Today: 4/10

• Compositional Semantics
  - Syntax-driven methods of assigning semantics to sentences
Meaning Representations

- We’re going to take the same basic approach to meaning that we took to syntax and morphology
- We’re going to create representations of linguistic inputs that capture the meanings of those inputs.
- But unlike parse trees and the like these representations aren’t primarily descriptions of the structure of the inputs...

Semantic Processing

- We’re going to discuss 2 ways to attack this problem (just as we did with parsing)
  - There’s the theoretically motivated correct and complete approach...
    - Computational/Compositional Semantics
  - And there are practical approaches that have some hope of being useful and successful.
    - Information extraction
Semantic Analysis

- Compositional Analysis
  - Create a FOL representation that accounts for all the entities, roles and relations present in a sentence.

- Information Extraction
  - Do a superficial analysis that pulls out only the entities, relations and roles that are of interest to the consuming application.

Representational Schemes

- We’re going to make use of First Order Predicate Calculus (FOPC) as our representational framework
  - Not because we think it’s perfect
  - All the alternatives turn out to be either too limiting or
  - They turn out to be notational variants
FOPC

• Allows for...
  - The analysis of truth conditions
    • Allows us to answer yes/no questions
  - Supports the use of variables
    • Allows us to answer questions through the use of variable binding
  - Supports inference
    • Allows us to answer questions that go beyond what we know explicitly

FOPC

• This choice isn’t completely arbitrary or driven by the needs of practical applications
• FOPC reflects the semantics of natural languages because it was designed that way by human beings
• In particular...
Meaning Structure of Language

• The semantics of human languages...
  - Display a basic predicate-argument structure
  - Make use of variables
  - Make use of quantifiers
  - Use a partially compositional semantics

Predicate-Argument Structure

• Events, actions and relationships can be captured with representations that consist of predicates and arguments to those predicates.
• Languages display a division of labor where some words and constituents function as predicates and some as arguments.
Predicate-Argument Structure

- Predicates
  - Primarily Verbs, VPs, PPs, Sentences
  - Sometimes Nouns and NPs
- Arguments
  - Primarily Nouns, Nominals, NPs, PPs
  - But also everything else; as we'll see it depends on the context

Example

- Mary gave a list to John.
- Giving(Mary, John, List)
- More precisely
  - Gave conveys a three-argument predicate
  - The first arg is the subject
  - The second is the recipient, which is conveyed by the NP in the PP
  - The third argument is the thing given, conveyed by the direct object
Not exactly

- When we say that
  - The first arg is the subject
- We really mean that the meaning underlying the subject phrase plays the role of the giver.

Better

- Turns out this representation isn’t quite as useful as it could be.
  - Giving(Mary, John, List)
- Better would be

$$\exists x, y \ \text{Giving}(x) \land \text{Giver}(Mary, x) \land \text{Given}(y, x) \land \text{Givee}(John, x) \land \text{Isa}(y, List)$$
Predicates

• The notion of a predicate just got more complicated...
• In this example, think of the verb/VP providing a template like the following:
  \[ \exists w, x, y, z \text{Giving}(x) \land \text{Giver}(w, x) \land \text{Given}(y, x) \land \text{Givee}(z, x) \]

• The semantics of the NPs and the PPs in the sentence plug into the slots provided in the template.

Semantic Analysis

• Semantic analysis is the process of taking in some linguistic input and assigning a meaning representation to it.
  - There a lot of different ways to do this that make more or less (or zero) use of syntax.
  - We’re going to start with the idea that syntax does matter.
    • The compositional rule-to-rule approach.
Compositional Analysis

- Principle of Compositionality
  - The meaning of a whole is derived from the meanings of the parts
- What parts?
  - The constituents of the syntactic parse of the input
- What could it mean for a part to have a meaning?

Example

- AyCaramba serves meat

\[ \exists e \text{ Serving}(e) \land \text{Server}(e, \text{AyCaramba}) \land \text{Served}(e, \text{Meat}) \]
Compositional Analysis

Augmented Rules

- We'll accomplish this by attaching semantic formation rules to our syntactic CFG rules
- Abstractly

\[ A \rightarrow \alpha_1...\alpha_n \quad \{ f(\alpha_1.sem, ..., \alpha_n.sem) \} \]

- This should be read as the semantics we attach to A can be computed from some function applied to the semantics of A's parts.
Example

- Easy parts...
  - NP -> PropNoun
  - NP -> MassNoun
  - PropNoun -> AyCaramba
  - MassMoun -> meat

- Attachments
  - {PropNoun.sem}
  - {MassNoun.sem}
  - {AyCaramba}
  - {MEAT}

Example

- S -> NP VP
- VP -> Verb NP
- Verb -> serves

\[ \lambda x \lambda y \exists e \text{ Serving}(e) \land \text{ Server}(e, y) \land \text{ Served}(e, x) \]
Lambda Forms

- A simple addition to FOPC
  - Take a FOPC sentence with variables in it that are to be bound.
  - Allow those variables to be bound by treating the lambda form as a function with formal arguments

\[ \lambda x P(x) \]

\[ \lambda x P(x)(Sally) \]

\[ P(Sally) \]

Example

```
S
  NP
    ProperNoun AyCaramba
  VP
    Verb serves
    NP
      MassNoun meat
```
Example

Break

• Read Chapters 16 and 17 (to be posted real soon now).
• Schedule
  - Next time lexical semantics
  - Then we’ll cover information extraction, discourse, IR/QA and then MT.
Syntax/Semantics Interface: Two Philosophies

1. Let the syntax do what syntax does well and don’t expect it to know much about meaning
   - In this approach, the lexical entry’s semantic attachments do all the work
2. Assume the syntax does know something about meaning
   - Here the grammar gets complicated and the lexicon simpler (constructional approach)

Example

- Mary freebled John the nim.
  - Who has it?
  - Where did he get it from?
  - Why?
Example

• Consider the attachments for the VPs
  VP -> Verb  NP  NP  rule  (gave Mary a book)
  VP -> Verb  NP  PP   (gave a book to Mary)

Assume the meaning representations should be the same for both. Under the lexicon-heavy scheme, the VP attachments are:
  VP.Sem(NP.Sem, NP.Sem)
  VP.Sem(NP.Sem, PP.Sem)

Example

• Under a syntax-heavy scheme we might want to do something like
  • VP -> V  NP  NP
    V.sem ^ Recip(NP1.sem) ^ Object(NP2.sem)
  • VP -> V  NP  PP
    V.Sem ^ Recip(PP.Sem) ^ Object(NP1.sem)
  • I.e the verb only contributes the predicate, the grammar “knows” the roles.
Integration

- Two basic approaches
  - Integrate semantic analysis into the parser (assign meaning representations as constituents are completed)
  - Pipeline... assign meaning representations to complete trees only after they're completed

Example

- From BERP
  - I want to eat someplace near campus
- Two parse trees, two meanings
Pros and Cons

• If you integrate semantic analysis into the parser as it is running...
  - You can use semantic constraints to cut off parses that make no sense
  - But you assign meaning representations to constituents that don’t take part in the correct (most probable) parse

Mismatches

• There are unfortunately some annoying mismatches between the syntax of FOPC and the syntax provided by our grammars...
• So we’ll accept that we can’t always directly create valid logical forms in a strictly compositional way
  - We’ll get as close as we can and patch things up after the fact.
Quantified Phrases

- Consider
  A restaurant serves meat.
- Assume that A restaurant looks like

  \[ \exists x \text{Isa}(x, \text{Restaurant}) \]

- If we do the normal lambda thing we get

  \[ \exists e \text{Serving}(e) \land \text{Server}(e, \exists x \text{Isa}(x, \text{Restaurant})) \land \text{Served}(e, \text{Meat}) \]

Complex Terms

- Allow the compositional system to pass around representations like the following as objects with parts:

  Complex-Term \rightarrow <\text{Quantifier} \ \text{var} \ \text{body}>

  \< \exists x \text{Isa}(x, \text{Restaurant}) >
Example

• Our restaurant example winds up looking like

\[ \exists e \text{Serving}(e) \land \text{Server}(e, \exists x \text{Isa}(x, \text{Restaurant})) \land \text{Served}(e, \text{Meat}) \]

• Big improvement...

Conversion

• So... complex terms wind up being embedded inside predicates. So pull them out and redistribute the parts in the right way...

\[ P(<\text{quantifier, var, body}>) \]

turns into

Quantifier var body connective P(var)
Example

\[ \text{Server}(e, < \exists x \text{Isa}(x, \text{Restaurant}) >) \implies \exists x \text{Isa}(x, \text{Restaurant}) \land \text{Server}(e, x) \]

Quantifiers and Connectives

- If the quantifier is an existential, then the connective is an ^ (and)

- If the quantifier is a universal, then the connective is an \(-\to\) (implies)
Multiple Complex Terms

• Note that the conversion technique pulls the quantifiers out to the front of the logical form...
• That leads to ambiguity if there's more than one complex term in a sentence.

Quantifier Ambiguity

• Consider
  - Every restaurant has a menu
  - That could mean that every restaurant has a menu
  - Or that There's some uber-menu out there and all restaurants have that menu
Quantifier Scope Ambiguity

\[ \forall x \text{Restaurant}(x) \Rightarrow \exists e, y \text{Having}(e) \land \text{Haver}(e, x) \land \text{Had}(e, y) \land \text{Isa}(y, \text{Menu}) \]

\[ \exists y \text{Isa}(y, \text{Menu}) \land \forall x \text{Isa}(x, \text{Restaurant}) \Rightarrow \exists e \text{Having}(e) \land \text{Haver}(e, x) \land \text{Had}(e, y) \]

Ambiguity

- This turns out to be a lot like the prepositional phrase attachment problem
- The number of possible interpretations goes up exponentially with the number of complex terms in the sentence
- The best we can do is to come up with weak methods to prefer one interpretation over another
Non-Compositionality

- Unfortunately, there are lots of examples where the meaning (loosely defined) can’t be derived from the meanings of the parts
  - Idioms, jokes, irony, sarcasm, metaphor, metonymy, indirect requests, etc

English Idioms

- Kick the bucket, buy the farm, bite the bullet, run the show, bury the hatchet, etc...
- Lots of these... **constructions** where the meaning of the whole is either
  - Totally unrelated to the meanings of the parts (kick the bucket)
  - Related in some opaque way (run the show)
The Tip of the Iceberg

- Describe this construction
  1. A fixed phrase with a particular meaning
  2. A syntactically and lexically flexible phrase with a particular meaning
  3. A syntactically and lexically flexible phrase with a partially compositional meaning
  4. ...

Example

- Enron is the tip of the iceberg.
  NP -> “the tip of the iceberg”
- Not so good... attested examples...
  - the tip of Mrs. Ford’s iceberg
  - the tip of a 1000-page iceberg
  - the merest tip of the iceberg
- How about
  - That’s just the iceberg’s tip.
Example

• What we seem to need is something like

• NP →
  An initial NP with tip as its head followed by
  a subsequent PP with of as its head and that
  has iceberg as the head of its NP
  And that allows modifiers like merest, Mrs.
  Ford, and 1000-page to modify the relevant
  semantic forms