What is meaning?

- No one knows for sure...
- Go read *http://plato.stanford.edu/entries/meaning/*...
- One of the most fundamental human faculties.
- Without the ability to process and communicate meaning, humans wouldn't have built complex artifacts and societies.
- Complex thoughts need a powerful tool to be conveyed efficiently and accurately, without relying on pointing/miming, etc.

Meaning is reference

- We use words to *refer*, i.e. talk *about* things in the world.
- There is a *correspondence* between fragments of a language and state-of-affairs in the world.
- So... we can evaluate the truth of sentences.
- Tarski: *Snow is white* is true iff snow is white.
- Referential theories of meaning are truth-theoretic.

Sense and reference (Frege)

- The morning star and the evening star are the same planet in the real world: Venus.
- The referent of both morning star and evening star are the same.
- But for someone who doesn't know they are the same, they are two different concepts.
- Separate 'sense' from 'reference'?

Meaning is conceptual

- Psycholinguistic tradition.
- Words are linked through associations which can be reliably extracted from humans.
  - Similarity: is a dog more similar to a cat or to an elephant?
  - Priming: is the word *cat* recognised quicker once I've seen *dog*?
  - Categories: cluster the following into sensible categories: *dog, fork, knife, cat, mouse, hammer, plate, screwdriver*

Meaning is use

- Distributionalist tradition (Harris, Firth in linguistics; Wittgenstein in philosophy).
- Firth: “You shall know a word by the company it keeps”.
- Wittgenstein: no essential properties, just context of utterance.

Meaning is signal passing

- The point of language is to communicate.
- Communication involves some signal passing between A and B. It assumes A $\neq$ B.

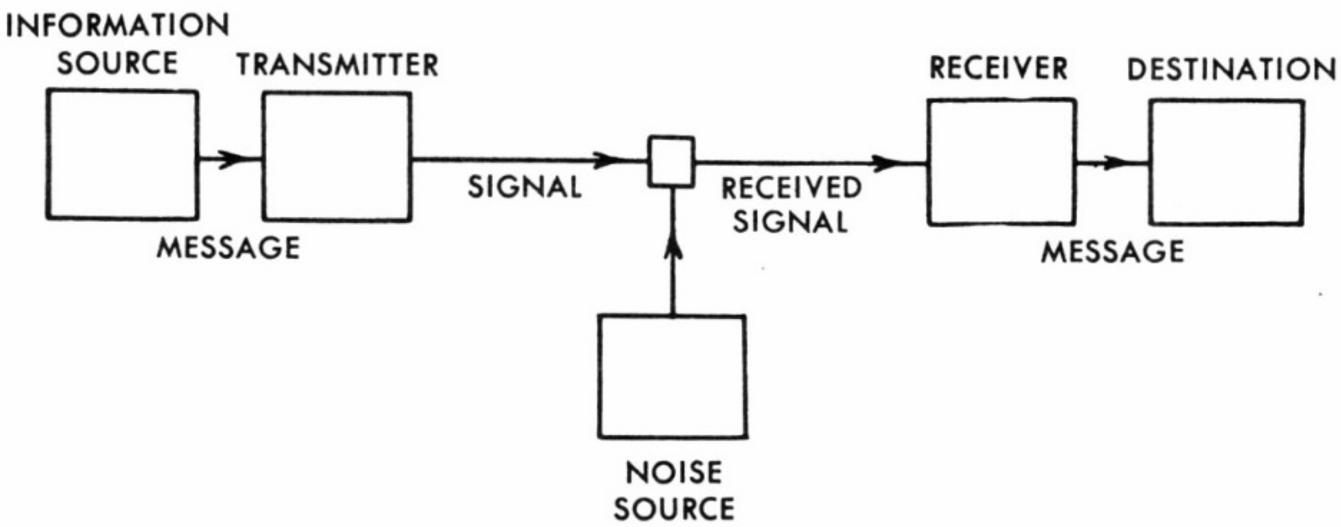

Fig. 1. — Schematic diagram of a general communication system.

Computational semantics: an overview

Aspects of computational semantics

- Syntax-semantics interface, parsing.
- Inference and entailment.
- Compositionality.
- Representation of meaning (including multimodal aspects).
- Semantic ambiguity.
- Lexical semantics and ontologies.
- ...

Syntax-semantics interface

- To what extent does the meaning of an expression depend on its syntactic structure? (And the other way round!)
- Note: at least in its referential sense, meaning is universal. Given the real world, it is generally true that *dogs are mammals*. But this may be expressed in many different ways in different languages.
- More on this today!

Inference and entailment

- Humans excel at inference:
  - The cat is on the sofa $\longrightarrow$ There is an animal on the sofa.
  - Google may buy Twitter $\longrightarrow$ Twitter may be sold to Google.
  - All cats are mammals $\longrightarrow$ My cat is a mammal.
  - Is the window open? $\longrightarrow$ I am cold.
- Some aspects of inference can be obtained through referential theories of meaning (the more logical ones). Others require more 'soft' reasoning.

Compositionality

- Frege: the meaning of an utterance is a function of the meaning of its parts.
  - *Bob is the fastest man on Earth.*
- Although... the meaning of words depends on the utterance they occur in.
  - *Bob is the fastest man on Earth.*
  - *Bob is the fastest man on Mars.*
  - Who is faster?

  - *I want a new bat for Christmas.*
  - *I saw several bats in the cave.*

Representations of meaning

- How we represent meaning depends heavily on the aspect we wish to emphasise. The meaning of a word can be:
  - a set (referential theories);
  - a structure in an ontology (conceptual theories);
  - a vector (distributional theories);
  - a combination of the above??
- The latest distributional representations do not only encapsulate linguistic meaning but also perceptual information.

Semantic ambiguity

- As in syntax, we find in ambiguity in semantics, both at the word and structural level.
- Word sense ambiguity: *bat, bank,*
- Structural ambiguity: *All students read a book.*
  - There is a book such that all students read that book.
  - For every student, that student read a book.
- Does it make sense to speak about word senses? Those are often arbitrary (compare two dictionaries!)
- Do humans always disambiguate? Probably not. (See underspecification.)

Lexical semantics and ontologies

- Can we write down the world's knowledge? Manually? Automatically?
- Can we formalise lexical relations such as synonymy, antonymy, hypernymy:
  - Synonymy: two words mean the same thing (or nearly the same thing?)
  - Antonymy: two (or several) words have incompatible meanings (*dead/alive*).
  - Hypernymy: the *is-a* relationship.

Formal semantics, briefly

Model-theoretic semantics

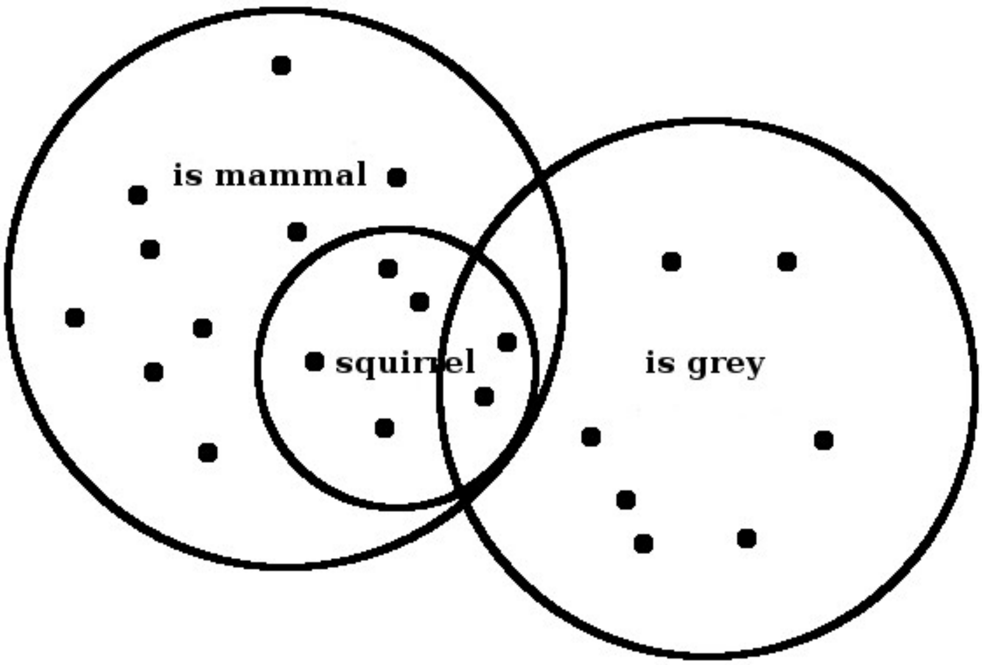

Photo: kuhmi, flickr, CC

Argument-predicate structure

- A model can be formally expressed in terms of predicates and their arguments:
  - One-place predicates: *squirrel, sleep, grey...* Those select a set of individuals (the set of squirrels, the set of things that sleep, the set of grey things...)
  - Two-place predicates: *love, friend-of, born-in...* Those select a set of ordered pairs of individuals (e.g. (Ada_Lovelace,1815), (Ferdinand_de_Saussure,1857)).
- We usually speak of the 'extension' or 'denotation' of the expression to refer to the individuals picked by the predicate.

Truth

- The functional view of model theory is that we can see the predicate-argument structure as a set of functions returning true of false according to the state of the world under consideration.
- Examples:
  - I(love(squirrel,nut)) = 1
  - I(born_in(Ada_Lovelace,2016)) = 0
- We talk of an ‘interpretation function’. The interpretation function can also return actual entities in the model:
  - I(squirrel(x)) = the set of squirrels

First-order logic

- Fix the state-of-affairs under consideration.
- Fix operators and their meaning.
- Define variables and their meaning.
- Evaluate formulas (predicates, sentences) according to the interpretation function.

Example

- Let's have a world with two squirrels, Steve and Squeaky. Both are sleeping.
- The denotation of the predicate squirrel, *squirrel'*, is the set {Steve, Squeaky}.
- Let's introduce some operators:
  - quantifiers: $\exists$ and $\forall$;
  - conjunction operators: $\wedge \longrightarrow$;
  - negation: $\neg$.

Example

- $P_1 = \exists x[squirrel'(x) \land sleep'(x)]$
  There exists an x such that x is a squirrel and x sleeps.
  $I(P_1) = 1$
- $P_2 = \forall x[squirrel'(x) \longrightarrow sleep'(x)]$
  For all x, it holds that if x is a squirrel then x sleeps.
  $I(P_2) = 1$
- $P_3 = \neg squirrel'(Steve)$
  Steve is not a squirrel.
  $I(P_3) = 0$

Syntax-semantics interface

- How can we relate the syntactic structure of sentences to their meaning?
- There isn't a one-to-one correspondence between syntactic and semantic structures.
- Squirrels like nuts:
  - S(NP(N(squirrels)) VP(V(like) (NP(N(nuts)))))
  - like'(squirrel',nut')
- Nuts are liked by squirrels:
  - S(NP(N nuts)) VP(V(are) V(V(liked) PP(P(by) N(squirrels))))
  - like'(squirrel', nut')

Syntax-semantics interface

- We need a representation which allows us to compactly express generalisations about the correspondence between syntax and semantics.
- In other words, we need to build the semantic representation of a sentence as we build its syntax (composition process).
- Let's first look at the formal semantics interpretation of this process.
- Then, we will consider a computational representation that allows us to do the same.

Example

- Here is a lambda term:
  - $\lambda x.sleep(x)$
- The prefix $\lambda x.$ binds the variable x in $sleep(x)$. It is said to *abstract* over x.
- Let's add an argument to the right of our expression:
  - $\lambda x.sleep(x)(kitty)$
- This is expression is called a *functional application*. The left-hand side is the *functor* and the right-hand side the *argument*.
- Performing β-conversion, we obtain $sleep(kitty)$.

Functional application

- Functional application has the form $Functor(Argument)$.
- It triggers β-conversion, by which the lambda-bound variables are replaced by the argument:
    - we strip off the λ prefix;
    - we remove the argument;
    - we replace all occurrences of the *lambda*-bound variable by the argument.

Beyond reference

Ontologies and lexical resources

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November 2016

Problems with set theory: The meaning of life

life'

Problems with set theory: What is (a) football?

(Search results on duckduckgo.com.)

Problems with set theory: Speaker dependence

- Meaning is speaker-dependent.
- What I mean by *cup* is not what you mean by *cup* (Labov 1978, Wierzbicka 1984).

The need for world knowledge

- It is not sufficient for a robot to be able to translate natural language into logical forms.
- It must be able to *recognise* objects and concepts, and to *reason* over their attributes:
  - A football is a round object made of leather or plastic.
  - If something is round, it will roll when pushed.

Intension

- There are different notions of *intension*. Today, we'll look at the 'informal' one.
- Intension is the conceptual content that allows us to identify an extension.
- E.g. I may never have seen a unicorn, but I have read enough descriptions of unicorns that I would know one if I saw it.

Structural approaches to world knowledge

- Structural representations of conceptual knowledge are known as ‘lexical resources’ or ‘ontologies’.
- **Lexical resources** mostly include information about the meaning of content words (sometimes including some proper nouns).
- The term **ontology** comes from the philosophical study of ‘what there is’. Ontologies mostly contain information about attributes of individuals (e.g. Mount Everest is 8848m high).
- Lexical resources / ontologies are structured in that they encapsulate specific relations about the meaning of a word.

WordNet

WordNet overview

- An online lexical database originally developed at Princeton University (for English!) Available at http://wordnet.princeton.edu/
- Open multilingual WordNet: a project by Francis Bond in Singapore. Available at http://compling.hss.ntu.edu.sg/omw/. (150 languages)
- WordNet can be used through NLTK:
    - *import nltk*
    - *from nltk.corpus import wordnet as wn*

WordNet structure

- Nouns, verbs, adjectives and adverbs organised into synonym sets (*synsets*).
- Each synset represents a *concept*: unlike in dictionaries, words are organised by meaning, not word form.
- Synsets are linked through various relations: synonymy, antonymy, hyponymy, meronymy, troponymy, entailment...
- WordNet 3.0: 117,000 synsets (mostly nouns: 82,000).

The lexical matrix

Word meanings	Word forms bank	eggplant	aubergine
C1	X		
C2	X		
C3		X	X

- *bank* is polysemous: it has more than one sense (corresponding to more than one concept).
- *eggplant* and *aubergine* are synonymous: the two word forms correspond to one concept only.
- Each WordNet synset corresponds to a word meaning (concept) rather than a word form. It lists different word forms for that concept.

Lexical relations: hyponymy

- Hyponymy is the *is-a* relation (also called *taxonomic* relation):
  - *cat* is a hyponymy of *mammal*;
  - *mammal* is a hypernym of *cat*.
- Hyponymy is the main relation in the WordNet noun hierarchy.
- Two synsets which are hyponyms of the same synset are called *co-hyponyms*. *cat* and *dog* are co-hyponyms.

Lexical relations: meronymy

- Meronymy is the *part-of* relation:
  - trunk is a meronym of *tree*;
  - *tree* is a holonym of *trunk*.
- There are several types of meronyms, depending on the notion of ‘part’ under consideration:
  - part-meronyms: *trunk/tree*
  - substance-meronyms: *heartwood/tree*
  - member-holonyms: *tree/forest*

Lexical relations: troponymy and entailment

- Troponymy and entailment are verb relations.
- The verb Y is a troponym of the verb X if Y means doing X in some particular manner (*fly* is a troponym of *move*).
- The verb Y is entailed by X if by doing X you must be doing Y (*sleep* is entailed by *snore*).
- Note: the verb relations are not well documented in WordNet.

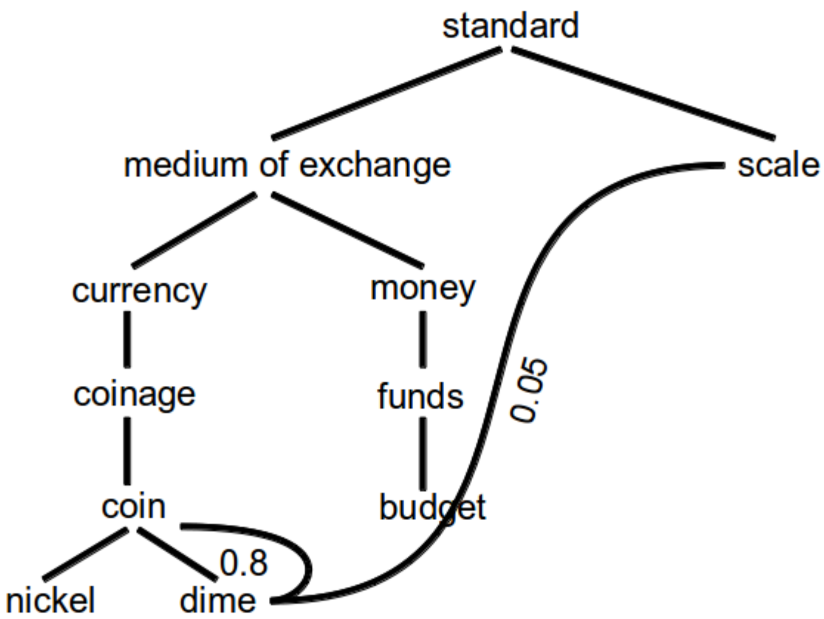
The noun hierarchy

- The noun hierarchy is organised as a tree, with one top node: *entity*.
- Entities can be *abstractions* or *physical entities*.
- Warning: the top of the WordNet hierarchy does not necessarily look sensible...

WordNet similarity

- It is possible to calculate similarity between synsets by following the WordNet graph.
- Intuition: the shorter the path between two nodes, the more similar two words are.

WordNet similarity



WordNet similarity

- Easiest way to compute similarity is by path length:

$$sim_{path}(s1, s2) = -log\, pathlen(s1, s2) \tag{1}$$

where *pathlen* is the number of edges in the shortest path.
- Problem: not every link in the path has the same length:
puppy is-a *dog*
phytoplankton is-a *living_thing*