Lexical Semantics

Ellie Pavlick
Google -> Brown
September 26, 2017

Thank you to Dipanjan Das for slides!
The meaning of a complex expression is determined by its structure and the meanings of its constituents.

“Principle of Compositionality” as defined in Stanford Encyclopedia of Philosophy
The meaning of a complex expression is determined by grammar and the meanings of its constituents.

“Principle of Compositionality”
The meaning of a complex expression is determined by grammar and the meanings of the individual words.

“Principle of Compositionality”
The meaning of a complex expression is determined by grammar and lexical semantics.

“Principle of Compositionality”
bug
Lexical Similarity
Lexical Similarity

insect  beetle

bug

error  glitch
Lexical Similarity

- bug
- insect
- mosquito
- beetle
- snafu
- f*ck up
- irritate
- annoy
- error
- fly
- imperfect

drive crazy
glitch
bother
problem
Word Sense Disambiguation

Mosquito:
- fly
- insect
- beetle

Annoy:
- bother
- irritate
- drive crazy

Bug:
- f*ck up
- glitch
- problem
- snafu
- error
- imperfection

Word Sense Disambiguation
Lexical Entailment

insect
mosquito
beetle
fly

annoy
bother
irritate
drive crazy

f*ck up
snafu
error
bug
problem

imperfection

error

problem

bug

mosquito
Semantic Frames
Lexical Composition

- insect
- mosquito
- beetle
- fly
- problem
- cause
- duration
- imperfection
- glitch
- bug
- snafu
- error
- f*ck up
- botherer
- botheree
- drive crazy
- annoy
- irritate
- bother

Drive crazy
Duration
Annoy
Irritate
Bother
Imperfection
Lexical Composition

- insect
- mosquito
- beetle
- fly
- botherer
- annoy
- irritate
- bother
- drive crazy
- huge
- problem
- botheree
- problem
- botherer
- duration
- imperfection
- error
- cause
- bug
- glitch
- snafu
- f*ck up
- error
- cause
- problem
- duration
- Imperfection
- error
- cause
bug
insect
beetle
mosquito
fly
annoy
irritate
bother
botherer
botheree
huge
problem
bug
snafu
error
near-disaster
imperfection
potential
problem
cause
duration
pick up
f*ck up
problem
problem
bug that is really
more of a feature,
no big deal
come to think of it
Lexical Composition
Outline

• Basic Lexical Semantics
  • Word Sense Disambiguation
  • Word Similarity
  • Lexical Entailment

• Beyond Single Words
  • Semantic Role Labeling
  • Lexical Composition (if we have time)
Word Senses

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.
Word Senses

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.

*Two different senses of the same word*
Word Senses

Word sense:

A discrete representation of one aspect of the meaning of a word

(Jurafsky and Martin, Chapter 19)

two senses of the same lexical item are called homonyms
WordNet

WordNet Search - 3.1
- WordNet home page - Glossary - Help

Word to search for: bass

Display Options: (Select option to change) Change

Key: "S:" = Show Synset (semantic) relations, "W:" = Show Word (lexical) relations
Display options for sense: (gloss) "an example sentence"

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"
Word Sense Disambiguation

I play **bass** in a jazz band.

She was grilling a **bass** on the stove top.
Supervised WSD

**Task definition:**
Given a lexicon (e.g. WordNet), classify the sense of a word in context

**Linear model:**

\[ p(\text{sense} \mid \text{word, context}) \propto \exp \phi \cdot f(\text{sense, word, context}) \]

feature function looking at the sense, word, context
Supervised WSD

Task definition:
Given a lexicon (e.g. WordNet), classify the sense of a word in context

\[ p(\text{sense} \mid \text{word, context}) \propto \exp \phi \cdot f(\text{sense, word, context}) \]

\[ = \frac{\exp \phi \cdot f(\text{sense, word, context})}{\sum_{\text{sense}'} \exp \phi \cdot f(\text{sense}', \text{word, context})} \]

summing over all senses for the word (e.g. from WordNet)
Supervised WSD

**Task definition:**
Given a lexicon (e.g. WordNet), classify the sense of a word in context

\[ p(\text{sense} \mid \text{word, context}) \propto \exp \text{DNN}(\text{sense, word, context}) \]
Verb

- **S: (v) be** (have the quality of being; (copula, used with an adjective or a predicate noun)) "John is rich"; "This is not a good answer"
- **S: (v) be** (be identical to; be someone or something) "The president of the company is John Smith"; "This is my house"
- **S: (v) be** (occupy a certain position or area; be somewhere) "Where is my umbrella?"; "The toolshed is in the back"; "What is behind this behavior?"
- **S: (v) exist, be** (have an existence, be extant) "Is there a God?"
- **S: (v) be** (happen, occur, take place) "I lost my wallet; this was during the visit to my parents' house"; "There were two hundred people at his funeral"; "There was a lot of noise in the kitchen"
- **S: (v) equal, be** (be identical or equivalent to) "One dollar equals 1,000 rubles these days!"
- **S: (v) constitute, represent, make up, comprise, be** (form or compose) "This money is my only income"; "The stone wall was the backdrop for the performance"; "These constitute my entire belonging"; "The children made up the chorus"; "This sum represents my entire income for a year"; "These few men comprise his entire army"
- **S: (v) be, follow** (work in a specific place, with a specific subject, or in a specific function) "He is a herpetologist"; "She is our resident philosopher"
- **S: (v) embody, be, personify** (represent, as of a character on stage) "Derek Jacobi was Hamlet"
- **S: (v) be** (spend or use time) "I may be an hour"
- **S: (v) be, live** (have life, be alive) "Our great leader is no more"; "My grandfather lived until the end of war"
- **S: (v) be** (to remain unmolested, undisturbed, or uninterrupted -- used only in infinitive form) "let her be"
- **S: (v) cost, be** (be priced at) "These shoes cost $100"
Unsupervised WSD

Task definition:
Induce the number of senses of each word and classify the sense for each word in context

1. For each word in context, compute a bunch of features
2. Cluster each such instance using a clustering algorithm
3. Cluster labels correspond to word senses

Self study: section 20.10 of J&M
**WSD -> Lexical Substitution**

**Task definition:**
Does word1 mean the same thing as word2 in context c? I.e. can treat sense as latent

In this world, one’s **word** is a promise

vow (1), utterance (1), tongue (1), speech (1)

Silverplate: code **word** for the historic mission that would end World War II.

phrase (3), term (2), verbiage (1), utterance (1), name (1) …

I think she only heard the last **words** of my speech.

bit (3), verbiage (2), part (2), vocabulary (1), terminology (1) …

CoInCo. Kremer et al., 2014
Thoughts?
Questions?
Comments?
Word Similarity

Task Definition:
Predicting how similar two words are.

The Distributional Hypothesis:
You shall know a word by the company it keeps!
(Firth, 1957)
A bottle of *Tesgüino* is on the table.

Everybody likes *tesgüino*.

*Tesgüino* makes you drunk.

We make *tesgüino* out of corn.

occurs before *drunk*

occurs after *bottle*

is the direct object of *likes*
Word Similarity

A bottle of Tesgüino is on the table.

Everybody likes tesgüino.

Tesgüino makes you drunk.

We make tesgüino out of corn.

occurs before drunk

occurs after bottle

is the direct object of likes

similar to beer, wine, whiskey and so forth

Jurafsky and Martin, 20.7
Word Similarity

\[ \vec{w} = (f_1, f_2, f_3, \ldots, f_n) \]

representation for a word

binary features indicating presence of the \( i^{th} \) word in a vocabulary in the word’s context

e.g.

\[ \text{Tesgüino} = (1, 1, 0, \ldots) \]
Word Similarity

\[
\vec{\text{Tesgüino}} = (1, 1, 0, \ldots)
\]

\[
\vec{\text{beer}} = (1, 1, 0, \ldots)
\]

Similarity between words can be measured using vector distance metrics
Vector-Space Models

• Words (or word senses) represented by a real-valued vector
  • departure from word sense being represented as discrete label
• Both type and token representations explored by the research area
Vector-Space Models

2-D projection of word vectors learned from *Pride and Prejudice* (http://www.ghostweather.com/files/word2vecpride/)
Modern Word Vector Models

- **word2vec**
  - Open-source package for learning word vectors from raw text
  - widely used across academia/industry
  - two models:
    - Skip-gram
    - CBOW
The Skip-Gram Model

**Given:**
- Corpus of words $w$
- And their contexts $c$

Consider the conditional probability $p(c|w)$

**Goal:**
Maximize the corpus probability

$$\arg \max_{\theta} \prod_{(w,c) \in D} p(c|w; \theta)$$

Full corpus \hspace{2cm} model parameters
The Skip-Gram Model

vector representation of context

vector representation of word

Expensive!

\[ p(c|w; \theta) = \frac{e^{v_c \cdot v_w}}{\sum_{c' \in C} e^{v_{c'} \cdot v_w}} \]

all possible contexts for word \( w \)

number of parameters in \( \theta \): \( d \times |V| + d \times |C| \)
Negative Sampling
Efficient way of deriving word embeddings

Consider a word-context pair: \((w, c)\)

Let the probability that this pair was observed in a corpus be:

\[
p(D = 1|w, c)
\]

Hence, the probability that the pair was not observed is:

\[
p(D = 0|w, c) = 1 - p(D = 1|w, c)
\]
**Negative Sampling**

**Parameterization:**

\[
p(D = 1|w, c; \theta) = \frac{1}{1 + e^{-v_c \cdot v_w}}
\]

**Learning objective:**

\[
\arg \max_\theta \prod_{(w,c) \in D} p(D = 1|c, w; \theta) \prod_{(w,c) \in D'} p(D = 0|c, w; \theta)
\]

negative word-context pairs sampled randomly
CBOW

• Further reading:

  • Another variant of the model: CBOW

Efficient Estimation of Word Representations in Vector Space
Mikolov, Chen, Corrado and Dean
Structured Contexts

Australian scientist discovers star with telescope
Structured Contexts

Australian scientist discovers star with telescope

Skip-Gram contexts with $n=2$

Levy and Goldberg, 2014
Structured Contexts

Australian scientist discovers star with telescope

Levy and Goldberg, 2014
Structured Contexts

Australian scientist discovers star with telescope

collapsing “prep” links

Australian scientist discovers star with telescope

Levy and Goldberg, 2014
### Qualitative Comparison

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<th>BoW5</th>
<th>BoW2</th>
<th>DEPS</th>
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*Captures semantic clusters*
Thoughts?
Questions?
Comments?
Lexical Entailment

2-D projection of word vectors learned from *Pride and Prejudice* (http://www.ghostweather.com/files/word2vecpride/)
Lexical Entailment

Related concept II: **synonymy**

words representing *identical* or *nearly identical* meanings

couch/sofa

vomit/throw up

car/automobile

*controversial definition*
Lexical Entailment

Related concept II: **antonymy**
words representing *opposite* meanings

long/short
big/little
cold/hot

*controversial definition
Lexical Entailment

Related concept III: **hyponymy**

one sense is more specific than another

car/vehicle
mango/fruit
chair/furniture
WordNet

WordNet Search - 3.1
- WordNet home page - Glossary - Help

Word to search for: bass

Display Options: (Select option to change) Change

Key: "S:" = Show Synset (semantic) relations, "W:" = Show Word (lexical) relations
Display options for sense: (gloss) "an example sentence"

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"
WordNet

Noun relations:

- **S: (n) bass** (the lowest part of the musical range)
  - *direct hypernym* / *inherited hypernym* / *sister term*
  - **S: (n) pitch** (the property of sound that varies with variation in the frequency of vibration)
  - **S: (n) sound property** (an attribute of sound)
    - **S: (n) property** (a basic or essential attribute shared by all members of a class) "a study of the physical properties of atomic particles"
  - **S: (n) attribute** (an abstraction belonging to or characteristic of an entity)
    - **S: (n) abstraction, abstract entity** (a general concept formed by extracting common features from specific examples)
  - **S: (n) entity** (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))
Distributional Signals

Contextual Similarities (Vanilla VSMs)

Lin and Pantel, 2001 (Alberta)
Mikolov et al., 2013 (Google)
Pennington et al., 2014 (Stanford)
Distributional Signals

Contextual Similarities (Vanilla VSMs)

Lin and Pantel, 2001 (Alberta)
Mikolov et al., 2013 (Google)
Pennington et al., 2014 (Stanford)

...converted from classical work to abstract expressionism after hearing Russian composer Igor Stravinsky's "Rite of Spring"

...South African contemporary artist, with abstract expressionism work featuring key aesthetics of the most sought after artists...
...converted from classical work to abstract expressionism after hearing Russian composer Igor Stravinsky's “Rite of Spring”...

...South African contemporary artist with abstract expressionism work featuring key aesthetics of the most sought after artists...
Weaknesses

Strengths

Contextual Similarities
Strengths

Contextual Similarities

dad/father vs. dad/lychee
Weaknesses

- dad/father vs. dad/mom

Strengths

- dad/father vs. dad/lychee

Contextual Similarities
Distributional Signals

Bilingual Translational Similarity

Bannard and Callison-Burch, 2005 (Edinburgh)
Kok and Brockett, 2010 (MSR)
Ganitkevitch et al., 2013 (Hopkins)
Distributional Signals

Bilingual Translational Similarity

Bannard and Callison-Burch, 2005 (Edinburgh)
Kok and Brockett, 2010 (MSR)
Ganitkevitch et al., 2013 (Hopkins)

…the directive include the extension to the period of protection for composers…

to favour the position of artists who have to travel throughout the community…

…la directive comprennent la prolongation de la durée de protection pour les artistes…

...favoriser la position des artistes qui doivent voyager à travers la communauté…
Distributional Signals

Bilingual Translational Similarity

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Bilingual Translations

Contextual Similarities

Strengths
- dad/father vs. dad/lychee

Weaknesses
- dad/father vs. dad/mom
Strengths

Contextual Similarities

Bilingual Translations

Strengths

dad/father vs. dad/lychee

dad/father vs. dad/mom

Weaknesses

dad/father vs. dad/mom
<table>
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Distributional Signals

“Hearst Patterns”

Hearst, 1992 (Berkeley)
Snow et al., 2006 (Stanford)
Movshovitz-Attias and Cohen, 2015 (CMU)
How do composers and other artists survive and work in today's musical theatre scene?

As Luciano Berio did in his “Recital for Cathy”, creative artists such as composers, theatre directors, choreographers, video artists or even circus …
How do composers and other artists survive and work in today's musical theatre scene?

As Luciano Berio did in his “Recital for Cathy”, creative artists such as composers, theatre directors, choreographers, video artists or even circus ...
**Contextual Similarities**
- dad/father vs. dad/lychee

**Bilingual Translations**
- dad/father vs. dad/mom

**Weaknesses**
- dad/father vs. dad/mom
- dad/parent vs. dad/lychee

**“Hearst Patterns”**
**Strengths**

- Contextual Similarities
  - dad/father vs. dad/lychee
- Bilingual Translations
  - dad/father vs. dad/mom
- "Hearst Patterns"
  - dad/parent vs. dad/lychee

**Weaknesses**

- Contextual Similarities
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Thoughts?
Questions?
Comments?
Semantic Roles

Some word senses (aka predicates) in text represent events.

Events have participants or roles (instantiated as arguments).

Predicate-argument structure at the type level can be stored in a lexicon.
Semantic Roles
Semantic Roles

Text my mom and tell her happy birthday.

Will it be nice out in the evening?

Can you remind me to text Cassie after work?

Do I need an umbrella?

Tell Steve I am running a bit late.

Don’t let me forget to pick up milk on the way home.

What will the weather be like tomorrow?
Semantic Roles

**Text** my mom and tell her happy birthday.

Will it **be nice out** in the evening?

Can you **remind** me to text Cassie after work?

Do I need an **umbrella**?

**Tell** Steve I am running a bit late.

Don’t let me **forget** to pick up milk on the way home.

What will the **weather** be like tomorrow?
What will the weather be like tomorrow?

Can you remind me to text Cassie after work?

Tell Steve I am running a bit late.

Don’t let me forget to pick up milk on the way home.

Will it be nice out in the evening?

Text my mom and tell her happy birthday.

Do I need an umbrella?

Tell Steve I am running a bit late.

What will the weather be like tomorrow?
Semantic Roles

- Send Text
- Check Weather
- Set Reminder
Semantic Roles

Send Text
- **required** Recipient
- **required** Message

Check Weather
- **required** Location
- **required** Day
- **optional** Time

Set Reminder
- **required** Date
- **required** Time
- **required** Message
- **optional** Recurrence
Semantic Roles

https://framenet.icsi.berkeley.edu

FrameNet Data

<table>
<thead>
<tr>
<th>Transportation_status</th>
<th>Trap</th>
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<td>Travel</td>
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<td>Undergo_change</td>
<td></td>
</tr>
<tr>
<td>Undergo_transformation</td>
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</tbody>
</table>

**Travel**

**Definition:**

In this frame a **Traveler** goes on a journey, an activity, generally planned in advance, in which the **Traveler** moves from a **Source** location to a **Goal** along a **Path** or within an **Area**. The journey can be accompanied by **Co-participants** and **Baggage**. The **Duration** or **Distance** of the journey, both generally long, may also be described as may be the **Mode_of_transportation**. Words in this frame emphasize the whole process of getting from one place to another, rather than profiling merely the beginning or the end of the journey.

*Ellen JOURNEYED to Europe with five suitcases.*

*Samantha JOURNEYED 2500 miles with her family by sea to China.*

*The Osbournes took a TRIP from Beverly Hills to London on the Concorde.*
Semantic Roles
Semantic Roles

I want a ticket from New York to Philly on Wednesday morning.
i want a ticket from **New York** to **philly** on **Wednesday morning**
i want a ticket from **new york** to **philly** on **wednesday morning**
Semantic Roles

i want a ticket from [new york] to [philly] on [wednesday] morning
i want a ticket from **new york** to **philly** on **wednesday morning**

I need to get to **Chicago** from **Detroit** sometime **tomorrow**

i want a **baltimore - charlotte** train in the **evening** on **fri.**

Show trips to **Atlanta** from **Miami** anytime **Saturday afternoon**
I need to get to Detroit from Chicago the morning of the 24th.

i want a ticket from new york to philly on wednesday anytime.
I need to get to Detroit from Chicago the morning of the 24th.

I want a ticket from New York to Philly on Wednesday anytime.
I need to get to Detroit from Chicago the morning of the 24th.
i want a ticket from new york to philly on wednesday anytime.
Semantic Roles

I need to get to Detroit from Chicago the morning of the 24th.
i want a ticket from New York to Philly on Wednesday anytime.

Semantic roles can come from a linear model or a neural network.
Thoughts?
Questions?
Comments?
Lexical Composition
Problems with Non-Compositional Semantics
Problems with Non-Compositional Semantics
Problems with Non-Compositional Semantics
Problems with Non-Compositional Semantics

American composer
composer
1950s American jazz composer
artist
Problems with Non-Compositional Semantics

[[modifier_1 modifier_2 \ldots modifier_k \text{ noun}]]
Problems with Non-Compositional Semantics

$O(\text{NM}^k)$
Problems with Non-Compositional Semantics

American jazz composer

$O \left( NM^k \right)$

$\sim 270,000,000,000,000$
Problems with Non-Compositional Semantics

American jazz composer

$O \left( N M^k \right)$

$\sim 270,000,000,000,000,000$

Problem #1: scalability
Problems with Non-Compositional Semantics
Problems with Non-Compositional Semantics

"1950s American jazz composer"

No results found for "1950s American jazz composer".
Problems with Non-Compositional Semantics

"1950s American jazz composer"

No results found for "1950s American jazz composer".

Problem #2: sparsity
Problems with Non-Compositional Semantics
Problems with Non-Compositional Semantics
Problems with Non-Compositional Semantics

- American composer
- composer
- American actor
- actor
- American author
- author
Problems with Non-Compositional Semantics

- American composer
- composer
- American actor
- actor
- American author
- author
- American singer
- singer
- singer
- singer
Problems with Non-Compositional Semantics

Problem #3: generalizability
Compositional Semantics
Compositional Semantics

composer

American composer
Compositional Semantics

composer

American

American composer
Compositional Semantics

American composer

composer

American composer
Compositional Semantics

composer

American composer
Compositional Semantics

composer

American composer
Compositional Semantics

Intrinsic Meaning

composer

American composer
Compositional Semantics

American composer

Semantic Containment

composer
Compositional Semantics

Class-Instance Identification

American composer

composer
Compositional Distributional Semantics

Nouns are vectors, adjectives are matrices: Representing adjective-noun constructions in semantic space. Baroni and Zamparelli 2010.
Compositional Distributional Semantics

| American | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| composer | 1 | 0 | 1 | 1 | 1 | 2 | 3 | 2 | 1 | 3 | 1 | 1 |

Nouns are vectors, adjectives are matrices: Representing adjective-noun constructions in semantic space. Baroni and Zamparelli 2010.
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Compositional Distributional Semantics

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Compositional Distributional Semantics
Compositional Distributional Semantics

pianist

composer
Compositional Distributional Semantics

American composer

French pianist
Compositional Distributional Semantics
Thoughts?
Questions?
Comments?
Summary
Summary

• Word Sense Disambiguation
  • Supervised/Unsupervised?

• Word Similarity/Lexical Entailment
  • Are "hot" and "cold" similar? What about "hot" and "summer"?

• Semantic Role Labeling
  • Never enough labeled data…

• Lexical Composition
  • Distributional, symbolic, or some of both?
Summary

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• Lexical Composition
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Thank you!