Lexical Semantics and Word Sense Disambiguation

Le Anh Cuong

Reading

- Chapter 19, 20 [1]

Outline

- Word Senses
- Relations between senses
- WordNet
- Event participants
- Word sense disambiguation
- Word similarity
- Semantic role labeling

Three Perspectives on Meaning

1. Lexical Semantics
   - The meanings of individual words
2. Formal Semantics (or Compositional Semantics or Sentential Semantics)
   - How those meanings combine to make meanings for individual sentences or utterances
3. Discourse or Pragmatics
   - How those meanings combine with each other and with other facts about various kinds of context to make meanings for a text or discourse.
   - Dialog or Conversation is often lumped together with Discourse.

Outline: Computational Lexical Semantics

- Introduction to Lexical Semantics
  - Word relations such as Homonymy, Polysemy, Synonymy
  - Online resources: WordNet
- Computational Lexical Semantics
  - Word Sense Disambiguation
    - Supervised
    - Semi-supervised
  - Word Similarity
    - Thesaurus-based
    - Distributional

Preliminaries

- What’s a word?
  - Definitions we’ve used over the class: Types, tokens, stems, roots, uninflected forms, etc…
- Lexeme: An entry in a lexicon consisting of a pairing of a form with a single meaning representation
- Lexicon: A collection of lexemes
- Lemma – citation form – uninflected form (used to represent a lexeme). Need to do morphological parsing to get from wordform to lemma (lemmatization)
- Lemma is part-of-speech specific (e.g., table N and V)

Relationships between word meanings

- Homonymy
- Polysemy
- Synonymy
- Antonymy
- Hypernomy
- Hyponomy
- Meronomy

Homonymy

- Lexemes that share a form
    - Phonological, orthographic or both
- But have unrelated, distinct meanings
- Clear example:
    - Bat (wooden stick-like thing) vs
    - Bat (flying scary mammal thing)
    - Or bank (financial institution) versus bank (riverside)
- Can be homophones, homographs, or both
    - Homophones:
        - Write and right
        - Piece and peace

Homonymy causes problems for NLP applications

- Text-to-Speech
  - Same orthographic form but different phonological form
    - Bass vs bass
    - Bow vs bow
    - Record vs record
- Information retrieval
  - Different meanings same orthographic form
    - QUERY: bat care
- Machine Translation
- Speech recognition

Polysemy

- The bank is constructed from red brick
  I withdrew the money from the bank

- Are those the same sense?
- What about river bank?

- What about: The food bank is having a donation drive next week.
- Different senses but some more related than others…
- When two senses are related semantically we call it polysemy (rather than homonymy)

Polysemy

- A single lexeme with multiple related meanings (bank the building, bank the financial institution)
- Most non-rare words have multiple meanings
  - The number of meanings is related to its frequency
  - Verbs tend more to polysemy
  - Distinguishing polysemy from homonymy isn’t always easy (or necessary)

Metaphor and Metonymy

- Specific types of polysemy
- Metaphor:
  - Germany will pull Slovenia out of its economic slump.
  - I spent 2 hours on that homework.
  - I put money into Google stock.
- Metonymy (use of one aspect of a concept or entity to refer to other aspects of the entity or to the entity itself)
  - The White House announced yesterday…
    - White House refers to the administration whose office is in the White House
  - This chapter talks about part-of-speech tagging
  - Bank (building) and bank (financial institution)

How do we know when a word has more than one sense?

- ATIS examples
  - Which flights serve breakfast?
  - Does America West serve Philadelphia?

- The “zeugma” test:

  - ?Does United serve breakfast and San Jose?

Synonyms

- Words that have the same meaning in some or all contexts
  - Filbert / hazelnut
  - Couch / sofa
  - Big / large
  - Automobile / car
  - Vomit / throw up
  - Water / H_2O
- Two lexemes are synonyms if they can be successfully substituted for each other in all situations
  - If so they have the same **propositional meaning**

Synonyms

- But there are few (or no) examples of perfect synonym
  - Why should that be?
  - 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 and H_2O
  - Large coke versus *big coke

Some more terminology

- Lemmas and word forms
  - A **lexeme** is an abstract pairing of meaning and form
  - A **lemma** or **citation form** is the grammatical form that is used to represent a lexeme
    - **Carpet** is the lemma for **carpets**
    - **Corpus** is the lemma for **corpora**
  - Specific surface forms carpets, sung, corpora are called **wordforms**
- The lemma bank has two senses:
  - Instead, a **bank** can hold the investments in…
  - But as agriculture burgeons on the east **bank**, the river will shrink even more
- A **sense** is a discrete representation of one aspect of the meaning of a word

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, for instance, became a kind of **big** sister to Benjamin.
  - ?Miss Nelson, for instance, 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 their meaning
- Otherwise, they are very similar!
  - Dark / light
  - Short / long
  - Hot / cold
  - Up / down
  - In / out
- More formally: antonyms can
  - Define a binary opposition or are at opposite ends of a scale (*long/short, fast/slow*)
  - Be reversives (describe a change of movement in opposite directions): *rise/fall, up/down*

Hyponym

- 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*
  - *Dog* is a hyponym of *animal*
  - *Mango* is a hyponym of *fruit*
- Conversely
  - *Vehicle* is a hypernym/superordinate of *car*
  - *Animal* is a hypernym of *dog*
  - *Fruit* is a hypernym of *mango*

Superordinate	Vehicle	Fruit	Furniture	mammal
Hyponym	Car	Mango	Chair	Dog

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)

II. Wordnet

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

Category	**Unique Forms**
Noun	117,097
Verb	11,488
Adjective	22,141
Adverb	4,601

Wordnet

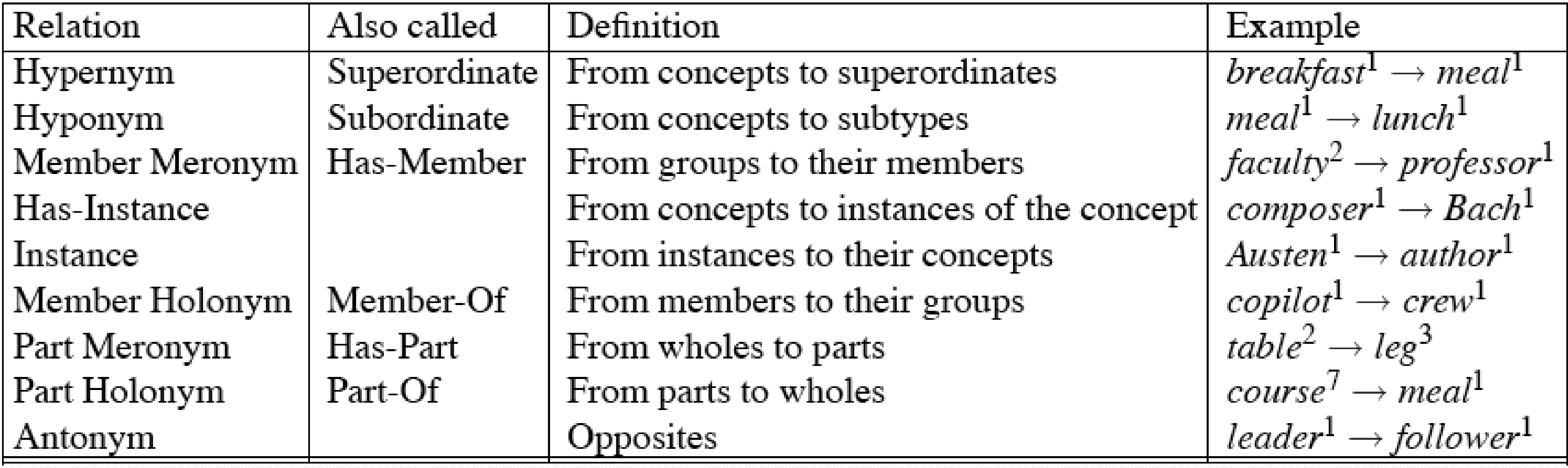
- Where it is:

- http://wordnetweb.princeton.edu/perl/webwn

Format of WordNet Entries

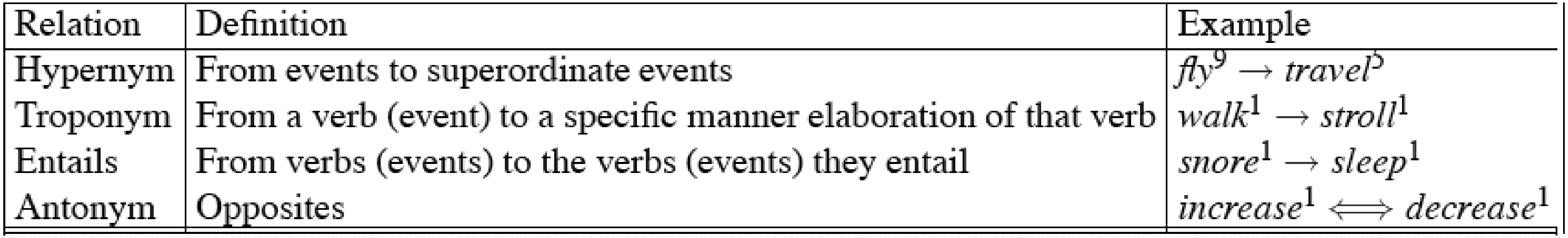
- The noun bass has 8 senses in wordnet:
- S: (n) **bass** (the lowest part of the musical range)
- S: (n) **bass**, bass part (the lowest part in polyphonic music)
- S: (n) **bass**, basso (an adult male singer with the lowest voice)
- S: (n) sea bass, **bass** (the lean flesh of a saltwater fish of 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)
- **And 1 Adjective Sense:**
- 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"*

WordNet Noun Relations



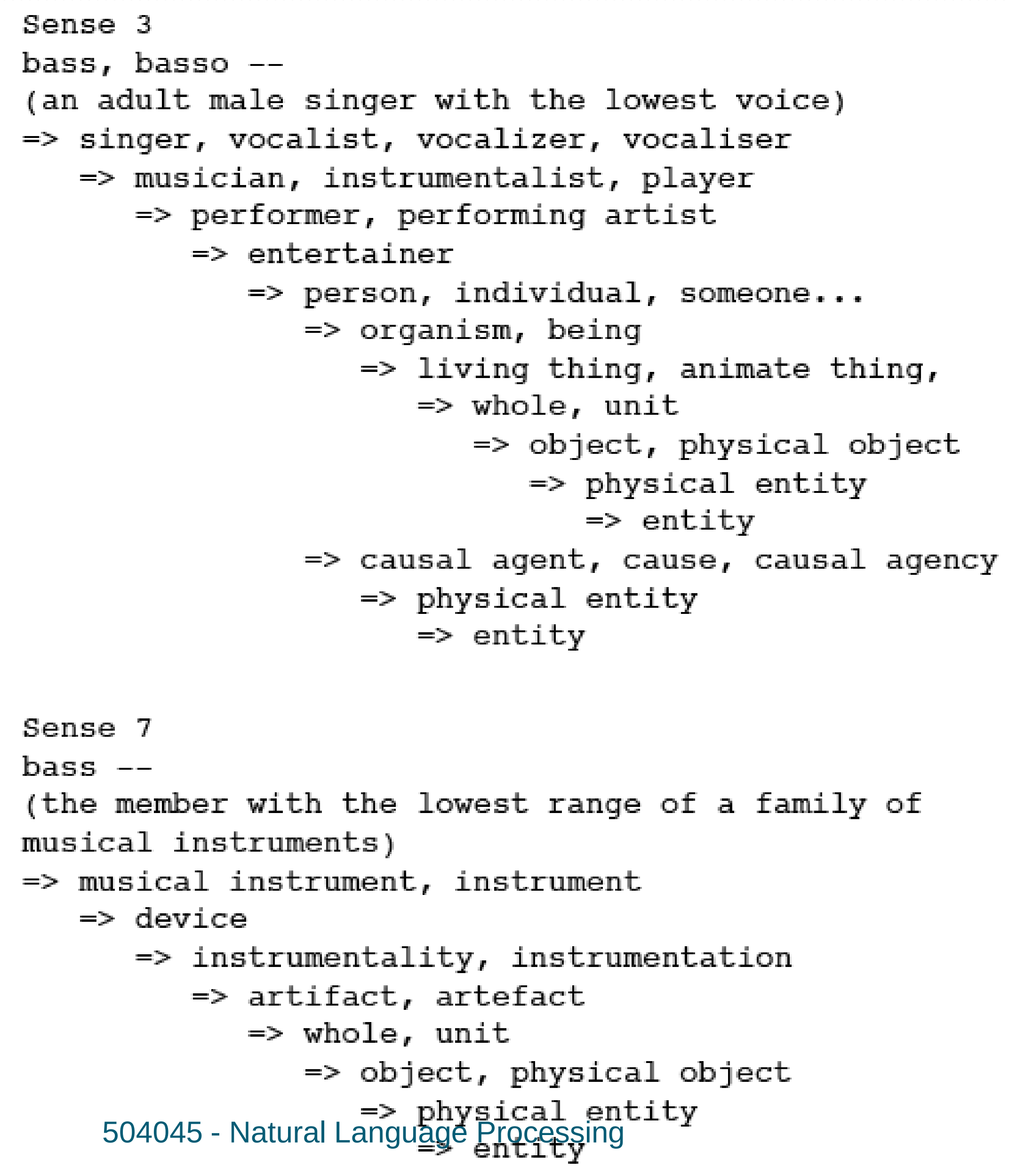
Relation	Also called	Definition	Example
Hypernym	Superordinate	From concepts to superordinates	*breakfast*^{1} → *meal*^{1}
Hyponym	Subordinate	From concepts to subtypes	*meal*^{1} → *lunch*^{1}
Member Meronym	Has-Member	From groups to their members	*faculty*^{2} → *professor*^{1}
Has-Instance		From concepts to instances of the concept	*composer*^{1} → *Bach*^{1}
Instance		From instances to their concepts	*Austen*^{1} → *author*^{1}
Member Holonym	Member-Of	From members to their groups	*copilot*^{1} → *crew*^{1}
Part Meronym	Has-Part	From wholes to parts	*table*^{2} → *leg*^{3}
Part Holonym	Part-Of	From parts to wholes	*course*^{7} → *meal*^{1}
Antonym		Opposites	*leader*^{1} → *follower*^{1}

WordNet Verb Relations



Relation	Definition	Example
Hypernym	From events to superordinate events	$\mathit{fly}^9 \rightarrow \mathit{travel}^5$
Troponym	From a verb (event) to a specific manner elaboration of that verb	$\mathit{walk}^1 \rightarrow \mathit{stroll}^1$
Entails	From verbs (events) to the verbs (events) they entail	$\mathit{snore}^1 \rightarrow \mathit{sleep}^1$
Antonym	Opposites	$\mathit{increase}^1 \Longleftrightarrow \mathit{decrease}^1$

WordNet Hierarchies



```
Sense 3
bass, basso --
(an adult male singer with the lowest voice)
=> singer, vocalist, vocalizer, vocaliser
   => musician, instrumentalist, player
      => performer, performing artist
         => entertainer
            => person, individual, someone...
               => organism, being
                  => living thing, animate thing,
                     => whole, unit
                        => object, physical object
                           => physical entity
                              => entity
               => causal agent, cause, causal agency
                  => physical entity
                     => entity


Sense 7
bass --
(the member with the lowest range of a family of
musical instruments)
=> musical instrument, instrument
   => device
      => instrumentality, instrumentation
         => artifact, artefact
            => whole, unit
               => object, physical object
                  => physical entity
                     => entity
```

How is "sense" defined in WordNet?

- The set of near-synonyms for a WordNet sense is called a synset (synonym set); it's their version of a sense or a concept.
- Example: chump as a noun to mean
  - 'a person who is gullible and easy to take advantage of'
  - **chump#1**, fool#2, gull#1, mark#9, patsy#1, fall guy#1, sucker#1, soft touch#1, mug#2 (a person who is gullible and easy to take advantage of)
- Each of these senses share this same gloss
- Thus, for WordNet, the meaning of this sense of chump *is* this list.

Word Sense Disambiguation (WSD)

- Given
  - A word in context,
  - A fixed inventory of potential word senses
- Decide which sense of the word this is
  - English-to-Spanish MT
    - Inventory is the set of Spanish translations
  - Speech Synthesis
    - Inventory is homographs with different pronunciations like bass and bow
  - Automatic indexing of medical articles
  - MeSH (Medical Subject Headings) thesaurus entries

Two variants of WSD task

- Lexical Sample task
  - Small pre-selected set of target words
  - And inventory of senses for each word
- All-words task
  - Every word in an entire text
  - A lexicon with senses for each word
  - Sort-of like part-of-speech tagging
    - Except each lemma has its own tagset

Approaches

- Supervised
- Semi-supervised
  - Unsupervised
    - Dictionary-based techniques
    - Selectional association
  - Lightly supervised
    - Bootstrapping
    - Preferred Selectional Association

Supervised Machine Learning Approaches

- Supervised machine learning approach:
  - A training corpus of ?
  - Used to train a classifier that can tag words in text
  - Just as in part-of-speech tagging, statistical MT.

- Summary of what we need:
  - The tag set ("sense inventory")
  - The training corpus
  - A set of features extracted from the training corpus
  - A classifier

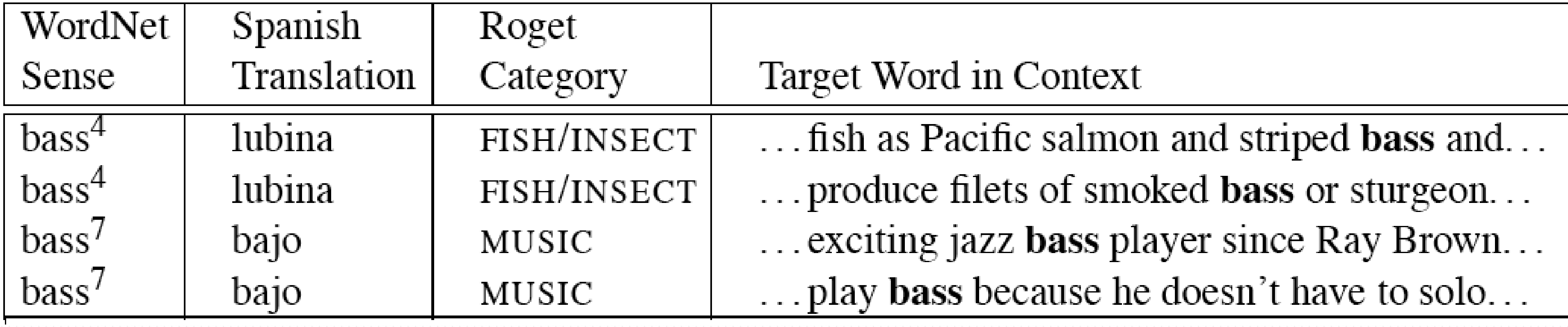
Supervised WSD 1: WSD Tag

- What’s a tag?

WordNet Bass

- The noun “bass” has 8 senses in WordNet
- S: (n) **bass#1** (the lowest part of the musical range)
- S: (n) **bass#2**, bass part#1 (the lowest part in polyphonic music)
- S: (n) **bass#3**, basso#1 (an adult male singer with the lowest voice)
- S: (n) sea bass#1, **bass#4** (the lean flesh of a saltwater fish of the family Serranidae)
- S: (n) freshwater bass#1, **bass#5** (any of various North American freshwater fish with lean flesh (especially of the genus Micropterus))
- S: (n) **bass#6**, bass voice#1, basso#2 (the lowest adult male singing voice)
- S: (n) **bass#7** (the member with the lowest range of a family of musical instruments)
- S: (n) **bass#8** (nontechnical name for any of numerous edible marine and freshwater spiny-finned fishes)

Inventory of sense tags for bass



WordNet Sense	Spanish Translation	Roget Category	Target Word in Context
bass^4	lubina	FISH/INSECT	. . . fish as Pacific salmon and striped **bass** and. . .
bass^4	lubina	FISH/INSECT	. . . produce filets of smoked **bass** or sturgeon. . .
bass^7	bajo	MUSIC	. . . exciting jazz **bass** player since Ray Brown. . .
bass^7	bajo	MUSIC	. . . play **bass** because he doesn't have to solo. . .

Supervised WSD 2: Get a corpus

- Lexical sample task:
  - Line-hard-serve corpus -4000 examples of each
  - Interestcorpus -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

- Weaver (1955)
- If one examines the words in a book, one at a time as through an opaque mask with a hole in it one word wide, then it is obviously impossible to determine, one at a time, the meaning of the words. [...] But if one lengthens the slit in the opaque mask, until one can see not only the central word in question but also say N words on either side, then if N is large enough one can unambiguously decide the meaning of the central word. [...] The practical question is : ``What minimum value of N will, at least in a tolerable fraction of cases, lead to the correct choice of meaning for the central word?"

- Dishes

- Bass

- washing *dishes* .
- simple *dishes* including
- convenient *dishes* to
- of *dishes* and

- free *bass* with
- pound *bass* of
- and *bass* player
- his *bass* while

- “In our house, everybody has a career and none of them includes washing *dishes*,” he says.
- In her tiny kitchen at home, Ms. Chen works efficiently, stir-frying several simple *dishes*, including braised pig’s ears and chcken livers with green peppers.
- Post quick and convenient *dishes* to fix when your in a hurry.
- Japanese cuisine offers a great variety of *dishes* and regional specialties

- We need more good teachers –right now, there are only a half a dozen who can play the free *bass* with ease.
- Though still a far cry from the lake's record 52-pound *bass* of a decade ago, "you could fillet these fish again, and that made people very, very happy." Mr. Paulson says.
- 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 again.
- Lowe caught his *bass* while fishing with pro Bill Lee of Killeen, Texas, who is currently in 144th place with two bass weighing 2-09.

Feature Vectors

- A simple representation for each observation (each instance of a target word)
  - Vectors of sets of feature/value pairs
  - I.e. files of comma-separated values
- These vectors should represent the window of words around the target

How big should that window be?

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, just as a sort of nod to gringo expectations perhaps
- Assume a window of +/-2 from the target

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Collocational

- Position-specific information about the words in the window
- guitar and bass player stand
- [guitar, NN, and, CC, player, NN, stand, VB]
- Wordn-2,POSn-2,wordn-1,POSn-1,Wordn+1POSn+1…
- In other words, a vector consisting of
- [position n word, position n part-of-speech…]

Bag-of-words

- Information about the words that occur within the window.
- First derive a set of terms to place in the vector.
- Then note how often each of those terms occurs in a given window.

Co-Occurrence Example

- Assume we've settled on a possible vocabulary of 12 words that includes guitar and player but not and and stand

- guitar and bass player stand
- [0,0,0,1,0,0,0,0,0,1,0,0]
- Which are the counts of words predefined as e.g.,
- [fish,fishing,viol, guitar, double,cello…

Classifiers

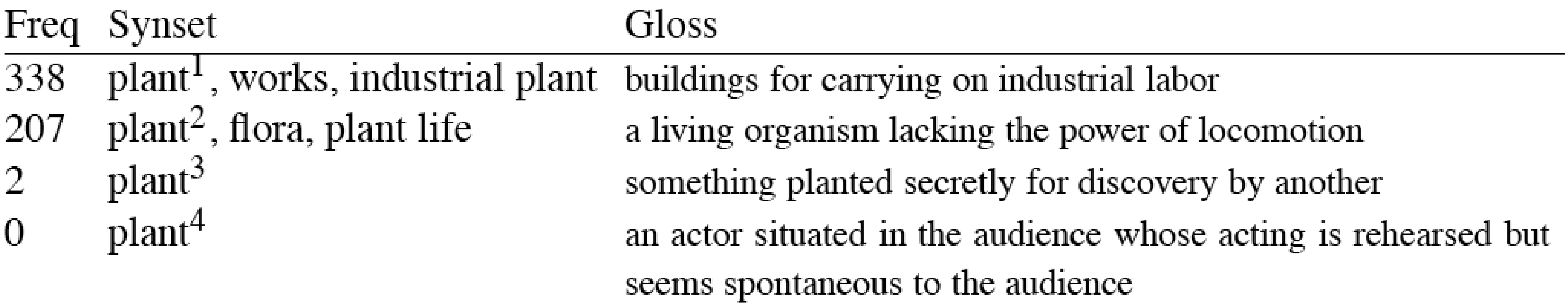
- Once we cast the WSD problem as a classification problem, then all sorts of techniques are possible
  - Naïve Bayes (the easiest thing to try first)
  - Decision lists
  - Decision trees
  - Neural nets
  - Support vector machines
  - Nearest neighbor methods…

WSD Evaluations and Baselines

- In vivo (end-to-end, extrinsic, task-based) versus in vitro (intrinsic as if a stand-alone system) evaluation
  - In vitro evaluation is most common now
    - Exact match **accuracy**
    - % of words tagged identically with manual sense tags
    - Usually evaluate using held-out data from same labeled corpus
      - Problems?
      - Why do we do it anyhow?
- Baselines
  - Most frequent sense
  - The Lesk algorithm (choose the sense whose dictionary gloss or definition shares the most words with the target word's neighborhood.

Most Frequent Sense

- WordNet senses are order in frequency order
- So “most frequent sense” in WordNet = “take the first sense”



Freq	Synset	Gloss
338	plant[1], works, industrial plant	buildings for carrying on industrial labor
207	plant[2], flora, plant life	a living organism lacking the power of locomotion
2	plant[3]	something planted secretly for discovery by another
0	plant[4]	an actor situated in the audience whose acting is rehearsed but seems spontaneous to the audience

Ceiling

- Human-inter-annotator agreement
  - Compare annotations of two humans
  - On same data
  - Given same tagging guidelines

- Human agreements on all-words corpora with WordNet style senses
  - 75%-80%