantic descriptors of each valency pattern are taken from **frame-specific semantic role names** (called **frame elements**),

and the syntactic terms are taken from a restricted set of grammatical function names and a detailed set of phrase types." [Fillmore 2007: 130]

FrameNet frames

Example The 'Cutting' frame, annotated: [framenet.icsi.berkeley.edu]



(Constructional Null Instantiation)

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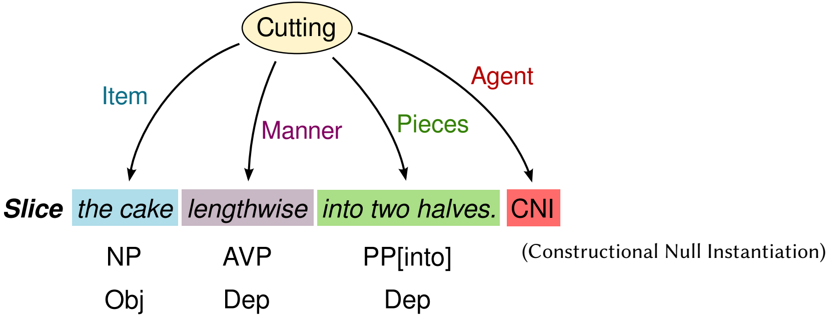


The FrameNet database:

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

FrameNet frames

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*

[framenet.icsi.berkeley.edu]

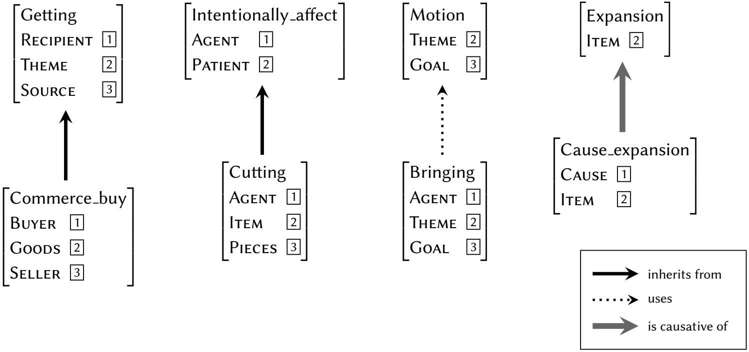
FrameNet frames

Frame-to-frame relations

[framenet.icsi.berkeley.edu]

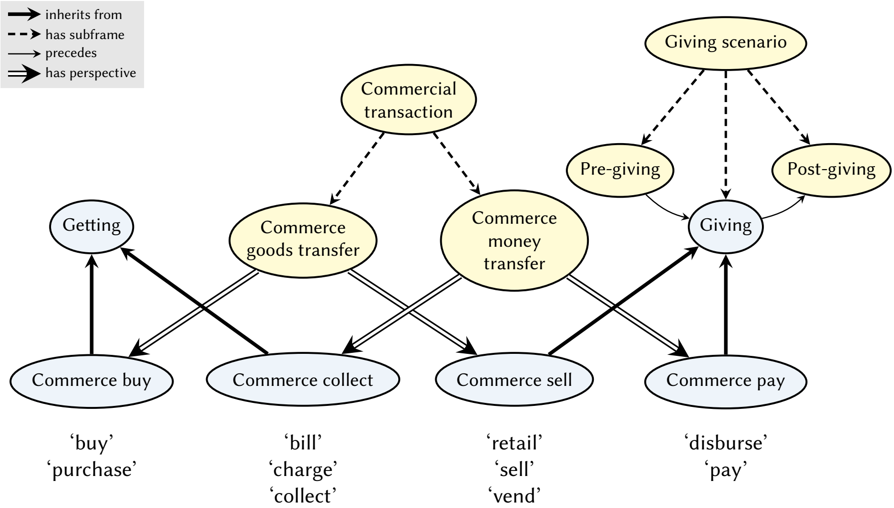
- Generalization relations: ‘inherits from’, ‘is perspective on’, ‘uses’
- Event structure relations: ‘is subframe of’, ‘precedes’
- Systematic relations: ‘is causative of’, ‘is inchoative of’

Examples



FrameNet frames

Example: Commercial transaction



[Fillmore/Baker 2010]

“Barsalou frames”

L. Barsalou (1992): *Frames, concepts, and conceptual fields*

“I propose that **frames** provide the **fundamental representation of knowledge** in **human cognition**.”

“[…] frame theorists generally assume that frames are rigid configurations of independent attributes, whereas I propose that frames are **dynamic relational structures** whose form is flexible and **context dependent**.” [Barsalou 1992: 21]

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S. Löbner (2014): *Evidence for Frames from Human Language*

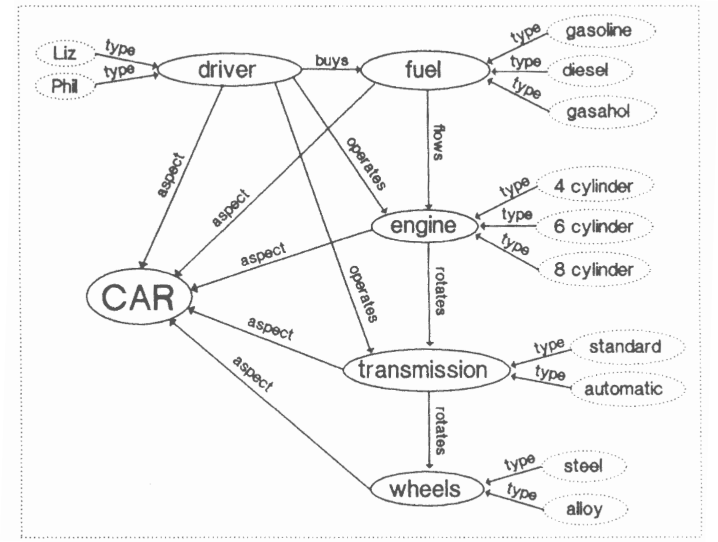
“Frame Hypothesis”

1. “The human cognitive system operates with a single general format of representations.”
2. “If the human cognitive system operates with one general format of representations, this format is essentially Barsalou frames.”

[Löbner 2014: 23f]

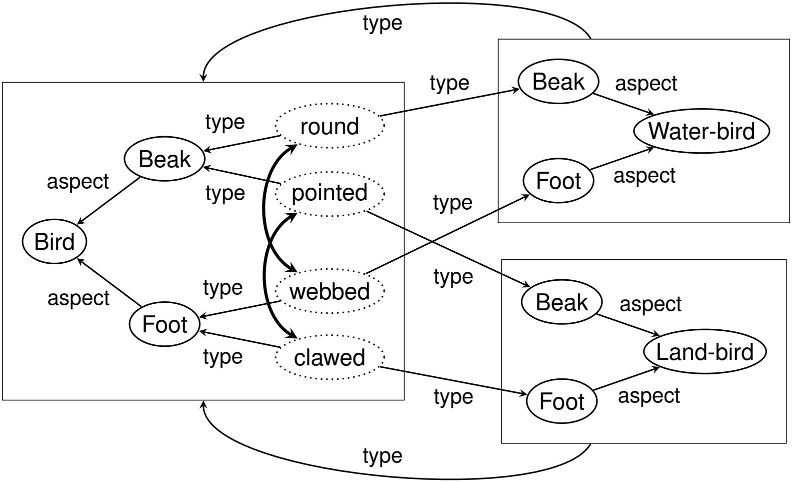
“Barsalou frames”

Example A partial frame for *car* [Barsalou 1992:30]



"Barsalou frames"

Example J. Ray's taxonomy of birds [Gamerschlag et al. 2014:6]



Frames and attributes

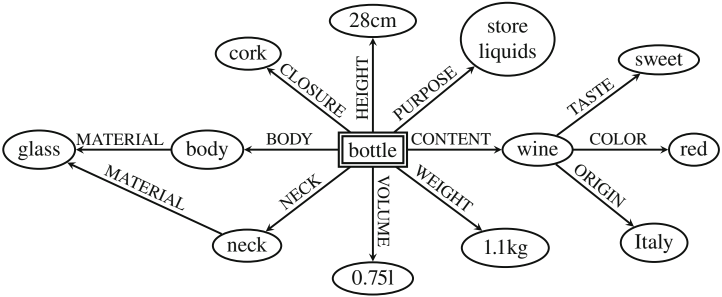
Kinds of attributes

[cf. Löbner 2014: 57]

- VOLUME, HEIGHT, WEIGHT: "dimensions" which assign an abstract value
- BODY, NECK (mereological attributes): constituent parts
- CONTENT, CLOSURE: functionally associated but independent entities
- PURPOSE: ≈ telic qualia, …

Example

[Gamerschlag/Gerland/Osswald/Petersen 2014: 9]



Frames according to this course

General properties

- 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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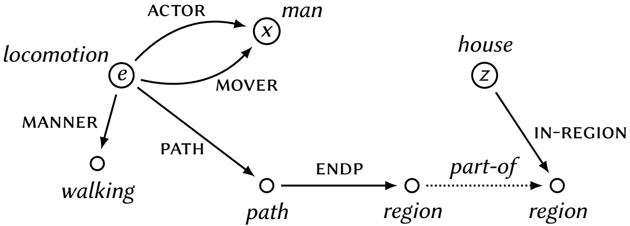
Basic assumptions

- **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.

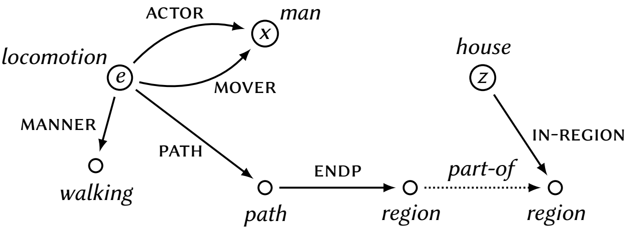
  $\rightsquigarrow$ inherently **structured representations** (models); composition by **unification** (under **constraints**)

Example


ACTOR
man
x
locomotion
e
MOVER
house
z
MANNER
IN-REGION
PATH
ENDP
part-of
walking
path
region
region

Frames according to this course

Example

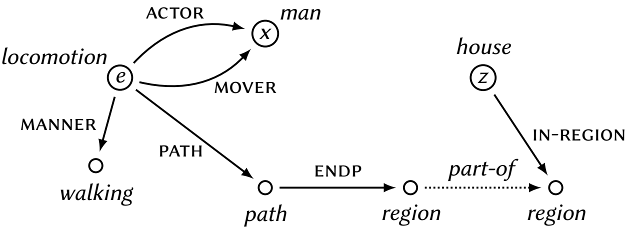


Ingredients

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

Frames according to this course

Example



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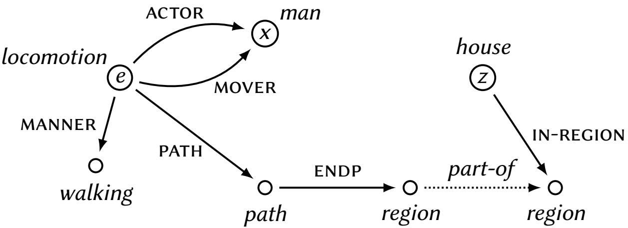

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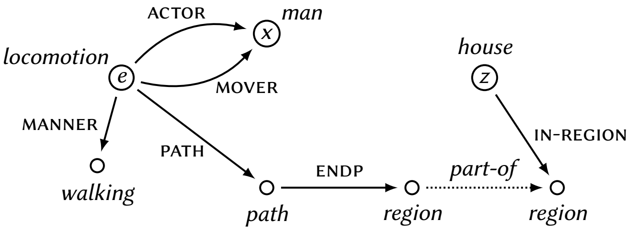

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- Node labels (variables, constants): e, x, z

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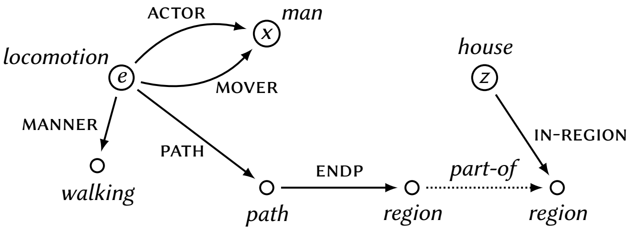

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Core property

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

Examples and preview

Example Lexical decomposition templates [Rappaport Hovav/Levin 1998]

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

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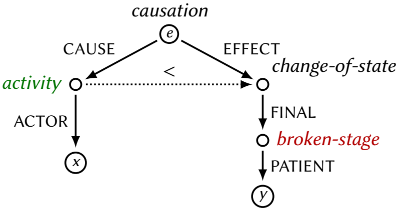

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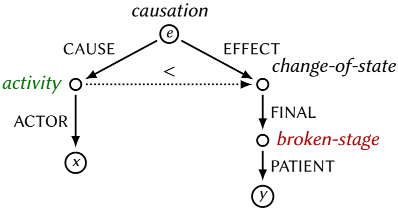

$$e\begin{bmatrix} \textit{causation} & \\ \text{CAUSE} & \begin{bmatrix} \textit{activity} & \\ \text{EFFECTOR} & x \end{bmatrix} \\ \text{EFFECT} & \begin{bmatrix} \textit{change-of-state} & \\ \text{FINAL} & \begin{bmatrix} \textit{broke-stage} & \\ \text{PATIENT} & y \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

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

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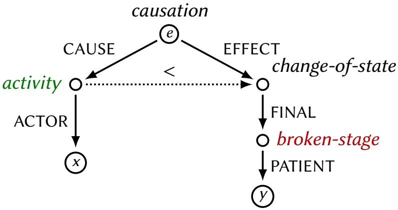

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$$\text{CAUSE} < \text{EFFECT}$$

Description in attribute-value logic

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

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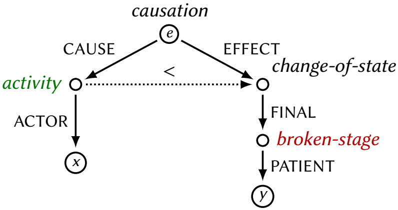

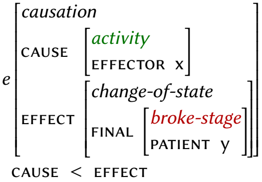

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$$\wedge\ \textsc{effect}\,(\textit{change-of-state} \wedge \textsc{final} : (\textit{broken-stage} \wedge \textsc{patient} \triangleq y))$$
$$\wedge\ \textsc{cause} < \textsc{effect})$$

Translation into first-order logic

$$\exists e' \exists e'' \exists s(\textit{causation}(e) \wedge \textsc{cause}(e, e') \wedge \textsc{effect}(e, e'') \wedge e' < e'' \wedge$$
$$\textit{activity}(e') \wedge \textsc{actor}(e', x) \wedge \textit{change-of-state}(e'') \wedge$$
$$\textsc{final}(e'', s) \wedge \textit{broken-stage}(s) \wedge \textsc{patient}(s, y))$$

Examples and preview

Example

(3) Anna ran

Examples and preview

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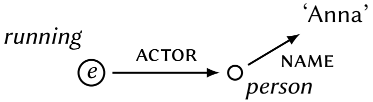
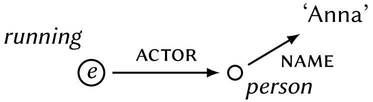


Examples and preview

Example

(3) Anna ran to the station.



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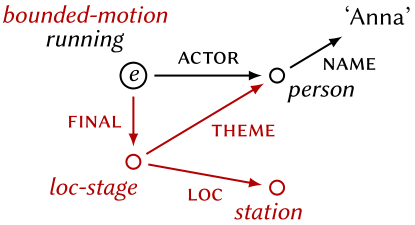

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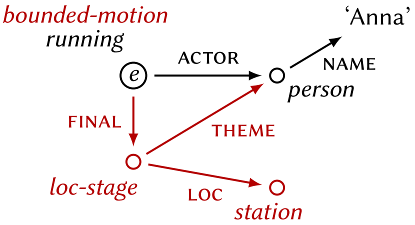

$$e\begin{bmatrix} \textit{running} \wedge \textit{bounded-motion} \\ \textsc{actor}\ \boxed{1}\begin{bmatrix} \textit{person} \\ \textsc{name}\ \text{`Anna'} \end{bmatrix} \\ \textsc{final}\ \begin{bmatrix} \textit{loc-stage} \\ \textsc{theme}\ \boxed{1} \\ \textsc{loc}\ [\textit{station}] \end{bmatrix} \end{bmatrix}$$

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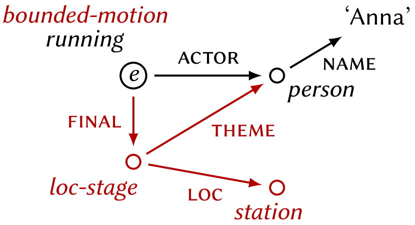

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Attribute-value logic

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

Example

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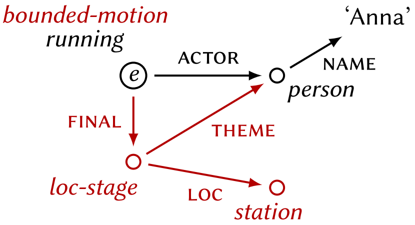

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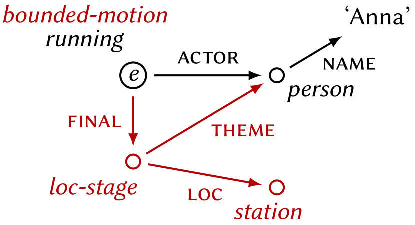
$$e \cdot (\mathit{running} \wedge \mathit{bounded\text{-}motion} \wedge \text{ACTOR} : (\mathit{person} \wedge \text{NAME} \triangleq \text{‘Anna’}) \\ \text{ACTOR} \doteq \text{FINAL THEME} \wedge \text{FINAL} : (\mathit{loc\text{-}stage} \wedge \text{LOC} : \mathit{station}))$$

Translation into first-order logic

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

Example

(3) Anna ran to the station.



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

Attribute-value logic

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

Constraints

$\textit{running} \Rrightarrow \textit{activity}$ (short for $\forall e(\textit{running}(e) \rightarrow \textit{activity}(e))$),

$\textit{loc-stage} \Rrightarrow \text{THEME} : \top \wedge \text{LOC} : \top, \ \ldots$

Some pros and cons of frame-based representations

Pros

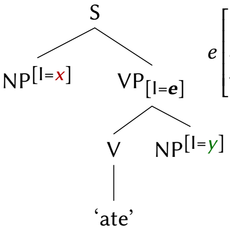
- **Concept-/object-oriented** representations are inherently supported.
- **Unification** of frames is **tractable** and straightforward.
- Attribute-based representations seem to be **cognitively adequate**.

Cons

- Proper, **non-functional relations** can represented but do not have a primary status.
- It is not straightforward how to represent **quantification**, **negation**, etc.

Example

(4) Adam ate an apple.

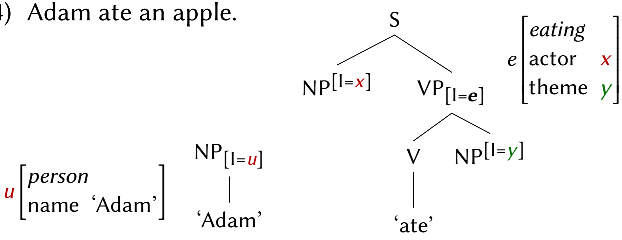


$$e\begin{bmatrix} \textit{eating} & \\ \text{actor} & x \\ \text{theme} & y \end{bmatrix}$$

Preview of the syntax-semantics interface

Example

(4) Adam ate an apple.



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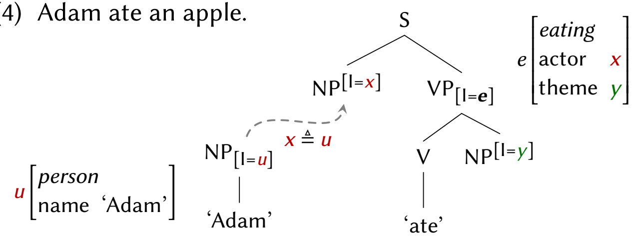

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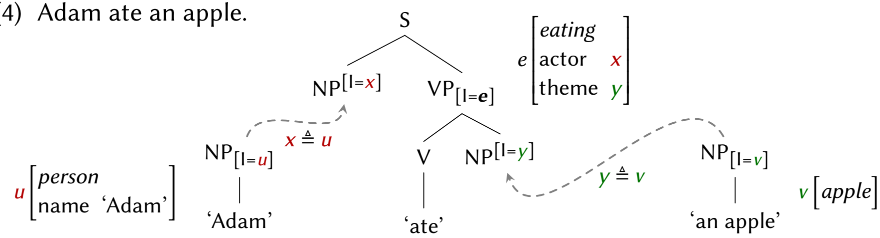

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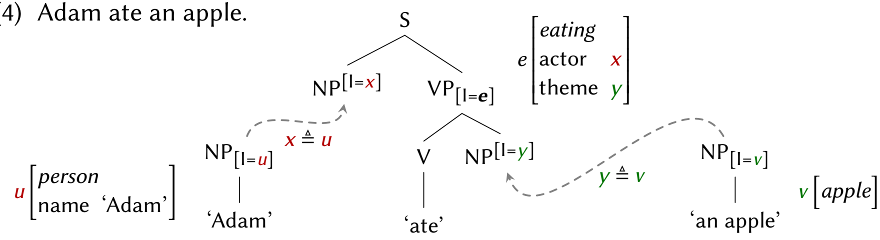

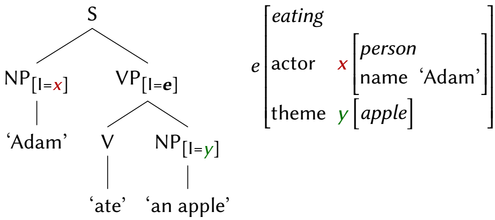

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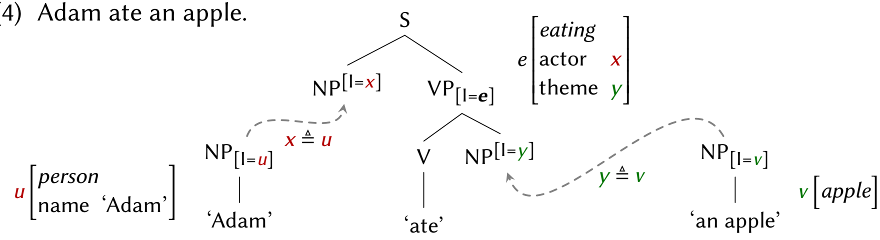
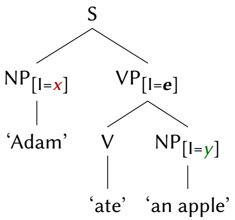
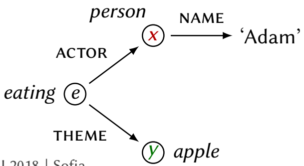




$$e\begin{bmatrix} \textit{eating} & & \\ \text{actor} & x & \begin{bmatrix} \textit{person} & \\ \text{name} & \text{`Adam'} \end{bmatrix} \\ \text{theme} & y & \begin{bmatrix} \textit{apple} \end{bmatrix} \end{bmatrix}$$



Preview of the syntax-semantics interface

Core components

- **Elementary construction**

  = elementary tree (argument projection) + semantic frame
  + linking of frame node variables to interface features in the tree

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- Semantic **composition** $\approx$ frame unification via identification of interface variables during substitution and adjunction.