Representing Meaning: Verb and Sentence Semantics

Lecture 18
Semantics Road Map

1. Lexical semantics
2. Vector semantics
3. Meaning representation languages and semantic roles
4. Compositional semantics, semantic parsing
5. Discourse and pragmatics
Learning Objectives

• Be able to distinguish between extension and intension
• Be able to apply the criteria for a good MRL (meaning representation language)
• Be able to represent simple English statements in first order logic (FOL)
  • Classical representation
  • Neo-Davidsonian representation
• Be able to state the strengths and weakness of two different classes of MRLs (FOL and description logics)
• Be able to explain the uses and value of semantic role labels
• Be able to provide a basic algorithm for semantic role labeling
Intension and Extension
Two Approaches to Semantics

• **Intentional**
  - Assumes that the word or utterance is intrinsically meaningful
  - Decompositional approaches to lexical semantics are intentional

• **Extentional**
  - Defines words and utterances by the the things in the world of which they are true
  - This lecture will concern *extentional* models of semantics
Word Meanings are Predicates and Predicates are Sets

The semantics of *red* (the word) are RED (the predicate)

RED =

The predicate is defined in terms of things in the world, not intrinsic qualities
RED(x) is the assertion that \( x \in \text{RED} \)

- HIT is the set of \( \langle x, y \rangle \) pairs where \( x \) hit \( y \)
- Asserting that \textit{Alan hit David} or \( \text{HIT}(\text{Alan, David}) \) is asserting that \( \langle \text{Alan, David} \rangle \) is an element of the set HIT
- Such assertions can be either true or false
This Lecture has Two Goals

• We will look at ways of representing the extension of verbs and sentences
• We will also look at semantic roles and how they relate to meaning representation languages (MRLs)
Desirable Properties of Meaning Representations
Meaning Representation?

For what kinds of tasks?

- Answering essay questions on an exam
- Deciding what to order at a restaurant
- Learning an activity via instructions
- Making an investment decision
- Recognizing an insult
Desirable Qualities: Verifiability

We want to be able to determine the truth of our representations.

“Does Udipi serve vegetarian food”? Is \texttt{SERVE}(Udipi, vegetarian food) in our knowledge base?

What is the relationship between the meaning of a sentence and the world as we know it?
Desirable Qualities: Unambiguous Representation

Let’s eat somewhere near campus.

(e.g., we want to eat at a place near campus)  (e.g., we eat places)

Our MRL must capture precisely one of these meanings—not both.
Desirable Qualities: Canonical Form

• “Mad Mex has vegetarian dishes.”
• “They have vegetarian food at Mad Mex.”
• “Vegetarian dishes are served at Mad Mex.”
• “Mad Mex serves vegetarian fare.”

Inputs that mean the same thing should have the same meaning representation.
Desirable Qualities: Inference, Variables, and Expressiveness

- “Can vegetarians eat at Mad Mex?”

- “I’d like to find a restaurant where I can get vegetarian food.”

  \text{SERVE}(x, \text{vegetarian food})

- “Delta flies Boeing 737s from Boston to New York.”
One Limitation: Literality

We will focus on the basic requirements for meaning representation.

The basic requirements do not include correctly interpreting statements like:

• “Ford was hemorrhaging money.”
• “I could eat a horse.”
What entities do we want to represent?

A meaning representation scheme should let us represent:

• **objects** (e.g., people, restaurants, cuisines)
• **properties of objects** (e.g., pickiness, noisiness, spiciness)
• **relations between objects** (e.g., \textsc{serve}(Oishii Bento, Japanese))
The Knowledge Base

It contains the things that we “know”

Our knowledge base

We can query it
The Candidates
“I have a car.”

$$\exists x, y Having(x) \land Haver(Speaker, x) \land HadThing(y, x) \land Car(y)$$
First-Order Logic
MRL #1: First-Order Logic

DressCode(ThePorch)
Cuisine(Udipi)

SERVES(UnionGrill, AmericanFood)
RESTAURANT(UnionGrill)

• \text{HAVE}(\text{Speaker}, \text{FiveDollars}) \land \neg \text{HAVE}(\text{Speaker}, \text{LotOfTime})
• \forall x \ \text{PERSON}(x) \Rightarrow \text{HAVE}(x, \text{FiveDollars})
• \exists x,y \ \text{PERSON}(x) \land \text{RESTAURANT}(y) \land \neg \text{HASVISITED}(x,y)
First Order Logic and Semantics

• Nouns correspond to one-place predicates:
  \textsc{Restaurant}(x) \hspace{1em} \text{is true if } x \text{ is a member of the set of restaurants}

• Adjectives correspond to one-place predicates:
  \textsc{Vegetarian}(x) \hspace{1em} \text{is true if } x \text{ is a member of the set of things that are vegetarian}

• Verbs correspond to one-place, two-place, or three-place predicates
  \textsc{Dine}(x) \hspace{1em} \text{as in } \textit{Noah dined.}
  \textsc{Eat}(x, y) \hspace{1em} \text{as in } \textit{Noah ate American food.}
  \textsc{Give}(x, y, z) \hspace{1em} \text{as in } \textit{The bad sushi gave Noah a stomach ache.}
As individual facts are added to a knowledge base, modus ponens can be used to fire applicable implication rules

An example of modus ponens:

\[
\text{\textsc{vegetarianrestaurant}}(\text{Udipi}) \\
\forall x \text{\textsc{vegetarianrestaurant}}(x) \Rightarrow \text{\textsc{Serves}}(x, \text{VegetarianFood}) \\
\text{\textsc{Serves}}(\text{Udipi, VegetarianFood})
\]
First Order Logic: Advantages

- Flexible
- Well-understood
- Widely used
Description Logics
MRL #2: Description Logics

- Goal of description logics: understand and specify semantics for slot-filler representations
- More restrictive than FOL
TBox and Abox are the components of a traditional KB

- **TBox**: contains the knowledge about categories or concepts in the application domain
  
  *All bistros are restaurants*
  
  *All restaurants are businesses*

- **ABox**: facts about individuals in the domain
  
  *Udipi is an Indian restaurant*
Categories and Subsumption

IndianRestaurant(Udipi)

\text{category} \hspace{1cm} \text{domain element}

\textit{Udipi is an Indian restaurant.}

\text{IndianRestaurant} \sqsubseteq \text{Restaurant}

\text{subsumed} \hspace{1cm} \text{subsumer}

\textit{All Indian restaurants are restaurants.}
Negation and Disjunction

IndianRestaurant \equiv \text{not} \text{ ItalianRestaurant}

*Indian restaurants can’t also be Italian restaurants.*

Restaurant \equiv (\text{or} \text{ ItalianRestaurant} \text{ IndianRestaurant} \text{ MexicanRestaurant})

*Restaurants are Italian restaurants, Indian restaurants, or Mexican restaurant.*
What are the relative advantages and disadvantages of FOL and description logics?

First Order Logic

Description Logics
Semantic Roles and Semantic Role Labeling
• Noah built an ark out of gopher wood.
• He loaded two of every animal onto the ark.
• Noah piloted the ark into stormy weather.
• When the skies cleared, all rejoiced.
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• He loaded two of every animal onto the ark.
• Noah piloted the ark into stormy weather.
• When the skies cleared, all rejoiced.
Paraphrase

• Noah built an ark out of gopher wood.
• An ark was built by Noah. It was made from gopher wood.
• Noah constructed an ark with wood from a gopher tree.
• Using gopher wood, Noah managed to put together an ark.
• Noah built an ark.
• ...
Traditional Semantic Roles Labels are Useful for Learning about Semantic Roles

• In the linguistics literature, one sees a number of common terms for semantic roles
  • Agent
  • Patient
  • Theme
  • Force
  • Experiencer
  • Stimulus
  • Recipient
  • Source
  • Goal
  • etc.

• These have their place, and are useful to know if you want to understand what a semantic role is, but are not widely used in NLP

• In NLP, we tend to use finer-grained (and sometimes cryptically named) semantic role labels
Traditional Semantic Roles

- David *threw* the *midterms* from *Pausch Bridge* to *the hillside below*.
  - David—agent
  - the *midterms*—theme
  - Pausch Bridge—source
  - the *hillside below*—goal
Neo-Davidsonian Representations Treat Events as Entities

• David threw the midterms from Pausch Bridge to the hillside below
  • THROW(David, midterms, PauschBridge, hillside)
  • ∃e THROW(e) ∧ AGENT(e, David) ∧ THEME(e, midterms) ∧ SOURCE(e, PauschBridge) ∧ GOAL(e, hillside)

• The midterms were thrown from Pausch Bridge
  • THROW(midterms, PauschBridge)
  • ∃e THROW(e) ∧ THEME(e, midterms) ∧ SOURCE(e, PauschBridge)
Semantic Role Labeling

**Input:** a sentence, paragraph, or document

**Output:** for each predicate*, labeled spans identifying each of its arguments.

*Predicates are sometimes identified in the input, sometimes not.
Predicates

• Noah built an ark out of gopher wood.
• An ark was built by Noah. It was made from gopher wood.
• Noah constructed an ark with wood from a gopher tree.
• Using gopher wood, Noah managed to put together an ark.
Predicates and Arguments

• Noah built an ark out of gopher wood.
• An ark was built by Noah. It was made from gopher wood.
• Noah constructed an ark with wood from a gopher tree.
• Using gopher wood, Noah managed to put together an ark.
Breaking, Eating, Opening

• John broke the window.
• The window broke.
• John is always breaking things.
• The broken window testified to John’s malfeasance.

• Eat!
• We ate dinner.
• We already ate.
• The pies were eaten up quickly.
• Our gluttony was complete.

• Open up!
• Someone left the door open.
• John opens the window at night.
Introducing PropBank

• Corpus (PTB) with propositions annotated
  • Predicates (verbs)
  • Arguments (semantic roles)

• Semantic roles are Arg0, Arg1, etc., each with a description
  • Arg0 is typically the most agent-like argument
  • Labels for other arguments are somewhat arbitrary
“Agree” in PropBank

- **arg0**: agreeer
- **arg1**: proposition
- **arg2**: other entity agreeing
- The group agreed it wouldn’t make an offer.
- Usually John agrees with Mary on everything
“Fall (move downward)” in PropBank

- **arg1**: logical subject, patient, thing falling
- **arg2**: extent, amount fallen
- **arg3**: starting point
- **arg4**: ending point
- **argM-loc**: medium
- **Sales** fell to $251.2 million from $278.8 million.
- **The average junk bond** fell by 4.2%.
- **The meteor** fell through the atmosphere, crashing into Cambridge.
Figure 20.16  Parse tree for a PropBank sentence, showing the PropBank argument labels. The dotted line shows the path feature NP[S]VP|VBD for ARG0, the NP-SBJ constituent *the San Francisco Examiner*. 
FrameNet

• A frame is a schematic representation of a situation involving various participants, and other conceptual roles

• In FrameNet, frames—not verbs—are first-class citizens
  • To a first approximation, verbs that relate to the same situation belong to the same frame
  • Roles are given fine-grained labels that are specific to the frame, but not the verb
  • Frames can center around words other than verbs
### Core roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATTRIBUTE</td>
<td>scalar property that the ITEM possesses</td>
</tr>
<tr>
<td>DIFFERENCE</td>
<td>distance by which an ITEM changes its position</td>
</tr>
<tr>
<td>FINAL_STATE</td>
<td>ITEM’s state after the change</td>
</tr>
<tr>
<td>FINAL_VALUE</td>
<td>position on the scale where ITEM ends up</td>
</tr>
<tr>
<td>INITIAL_STATE</td>
<td>ITEM’s state before the change</td>
</tr>
<tr>
<td>INITIAL_VALUE</td>
<td>position on the scale from which the ITEM moves</td>
</tr>
<tr>
<td>ITEM</td>
<td>entity that has a position on the scale</td>
</tr>
<tr>
<td>VALUE_RANGE</td>
<td>portion of the scale along which values of 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>length of time over which the change occurs</td>
</tr>
<tr>
<td>SPEED</td>
<td>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</td>
</tr>
</tbody>
</table>
- **Verbs**: advance, climb, decline, decrease, diminish, dip, double, drop, dwindle, edge, explode, fall, fluctuate, gain, grow, increase, jump, move, mushroom, plummet, reach, rise, rocket, shift, skyrocket, slide, soar, swell, swing, triple, tumble

- **Nouns**: decline, decrease, escalation, explosion, fall, fluctuation, gain, growth, hike, increase, rise, shift, tumble

- **Adverb**: increasingly
How Can We Build an SRL System?

(1) Parse
(2) For each predicate word in the parse:
    For each node in the parse:
        Classify the node with respect to the predicate