Computational Linguistics: Semantics II

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Contents

1. Recall: Formal Semantics Main questions

The main questions are:

1. What does a given sentence mean?
2. How is its meaning built?
3. How do we infer some piece of information out of another?

1.1. Building Meaning Representations

To build a meaning representation we need to fulfill three tasks:

Task 1 Specify a reasonable **syntax** for the natural language fragment of interest.

Task 2 Specify semantic representations for the **lexical items**.

Task 3 Specify the **translation** of constituents **compositionally**. That is, we need to specify the translation of such expressions in terms of the translation of their parts, parts here referring to the substructure given to us by the syntax.

Moreover, when interested in Computational Semantics, all three tasks need to be carried out in a way that leads to computational implementation naturally.

1.2. Lambda-calculus: Functional Application

Summing up:

- FA has the form: Functor(Argument). E.g. $(\lambda x.love(x, mary))(john)$
- FA triggers a very simple operation: Replace the λ-bound variable by the argument. E.g. $(\lambda x.love(x, mary))(john) \Rightarrow love(john, mary)$

Exercise 1 and 2.

2. Extending the lexicon

Before we have left open the question of what does an expression like “a” contribute to?

FOL does not give us the possibility to express its meaning representation.

We will see now that instead lambda terms provide us with the proper expressivity.

2.1. Quantified NP

a) Every male student of the EM in LCT attends the Comp Ling course.

b) No male student of the EM in LCT attend the Logic course.

a) means that if Grady and Ha constitute the set of the male students of the EM in LCT, then it is true for both of them that they attend the Comp. Ling course.

b) means that for none of the individual members of the set of male students of the EM in LCT it is true that he attends the Logic course.

What is the interpretation of "every male student" and of "no male student"?

Individual constants used to denote specific individuals cannot be used to denote quantified expressions like "every man", "no student", "some friends".

Quantified-NPs like "every man", "no student", "some friends" are called non-referential.

2.2. Generalized Quantifiers

A Generalized Quantifier (GQ) is a set of properties, i.e. **a set of sets-of-individuals**.

For instance, "every man" denotes the set of properties that every man has. The property of "walking" is in this set iff every man walks. For instance,

$$
\begin{array}{lcl}
[\![\texttt{man}]\!] & = & \{a, b, c\}; \\
[\![\texttt{fat}]\!] & = & \{a, b, c, d\}; \\
[\![\texttt{dog}]\!] & = & \{d\}; \\
[\![\texttt{run}]\!] & = & \{a, b\}; \\
[\![\texttt{jump}]\!] & = & \{b, c, d\}; \\
[\![\texttt{laugh}]\!] & = & \{b, d\};
\end{array}
$$

Which is the interpretation of "every man"?

$$[\![\texttt{every man}]\!] = \{X | [\![\texttt{man}]\!] \subseteq X\} = \{\{a, b, c\}, \{a, b, c, d\}\} = \{[\![\texttt{man}]\!], [\![\texttt{fat}]\!]\}$$

2.3. Generalized Quantifiers

$$\begin{array}{lcl}
[\![\texttt{no man}]\!] & = & \{X \subseteq E \mid [\![\texttt{man}]\!] \cap X = \emptyset\}. \\
[\![\texttt{some man}]\!] & = & \{X \subseteq E \mid [\![\texttt{man}]\!] \cap X \neq \emptyset\}. \\
[\![\texttt{every man}]\!] & = & \{X \subseteq E \mid [\![\texttt{man}]\!] \subseteq X\}. \\
[\![\texttt{man which VP}]\!] & = & [\![\texttt{man}]\!] \cap [\![\texttt{VP}]\!].
\end{array}$$

Therefore, determiners are as below:

$$\begin{array}{lcl}
[\![\texttt{no N}]\!] & = & \{X \subseteq E \mid [\![\texttt{N}]\!] \cap X = \emptyset\}. \\
[\![\texttt{some N}]\!] & = & \{X \subseteq E \mid [\![\texttt{N}]\!] \cap X \neq \emptyset\}. \\
[\![\texttt{every N}]\!] & = & \{X \subseteq E \mid [\![\texttt{N}]\!] \subseteq X\}. \\
[\![\texttt{N which VP}]\!] & = & [\![\texttt{N}]\!] \cap [\![\texttt{VP}]\!].
\end{array}$$

Generalized quantifiers have attracted the attention of many researchers working on the interaction between logic and linguistics.

3. Determiners

Which is the lambda term representing quantifiers like “nobody”, “everybody”, “a man”or “every student” or a determiners like “a”, “every” or “no” ?

We know how to represent in FOL the following sentences

- “Nobody left”
  $\neg\exists x.\texttt{left}(x)$
- “Everybody left”
  $\forall x.\texttt{left}(x)$
- “Every student left”
  $\forall x.\texttt{Student}(x) \to \texttt{left}(x)$
- “A student left”
  $\exists x.\texttt{Student}(x) \wedge \texttt{left}(x)$
- “No student left”
  $\neg\exists x.\texttt{Student}(x) \wedge \texttt{left}(x)$

But how do we reach these meaning representations starting from the lexicon?

3.1. Determiners (cont'd)

Let's start representing "a man" as $\exists x.man(x)$. Applying the rules we have seen so far, we obtain that the representation of "A man loves Mary" is:

$$love(\exists x.man(x), mary)$$

which is clearly wrong.

Notice that $\exists x.man(x)$ just isn't the meaning of "a man". If anything, it translates the complete sentence "There is a man".

3.2. Determiners (Cont'd)

Let's start from what we have, namely "man" and "loves Mary":

$\lambda y.man(y)$, $\lambda x.love(x, mary)$.

Hence, the term representing "a" is:

$$\lambda X.\lambda Y.\exists z.X(z) \wedge Y(z)$$

Try to obtain the meaning representation for "a man", and the "a man loves Mary".

By β-conversion twice we obtain that "a man" is $\lambda Y.\exists z.\mathtt{Man}(z) \wedge Y(z)$, and then $\exists z.\mathtt{Man}(z) \wedge love(z, mary)$

4. Lambda terms and CFG

We will look at the compositional approach to the syntax-semantics interface and build the meaning representation in parallel to the syntactic tree. This reduces to have a **rule-to-rule** system, i.e. each syntactic rule correspond to a semantic rule.

Syntactic Rule 1 $S \rightarrow NP\ VP$

Semantic Rule 1 If the logical form of the NP is α and the logical form of the VP is β then the logical form for the S is $\beta(\alpha)$.

Syntactic Rule 2 $VP \rightarrow TV\ \ NP$

Semantic Rule 2 If the logical form of the TV is α and the logical form of the NP is β then the logical form for the VP is $\alpha(\beta)$.

4.1. Augumenting CFG with terms

That can also be abbreviated as below where γ, α and β are the meaning representations of S, NP and VP, respectively.

$$S(\gamma) \rightarrow NP(\alpha)\ VP(\beta) \qquad \gamma = \beta(\alpha)$$

This implies that lexical entries must now include semantic information. For instance, a way of writing this information is as below.

$$TV(\lambda x.\lambda y.wrote(y, x)) \rightarrow wrote$$

4.1.1. Exercise (a) Write the semantic rules for the following syntactic rules:

```
s --> np vp
vp --> iv
vp --> tv np
np --> det n
n --> adj n
n --> student
det --> a
adj --> tall
```

(b) apply these labeled rules to build the partial labeled parse trees for "A student" and "A tall student".

4.2. Quantified NP: class

In attempting to extend the technique of compositional semantics we run into problems with e.g. the rule for quantified noun phrases (QP).

QP should belong to the same category of noun phrases, as suggested by the substitution test or the coordination test. E.g.

1. I will bring here **every student** and **Mary**.
2. I will bring here **John** and Mary.

4.3. Quantified NP: terms and syntactic rules

We have seen that the term of a quantifier like "every student" is $\lambda Y.\forall z.Student(z) \rightarrow Y(z)$, which is of type $(e \rightarrow t) \rightarrow t$. Hence the sentence,

Every student left.

is obtained by applying the quantified noun phrase to the verb. In other words, if "Everybody" is of category NP we need the rule below:

$$S(\gamma) \rightarrow NP(\alpha)\ VP(\beta) \qquad \gamma = \alpha(\beta)$$

4.4. Quantified NP and Proper Nouns

This has brought semanticists to change the meaning representation of the noun phrase too, since they have to be of the same "sort". E.g, "John" could be represented as

$$\lambda X.X(john)$$

a function of the same type as the quantified NP, i.e. $(e \to t) \to t$.

ie., what would be its set-theoretical meaning?

5. Practical info

Lab on Prolog: Next week two hours instead of tomorrow?!