On meanings and their representations without and within language

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Talk outline

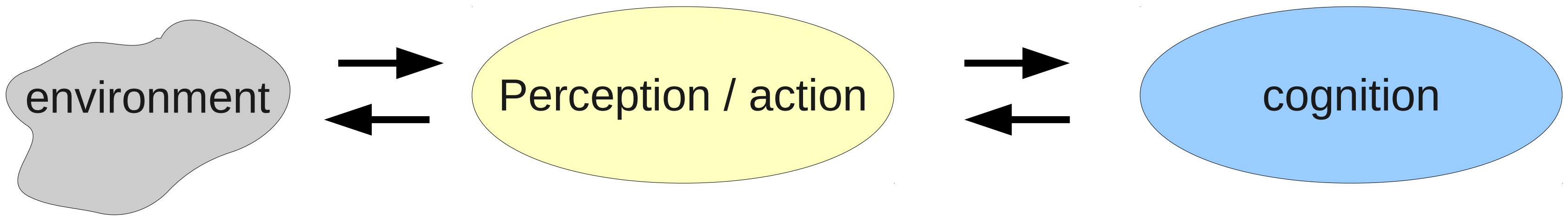
- empirical issues (philosophy, cognitive psychology, linguistics)
  - standard theories of cognition vs grounded cognition
  - empirical evidence for grounded cognition and language
- Language – cognitive grammar
- computational issues (AI) (amodal symbols)
- Examples: theories (Barsalou et al, 2008; Evans, 2009)
- Examples: computational models (Frank, 2009; Roy, 2005; Steels, 2005)
- Summary and open questions

A snapshot of history

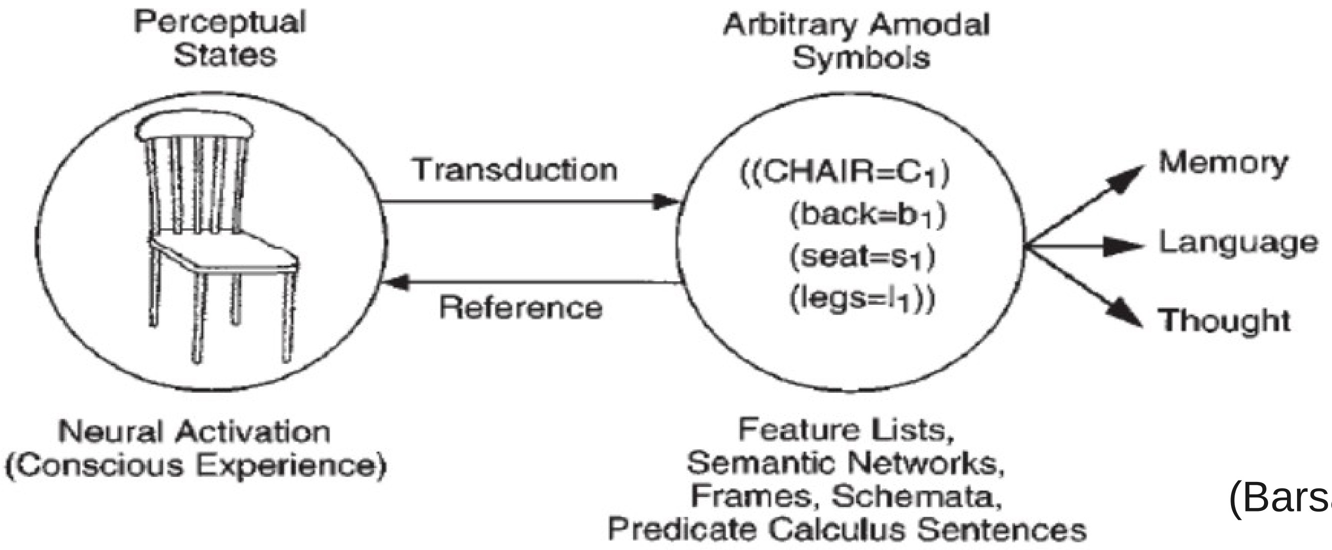
- Ancient (and medieval) philosophers assumed that modal representations and imagery represent knowledge.
- Behaviorists (late 19th century) attacked studies of introspection, banishing imagery from psychology for not being sufficiently scientific.
- Cognitive revolution (1950s) – new forms of representation inspired by major developments in logic, linguistics and computer science, adopted a wide variety of amodal representations (feature lists, semantic networks, frames).
- Amodal theories were adopted largely because they
  - provide elegant and powerful formalisms for representing knowledge
  - capture important intuitions about the symbolic character of cognition
  - could be implemented in artificial intelligence
- Dual Code theory (Paivio, 1971) – interaction between linguistic and conceptual systems
- Amodal theories lack empirical evidence; that grows in favour of grounded theories.

Standard theories of cognition

- They assume that knowledge resides in a semantic memory system separate from the brain's modal systems for perception, action and introspection.
- Representations in modal systems are transduced into amodal symbols (i.e. non-perceptual) that represent knowledge about experience in semantic memory.
- Once this knowledge exists, it supports the spectrum of cognitive processes from perception to thought.



Amodal conceptual representations

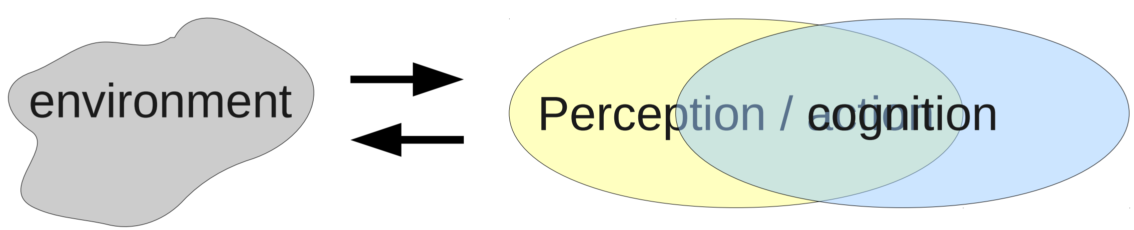


(Barsalou, 1999)

- Basic assumption: Internal (cognitive) structure does not resemble the perceptual states from which they originate.
- E.g., amodal representation of the colour of an object in the absence of that object is located in a different neural system from the representations of that colour during the process of perception.

Grounded cognition

- grounded ~ anchored in the physical world (= embodied + embedded) in various ways
  - embodied ~ agent has a body that provides direct sensations and allows actions
  - embedded ~ situated in an environment that provides concrete experience



Features of grounded cognition

(Wilson, 2002):

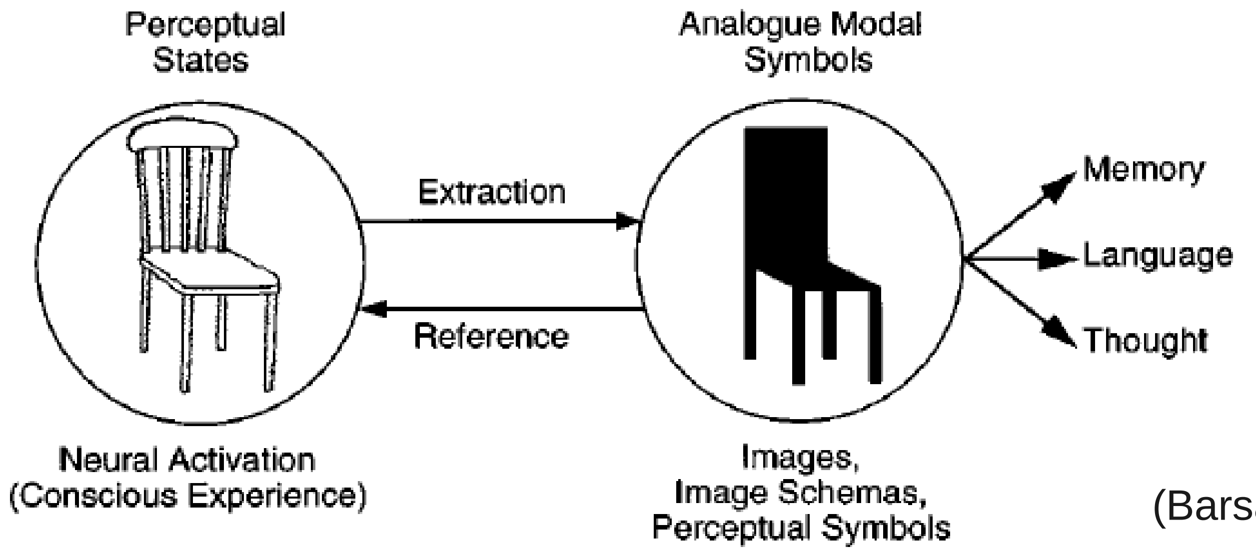
- Cognition is situated (sensory-motor interaction with environment)
- Cognition is time-pressured (environment driven or self-imposed)
- Cognitive off-loading into the environment (external memory)
- Environment as a part of the cognitive system
- Cognition is for action (vision and language serve action)
- Off-line cognition is body based (sensory-motor simulations)

- Accumulating empirical evidence (behavioral experiments, lesion data, imaging)

Theories of grounded cognition

- They are 'only' descriptive but have nevertheless generated testable hypotheses for empirical research; an important goal is to implement and formalize these theories
- Cognitive linguistics theories
  - abstract concepts are grounded metaphorically in embodied and situated knowledge (Lakoff & Johnson)
  - grounding the syntax and semantics of natural language in experience (Langacker, Talmy)
- Theories of situated cognition
  - Central role of perception and action in cognition, and social interaction
  - Importance of robotics approach
- Cognitive simulation theories
  - Perceptual symbol systems (Barsalou, 1999) – cognition as internal multi-modal simulation
  - Memory theories (Glenberg, 1997) – memory serves to control situated action
- Social simulation theories
  - ability to understand mental states of others (by simulating them with our own mind)

Perceptual symbol systems



(Barsalou, 1999)

- Basic assumption: Subsets of perceptual states in sensory-motor systems are extracted and stored in long-term memory to function as symbols. As a result, the internal structure of these symbols is modal, and they are analogically related to the perceptual states that produced them.
- Example: Barsalou (1999) – theoretical framework for embodiment of knowledge (including language)

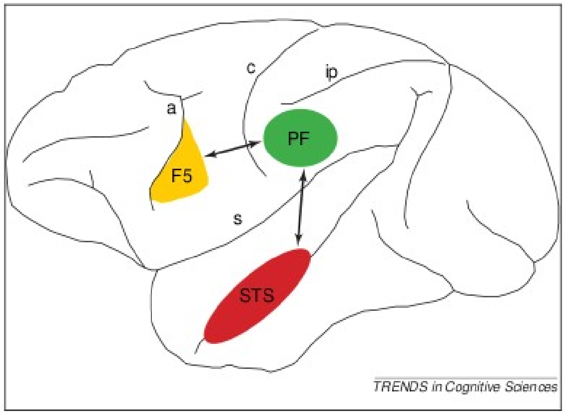
Mental images or propositions?

• **Images**	**Words**
– analogical	symbolic
– capture concrete information	abstract
– spatial relations	categorical information
– features conveyed simultaneously	sequentially

- How do we represent what we know in our mind?
  - mental images (scenarios) or mental narratives (words)?
  - Or both, according to dual-code theory (Paivio, 1969)?

UNDER(TABLE,CAT)

Two hypotheses of action understanding



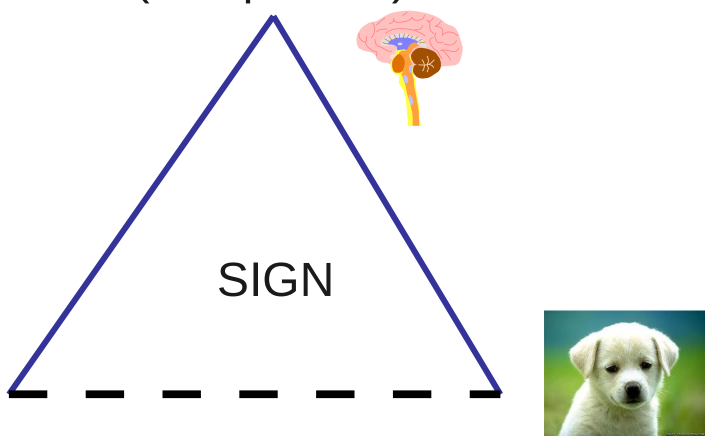
- Understanding without language
- visual hypothesis
  - analyse different elements of an action visually
  - does not require motor involvement, and could on visual perceptual representations alone
- direct matching hypothesis: embodied view
  - Map visual representations of the observed action onto motor representations of that action (e.g. Rizzolatti et al, 2001)
  - Important discovery of the mirror neuron system in macaques and humans (Gallese et al, 1986; ...; Mukamel et al, 2010)
    - Mirror neurons fire when an agent performs an action but also when the agent observes another agent perform that action.
    - MNS – neural substrate for action understanding

Semiotic triangle

(Peirce, 1867)

concept

(interpretant)



symbol

(representamen)

/dog/

referent

(object)

Types of sign:

Icon 

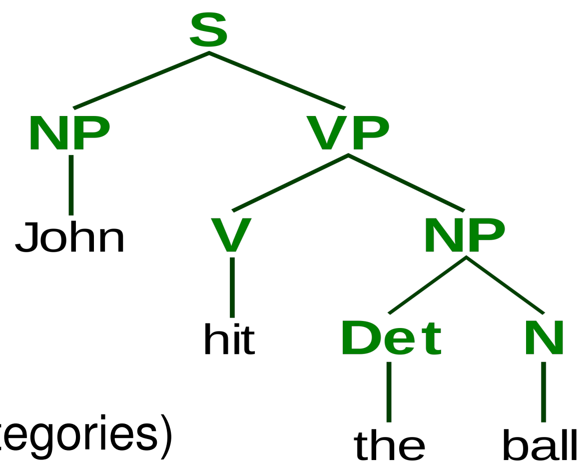
Index 

symbol 

Language components

Aspects of language:

- Phonology: cat → /kæt/
- Grammar:
  - morphology: anti|abort|ion|ist|s
    syntax: *John hit the ball* → N (V ((D) (N))
- Semantics: agent - action - patient (semantic categories)
- Pragmatics



Hierarchy of building blocks:

phonemes → syllables → words → phrases → sentences → pragmatics (discourse) …

- language is hierarchical

Language has recursive structure (right branching, center embedding)

Effect of language on cognition

- reverse effect is (relatively) well understood
- revival of the linguistic relativity hypothesis (opposed to Chomsky's universality h.):
- speaker's language affects the mental representations used when thinking about time, space and causal relations (Boroditsky, 2010)
- second language learning boosts general cognition
- Boroditsky: language functions as a modulator of the conceptual system that is able to develop (prepare for use) various conceptual schemas

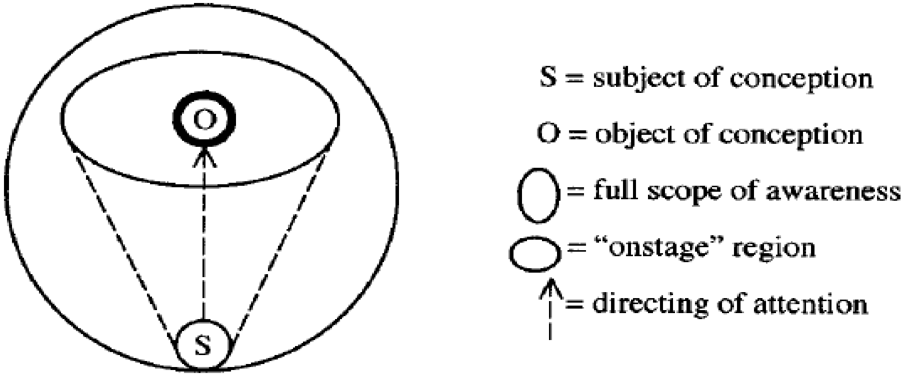
Cognitive linguistics

- CL = modern alternative to generative grammar (in which syntax is crucial)
- CL adheres to three central claims (Croft & Cruse 2004):
  1. there is no autonomous linguistic faculty in the mind (no language-specific module)
  2. grammar is conceptualization (linguistic knowledge is essentially conceptual),
  3. knowledge of language arises out of language use
- Has two components:
  - cognitive semantics
  - cognitive grammar (construction grammars) – syntax subserves semantics

Cognitive grammar

(Langacker, 1987)

- Primary unit: Symbol = pair of semantic structure + phonological label
- Grammar is meaningful, because:
  - lexical items have meanings in their own right
  - Grammar allows us to construct and symbolize the more elaborate meanings of complex expressions (phrases, sentences)
- Linguistic structures are motivated by general cognitive processes: CG makes extensive use of principles of gestalt psychology and draws analogies between linguistic structure and aspects of visual perception.



Construction grammar

(Goldberg, 1995)

1. Primary unit of grammar is the grammatical construction rather than the atomic syntactic unit and the combining rules.

2. Language grammar is made up of taxonomies of families of constructions.

- Grammatical construction =

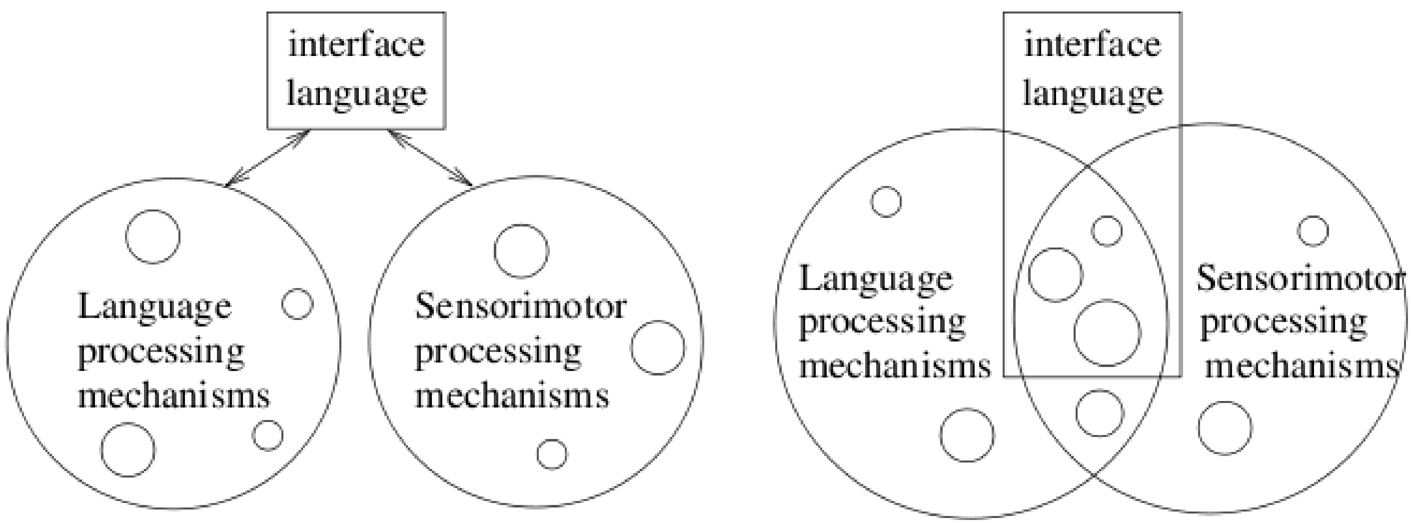
Construction is treated like a sign (symbol). Types:

1. Lexically fixed (idioms), e.g. “*to kick the bucket*”

2. Argument structure schemata, e.g. [S V IO DO] expresses the semantic content “S transfers DO to IO”, “*The old lady crutched the goalie the ball*”

Theory of grounded language syntax

- Proposed link between natural language syntax and sensorimotor cognition (Knott, MIT Press, to appear)
  - shared mechanisms assumed: (deep) logical form of sentence ↔ sensorimotor processes)
  - Chomsky's minimalist syntactic theory focused on



(a) Modular mechanisms (b) Shared mechanisms

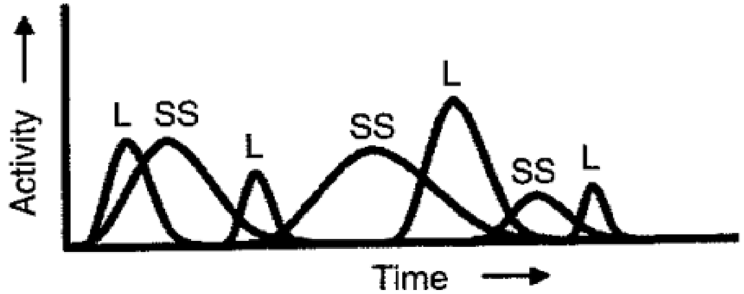
Theories of semantics

- Semantics: The most important and most difficult aspect of language
- Realist semantics – there exist objects (physical or mental) that are the meanings of linguistic expressions.
  - Extensional ~ meanings are objects in the world (Frege, Tarski)
    - e.g. a property is defined as a set of objects (meaning of 'small' = {all small objects})
  - Intensional ~ meanings are mappings to possible worlds (Kripke)
    - meaning (of proposition) reduced to truth-conditional values.
- Cognitive semantics – meanings are mental representations that are formed during agent's experience with the world (Johnson, Lakoff,...)
  - prototype theory (Rosch, 1983) $\rightarrow$ starts with basic-level categorization
  - consistent with grounded theories of cognition
  - Features: gradedness, context dependence

Language and situated simulation (LASS) theory of conceptual processing

(Barsalou et al, 2008)

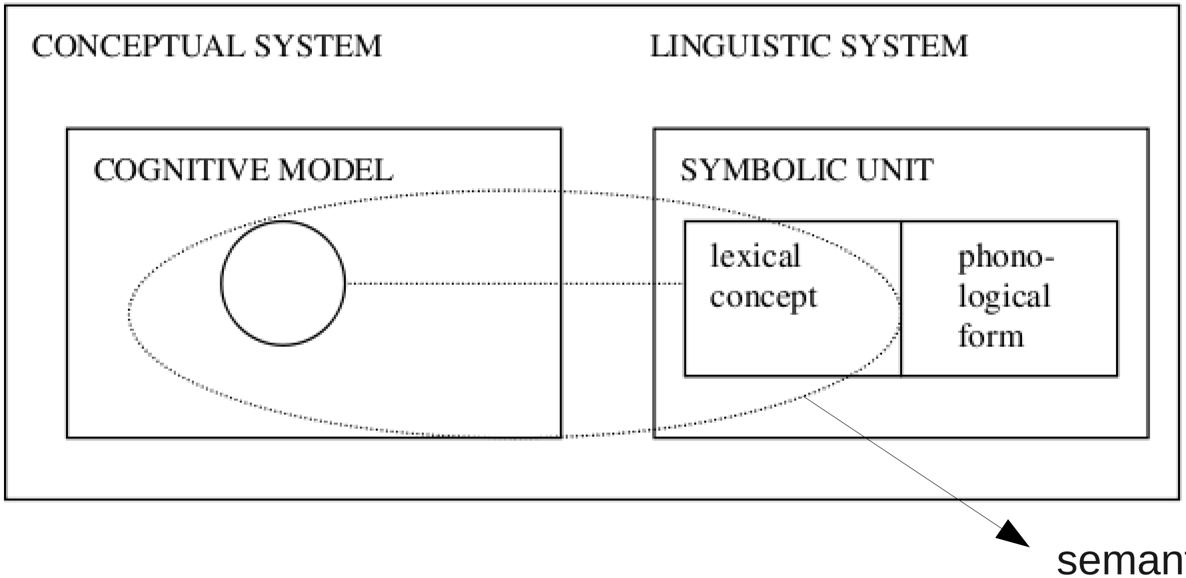
- Provides hypotheses how we understand language
- Representation and processing of concepts relies heavily on both linguistic system (LS) and situated simulation (SS)
- LS operates on linguistic forms, is faster, but flatter and sometimes suffices to yield understanding (e.g. lexical decision).
- SS operates on concepts, is slower, but deeper and most often is necessary to provide understanding.
- Both systems are exquisitely sensitive to the statistical structure of their respective domains
- Both systems interact online during sentence understanding



- Consistent in part with dual-code theory (Paivio, 1971). But dual-code theory, unlike LASS, postulates linguistic system as central.

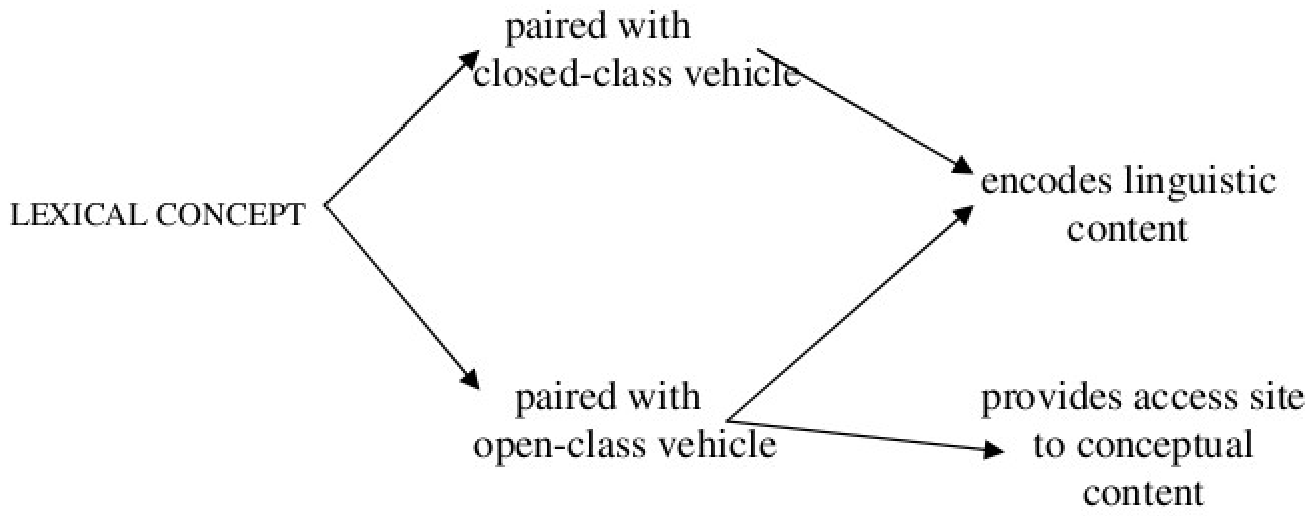
Theory of Lexical Concepts and Cognitive Models (LCCM)

(Evans, 2009)



- LCCM draws on theories of cognitive grammar (Langacker, 1987), cognitive semantics (Talmy, 2000) and perceptual symbols (Barsalou, 1999)
- Conceptual system – non-linguistic knowledge captured from perceptual experience that is made of perceptual states. This knowledge derives from sensory-motor experience, proprioception and subjective experience.
- Linguistic system – the collection of symbolic units comprising a language, and the various relationships holding between them.

LCCM: distinction in lexical content



schematic
semantic

detailed
perceptual

- Conceptual content is very detailed, continuously graded (analogue), e.g.
    a) *The teacher scrawled in <u>red</u> ink all over the assignment.*
    b) *The <u>red</u> squirrel is in danger of becoming extinct in the British isles.*
- Linguistic content encodes knowledge in parametric fashion (highly reductive)
    - e.g. time-reference (*kick**s**, kick**ed***)**,** boundedness (***has left, is*** *leav**ing***)

Computational (AI) approaches to meaning

- Representations of meaning should be formalizable,
  otherwise we cannot understand mechanisms and make predictions.
- What kind of information processing?
- Representations? Should be grounded in the world
- (amodal) symbolic vs subsymbolic (modal) reps
- Source of confusion: all types of computations (algorithms) can be implemented in a digital computer (rendering them symbolic)
- Alternative solutions to the symbol grounding problem possible
- Theory developed at FMPH – distinguishing criteria (Šefránek, Takáč)
    - applicable to concepts, properties, situations
- symbolic AI will most likely remain a viable alternative (ontologies, web)

Representation of word meaning

- How can the meaning become intrinsic to the agent, rather than being dependent on external interpreter? (symbol grounding problem)
- Grounded theories: word meaning is a multi-modal representation drawing on sensory-motor features (acquired during experience)
  - strong context dependency (e.g. the meaning of '*small*')
- Distributional theories: word co-occurrence (context) in the text provides word meaning (Landauer & Dumais, 1997; Burgess & Lund, 1997)
  - require huge corpora, but match well human judgments
- What unifies the two views is the important role of statistics (as opposed to generative linguistics view)

Distributional theories of word meaning

- Representation of word meaning is a distributed numerical vector of co-occurrences with other words (rows in the co-occurrence matrix).
- Words (w_i) with similar meanings tend to occur in similar contexts and therefore have similar meaning representations.
- subject to symbol grounding problem (Harnad, 1990), inspired by Chinese room argument (Searle, 1980)
- Argument against grounding: During sentence comprehension, maybe not all words have to be grounded to acquire meaning.

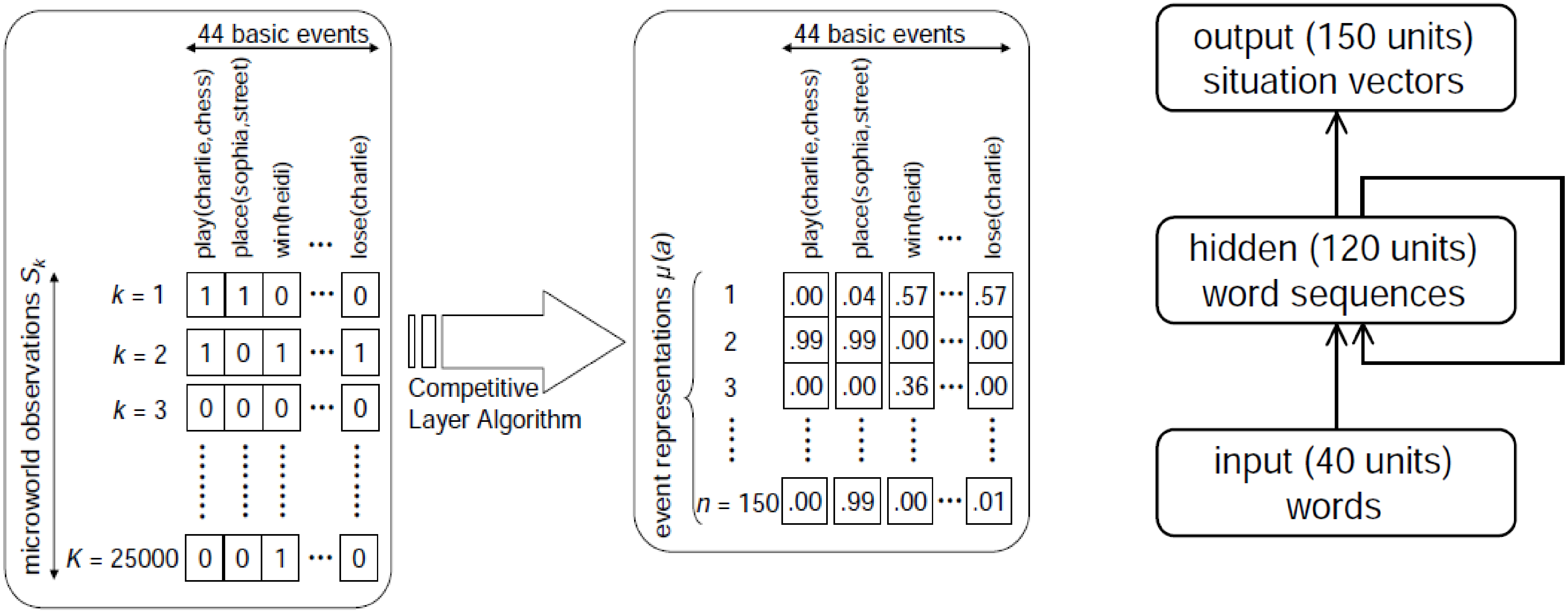
Representation
s in matrix rows

	w_1	w_2	w_3	....	w_m
w_1		5	13	....	8
w_2	5		2	....	11
w_3	13	2		....	6
....	....	....	....	....	....
w_m	8	11	6	....	

Sentence comprehension model

(Frank, 2009)

- A purely connectionist model, shows systematic behavior
- Sentence understanding = mapping from the sentence to meaning representation
- Semantic systematicity developes robustly, it derives from the structure in the world.
- amodal situation reps, training data prepared, not scalable

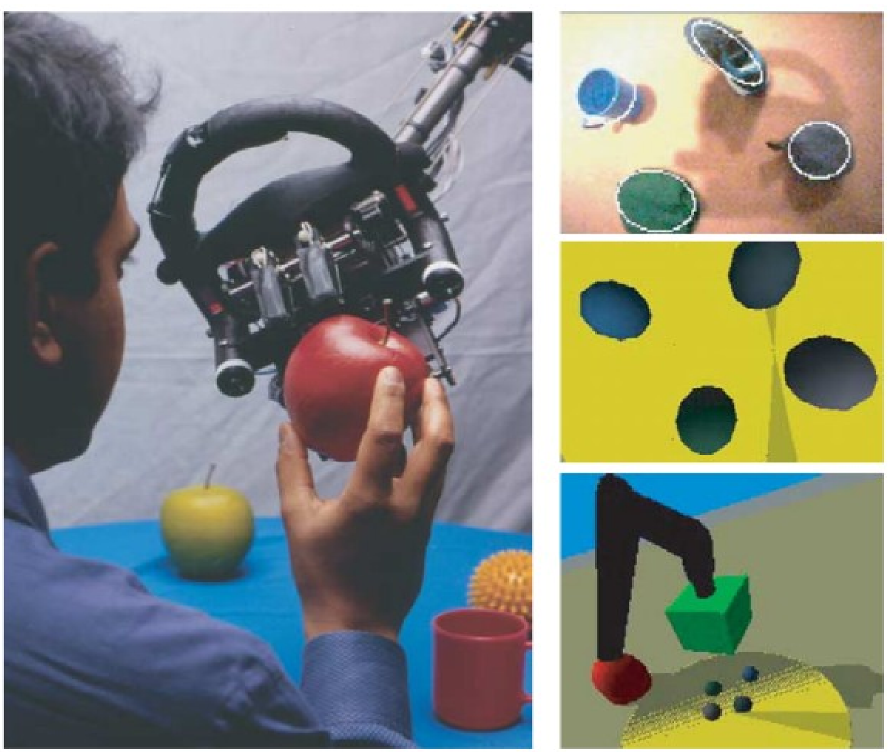


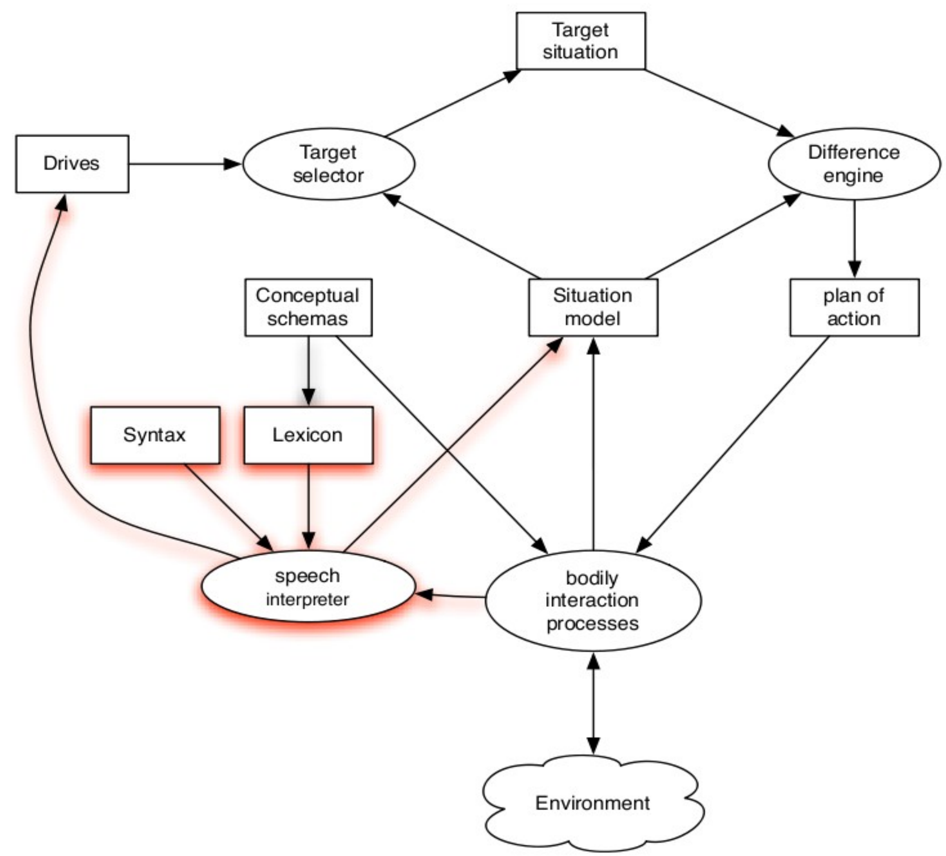
Language grounding in robots

(Roy, 2005)

Ripley – conversational robot

- Understands commands, performs accordingly, standard AI used
- No autonomous grounding, though (all knowledge preprogrammed)

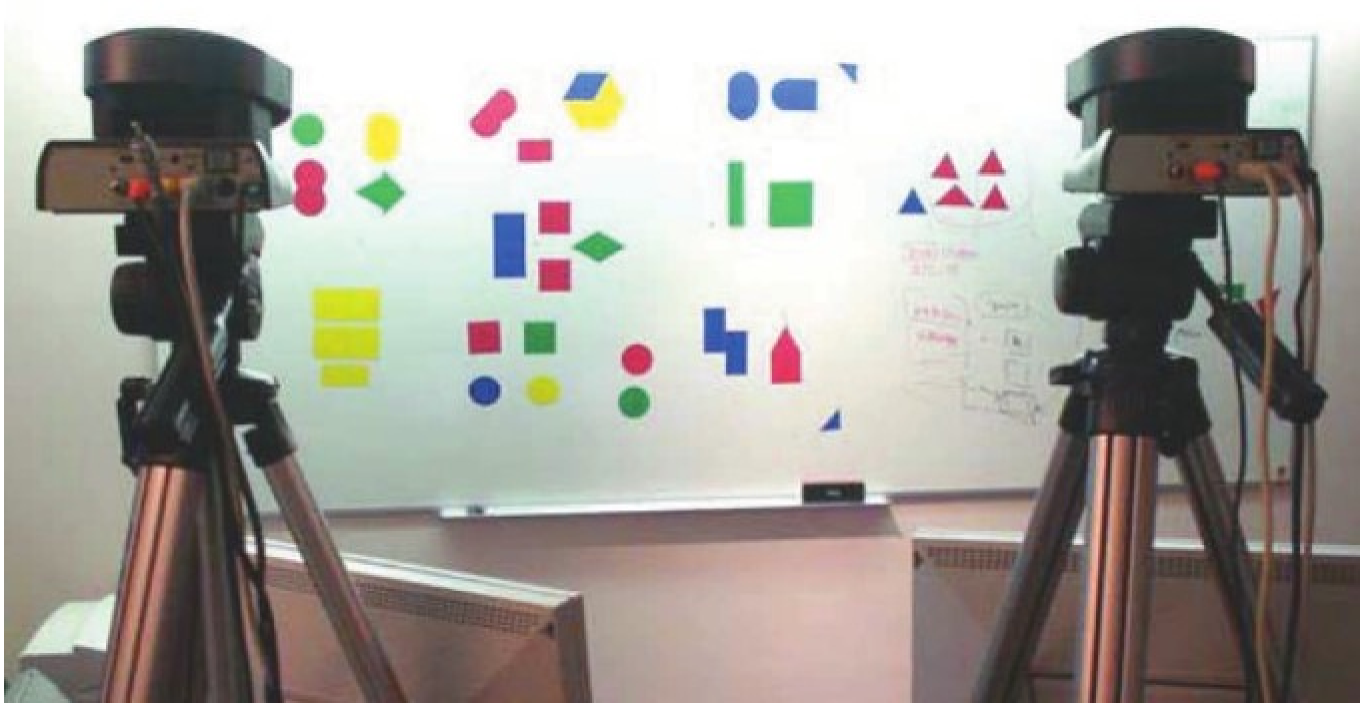




Grounding via language games

(Steels, 2005)

- Robots acquire meanings autonomously, by self-organization during interactions (cultural evolution) with the world and each others.
- Substrate does not matter, neither do representations (symbolic/NN)



Summary and open questions

- Symbolic cognition is elegant, powerful, and intuitively well understandable, however it lacks empirical support.
- Empirical evidence for grounded theories of cognition & language: overarching theory and computational models missing
- Cognitive linguistics views
- Linguistic system boosts cognitive processing.
- What is the contribution of LS to meanings?
- Interaction b/w conceptual and linguistic systems?
- Computational solutions to the symbol grounding problem possible.