Lexical Semantics and Word Sense Disambiguation

Announcements

- Midterm sample questions on website
- Next class: midterm review for part of the class. Post your wishes for topics for the review on Piazza
- HW1 grades out. Mean is 81. Nice going!
- Following topics: semantic parsing, then to distributed semantics and word embeddings, neural nets.

Polysemy

- The **bank** is constructed from red brick
  I withdrew the money from the **bank**
- Are those the same sense?
- Or consider the following WSJ example
  - While some banks furnish sperm only to married women, others are less restrictive
  - Which sense of bank is this?
    - Is it distinct from (homonymous with) the river bank sense?
    - How about the savings bank sense?

…nse of "bank" is in the sentence "While som… …ish sperm only to married women, others are … restrictive?

river bank

savings bank

other

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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.
- Metonymy
  - The White House announced yesterday.
  - 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

- Word that have the same meaning in some or all contexts.
  - filbert / hazelnut
  - couch / sofa
  - big / large
  - automobile / car
  - vomit / throw up
  - Water / H_20
- 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 synonymy.
  - 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_20

Some more terminology

- Lemmas and wordforms
  - 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***
    - ***Dormir*** is the lemma for ***duermes*.**
  - Specific surface forms *carpets, sung, duermes* are called **wordforms**
- The lemma *bank* has two **senses:**
  - Instead, a **bank** can hold the investments in a custodial account in the client's name
  - 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 at opposite ends of a scale (*long/short, fast/slow*)
  - Be **reversives**: *rise/fall, up/down*

uld we say that antonyms are very similar? H they similar?

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Hyponymy

- 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

Hypernymy 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)

y would hypernyms/hyponyms be important constructing a meaning representation?

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II. WordNet

- A hierarchically organized lexical database
- On-line thesaurus + aspects of a dictionary
  - Versions for other languages are under development

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

WordNet

- Where it is:
  - https://wordnet.princeton.edu/

Format of Wordnet Entries

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

The adjective "bass" has 1 sense in WordNet.
1. bass^{1}, deep^{6} - (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	$breakfast^1 \rightarrow meal^1$
Hyponym	Subordinate	From concepts to subtypes	$meal^1 \rightarrow lunch^1$
Member Meronym	Has-Member	From groups to their members	$faculty^2 \rightarrow professor^1$
Has-Instance		From concepts to instances of the concept	$composer^1 \rightarrow Bach^1$
Instance		From instances to their concepts	$Austen^1 \rightarrow author^1$
Member Holonym	Member-Of	From members to their groups	$copilot^1 \rightarrow crew^1$
Part Meronym	Has-Part	From wholes to parts	$table^2 \rightarrow leg^3$
Part Holonym	Part-Of	From parts to wholes	$course^7 \rightarrow meal^1$
Antonym		Opposites	$leader^1 \rightarrow follower^1$

WordNet Verb Relations

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

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]}

- Each of these senses share this same gloss
- Thus for WordNet, the meaning of this sense of chump *is* this list.

Wordnet example

Word Sense Disambiguation

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 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 new text
  - Just as we saw for 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**

What would be a good training corpus for sense disambiguation?

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Supervised WSD 1: WSD Tags

- What’s a tag?

WordNet

- http://www.cogsci.princeton.edu/cgi-bin/webwn

WordNet Bass

The noun ``bass'' has 8 senses in WordNet

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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)

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
  - *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

- 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

plates or food: "convenient dishes to"

plates

food

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plates or food: "of dishes and "

plates

food

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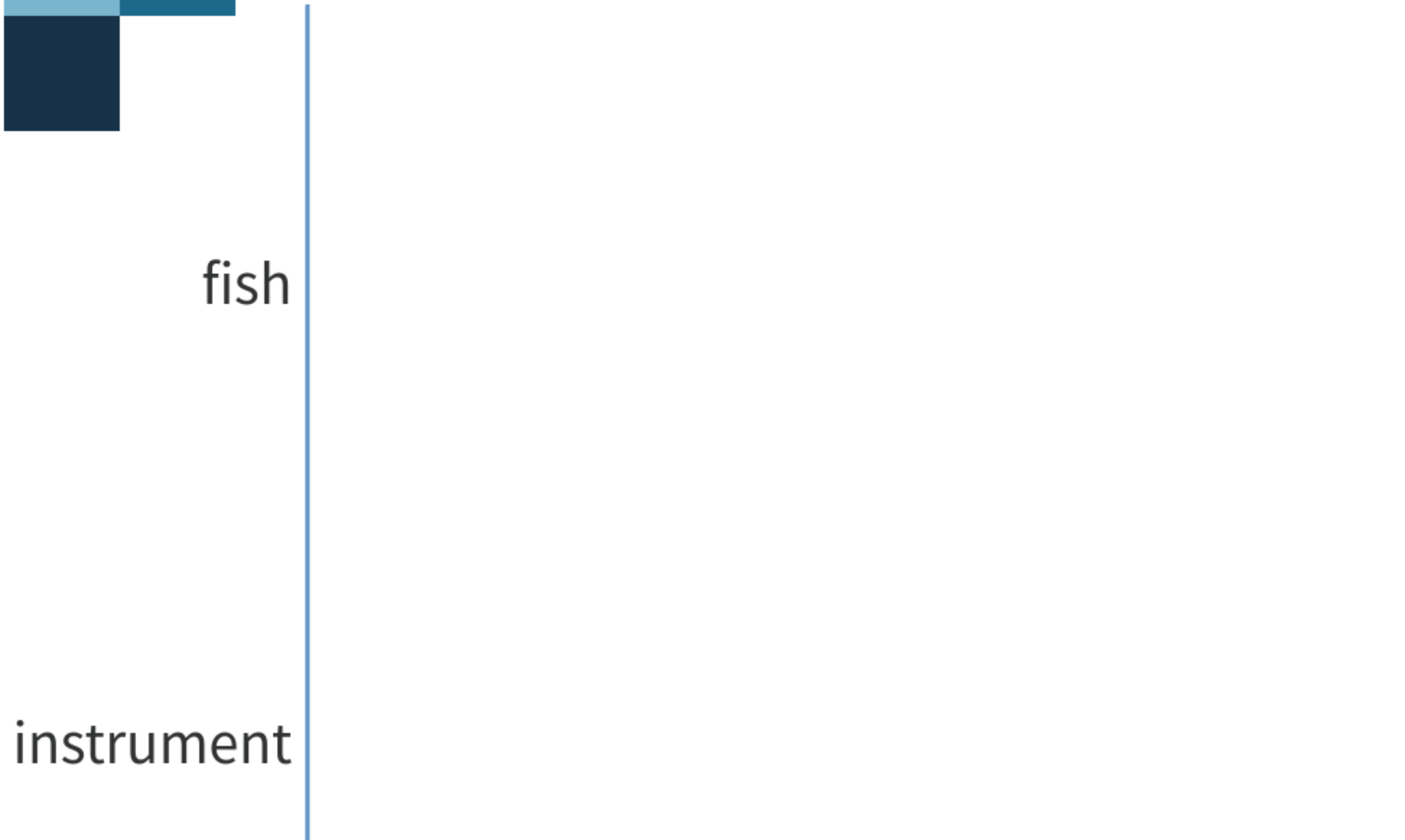
"free bass with"



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pound bass of

fish

instrument

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- “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

Examples

- Example text
  - 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

Collocational

- Position-specific information about the words in the window
- guitar and bass player stand
  - [guitar, NN, and, CC, player, NN, stand, VB]
  - $Word_{n-2}$, POS_{n-2}, $word_{n-1}$, POS_{n-1}, $Word_{n+1}$ POS_{n+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…

Classifiers

- The choice of technique, in part, depends on the set of features that have been used
  - Some techniques work better/worse with features with numerical values
  - Some techniques work better/worse with features that have large numbers of possible values
    - For example, the feature **the word to the left** has a fairly large number of possible values

Naïve Bayes

- $\hat{s} = \underset{s \in S}{\arg\max}\, p(s|V)$, or $\underset{s \in S}{\arg\max} \frac{p(V|s)\,p(s)}{p(V)}$
- Where s is one of the senses S possible for a word w and V the input vector of feature values for w
- Assume features *independent*, so probability of V is the product of probabilities of each feature, given s, so
- $p(V|s) = \prod_{j=1}^{n} p(v_j|s)$

  p(V) same for any ŝ
- Then $\hat{s} = \underset{s \in S}{\arg\max}\, p(s) \prod_{j=1}^{n} p(v_j|s)$

- How do we estimate p(s) and $p(v_j|s)$?
  - $p(s_i)$ is max. likelihood estimate from a sense-tagged corpus $(count(s_i,w_j)/count(w_j))$ – how likely is bank to mean 'financial institution' over all instances of bank?
  - $P(v_j|s)$ is max. likelihood of each feature given a candidate sense $(count(v_j,s)/count(s))$ – how likely is the previous word to be 'river' when the sense of bank is 'financial institution'

- Calculate $$\hat{s} = \arg\max_{s \in S} p(s) \prod_{j=1}^{n} p(v_j|s)$$

  take the highest scoring sense as the most likely choice

Naïve Bayes Test

- On a corpus of examples of uses of the word line, naïve Bayes achieved about 73% correct

- Good?

Decision Lists: another popular method

- A case statement….

Rule		Sense
fish within window	$\Rightarrow$	**bass**^{1}
striped bass	$\Rightarrow$	**bass**^{1}
guitar within window	$\Rightarrow$	**bass**^{2}
bass player	$\Rightarrow$	**bass**^{2}
piano within window	$\Rightarrow$	**bass**^{2}
tenor within window	$\Rightarrow$	**bass**^{2}
sea bass	$\Rightarrow$	**bass**^{1}
play/V bass	$\Rightarrow$	**bass**^{2}
river within window	$\Rightarrow$	**bass**^{1}
violin within window	$\Rightarrow$	**bass**^{2}
salmon within window	$\Rightarrow$	**bass**^{1}
on bass	$\Rightarrow$	**bass**^{2}
bass are	$\Rightarrow$	**bass**^{1}

Learning Decision Lists

- Restrict the lists to rules that test a single feature (1-decisionlist rules)
- Evaluate each possible test and rank them based on how well they work.
- Glue the top-N tests together and call that your decision list.

Yarowsky

- On a binary (homonymy) distinction used the following metric to rank the tests

$$\frac{P(\mathrm{Sense}_1 \mid Feature)}{P(\mathrm{Sense}_2 \mid Feature)}$$

- This gives about 95% on this test…

WSD Evaluations and baselines

- *In vivo* versus *in vitro* 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

Most Frequent Sense

- Wordnet senses are ordered 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%

Unsupervised Methods WSD: Dictionary/Thesaurus methods

- The Lesk Algorithm
- Selectional Restrictions

Simplified Lesk

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:

$bank^1$	Gloss:	a financial institution that accepts deposits and channels the money into lending activities
	Examples:	"he cashed a check at the bank", "that bank holds the mortgage on my home"
$bank^2$	Gloss:	sloping land (especially the slope beside a body of water)
	Examples:	"they pulled the canoe up on the bank", "he sat on the bank of the river and watched the currents"

Original Lesk: pine cone

pine	1	kinds of evergreen tree with needle-shaped leaves
	2	waste away through sorrow or illness
cone	1	solid body which narrows to a point
	2	something of this shape whether solid or hollow
	3	fruit of certain evergreen trees

Corpus Lesk

- Add corpus examples to glosses and examples
- The best performing variant

Disambiguation via Selectional Restrictions

- “Verbs are known by the company they keep”
  - Different verbs select for different thematic roles

    wash the ***dishes*** (takes washable-thing as patient)

    serve delicious ***dishes*** (takes food-type as patient)
- Method: another semantic attachment in grammar
  - Semantic attachment rules are applied as sentences are syntactically parsed, e.g.

    VP --> V NP

    V→ serve <theme> {theme:food-type}
  - Selectional restriction violation: no parse

- But this means we must:
  - Write selectional restrictions for each sense of each predicate – or use FrameNet
    - Serve alone has 15 verb senses
  - Obtain hierarchical type information about each argument (using WordNet)
    - How many hypernyms does dish have?
    - How many words are hyponyms of dish?
- But also:
  - Sometimes selectional restrictions don't restrict enough (Which dishes do you like?)
  - Sometimes they restrict too much (Eat dirt, worm! I'll eat my hat!)
- Can we take a statistical approach?

Semi-supervised Bootstrapping

- What if you don't have enough data to train a system…
- Bootstrap
  - Pick a word that you as an analyst think will co-occur with your target word in particular sense
  - Grep through your corpus for your target word and the hypothesized word
  - Assume that the target tag is the right one

Bootstrapping

- For bass
  - Assume play occurs with the music sense and fish occurs with the fish sense

Sentences extracting using "fish" and "play"

more good teachers – right now, there are only a half a dozen who car with ease.

ic guitar and **bass play**er stand off to one side, not really part of the scer nod to gringo expectations perhaps.

e New Jersey Jazz Society, in a fund-raiser for the American Jazz Hall his historic night next Saturday, Harry Goodman, Mr. Goodman's br yer at the original concert, will be in the audience with other family mer

archers said the worms spend part of their life cycle in such **fish** as Pacif ed **bass** and Pacific rockfish or snapper.

l started when **fish**ermen decided the striped **bass** in Lake Mead were tc

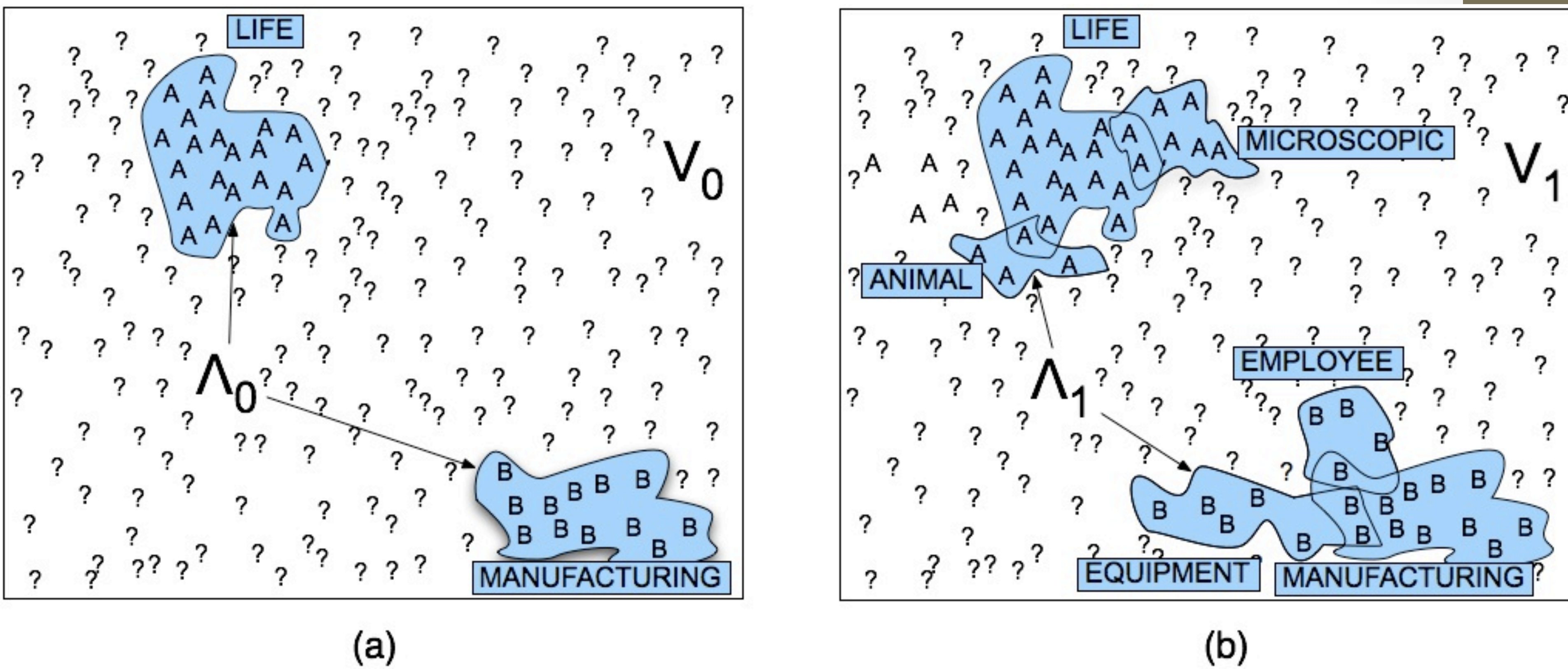
still a far cry from the lake's record 52-pound **bass** of a decade ago, "y e **fish** again, and that made people very, very happy," Mr. Paulson says.

Where do the seeds come from?

1) Hand labeling
2) "One sense per discourse":
   - The sense of a word is highly consistent within a document - Yarowsky (1995)
   - True for topic dependent words
   - Not so true for other POS like adjectives and verbs, e.g. make, take
   - Krovetz (1998) "More than one sense per discourse" argues it isn't true at all once you move to fine-grained senses
3) One sense per collocation:
   - A word reoccurring in collocation with the same word will almost surely have the same sense.

Slide adapted from Chris Manning

Stages in the Yarowsky bootstrapping algorithm



Problems

- Given these general ML approaches, how many classifiers do I need to perform WSD robustly
  - One for each ambiguous word in the language
- How do you decide what set of tags/labels/senses to use for a given word?
  - Depends on the application

WordNet Bass

- Tagging with this set of senses is an impossibly hard task that's probably overkill for any realistic application

1. bass - (the lowest part of the musical range)
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Senseval History

- ACL-SIGLEX workshop (1997)
  - Yarowsky and Resnik paper
- SENSEVAL-I (1998)
  - Lexical Sample for English, French, and Italian
- SENSEVAL-II (Toulouse, 2001)
  - Lexical Sample and All Words
  - Organization: Kilkgarriff (Brighton)
- SENSEVAL-III (2004)
- SENSEVAL-IV -> SEMEVAL (2007)
- SEMEVAL (2010)
- SEMEVAL 2017: http://alt.qcri.org/semeval2017/index.php?id=tasks

SLIDE ADAPTED FROM CHRIS MANNING

WSD Performance

- Varies widely depending on how difficult the disambiguation task is
- Accuracies of over 90% are commonly reported on some of the classic, often fairly easy, WSD tasks (pike, star, interest)
- Senseval brought careful evaluation of difficult WSD (many senses, different POS)
- Senseval 1: more fine grained senses, wider range of types:
  - Overall: about 75% accuracy
  - Nouns: about 80% accuracy
  - Verbs: about 70% accuracy

Summary

- Lexical Semantics
  - Homonymy, Polysemy, Synonymy
  - Thematic roles
- Computational resource for lexical semantics
  - WordNet
- Task
  - Word sense disambiguation
- Next: semantic parsing