Semantics: Roles and Relations

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CS 295: STATISTICAL NLP
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Based on slides from Jan Jurafsky, Noah Smith, Nathan Schneider, and everyone else they copied from.
Outline

- Structured Perceptron
- Word Senses
- Semantic Roles
Outline

1. Structured Perceptron
2. Word Senses
3. Semantic Roles
Structured Prediction

\[ f(x) = \arg \max_{y \in Y} \frac{\exp \theta \cdot \phi(x, y)}{\exp \sum_{y} \theta \cdot \phi(x, y)} \]

set of seq \( y \in Y \)

set of trees \( y_1, \ldots, y_n \)
Likelihood Learning

\[ L(\{x_i, y_i\}, \theta) = \log \prod_i P(y_i | x_i) = \sum_i \theta \cdot \phi(x_i, y_i) - \log \sum_y e^{\theta \cdot \phi(x_i, y_i)} \]

\[ = \sum_i \theta \cdot \phi(x_i, y_i) - \log \sum_y e^{\theta \cdot \phi(x_i, y_i)} \]

\[ \frac{\partial L}{\partial \theta_k} = \sum_i \phi_k(x_i, y_i) - \sum_y P(y | x_i) \phi_k(x_i, y) \]

\[ \text{Exp feat counts acc. to } \theta \]

\[ \text{Exp feat counts in the data} \]
Perceptron Algorithm

\[ \theta_0 \leftarrow [0 \ldots 0] \]

pick random \((x_t, y_t)\):

\[ \hat{y}_t = \arg\max_{y} \theta \cdot \phi(\hat{n}_t, y) \]

\[ \theta_t \leftarrow \theta_{t-1} + (\phi(x_t, y_t) - \phi(x_t, \hat{y}_t)) \]

return \(\theta_T\)
Structured Perceptron

\[ \phi (y_k) \]

\[ \phi (\hat{y}_k) \]

model's feat counts
Structured Hinge Loss

$$\ell (\{x_i, y_i\}, \theta) = \sum_i \theta \cdot \phi(x_i, y_i) - \argmax_y \theta \cdot \phi(x_i, y)$$
Weight Averaging

\[ \Theta_t \leftarrow \Theta_{t-1} + \phi(x, y_t) - \phi(x, \hat{y}_t) \]

\[ \Theta_t \leq \frac{\Theta_t}{T} \]
Outline

- Structured Perceptron
- Word Senses
- Semantic Roles
Words and 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.

Senses

• bank$^1$: financial institution
• bank$^2$: sloping mound

Each word can have many senses.
Most non-rare words in English do.
Homonymy

*Same form, completely different meanings...*

**Homographs**
- bank
  - bank\(^1\) ➔ bank\(^2\)
  - bat\(^1\) ➔ bat\(^2\)

**Homophones**
- write
  - write\(^1\) ➔ right\(^2\)
  - peace
    - peace\(^1\) ➔ piece\(^2\)

**Applications**

**Information Retrieval**
- “bat care”

**Machine Translation**
- Bat: murcielago or bate?

**Text to Speech**
- “bass” (fish) or “bass” (guitar)

**Speech to Text**
- “piece” or “peace”
Polysemy

The bank was constructed in 1875 out of local brick. I withdrew the money from the bank.

Same form, but very related meanings...

Metronymy Systemic relationship between senses.

Building ↔ Organization school, university, hospital

Author ↔ Works of the Author Jane Austen wrote Emma I love Jane Austen!

Tree ↔ Fruit Plums have beautiful blossoms I ate a preserved plum
Multiple senses or not?

Which flights *serve* breakfast?
Does Lufthansa *serve* Philadelphia?

“Zeugma” Test

Does Lufthansa *serve* breakfast and San Jose?

Sounds weird, so there are multiple senses of “serve”.

You are free to execute your laws, and your citizens, as you see fit.

*Riker, Star Trek: The Next Generation*
How do we define the sense?

Dictionary

right  adj. located nearer the right hand esp. being on the right when facing the same direction as the observer.

left  adj. located nearer to this side of the body than the right.

red  n. the color of blood or a ruby.

blood  n. the red liquid that circulates in the heart, arteries and veins of animals.

Define senses in relation to other senses!
Synonyms

Substitute one for the other in any sentence.

Perfect synonymy, doesn’t exist
Many things define acceptability: politeness, slang, register, genre

Substitute one for the other in most sentence.

couch / sofa
big / large
automobile / car
vomit / throw up
water / H₂O

Synonymy is between sense, not words
Antonyms

Sense that are opposite with respect to one feature of meaning.. otherwise very similar!

- dark/light
- hot/cold
- short/long
- up/down
- fast/slow
- rise/fall
- in/out
- big/little

Binary Opposition

Or at opposite ends of a scale

- dark/light
- hot/cold
- short/long
- big/little
- fast/slow
- rise/fall
- up/down
- in/out

Reversives

Opposite directions or change
Hyponymy and Hypernymy

**Hyponyms / Subordinate**

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*

**Hypernyms / Superordinate**

Conversely **hypernym** denotes one is a superclass of the other

- *vehicle* is a hypernym of *car*
- *fruit* is a hypernym of *mango*
## WordNet

<table>
<thead>
<tr>
<th>Category</th>
<th>Unique Strings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noun</td>
<td>117,798</td>
</tr>
<tr>
<td>Verb</td>
<td>11,529</td>
</tr>
<tr>
<td>Adjective</td>
<td>22,479</td>
</tr>
<tr>
<td>Adverb</td>
<td>4,481</td>
</tr>
</tbody>
</table>

### Noun
- \textbf{S: (n) bass} (the lowest part of the musical range)
- \textbf{S: (n) bass, bass part} (the lowest part in polyphonic music)
- \textbf{S: (n) bass, basso} (an adult male singer with the lowest voice)
- \textbf{S: (n) sea bass, bass} (the lean flesh of a saltwater fish of the family Serranidae)
- \textbf{S: (n) freshwater bass, bass} (any of various North American freshwater fish with lean flesh (especially of the genus Micropterus))
- \textbf{S: (n) bass, bass voice, basso} (the lowest adult male singing voice)
- \textbf{S: (n) bass} (the member with the lowest range of a family of musical instruments)
- \textbf{S: (n) bass} (nontechnical name for any of numerous edible marine and freshwater spiny–finned fishes)

### Adjective
- \textbf{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 Hierarchy

- **S:** (n) **bass, basso** (an adult male singer with the lowest voice)
  - **direct hyponym / inherited hyponym / sister term**
    - **S:** (n) **singer, vocalist, vocalizer, vocaliser** (a person who sings)
      - **S:** (n) **musician, instrumentalist, player** (someone who plays a musical instrument (as a profession))
        - **S:** (n) **performer, performing artist** (an entertainer who performs a dramatic or musical work for an audience)
        - **S:** (n) **entertainer** (a person who tries to please or amuse)
          - **S:** (n) **person, individual, someone, somebody, mortal, soul** (a human being) "there was too much for one person to do"
          - **S:** (n) **organism, being** (a living thing that has (or can develop) the ability to act or function independently)
            - **S:** (n) **living thing, animate thing** (a living (or once living) entity)
              - **S:** (n) **whole, unit** (an assemblage of parts that is regarded as a single entity) "how big is that part compared to the whole?"; "the team is a unit"
              - **S:** (n) **object, physical object** (a tangible and visible entity; an entity that can cast a shadow) "it was full of rackets, balls and other objects"
                - **S:** (n) **physical entity** (an entity that has physical existence)
                  - **S:** (n) **entity** (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))
# Noun Relations

<table>
<thead>
<tr>
<th>Relation</th>
<th>Also Called</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypernym</td>
<td>Superordinate</td>
<td>From concepts to superordinates</td>
<td>breakfast\textsuperscript{1} \rightarrow meal\textsuperscript{1}</td>
</tr>
<tr>
<td>Hyponym</td>
<td>Subordinate</td>
<td>From concepts to subtypes</td>
<td>meal\textsuperscript{1} \rightarrow lunch\textsuperscript{1}</td>
</tr>
<tr>
<td>Instance Hypernym</td>
<td>Instance</td>
<td>From instances to their concepts</td>
<td>Austen\textsuperscript{1} \rightarrow author\textsuperscript{1}</td>
</tr>
<tr>
<td>Instance Hyponym</td>
<td>Has-Instance</td>
<td>From concepts to concept instances</td>
<td>composer\textsuperscript{1} \rightarrow Bach\textsuperscript{1}</td>
</tr>
<tr>
<td>Member Meronym</td>
<td>Has-Member</td>
<td>From groups to their members</td>
<td>faculty\textsuperscript{2} \rightarrow professor\textsuperscript{1}</td>
</tr>
<tr>
<td>Member Holonym</td>
<td>Member-Of</td>
<td>From members to their groups</td>
<td>copilot\textsuperscript{1} \rightarrow crew\textsuperscript{1}</td>
</tr>
<tr>
<td>Part Meronym</td>
<td>Has-Part</td>
<td>From wholes to parts</td>
<td>table\textsuperscript{2} \rightarrow leg\textsuperscript{3}</td>
</tr>
<tr>
<td>Part Holonym</td>
<td>Part-Of</td>
<td>From parts to wholes</td>
<td>course\textsuperscript{7} \rightarrow meal\textsuperscript{1}</td>
</tr>
<tr>
<td>Substance Meronym</td>
<td></td>
<td>From substances to their subparts</td>
<td>water\textsuperscript{1} \rightarrow oxygen\textsuperscript{1}</td>
</tr>
<tr>
<td>Substance Holonym</td>
<td></td>
<td>From parts of substances to wholes</td>
<td>gin\textsuperscript{1} \rightarrow martini\textsuperscript{1}</td>
</tr>
<tr>
<td>Antonym</td>
<td></td>
<td>Semantic opposition between lemmas</td>
<td>leader\textsuperscript{1} \leftrightarrow follower\textsuperscript{1}</td>
</tr>
<tr>
<td>Derivationally Related Form</td>
<td></td>
<td>Lemmas w/same morphological root</td>
<td>destruction\textsuperscript{1} \leftrightarrow destroy\textsuperscript{1}</td>
</tr>
</tbody>
</table>
# Verb Relations

<table>
<thead>
<tr>
<th>Relation</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypernym</td>
<td>From events to superordinate events</td>
<td>$fly^9 \rightarrow travel^5$</td>
</tr>
<tr>
<td>Troponym</td>
<td>From events to subordinate event (often via specific manner)</td>
<td>$walk^1 \rightarrow stroll^1$</td>
</tr>
<tr>
<td>Entails</td>
<td>From verbs (events) to the verbs (events) they entail</td>
<td>$snore^1 \rightarrow sleep^1$</td>
</tr>
<tr>
<td>Antonym</td>
<td>Semantic opposition between lemmas</td>
<td>$increase^1 \leftrightarrow decrease^1$</td>
</tr>
<tr>
<td>Derivationally</td>
<td>Lemmas with same morphological root</td>
<td>$destroy^1 \leftrightarrow destruction^1$</td>
</tr>
<tr>
<td>Related Form</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Word Sense Disambiguation

The **bass** line of the song is too weak.

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Outline

- Structured Perceptron
- Word Senses
- Semantic Roles
Meaning is Subtle

I’m thrilled to visit sunny California.
I’m thrilled to visit California, where the weather is sunny.
I’m thrilled to visit California, where it’s sunny.
I’m excited to visit California, where it’s sunny.
I’m excited to visit California, where it’s sunny out.
I’m excited to spend time in California, where it’s sunny out.
I’m not excited to visit sunny California.
I’m thrilled to visit sunny Florida.
I’m thrilled to visit sunny Mountain View.
I’m thrilled to visit California because it’s sunny.
I’m sort of happy about the California visit.
Verbs are key!

- Mary opened the door.
  The door opened.

- John slices the bread with a knife.
  The bread slices easily.
  The knife slices easily.

- Mary loaded the truck with hay.
  Mary loaded hay onto the truck.
  The truck was loaded with hay (by Mary).
  Hay was loaded onto the truck (by Mary).

- John got Mary a present.
  John got a present for Mary.
  Mary got a present from John.
Syntax ≠ Semantics

John broke the window.
The window was broken by John.
The rock broke the window.
John broke the window with Sam.
John broke the window with a rock.
Need for “Roles”

The police officer *detained* the subject at the scene of the crime.

**Who?**  The police officer  
**Did what?**  detained  
**To whom?**  The subject  
**Where?**  at the scene of the crime  
**When?**  -
Thematic Roles

Agent: The waiter spilled the soup.
Experiencer: John has a headache.
Content: The wind blows debris into our yard.
Force: Jesse broke the window.
Theme: Mona asked, “You met Mary Ann at the supermarket?”
Result: He poached catfish, stunning them with a shocking device.
Source: I flew in from Boston.
Beneficiary: Ann Callahan makes hotel reservations for her boss.
Goal: I drove to Portland.
Difficult to have a good set of roles that works all the time, where each role can have a small, concrete definition

47 high-level classes, divided into 193 more specific classes
- Levin (1993), VerbNet

Fewer Roles
- PropBank
  "Proto"-arguments, shared across verbs
  Exact definition depends on verb sense

More Roles
- FrameNet
  Each verb sense is part of a "frame"
  Each frame has its own arguments
Prop Bank

- “Frames” are verb senses
- Arguments of each verb are mapped onto Arg0, Arg1, Arg2
- Arguments are always constituents (annotated over syntax)

fall.01 (move downward)
- ARG1: logical subject, patient, thing falling
- ARG2: extent, amount fallen
- ARG3: starting point
- ARG4: ending point
- ARGM-LOC: medium

fall.08 (fall back on)
- ARG0: thing falling back
- ARG1: thing fallen back on

fall.10 (fall for a trick)
- ARG1: the fool
- ARG2: the trick
FrameNet

- “Frames” can be any content word (~1000 frames)
- Each frame has its own argument roles, everything is hierarchical
- Annotated without syntax, arguments can be anything
“Change position on a scale”

<table>
<thead>
<tr>
<th>VERBS:</th>
<th>dwindle</th>
<th>move</th>
<th>soar</th>
<th>escalation</th>
<th>shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>advance</td>
<td>edge</td>
<td>mushroom</td>
<td>swell</td>
<td>explosion</td>
<td>tumble</td>
</tr>
<tr>
<td>climb</td>
<td>explode</td>
<td>plummet</td>
<td>swing</td>
<td>fall</td>
<td></td>
</tr>
<tr>
<td>decline</td>
<td>fall</td>
<td>reach</td>
<td>triple</td>
<td>fluctuation</td>
<td></td>
</tr>
<tr>
<td>decrease</td>
<td>fluctuate</td>
<td>rise</td>
<td>tumble</td>
<td>gain</td>
<td>growth</td>
</tr>
<tr>
<td>diminish</td>
<td>gain</td>
<td>rocket</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dip</td>
<td>grow</td>
<td>shift</td>
<td></td>
<td>hike</td>
<td></td>
</tr>
<tr>
<td>double</td>
<td>increase</td>
<td>skyrocket</td>
<td>decline</td>
<td>increase</td>
<td></td>
</tr>
<tr>
<td>drop</td>
<td>jump</td>
<td>slide</td>
<td>decrease</td>
<td>rise</td>
<td></td>
</tr>
</tbody>
</table>

| ADVERBS:     | increasingly |        |        |           |       |
|              |              |        |        |           |       |
|              |              |        |        |           |       |

<table>
<thead>
<tr>
<th>NOUNS:</th>
<th>hike</th>
<th>increase</th>
<th>rise</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

FrameNet also codes relationships between frames, allowing frames to inherit from each other, or representing relations between frames like causation (and generalizations among frame elements in different frames can be representing by inheritance as well). Thus, there is a Cause change of position on a scale frame that is linked to the Change of position on a scale frame by the cause relation, but that adds an AGENT role and is used for causative examples such as the following:

\[(22.26) \{\text{AGENT} \text{They} \text{raised} \text{the price of their soda} \{\text{DIFFERENCE by 2\%}}.\]
### Core Roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATTRIBUTE</td>
<td>The ATTRIBUTE is a scalar property that the ITEM possesses.</td>
</tr>
<tr>
<td>DIFFERENCE</td>
<td>The distance by which an ITEM changes its position on the scale.</td>
</tr>
<tr>
<td>FINAL_STATE</td>
<td>A description that presents the ITEM’s state after the change in the ATTRIBUTE’s value as an independent predication.</td>
</tr>
<tr>
<td>FINAL_VALUE</td>
<td>The position on the scale where the ITEM ends up.</td>
</tr>
<tr>
<td>INITIAL_STATE</td>
<td>A description that presents the ITEM’s state before the change in the ATTRIBUTE’s value as an independent predication.</td>
</tr>
<tr>
<td>INITIAL_VALUE</td>
<td>The initial position on the scale from which the ITEM moves away.</td>
</tr>
<tr>
<td>ITEM</td>
<td>The entity that has a position on the scale.</td>
</tr>
<tr>
<td>VALUE_RANGE</td>
<td>A portion of the scale, typically identified by its end points, along which the values of the ATTRIBUTE fluctuate.</td>
</tr>
</tbody>
</table>

### Some Non-Core Roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DURATION</td>
<td>The length of time over which the change takes place.</td>
</tr>
<tr>
<td>SPEED</td>
<td>The rate of change of the VALUE.</td>
</tr>
<tr>
<td>GROUP</td>
<td>The GROUP in which an ITEM changes the value of an ATTRIBUTE in a specified way.</td>
</tr>
</tbody>
</table>
“Change position on a scale”

[ITEM Oil] *rose* [ATTRIBUTE in price] [DIFFERENCE by 2%].
[ITEM It] has *increased* [FINAL_STATE to having them 1 day a month].
[ITEM Microsoft shares] *fell* [FINAL_VALUE to 7 5/8].
[ITEM Colon cancer incidence] *fell* [DIFFERENCE by 50%] [GROUP among men].

a steady *increase*  [INITIAL_VALUE from 9.5] [FINAL_VALUE to 14.3] [ITEM in dividends]

a [DIFFERENCE 5%] [ITEM dividend] *increase*...
Relations between Frames

Inherits from:  
Is Inherited by:  
Perspective on:  
Is Perspectivized in:  
Uses:  
Is Used by:  
Subframe of:  
Has Subframe(s):  
Precedes:  
Is Preceded by:  
Is Inchoative of:  
Is Causative of:  

---
You can’t blame the program for being unable to identify it.

The San Francisco Examiner issued a special edition yesterday.
Approach to SRL Predictions
Features for SRL

Headword of constituent: Examiner
Headword POS: NNP
Voice of the clause: Active
Subcategorization of pred: VP -> VBD NP PP
Named Entity type of constituent: ORGANIZATION
First and last words of constituent: The, Examiner
Linear position, clause re: predicate: before
Path features: NP↑S↓VP↓VBD
Typical SRL Pipeline

**Pruning**
Use rules to filter out unlikely constituents.

**Identification**
Use a classifier to further filter constituents.

**Classification**
Use a classifier predict multiple roles for each constituent.

**Joint Inference**
Jointly predict a consistent set of roles.
Selectional Restrictions

I want to eat someplace nearby.

Interpretation 1

someplace nearby is a location adjunct (intransitive)

Interpretation 2

someplace nearby is a direct object (transitive verb)

Why is Interpretation 2 unlikely?

Theme of “eat” is usually edible.

Introduce constraints based on WordNet
In this case, it should be “food, nutrient”
Selectional Preferences!

Instead of restrictions, measure association scores for each role. how often a class/noun appears as an argument.

<table>
<thead>
<tr>
<th>Class</th>
<th>Nouns</th>
</tr>
</thead>
<tbody>
<tr>
<td>eat</td>
<td>food#n1, aliment#n1, entity#n1, solid#n1, food#n2</td>
</tr>
<tr>
<td>drink</td>
<td>fluid#n1, liquid#n1, entity#n1, alcohol#n1, beverage#n1</td>
</tr>
<tr>
<td>appoint</td>
<td>individual#n1, entity#n1, chief#n1, being#n2, expert#n1</td>
</tr>
<tr>
<td>publish</td>
<td>abstract_entity#n1, piece_of_writing#n1, communication#n2, publication#n1</td>
</tr>
</tbody>
</table>
Upcoming...

Homework
- Homework 3 is due on February 27
- Write-up and data will be released very soon.

Project
- Status report due in ~2 weeks: March 2, 2017
- Instructions coming soon
- Only 5 pages

Summaries
- Paper summaries: February 17, February 28, March 14
- Only 1 page each