Lexical Semantics and Word Senses

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Today's lecture

1. Lexical semantics
   - Meaning of words
   - Relation between different meanings
2. WordNet
   - An ontology structure of word senses
   - Similarity between words
3. Distributional semantics
   - Similarity between words
   - Word sense disambiguation

What is the meaning of a word?

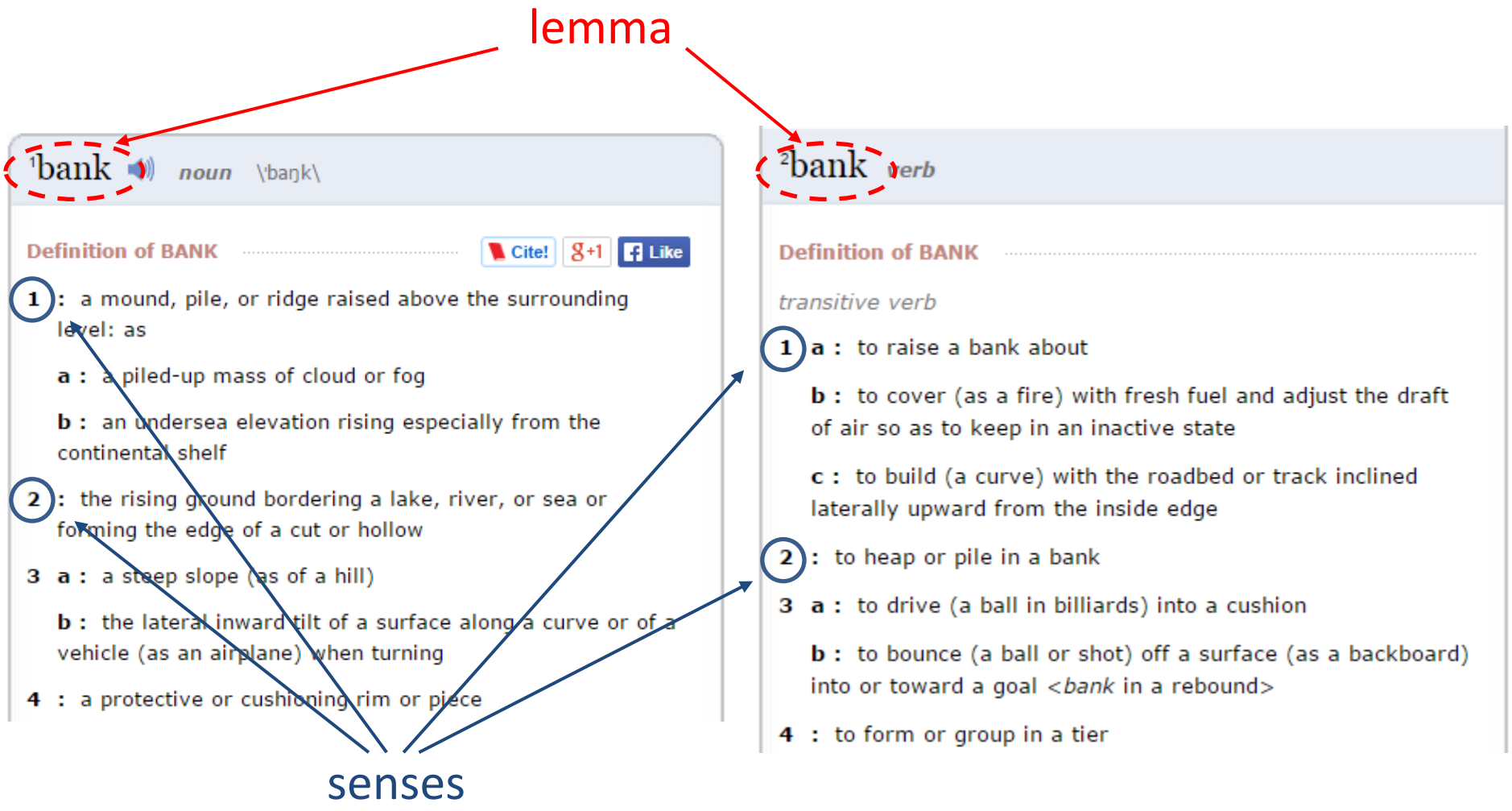
- Most words have many different senses
  - dog = animal or sausage?
  - lie = to be in a horizontal position or a false statement made with deliberate intent
- What are the relations of different words in terms of meaning?
  - Specific relations between senses
    - Animal is more general than dog
  - Semantic fields
    - Money is related to bank

"a set of words grouped, referring to a specific subject … not necessarily synonymous, but are all used to talk about the same general phenomenon" - wiki

Word senses

- What does ‘bank’ mean?
  - A financial institution
    - E.g., “US bank has raised interest rates.”
  - A particular branch of a financial institution
    - E.g., “The bank on Main Street closes at 5pm.”
  - The sloping side of any hollow in the ground, espe cially when bordering a river
    - E.g., “In 1927, the bank of the Mississippi flooded.”
  - A ‘repository’
    - E.g., “I donate blood to a blood bank.”

Lexicon entries



Some terminologies

- **Word forms**: runs, ran, running; good, better, best
  - Any, possibly inflected, form of a word
- **Lemma** (citation/dictionary form): run; good
  - A basic word form (e.g. infinitive or singular nominative noun) that is used to represent all forms of the same word
- **Lexeme**: RUN(V), GOOD(A), $BANK^1$(N), $BANK^2$(N)
  - An abstract representation of a word (and all its forms), with a part-of-speech and a set of related word senses
  - Often just written (or referred to) as the lemma, perhaps in a different FONT
- **Lexicon**
  - A (finite) list of lexemes

Make sense of word senses

- Polysemy
  - A lexeme is polysemous if it has different related senses

bank = financial institution or a building

Make sense of word senses

- Homonyms
  - Two lexemes are homonyms if their senses are unrelated, but they happen to have the same spelling and pronunciation

bank = financial institution or river bank

Relations between senses

- Symmetric relations
  - Synonyms: couch/sofa
    - Two lemmas with the same sense
  - Antonyms: cold/hot, rise/fall, in/out
    - Two lemmas with the opposite sense
- Hierarchical relations:
  - Hypernyms and hyponyms: pet/dog
    - The hyponym (dog) is more specific than the hypernym (pet)
  - Holonyms and meronyms: car/wheel
    - The meronym (wheel) is a part of the holonym (car)

WordNet

George Miller, Cognitive Science Laboratory of Princeton University, 1985

- A very large lexical database of English:
  - 117K nouns, 11K verbs, 22K adjectives, 4.5K adverbs
- Word senses grouped into synonym sets ("synsets") linked into a conceptual-semantic hierarchy
  - 82K noun synsets, 13K verb synsets, 18K adjectives synsets, 3.6K adverb synsets
  - Avg. # of senses: 1.23/noun, 2.16/verb, 1.41/adj, 1.24/adverb
- Conceptual-semantic relations
  - hypernym/hyponym

A WordNet example

- http://wordnet.princeton.edu/

Hierarchical synset relations: nouns

- **Hypernym/hyponym** (between concepts)
  - The more general 'meal' is a hypernym of the more specific 'breakfast'
- **Instance hypernym/hyponym** (between concepts and instances)
  - Austen is an instance hyponym of author

Jane Austen, 1775–1817, English novelist

- **Member holonym/meronym** (groups and members)
  - professor is a member meronym of (a university's) faculty
- **Part holonym/meronym** (wholes and parts)
  - wheel is a part meronym of (is a part of) car.
- **Substance meronym/holonym** (substances and components)
  - flour is a substance meronym of (is made of) bread

WordNet hypernyms & hyponyms

- S: (n) **bank** (sloping land (especially the slope beside a body of water))
  - *direct hyponym* / *full hyponym*
    - S: (n) riverbank, riverside (the bank of a river)
    - S: (n) waterside (land bordering a body of water)
  - ***direct hypernym*** / *inherited hypernym* / *sister term*
    - S: (n) slope, incline, side (an elevated geological formation)
  - *derivationally related form*
- S: (n) depository financial institution, **bank**, banking concern, banking company (a financial institution that accepts deposits and channels the money into lending activities)
  - *direct hyponym* / *full hyponym*
    - S: (n) credit union (a cooperative depository financial institution whose members can obtain loans from their combined savings)
      - *direct hypernym* / *inherited hypernym* / *sister term*
        - S: (n) depository financial institution, **bank**, banking concern, banking company (a financial institution that accepts deposits and channels the money into lending activities)
    - S: (n) Federal Reserve Bank, reserve bank (one of 12 regional banks that monitor and act as depositories for banks in their region)
    - S: (n) agent bank (a bank that acts as an agent for a foreign bank)
    - S: (n) commercial bank, full service bank (a financial institution that accepts demand deposits and makes loans and provides other services for the public)

Hierarchical synset relations: verbs

the presence of a 'manner' relation between two lexemes

- Hypernym/troponym (between events)
  - travel/fly, walk/stroll
  - Flying is a troponym of traveling: it denotes a specific manner of traveling
- Entailment (between events):
  - snore/sleep
    - Snoring entails (presupposes) sleeping

WordNet similarity

- Path based similarity measure between words
  - Shortest path between two concepts (Leacock & Chodorow 1998)
    - sim = 1/|shortest path|
  - Path length to the root node from the least common subsumer (LCS) of the two concepts (Wu & Palmer 1994)
    - sim = $2*depth(LCS)/(depth(w_1)+depth(w_2))$

the most specific concept which is an ancestor of both A and B.

- http://wn-similarity.sourceforge.net/

WordNet::Similarity

Measure	Word 1	Word 2	Score	Trace
path	apple#n#1	pizza#n#1	0.0909	HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 matter#n#3 solid#n#1 food#n#2 produce#n#1 edible_fruit#n#1 apple#n#1 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 object#n#1 whole#n#2 natural_object#n#1 plant_part#n#1 plant_organ#n#1 reproductive_structure#n#1 fruit#n#1 edible_fruit#n#1 apple#n#1 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 object#n#1 whole#n#2 natural_object#n#1 plant_part#n#1 plant_organ#n#1 reproductive_structure#n#1 fruit#n#1 pome#n#1 apple#n#1 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 matter#n#3 substance#n#7 food#n#1 nutriment#n#1 dish#n#2 pizza#n#1 Shortest path: apple#n#1 edible_fruit#n#1 produce#n#1 food#n#2 solid#n#1 matter#n#3 substance#n#7 food#n#1 nutriment#n#1 dish#n#2 pizza#n#1 Path length = 11
path	apple#n#2	pizza#n#1	0.0526	HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 object#n#1 whole#n#2 living_thing#n#1 organism#n#1 plant#n#2 vascular_plant#n#1 woody_plant#n#1 tree#n#1 angiospermous_tree#n#1 fruit_tree#n#1 apple_tree#n#1 apple#n#2 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 matter#n#3 substance#n#7 food#n#1 nutriment#n#1 dish#n#2 pizza#n#1 Shortest path: apple#n#2 apple_tree#n#1 fruit_tree#n#1 angiospermous_tree#n#1 tree#n#1 woody_plant#n#1 vascular_plant#n#1 plant#n#2 organism#n#1 living_thing#n#1 whole#n#2 object#n#1 physical_entity#n#1 matter#n#3 substance#n#7 food#n#1 nutriment#n#1 dish#n#2 pizza#n#1 Path length = 19

WordNet::Similarity

Measure	Word 1	Word 2	Score	Trace
wup	apple#n#1	pizza#n#1	0.4444	HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 matter#n#3 solid#n#1 food#n#2 produce#n#1 edible_fruit#n#1 apple#n#1 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 object#n#1 whole#n#2 natural_object#n#1 plant_part#n#1 plant_organ#n#1 reproductive_structure#n#1 fruit#n#1 edible_fruit#n#1 apple#n#1 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 object#n#1 whole#n#2 natural_object#n#1 plant_part#n#1 plant_organ#n#1 reproductive_structure#n#1 fruit#n#1 pome#n#1 apple#n#1 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 matter#n#3 substance#n#7 food#n#1 nutriment#n#1 dish#n#2 pizza#n#1 Lowest Common Subsumers: matter#n#3 (Depth=4) Depth(apple#n#1) = 9 Depth(pizza#n#1) = 9
wup	apple#n#2	pizza#n#1	0.25	HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 object#n#1 whole#n#2 living_thing#n#1 organism#n#1 plant#n#2 vascular_plant#n#1 woody_plant#n#1 tree#n#1 angiospermous_tree#n#1 fruit_tree#n#1 apple_tree#n#1 apple#n#2 HyperTree: *Root*#n#1 entity#n#1 physical_entity#n#1 matter#n#3 substance#n#7 food#n#1 nutriment#n#1 dish#n#2 pizza#n#1 Lowest Common Subsumers: physical_entity#n#1 (Depth=3) Depth(apple#n#2) = 15 Depth(pizza#n#1) = 9

Distributional hypothesis

- What is tezgüino?
  - A bottle of tezgüino is on the table.
  - Everybody likes tezgüino.
  - Tezgüino makes you drunk.
  - We make tezgüino out of corn.
- The contexts in which a word appears tell us a lot about what it means

Recap: Lexical semantics

- Meaning of words
  - Within a word
    - Polysemy and homonyms
  - Between words
    - Symmetric relations
      - Synonyms and antonyms
    - Hierarchical relations
      - Hypernyms and hyponyms
      - Holonyms and meronyms

Recap: WordNet

- An ontology structure of word senses
  - Nodes on the graph: synonym sets
  - Conceptual-semantic relations
  - Similarity
    - Shortest path between two concepts
    - Path length to the root node from the least common subsumer (LCS) of the two concepts

Distributional semantics

- Use the contexts in which words appear to measure their similarity
  - Assumption: similar contexts => similar meanings
  - Approach: represent each word w as a vector of its contexts c
    - Vector space representation
    - Each dimension corresponds to a particular context c_n
    - Each element in the vector of w captures the degree to which the word w is associated with the context c_n
  - Similarity metric
    - Cosine similarity

How to define the contexts

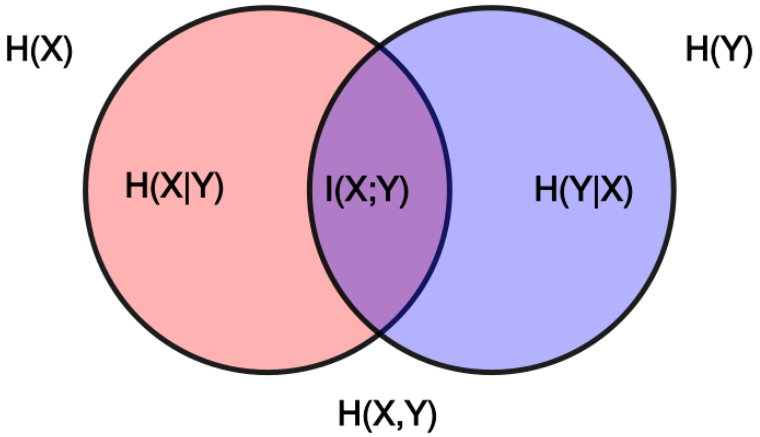
- Nearby words
  - w appears near c if c occurs within $\pm k$ words of w
    - It yields fairly broad thematic relations
  - Decide on a fixed vocabulary of N context words $c_1 .. c_N$
    - Prefer words occur frequently enough in the corpus but not too frequent (i.e., avoid stopwords)
  - Co-occurrence count of word w and context c as the corresponding element in the vector
    - Pointwise Mutual Information (PMI)
- Grammatical relations
  - How often is w used as the subject of the verb c?
  - Fine-grained thematic relations

within a sentence

Mutual information

- Relatedness between two random variables

$$-I(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log\left(\frac{p(x,y)}{p(x)p(y)}\right)$$



Pointwise mutual information

within a sentence

- PMI between w and c using a fixed window of $\pm k$ words
  - $PMI(w;c) = p(w,c)\log(\frac{p(w,c)}{p(w)p(c)})$

How often w and c co-occur inside a window | How often *w* occurs | How often *c* occurs

Word sense disambiguation

- What does this word mean?
  - This **plant** needs to be watered each day.
    - living plant
  - This **plant** manufactures 1000 widgets each day.
    - factory
- Word sense disambiguation (WSD)
  - Identify the sense of content words (noun, verb, adjective) in context (assuming a fixed inventory of word senses)

Dictionary-based methods

- A dictionary/thesaurus contains glosses and examples of a word

bank[1]

Gloss: a financial institution that accepts deposits and channels the money into lending activities

Examples: *"he cashed the 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 current"

Lesk algorithm

- Compare the context with the dictionary definition of the sense

  - Construct the **signature** of a word in context by the signatures of its senses in the dictionary
    - **Signature** = set of context words (in examples/gloss or in context)
  - Assign the dictionary sense whose gloss and examples are the most **similar** to the context in which the word occurs
    - Similarity = size of intersection of context signature and sense signature

Sense signatures

bank[1]

Gloss: a financial institution that accepts deposits and channels the money into lending activities

Examples: *"he cashed the check at the bank",*
"that bank holds the mortgage on my home"

***Signature**(bank[1]) = {financial, institution, accept, deposit, channel, money, lend, activity, cash, check, hold, mortgage, 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 current"

***Signature**(bank[1]) = {slope, land, body, water, pull, canoe, sit, river, watch, current}*

Signature of target word

"The bank refused to give me a loan."

- Simplified Lesk
  - Words in context
  - *Signature(bank) = {refuse, give, loan}*
- Original Lesk
  - Augmented signature of the target word
  - *Signature(bank) = {**refuse**, reject, request,... , **give**, gift, donate,... **loan**, money, borrow,...}*

Learning-based Methods

- Will be discussed in the lecture of "Text Categorization"
  - Basically treat each sense as an independent class label
  - Construct classifiers to assign each instance with context into the classes/senses

What you should know

- Lexical semantics
  - Relationship between words
  - WordNet
- Distributional semantics
  - Similarity between words
  - Word sense disambiguation

Today's reading

- Speech and Language Processing
  - Chapter 19: Lexical Semantics
  - Chapter 20: Computational Lexical Semantics