Compositional Semantics: Quantification and Underspecification

COMP-599

Oct 29, 2015
Correction

Beta reduction/function application is left associative:
\[ x \ y \ z = ((x \ y) \ z) \]

Let’s redo the third case:
\[ (\lambda x. \ x \ x) \ (\lambda y. \ y \ x) \ z \]
Outline

Syntax-driven semantic composition
Quantifiers
Generalized quantifiers
Underspecification
Syntax-Driven Semantic Composition

Augment CFG trees with lambda expressions

- Syntactic composition = function application

Semantic attachments:

\[ A \rightarrow \alpha_1 \ldots \alpha_n \rightarrow \{ f(\alpha_j.sem, \ldots, \alpha_k.sem) \} \]

syntactic composition         semantic attachment
Proper Nouns

Proper nouns are FOL constants

\[ PN \rightarrow COMP599 \quad \{COMP599\} \]

Actually, we will **type-raise** proper nouns

\[ PN \rightarrow COMP599 \quad \{\lambda x. x(COMP599)\} \]

- It is now a function rather than an argument.
- We will see why we do this.

NP rule:

\[ NP \rightarrow PN \quad \{PN.sem\} \]
Common Nouns

Common nouns are predicates inside a lambda expression of type \( \langle e, t \rangle \)

- Takes an entity, tells you whether the entity is a member of that class

\[
N \rightarrow \text{student} \quad \{\lambda x. \text{Student}(x)\}
\]

Let’s talk more about common nouns next class when we also talk about quantifiers.
Intransitive Verbs

We introduce an event variable $e$, and assert that there exists a certain event associated with this verb, with arguments.

\[ V \rightarrow \text{rules} \quad \{ \lambda x. \exists e. \text{Rules}(e) \land \text{Ruler}(e, x) \} \]

Then, composition is

\[ S \rightarrow NP \; VP \quad \{ NP.\text{sem}(VP.\text{sem}) \} \]

Let’s derive the representation of the sentence “COMP-599 rules”
Neo-Davidsonian Event Semantics

Notice that we have changed how we represent events

**Method 1:** multi-place predicate

\[ \text{Rules}(x) \]

**Method 2:** Neo-Davidsonian version with event variable

\[ \exists e. \text{Rules}(e) \land \text{Ruler}(e, x) \]

Reifying the event variable makes things more flexible

- Optional elements such as location and time, passives
- Add information to the event variable about tense, modality
Transitive Verbs

Transitive verbs

\[ V \rightarrow enjoys \]
\[ \{ \lambda w. \lambda z. w(\lambda x. \exists e. \text{Enjoys}(e) \land \text{Enjoyer}(e, z) \land \text{Enjoyee}(e, x)) \} \]

\[ VP \rightarrow V \ NP \quad \{ V. \text{sem}(NP. \text{sem}) \} \]
\[ S \rightarrow NP \ VP \quad \{ NP. \text{sem}(VP. \text{sem}) \} \]

**Exercise:** verify that this works with the sentence “Jackie enjoys COMP-599”
Quantifiers

Universal quantifiers

• *all, every*

*All students like COMP-599.*

\[ \forall x. \text{Student}(x) \rightarrow \text{Like}(x, \text{COMP-599}) \]

Existential quantifiers

• *a, an, some*

*Some/A student likes COMP-599.*

\[ \exists x. \text{Student}(x) \land \text{Like}(x, \text{COMP-599}) \]

Why \( \rightarrow \) for the universal quantifier, but \( \land \) for the existential one?
Russell (1905)’s Definite Descriptions

How to express “the student” in FOL?

- e.g., *The student took COMP-599.*

Need to enforce three properties:

1. There is an entity who is the student.
2. There is at most one thing being referred to who is a student.
3. The student participates in some predicate, here, “*took COMP-599*.”
The King of France is Bald

Property 1 is important. Consider “The King of France is bald.”

Solution 1:

- Define a new constant for KING-OF-FRANCE, much like for proper nouns.

FOL MR becomes \textit{Bald}(\textit{KING–OF–FRANCE})

What is the problem with this solution?
Definite Articles

The student took COMP-599:

1. There is an entity who is the student.
2. There is at most one thing being referred to who is a student.
3. The student participates in some predicate.

What is the range of this existential quantifier?

$\exists x. \text{Student}(x) \land \forall y. (\text{Student}(y) \rightarrow y = x) \land \text{took}(x, \text{COMP-599})$

For simplicity, for now, assume took is a predicate, rather than use event variables.
Incorporating into Syntax

Now, let’s incorporate this to see how lambda calculus can deal with this compositionally.

Semantic attachment for lexical rule for *every*:

$\text{Det} \rightarrow \text{every} \quad \{\lambda P.\lambda Q.\forall x. P(x) \rightarrow Q(x)\}$

What do $P$ and $Q$ represent?
Every Student Likes COMP-599

\[ \text{Det} \rightarrow \text{every} \{ \lambda P. \lambda Q. \forall x. P(x) \rightarrow Q(x) \} \]

\[ \text{NP} \rightarrow \text{Det N} \{ \text{Det. sem}(N.\text{sem}) \} \]

Let’s do the derivation of *Every student likes COMP-599*.

Recall:

\[ \text{VP} \rightarrow V \text{ NP} \{ \text{V. sem}(\text{NP. sem}) \} \]

\[ S \rightarrow \text{NP VP} \{ \text{NP. sem}(\text{VP. sem}) \} \]

\[ V \rightarrow \text{likes} \]

\[ \{ \lambda w. \lambda z. w(\lambda x. \exists e. \text{Likes}(e) \land \text{Likerc}(e, z) \land \text{Likeee}(e, x)) \} \]

Using explicit event variables again.
Questions and Exercise

What are the lexical rules with semantic attachments for *a*? For *the*?

Come up with the derivation of *COMP-599* *likes every student*. 
Adjectives

Can we figure out the pattern for adjectives?

\[
\text{student} \quad \lambda x. \text{Student}(x)
\]

\[
\text{smart student} \quad \lambda x. \text{Smart}(x) \land \text{Student}(x)
\]

\[
\text{smart} \quad ?
\]

Also need an augmented rule for \( N \rightarrow A \; N \)
Scopal Ambiguity: Multiple Quantifiers

What are the possible readings for the following?

*Every student took a course.*

This is known as **scopal ambiguity**.
Scopal Ambiguity

Every student took a course.

\[ \text{every} > a \]
\[ \forall x. \text{Student}(x) \rightarrow (\exists y. \text{Course}(y) \wedge \exists e. \text{took}(e) \wedge \text{taker}(e, x) \wedge \text{takee}(e, y)) \]

\[ a > \text{every} \]
\[ \exists y. \text{Course}(y) \wedge (\forall x. \text{Student}(x) \rightarrow \exists e. \text{took}(e) \wedge \text{taker}(e, x) \wedge \text{takee}(e, y)) \]

Would like a way to derive both of these readings from the syntax. What would we get with our current method?
Underspecification

Solution: Derive a representation that allows for both readings

Underspecified representation – A meaning representation that can embody all possible readings without explicitly enumerating all of them.

Other cases where this is useful:

- We are genuinely missing some information (e.g., the tense information), so we choose not to include it in the meaning representation.
Cooper Storage (1983)

Associate a store with each FOL expression that allows both readings to be recovered.

*Every student took a course.*

\[
\exists e. \text{took}(e) \land \text{taker}(e, s_1) \land \text{takee}(e, s_2)
\]

\[
(\lambda Q. \forall x. \text{Student}(x) \to Q(x), 1),
\]

\[
(\lambda Q. \exists y. \text{Course}(y) \land Q(y), 2)
\]
Once we know which reading we want (e.g., by looking at the context), recover the store:

1. Select order to incorporate quantifiers
2. For each quantifier:
   • Introduce lambda abstraction over the appropriate index variable
   • Do beta-reduction
Example: 1, then 2

Every student took a course.

\[ \exists e. \text{took}(e) \land \text{taker}(e, s_1) \land \text{takee}(e, s_2) \]

\[ (\lambda Q. \forall x. \text{Student}(x) \rightarrow Q(x), 1), \]

\[ (\lambda Q. \exists y. \text{Course}(y) \land Q(y), 2) \]

1 first:

\[ (\lambda Q. \forall x. \text{Student}(x) \rightarrow Q(x)) \]

\[ (\lambda s_1. \exists e. \text{took}(e) \land \text{taker}(e, s_1) \land \text{takee}(e, s_2)) \]

\[ = \forall x. \text{Student}(x) \rightarrow \exists e. \text{took}(e) \land \text{taker}(e, x) \land \text{takee}(e, s_2) \]

Then 2:

\[ (\lambda Q. \exists y. \text{Course}(y) \land Q(y)) \]

\[ (\lambda s_2. \forall x. \text{Student}(x) \rightarrow \exists e. \text{took}(e) \land \text{taker}(e, x) \land \text{takee}(e, s_2)) \]

\[ = \exists y. \text{Course}(y) \land \forall x. \text{Student}(x) \rightarrow \exists e. \text{took}(e) \land \text{taker}(e, x) \land \text{takee}(e, y) \]
Compositional Rules

We also need new rules with semantic attachments for our quantifiers:

- Composing quantifier with N is now modifying the *inside* part of a store
- An NP is now introduces a new index variable, which is wrapped in a lambda expression
What is the semantic attachment for NP -> Det N? Use .sem.store to access the store.
Exercise

Finish the derivation for the underspecified representation of *Every student took a course.*

Recall:

\[ VP \rightarrow V \; NP \quad \{ V.sem(NP.sem) \} \]

\[ S \rightarrow NP \; VP \quad \{ NP.sem(VP.sem) \} \]

\[ V \rightarrow took \quad \{ \lambda w. \lambda z. w(\lambda x. \exists e. Took(e) \land Taker(e,z) \land Takeee(e,x)) \} \]

\[ Det \rightarrow every \quad \{ (\lambda P. \lambda Q. \forall x. P(x) \rightarrow Q(x)) \} \]

\[ N \rightarrow student \quad \{ \lambda x. Student(x) \} \]
Question

How would we disambiguate between the possible readings?
Machine Learning Approaches


Frame as a classification task. Higgins and Sadock investigate for two quantifiers, Manshadi and Allen extend it to > 2 quantifiers.
Higgins and Sadock

Class labels:

- 0  No scopal interaction
- 1  First quantifier > second quantifier
- 2  Second quantifier > first quantifier

Features

- POS tags
- Quantifiers themselves as lexical items
- Positions of the two relative to each other in the syntax tree, and the intervening nodes

Tried several standard classifiers (Naïve Bayes, MaxEnt (a.k.a. logical regression), perceptron)
Results

Table 7
Performance of the single-layer perceptron, summed over all 10 test runs.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Percentage correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>First has wide scope</td>
<td>182</td>
<td>99</td>
<td>182/281 = 64.8%</td>
</tr>
<tr>
<td>Second has wide scope</td>
<td>35</td>
<td>29</td>
<td>35/64 = 54.7%</td>
</tr>
<tr>
<td>No scope interaction</td>
<td>468</td>
<td>77</td>
<td>468/545 = 85.9%</td>
</tr>
<tr>
<td>Total</td>
<td>685</td>
<td>205</td>
<td>685/890 = 77.0%</td>
</tr>
</tbody>
</table>

Why is 77.0% perhaps a bit misleading?
Other Aspects of Semantics

Plurals; count vs. mass nouns
Tense, aspect, time
Modality
   Epistemic modality (how likely is something?)
   Deontic modality (you should or must do something)
Semantics beyond the sentence level
   Reference resolution (e.g., pronouns, anaphora)

There are formal analyses for all of these, and statistical models for most of them too (but some more than others).