Computational Semantics
Chapter 18

Lecture #12

November 2012

We will not do all of this…

Semantic Analysis

- Semantic analysis is the process of taking in some linguistic input and producing a meaning representation for it.
  - There are many ways of doing this, ranging from completely ad hoc domain specific methods to more theoretically founded by not quite useful methods.
  - Different methods make more or less (or no) use of syntax
  - We're going to start with the idea that syntax does matter
    - The compositional rule-to-rule approach

Compositional Analysis

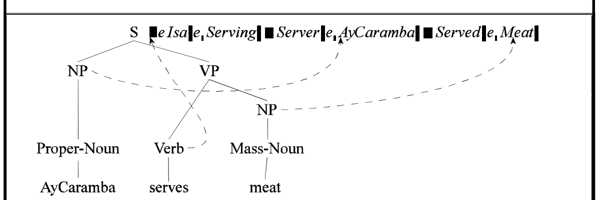
- Principle of Compositionality
  - The meaning of a whole is derived from the meanings of the parts
- What parts?
  - The constituents of the syntactic parse of the input.

Example

- AyCaramba serves meat.

$$\exists e\ Serving(e) \wedge Server(e, AyCaramba) \wedge Served(e, Meat)$$

Compositional Analysis



Compositional Semantics

- Note in the previous example:
- Part of the meaning derives from the people and activities it's about (predicates and arguments, or, nouns and verbs) and part from the way they are ordered and related grammatically: syntax
- Question: can we link up syntactic structures to a corresponding semantic representation to produce the 'meaning' of a sentence in the course of parsing it?

Specific vs. General-Purpose Rules

- We don't want to have to specify for every possible parse tree what semantic representation it maps to
- We want to identify general mappings from parse trees to semantic representations:
  - Again (as with feature structures) we will augment the lexicon and the grammar
  - Rule-to-rule hypothesis: a mapping exists between rules of the grammar and rules of semantic representation

Semantic Attachments

- Extend each grammar rule with instructions on how to map the components of the rule to a semantic representation (grammars are getting complex)

  S → NP VP {VP.sem(NP.sem)}

- Each semantic function is defined in terms of the semantic representation of choice
- Problem: how to define these functions and how to specify their composition so we always get the meaning representation we want from our grammar?

Augmented Rules

- Let's look at this a little more abstractly. Consider the general case of a grammar rule:

$$A \rightarrow \alpha_1 \ldots \alpha_n \quad \{f(\alpha_1.sem, \ldots \alpha_n.sem)\}$$

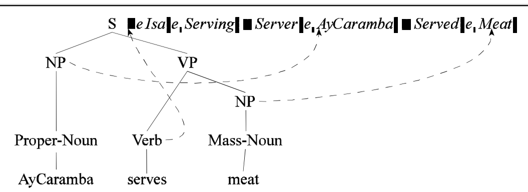
- This should be read as the semantics we attach to A can be computed from some function applied to the semantics of A's parts.

Augmented Rules

- As we'll see the class of actions performed by *f* in the following rule can be quite restricted.

$$A \rightarrow \alpha_1 \ldots \alpha_n \quad \{f(\alpha_1.sem, \ldots \alpha_n.sem)\}$$

Compositional Analysis



A 'Simple' Example

AyCaramba serves meat.

- Associating constants with constituents
  - ProperNoun → AyCaramba {AyCaramba}
  - MassNoun → meat {Meat}
- Defining functions to produce these from input
  - NP → ProperNoun {ProperNoun.sem}
  - NP → MassNoun {MassNoun.sem}
- Assumption: meaning reps of children are passed up to parents for non-branching constituents

- Verbs here are where the action is
  - V → serves { ∃ (e,x,y) Isa(e,Serving) ^ Server(e,x) ^ Served(e,y)}
  - Will every verb have its own distinct representation?
  - Predicate(Agent,Patient)…
- How do we combine these pieces?
  - VP → V NP {????}
  - Goal: ∃ (e,x) Isa(e,Serving) ^ Server(e,x) ^ Served(e,Meat)
  - S → NP VP {????}
  - Goal: ∃ (e) Isa(e,Serving) ^ Server(e, AyCaramba) ^ Served(e,Meat)
  - VP and S semantics must tell us
    - Which variables are to be replaced by which arguments?
    - How is this replacement done?

Lambda Notation

- Extension to FOPC
  - λ x P(x)
  - λ + variable(s) + FOPC expression in those variables
- Lambda binding
  - Apply lambda-expression to logical terms to bind lambda-expression's parameters to terms (lambda reduction)
  - Simple process: substitute terms for variables in lambda expression

    λxP(x)(car)

    P(car)

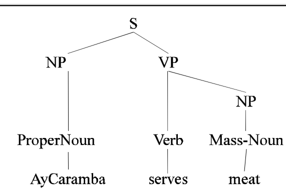
- Lambda notation provides requisite verb semantics
  - Formal parameter list makes variables within the body of the logical expression available for binding to external arguments provided by e.g. NPs
  - Lambda reduction implements the replacement
- Semantic attachment for grammar rules:
  - S → NP VP {VP.sem(NP.sem)}
  - VP → V NP {V.sem(NP.sem)}
  - V → serves {???}

  { ∃ (e,x,y) Isa(e,Serving) ^ Server(e,y) ^ Served(e,x)} becomes

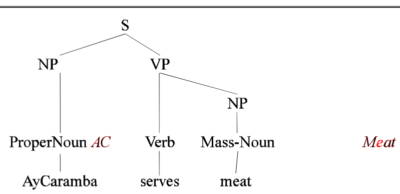
  {λy λx ∃ (e) Isa(e,Serving) ^ Server(e,x) ^ Served(e,y)}

  - Now 'x' is available to be bound when V.sem is applied to NP.sem, and 'y' is available to be bound when the S rule is applied.

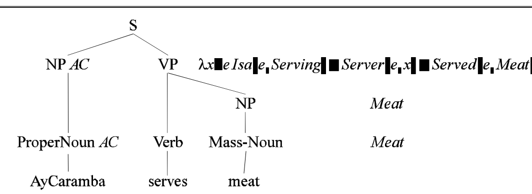
Example



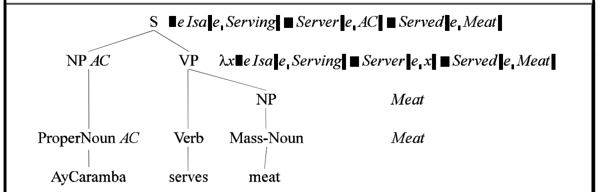
Example



Example



Example



Key Points

- Each node in a tree corresponds to a rule in the grammar
- Each grammar rule has a semantic rule associated with it that specifies how the semantics of the LHS of that rule can be computed from the semantics of its daughters.

Strong Compositionality

- The semantics of the whole is derived solely from the semantics of the parts.

  (i.e. we ignore what's going on in other parts of the tree).

Predicate-Argument Semantics

- The functions/operations permitted in the semantic rules fall into two classes
  - Pass the semantics of a daughter up unchanged to the mother
  - Apply (as a function) the semantics of one of the daughters of a node to the semantics of the other daughters

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

$$\exists x\ Isa(x, Restaurant)$$

- If we do the normal lambda thing we get

$$\exists e Serving(e) \wedge Server(e, \exists x Isa(x, Restaurant)) \wedge Served(e, Meat)$$

Complex Terms

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

```
Complex-Term → <Quantifier var body>
```

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

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Example

- Our restaurant example winds up looking like

$$\exists e Serving(e) \wedge Server(e, < \exists x Isa(x, Restaurant) >) \wedge Served(e, Meat)$$

- Big improvement…

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Conversion

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

P(<quantifier, var, body>)
`turns into`
Quantifier var body connective P(var)

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Example

$$Server(e, < \exists\, x\ Isa(x, \text{Restaurant}) >)$$
$$\Rightarrow$$
$$\exists\, x\ Isa(x, \text{Restaurant}) \wedge Server(e, x)$$

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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 -> (implies)

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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.

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Quantifier Ambiguity

- Consider
  - Every restaurant has a menu
  - Every restaurant has a beer.
  - I took a picture of everyone in the room.

  - That could mean that
    every restaurant has a menu
  - Or that
    There's some super-menu out there and all restaurants have that menu

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Quantifier Scope Ambiguity

$$\forall x Restaurant(x) \Rightarrow$$
$$\exists e, y Having(e) \wedge Haver(e,x) \wedge Had(e,y) \wedge Isa(y, Menu)$$

$$\exists y Isa(y, Menu) \wedge \forall x Isa(x, Restaurant) \Rightarrow$$
$$\exists e Having(e) \wedge Haver(e,x) \wedge Had(e,y)$$

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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

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Doing Compositional Semantics

- To incorporate semantics into grammar we must
  - Figure out right representation for a single constituent based on the parts of that constituent (e.g. Adj)
  - Figure out the right representation for a category of constituents based on other grammar rules making use of that constituent (e.g Nom→ Adj Nom)
- This gives us a set of function-like semantic attachments incorporated into our CFG
  - E.g. Nom → Adj Nom {λx Nom.sem(x) ^ Isa(x,Adj.sem)}

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What do we do with them?

- As we did with feature structures:
  - Alter an Early-style parser so when constituents (dot at the end of the rule) are completed, the attached semantic function is applied and a meaning representation created and stored with the state
- Or, let parser run to completion and then walk through resulting tree running semantic attachments from bottom-up

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Option 1 (Integrated Semantic Analysis)

S → NP VP {VP.sem(NP.sem)}
  - VP.sem has been stored in state representing VP
  - NP.sem has been stored with the state for NP
  - When rule completed, go get value of VP.sem, go get NP.sem, and apply VP.sem to NP.sem
  - Store result in S.sem.
- As fragments of input parsed, semantic fragments created
- Can be used to block ambiguous representations

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Drawback

- You also perform semantic analysis on orphaned constituents that play no role in final parse
- Hence, case for pipelined approach: Do semantics ***after*** syntactic parse
- But….

- Let's look at some other examples….

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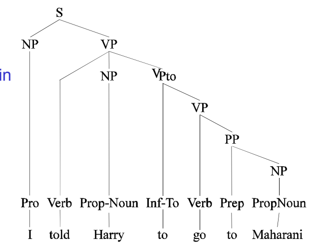
Harder Example

- What makes this hard?

- What role does Harry play in all this?



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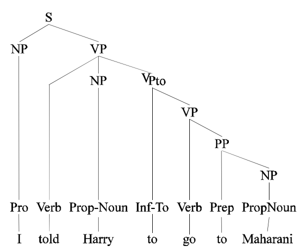
Harder Example

∃ e,f,x Isa(e, Telling) ^
Isa(f, Going) ^
Teller(e, Speaker) ^
Tellee(e, Harry) ^
ToldThing(e, f) ^
Goer(f, Harry) ^
Destination(f, x)



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Harder Example

- The VP for told is VP -> V NP VPto
  - So you do what?
    - Apply the semantic function attached to VPTO the semantics of the NP; this binds Harry as the goer of the going.
    - Then apply the semantics of the V to the semantics of the NP; this binds Harry as the Tellee of the Telling
    - And to the result of the first application to get the right value of the told thing.

    V.Sem(NP.Sem, VPto.Sem(NP.Sem))

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Harder Example

- That's a little messy and violates the notion that the grammar ought not to know much about what is going on in the semantics…
- Better might be
  - V.sem(NP.Sem, VPto.Sem) ????
  - VPto.sem(V.sem, NP.sem)???
  - i.e Apply the semantics of the head verb to the semantics of its arguments.
  - Complicate the semantics of the verb inside VPto to figure out what's going on.

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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 the work
2. Assume the syntax does know about meaning
   - Here the grammar gets complicated and the lexicon simpler

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Example

- Consider the attachments for the VPs

  VP -> Verb NP NP (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 attachments are:

  VP.Sem(NP.Sem, NP.Sem)

  VP.Sem(NP.Sem, PP.Sem)

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Example

- Under the 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.

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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

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Example

- From BERP
  - I want to eat someplace near campus
  - Somebody tell me the two meanings…

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Pros and Cons

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

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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

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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)

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

The Tip of the Iceberg

- Describing this particular 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

Constructional Approach

- Syntax and semantics aren't separable in the way that we've been assuming
- Grammars contain form-meaning pairings that vary in the degree to which the meaning of a constituent (and what constitutes a constituent) can be computed from the meanings of the parts.

Constructional Approach

- So we'll allow both

  VP → V NP {V.sem(NP.sem)}

  and

  VP → Kick-Verb the bucket {λ x Die(x)}

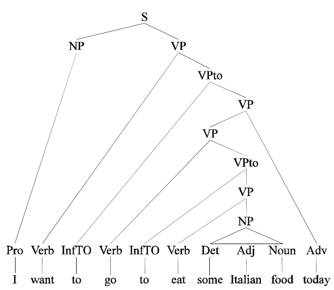
Computational Realizations

- Semantic grammars
  - Simple idea, dumb name
- Cascaded finite-state transducers
  - Just like Chapter 3

Semantic Grammars

- One problem with traditional grammars is that they don't necessarily reflect the semantics in a straightforward way
- You can deal with this by…
  - Fighting with the grammar
    - Complex lambdas and complex terms, etc
  - Rewriting the grammar to reflect the semantics
    - And in the process give up on some syntactic niceties

BERP Example



BERP Example

- How about a rule like the following…

```
Request → I want to go to eat FoodType Time
                    { some attachment }
```


Semantic Grammar

- The term semantic grammar refers to the motivation for the grammar rules
- The technology (plain CFG rules with a set of terminals) is the same as we've been using
- The good thing about them is that you get exactly the semantic rules you need
- The bad thing is that you need to develop a new grammar for each new domain

Semantic Grammars

- Typically used in conversational agents in constrained domains
  - Limited vocabulary
  - Limited grammatical complexity
  - Chart parsing (Earley) can often produce all that's needed for semantic interpretation even in the face of ungrammatical input.