

# Word Meaning and Similarity

Word Senses and  
Word Relations

Slides are adapted from Dan Jurafsky

# Reminder: 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

Wordform	Lemma
banks	bank
sung	sing
duermes	dormir

# Lemmas have senses

- One lemma “bank” can have many meanings:

Sense 1: • ...a **bank**<sub>1</sub> can hold the investments in a custodial account...

Sense 2: • “...as agriculture burgeons on the east **bank**<sub>2</sub> the river will shrink even more”

- **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 but have unrelated, distinct meanings:

- **bank<sub>1</sub>**: financial institution, **bank<sub>2</sub>**: sloping land
- **bat<sub>1</sub>**: club for hitting a ball, **bat<sub>2</sub>**: 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)

# Polysemy

- 1. The **bank** was constructed in 1875 out of local red brick.
- 2. I withdrew the money from the **bank**
- Are those the same sense?
  - Sense 2: “A financial institution”
  - Sense 1: “The building belonging to a financial institution”
- A **polysemous** word has **related** meanings
  - Most non-rare words have multiple meanings

# Metonymy or Systematic Polysemy: A systematic relationship between senses

- Lots of types of polysemy are systematic
  - School, university, hospital
  - All can mean the institution or the building.
- A systematic relationship:
  - Building ↔ Organization
- Other such kinds of systematic polysemy:

Author (Jane Austen wrote Emma)

↔ Works of Author (I love Jane Austen)

Tree (Plums have beautiful blossoms)

↔ Fruit (I ate a preserved plum)

# 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

- Word that have the same meaning in some or all contexts.
  - filbert / hazelnut
  - couch / sofa
  - big / large
  - automobile / car
  - vomit / throw up
  - Water / H<sub>2</sub>O
- Two lexemes are synonyms
  - if they can be 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.
  - 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/H<sub>2</sub>O
  - 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*

<b>Superordinate/hyper</b>	vehicle	fruit	furniture
<b>Subordinate/hyponym</b>	car	mango	chair

# 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

# Hyponyms and Instances

- WordNet 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...`

# **Word Meaning and Similarity**

Word Senses and  
Word Relations



# Word Meaning and Similarity

WordNet and other  
Online Thesauri

# Applications of Thesauri and Ontologies

- Information Extraction
- Information Retrieval
- Question Answering
- Bioinformatics and Medical Informatics
- Machine Translation

# WordNet 3.0

- A hierarchically organized lexical database
- On-line thesaurus + aspects of a dictionary
  - Some other languages available or under development
    - (Arabic, Finnish, German, Portuguese...)

Category	Unique Strings
Noun	117,798
Verb	11,529
Adjective	22,479
Adverb	4,481

# 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<sup>1</sup>, fool<sup>2</sup>, gull<sup>1</sup>, mark<sup>9</sup>, patsy<sup>1</sup>, fall guy<sup>1</sup>,  
sucker<sup>1</sup>, soft touch<sup>1</sup>, mug<sup>2</sup>
- Each of **these** senses have this same gloss
  - (Not **every** sense; sense 2 of gull is the aquatic bird)



# WordNet Noun Relations

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

# WordNet 3.0

- Where it is:
  - <http://wordnetweb.princeton.edu/perl/webwn>
- Libraries
  - Python: WordNet from NLTK
    - <http://www.nltk.org/Home>
  - Java:
    - JWNL, extJWNL on sourceforge



# MeSH: Medical Subject Headings thesaurus from the National Library of Medicine

- **MeSH (Medical Subject Headings)**
  - 177,000 entry terms that correspond to 26,142 biomedical “headings”

- **Hemoglobins**

Synset

**Entry Terms:** Eryhem, Ferrous Hemoglobin, Hemoglobin

**Definition:** The oxygen-carrying proteins of ERYTHROCYTES. They are found in all vertebrates and some invertebrates. The number of globin subunits in the hemoglobin quaternary structure differs between species. Structures range from monomeric to a variety of multimeric arrangements

# The MeSH Hierarchy

1. + Anatomy [A]
2. + Organisms [B]
3. + Diseases [C]
4. - Chemicals and Drugs [D]
  - [Inorganic Chemicals \[D01\]](#) +
  - [Organic Chemicals \[D02\]](#) +
  - [Heterocyclic Compounds \[D03\]](#) +
  - [Polycyclic Compounds \[D04\]](#) +
  - [Macromolecular Substances \[D05\]](#) +
  - [Hormones, Hormone Substitutes, and](#)
  - [Enzymes and Coenzymes \[D08\]](#) +
  - [Carbohydrates \[D09\]](#) +
  - [Lipids \[D10\]](#) +
  - [Amino Acids, Peptides, and Proteins](#)
  - [Nucleic Acids, Nucleotides, and Nucl](#)
  - [Complex Mixtures \[D20\]](#) +
  - [Biological Factors \[D23\]](#) +
  - [Biomedical and Dental Materials \[D25\]](#) +
  - [Pharmaceutical Preparations \[D26\]](#) +

## [Amino Acids, Peptides, and Proteins \[D12\]](#)

### [Proteins \[D12.776\]](#)

#### [Blood Proteins \[D12.776.124\]](#)

[Acute-Phase Proteins \[D12.776.124.050\]](#) +

[Anion Exchange Protein 1, Erythrocyte \[D12.776.124.078\]](#)

[Ankyrins \[D12.776.124.080\]](#)

[beta 2-Glycoprotein I \[D12.776.124.117\]](#)

[Blood Coagulation Factors \[D12.776.124.125\]](#) +

[Cholesterol Ester Transfer Proteins \[D12.776.124.197\]](#)

[Fibrin \[D12.776.124.270\]](#) +

[Glycophorin \[D12.776.124.300\]](#)

[Hemocyanin \[D12.776.124.337\]](#)

▶ [Hemoglobins \[D12.776.124.400\]](#)

[Carboxyhemoglobin \[D12.776.124.400.141\]](#)

[Erythrocyruorins \[D12.776.124.400.220\]](#)

# Uses of the MeSH Ontology

- Provide synonyms (“entry terms”)
  - E.g., glucose and dextrose
- Provide hypernyms (from the hierarchy)
  - E.g., glucose ISA monosaccharide
- Indexing in MEDLINE/PubMED database
  - NLM’s bibliographic database:
    - 20 million journal articles
    - Each article hand-assigned 10-20 MeSH terms

# Word Meaning and Similarity

WordNet and other  
Online Thesauri

# Word Meaning and Similarity

Word Similarity:  
Thesaurus Methods

# Word Similarity

- **Synonymy**: a binary relation
  - Two words are either synonymous or not
- **Similarity (or distance)**: a looser metric
  - Two words are more similar if they share more features of meaning
- Similarity is properly a relation between **senses**
  - The word “bank” is not similar to the word “slope”
  - Bank<sup>1</sup> is similar to fund<sup>3</sup>
  - Bank<sup>2</sup> is similar to slope<sup>5</sup>
- But we’ll compute similarity over both words and senses

# Why word similarity

- Information retrieval
- Question answering
- Machine translation
- Natural language generation
- Language modeling
- Automatic essay grading
- Plagiarism detection
- Document clustering

# Word similarity and word relatedness

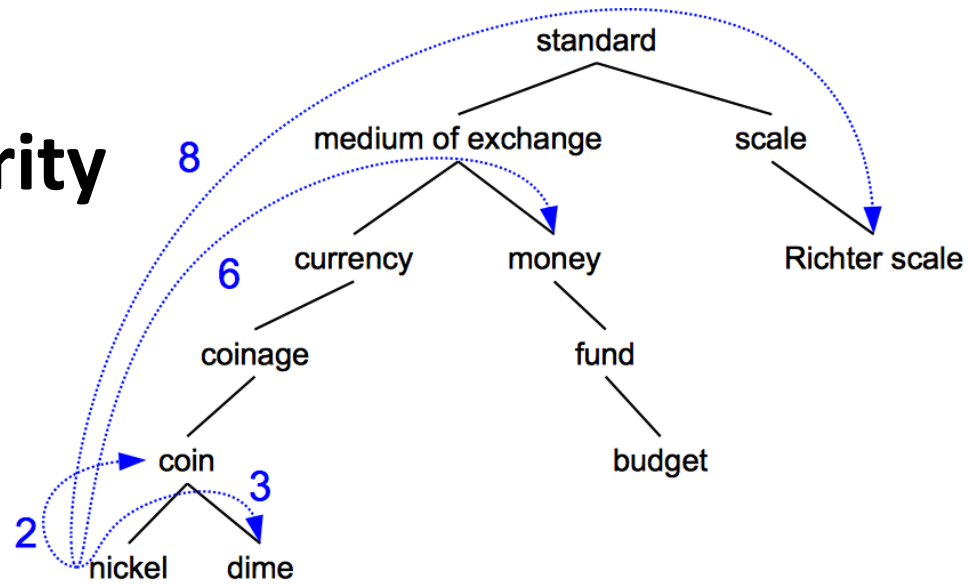
- We often distinguish **word similarity** from **word relatedness**
  - **Similar words**: near-synonyms
  - **Related words**: can be related any way
    - car, bicycle: **similar**
    - car, gasoline: **related**, not similar



# 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



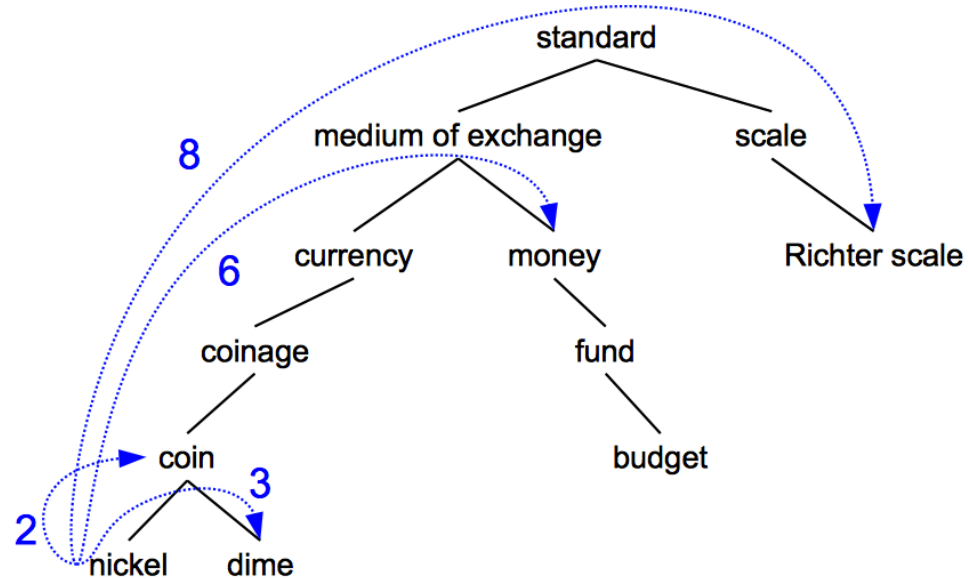
- Two concepts (senses/synsets) are similar if they are near each other in the thesaurus hierarchy
  - =have a short path between them
  - concepts have path 1 to themselves

# Refinements to path-based similarity

- $\text{pathlen}(c_1, c_2) = 1 + \text{number of edges in the shortest path in the hypernym graph between sense nodes } c_1 \text{ and } c_2$
- 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

$$\text{simpath}(c_1, c_2) = 1/\text{pathlen}(c_1, c_2)$$



$$\text{simpath}(\textit{nickel}, \textit{coin}) = 1/2 = .5$$

$$\text{simpath}(\textit{fund}, \textit{budget}) = 1/2 = .5$$

$$\text{simpath}(\textit{nickel}, \textit{currency}) = 1/4 = .25$$

$$\text{simpath}(\textit{nickel}, \textit{money}) = 1/6 = .17$$

$$\text{simpath}(\textit{coinage}, \textit{Richter scale}) = 1/6 = .17$$

# 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. Using information content to evaluate semantic similarity in a taxonomy. IJCAI

- 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)
    - $P(\text{root})=1$
  - The lower a node in hierarchy, the lower its probability

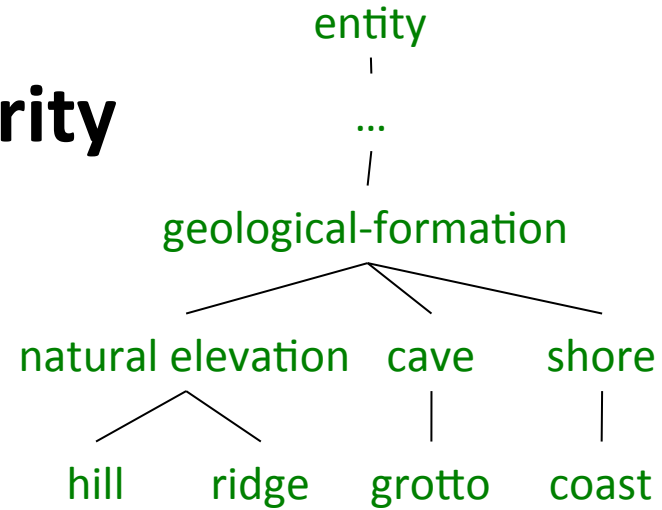
# Information content similarity

- Train by counting in a corpus

- Each instance of `hill` counts toward frequency of *natural elevation*, *geological formation*, *entity*, etc

- Let  $\text{words}(c)$  be the set of all words that are children of node  $c$

- $\text{words}(\text{"geo-formation"}) = \{\text{hill, ridge, grotto, coast, cave, shore, natural elevation}\}$
- $\text{words}(\text{"natural elevation"}) = \{\text{hill, ridge}\}$

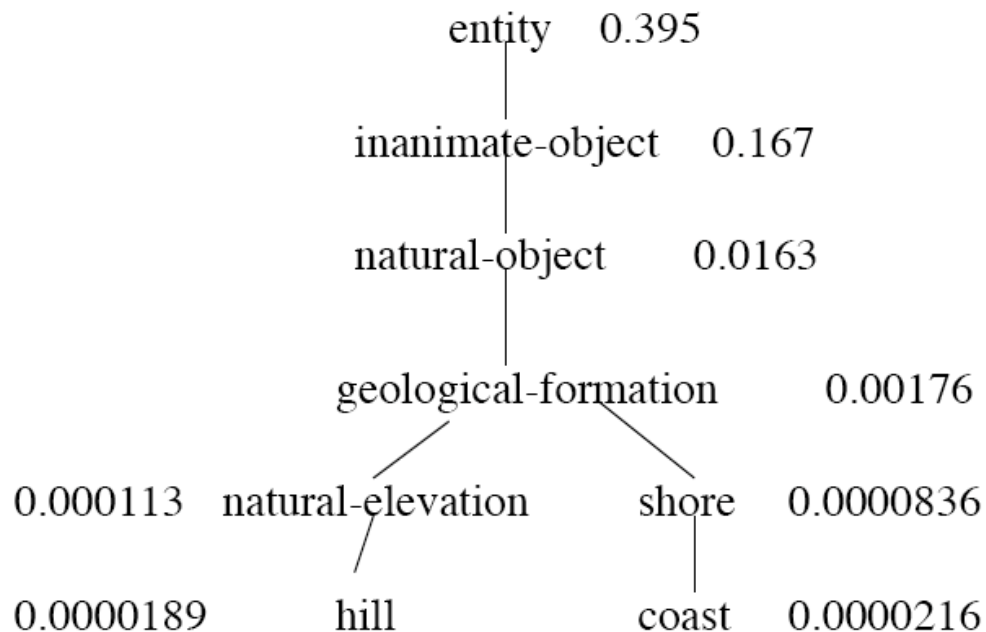


$$P(c) = \frac{\sum_{w \in \text{words}(c)} \text{count}(w)}{N}$$

# Information content similarity

- WordNet hierarchy augmented with probabilities  $P(c)$

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





# Information content: definitions

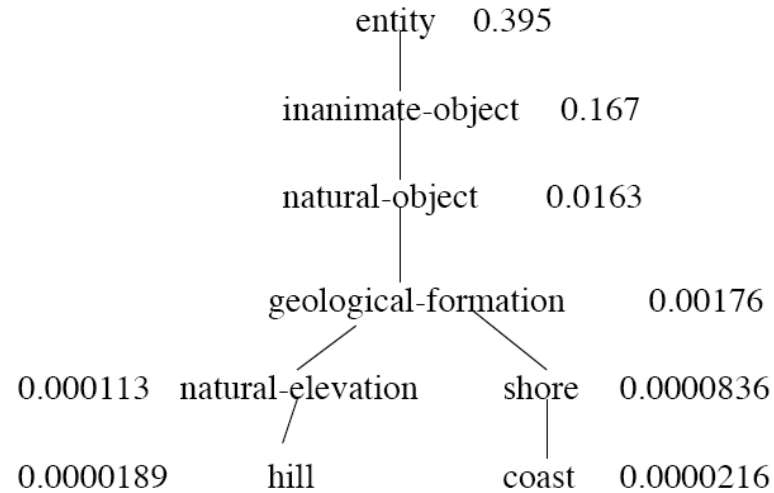
- Information content:

$$IC(c) = -\log P(c)$$

- Most informative subsumer  
(Lowest common subsumer)

$$LCS(c_1, c_2) =$$

The most informative (lowest) node in the hierarchy subsuming both  $c_1$  and  $c_2$



# Using information content for similarity: the Resnik method

Philip Resnik. 1995. Using Information Content to Evaluate Semantic Similarity in a Taxonomy. IJCAI 1995.  
Philip Resnik. 1999. Semantic Similarity in a Taxonomy: An Information-Based Measure and its Application to Problems of Ambiguity in Natural Language. JAIR 11, 95-130.

- 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
- Commonality:  $IC(\text{common}(A,B))$
- Difference:  $IC(\text{description}(A,B)) - IC(\text{common}(A,B))$

# Dekang Lin similarity theorem

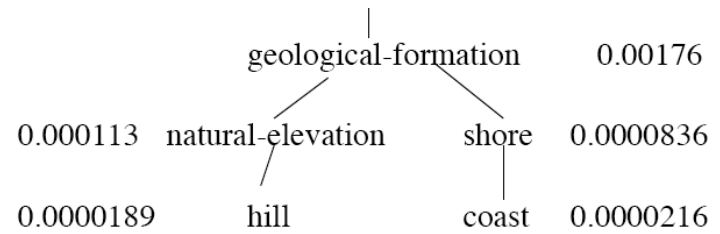
- The similarity between A and B is measured by the ratio between the amount of information needed to state the commonality of A and B and the information needed to fully describe what A and B are

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

- 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



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

$$\begin{aligned} \text{sim}_{Lin}(\text{hill}, \text{coast}) &= \frac{2 \log P(\text{geological-formation})}{\log P(\text{hill}) + \log P(\text{coast})} \\ &= \frac{2 \ln 0.00176}{\ln 0.0000189 + \ln 0.0000216} \\ &= .59 \end{aligned}$$

# The (extended) Lesk Algorithm

- A thesaurus-based measure that looks at **glosses**
- Two concepts are similar if their glosses contain similar words
  - *Drawing paper*: **paper** that is **specially prepared** for use in drafting
  - *Decal*: the art of transferring designs from **specially prepared paper** to a wood or glass or metal surface
- For each  $n$ -word phrase that's in both glosses
  - Add a score of  $n^2$
  - **Paper** and **specially prepared** for  $1 + 2^2 = 5$
  - Compute overlap also for other relations
    - glosses of hypernyms and hyponyms

# Summary: thesaurus-based similarity

$$\text{sim}_{\text{path}}(c_1, c_2) = \frac{1}{\text{pathlen}(c_1, c_2)}$$

$$\text{sim}_{\text{resnik}}(c_1, c_2) = -\log P(\text{LCS}(c_1, c_2)) \quad \text{sim}_{\text{lin}}(c_1, c_2) = \frac{2\log P(\text{LCS}(c_1, c_2))}{\log P(c_1) + \log P(c_2)}$$

$$\text{sim}_{\text{jiangconrath}}(c_1, c_2) = \frac{1}{\log P(c_1) + \log P(c_2) - 2\log P(\text{LCS}(c_1, c_2))}$$

$$\text{sim}_{\text{eLesk}}(c_1, c_2) = \sum_{r, q \in \text{RELS}} \text{overlap}(\text{gloss}(r(c_1)), \text{gloss}(q(c_2)))$$

# Libraries for computing thesaurus-based similarity

- NLTK
  - [http://nltk.github.com/api/nltk.corpus.reader.html?highlight=similarity-nltk.corpus.reader.WordNetCorpusReader.res\\_similarity](http://nltk.github.com/api/nltk.corpus.reader.html?highlight=similarity-nltk.corpus.reader.WordNetCorpusReader.res_similarity)
- 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
- Intrinsic Evaluation:
  - Correlation between algorithm and human word similarity ratings
    - Wordsim353: 353 noun pairs rated 0-10.  $sim(plane, car)=5.77$
  - Taking TOEFL multiple-choice vocabulary tests
    - Levied is closest in meaning to:  
imposed, believed, requested, correlated

# Word Meaning and Similarity

Word Similarity:  
Thesaurus Methods