Conceptual Fingerprints: Lexical Decomposition by Means of Frames – a Neuro-cognitive Model

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Forschergruppe Funktionalbegriffe und Frames (FOR 600)

classifying concepts

person, pope, house, verb, sun, Mary, wood, brother, mother, meaning, distance, spouse, argument, entrance

classifying concepts: arity

arity:1	person, pope, house, verb, sun, Mary, wood
arity:>1	brother, mother, meaning, distance, spouse, argument, entrance

classifying concepts: uniqueness of reference

	no unique reference	unique reference
arity:1	person, house, verb, wood	Mary, pope, sun
arity:>1	brother, argument, entrance	mother, meaning, distance, spouse

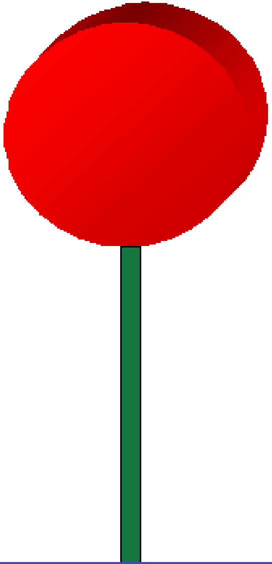
concept types (Löbner)

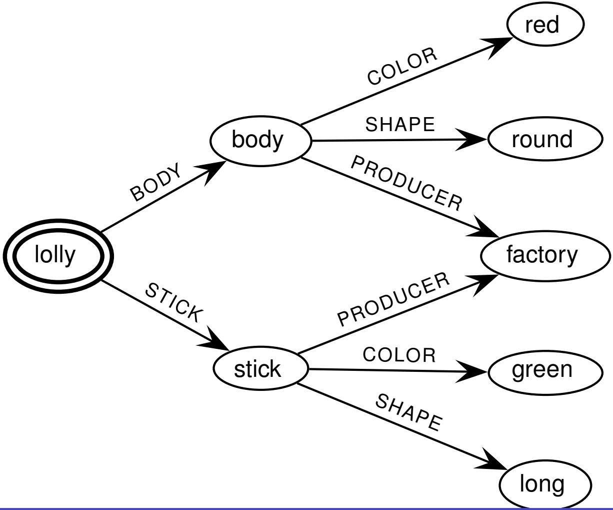
	no unique reference	unique reference	
arity:1	person, house, verb, wood	Mary, pope, sun	
arity:>1	brother, argument, entrance	mother, meaning, distance, spouse	**relational**
		identificational	

concept types (Löbner)

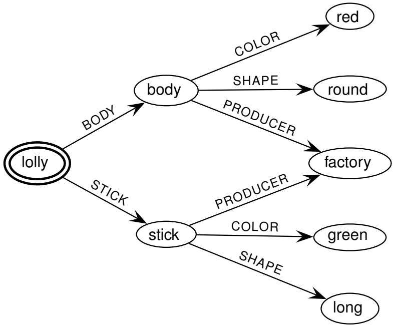
SC: sortal concept INDEFINITE person, house, verb, wood	**IC: individual concept** DEFINITE Mary, pope, sun
RC: (proper) relational concept INDEFINITE + POSSESSIVE brother, argument, entrance	**FC: functional concept** DEFINITE + POSSESSIVE mother, meaning, distance, spouse

lolly-frame (sortal concept)





sortal-frame definition

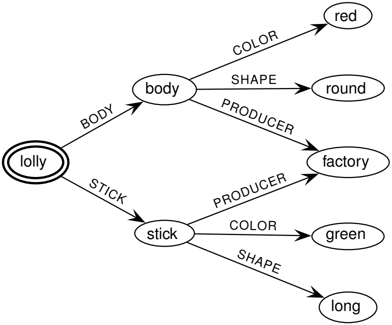


Definition

Sortal frames are rooted connected, directed acyclic graphs with

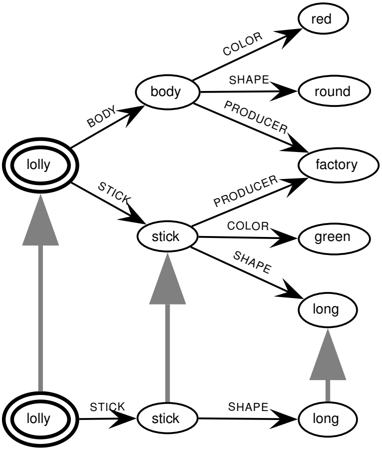
- one central node (= root node)
- nodes labeled with types
- edges labeled with attributes
- no node with two equally labeled outgoing edges

AVM-abstraction of sortal frames



$$\left[\begin{array}{ll} \text{BODY}: & \left[\begin{array}{ll} \text{COLOR}: & \text{red} \\ \text{SHAPE}: & \text{round} \\ \text{PRODUCER}: & \boxed{1}\ \text{factory} \end{array}\right]_{\textit{body}} \\ \text{STICK}: & \left[\begin{array}{ll} \text{COLOR}: & \text{green} \\ \text{SHAPE}: & \text{long} \\ \text{PRODUCER}: & \boxed{1}\ \text{factory} \end{array}\right]_{\textit{stick}} \end{array}\right]_{\textit{lolly}}$$

subsumption



$$\left[\text{STICK}:\ \left[\text{SHAPE}:\ \text{long}\right]_{\mathit{stick}}\right]_{\mathit{lolly}} \sqsubseteq$$

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attributes in frames

Barsalou, 1992: *Frames, Concepts, and Conceptual Fields*

"I define an attribute as a **concept** that describes an aspect of at least some category member."
"Values are subordinate concepts of an attribute."

Guarino, 1992: *Concepts, attributes and arbitrary relations*

"We define attributes as **concepts** having an associate relational interpretation, allowing them to act as conceptual components as well as concepts on their own."

interpretation of functional concepts

denotational interpretation

A functional concept denotes a set of entities:

$$\delta : \mathcal{R} \to 2^{\mathcal{U}}$$

$\delta(\text{mother}) = \{m \mid m \text{ is the mother of someone}\}$

relational interpretation

A functional concept has also a relational interpretation:

$$\varrho : \mathcal{R} \to 2^{\mathcal{U} \times \mathcal{U}}$$

$\varrho(\text{mother}) = \{(p, m) \mid m \text{ is the mother of } p\}$

consistency postulate (Guarino, 1992)

Any value of an relationally interpreted functional concept is also an instance of the denotation of that concept.

If $(p, m) \in \varrho(\text{mother})$, then $m \in \delta(\text{mother})$.

attributes in frames

thesis:

Attributes in frames are relationally interpreted functional concepts!

consequence:

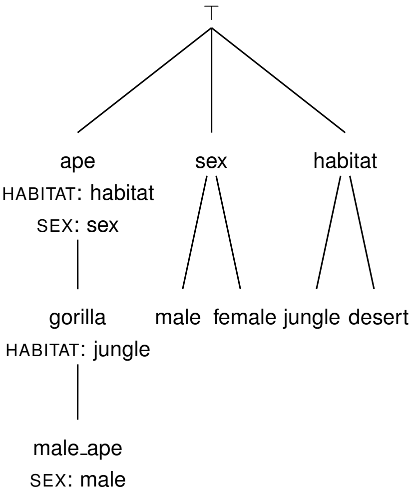
Sortal frames decompose sortal concepts into functional concepts!

type signatures (adapted from Carpenter 1992)

Definition

Approp : $\mathrm{ATTR} \times \mathrm{TYPE} \rightarrow \mathrm{TYPE}$ is an appropriateness specification on $(\mathrm{TYPE}, \sqsupseteq)$ if $\mathrm{ATTR} \subseteq \mathrm{TYPE}$ and $\forall a \in \mathrm{ATTR}$:

- **attribute introduction:** $\exists \mathrm{Intro}(a) \in \mathrm{TYPE}$ with:
  - $\mathrm{Approp}(a, \mathrm{Intro}(a)) = a$ and
  - $\forall t \in \mathrm{TYPE}$: if $\mathrm{Approp}(a, t)$ is defined, then $\mathrm{Intro}(a) \sqsubseteq t$.
- **specification closure:** If $\mathrm{Approp}(a, s)$ is defined and $s \sqsubseteq t$, then $\mathrm{Approp}(a, s) \sqsubseteq \mathrm{Approp}(a, t)$.
- **attribute consistency:** If $\mathrm{Approp}(a, s) = t$, then $a \sqsubseteq t$.



Frames and Typicality

instantiation function

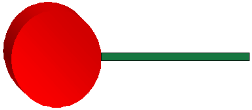
$$d : \text{TYPE} \times \mathcal{U} \rightarrow [0,1]$$

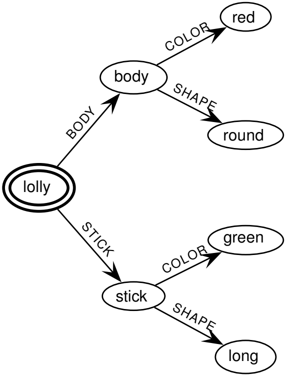
degree to which an object of the universe $\mathcal{U}$ instantiates a certain type

reference-shifting function

$$\sigma : \mathcal{U} \times \Pi \rightarrow \mathcal{U}$$

maps every object of the universe relative to the path in question onto the same or another object of the universe





Frames and Typicality

classical bi-valued case

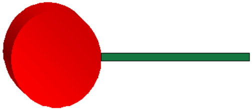
$$d(C,x) = \min_{m \in \textsc{MaxPath}} d(\Theta(m), \sigma(x,m))$$

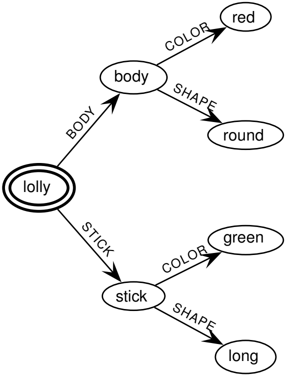
an object x is to be subsumed under the decomposed concept C iff all the types of the end nodes are properly instantiated ($\Theta(m)$ denotes the type of path m)

typicality values

$$d(C,x) \geq \min_{m \in \textsc{MaxPath}} \max_{t \in \textsc{alt}(m)} \tau(C,m,t)\, d(t, \sigma(x,m))$$

$\tau(C,m,t)$ tells how typical the type t is for the object $\sigma(x,m)$ given that x instantiates C





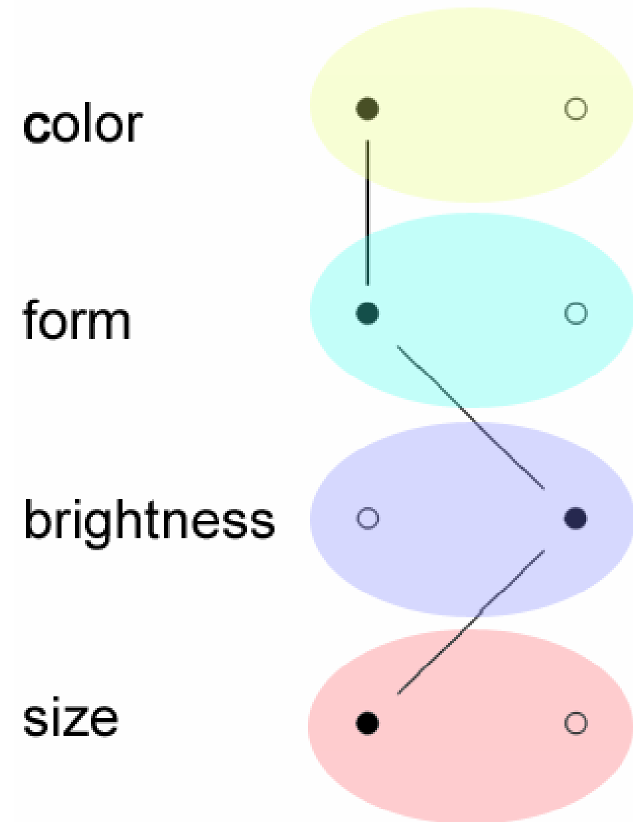
Coherency Chains

$$d(C,x) \geq \min_{m \in \textsc{MaxPath}} \max_{t \in \textsc{alt}(m)} \tau(C,m,t)\, d(t, \sigma(x,m))$$

- Assumption: Concept *C* is completely decomposable into a fully specified sortal frame.
- Lowest boundary of the degree to which the network represents an object x under the concept

  =

  strength of the strongest weighted coherency chain.
- Any coherence chain is regarded just as strong as the weakest weighted coherence in the chain.



Coherence chain representing an object as a cherry.

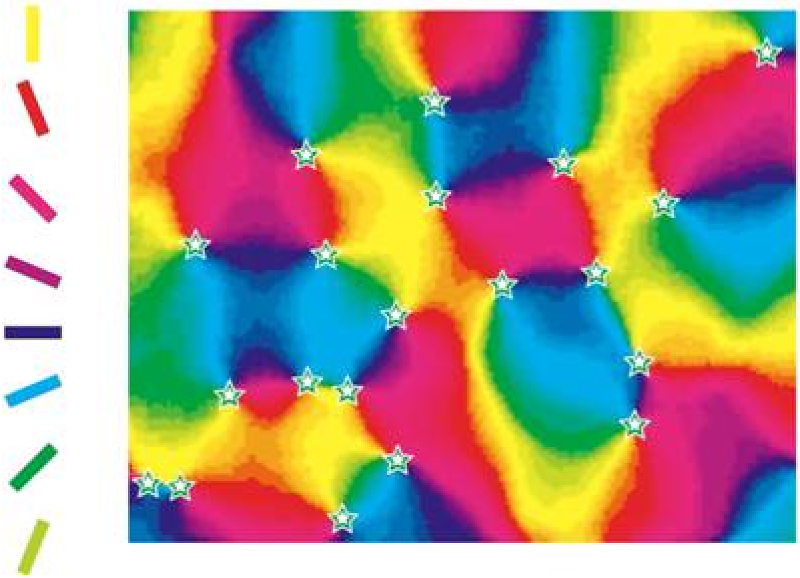
Neurobiological Hypotheses

Topology of Neural Feature Maps

Cells coding for properties of some feature dimension are organized in clusters with a twofold topological structure:

-Neighboring regions of cells (hypercolumns) correspond to neighboring receptive fields.

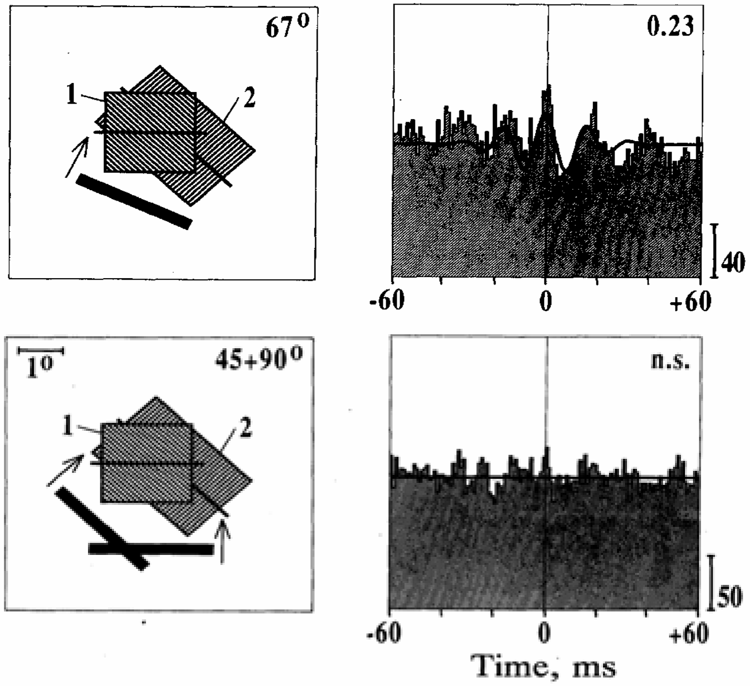
-Columns (i.e., clusters of cells with the same receptive field and similar feature sensitivity) fan around a pinwheel center.



Orientation map of cat visual cortex. Colors code orientations as indicated by the colored bars. Pinwheel centers are marked (Crair et al. 1997).

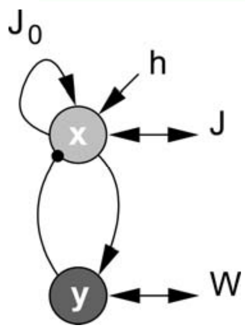
Object-Related Synchronization

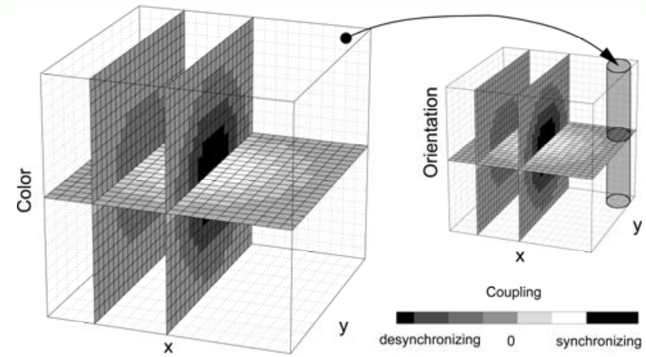
Cells coding properties of the same object synchronize; cells coding properties of different objects de-synchronize.



Two cells from different columns of area 17 of cat visual cortex with overlapping receptive fields are recorded (from Engel et al. 1991).

Oscillatory Network Simulations





- Gestalt principles: Neighboring stimulus elements with like properties are grouped into one object
- Implementation: Oscillators activated by neighboring stimulus elements with like properties synchronize, oscillators activated by neighboring stimulus elements with unlike properties de-synchronize.
  (Maye, *Neurocomputing*, 2003; Maye & Werning, *Neurocomputing,* 2004, *Chaos & Complexity Letters*, 2007)