Embeddings in Natural Language Processing

Introduction

Eva Maria Vecchi

Computational Linguistics Fall School 2019
IMS, University of Stuttgart

September 9, 2019

Scheduling

- Course: September 9–13, 9:00–12:00, Ground Floor Seminar Room
- Website: `www.vecchi.com/eva/teaching/embeddingsNLP.html`
- My Contact: `evamariavecchi@gmail.com`

ECTS Credits

- Select specific topic relevant to Embeddings in NLP
  - *to be pre-approved by me*
  - generally content of 1-2 scientific papers
- Submit the following:
  1. Literature review of scientific literature
  2. Practical implementation on the topic (e.g., re-implementation of system, new data, evaluation using different embeddings, comparison of systems/parameters)

Eva Maria Vecchi

- **2005**: B.A. in Linguistics, with minors in Mathematics and Italian from University of Colorado at Boulder
- **2007**: M.Sc. in Computational Linguistics from Georgetown University
- **2005-2007**: Worked at MITRE and The Federation of American Scientists
- **2008-2010**: Research Fellow at Center for National Research at Pisa, Italy
- **2010-2013**: Ph.D. in Cognitive and Brain Sciences at CIMeC, University of Trento, Italy
- **2014-2017**: Post-doctoral researcher at University of Cambridge: Computer Laboratory
- **2017-2018**: Post-doctoral researcher at University of Stuttgart, IMS
- **2019**: Guest Lecturer at CIS, Ludwig-Maximilians-Universität, Munich

Research Interests

- Distributional/Computational Semantics
- Compositionality & Formal Semantics
- Machine Learning in NLP
- Meaning Representation
- Cognitive Computing

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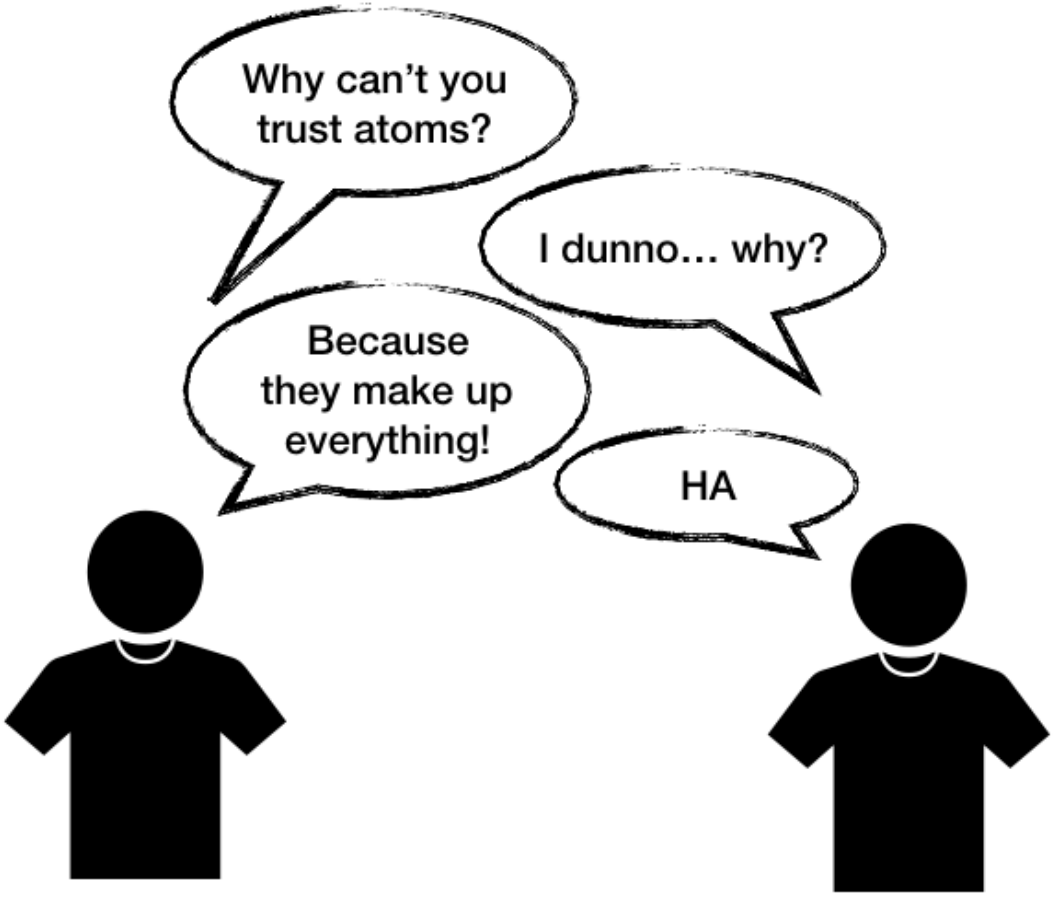
Modeling Meaning: ***Why?***

Ultimate Goal: "Understand" language like humans



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Language: one of the most fundamental human abilities

- Language allows us to speak about complex objects that (we think) **exist in the real world**:
  - *Look at that chair with the velvet back, the one with the flowery English pattern.*
  - *Insulin is a peptide hormone produced by beta cells of the pancreatic islets.*
  - *I'm jealous. It's not that I want that car, but I don't think he should have it either.*
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Credit: Herbelot 2018

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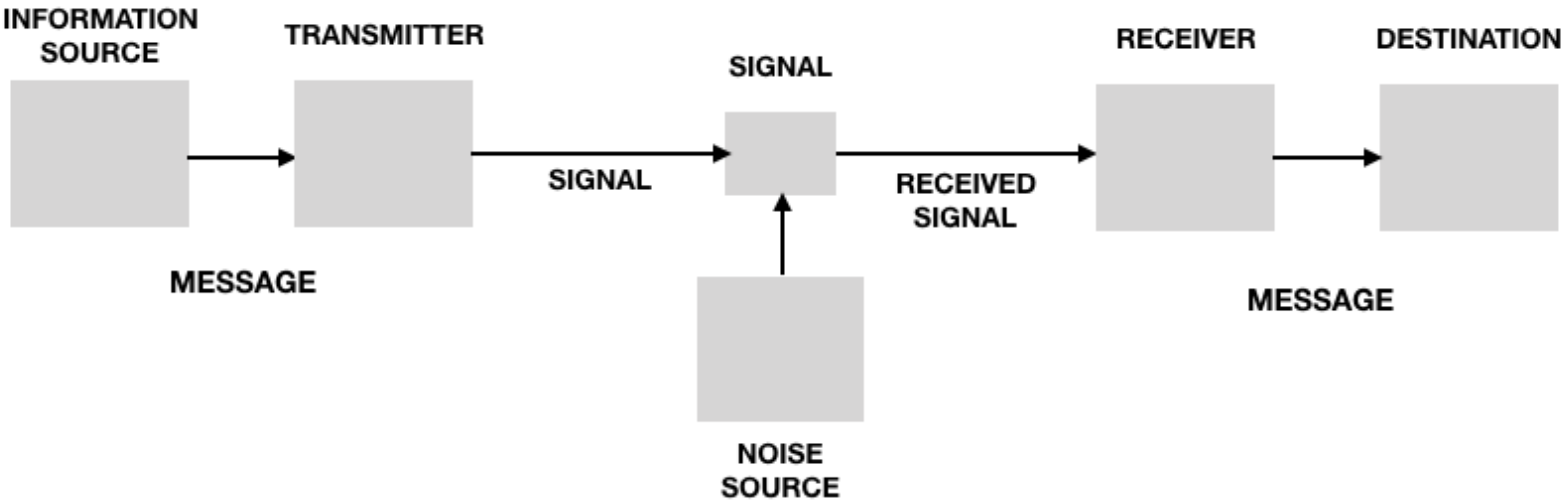
- In fact, utterances can be meaningless if *meaning* is taken to be a relation between words and items in the real world.

(Credit: Herbelot 2018)

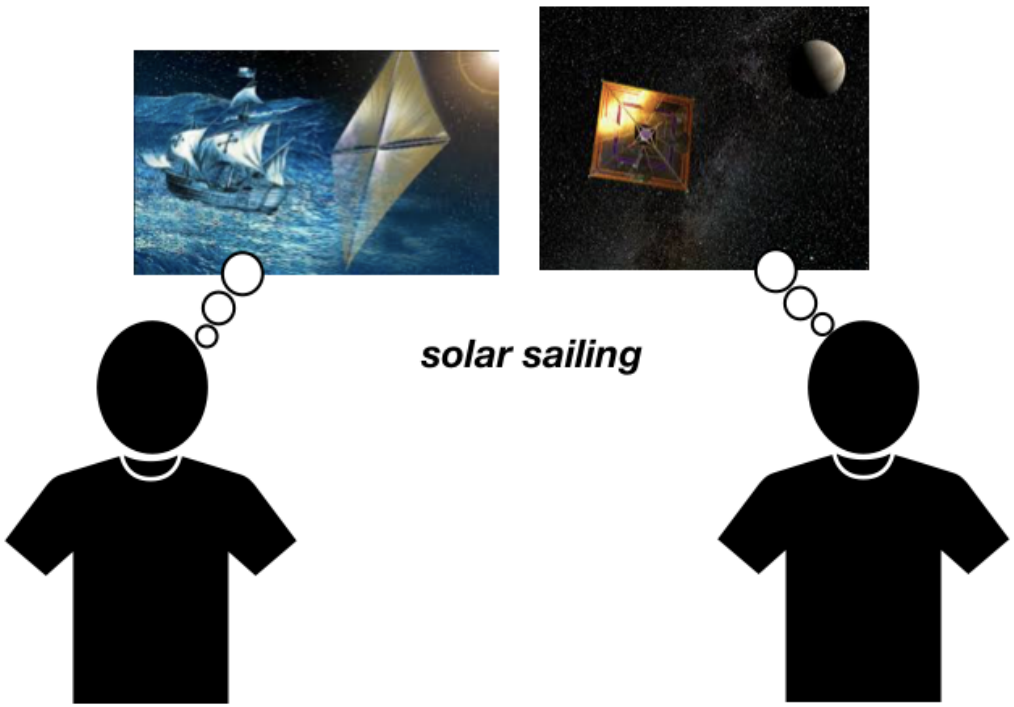
Language for communication



- A message has to be passed in a way that whatever was in the head of the speaker ends up in the head of the hearer.

(Credit: Herbelot 2018)

Language for conceptualization



- Composition of existing linguistic constituents lead to new concepts.
- Each speaker has their own conceptual space, made of previous experiences and their own (infinite) creativity.

(Credit: Herbelot 2018)

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1. Define *meaning*: What does it mean to understand language? What are the components of meaning?
2. Define and understand phenomena involved in human capacity to process meaning in language
3. Determine methods that computationally elaborate components of meaning such that they approximate the phenomena of natural language **and** remain computationally-friendly and efficient.

Thought exercise: Defining meaning

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   - INSTANCE_1: Cloudless sunny day
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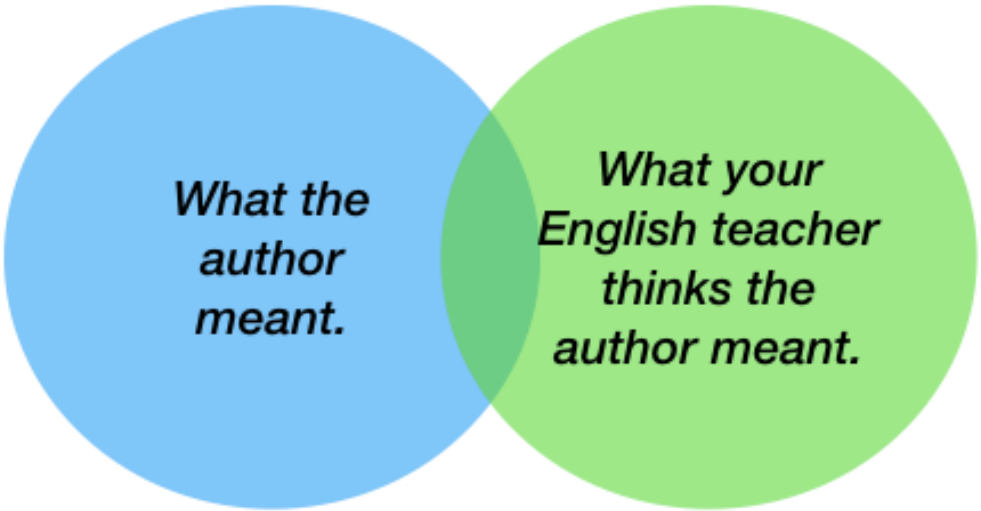
   - Contribution of **context** to meaning

Overdoing it...



For instance: "The curtains were blue."

What your teacher thinks: "The curtains represent his immense depression and his lack of will to carry on."

*What the author meant: "The curtains were *%$!& blue."*

Courtesy of *The Language Nerds*

Meaning in a nutshell

- Meaning is **extension** / reference: it 'points' at things in the world;

(Credit: Herbelot 2018)

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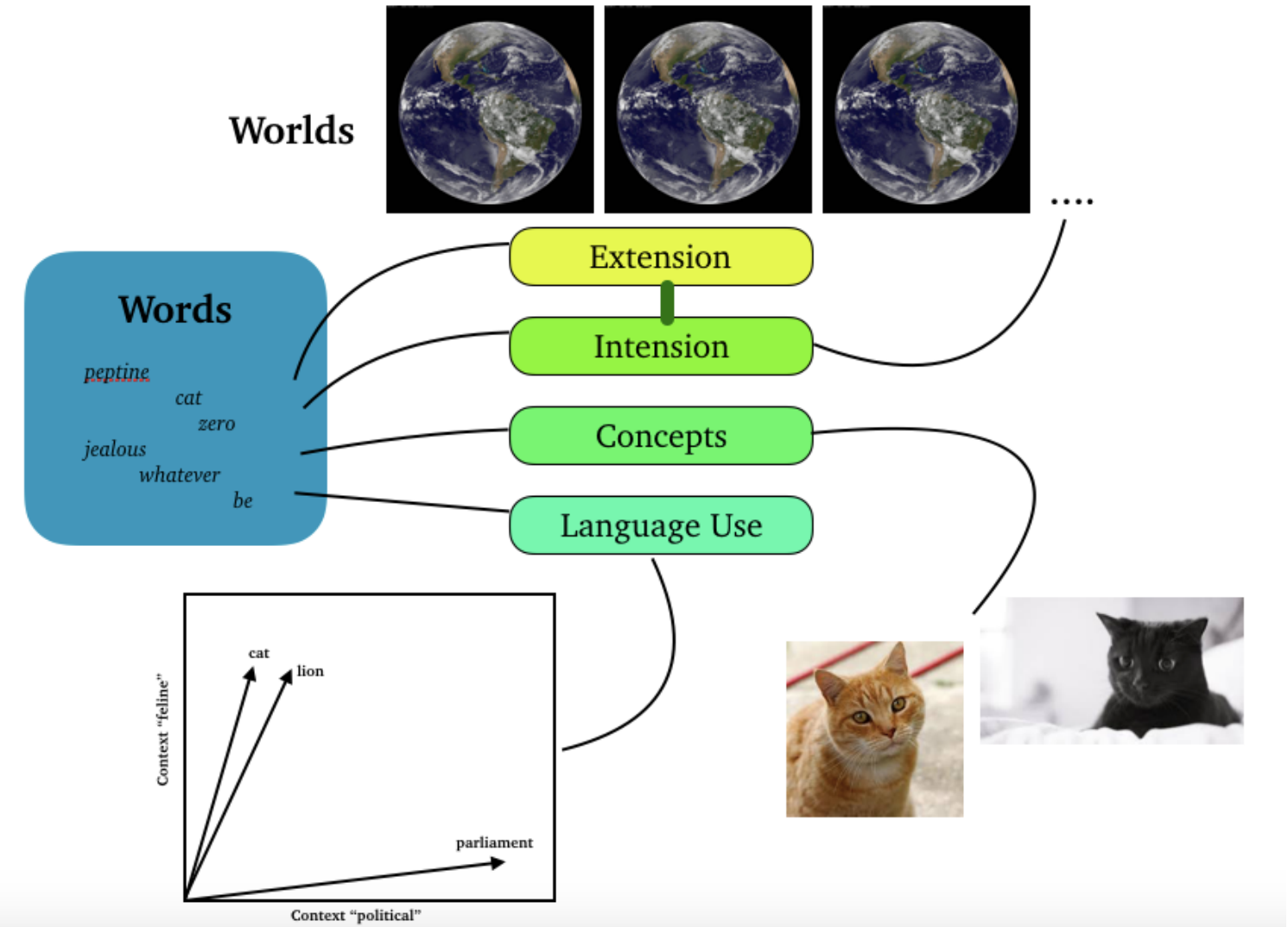
- Meaning is **conceptual**: linguistic constituents activate cognitive processes involving extra-linguistic features;
- Meaning is **use**: linguistics constituents have certain patterns of use across a community

(Credit: Herbelot 2018)

Modeling Meaning



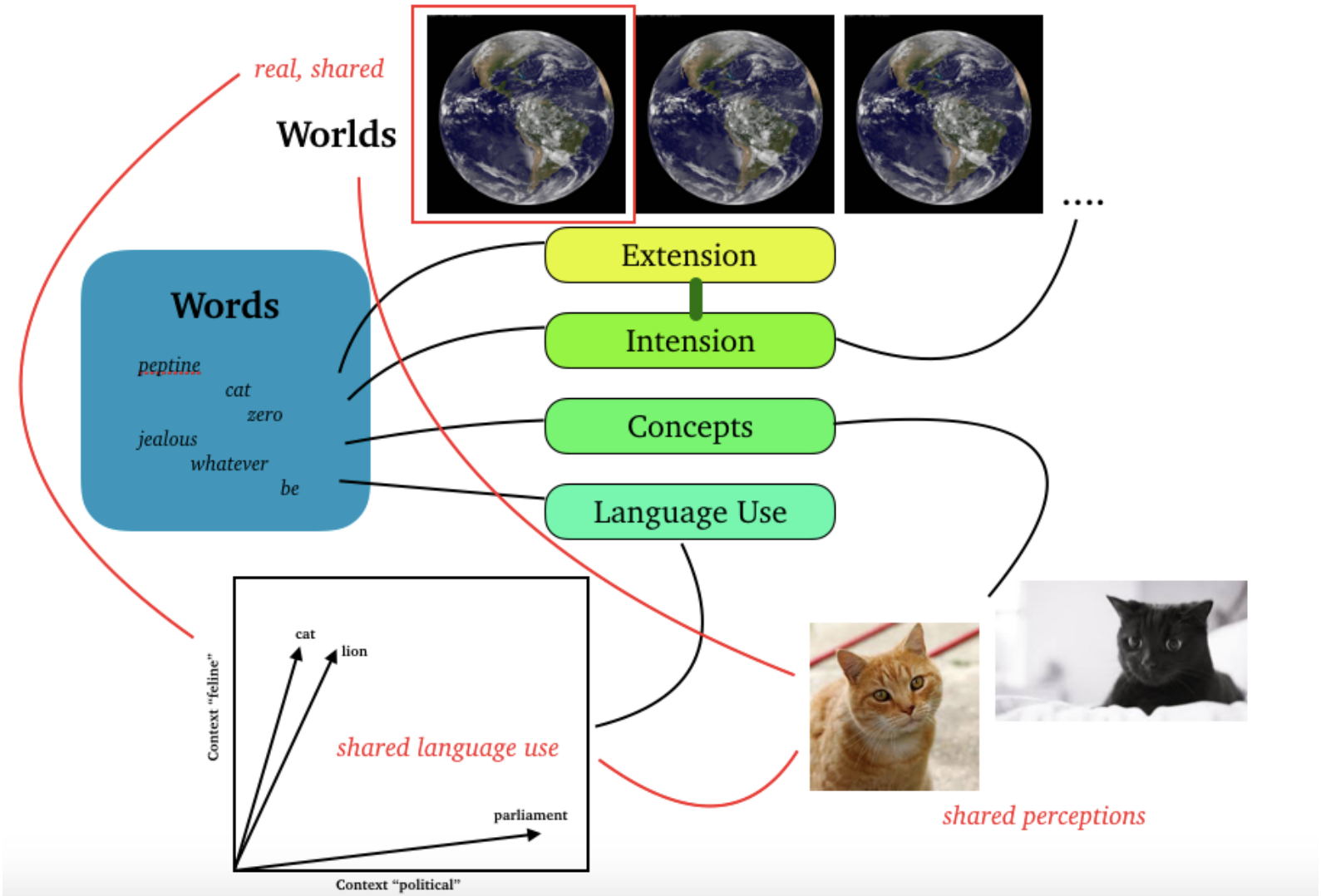
(Credit: Herbelot 2018)

Integration with the real world

- A system that learns extensions must be able to link language to the world.
- What is a bike, a bus? What do *how*, *many* and *how many* mean?
- Formal meaning of bus: *bus'* (the set of buses in a world)
- *bus'* assumes that the speaker holds entities of *bus* in their head (a model), but how do those relate to the actual world? Via perception.

(Credit: Herbelot 2018)

Constraints: Communication



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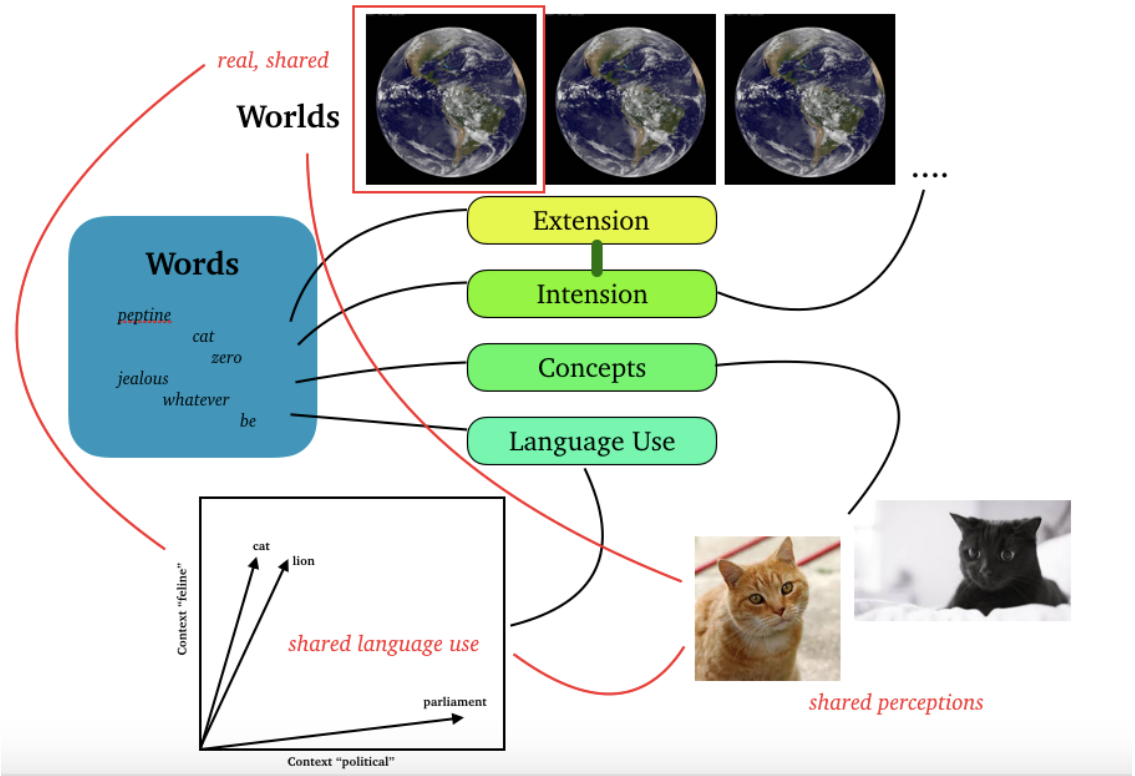
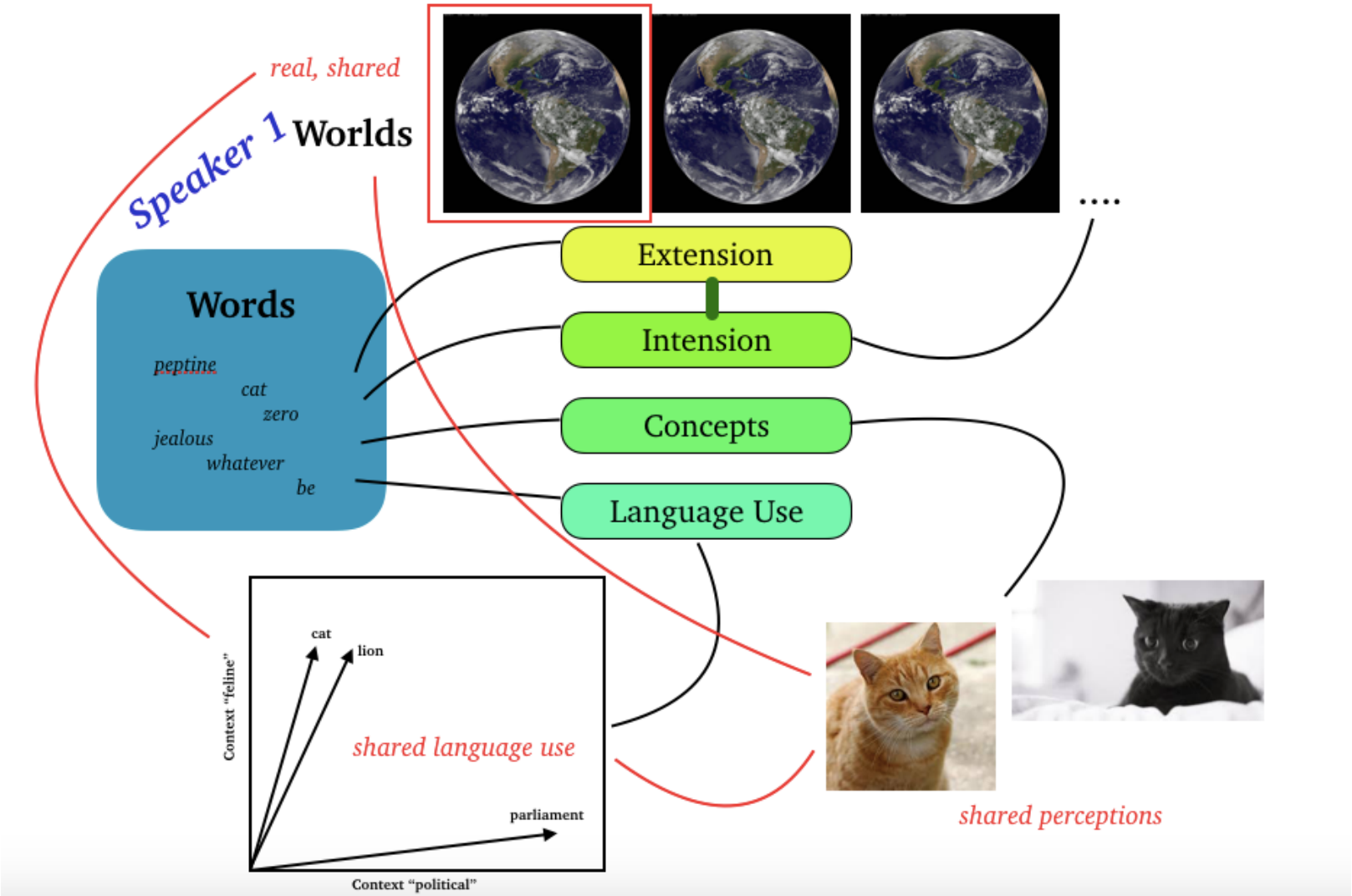


Since we share the real world and (roughly) share our perceptions of it, sharing labels (words) for certain categories allows us to successfully refer. Since we see the same world, we are bound to say the same kind of things about it, so we share language use, which is anchored in perception.

(Credit: Herbelot 2018)

Constraints: Individuality



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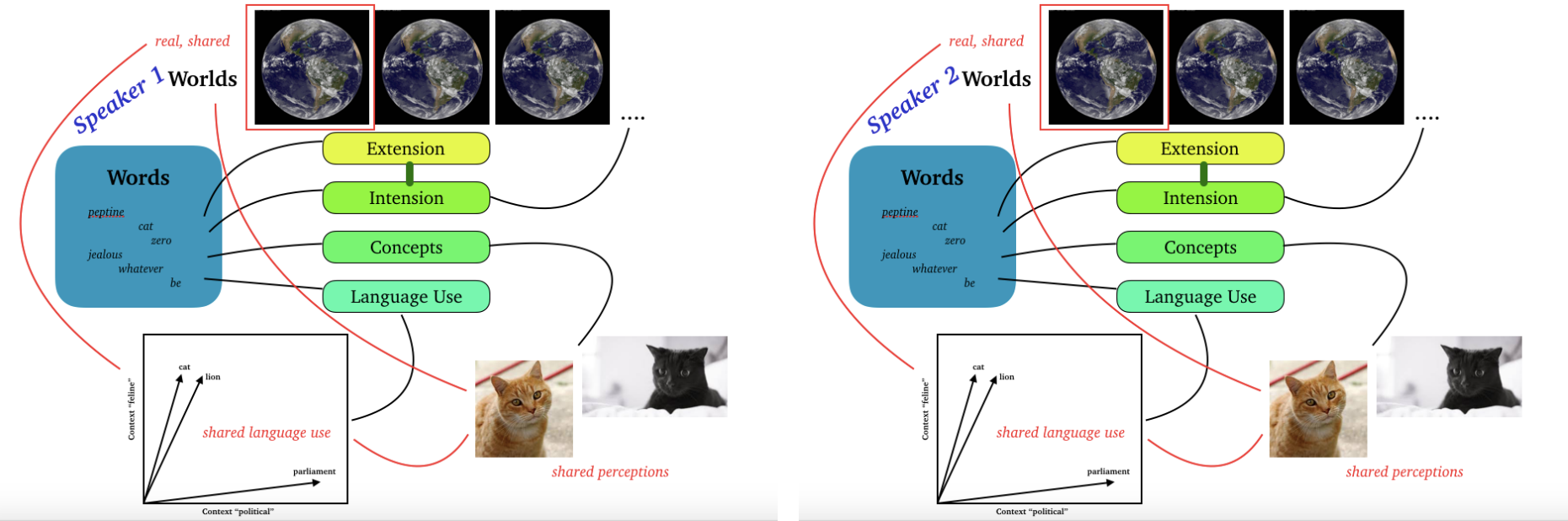

Since we don't share the same experiences of the world, and since concept composition happens in the mind (separate minds), we are bound to have separate conceptual spaces, separate language use, separate extensions, separate possible worlds, separate intensions.

(Credit: Herbelot 2018)

Larger constituents and compositionality

black cat =  + 

= 

Larger constituents and compositionality

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=  + 

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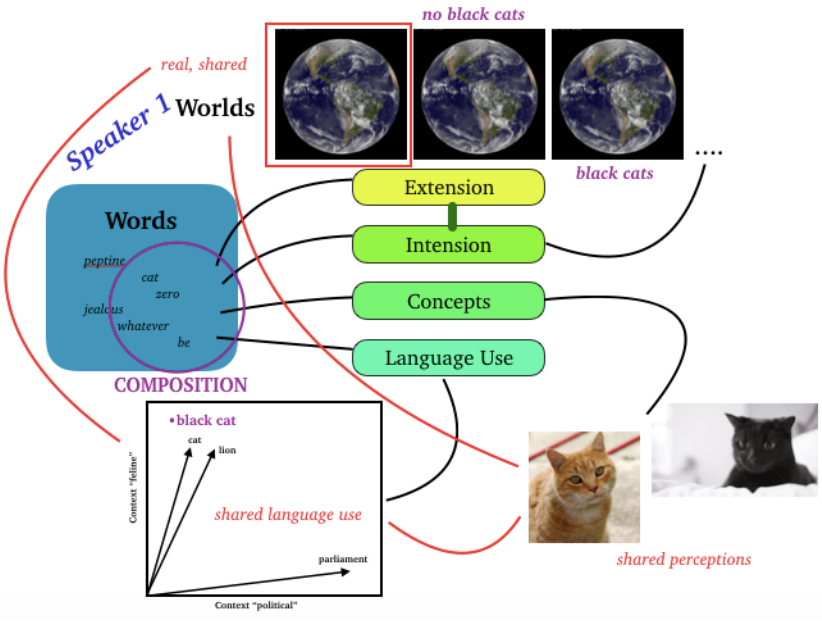

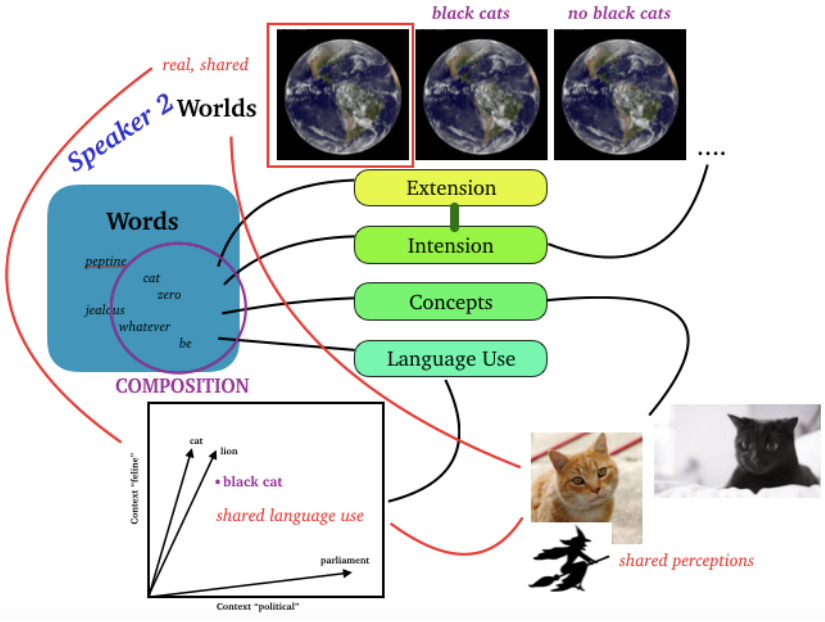

(Credit: Herbelot 2018)

Language in Use

1. Pragmatics
   - How does the *broader* context affect meaning? (situation of utterance, community of speaker, etc)
   - How does a community contribute to the emergence and spread of meanings? (del Tredici & Fernandez, 2017)

Language in Use

Katherine Johnson, *computer* at NASA, 1966

Much less reliable *computer* at NASA, late 1960s

2. Dynamicity of the lexicon
   - The use of *computer* changed meaning over the years.
   - Every utterance changes the meaning to its linguistic constituents.
   - Members of a community are not necessarily fully in sync.

(Credit: Herbelot 2018)

How hard is it to model meaning, then?

(Example from Teufel 2017)

Semantics

Semantics

- Semantics is the study of meaning communicated through language.
- Semantics (and pragmatics) are the glue that connect language to the real world.
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- Let's start at the word-level: Lexical Semantics

Word Meaning

I saw my mother just now.

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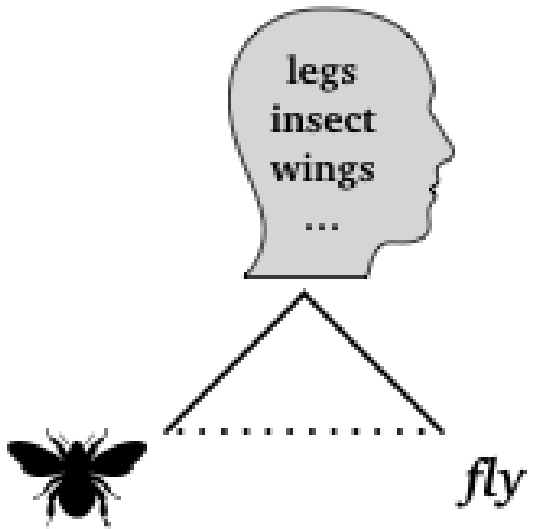
I saw my <u>mother</u> just now.

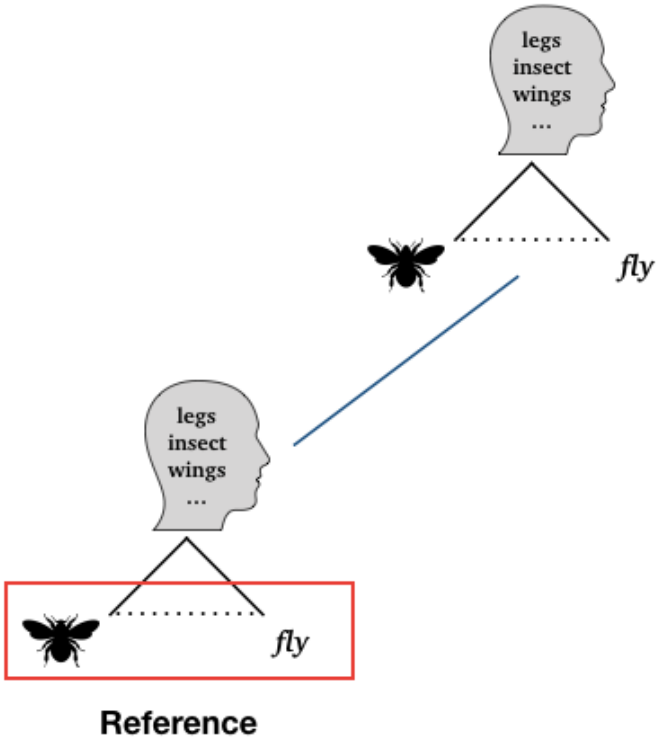
- We know that the speaker saw a female human, someone who is older than the speaker and is of a specific relation to the speaker
- Lexical relations (e.g. between *woman* and *mother*) are central to the way speakers and hearers construct meaning
- Links between linguistic and world knowledge also major factor in determining word meaning

Word Meaning



(Credit: Handke 2012)

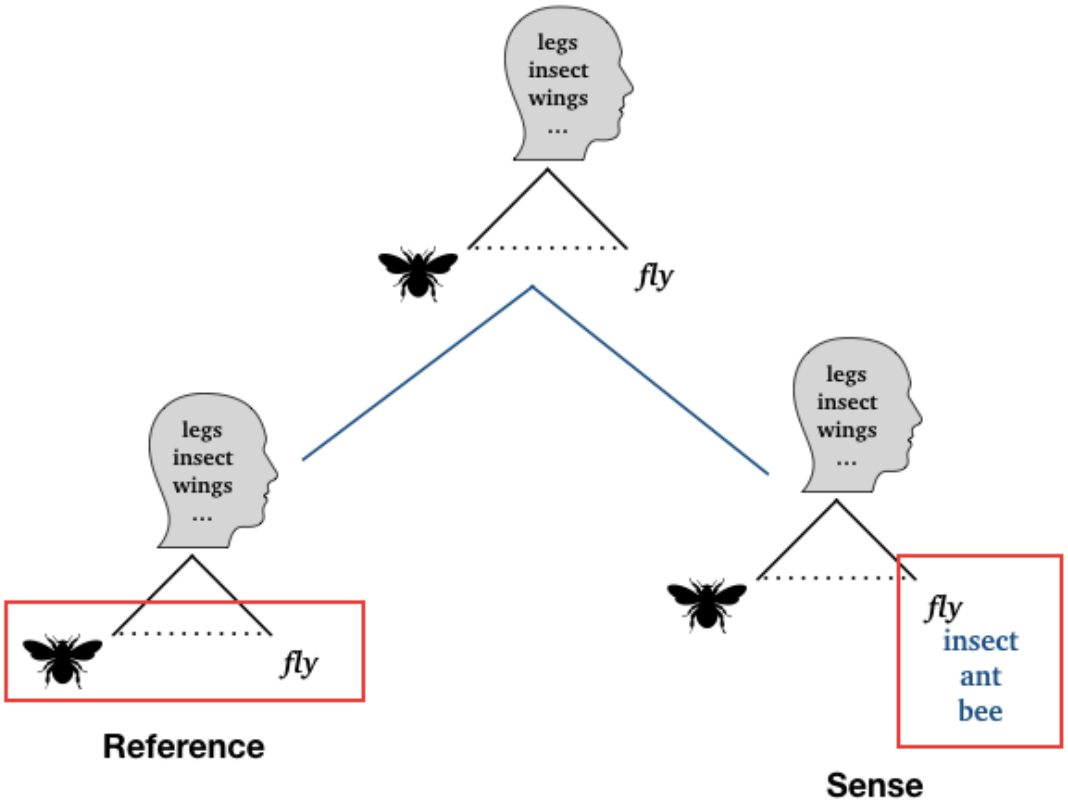
Word Meaning: Reference



Referential Semantics: Word meaning described as a relationship between linguistic elements and the non-linguistic world and experiences.

(Credit: Handke 2012)

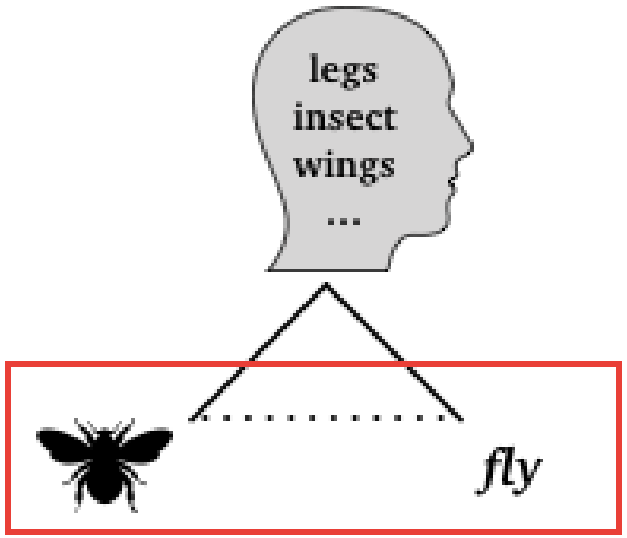
Word Meaning: Sense



Lexical Semantics: Word meaning described within a complex relationship between the linguistic elements themselves.

(Credit: Handke 2012)

Reference as a Theory of Meaning



Reference

- To give the meaning of a word, one shows what it denotes in the real world
- FLY: animate, insect, 2 wings, 6 legs, ...
- COOKING: action

(Credit: Handke 2012)

Reference as a Theory of Meaning

proper names	denote	individuals
common names	”	sets of individuals
verbs	”	actions
adjectives	”	properties of individuals
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But . . .

- Real-world referents for words like *so*, *not*, *very*, *but*, *of*?
- In the painting **a unicorn** is ignoring a maiden.
- **World War III** might be about to start.
- **Father Christmas** might not visit you this year.
- I am in **love**.

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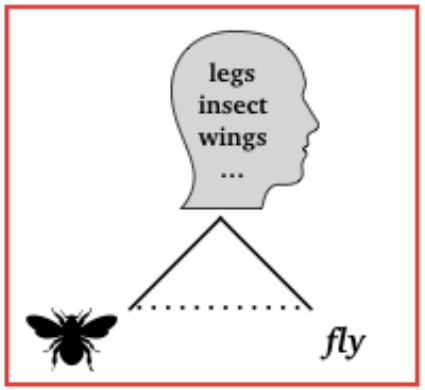
- Meaning > Reference
- Because we understand the expression *President of Egypt*, we can use it to refer to a particular individual at any given time
  $\longrightarrow$ **Sense** (aka Intension)

Concepts

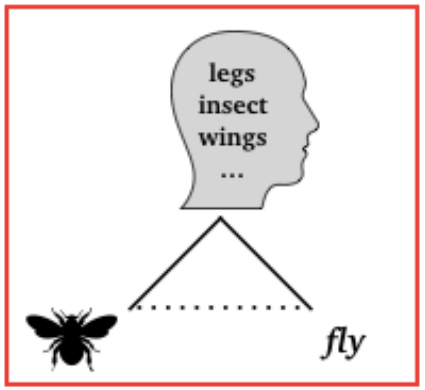


The Semiotic Triangle
Ogden/Richards (1923)

- Level needed between words and the world: *a mental representation*

(Credit: Handke 2012)

Concepts



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Ogden/Richards (1923)

- Level needed between words and the world: *a mental representation*
- Hypothesize that the sense of words, while mental, is not visual but abstract: **a concept**

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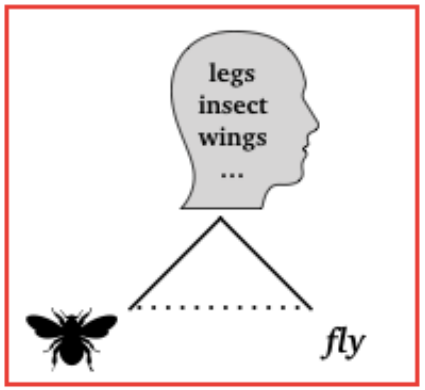
Concepts



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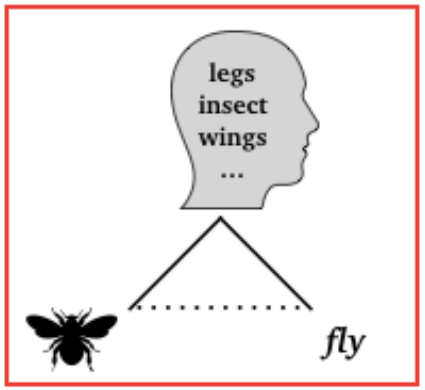

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- Question 1: What form can we assign to concepts?
- Question 2: How do children acquire them, along with their linguistic labels?

(Credit: Handke 2012)

Necessary and sufficient conditions

- x is a lion if and only if L.
- where L is a list of attributes
  - x is an animal,
  - x has four legs,
  - x is a carnivore,
  - x is a feline,
  - x has a mane, ...

Class Activity

Say words are labels for concepts, and a concept can be defined by a set of necessary and sufficient conditions (attributes). For each word, establish sets of attributes that would distinguish it from its companions in the group:

1. cake biscuit/cookie bread roll cracker
2. boil fry bake simmer grill roast

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Prototype Theory

Prototype Theory (Eleanor Rosch, 1970's): Theory to represent idea of family resemblances (Wittgenstein)

- **Prototype**: an "ideal" or "typical" example of a category
- A test case is compared with prototype, and if similar, will be considered a member of the category, otherwise it will not.
- Notion of **fuzzy boundaries**: some members are "better" members than others.
- Other approaches to typicality include Frames (Fillmore, 1982) and Idealized Cognitive Models (Lakoff, 1987).

Conceptual Theories

- word-fields
- componential analysis
- semantic networks: computational approach
- prototype theory: cognitive approach
- meaning postulates: logic-based

(Credit: Handke 2012)

Approach 1: Decompositional Semantics

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boy	girl
+ human — female — adult	+ human + female — adult

man	woman
+ human — female + adult	+ human + female + adult

Word Meaning?

He scored with his left **foot**[1].

They made camp at the **foot**[2] of the mountain.

I ate a **foot**[3]-long hot dog.

Lexical Relations and Meaning

Lexical relations are central to the way speakers and hearers construct meaning

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1 a. My bank manager has just been murdered.
   b. My bank manager is dead
   c. My bank will be getting a new manager

2 a. This bicycle belongs to Sinead.
   b. Sinead owns this bicycle.
   c. Sinead rides a bicycle.

3 a. Rob has failed his statistics exam.
   b. Rob hasn't passed his statistics exam.
   c. Rob can't bank on a glittering career as a statistician.

Lexical Semantics

1. Represent the meaning of each word in the language; and
2. Show to the meanings of words in a language are interrelated

What can we do with Lexical Semantics?

- Recognize word senses in text (manually and automatically)
- Define similarities between words
- Determine how strongly a verb "goes with" its subject (selectional preferences)
- Recognize and interpret figurative uses of words
- Describe relations between words (or better, between word senses)

Lexical Relations

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   - couch/sofa boy/lad lawyer/attorney large/big
2. **Antonymy**: Words which are opposite in meaning
   - dead/alive pass/fail hit/miss (complementary)
   - hot (warm tepid cool) cold (gradable)
   - (go) up/down (turn) right/left (reverses)
   - own/belong to employer/employee (converses)

Lexical Relations

3. **Hyponymy**: Relation of (taxonomic) inclusion, aka subset
   - *dog* and *cat* are hyponyms of *animal*
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5. **Meronymy**: *Part-whole* relationship between lexical items
   - *cover* and *page* are meronyms of *book*
   - *engine* and *door* are meronyms of *car*

Lexical Relations

6. **Homonymy**: Unrelated senses of the same phonological word
   - lap/lap ring/wring bear/bear not/knot

Lexical Relations

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   - lap/lap ring/wring bear/bear not/knot
7. **Polysemy**: Like homonymy, but senses are judged to be related
   - **hook** (n): **1**. a piece of curved material. **2**. a trap or snare. **3**. short for fish-hook. **4**. something that attracts. ...

Problem with pinning down word meaning

1. Collocations: e.g. *strong* vs. *powerful*
   - *strong argument* and *powerful argument*
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   - The bears are here for the salmon run.
4. Ambiguity and vagueness: Do the uses of *run* above have different senses (ambiguous), or share the same sense (vague)?

Class activity: Word senses of "SHOWER"

- Handout: corpora (BNC) examples of uses of *shower*
- `https://www.vecchi.com/eva/teaching/embeddingsNLP/shower_example.pdf`
- How many senses does *shower* have?
- Note: disregard *shower* if it occurs in a compound noun (e.g. *shower curtain*)

(Credit: Teufel 2017 T673 Lexical Semantics)

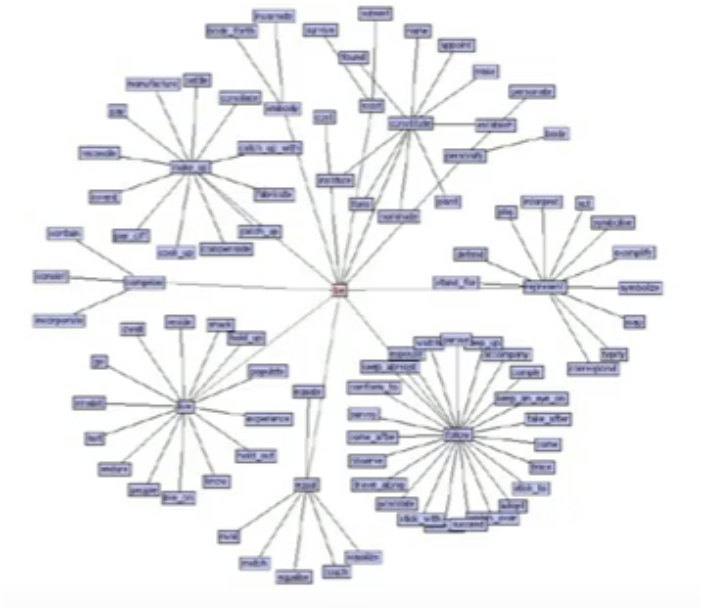
Noun

- S: (n) **shower#1** (a plumbing fixture that sprays water over you) *"they installed a shower in the bathroom"*
- S: (n) **shower#2**, shower bath#2 (washing yourself by standing upright under water sprayed from a nozzle) *"he took a shower after the game"*
- S: (n) **shower#3**, rain shower#1 (a brief period of precipitation) *"the game was interrupted by a brief shower"*
- S: (n) **shower#4**, cascade#3 (a sudden downpour (as of tears or sparks etc) likened to a rain shower) *"a little shower of rose petals"; "a sudden cascade of sparks"*
- S: (n) exhibitor#1, exhibitioner#1, **shower#5** (someone who organizes an exhibit for others to see)
- S: (n) **shower#6** (a party of friends assembled to present gifts (usually of a specified kind) to a person) *"her friends organized a baby shower for her when she was expecting"*

Verb

- S: (v) lavish#1, **shower#1** (expend profusely; also used with abstract nouns) *"He was showered with praise"*
- S: (v) **shower#2** (spray or sprinkle with) *"The guests showered rice on the couple"*
- S: (v) **shower#3** (take a shower; wash one's body in the shower) *"You should shower after vigorous exercise"*
- S: (v) **shower#4**, shower down#1 (rain abundantly) *"Meteors showered down over half of Australia"*
- S: (v) **shower#5** (provide abundantly with) *"He showered her with presents"*

Approach 2: Semantic Ontologies and WordNet



- WordNet is a lexical resource that organizes words according to their semantic relations
- Words have different senses
- Each sense is associated with a synset (set of words that are roughly synonymous for a particular sense)
- These synsets are associated with one another using semantic relations (note synonymy is treated differently)

Word meaning in WordNet

fish#1 (any of various mostly cold-blooded aquatic vertebrates usually having scales and breathing through gills)

- aquatic vertebrate (animal living wholly or chiefly in or on water)
- vertebrate, craniate (animals having a bony or cartilaginous skeleton with a segmented spinal column and a large brain enclosed in a skull or cranium)
- chordate (any animal of the phylum Chordata having a notochord or spinal column)
- animal, animate being, beast, brute, creature, fauna (a living organism characterized by voluntary movement)
- organism, being (a living thing that has (or can develop) the ability to act or function independently)
- living thing, animate thing (a living (or once living) entity)
- whole, unit (an assemblage of parts that is regarded as a single entity)
- ...

Limitations of WordNet and Semantic Ontologies

- WordNet is a glorified thesaurus
- Requires many years and depends on skilled lexicographers, inconsistencies throughout the resource
- Ontology is only as good as ontologist(s) - it is not only data

Approach 3: Distributional semantics

Landauer and Dumais 1997, Turney and Pantel 2010, ...

he curtains open and the nnnn shining in on the barely
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rough the night with the nnnn shining so brightly , it
made in the light of the nnnn . It all boils down , wr
surely under a crescent nnnn , thrilled by ice-white
sun , the seasons of the nnnn ? Home , alone , Jay pla
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un and the temple of the nnnn , driving out of the hug
in the dark and now the nnnn rises , full and amber a
bird on the shape of the nnnn over the trees in front
But I could n't see the nnnn or the stars , only the
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they love the sun , the nnnn and the stars . None of
the light of an enormous nnnn . The plash of flowing w
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Thanks, see you tomorrow!

https://www.vecchi.com/eva/teaching/embeddingsNLP.html