CS 6120/CS 4120: Natural Language Processing

Instructor: Prof. Lu Wang
College of Computer and Information Science
Northeastern University
Webpage: www.ccs.neu.edu/home/luwang
Logistics

• Assignment 1 is released, due on Feb 13th, 11:59pm

• Quiz solution is posted on Blackboard.
  • For quizzes of 1,3,5,7, please see Nikhil if you have questions wrt grading.
  • For quizzes of 0,2,4,6,8, please see Parmeet.

• All questions related to the course should be posted on Piazza

• Tentative final exam time: 1-3pm, April 26. Location: TBD
Outline

• Word Senses and Word Relations
• Word Similarity
• Word Sense Disambiguation
Terminology: lemma and wordform

• **A lemma or citation form**
  • Same stem, part of speech, rough semantics

• **A wordform**
  • The inflected word as it appears in text

<table>
<thead>
<tr>
<th>Wordform</th>
<th>Lemma</th>
</tr>
</thead>
<tbody>
<tr>
<td>banks</td>
<td>bank</td>
</tr>
<tr>
<td>sung</td>
<td>sing</td>
</tr>
<tr>
<td>duermes</td>
<td>dormir</td>
</tr>
</tbody>
</table>
Lemmas have senses

• One lemma “bank” can have many meanings:

  Sense 1: • …a bank\textsubscript{1} can hold the investments in a custodial account…
  • “…as agriculture burgeons on the east bank\textsubscript{2} the river will shrink even more”

  Sense 2: 

• Sense (or word sense)
  • A discrete representation of an aspect of a word’s meaning.

• The lemma bank here has two senses
Homonymy

**Homonyms**: words that share a form (spell or sound alike) but have unrelated, distinct meanings:

- \( \text{bank}_1 \): financial institution, \( \text{bank}_2 \): sloping land
- \( \text{bat}_1 \): club for hitting a ball, \( \text{bat}_2 \): nocturnal flying mammal

1. Homographs (bank/bank, bat/bat)
2. Homophones:
   1. Write and right
   2. Piece and peace
Homonymy causes problems for NLP applications

- Information retrieval
  - “bat care”
- Machine Translation
  - **bat**: murciélago (animal) or bate (for baseball)
- Text-to-Speech
  - **bass**: (stringed instrument) vs. bass (fish)
• 1. The bank was constructed in 1875 out of local red brick.
• 2. I withdrew the money from the bank
Polysemy

1. The bank was constructed in 1875 out of local red brick.
2. I withdrew the money from the bank
3. Are those the same sense?
   - Sense 1: “The building belonging to a financial institution”
   - Sense 2: “A financial institution”

A polysemous word has related meanings
   - Most non-rare words have multiple meanings
Lots of types of polysemy are systematic
- School, university, hospital
  - All can mean the institution or the building.

A systematic relationship:
- Building $\leftrightarrow$ Organization

Other such kinds of systematic polysemy:
- Author ($\langle$Jane Austen wrote Emma$\rangle$)
  $\leftrightarrow$ Works of Author ($\langle$I love Jane Austen$\rangle$)
- Tree ($\langle$Plums have beautiful blossoms$\rangle$)
  $\leftrightarrow$ Fruit ($\langle$I ate a preserved plum$\rangle$)
How do we know when a word has more than one sense?

• The “zeugma” test: Two senses of serve?
  • Which flights serve breakfast?
  • Does Lufthansa serve Philadelphia?
  • Does Lufthansa serve breakfast and San Jose?

• Since this conjunction sounds weird,
  • we say that these are two different senses of “serve”
Synonyms

• Words that have the same meaning in some or all contexts.
  • filbert / hazelnut
  • couch / sofa
  • big / large
  • automobile / car
  • vomit / throw up
  • Water / H₂O

• Two words are synonyms if they can be substituted for each other in all situations (strict/perfect definition).
Synonyms

• But there are few (or no) examples of perfect synonymy.
  • Even if many aspects of meaning are identical
  • Still may not preserve the acceptability based on notions of politeness, slang, register, genre, etc.

• Example:
  • Water/H₂O
  • Big/large
  • Brave/courageous
Synonymy is a relation between senses rather than words

• Consider the words *big* and *large*

• Are they synonyms?
  • How *big* is that plane?
  • Would I be flying on a *large* or small plane?

• How about here:
  • Miss Nelson became a kind of *big* sister to Benjamin.
  • Miss Nelson became a kind of *large* sister to Benjamin.

• Why?
  • *big* has a sense that means being older, or grown up
  • *large* lacks this sense
Antonyms

• Senses that are opposites with respect to one feature of meaning
  • Otherwise, they are very similar!
    dark/light   short/long   fast/slow   rise/fall
    hot/cold   up/down   in/out

• More formally: antonyms can
  • define a binary opposition or be at opposite ends of a scale
    • long/short, fast/slow

• Be **reversives**:  
  • rise/fall, up/down
Hyponymy and Hypernymy

• One sense is a **hyponym** of another if the first sense is more specific, denoting a subclass of the other
  - *car* is a hyponym of *vehicle*
  - *mango* is a hyponym of *fruit*

• Conversely **hypernym/superordinate** ("hyper is super")
  - *vehicle* is a hypernym of *car*
  - *fruit* is a hypernym of *mango*

<table>
<thead>
<tr>
<th>Superordinate/hypernym</th>
<th>vehicle</th>
<th>fruit</th>
<th>furniture</th>
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<td>Subordinate/hyponym</td>
<td>car</td>
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<td>chair</td>
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Hyponymy more formally

• Extensional:
  • The class denoted by the superordinate extensionally includes the class denoted by the hyponym

• Entailment:
  • A sense A is a hyponym of sense B if being an A entails being a B

• Hyponymy is usually transitive
  • (A hypo B and B hypo C entails A hypo C)

• Another name: the IS-A hierarchy
  • A IS-A B (or A ISA B)
  • B subsumes A

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*Applications in textual entailment or reasoning or machine comprehension*
Hyponyms and Instances

• WordNet (introduced later) has both **classes** and **instances**.
• An **instance** is an individual, a proper noun that is a unique entity
  • San Francisco is an **instance** of **city**
• But **city** is a class
  • **city** is a **hyponym** of **municipality**...**location**...
Meronymy

• The part-whole relation
  • A leg is part of a chair; a wheel is part of a car.
• Wheel is a **meronym** of car, and car is a **holonym** of wheel.
WordNet 3.0

• A hierarchically organized lexical database
• On-line thesaurus + aspects of a dictionary

<table>
<thead>
<tr>
<th>Category</th>
<th>Unique Strings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noun</td>
<td>117,798</td>
</tr>
<tr>
<td>Verb</td>
<td>11,529</td>
</tr>
<tr>
<td>Adjective</td>
<td>22,479</td>
</tr>
<tr>
<td>Adverb</td>
<td>4,481</td>
</tr>
</tbody>
</table>
EuroWordNet

- WordNets for
  - Dutch
  - Italian
  - Spanish
  - German
  - French
  - Czech
  - Estonian
Senses of “bass” in Wordnet

Noun

- **S: (n) bass** (the lowest part of the musical range)
- **S: (n) bass, bass part** (the lowest part in polyphonic music)
- **S: (n) bass, basso** (an adult male singer with the lowest voice)
- **S: (n) sea bass, bass** (the lean flesh of a saltwater fish of the family Serranidae)
- **S: (n) freshwater bass, bass** (any of various North American freshwater fish with lean flesh (especially of the genus Micropterus))
- **S: (n) bass, bass voice, basso** (the lowest adult male singing voice)
- **S: (n) bass** (the member with the lowest range of a family of musical instruments)
- **S: (n) bass** (nontechnical name for any of numerous edible marine and freshwater spiny–finned fishes)

Adjective

- **S: (adj) bass, deep** (having or denoting a low vocal or instrumental range) "a deep voice"; "a bass voice is lower than a baritone voice"; "a bass clarinet"
How is “sense” defined in WordNet?

• The **synset (synonym set)**, the set of near-synonyms, instantiates a sense or concept, with a **gloss**

• Example: chump as a noun with the **gloss**:
  “a person who is gullible and easy to take advantage of”

• This sense of “chump” is shared by 9 words:
  chump$^1$, fool$^2$, gull$^1$, mark$^9$, patsy$^1$, fall guy$^1$, sucker$^1$, soft touch$^1$, mug$^2$

• Each of these senses have this same gloss
  • (Not **every** sense; sense 2 of gull is the aquatic bird)
WordNet Hypernym Hierarchy for “bass”

- **S:** (n) **bass, basso** (an adult male singer with the lowest voice)
  - *direct hypernym / inherited hypernym / sister term*
  - **S:** (n) **singer, vocalist, vocalizer, vocaliser** (a person who sings)
  - **S:** (n) **musician, instrumentalist, player** (someone who plays a musical instrument (as a profession))
    - **S:** (n) **performer, performing artist** (an entertainer who performs a dramatic or musical work for an audience)
    - **S:** (n) **entertainer** (a person who tries to please or amuse)
  - **S:** (n) **person, individual, someone, somebody, mortal, soul** (a human being) "there was too much for one person to do"
  - **S:** (n) **organism, being** (a living thing that has (or can develop) the ability to act or function independently)
    - **S:** (n) **living thing, animate thing** (a living (or once living) entity)
      - **S:** (n) **whole, unit** (an assemblage of parts that is regarded as a single entity) "how big is that part compared to the whole?"; "the team is a unit"
      - **S:** (n) **object, physical object** (a tangible and visible entity; an entity that can cast a shadow) "it was full of rackets, balls and other objects"
      - **S:** (n) **physical entity** (an entity that has physical existence)
      - **S:** (n) **entity** (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))
### WordNet Noun Relations

<table>
<thead>
<tr>
<th>Relation</th>
<th>Also Called</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypernym</td>
<td>Superordinate</td>
<td>From concepts to superordinates</td>
<td>( \text{breakfast}^1 \rightarrow \text{meal}^1 )</td>
</tr>
<tr>
<td>Hyponym</td>
<td>Subordinate</td>
<td>From concepts to subtypes</td>
<td>( \text{meal}^1 \rightarrow \text{lunch}^1 )</td>
</tr>
<tr>
<td>Instance Hypernym</td>
<td>Instance</td>
<td>From instances to their concepts</td>
<td>( \text{Austen}^1 \rightarrow \text{author}^1 )</td>
</tr>
<tr>
<td>Instance Hyponym</td>
<td>Has-Instance</td>
<td>From concepts to concept instances</td>
<td>( \text{composer}^1 \rightarrow \text{Bach}^1 )</td>
</tr>
<tr>
<td>Member Meronym</td>
<td>Has-Member</td>
<td>From groups to their members</td>
<td>( \text{faculty}^2 \rightarrow \text{professor}^1 )</td>
</tr>
<tr>
<td>Member Holonym</td>
<td>Member-Of</td>
<td>From members to their groups</td>
<td>( \text{copilot}^1 \rightarrow \text{crew}^1 )</td>
</tr>
<tr>
<td>Part Meronym</td>
<td>Has-Part</td>
<td>From wholes to parts</td>
<td>( \text{table}^2 \rightarrow \text{leg}^3 )</td>
</tr>
<tr>
<td>Part Holonym</td>
<td>Part-Of</td>
<td>From parts to wholes</td>
<td>( \text{course}^7 \rightarrow \text{meal}^1 )</td>
</tr>
<tr>
<td>Substance Meronym</td>
<td></td>
<td>From substances to their subparts</td>
<td>( \text{water}^1 \rightarrow \text{oxygen}^1 )</td>
</tr>
<tr>
<td>Substance Holonym</td>
<td></td>
<td>From parts of substances to wholes</td>
<td>( \text{gin}^1 \rightarrow \text{martini}^1 )</td>
</tr>
<tr>
<td>Antonym</td>
<td></td>
<td>Semantic opposition between lemmas</td>
<td>( \text{leader}^1 \leftrightarrow \text{follower}^1 )</td>
</tr>
<tr>
<td>Derivationally Related Form</td>
<td></td>
<td>Lemmas w/same morphological root</td>
<td>( \text{destruction}^1 \leftrightarrow \text{destroy}^1 )</td>
</tr>
</tbody>
</table>
# WordNet Verb Relations

<table>
<thead>
<tr>
<th>Relation</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypernym</td>
<td>From events to superordinate events</td>
<td>( \text{fly}^9 \rightarrow \text{travel}^5 )</td>
</tr>
<tr>
<td>Troponym</td>
<td>From events to subordinate event (often via specific manner)</td>
<td>( \text{walk}^1 \rightarrow \text{stroll}^1 )</td>
</tr>
<tr>
<td>Entails</td>
<td>From verbs (events) to the verbs (events) they entail</td>
<td>( \text{snore}^1 \rightarrow \text{sleep}^1 )</td>
</tr>
<tr>
<td>Antonym</td>
<td>Semantic opposition between lemmas</td>
<td>( \text{increase}^1 \leftrightarrow \text{decrease}^1 )</td>
</tr>
<tr>
<td>Derivationally Related Form</td>
<td>Lemmas with same morphological root</td>
<td>( \text{destroy}^1 \leftrightarrow \text{destruction}^1 )</td>
</tr>
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</table>

Our discussion of compositional semantic analyzers in Chapter 15 pretty much ignored the issue of lexical ambiguity. It should be clear by now that this is an unreasonable approach. Without some means of selecting correct senses for the words in an input, the enormous amount of homonymy and polysemy in the lexicon would quickly overwhelm any approach in an avalanche of competing interpretations.
WordNet: Viewed as a graph

We note that each word sense univocally identifies a single synset. For instance, given the word sense "car" the corresponding synset \{car, auto, automobile, machine, motorcar\} is univocally determined. In Figure 3 we report an excerpt of the WordNet semantic network containing the "car" synset. For each synset, WordNet provides the following information:

- A gloss, that is, a textual definition of the synset possibly with a set of usage examples (e.g., the gloss of "car" is "a 4-wheeled motor vehicle; usually propelled by an internal combustion engine; 'he needs a car to get to work' ").

- Lexical and semantic relations, which connect pairs of word senses and synsets, respectively: while semantic relations apply to synsets in their entirety (i.e., to all members of a synset), lexical relations connect word senses included in the respective synsets. Among the latter we have the following:
  - Antonymy: \(X\) is an antonym of \(Y\) if it expresses the opposite concept (e.g., "good" is the antonym of "bad"). Antonymy holds for all parts of speech.
  - Pertainymy: \(X\) is an adjective which can be defined as "of or pertaining to" a noun \(Y\) (e.g., "dental" pertains to "tooth").
  - Nominalization: a noun \(X\) nominalizes a verb \(Y\) (e.g., "service" nominalizes the verb "serve").

Among the semantic relations we have the following:

- Hypernymy (also called kind-of or is-a): \(Y\) is a hypernym of \(X\) if every \(X\) is a (kind of) \(Y\) (e.g., "motor vehicle" is a hypernym of "car"). Hypernymy holds between pairs of nominal or verbal synsets.

WordNet 3.0

• Where it is:
  • [http://wordnetweb.princeton.edu/perl/webwn](http://wordnetweb.princeton.edu/perl/webwn)

• Libraries
  • Python: WordNet from NLTK
    • [http://www.nltk.org/Home](http://www.nltk.org/Home)
  • Java:
    • JWNL, extJWNL on sourceforge
Outline

• Word Senses and Word Relations
• Word Similarity
• Word Sense Disambiguation
Why word similarity

• A practical component in lots of NLP tasks
  • Question answering
  • Natural language generation
  • Automatic essay grading
  • Plagiarism detection

• A theoretical component in many linguistic and cognitive tasks
  • Historical semantics
  • Models of human word learning
  • Morphology and grammar induction
Word Similarity

- **Synonymy**: a binary relation
  - Two words are either synonymous or not

- **Similarity (or distance)**: a looser metric (more useful in practice!)
  - Two words are more similar if they share more features of meaning

- Similarity is properly a relation between **senses**
  - Bank$^1$ is similar to fund$^3$
  - Bank$^2$ is similar to slope$^5$

- But we’ll compute similarity over both words and senses
WordNet: Viewed as a graph

We note that each word sense univocally identifies a single synset. For instance, given `car` the corresponding synset `{car 1 n, auto 1 n, automobile 1 n, machine 4 n, motorcar 1 n}` is univocally determined. In Figure 3 we report an excerpt of the WordNet semantic network containing the `car 1 n` synset. For each synset, WordNet provides the following information:

- A gloss, that is, a textual definition of the synset possibly with a set of usage examples (e.g., the gloss of `car 1 n` is "a 4-wheeled motor vehicle; usually propelled by an internal combustion engine; 'he needs a car to get to work' ").
- Lexical and semantic relations, which connect pairs of word senses and synsets, respectively: while semantic relations apply to synsets in their entirety (i.e., to all members of a synset), lexical relations connect word senses included in the respective synsets. Among the latter we have the following:
  - Antonymy: `X` is an antonym of `Y` if it expresses the opposite concept (e.g., `good 1 a` is the antonym of `bad 1 a`). Antonymy holds for all parts of speech.
  - Pertainymy: `X` is an adjective which can be defined as "of or pertaining to" a noun (or, rarely, another adjective) (e.g., `dental 1 a` pertains to `tooth 1 n`).
  - Nominalization: a noun `X` nominalizes a verb `Y` (e.g., `service 2 n nominalizes the verb `serve 4 v`).

Among the semantic relations we have the following:

- Hypernymy (also called kind-of or is-a): `Y` is a hypernym of `X` if every `X` is a (kind of) `Y` (motor vehicle 1 n is a hypernym of car 1 n). Hypernymy holds between pairs of nominal or verbal synsets.


Two classes of similarity algorithms

• Thesaurus-based algorithms
  • Are words “nearby” in hypernym hierarchy?
  • Do words have similar glosses (definitions)?

• Distributional algorithms
  • Do words have similar distributional contexts?
Path-based similarity

- Two concepts (senses/synsets) are similar if they are near each other in the thesaurus hierarchy
  - have a short path between them
  - concepts have path 1 to themselves
Refinements to path-based similarity

• \( \text{pathlen}(c_1, c_2) = 1 + \text{number of edges in the shortest path} \) in the hypernym graph between sense nodes \( c_1 \) and \( c_2 \)
• ranges from 0 to 1 (identity)

• \( \text{simpath}(c_1, c_2) = \frac{1}{\text{pathlen}(c_1, c_2)} \)

• \( \text{wordsim}(w_1, w_2) = \max_{c_1 \in \text{senses}(w_1), c_2 \in \text{senses}(w_2)} \text{sim}(c_1, c_2) \)
Example: path-based similarity
\[ \text{simpath}(c_1, c_2) = \frac{1}{\text{pathlen}(c_1, c_2)} \]

\[ \text{simpath}(\text{nickel}, \text{coin}) = \frac{1}{2} = .5 \]
\[ \text{simpath}(\text{fund}, \text{budget}) = \frac{1}{2} = .5 \]
\[ \text{simpath}(\text{nickel}, \text{currency}) = \frac{1}{4} = .25 \]
\[ \text{simpath}(\text{nickel}, \text{money}) = \frac{1}{6} = .17 \]
\[ \text{simpath}(\text{nickel}, \text{standard}) = \frac{1}{6} = .17 \]
Problem with basic path-based similarity

• Assumes each link represents a uniform distance
  • But *nickel* to *money* seems to us to be closer than *nickel* to *standard*
  • Nodes high in the hierarchy are very abstract

• We instead want a metric that
  • Represents the cost of each edge independently
  • Words connected only through abstract nodes
    • are less similar
Information content similarity metrics

Resnik 1995

• Let’s define \( P(c) \) as:
  • The probability that a randomly selected word in a corpus is an instance of concept \( c \)
  • Formally: there is a distinct random variable, ranging over words, associated with each concept in the hierarchy
    • for a given concept, each observed noun is either
      • a member of that concept with probability \( P(c) \)
      • not a member of that concept with probability \( 1 - P(c) \)
  • All words are members of the root node (Entity)
    • \( P(\text{root}) = 1 \) (in practice, it may not be 1)
  • The lower a node in hierarchy, the lower its probability
Information content similarity

- Train by counting in a corpus
  - Each instance of hill counts toward frequency of natural elevation, geological formation, entity, etc
- Let words(c) be the set of all words/phrases that are children of node c
  - words("geo-formation") = {hill, ridge, grotto, coast, cave, shore, natural elevation}
  - words("natural elevation") = {hill, ridge}

\[
P(c) = \frac{\sum \text{count}(w)}{N}
\]
Information content similarity

- WordNet hierarchy augmented with probabilities P(c)

• **Information content:**
  \[ \text{IC}(c) = -\log P(c) \]

• **Most informative subsumer** (Lowest common subsumer)
  \[ \text{LCS}(c_1, c_2) = \]
  The most informative (lowest) node in the hierarchy subsuming both \( c_1 \) and \( c_2 \)
Using information content for similarity: the Resnik method


• The similarity between two words is related to their common information
• The more two words have in common, the more similar they are
• Resnik: measure common information as:
  • The information content of the most informative (lowest) subsumer (MIS/LCS) of the two nodes

\[ \text{sim}_{\text{resnik}}(c_1,c_2) = -\log P(\text{LCS}(c_1,c_2)) \]
Dekang Lin method

Dekang Lin. 1998. An Information-Theoretic Definition of Similarity. ICML

• Intuition: Similarity between A and B is not just what they have in common
• The more **differences** between A and B, the less similar they are:
  • Commonality: the more A and B have in common, the more similar they are
  • Difference: the more differences between A and B, the less similar
Dekang Lin similarity theorem

• The similarity between A and B is measured by the ratio between the amount of information needed to state the commonality of A and B and the information needed to fully describe what A and B are

\[
sim_{Lin}(A, B) \propto \frac{IC(common(A, B))}{IC(description(A, B))}
\]

• Lin (altering Resnik) defines IC(common(A,B)) as 2 x information of the LCS

\[
sim_{Lin}(c_1, c_2) = \frac{2 \log P(LCS(c_1, c_2))}{\log P(c_1) + \log P(c_2)}
\]
Lin similarity function

\[ \text{sim}_\text{Lin}(A, B) = \frac{2 \log P(LCS(c_1, c_2))}{\log P(c_1) + \log P(c_2)} \]

\[ \text{sim}_\text{Lin}(\text{hill, coast}) = \frac{2 \log P(\text{geological-formation})}{\log P(\text{hill}) + \log P(\text{coast})} \]

\[ = \frac{2 \ln 0.00176}{\ln 0.0000189 + \ln 0.0000216} \]

\[ = 0.59 \]
Libraries for computing thesaurus-based similarity

• NLTK

• WordNet::Similarity
  • http://wn-similarity.sourceforge.net/
  • Web-based interface:
    • http://marimba.d.umn.edu/cgi-bin/similarity/similarity.cgi
Evaluating similarity

• Extrinsic (task-based, end-to-end) Evaluation:
  • Question answering
  • Spell checking
  • Essay grading
  • Word sense disambiguation

• Intrinsic Evaluation:
  • Correlation between algorithm and human word similarity ratings
    • Wordsim353: 353 noun pairs rated 0-10. \( \text{sim}(\text{plane}, \text{car})=5.77 \)
  • Taking multiple-choice vocabulary tests
    • Levied is closest in meaning to:
      imposed, believed, requested, correlated
Outline

• Word Senses and Word Relations
• Word Similarity
• Word Sense Disambiguation
Lexical Ambiguity

• Most words in natural languages have multiple possible meanings.
  • “pen” (noun)
    • The dog is in the pen.
    • The ink is in the pen.
  • “take” (verb)
    • Take one pill every morning.
    • Take the first right past the stoplight.
Lexical Ambiguity

• Most words in natural languages have multiple possible meanings.
  • “pen” (noun)
    • The dog is in the pen.
    • The ink is in the pen.
  • “take” (verb)
    • Take one pill every morning.
    • Take the first right past the stoplight.

• Syntax helps distinguish meanings for different parts of speech of an ambiguous word.
  • “conduct” (noun or verb)
    • John’s conduct in class is unacceptable.
    • John will conduct the orchestra on Thursday.
Motivation for Word Sense Disambiguation (WSD)

• Many tasks in natural language processing require disambiguation of ambiguous words.
  • Question Answering
  • Information Retrieval
  • Machine Translation
  • Text Mining
  • Phone Help Systems
Senses Based on Needs of Translation

• Only distinguish senses that are translate to different words in some other language.
  • play: tocar vs. jugar
  • know: conocer vs. saber
  • be: ser vs. estar
  • leave: salir vs dejar
  • take: llevar vs. tomar vs. sacar

• May still require overly fine-grained senses
  • river in French is either:
    • fleuve: flows into the ocean
    • rivièrè: does not flow into the ocean
Word Sense Disambiguation (WSD)

• Given
  • A word in context (*The dog is in the pen*)
  • A fixed inventory of potential word senses (*pen*¹, *pen*²)
  • Decide which sense of the word this is

• What set of senses?
  • In general: the senses in a thesaurus like WordNet
  • English-to-Spanish MT: set of Spanish translations
  • Speech Synthesis: homographs like *bass* and *bow*
Two variants of WSD task

• Lexical Sample task
  • Small pre-selected set of target words (*line*, *plant*)
  • And inventory of senses for each word
  • *Supervised machine learning: train a classifier for each word*

• All-words task
  • Every word in an entire text
  • A lexicon with senses for each word
  • Data sparseness: can’t train word-specific classifiers
WSD Methods

• Supervised Machine Learning
• Thesaurus/Dictionary Methods
• Semi-Supervised Learning [Leave it as your homework]
Supervised Machine Learning Approaches

• Supervised machine learning approach:
  • a training corpus of words tagged in context with their sense
  • used to train a classifier that can tag words in new text

• Summary of what we need:
  • the tag set (“sense inventory”)
  • the training corpus
  • A set of features extracted from the training corpus
  • A classifier
Supervised WSD 1: WSD Tags

• What’s a tag?
  A dictionary sense?

• For example, for WordNet an instance of “bass” in a text has 8 possible tags or labels (bass1 through bass8, as noun).
8 senses of “bass” 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)
Supervised WSD 2: Get a corpus

• Lexical sample task:
  • Line-hard-serve corpus - 4000 examples of each
  • Interest corpus - 2369 sense-tagged examples

• All words:
  • Semantic concordance: a corpus in which each open-class word is labeled with a sense from a specific dictionary/thesaurus.
    • SemCor: 234,000 words from Brown Corpus, manually tagged with WordNet senses
    • SENSEVAL-3 competition corpora - 2081 tagged word tokens
Supervised WSD 3: Extract feature vectors
Feature vectors

• A simple representation for each observation
  (each instance of a target word)
  • **Vectors** of sets of feature/value pairs
  • Represented as an ordered list of values
  • These vectors represent, e.g., context---the window of words around the target
Lexical Ambiguity

• Most words in natural languages have multiple possible meanings.
  • “pen” (noun)
    • The dog is in the pen.
    • The ink is in the pen.
  • “take” (verb)
    • Take one pill every morning.
    • Take the first right past the stoplight.
Two kinds of features in the vectors

• **Collocational** features and **bag-of-words** features
  
  • **Collocational**
    • Features about words at **specific** positions near target word
      • Often limited to just word identity and POS
  
  • **Bag-of-words**
    • Features about words that occur anywhere in the window (regardless of position)
      • Typically limited to frequency counts
Examples

• Example text (WSJ):
  An electric guitar and bass player stand off to one side not really part of the scene

• Assume a window of +/- 2 from the target
Examples

• Example text (WSJ)
  An electric guitar and bass player stand off to one side not really part of the scene,

• Assume a window of +/- 2 from the target
Collocational features

- Position-specific information about the words and collocations in window

- \textbf{guitar} and \textbf{bass} \textbf{player} \textbf{stand}

$[w_{i-2}, \text{POS}_{i-2}, w_{i-1}, \text{POS}_{i-1}, w_{i+1}, \text{POS}_{i+1}, w_{i+2}, \text{POS}_{i+2}, w_{i-2}^{i-1}, w_{i+1}^{i+1}]$

[guitar, NN, and, CC, player, NN, stand, VB, and guitar, player stand]

- word 1,2,3 grams in window of ±3 is common
Bag-of-words features

• “an unordered set of words” – position ignored
• Counts of words occur within the window.
• First choose a vocabulary
• Then count how often each of those terms occurs in a given window
  • sometimes just a binary “indicator” 1 or 0
Co-Occurrence Example

• Assume we’ve settled on a possible vocabulary of 12 words in “bass” sentences:

[fishing, big, sound, player, fly, rod, pound, double, runs, playing, guitar, band]

• The vector for:
  
guitar and bass player stand
  
[0,0,0,1,0,0,0,0,0,0,1,0]
Syntactic Relations
(Ambiguous Verbs)

• For an ambiguous verb, it is very useful to know its direct object.
  • “played the game”
  • “played the guitar”
  • “played the risky and long-lasting card game”
  • “played the beautiful and expensive guitar”
  • “played the big brass tuba at the football game”
  • “played the game listening to the drums and the tubas”

• May also be useful to know its subject:
  • “The game was played while the band played.”
  • “The game that included a drum and a tuba was played on Friday.”
Syntactic Relations  
(Ambiguous Nouns)

• For an ambiguous noun, it is useful to know what verb it is an object of:
  • “played the piano and the horn”
  • “wounded by the rhinoceros’ horn”

• May also be useful to know what verb it is the subject of:
  • “the bank near the river loaned him $100”
  • “the bank is eroding and the bank has given the city the money to repair it”
Syntactic Relations
(Ambiguous Adjectives)

• For an ambiguous adjective, it useful to know the noun it is modifying.
  • “a brilliant young man”
  • “a brilliant yellow light”
  • “a wooden writing desk”
  • “a wooden acting performance”
Classification: definition

• **Input:**
  • a word \( w \) and some features \( f \)
  • a fixed set of classes \( C = \{c_1, c_2, ..., c_J\} \)

• **Output:** a predicted class \( c \in C \)
Classification Methods:
Supervised Machine Learning

• **Input:**
  • a word $w$ in a text window $d$ *(which we’ll call a “document”)*
  • a fixed set of classes $C = \{c_1, c_2, \ldots, c_J\}$
  • A training set of $m$ hand-labeled text windows again called “documents” $(d_1, y_1), \ldots, (d_m, y_m)$, $y_m$ is in $C$

• **Output:**
  • a learned classifier $\gamma: d \rightarrow c$
Classification Methods:
Supervised Machine Learning

• Any kind of classifier
  • Naive Bayes
  • Logistic regression
  • Neural Networks
  • Support-vector machines
  • k-Nearest Neighbors

• ...
Applying Naive Bayes to WSD

- $P(c)$ is the prior probability of that sense
  - Counting in a labeled training set.
- $P(w|c)$ conditional probability of a word given a particular sense
  - $P(w|c) = \text{count}(w,c)/\text{count}(c)$
- We get both of these from a tagged corpus like SemCor
Choosing a class:

\[ P(f \mid d5) \propto \frac{3}{4} \times \frac{2}{14} \times \frac{1}{14} \]
\[ \approx 0.00003 \]

\[ P(g \mid d5) \propto \frac{1}{4} \times \frac{2}{9} \times \frac{2}{9} \]
\[ \approx 0.00006 \]
WSD Evaluations and baselines

• Best evaluation: extrinsic (‘end-to-end’, `task-based’) evaluation
  • Embed WSD algorithm in a task and see if you can do the task better!

• What we often do for convenience: intrinsic evaluation
  • Exact match sense accuracy
    • % of words tagged identically with the human-manual sense tags
  • Usually evaluate using held-out data/test data from same labeled corpus

• Baselines
  • Most frequent sense
  • The Lesk algorithm
Most Frequent Sense

- WordNet senses are ordered in frequency order
- So “most frequent sense” in WordNet = “take the first sense”
- Sense frequencies come from the *SemCor* corpus

<table>
<thead>
<tr>
<th>Freq</th>
<th>Synset</th>
<th>Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>338</td>
<td>plant(^1), works, industrial plant</td>
<td>buildings for carrying on industrial labor</td>
</tr>
<tr>
<td>207</td>
<td>plant(^2), flora, plant life</td>
<td>a living organism lacking the power of locomotion</td>
</tr>
<tr>
<td>2</td>
<td>plant(^3)</td>
<td>something planted secretly for discovery by another</td>
</tr>
<tr>
<td>0</td>
<td>plant(^4)</td>
<td>an actor situated in the audience whose acting is rehearsed but</td>
</tr>
<tr>
<td></td>
<td></td>
<td>seems spontaneous to the audience</td>
</tr>
</tbody>
</table>
The Simplified Lesk algorithm

• Let’s disambiguate “bank” in this sentence:
  The bank can guarantee deposits will eventually cover future tuition costs because it invests in adjustable-rate mortgage securities.

• given the following two WordNet senses:

<table>
<thead>
<tr>
<th>bank¹</th>
<th>Gloss:</th>
<th>a financial institution that accepts deposits and channels the money into lending activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Examples:</td>
<td>“he cashed a check at the bank”, “that bank holds the mortgage on my home”</td>
</tr>
<tr>
<td>bank²</td>
<td>Gloss:</td>
<td>sloping land (especially the slope beside a body of water)</td>
</tr>
<tr>
<td></td>
<td>Examples:</td>
<td>“they pulled the canoe up on the bank”, “he sat on the bank of the river and watched the currents”</td>
</tr>
</tbody>
</table>
The Simplified Lesk algorithm

Choose sense with most word overlap between gloss and context (not counting function words)

The **bank** can guarantee **deposits** will eventually cover future tuition costs because it invests in adjustable-rate **mortgage** securities.

<table>
<thead>
<tr>
<th>bank(^1)</th>
<th>Gloss: a financial institution that accepts <strong>deposits</strong> and channels the money into lending activities</th>
<th>Examples: “he cashed a check at the bank”, “that bank holds the <strong>mortgage</strong> on my home”</th>
</tr>
</thead>
<tbody>
<tr>
<td>bank(^2)</td>
<td>sloping land (especially the slope beside a body of water)</td>
<td>“they pulled the canoe up on the bank”, “he sat on the bank of the river and watched the currents”</td>
</tr>
</tbody>
</table>
The Corpus Lesk algorithm

• Assumes we have some sense-labeled data (like SemCor)
• Take all the sentences with the relevant word sense:
  
  These short, "streamlined" meetings usually are sponsored by local banks¹, Chambers of Commerce, trade associations, or other civic organizations.
• Now add these to the gloss + examples for each sense, call it the “signature” of a sense.
• Choose sense with most word overlap between context and signature.
Corpus Lesk: IDF weighting

• Instead of just removing function words
  • Down-weights words that occur in every “document” (gloss, example, etc)
    • These are generally function words, but is a more fine-grained measure

• Weigh each overlapping word by **inverse document frequency**
Corpus Lesk: IDF weighting

• Weigh each overlapping word by inverse document frequency
  • $N$ is the total number of documents
  • $df_i = "\text{document frequency of word } i\"$
  • $= \# \text{ of documents with word } i$

$$\text{idf}_i = \log \left( \frac{N}{df_i} \right)$$

$$\text{score}(\text{sense}_i, \text{context}_j) = \sum_{w \in \text{overlap}(\text{signature}_i, \text{context}_j)} \text{idf}_w$$
Semi-Supervised Learning

**Problem**: supervised and dictionary-based approaches require large hand-built resources

What if you don’t have so much training data?

**Solution**: Bootstrapping

Generalize from a very small hand-labeled seed-set.
Bootstrapping

• For bass
  • Rely on “One sense per collocation” rule
    • A word reoccurring in collocation with the same word will almost surely have the same sense.
  • the word play occurs with the music sense of bass
  • the word fish occurs with the fish sense of bass
Sentences extracting using “fish” and “play”

<table>
<thead>
<tr>
<th>We need more good teachers – right now, there are only a half a dozen who can play the free bass with ease.</th>
</tr>
</thead>
<tbody>
<tr>
<td>An electric guitar and bass player stand off to one side, not really part of the scene, just as a sort of nod to gringo expectations perhaps.</td>
</tr>
<tr>
<td>The researchers said the worms spend part of their life cycle in such fish as Pacific salmon and striped bass and Pacific rockfish or snapper.</td>
</tr>
<tr>
<td>And it all started when fishermen decided the striped bass in Lake Mead were too skinny.</td>
</tr>
</tbody>
</table>
Summary: generating seeds

1) Hand labeling

2) “One sense per collocation”:
   • A word reoccurring in collocation with the same word will almost surely have the same sense.

3) “One sense per discourse”:
   • The sense of a word is highly consistent within a document - Yarowsky (1995)
   • (At least for non-function words, and especially topic-specific words)
Summary

• Word Sense Disambiguation: choosing correct sense in context
• Applications: MT, QA, etc.
• Three classes of Methods
  • Supervised Machine Learning: Naive Bayes classifier
  • Thesaurus/Dictionary Methods
  • Semi-Supervised Learning
• Main intuition
  • There is lots of information in a word’s context
  • Simple algorithms based just on word counts can be surprisingly good