Algorithms for Natural Language Processing

Lexical Semantics:
Word senses, relations, and classes

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(based on slides by Philipp Koehn and Sharon Goldwater)

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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 (after that)

- 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 David Cameron go on vacation?

- Text available to the machine
  
  David Cameron spent his 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
WordNet

- Some of these problems can be solved with a good ontology, e.g., WordNet

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

- 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)
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).
<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 <em>mink</em> drank some water / She likes to wear <em>mink</em></td>
</tr>
<tr>
<td>Animal/Object for personality</td>
<td>Chicken, sheep, pig, snake, star*, rat*, doll*</td>
<td>The <em>chicken</em> drank some water / He is a <em>chicken</em></td>
</tr>
<tr>
<td>Animal for meat</td>
<td>Chicken, lamb, fish, shrimp, salmon*, rabbit*, lobster*</td>
<td>The chicken drank some water / The <em>chicken</em> 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 <em>arm</em> was reupholstered</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 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 <em>bottle</em> is made of steel / He drank half of the <em>bottle</em></td>
</tr>
<tr>
<td>Word for question</td>
<td>Price, weight, speed</td>
<td>The <em>price</em> of the coffee was low / John asked the <em>price</em> of the coffee</td>
</tr>
<tr>
<td>Pattern</td>
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<td>Example Sentences</td>
</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>
<td>Participating Senses</td>
<td>Example Sentences</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------------------------------------------------</td>
<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>
How many senses?

- 5 min. exercise: How many senses does the word *interest* have?
How many senses?
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!
Lexicography requires data
Lumping vs. Splitting

• For any given word, lexicographer faces the choice:
  – **Lump** usages into a small number of senses? or
  – **Split** senses to reflect fine-grained distinctions?
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: (usually plural) a social group whose members control some field of activity and who have common aims, Synonym: interest group
Synsets and Relations in WordNet

- **Synsets** (“synonym sets”, effectively senses) are the basic unit of organization in WordNet.
  - Each synset is specific to nouns (.n), verbs (.v), adjectives (.a, .s), or adverbs (.r).
  - Synonymous words belong to the same synset: car\(^1\) (car.n.01) = \{car, auto, automobile\}.
  - Polysemous words belong to multiple synsets: car\(^1\) vs. car\(^4\) = \{car, elevator car\}. Numbered roughly in descending order of frequency.

- Synsets are organized into a **network** by several kinds of relations, including:
  - **Hypernymy** (Is-A): hyponym \{ambulance\} is a kind of hypernym car\(^1\)
  - **Meronymy** (Part-Whole): meronym \{air bag\} is a part of holonym car\(^1\)
Visualizing WordNet
Using WordNet

• NLTK provides an excellent API for looking things up in WordNet:

```python
>>> from nltk.corpus import wordnet as wn
>>> wn.synsets('car')
[Synset('car.n.01'), Synset('car.n.02'),
 Synset('car.n.03'),
 Synset('car.n.04'), Synset('cable_car.n.01')]
>>> wn.synset('car.n.01').definition()
u'a motor vehicle with four wheels; usually
 propelled by an internal combustion engine'
>>> wn.synset('car.n.01').hypernyms()
[Synset('motor_vehicle.n.01')]
```

• (WordNet uses an obscure custom file format, so reading the files directly is not recommended!)
Polysemy and Coverage in WordNet

- Online stats:
  - 155k unique strings, 118k unique synsets, 207k pairs
  - nouns have an average 1.24 senses (2.79 if excluding monosemous words)
  - verbs have an average 2.17 senses (3.57 if excluding monosemous words)

- Too fine-grained?

- WordNet is a snapshot of the English lexicon, but by no means complete.
  - E.g., consider **multiword expressions** (including noncompositional expressions, idioms): *hot dog, take place, carry out, kick the bucket* are in WordNet, but not *take a break, stress out, pay attention*
  - Neologisms: *hoodie, facepalm*
  - Names: *Microsoft*
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.
SemCor in NLTK

In the SemCor corpus, words and multiword units are annotated with their part of speech:

```python
>>> semcor.tagged_sents()[0]
[Tree('DT', ['The']),
 Tree('NNP', ['Fulton', 'County', 'Grand', 'Jury']),
 Tree('VB', ['said']),
 Tree('NN', ['Friday']),
 Tree('DT', ['an']),
 Tree('NN', ['investigation']),
 Tree('IN', ['of']),
 Tree('NN', ['Atlanta']), ...]
```

Each sentence consists of a series of chunks with 1 or more words.

In the tagset used in SemCor, DT = determiner, NN = common noun, NNP = proper noun, VB = verb, etc.
**SemCor in NLTK**

In addition, nouns, verbs, adjectives, and adverbs are annotated with a **WordNet synset**: 

```python
>>> semcor.tagged_sents(tag='sem')[0]
[['The'],
 Tree(Lemma('group.n.01.group'), [Tree('NE',
    ↦ ['Fulton', 'County', 'Grand', 'Jury'])]),
 Tree(Lemma('state.v.01.say'), ['said']),
 Tree(Lemma('friday.n.01.Friday'), ['Friday']),
 ['an'],
 Tree(Lemma('probe.n.01.investigation'),
    ↦ ['investigation']),
 ['of'],
 Tree(Lemma('atlanta.n.01.Atlanta'), ['Atlanta'])],
```

Note that *Fulton County Grand Jury* is a **named entity** (NE) not in WordNet, so it receives a high-level synset `group.n.01`.
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

- Popular topic, data driven methods perform well
WSD as classification

- Given a word token in context, which sense (class) does it belong to?

- We can train a supervised classifier, assuming 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
Semantic Classes

- Other approaches, such as named entity recognition and supersense tagging, define coarse-grained semantic categories like PERSON, LOCATION, ARTIFACT.

- Like senses, can disambiguate: APPLE as ORGANIZATION vs. FOOD.

- Unlike senses, which are refinements of particular words, classes are typically larger groupings.

- Unlike senses, classes can be applied to words/names not listed in a lexicon.
Named Entity Recognition

- Recognizing and classifying proper names in text is important for many applications. A kind of information extraction.

- Different datasets/named entity recognizers use different inventories of classes.
  - Smaller: PERSON, ORGANIZATION, LOCATION, MISCELLANEOUS
  - Larger: sometimes also PRODUCT, WORK_OF_ART, HISTORICAL_EVENT, etc., as well as numeric value types (TIME, MONEY, etc.)

- NER systems typically use some form of feature-based sequence tagging, with features like capitalization being important.

- Lists of known names called gazetteers are also important.
Supersenses

- As a practical measure, WordNet noun and verb synset entries were divided into multiple files ("lexicographer files") on a semantic basis.

- Later, people realized these provided a nice inventory of high-level semantic classes, and called them **supersenses**.

- Supersenses offer an alternative, broad-coverage, language-neutral approach to corpus annotation.
### Supersenses

<table>
<thead>
<tr>
<th>N:TOPS</th>
<th>N:OBJECT</th>
<th>V:COGNITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>N:ACT</td>
<td>N:PERSON</td>
<td>V:COMMUNICATION</td>
</tr>
<tr>
<td>N:ANIMAL</td>
<td>N:PHENOMENON</td>
<td>V:COMPETITION</td>
</tr>
<tr>
<td>N:ARTIFACT</td>
<td>N:PLANT</td>
<td>V:CONSUMPTION</td>
</tr>
<tr>
<td>N:ATTRIBUTE</td>
<td>N:POSSESSION</td>
<td>V:CONTACT</td>
</tr>
<tr>
<td>N:BODY</td>
<td>N:PROCESS</td>
<td>V:CREATION</td>
</tr>
<tr>
<td>N:COGNITION</td>
<td>N:QUANTITY</td>
<td>V:EMOTION</td>
</tr>
<tr>
<td>N:COMMUNICATION</td>
<td>N:RELATION</td>
<td>V:MOTION</td>
</tr>
<tr>
<td>N:EVENT</td>
<td>N:SHAPE</td>
<td>V:PERCEPTION</td>
</tr>
<tr>
<td>N:FEELING</td>
<td>N:STATE</td>
<td>V:POSSESSION</td>
</tr>
<tr>
<td>N:FOOD</td>
<td>N:SUBSTANCE</td>
<td>V:SOCIAL</td>
</tr>
<tr>
<td>N:GROUP</td>
<td>N:TIME</td>
<td>V:STATIVE</td>
</tr>
<tr>
<td>N:LOCATION</td>
<td></td>
<td>V:WEATHER</td>
</tr>
<tr>
<td>N:MOTIVE</td>
<td></td>
<td>V:CHANGE</td>
</tr>
</tbody>
</table>

- The **supersense tagging** goes beyond NER to cover all nouns and verbs.
In order to support technologies like question answering, we need ways to reason computationally about meaning. Lexical semantics addresses meaning at the word level.

- Words can be ambiguous (**polysemy**), sometimes with related meanings, and other times with unrelated meanings (**homonymy**).
- Different words can mean the same thing (**synonymy**).

Computational lexical databases, notably WordNet, organize words in terms of their meanings.

- **Synsets** and relations between them such as hypernymy and meronymy.
Summary (2)

- **Word sense disambiguation** is the task of choosing the right sense for the context.
  - Classification with contextual features
  - Relying on dictionary senses has limitations in granularity and coverage

- **Semantic classes**, as in NER and supersense tagging, are a coarser-grained representation for semantic disambiguation and generalization.