

# Semantic analysis of text and speech

*SGN-9206 Signal processing graduate seminar II, Fall 2007*

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## Outline

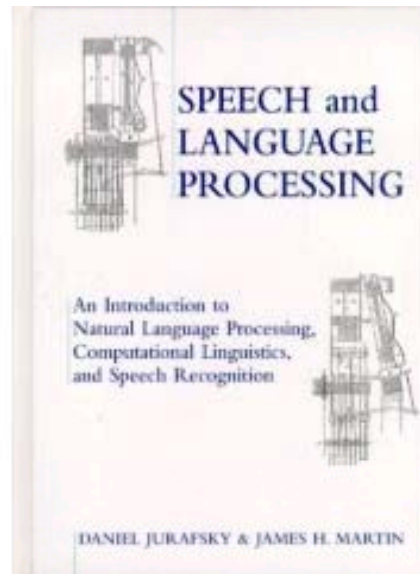
- What is semantic analysis
- Terminology and related concepts
- Viewpoints and approaches to semantic analysis
- Applications
- Scope of this course

# Course implementation

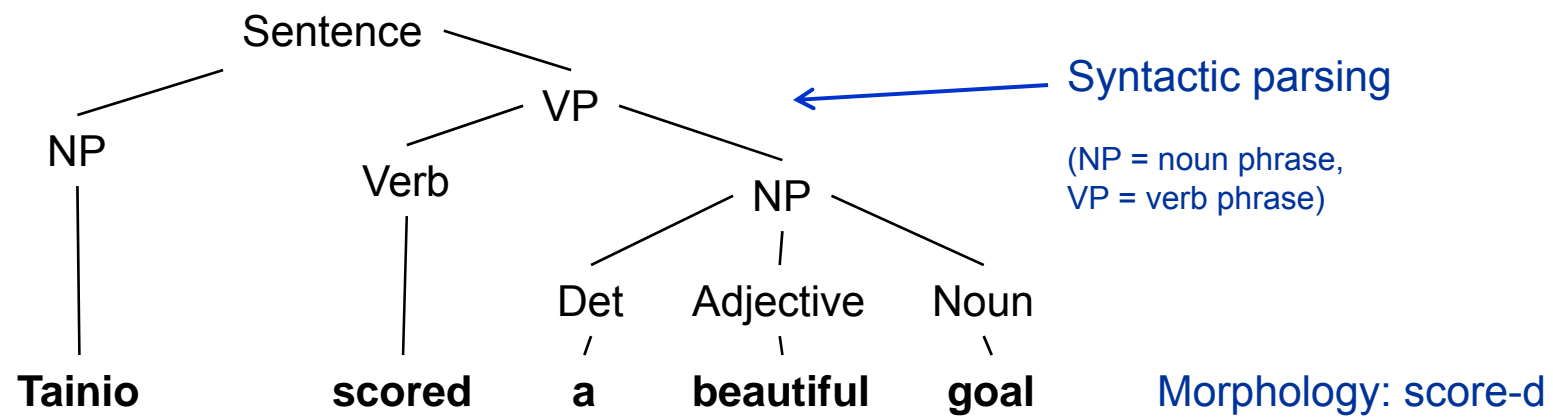
- See the web-page

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

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



# What is semantic analysis?



# 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  $\approx$  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

$$\begin{aligned} &\exists x \textit{Restaurant}(x) \wedge \textit{Serves}(x, \textit{ChineseFood}) \\ &\wedge \textit{Near}(\textit{LocationOf}(x), \textit{LocationOf}(TUT)) \end{aligned}$$

- 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.

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

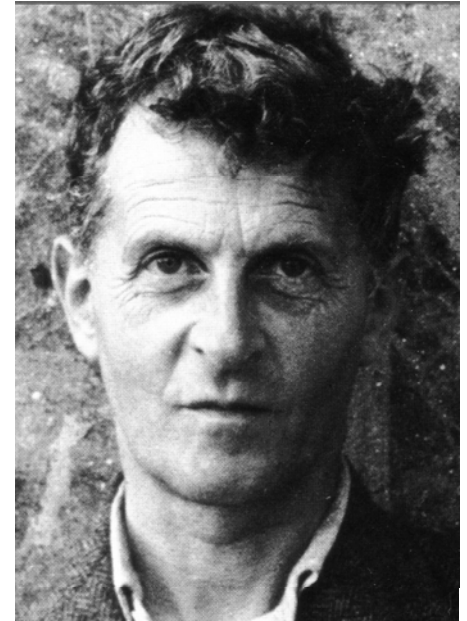
→ restricting to a certain domain allows the use of specific **patterns**, rules, expectations etc.

- customer at a restaurant
  - buying train tickets
  - ...
- pragmatics, socially probable set of "moves" in a certain context

C <sub>1</sub> :	I need to travel in May.
A <sub>1</sub> :	And, what day in May did you want to travel?
C <sub>2</sub> :	OK uh I need to be there for a meeting that's from the 12th to the 15th.
A <sub>2</sub> :	And you're flying into what city?
C <sub>3</sub> :	Seattle.
A <sub>3</sub> :	And what time would you like to leave Pittsburgh?
C <sub>4</sub> :	Uh hmm I don't think there's many options for non-stop.
A <sub>4</sub> :	Right. There's three non-stops today.
C <sub>5</sub> :	What are they?
A <sub>5</sub> :	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 <sub>6</sub> :	OK I'll take the 5ish flight on the night before on the 11th.
A <sub>6</sub> :	On the 11th? OK. Departing at 5:55pm arrives Seattle at 8pm, U.S. Air flight 115.
C <sub>7</sub> :	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)



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

- 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.

# 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  $\neq$  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.**

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  $\frac{1}{2}$  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)

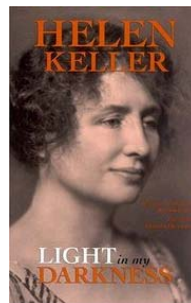
- "Educate" computers instead of program them?
  - the idea: program only a basic learning algorithm, then let it learn the rest
  - but: sensory abilities (vision, hearing) are missing too
  - but: it takes circa 20 years for a human being to "grow up" mentally...  
the world is complex and many things 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)



**timbrel** /'tɪmbɹ(ə)l/ *n.* & *v.* *arch.* E16. [Perh. dim. of **TIMBRE** *n.*<sup>1</sup>: see **-EL**<sup>2</sup>.] **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** /tɪmbʌk'tuː/ *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 *tīmi* time, good time, prosperity, f. Gmc, f. base of **TIDE** *n.*, which was superseded by *time* in the strictly temporal senses.] **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)

**Container** [Container]  
**Semantic Type**  
 Container

The **Container** holds the **Food** to which heat is applied.

**BOIL** the potatoes **in a medium-sized pan**.

Things that apply the heat directly are **Heating Instruments**, e.g. crock-pot, electric skillet.

**Cook** [Cook]  
**Semantic Type**  
 Sentient

The **Cook** applies heat to the **Food**.

**Drew SAUTEED** the garlic in butter.

**Food** [Food]

**Food** is the entity to which heat is applied by the **Cook**.

Suzy usually **STEAMS** the broccoli.

In instructional imperatives, this FE, which would be used for the (missing) object, is tagged CNI:

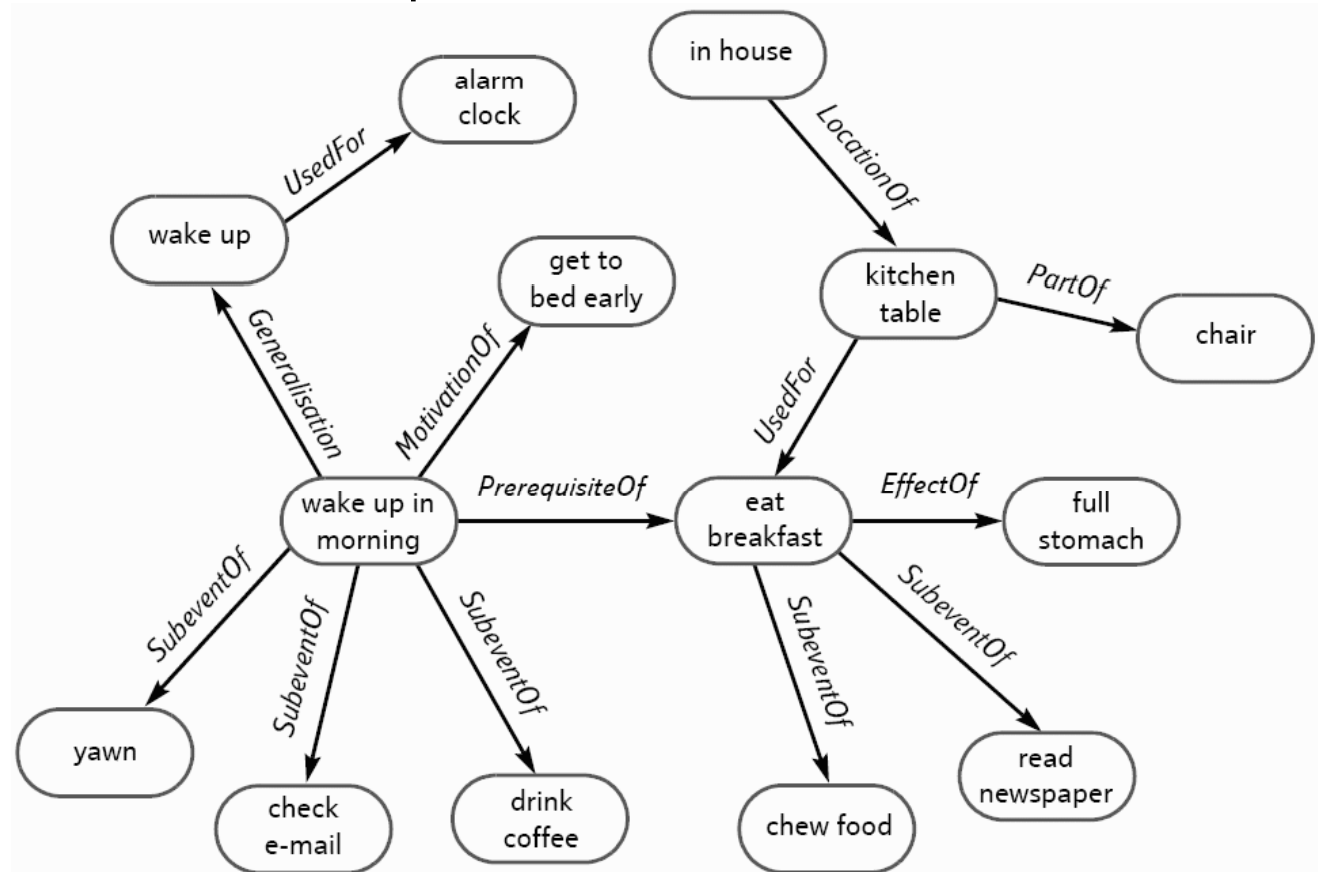
**COOK** on low heat for two hours. **CNI**

# 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