Semantic analysis of text and speech

SGN-9206 Signal processing graduate seminar II, Fall 2007

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Outline

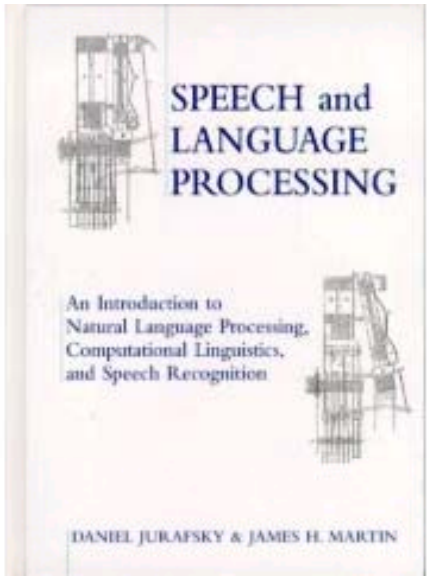
- What is semantic analysis
- Terminology and related concepts
- Viewpoints and approaches to semantic analysis
- Applications
- Scope of this course

Course implementation

- See the web-page

  http://www.cs.tut.fi/~klap/SGN-9206/

- Book ”Speech and language processing” by Jurafsky & Martin + selected articles

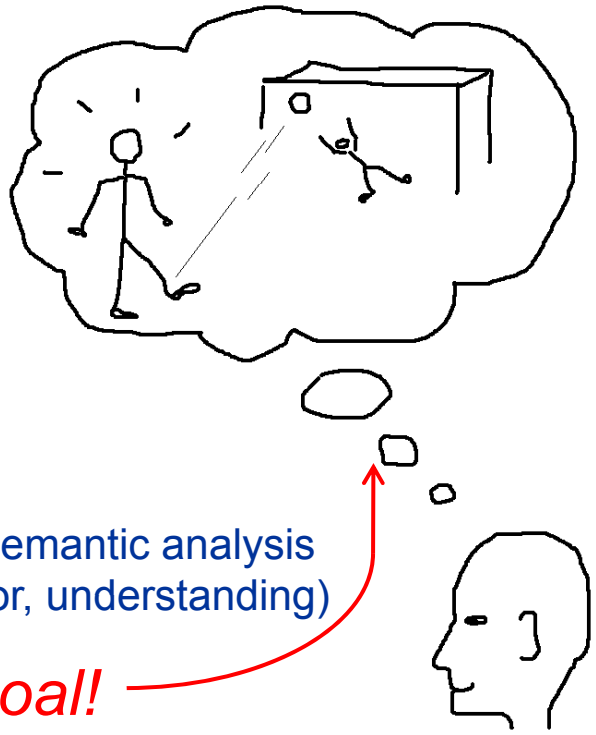


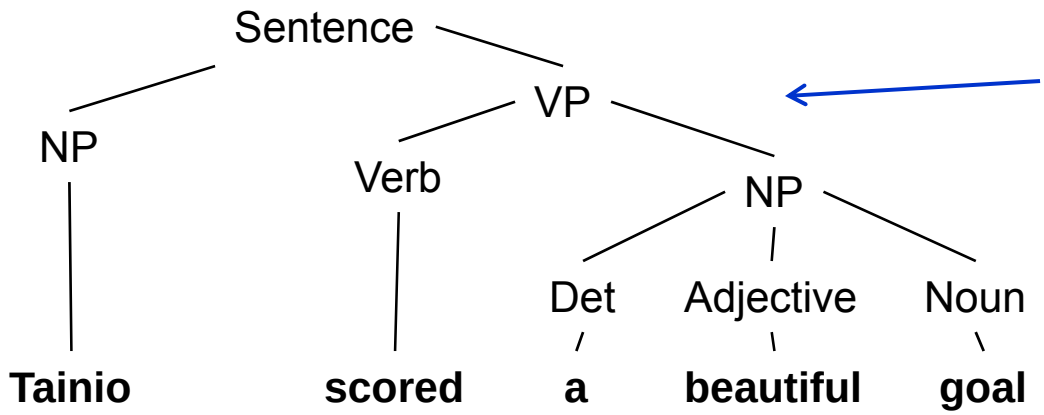
What is semantic analysis?

Language generation

Tainio scored a beautiful goal!

Semantic analysis (or, understanding)





Syntactic parsing

(NP = noun phrase, VP = verb phrase)

Morphology: score-d

Semantic analysis

= figure out the meaning of linguistic input (construct meaning representations)

= process language to produce common-sense knowledge about the world (extract data and construct models of the world)

- Lexical semantics
  - meanings of component words
  - word sense disambiguation (e.g. ”country” in political or musical sense)
- Compositional semantics
  - how words combine to form larger meanings

- Roughly: semantic analysis ≈ understanding language

What is language ”understanding”

- What exactly is meant by ”understanding” an utterance?

1. Extracting knowledge about the world from the utterance
   - in the case of concrete, physical things: ultimately translating linguistic input to physical and geometrical terms... uh huh
2. ”Understanding language means *knowing how to use it. - - -* To master a technique.” [Wittgenstein]
3. At matriculation examination: the student is presented with a portion of text or speech and then asked questions about it
4. ...

- It is difficult to give one generic definition
- Thinking of a concrete *application* of semantic analysis is probably the best way of defining the problem

Semantic analysis vs. other areas of natural language processing

- Phonetics: the study of linguistic sounds
- Morphology: the study of the meaning components of words
  - scored = score –d = Verb *score* + past tense
  - employ, employee, employment, ...
- Syntax: the study of the structural relationship between words
  - see the parse tree of the football example
- Semantics: the study of meaning
- Pragmatics: the study of how language is used to accomplish goals; discourse conventions (turn taking, politeness, etc.); relation between language and context-of-use

- Semantic analysis often requires syntactic parsing, pragmatics etc. too (in some form; not necessarily formal linguistics)

Approaches to semantic analysis

- Predicate logic
  - The sentence
    ”a restaurant that serves Chinese food near TUT”
    corresponds to the meaning representation
    $\exists x\ Restaurant(x) \wedge Serves(x, ChineseFood) \wedge Near(LocationOf(x), LocationOf(TUT))$
  - semantic analysis = creating meaning representations from ling. input
  - logical propositions enable inference
  - scalability problem (large vocabulary or unrestricted domain)

Approaches to semantic analysis

- Statistical approach
  - statistical machine translation (as an example)
    - find a bilingual database (e.g. parliamentary proceedings in two languages)
    - learn an alignment: words and phrases that correspond to each other
    - learn word order in the target language (probabilities of target word strings)
    - translate by matching source fragments agains a database of real examples, identifying the corresponding translation fragments, and then recombining these to give the target text
    - example:

(1) He buys a book on international politics.

(2) a. He buys a notebook.
Kare wa nōto o kau.
HE topic NOTEBOOK obj BUY.

b. I read a book on international politics.
Watashi wa kokusai seiji nitsuite kakareta hon o yomu.
I topic INTERNATIONAL POLITICS ABOUT CONCERNED BOOK obj READ.

(3) *Kare wa kokusai seiji nitsuite kakareta hon o kau.*

[H.Somers, "Review article: Example-based machine translation"]

Approaches to semantic analysis

- Information retrieval
  - Google solves a certain part of the problem in a statistical way: answers to ”trivial” kind of questions can be located using a web search engine
  - assumes an database (Internet) and a clever page ranking system

Approaches to semantic analysis

- Domain knowledge driven analysis
  - expect certain ”slots” of information to be filled in
  - football example in the beginning: hearer is aware of missing details and may expect to hear them
  - another example: booking a flight

→ restricting to a certain domain allows the use of specific **patterns**, rules, expectations etc.

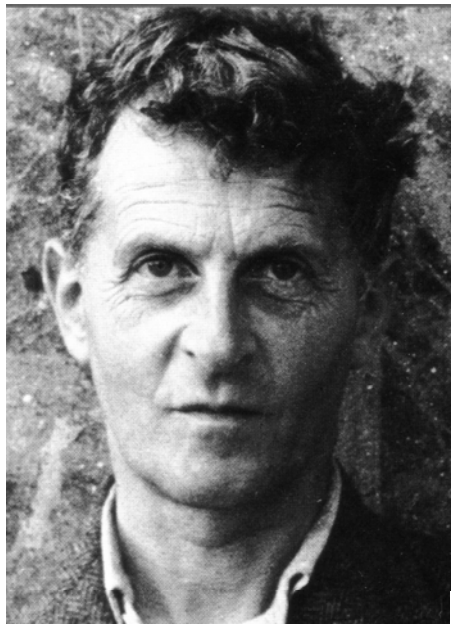
- customer at a restaurant
- buying train tickets
- ...

  - pragmatics, socially probable set of ”moves” in a certain context

C_1:	I need to travel in May.
A_1:	And, what day in May did you want to travel?
C_2:	OK uh I need to be there for a meeting that's from the 12th to the 15th.
A_2:	And you're flying into what city?
C_3:	Seattle.
A_3:	And what time would you like to leave Pittsburgh?
C_4:	Uh hmm I don't think there's many options for non-stop.
A_4:	Right. There's three non-stops today.
C_5:	What are they?
A_5:	The first one departs PGH at 10:00am arrives Seattle at 12:05 their time. The second flight departs PGH at 5:55pm, arrives Seattle at 8pm. And the last flight departs PGH at 8:15pm arrives Seattle at 10:28pm.
C_6:	OK I'll take the 5ish flight on the night before on the 11th.
A_6:	On the 11th? OK. Departing at 5:55pm arrives Seattle at 8pm, U.S. Air flight 115.
C_7:	OK.

Figure 19.5 A fragment from a telephone conversation between a client (C) and a travel agent (A) (repeated from Figure 19.1).

Ludwig Wittgenstein (1889-1951)



- Let's contrast his early and later philosophy
- Early philosophy [*Tractatus Logico-Philosophicus*]
  - Language consists of propositions, the world consists of facts. These two connect.
    - Language ←→ World
    - propositions ←→ facts
    - elementary propositions ←→ states of affairs
    - names ←→ objects
  - *Facts* are composed of *states of affairs*, which are composed of *objects*
    - 1. The world is all that is the case
    - 2. What is the case – a fact – is the existence of states of affairs.
    - 3. A logical picture of facts is a thought
    - 4.01 A proposition is a picture of reality
    - ....
    - 7. Whereof we cannot speak, thereof we must be silent.

[A.C.Grayling, "Wittgenstein", Oxford Univ. Press]

Ludwig Wittgenstein (1889-1951)

- Wittgenstein later rejected his early philosophy
  - **early**: language has a single underlying logic, which can be explained by analyzing language and the world and their (picturing) relation
  - **later**: language is a vast collection of different practices
- Later philosophy
  - language resembles a ”game”: it is based on agreed-upon rules
  - what consitutes a rule is our collective use of it (general practice, custom)
  - understanding language means knowing how to use it
- Lesson to learn: language ≠ propositional logic
  - language, concepts & expressions are dynamic (not objective and rigid)
  - ”propositional logic” (~ early phi.) vs. ”statistics of usage” (~ later phi.)
- Predicate logic may still be good for meaning representations

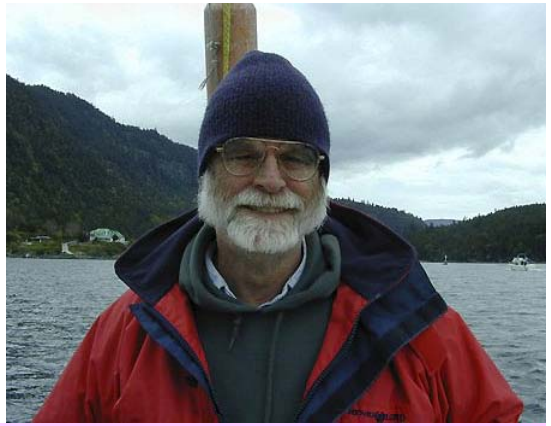
Applications of semantic analysis

- Information extraction
  - extract small amounts of pertinen information from large bodies of text
  - find an answer to a question for example
- Text summarization
- Information retrieval (cf. Google) and document classification
- Machine translation
- Human-computer interaction
  - conversational agents: book plane tickets, query for a restaurant, ...
- Expert systems
  - free help: ”please show me how to widen the margins of my document”
- Surveillance

Applications of semantic analysis

- Several well-defined problems and applications yet unsolved
- List on the right is from Jim Gray's Turing talk: "*What next? A few remaining problems in IT*"

  # 9. Build a system that, given text corpus, can answer questions about the text and summarize it as quickly and precisely as a human expert.



Jim Gray

The List (Red is Turing Complete)

1. Devise an architecture that scales up by 10^6.
2. The Turing test: win the impersonation game 30% of the time.
   a. 3.Read and understand as well as a human.
   b. 4.Think and write as well as a human.
3. Hear as well as a person (native speaker): speech to text.
4. Speak as well as a person (native speaker): text to speech.
5. See as well as a person (recognize).
6. Illustrate as well as a person (done!) but virtual reality is still a major challenge.
7. A copy-protection and payment scheme that protects IP owner and user.
8. Remember what is seen and heard and quickly return it on request.
9. Build a system that, given a text corpus, can answer questions about the text and summarize it as quickly and precisely as a human expert.
10. Do 9 for Sounds: conversations, music.
11. Do 9 for Images: pictures, art, movies.
12. Simulate being some other place as an observer (Tele-Past) and a participant (Tele-Present).
13. Automatic Programming: Given a specification, build a system that implements the spec. Prove that the implementation matches the spec. Do it better than a team of programmers.
14. Build a system used by millions of people each day but administered by a ½ time person.
15. Do 15 and prove it only services authorized users.
16. Do 15 and prove it is almost always available: (out less than 1 second per 100 years).

Why is semantic analysis difficult

- Ambiguity of language
  - ”***I made her duck***”, for example, could mean [Jurafsky&Martin]
    - I cooked waterfowl for her.
    - I created the (plaster?) duck she owns.
    - I caused her to quickly lower her head or body.
    - I waved my magic wand and turned her into undifferentiated waterfowl.
- Commonsense knowledge is typically omitted from social communications
  - example: ”Laura hid George’s car keys. He was drunk.”
- Language understanding often requires unsound inference
  - abduction ((A $\Rightarrow$ B) and B) → infer A (which is not sound logic)
- Language is dynamic: allows defining new terms, allegory, etc.
- Symbol grounding

Why is semantic analysis important?

- Power of language: transfer thoughts from a head to another
  - transfer between brains and a computer as well?
- Language is a very generic representation (the most generic?)
  - words can describe almost anything
  - ability to reason with language → ability to reason about almost anything (assuming the ability to construct a model of the world, too)
  - symbol grounding problem

- Example: a person reading a novel

  → a large part of reader's conscious thoughts stem from the text of the book and the meaning representations thus evoked

Comparison with artificial intelligence (AI)

- ”Educate” computers instead of program them?
  - the idea: program only a basic learning algorithm, then let it learn the rest
  - but: sensory abilities (vision, hearing) are missing too
  - but: it takes circa 20 years for a human being to ”grow up” mentally... the world is complex and many things are not what they seem
- The language understanding problem is sometimes characterized as “AI-complete”
  - requires extensive knowledge about the world and the ability to manipulate it
  - Turing test is based on this observation
  - solutions to toy problems often do not scale to wider domains
- Relation to compilers

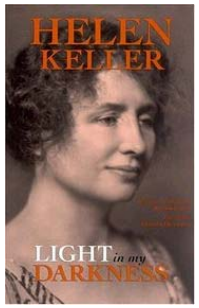
Resources: Web

- Why do semantic analysis now? There are some new resources
- Growth of the Internet has produced an important resource for semantic analysis
  - discussion forums, wiki, books, etc.
  - specific resources: WordNet (Princeton), FrameNet (Berkeley), ConceptNet (MIT)
  - machine translation: bilingual data repositories (official sources such as EU and parliaments) – many things have already been translated once

Resources: dictionaries

- Dictionaries like this existed for a long time [The new shorter Oxford English dictionary]

- How about analyzing meaning by looking up in a dictionary?!
  - breaking down words into ”simpler” words is not straightforward
  - symbol grounding problem: ”terminal” concepts must be associated with physical or sensory data
    - but: Helen Keller case (a deaf-blind college graduate)



timbrel /ˈtɪmbr(ə)l/ *n.* & *v. arch.* E16. [Perh. dim. of TIMBRE *n.*¹: see -EL².] **A** *n.* A musical percussion instrument, *esp.* one able to be held up in the hand, as a tambourine. E16. **B** *v.t.* & *i.* Infl. **-ll-**, ***-l-**. Play or accompany on a timbrel. E17.

Timbuctoo /tɪmbʌkˈtuː/ *n.* Also **Timbuktu**. M19. [*Timbuktu*, a town on the edge of the Sahara in Mali, W. Africa.] Any extremely distant or remote place.

time /tʌɪm/ *n.* [OE *tīma* = ON *tími* time, good time, prosperity, f. Gmc, f. base of TIDE *n.*, which was superseded by *time* in the strictly temporal senses.] **I 1** A finite extent of continued existence; e.g. the interval between two events, or the period during which an action or state continues; a period referred to in some way. OE. **b** In biblical translations: a space of time, usu. taken to be a year. LME. **c** *ellipt.* A long time. M19. **2** *sing.* & (now usu.) in *pl.* A period in history, a period in the existence of the world; an age, an era; *the time(s)*, the present age, the age being considered. OE. **3** With possess. or *of*: the period contemporary with the person specified. OE. **4** A period of existence or action; *spec.* a person's lifetime. OE. **b** The period of a woman's pregnancy or an animal's gestation. Cf. sense 13 below. OE. **c** *sing.* & (usu.) in *pl.* A woman's periods; menstruation. M16. **d** A person's term of apprenticeship. M17. **e** *Fencing.* The period of initiation and performance of an action, e.g. an opportunity to attack given by an opponent's making of a movement. E18. **f** A period of imprisonment. Chiefly in *do time*. *slang*. L18. **5** Length of time sufficient, necessary, or desired; available time, time at one's disposal; *Broadcasting* time in a transmission that can be bought, e.g. for advertising. ME. **b** Length of time taken to run a race or complete an event; progress in a race

Resources: WordNet (1985@Princeton →)

- Probably the most popular and widely used resource for SA
- Database of words
  - mainly nouns, verbs, and adjectives, organized into discrete senses (Fig.16.2)
  - linked by a few semantic relations such as the synonym and "is-a" hierarchical relations (Fig. 16.7)

The noun "bass" has 8 senses in WordNet.
1. bass - (the lowest part of the musical range)
2. bass, bass part - (the lowest part in polyphonic music)
3. bass, basso - (an adult male singer with the lowest voice)
4. sea bass, bass - (flesh of lean-fleshed saltwater fish of the family Serranidae)
5. freshwater bass, bass - (any of various North American lean-fleshed freshwater fishes especially of the genus Micropterus)
6. bass, bass voice, basso - (the lowest adult male singing voice)
7. bass - (the member with the lowest range of a family of musical instruments)
8. bass - (nontechnical name for any of numerous edible marine and freshwater spiny-finned fishes)

Figure 16.2 A portion of the WordNet 1.6 entry for the noun *bass*.

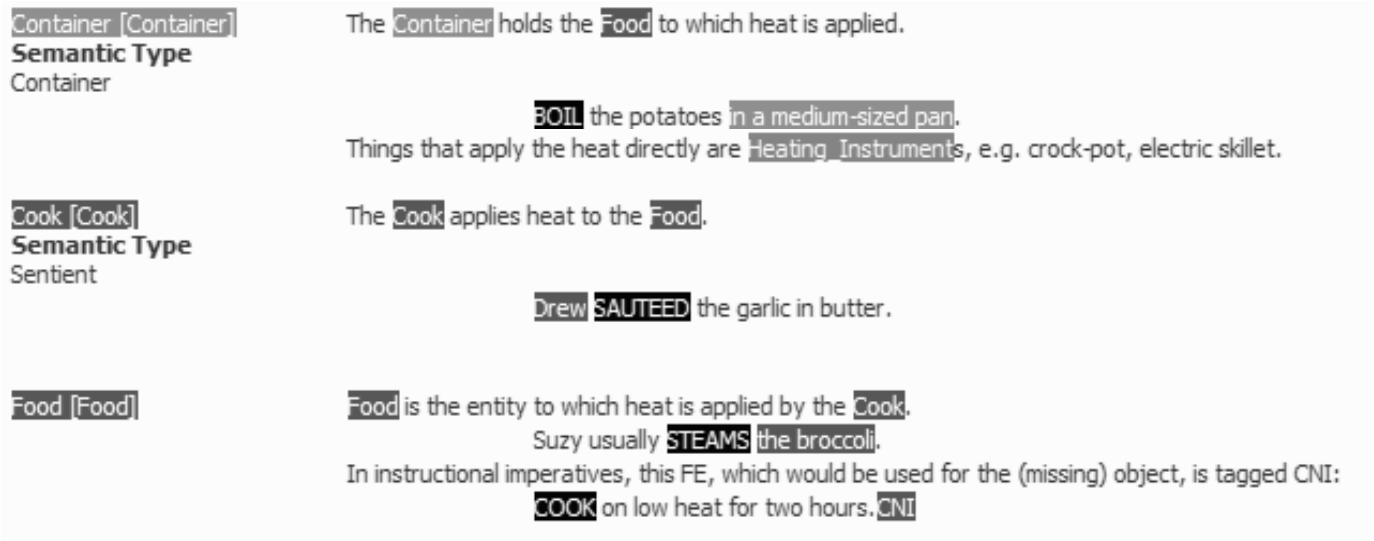
```
Sense 3
bass, basso --
(an adult male singer with the lowest voice)
=> singer, vocalist
   => musician, instrumentalist, player
      => performer, performing artist
         => entertainer
            => person, individual, someone...
               => life form, organism, being...
                  => entity, something
               => causal agent, cause, causal agency
                  => entity, something

Sense 7
bass --
(the member with the lowest range of a family of
musical instruments)
=> musical instrument
   => instrument
      => device
         => instrumentality, instrumentation
            => artifact, artefact
               => object, physical object
                  => entity, something
```

Figure 16.7 Hyponymy chains for two separate senses of the lexeme *bass*. Note that the chains are completely distinct, only converging at *entity*.

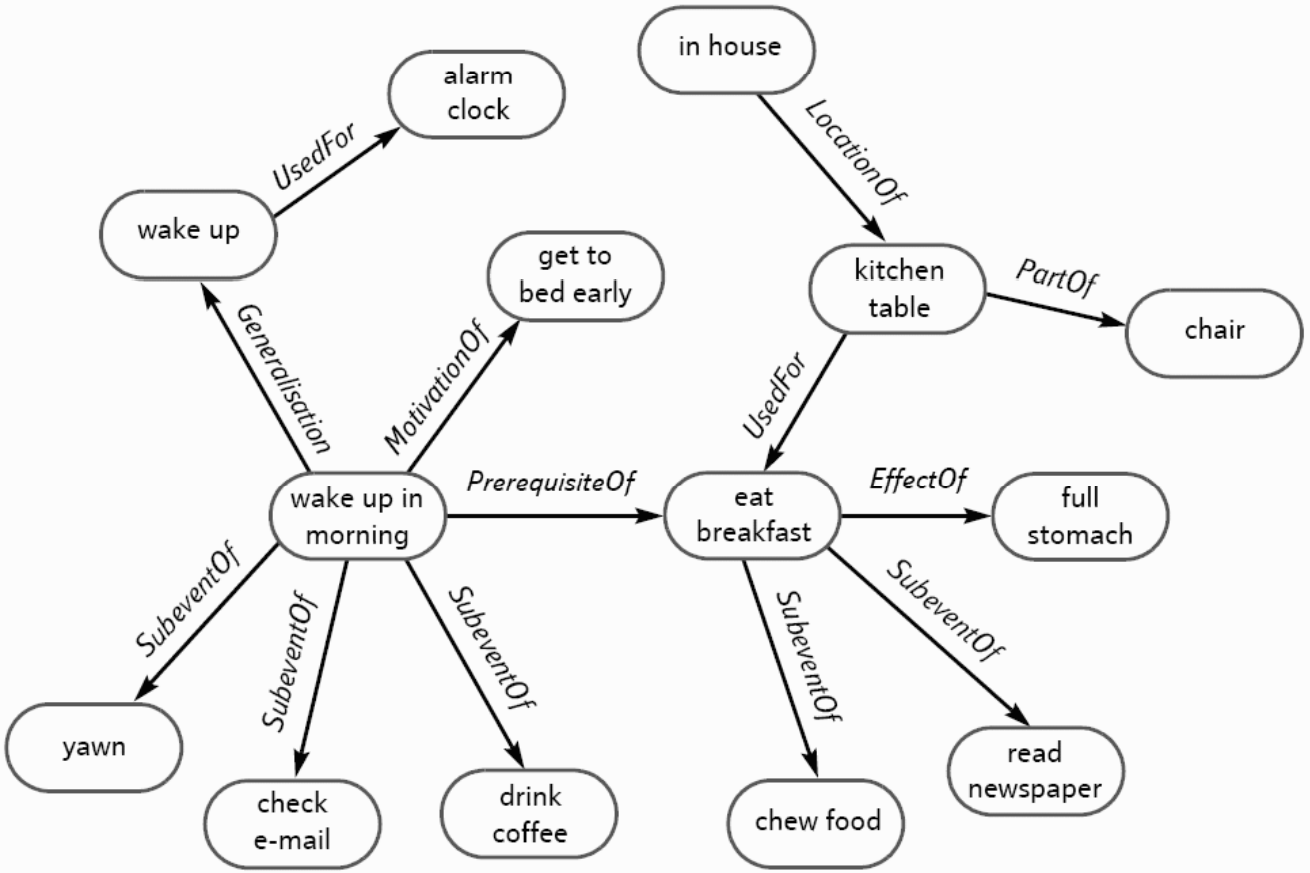
Resources: FrameNet (1997@Berkeley →)

- Semantic frame describes a certain situation, object, or event
- For example, the word *bake* has different senses which appear in different semantic frames
  - Apply_heat frame: ”*Michelle **baked** the potatoes for 45 minutes*.”
  - Cooking_creation frame: ”*Michelle **baked** her mother a cake for birthday*.”
  - Absorb_heat frame: ”*The potatoes have to **bake** for more than 30 minutes*.”
- Apply_heat frame includes of the following elements (and more)



Resources: ConceptNet (2002@MIT →)

- Richer set of semantic relations than in WordNet
  - WordNet: synonyms and is-a hierarchies
  - ConceptNet: EffectOf, DesireOf, CapableOf...
- ConceptNet
  - nodes: semistructured English fragments
  - archs: twenty semantic relations



Scope of this course

- Investigate different approaches to semantic analysis
- Discuss what works, what doesn't, and why
  - why some previous attempts failed?
  - why some simple-seeming approaches turn out good?
  - think creatively
  - view reviewed methods as a starting point, not as the final answer
- Three main goals
  1. learn the predicate logic approach
  2. learn some statistical techniques
  3. know the existing resources (WordNet, FrameNet, ConceptNet,...)
- Emphasis on text and not so much on speech

Seminar topics (choose yours)

- Predicate logic approach:
  Meaning representations. 45 min.
  First order predicate calculus. 45 min.
  Syntax-driven semantic analysis. 45 min
  Idioms, robustness, and special issues. 45 min
- Lexical semantics:
  Introduction to lexical semantics and WordNet (Princeton). 45 min.
  Word sense disambiguation. 45 min
  Latent semantic analysis. 45 min
- Information retrieval
  Classical methods. 45 min.
  How Google works? 45 min
- (Pragmatics. 2 x 45 min)
- Machine translation
  Introduction and overview. 45 min
  Statistical machine translation. 45 min