Semantic analysis of text and speech

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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


- Book "Speech and language processing" by Jurafsky & Martin
  + selected articles
What is semantic analysis?

Language generation

Semantic analysis (or, understanding)

Tainio scored a beautiful goal!

Syntactic parsing

(Morphology: score-d)

(sentence = NP, VP, Verb, Det, Adjective, Noun)
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
    \[
    \exists x \: \text{Restaurant}(x) \land \text{Serves}(x, \text{ChineseFood}) \land \text{Near}(\text{LocationOf}(x), \text{LocationOf}(\text{TUT}))
    \]
  - 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 against 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.
    2. 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

| C1: | I need to travel in May. |
| A1: | And, what day in May did you want to travel? |
| C2: | OK uh I need to be there for a meeting that's from the 12th to the 15th. |
| A2: | And you're flying into what city? |
| C3: | Seattle. |
| A3: | And what time would you like to leave Pittsburgh? |
| C4: | Uh hmm I don't think there's many options for non-stop. |
| A4: | Right. There's three non-stops today. |
| C5: | What are they? |
| A5: | 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. |
| C6: | OK I'll take the 5ish flight on the night before on the 11th. |
| C7: | 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 $\leftrightarrow$ World
    - propositions $\leftrightarrow$ facts
    - elementary propositions $\leftrightarrow$ states of affairs
    - names $\leftrightarrow$ 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 constitutes 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 pertinent 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.

**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. Read and understand as well as a human.
   b. 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.
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 $1/2$ 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 \((A \Rightarrow B) \text{ and } B \Rightarrow \text{ infer } A\) (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

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*timbre* /ˈtɪmbr(ə)l/ n. & v. arch. E16. [Perh. dim. of *timbre* n.\(^1\); see -EL.\(^2\).] A n. A musical percussion instrument, esp. one able to be held up in the hand, as a tambourine. E16. B v.t. & i. Inf. -II-., -I-. Play or accompany on a timbrel. E17.

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

*time* /taɪm/ n. [OE *tīma* = ON *timi* time, good time, prosperity, f. Gmc, f. base of *tīd* n., which was superseded by *time* in the strictly temporal senses.] I n 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)

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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. base (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.

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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