Semantic parsing

• Semantic parsing with CCG is simply syntactic parsing, assuming mapping from syntactic primitives to logical forms.

• But this encounters two problems:
  • We don’t have those manual mappings (task-specific).
  • We can’t parse anything not in our lexicon.

From last time
Learning from logical forms

- We can train a semantic parser in a number of ways:
  - Full derivational trees (CCGBank)
  - Logical forms (Zettlemoyer and Collins 2005)
  - Denotations (Berant et al. 2013)
Learning from trees

```
\begin{align*}
  & S \\
  & \lambda x. \text{state}(x) \land (\text{borders}(x, \text{texas})) \\
\end{align*}
```

```
\begin{align*}
  & (S/S\backslash NP) \\
  & \lambda g. \lambda x. \text{state}(x) \land g(x) \\
\end{align*}
```

```
\begin{align*}
  & (S\backslash NP) \\
  & \lambda y (\text{borders}(y, \text{texas})) \\
\end{align*}
```

```
\begin{align*}
  & (S/S\backslash NP)/N \\
  & \lambda f. \lambda g. \lambda x. f(x) \lor g(x) \\
  & \lambda x. \text{state}(x) \\
\end{align*}
```

```
\begin{align*}
  & (S\backslash NP)/NP \\
  & \lambda x. \lambda y (\text{borders}(y, x)) \\
  & \text{texas} \\
\end{align*}
```

```
\begin{align*}
  & \text{what} \\
  & \text{states} \\
  & \text{border} \\
  & \text{texas} \\
\end{align*}
```
Learning from logical forms

<table>
<thead>
<tr>
<th>sentence</th>
<th>what states border texas</th>
</tr>
</thead>
<tbody>
<tr>
<td>logical form</td>
<td>λx.state(x) ^ borders(x, texas)</td>
</tr>
</tbody>
</table>

Two core ideas:

- We’ll learn the lexicon (including the lambda expressions)
- We’ll learn CCG parser from that lexicon, and treat the true tree as a latent variable
Learning from logical forms

• For all <sentence, logical form> pairs in training data, maximize the probability of the logical form by marginalizing over the joint probability:

\[
P(L \mid S; \theta) = \sum_T P(L, T \mid S; \theta)
\]

• Where

\[
P(L, T \mid S; \theta) = \frac{\exp(f(L, T, S)\top \theta)}{\sum_{L,T} \exp(f(L, T, S)\top \theta)}
\]

Start with random values for \(\theta\); update with SGD
Learning from logical forms

- Learning from logical forms is means we don’t need training data in the form of full CCG derivations + semantically enriched lexicon.

- But we do still need training data in the form of logical forms.

<table>
<thead>
<tr>
<th>Logical Form</th>
<th>Syntactic Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah borders Idaho</td>
<td>borders(utah,idaho)</td>
</tr>
<tr>
<td>number of dramas starring tom cruise</td>
<td>???</td>
</tr>
</tbody>
</table>
## Learning from denotations

<table>
<thead>
<tr>
<th>sentence</th>
<th>what states border texas</th>
</tr>
</thead>
<tbody>
<tr>
<td>logical form</td>
<td>$\lambda x.\text{state}(x) \land \text{borders}(x, \text{texas})$</td>
</tr>
<tr>
<td>denotation</td>
<td><strong>new_mexico, oklahoma, arkansas, louisiana</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>sentence</th>
<th>number of dramas starring tom cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>logical form</td>
<td>$\text{count}(\lambda x.\text{genre}(x,\text{drama}) \land \exists y.\text{performance}(x,y) \land \text{actor}(y,\text{tom_cruise}))$</td>
</tr>
<tr>
<td>denotation</td>
<td><strong>28</strong></td>
</tr>
</tbody>
</table>
## Learning from denotations

<table>
<thead>
<tr>
<th>sentence</th>
<th>what states border texas</th>
</tr>
</thead>
<tbody>
<tr>
<td>logical form</td>
<td>( \lambda x. \text{state}(x) \land \text{borders}(x, \text{texas}) )</td>
</tr>
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<td><strong>new_mexico, oklahoma, arkansas, louisiana</strong></td>
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<thead>
<tr>
<th>sentence</th>
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</tr>
<tr>
<td>denotation</td>
<td><strong>28</strong></td>
</tr>
</tbody>
</table>
Learning from denotations

• How could we use the principles of learning from logical forms to learn from denotations?

• The meaning of a sentence is the set of possible worlds consistent with that statement.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah borders Idaho</td>
<td>TRUE</td>
</tr>
<tr>
<td>number of dramas starring tom cruise</td>
<td>28</td>
</tr>
</tbody>
</table>
Learning from denotations

• Basic idea: maximize the probability of the tree $T$ / logical form $z$ that, when executed against a knowledge base $\mathcal{K}$, yield the correct denotation $y$
Why do we need CCG (or a syntactic representation) at all?

• It provides the scaffolding for learning by encoding our assumptions about the problem (compositionality)

• Meaning is built from parts, so let’s learn to decompose our answers (denotations, logical forms) into those parts.
Event semantics

Pat gives Sal a book

$\exists x. \text{book}(x) \land \text{GIVE}(\text{Pat}, \text{Sal}, x)$
Event semantics

Yesterday, Pat gave Sal a book reluctantly

\[ \exists x. \text{book}(x) \land \text{GIVE}(\text{Pat}, \text{Sal}, x, \text{yesterday}, \text{reluctantly}) \]

- One option: extend the arity of the relation (require more arguments)
- But that’s not great because we need a separate predicate for every possible combination of arguments (even those that aren’t required).
Event semantics

We can reify the event to an existentially quantified variable of its own, and then use it as an argument in other relations.

\[ \exists e, x. \text{GIVE-EVENT}(e) \]
\[ \land \text{GIVER}(e, \text{Pat}) \]
\[ \land \text{GIFT}(e, x) \]
\[ \land \text{BOOK}(x) \]
\[ \land \text{RECIPIENT}(e, \text{Sal}) \]
\[ \land \text{TIME}(e, \text{yesterday}) \]
\[ \land \text{MANNER}(e, \text{reluctantly}) \]
Event semantics

Neo-Davidson event semantics: the event is central, and relations are predicated of the event. Each argument of an event holds its own relation.

\[ \exists e, x. \text{GIVE-EVENT}(e) \]
\[ \land \text{GIVER}(e, \text{Pat}) \]
\[ \land \text{GIFT}(e, x) \]
\[ \land \text{BOOK}(x) \]
\[ \land \text{RECIPIENT}(e, \text{Sal}) \]
\[ \land \text{TIME}(e, \text{yesterday}) \]
\[ \land \text{MANNER}(e, \text{reluctantly}) \]

In model-theoretic semantics, each of these has a denotation in a world model.

Eisenstein 2017
Event semantics

Sasha broke the window

\[ \exists e, y. \text{BREAKING-EVENT}(e) \land \text{BREAKER}(e, \text{Sasha}) \land \text{BROKEN-THING}(e, y) \land \text{WINDOW}(y) \]

Pat opened the door

\[ \exists e, y. \text{OPENING-EVENT}(e) \land \text{OPENER}(e, \text{Pat}) \land \text{OPENED-THING}(e, y) \land \text{DOOR}(y) \]
Event semantics

In model-theoretic semantics, each of these has some denotation in the world model.

Example: WINDOW has a identifier in some knowledge base (e.g., Freebase) uniquely identifying its properties.

\[ \exists e, y. \text{BREAKING-EVENT}(e) \]
\[ \land \text{BREAKER}(e, \text{Sasha}) \]
\[ \land \text{BROKEN-THING}(e, y) \]
\[ \land \text{WINDOW}(y) \]

\[ \exists e, y. \text{OPENING-EVENT}(e) \]
\[ \land \text{OPENER}(e, \text{Pat}) \]
\[ \land \text{OPENED-THING}(e, y) \]
\[ \land \text{DOOR}(y) \]
Event semantics

This requires a comprehensive representation of the world

\[\exists e,y. \text{BREAKING-EVENT}(e) \land \text{BREAKER}(e,\text{Sasha}) \land \text{BROKEN-THING}(e,y) \land \text{WINDOW}(y)\]

\[\exists e,y. \text{OPENING-EVENT}(e) \land \text{OPENER}(e,\text{Pat}) \land \text{OPENED-THING}(e,y) \land \text{DOOR}(y)\]
Shallow semantics

\[ \exists e, y. \text{EVENT}(e) \]
\[ \land \text{CAUSER-OF-ACTION}(e, \text{Sasha}) \]
\[ \land \text{RECIPIENT-OF-ACTION}(e, y) \]
\[ \land \text{“window”}(y) \]

\[ \exists e, y. \text{OPENING-EVENT}(e) \]
\[ \land \text{CAUSER-OF-ACTION}(e, \text{Pat}) \]
\[ \land \text{RECIPIENT-OF-ACTION}(e, y) \]
\[ \land \text{“door”}(y) \]

\[ \exists e, y. \text{BREAKING-EVENT}(e) \]
\[ \land \text{BREAKER}(e, \text{Sasha}) \]
\[ \land \text{BROKEN-THING}(e, y) \]
\[ \land \text{WINDOW}(y) \]

\[ \exists e, y. \text{OPENING-EVENT}(e) \]
\[ \land \text{OPENER}(e, \text{Pat}) \]
\[ \land \text{OPENED-THING}(e, y) \]
\[ \land \text{DOOR}(y) \]

These roles have a lot in common: direct causal responsibility for the events, have volition, often animate
Shallow semantics

\exists e, y. \text{EVENT}(e)
\land \text{AGENT}(e, \text{Sasha})
\land \text{THEME}(e, y)
\land \text{"window"}(y)

\exists e, y. \text{BREAKING-EVENT}(e)
\land \text{BREAKER}(e, \text{Sasha})
\land \text{BROKEN-THING}(e, y)
\land \text{WINDOW}(y)

\exists e, y. \text{EVENT}(e)
\land \text{AGENT}(e, \text{Pat})
\land \text{THEME}(e, y)
\land \text{"door"}(y)

\exists e, y. \text{OPENING-EVENT}(e)
\land \text{OPENER}(e, \text{Pat})
\land \text{OPENED-THING}(e, y)
\land \text{DOOR}(y)
Shallow semantics

Agent: Sasha
Theme: window

Agent: Pat
Theme: door

\( \exists e, y. \text{BREAKING-EVENT}(e) \)
\( \land \text{BREAKER}(e, \text{Sasha}) \)
\( \land \text{BROKEN-THING}(e, y) \)
\( \land \text{WINDOW}(y) \)

\( \exists e, y. \text{OPENING-EVENT}(e) \)
\( \land \text{OPENER}(e, \text{Pat}) \)
\( \land \text{OPENED-THING}(e, y) \)
\( \land \text{DOOR}(y) \)
Thematic roles

Thematic roles capture the semantic commonality among arguments for different relations (predicates)

- John broke the window
- The window was broken by John

Different syntactic roles, but the same thematic role.
## Thematic roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent</td>
<td>The volitional causer of an event</td>
</tr>
<tr>
<td>Experiencer</td>
<td>The experiencer of an event</td>
</tr>
<tr>
<td>Force</td>
<td>The non-volitional causer of the event</td>
</tr>
<tr>
<td>Theme</td>
<td>The participant most directly affected by an event</td>
</tr>
<tr>
<td>Result</td>
<td>The end product of an event</td>
</tr>
<tr>
<td>Content</td>
<td>The proposition or content of a propositional event</td>
</tr>
<tr>
<td>Instrument</td>
<td>An instrument used in an event</td>
</tr>
<tr>
<td>Beneficiary</td>
<td>The beneficiary of an event</td>
</tr>
<tr>
<td>Source</td>
<td>The origin of the object of a transfer event</td>
</tr>
<tr>
<td>Goal</td>
<td>The destination of an object of a transfer event</td>
</tr>
</tbody>
</table>
## Thematic roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent</td>
<td><em>The waiter</em> spilled the soup.</td>
</tr>
<tr>
<td>Experiencer</td>
<td>John has <em>a headache</em>.</td>
</tr>
<tr>
<td>Force</td>
<td><em>The wind</em> blows debris from the mall into our yards.</td>
</tr>
<tr>
<td>Theme</td>
<td>Only after Benjamin Franklin broke <em>the ice</em>...</td>
</tr>
<tr>
<td>Result</td>
<td>The city built <em>a regulation-size baseball diamond</em>...</td>
</tr>
<tr>
<td>Content</td>
<td>Mona asked “<em>You met Mary Ann at a supermarket?</em>”</td>
</tr>
<tr>
<td>Instrument</td>
<td>He poached catfish, stunning them with <em>a shocking device</em>...</td>
</tr>
<tr>
<td>Beneficiary</td>
<td>Whenever Ann makes hotel reservations for <em>her boss</em>...</td>
</tr>
<tr>
<td>Source</td>
<td>I flew in from <em>Boston</em>.</td>
</tr>
<tr>
<td>Goal</td>
<td>I drove to <em>Portland</em>.</td>
</tr>
</tbody>
</table>

SLP3
Thematic roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Goal</td>
<td>The destination of an object of a transfer event</td>
</tr>
</tbody>
</table>

- John broke the window
- The window was broken by John
- John broke the window with a rock
- The rock broke the window
- The window broke
Thematic roles

The thematic roles for verbs generally are predictable by the syntactic position of the argument (specific to each verb class). Some allow for consistent alternations:

Doris gave the book to Cary

Doris gave Cary the book
Thematic roles

• Thematic roles are very useful but difficult to formally define AGENT, THEME, etc.

• At the same time, they may be too coarse for some applications.
Thematic roles

- The cook opened the jar with the new gadget
- The new gadget opened the jar
- Shelly ate the sliced banana with a fork
- *The fork ate the sliced banana

Intermediary instruments can be subjects

Enabling instruments cannot

Levin and Rappaport Hovav 2005; SLP3
Coarsening: Proto-roles

• Proto-roles = generalized thematic roles

• Proto-agent: causing an event, having volition wrt event, moving, acting with intention

• Proto-patient: change of state, causally affected by event)
Propbank

• Sentences from the Penn Treebank annotated with proto-roles, along with lexical entries for each sense of a verb identifying the specific meaning of each proto-role for that verb sense.

https://propbank.github.io
(22.11) **agree.01**

Arg0: Agreer  
Arg1: Proposition  
Arg2: Other entity agreeing  

Ex1: [Arg0 The group] *agreed* [Arg1 it wouldn’t make an offer].
Ex2: [ArgM-TMP Usually] [Arg0 John] *agrees* [Arg2 with Mary] [Arg1 on everything].

(22.12) **fall.01**

Arg1: Logical subject, patient, thing falling  
Arg2: Extent, amount fallen  
Arg3: start point  
Arg4: end point, end state of arg1  

Ex1: [Arg1 Sales] *fell* [Arg4 to $25 million] [Arg3 from $27 million].
Ex2: [Arg1 The average junk bond] *fell* [Arg2 by 4.2%].
Verb-specific argument structures lets us map the commonalities among the different surface forms

• \([\text{Arg}_0 \text{ Big Fruit Co. }]\) increased \([\text{Arg}_1 \text{ the price of bananas}]\).

• \([\text{Arg}_1 \text{ The price of bananas}]\) was increased again \([\text{Arg}_0 \text{ by Big Fruit Co.}]\).

• \([\text{Arg}_1 \text{ The price of bananas}]\) increased \([\text{Arg}_2 5\%]\).
Verb-specific argument structures lets us map the commonalities among the different surface forms

- \( [\text{Arg}0 \text{ Big Fruit Co. }] \text{ increased} \ [\text{Arg}1 \text{ the price of bananas}]. \)

- \( [\text{Arg}1 \text{ The price of bananas}] \text{ was increased again} \ [\text{Arg}0 \text{ by Big Fruit Co. }] \)

- \( [\text{Arg}1 \text{ The price of bananas}] \text{ increased} \ [\text{Arg}2 \text{ 5%}]. \)
• [Arg1 The price of bananas] increased [Arg2 5%].

• [Arg1 The price of bananas] rose [Arg2 5%].

• There has been a [Arg2 5%] rise [Arg1 in the price of bananas].
FrameNet

- Propbank maps argument structure for individual verb senses
- FrameNet maps argument structure for frames, which are evoked by a lexical unit (typically a verb)

https://framenet.icsi.berkeley.edu/fndrupal/framenet_data
Frames

<table>
<thead>
<tr>
<th>AI</th>
<th>Cognitive Psychology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minksky 1974</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sociology</td>
</tr>
<tr>
<td></td>
<td>Goffman 1975</td>
</tr>
<tr>
<td>Linguistics</td>
<td></td>
</tr>
<tr>
<td>Fillmore 1975, 1982, Tannen 1979</td>
<td>Media Studies</td>
</tr>
<tr>
<td></td>
<td>Entman 1993</td>
</tr>
</tbody>
</table>
Frames

John went into a restaurant. He ordered a hamburger and coke. He asked the waitress for the check and left.

(Schank & Abelson 75)
Frames

• “A frame is a data-structure for representing a stereotyped situation” (Minsky 1975)

• By the term ‘frame’ I have in mind any system of concepts related in such a way that to understand any one of them you have to understand the whole structure in which it fits; when one of the things in such a structured is introduced … all of the others are automatically made available.” (Fillmore 1982)
Who did what to whom?

• John *bought* the car at the dealership

• The car was *bought* by John

• John’s *purchase* of the car

• The *sale* of the car cleared their inventory.
Who did what to whom?

- John bought the car at the dealership
- The car was bought by John
- John’s purchase of the car
- The sale of the car cleared their inventory.
Who did what to whom?

- John bought the car at the dealership
- The car was bought by John
- John’s purchase of the car
- The sale of the car cleared their inventory.
Semantic Frame

**APPLY_HEAT**

- **Lexical units:**
  
  bake.v, barbecue.v, blanch.v, boil.v, braise.v, broil.v, brown.v, char.v, coddle.v, cook.v, deep fry.v, fry.v, grill.v, microwave.v, parboil.v, plank.v, poach.v, roast.v, saute.v, scald.v, sear.v, simmer.v, singe.v, steam.v, steep.v, stew.v, toast.v

- **Core Frame Elements:**

<table>
<thead>
<tr>
<th>Cook</th>
<th>The Cook applies heat to the Food.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Food is the entity to which heat is applied by the Cook.</td>
</tr>
<tr>
<td>Heating instrument</td>
<td>The entity that directly supplies heat to the Food</td>
</tr>
<tr>
<td>Container</td>
<td>The Container holds the Food to which heat is applied.</td>
</tr>
<tr>
<td>Temperature setting</td>
<td>The Temperature_setting of the Heating_instrument for the Food.</td>
</tr>
</tbody>
</table>
## Semantic Frame

### DESTROY

- **Lexical units:**
  
  annihilate.v, annihilation.n, blast.v, blow up.v, demolish.v, demolition.n, destroy.v, destruction.n, destructive.a, devastate.v, devastation.n, dismantle.v, dismantlement.n, lay waste.v, level.v, obliterate.v, obliteration.n, raze.v, ruin.v, take out.v, unmake.v, vaporize.v

- **Core Frame Elements:**

<table>
<thead>
<tr>
<th>Cause</th>
<th>The event or entity which is responsible for the destruction of the Patient.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destroyer</td>
<td>The conscious entity, generally a person, that performs the intentional action that results in the Patient’s destruction.</td>
</tr>
<tr>
<td>Patient</td>
<td>The entity which is destroyed by the Destroyer.</td>
</tr>
</tbody>
</table>
Semantic representations

Two different perspectives on a commercial transaction
Multilingual frames

I bought a car from you

Sie verkauft mir ein Auto

BUYER

GOODS

SELLER

nsubj

dobj

prep

det

pobj

SB

DA

NK

OA
Multilingual frames

- French
- Chinese
- Brazilian Portuguese
- German
- Spanish
- Japanese
- Swedish
- Korean

https://framenet.icsi.berkeley.edu/fndrupal/framenets_in_other_languages
Semantic role labeling

- Input: a sentence
- Output:
  - A list of predicates, each containing:
    - a label (e.g., Framenet frame)
    - a span
    - a set of arguments, each containing:
      - a label (thematic role, FrameNet role)
      - a span
Semantic role labeling

FrameNet

[You] can’t [blame] [the program] [for being unable to identify it]
COGNIZER TARGET EVALUnee REASON

PropBank

[The San Francisco Examiner] issued [a special edition] [yesterday]
ARG0 TARGET ARG1 ARGM-TMP

How would we do this?