ANLP Lecture 20
Lexical Semantics:
Word senses, relations and disambiguation

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(based on slides by Thompson, Goldwater, Schneider, Lascarides, and Koehn)

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So far, we have focused on linguistics, models and algorithms for:
- Words and sequences
- Syntactic structure

We also motivated syntactic structure with reference to meaning (specifically, compositional semantics).

But we haven't talked much about meaning itself.

So, let's get started! For the rest of the course:
- semantics of words, sentences, and documents
- also lectures about the bigger picture: data, annotation, evaluation, and real issues in research (including guest lectures).
Meaning

➤ The grand goal of artificial intelligence
➤ machines that do not mindlessly process data
➤ ... but that ultimately **understand** its meaning
➤ But how do we know if we succeeded?
Eliza

A famous computer program from 1969 shows people can be easily fooled into thinking that machines have some deep understanding.

**young woman:** Men are all alike.
**eliza:** In what way?
**young woman:** They’re always bugging us about something specific or other.
**eliza:** Can you think of a specific example?
**young woman:** Well, my boyfriend made me come here.
**eliza:** Your boyfriend made you come here?
**young woman:** He says I’m depressed much of the time.
**eliza:** I am sorry to hear you are depressed.
**young woman:** It’s true. I’m unhappy.
**eliza:** Do you think coming here will help you not to be unhappy?

Online demo: https://www.masswerk.at/elizabot/
What is meaning? What is understanding?

- These are deep philosophical questions
- NLP usually takes a more pragmatic view: can the computer behave as though it understands (in order to do what we want)?
  - Dialogue systems (e.g., Eliza)
  - Machine translation
  - Question answering
- What issues will we face in building such systems?
A Concrete Goal

- We would like to build
  - a machine that answers questions in natural language.
  - may have access to knowledge bases
  - may have access to vast quantities of English text
- Basically, a smarter Google
- This is typically called **Question Answering** (QA for short)
To build our QA system we will need to deal with issues in **semantics**, i.e., meaning.

- **Lexical semantics**: the meanings of individual words (next few lectures)
- **Sentential semantics**: how word meanings combine (later on)
- Consider some examples to highlight problems in lexical semantics
Example Question

- Question
  
  *When was Barack Obama born?*

- Text available to the machine
  
  *Barack Obama was born on August 4, 1961*

- This is easy.
  
  - just phrase a Google query properly:
    "Barack Obama was born on *"

  - syntactic rules that convert questions into statements are straight-forward
Example Question (2)

▸ Question

*What plants are native to Scotland?*

▸ Text available to the machine

*A new chemical plant was opened in Scotland.*

▸ What is hard?

▸ words may have different meanings
  ▸ Not just different parts of speech
  ▸ But also different (*senses*) for the same PoS

▸ we need to be able to disambiguate between them
Example Question (3)

▶ Question

*Where did Theresa May go on vacation?*

▶ Text available to the machine

*Theresa May spent her holiday in Cornwall*

▶ What is hard?

▶ different words may have the same meaning (*synonyms*)

▶ we need to be able to match them
Example Question (4)

- **Question**
  
  *Which animals love to swim?*

- **Text available to the machine**
  
  *Polar bears love to swim in the freezing waters of the Arctic.*

- **What is hard?**
  
  - one word can refer to a subclass (**hyponym**) or superclass (**hypernym**) of the concept referred to by another word
  
  - we need to have database of such **A is-a-kind-of B** relationships, called an **ontology**
Question

What is a good way to remove wine stains?

Text available to the machine

Salt is a great way to eliminate wine stains

What is hard?

words may be related in other ways, including similarity and gradation

we need to be able to recognize these to give appropriate responses
Example Question (6)

Question

Did Poland reduce its carbon emissions since 1989?

Text available to the machine

Due to the collapse of the industrial sector after the end of communism in 1989, all countries in Central Europe saw a fall in carbon emissions.

Poland is a country in Central Europe.

What is hard?
- we need lots of facts
- we need to do inference
  - a problem for sentential, not lexical, semantics
Some of these problems can be solved with a good ontology.

**WordNet** (for English: see http://wordnet.princeton.edu/) is a hand-built ontology containing 117,000 **synsets**: sets of synonymous words.

Synsets are connected by relations such as
- hyponym/hypernym (IS-A: chair-furniture)
- meronym (PART-WHOLE: leg-chair)
- antonym (OPPOSITES: good-bad)

**globalwordnet.org** now lists wordnets in over 50 languages (but variable size/quality/licensing)
An example of a synset (JM3):

\textit{chump}^{1}, \textit{fool}^{2}, \textit{gull}^{1}, \textit{mark}^{9}, \textit{patsy}^{1}, \textit{fall guy}^{1}, \textit{ sucker}^{1}, \textit{soft touch}^{1}, \textit{mug}^{2}
Word Sense Ambiguity

- Not all problems can be solved by WordNet alone.
- Two completely different words can be spelled the same (homonyms):
  - I put my money in the *bank*. vs. He rested at the *bank* of the river.
  - You *can* do it! vs. She bought a *can* of soda.
- More generally, words can have multiple (related or unrelated) senses (polysemes)
- Polysemous words often fall into (semi-)predictable patterns: see next slides (from Hugh Rabagliati in PPLS)
  - ‘*’ is for words where the non-literal reading is a bit harder to get without some context
<table>
<thead>
<tr>
<th>Pattern</th>
<th>Participating Senses</th>
<th>Example Sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal for fur</td>
<td>Mink, chinchilla, rabbit, beaver,</td>
<td>The <em>mink</em> drank some water / She likes to wear <em>mink</em></td>
</tr>
<tr>
<td></td>
<td>raccoon*, alpaca*, crocodile*</td>
<td></td>
</tr>
<tr>
<td>Animal/Object for personality</td>
<td>Chicken, sheep, pig, snake, star*,</td>
<td>The <em>chicken</em> drank some water / He is a <em>chicken</em></td>
</tr>
<tr>
<td></td>
<td>rat*, doll*</td>
<td></td>
</tr>
<tr>
<td>Animal for meat</td>
<td>Chicken, lamb, fish, shrimp, salmon*,</td>
<td>The chicken drank some water / The <em>chicken</em> is tasty</td>
</tr>
<tr>
<td></td>
<td>rabbit*, lobster*</td>
<td></td>
</tr>
<tr>
<td>Artifact for activity</td>
<td>Shower, bath, sauna, baseball,</td>
<td>The shower was leaking / The shower was relaxing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body part for object part</td>
<td>Arm, leg, hand, face, back*, head*,</td>
<td>John’s <em>arm</em> was tired / The <em>arm</em> was reupholstered</td>
</tr>
<tr>
<td></td>
<td>foot*, shoulder*, lip*</td>
<td></td>
</tr>
<tr>
<td>Building for people</td>
<td>Church, factory, school, airplane,</td>
<td>The <em>church</em> was built 20 years ago / The <em>church</em> sang a song</td>
</tr>
<tr>
<td>Complement Coercion</td>
<td>Begin, start, finish, try</td>
<td>John <em>began</em> reading the book / John <em>began</em> the book</td>
</tr>
<tr>
<td>Container for contents</td>
<td>Bottle, can, pot, pan, bowl*, plate*,</td>
<td>The bottle is made of steel / He drank half of the <em>bottle</em></td>
</tr>
<tr>
<td></td>
<td>box*, bucket*</td>
<td></td>
</tr>
<tr>
<td>Word for question</td>
<td>Price, weight, speed</td>
<td>The price of the coffee was low / John asked the <em>price</em> of the coffee</td>
</tr>
<tr>
<td>Pattern</td>
<td>Participating Senses</td>
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</tr>
<tr>
<td>---------------------------------</td>
<td>------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Figure for Ground</td>
<td>Window, door, gate, goal</td>
<td>The window is broken / The cat walked through the window</td>
</tr>
<tr>
<td>Grinding</td>
<td>Apple, chair, fly</td>
<td>The apple was tasty / There is apple all over the table</td>
</tr>
<tr>
<td>Instrument for action</td>
<td>Hammer, brush, shovel, tape, lock*, bicycle*, comb*, saw*</td>
<td>The hammer is heavy / She hammered the nail into the wall</td>
</tr>
<tr>
<td>Instance of an entity for kind</td>
<td>Tennis, soccer, cat, dog, class*, dinner*, chair*, table*</td>
<td>Tennis was invented in England / Tennis was fun today</td>
</tr>
<tr>
<td>Location / Place at location</td>
<td>Bench, land, floor, ground, box*, bottle*, jail*</td>
<td>The bench was made of pine / The coach benched the player</td>
</tr>
<tr>
<td>Object for placing at goal</td>
<td>Water, paint, salt, butter, frame*, dress*, oil*</td>
<td>The water is cold / He watered the plant</td>
</tr>
<tr>
<td>Object for taking from source</td>
<td>Milk, dust, weed, peel, pit*, skin*, juice*</td>
<td>The milk tastes good / He milked the cow</td>
</tr>
<tr>
<td>Material for artifact</td>
<td>Tin, iron, china, glass, linen*, rubber*, nickel*, fur*</td>
<td>Watch out for the broken glass / He filled the glass with water</td>
</tr>
<tr>
<td>Occupation for role in action</td>
<td>Boss, nurse, guard, tutor</td>
<td>My boss is nice / He bossed me around</td>
</tr>
<tr>
<td>Pattern</td>
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</tr>
<tr>
<td>-------------------------------</td>
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<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Place for an event</td>
<td>Vietnam, Korea, Waterloo, Iraq</td>
<td>It is raining in Vietnam / John was shot during Vietnam</td>
</tr>
<tr>
<td>Place for an institution</td>
<td>White House, Washington, Hollywood, Pentagon, Wall Street*, Supreme Court</td>
<td>The White House is being repainted / The White House made an announcement</td>
</tr>
<tr>
<td>Plant for food or material</td>
<td>Corn, broccoli, coffee, cotton, lettuce*, eggs*, oak*, pine*</td>
<td>The large field of corn / The corn is delicious</td>
</tr>
<tr>
<td>Portioning</td>
<td>Water, beer, jam</td>
<td>She drank some water / She bought three waters</td>
</tr>
<tr>
<td>Publisher for product</td>
<td>Newspaper, magazine, encyclopedia, Wall Street Journal*, New York Times*</td>
<td>The newspaper is badly printed / The newspaper fired three employees</td>
</tr>
<tr>
<td>Artist for product</td>
<td>Writer, artist, composer, Shakespeare, Dickens*, Mozart*, Picasso*</td>
<td>The writer drank a lot of wine / The writer is hard to understand</td>
</tr>
<tr>
<td>Visual Metaphor</td>
<td>Beam, belt, column, stick, bug*, leaf*</td>
<td>Most of the weight rests on the beam / There was a beam of light</td>
</tr>
</tbody>
</table>
Another name for one of those

- **Instance of an entity for kind** is a kind of **abstraction**
- So common we barely notice it
- Some examples, using the call sign of an airplane flight:

  EZY386 will depart from gate E17 at 2010  
  [announcement]
  Just arrived on EZY386  
  [text message]
  EZY386 flies from Stansted to Avalon
  EZY386 is easyJet’s 3rd most popular flight to Avalon
  I prefer EZY386 to EZY387
  EZY386 has an 102% on-time record
  EZY386 was cancelled yesterday
  EZY386 was delayed because of a problem with one of its engines
How many senses?

- How many senses does the noun *interest* have?
  - She pays 3% *interest* on the loan.
  - He showed a lot of *interest* in the painting.
  - Microsoft purchased a controlling *interest* in Google.
  - It is in the national *interest* to invade the Bahamas.
  - I only have your best *interest* in mind.
  - Playing chess is one of my *interests*.
  - Business *interests* lobbied for the legislation.

- Are these seven different senses? Four? Three?
- Also note: distinction between polysemy and homonymy not always clear!
WordNet senses for interest

S1: a sense of concern with and curiosity about someone or something, Synonym: involvement

S2: the power of attracting or holding one’s interest (because it is unusual or exciting etc.), Synonym: interestingness

S3: a reason for wanting something done, Synonym: sake

S4: a fixed charge for borrowing money; usually a percentage of the amount borrowed

S5: a diversion that occupies one’s time and thoughts (usually pleasantly), Synonyms: pastime, pursuit

S6: a right or legal share of something; a financial involvement with something, Synonym: stake

S7: (usu. plural) a social group whose members control some field of activity and who have common aims, Synonym: interest group
How to test for multiple sense?

Different senses: independent truth conditions, different syntactic behaviour, and independent sense relations. A technique to separate senses is to conjoin two uses of a word in a single sentence (JM3):

(a) Which of those flights serve breakfast?
(b) Does Midest Express serve Philadelphia?
(c) Does Midwest Express serve breakfast and Philadelphia?
Polysemy in WordNet

- Polysemous words are part of multiple synsets
- This is why relationships are defined between synsets, not words
- On average,
  - nouns have 1.24 senses (2.79 if excluding monosemous words)
  - verbs have 2.17 senses (3.57 if excluding monosemous words)
- Is Wordnet too fine grained?

Stats from:
http://wordnet.princeton.edu/wordnet/man/wnstats.7WN.html
Different sense $=$ different translation

- Another way to define senses: if occurrences of the word have different translations, that’s evidence for multiple senses.
- Example interest translated into German:
  - Zins: financial charge paid for loan (Wordnet sense 4)
  - Anteil: stake in a company (Wordnet sense 6)
  - Interesse: all other senses
- Other examples might have distinct words in English but a polysemous word in German.
Word sense disambiguation (WSD)

- For many applications, we would like to disambiguate senses
  - we may be only interested in one sense
  - searching for chemical plant on the web, we do not want to know about chemicals in bananas

- Task: Given a polysemous word, find the sense in a given context

- As we’ve seen, this can be formulated as a classification task.
WSD as classification

- Given word token in context, which sense (class) is it?
- Just train a classifier, if we have sense-labeled training data:
  - She pays 3% interest/INTEREST-MONEY on the loan.
  - He showed a lot of interest/INTEREST-CURIOSITY in the painting.
  - Playing chess is one of my interests/INTEREST-HOBBY.
- SensEval and later SemEval competitions provide such data
  - held every 1-3 years since 1998
  - provide annotated corpora in many languages for WSD and other semantic tasks
Classifiers for WSD

As usual, lots of options:

▶ We’ve discussed Naive Bayes, logistic regression, neural nets; many others available...

For many of these, need to choose relevant features. For example,

▶ Directly neighboring words:
  ▶ **interest** paid, rising **interest**, lifelong **interest**, **interest** rate

▶ Any content words in a 50 word window
  ▶ pastime, financial, lobbied, pursued

▶ Syntactically related words, topic of the text, part-of-speech tag, surrounding part-of-speech tags, etc ...
Evaluation of WSD

- **Extrinsic**: test as part of IR, QA, or MT system
- **Intrinsic**: evaluate classification accuracy or precision/recall against gold-standard senses
- **Baseline**: choose the most frequent sense (sometimes hard to beat)
Issues with WSD

- Not always clear how fine-grained the gold-standard should be
- Classifiers must be trained separately for each word
  - Hard to learn anything for infrequent or unseen words
  - Requires new annotations for each new word
  - Motivates unsupervised and semi-supervised methods
When we don’t have labeled data...

What to do when we do not have many labeled data or none at all?

▶ Semi-supervised WSD (bootstrapping, the Yarowsky algorithm):
  ▶ Start with a seed of labeled data
  ▶ Learn a classifier and apply it on unseen data
  ▶ Choose most confident predictions, add to training and repeat
  ▶ Uses two heuristics: one sense per collocation (to create the seeds) and one sense per discourse

▶ Unsupervised WSD (Word Sense Induction): use clustering

See more in JM3 C.7-C.8 (optional)
Summary

- Aspects of lexical semantics:
  - Word senses, and methods for disambiguating.
  - Lexical semantic relationships, like synonymy, hyponymy, and meronymy.
  - Disambiguation: Different senses need to be distinguished

- Resources that provide annotated data for lexical semantics:
  - WordNet (senses, relations)
  - SensEval datasets