**Orientation**

- 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?

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

Semantics

• 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 (senses)
  – 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?
  – 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?
  – words can refer to a subset (hyponym) or superset (hypernym)
    of the concept referred to by another word
  – we need to have database of such A is-a B relationships, called
    an ontology

Example Question (5)

• 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 to do inference
  – a problem for sentential, not lexical, semantics

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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 (*polysems*)

- Polysemous words often fall into (semi-)predictable patterns: see next slides (from Hugh Rabagliati in PPLS).

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WordNet

- 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)

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<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, raccoon*, alpaca*, crocodile*</td>
<td>The mink drank some water / She likes to wear mink</td>
</tr>
<tr>
<td>Animal/Object for personality</td>
<td>Chicken, sheep, pig, snake, star*, rat*, doll*</td>
<td>The chicken drank some water / He is a chicken</td>
</tr>
<tr>
<td>Animal for meat</td>
<td>Chicken, lamb, fish, shrimp, salmon*, rabbit*, lobster*</td>
<td>The chicken drank some water / The chicken is tasty</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>Body part for object part</td>
<td>Arm, leg, hand, face, back*, head*, foot*, shoulder*, lip*,</td>
<td>John’s arm was tired / The arm was reupholstered</td>
</tr>
<tr>
<td>Building for people</td>
<td>Church, factory, school, airplane,</td>
<td>The church was built 20 years ago / The church sang a song</td>
</tr>
<tr>
<td>Complement Coercion</td>
<td>Begin, start, finish, try</td>
<td>John began reading the book / John began the book</td>
</tr>
<tr>
<td>Container for contents</td>
<td>Bottle, can, pot, pan, bowl*, plate*, box*, bucket*</td>
<td>The bottle is made of steel / He drank half of the bottle</td>
</tr>
<tr>
<td>Word for question</td>
<td>Price, weight, speed</td>
<td>The price of the coffee was low / John asked the price of the coffee</td>
</tr>
</tbody>
</table>
### How many senses?

- How many senses does the word *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*

<table>
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<tr>
<th>Pattern</th>
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<th>Example Sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>a sense of concern with and curiosity about someone or something, Synonym: involvement</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>the power of attracting or holding one’s interest (because it is unusual or exciting etc.), Synonym: interestingness</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>a reason for wanting something done, Synonym: sake</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>a fixed charge for borrowing money; usually a percentage of the amount borrowed</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>a diversion that occupies one’s time and thoughts (usually pleasantly), Synonyms: pastime, pursuit</td>
<td></td>
</tr>
<tr>
<td>S6</td>
<td>a right or legal share of something; a financial involvement with something, Synonym: stake</td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td>(usu. plural) a social group whose members control some field of activity and who have common aims, Synonym: interest group</td>
<td></td>
</tr>
</tbody>
</table>
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

Sharon Goldwater Word senses and relations 20

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.

Different sense = different translation

- Another way to define senses: if occurrences of the word have different translations, these indicate different sense
- Example interest translated into German
  - Zins: financial charge paid for load (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.

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 ...

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 (see JM3 17.7-17.8: optional)

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)

Another property of words: semantic roles

- Often we want to know who did what to whom?

- But the same event and participants can have different syntactic realizations:
  
  - Sandy broke the glass. vs. The glass was broken by Sandy.
  - She gave the boy a book. vs. She gave a book to the boy.

- Instead of focusing on syntax, consider the semantic roles (also called thematic roles) defined by each event.
Argument Structure and Alternations

- Mary opened the door
  The door opened
- John slices bread with a knife
  This bread slices easily
  The knife slices cleanly
- Mary loaded the truck with hay
  Mary loaded hay onto the truck
  The truck was loaded with hay (by Mary)
  The hay was loaded onto the truck (by Mary)
- John gave a present to Mary
  John gave Mary a present

Syntax-Semantics Relationship

Commonly used thematic roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent</td>
<td>The boy kicked his toy</td>
</tr>
<tr>
<td>Theme</td>
<td>The boy kicked his toy</td>
</tr>
<tr>
<td>Experiencer</td>
<td>The boy felt sad</td>
</tr>
<tr>
<td>Result</td>
<td>The girl built a shelf with power tools</td>
</tr>
<tr>
<td>Instrument</td>
<td>The girl built a shelf with power tools</td>
</tr>
<tr>
<td>Source</td>
<td>She came from home</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

- J&M give definitions and additional roles

Syntax is not enough!

- Note different dependency labels to each argument:

Syntax-Semantics Relationship

Commonly used thematic roles
Issues with thematic roles

- No universally agreed-upon set of roles
- Items with the “same” role (e.g., Instrument) may not behave quite the same
  
  Sandy opened the door with a key  
  The key opened the door
  Sandy ate the salad with a fork  
  *The fork ate the salad
- The two main NLP resources for thematic roles avoid these problems by defining very fine-grained roles:
  - Specific to individual verbs only (PropBank)
  - Specific to small groups of verbs (FrameNet)

Semantic role labelling

- The NLP task of identifying which words/phrases play which roles in an event.
- Supervised classification:
  - Resource data is PropBank: Repository of frame files for each verb (more shortly) plus annotations on constituents in Penn treebank with their semantic roles (wrt the relevant frame roles).
  - Features are mostly related to syntactic structure and the particular words involved
- Current research focuses on reducing the need for training data (e.g., to work on non-English languages)

PropBank

- Abstracts away from syntax to predicate-argument structures.
- Predicate-argument lexicon plus annotations of full WSJ PTB corpus and other data (such as OntoNotes).
- Originally verbs only; now has many nouns, adjectives, light verbs constructions etc.
- Strongly lexicalised: no synonymy, hypernymy etc. of predicates with different stems; very coarse grained sense distinctions.

Example Frame Roles: load

Mary loaded the truck with hay at the depot on Friday

- load: load.01 ‘cause to be burdened’
  Arg0-PAG: loader, agent
  Frame roles:
  Arg1-GOL: beast of burden
  Arg2-PPT: cargo
  Arg3-MNR: instrument

- load up: load.02 ‘phrasal cause to be burdened’
  Frame roles are the same as load.01

- load: load.03 ‘fix, set up to cheat’
  Arg0-PAG: cheater
  Frame roles:
  Arg1-GOL: thing loaded (dice, the deck, etc)
  Arg2-PPT: with what

- All sentences can have temporal, spatial adjuncts (AM-TMP, AM-LOC). . .
**PropBank**

Penn treebank annotated with Arg0, Arg1 etc, and verb with its sense; so specific semantic role recoverable.

*Mary loaded* the truck with hay at the depot on Friday.

<table>
<thead>
<tr>
<th>load.01</th>
<th>AM-LOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0 loader</td>
<td>AM-TMP</td>
</tr>
<tr>
<td>A1 bearer</td>
<td>AM-PRP</td>
</tr>
<tr>
<td>A2 cargo</td>
<td>AM-MNR</td>
</tr>
</tbody>
</table>

*Mary loaded* hay onto the truck at the depot on Friday.

**Semantic Role Labelling**

Traditional pipeline:

1. Either assume or compute syntactic parse and predicate senses

2. **Argument identification** (deterministic): select the predicate’s argument phrases (by parsing the parse tree)

3. **Argument classification**: select a role for each argument (wrt to the frame role for the predicate’s sense).
   - Useful feature: predicate-to-argument path in the tree (e.g., NP-S-VP-V).

**Problems**

- Numbered roles are predicate specific:
  - load.01.ARG1: beast of burden
  - put.01.ARG1: thing.put
  - put.01.ARG2: beast of burden.

- Other resources (e.g., FrameNet: see JM3) try to generalise via verb classes;
  but less treebank data.

**Summary**

- Aspects of lexical semantics:
  - Word senses, and methods for disambiguating.
  - Lexical semantic relationships, like synonymy, hyponymy, and meronymy.
  - Semantic roles: the roles of each argument in an event.

- Resources that provide annotated data for lexical semantics:
  - WordNet (senses, relations)
  - Propbank, FrameNet (semantic roles)