Semantics and Pragmatics of NLP
The Semantics of Discourse: Overview

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Outline

1. Shortcoming of FOL approaches to semantics
   - Anaphora across sentence boundaries

2. Changing the Approach: Discourse Representation Theory
   - A new way of constructing LF
   - A new way of interpreting LF
Motivation for DRT

Pronouns:

(1) John owns a car. It is red.

\[
\exists x (\text{CAR}(x) \land \text{OWN}(j, x)) \land \text{RED}(y)
\]

Wrong:

complex construction:

\[
\exists x (\text{CAR}(x) \land \text{OWN}(j, x) \land \text{RED}(x))
\]

Problems with:

(2) John doesn’t own a car. ??It is red.

\[
\neg \exists x (\text{CAR}(x) \land \text{OWN}(j, x) \land \text{RED}(x))
\]

Not recording the right relationship between meaning and context.
More Problems: Time

(3) John entered the room. He sat down. He lit a cigarette. It was pitch dark.

Talking about Time: (sentences true or false at a time)

\[ M \models_t P\phi \] iff there is a time \( t' \prec t \) and \( M \models_{t'} \phi \)

\[ M \models_t F\phi \] iff there is a time \( t' \succ t \) and \( M \models_{t'} \phi \)

Wrong:

\[ Ps_1 \land Ps_2 \]

Wrong and complex construction:

\[ P(s_1 \land Fs_2) \]

Complex construction:

\[ P(Ps_1 \land s_2) \]

And what about difference between events and states??

Not recording the right relationship between meaning and context
More Problems: Presuppositions

Interferes with compositionality of LF construction:

(4) John’s son is bald.
(5) If baldness is hereditary, then John’s son is bald.
(6) If John has a son, then John’s son is bald.

These are all examples of anaphora.
When we utter *A woman snorts*, we don’t simply make a claim about the world, we also *change the context in which subsequent utterances are interpreted*.

**Anaphora**: semantics involving a relationship between what the anaphor denotes and an *antecedent* in that context.

- For pronouns the relationship is =

The structure of the context constrains what can, and cannot, be antecedents ((1) vs. (2)).
John owns a car. It is red

- Start a new discourse with an empty box:

- expand this box with information from the first sentence:

  | x, y |
  | john(x), car(y) |
  | own(x, y) |

  ⇐ discourse referents: Things the discourse is about.
  ⇐ conditions: relations and properties among discourse referents.

Proper names are now conditions; so all NPs introduce a discourse referent and the Nbar introduces conditions on it.
Processing the Second Sentence

*John owns a car. It is red*

- Pronoun is an NP, and so like all NPs it introduces a new discourse referent \( z \).
- The VP contributes \( \text{red}(z) \) (as before).
- Pronouns are special! They introduce an equality condition to a discourse referent (of same number and gender) in the context:

<table>
<thead>
<tr>
<th></th>
<th>x, y, z</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>John</strong></td>
<td>john(x),</td>
</tr>
<tr>
<td><strong>owns</strong></td>
<td>own(x, y)</td>
</tr>
<tr>
<td><strong>car</strong></td>
<td></td>
</tr>
<tr>
<td><strong>is red</strong></td>
<td>red(z),</td>
</tr>
</tbody>
</table>

- So \( z=y \):
LF Construction has Changed!

Before:

**Compositionality:** the contribution to LF of an NL expression determined entirely by the contributions of its (syntactic) daughters.

Now:

- Adding \( z=y \) is *not* compositional!
- Construction now depends on what’s already in the box, and not just on syntax.
- This accurately reflects the fact that the meaning of a pronoun is dependent on context.
Negation

\textit{John doesn’t own a car. It is red}

- Use $\neg$ to indicate what’s false:

\[
\begin{array}{c}
  x \\
  \hline
  \text{john}(x) \\
  \hline
  y \\
  \hline
  \neg \text{car}(y) \\
  \hline
  \neg \text{own}(x, y)
\end{array}
\]

- So we get boxes inside boxes!
The antecedent discourse referent for a pronoun must be introduced in the same box or a ‘bigger’ box.

*It is red* is *outside* the negation; *y* is *inaccessible* and pronoun is uninterpretable.

Construction is dependent on *form*; not on interpretation.
Important things we’ll ignore for now

Selectional restrictions:

(7) John petted his cat. He purred affectionately.

Coherence:

(8) John can open Bill’s safe. He knows the combination.

Will also gloss over grammatical constraints:

- *John loves him_{john}
- John buys a new car every year. It is/They are always red.
- John buys a new car every year. Last year it was/*they were red.

Want to focus on the interaction between anaphora and logical structure: *not, if. . . then*, quantifiers etc.
Why use the funny box notation?

Answers:

- One can translate certain DRS fragments into FOL with discourse referents being free variables.
- BUT:
  - If one did this during LF construction, then the hierarchical structure of DRSs would be lost, and this plays an important part in constraining how to insert new material.
  - It’s more convenient to use the box notation.
(9) Every farmer who owns a donkey beats it.

\[
\begin{array}{c|c|c}
  x, y & \text{farmer}(x) & \text{donkey}(y) \\
  \text{owns}(x, y) & \Rightarrow & \text{beats}(x, y)
\end{array}
\]
(10) A farmer owns a donkey.
\[ \exists x \exists y \left( \text{FARMER}(x) \land \text{DONKEY}(y) \land \text{OWN}(x, y) \right) \]

\[ \begin{array}{|c|}
\hline
x, y \\
\hline
\text{farmer}(x) \\
\text{donkey}(y) \\
\text{own}(x, y) \\
\hline
\end{array} \]

(11) It’s not the case that all farmers don’t own a donkey.
\[ \neg \forall x \left( \text{FARMER}(x) \rightarrow \neg \exists y \left( \text{DONKEY}(y) \land \text{OWN}(x, y) \right) \right) \]

\[ \begin{array}{|c|}
\hline
\neg \\
\hline
x \\
\text{farmer}(x) \\
\hline
\Rightarrow \\
\hline
y \\
\text{donkey}(y) \\
\text{own}(x, y) \\
\hline
\end{array} \]
DRS Languages

- DRSs can be nested and combined using ¬, ∨, ⇒.
  - if $K_1$ and $K_2$ are DRSs, then $\neg K_1$, $K_1 \lor K_2$ and $K_1 \Rightarrow K_2$ are DRS conditions.

- They also contain predicate symbols (e.g., woman, love), like FOL does.
  - $\text{woman}(x)$ and $\text{love}(x,y)$ are atomic DRS conditions

- DRS languages contain symbols $x, y, \ldots$, they’re called discourse referents, not variables.

- (Vanilla) DRS languages don’t contain $\forall$ or $\exists$.
  - Quantification is implicit, in the semantics of DRSs
Informal Semantics: Boxes as Pictures

A DRS is *satisfied* in a model iff it is an accurate image of the information recorded inside the model.

*A woman snorts. She collapses.*

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>woman(x)</td>
<td>snort(x)</td>
</tr>
<tr>
<td>collapse(y), x=y</td>
<td></td>
</tr>
</tbody>
</table>

is satisfied iff it is possible to associate the discourse referents x and y with entities in the model such that:

1. the first entity is a woman and snorts
2. the second entity collapses and is equal to the first entity.
More Informal Semantics: Complex Conditions

**Negated DRS:** satisfied iff it is *not* possible to find the picture inside the model.

**Disjunctive DRSs:** satisfied iff at least one of the pictures can be found in the model.

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>man(x)</td>
<td>woman(y)</td>
</tr>
</tbody>
</table>

\[ x \Rightarrow y \]

\[ \text{love}(x,y) \]

No matter which entities we use to verify the antecedent picture, we can verify the consequent picture (with those entities plus others).
Accessibility

- It’s a *geometrical* concept: configuration of DRSs; how they’re nested.
- Discourse referents introduced in DRS $K_1$ are accessible to (anaphoric) conditions in DRS $K_2$ iff $K_1$ *subordinates* $K_2$ or $K_1$ *equals* $K_2$. 
So what’s Subordination then?

$K_1$ subordinates $K_2$ iff:

1. $K_1$ contains the DRS condition $\neg K_2$; or
2. $K_1$ contains the DRS condition $K_2 \Rightarrow K$ or $K \Rightarrow K_2$; or
3. $K_1$ contains the DRS condition $K_2 \lor K$ or $K \lor K_2$; or
4. $K$ contains the condition $K_1 \Rightarrow K_2$; or
5. $K_1$ subordinates $K$ and $K$ subordinates $K_2$ (transitive closure).
To see if $K_1$ subordinates $K_2$

1. Start at $K_2$;
2. If there’s a DRS immediately to your left, move to that.
3. If not, but there’s a DRS immediately up, move to that.
4. else, stop.

if $K_1$ is on this path, then $K_1$ subordinates $K_2$
Starting at k6...

Path is: k6, k2, k1
So discourse referents introduced in k5, k4 and k3 would be *inaccessible* to conditions in k6.
Another Example

<table>
<thead>
<tr>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>John(x)</td>
</tr>
<tr>
<td>y, z</td>
</tr>
<tr>
<td>woman(y)</td>
</tr>
<tr>
<td>man(z)</td>
</tr>
</tbody>
</table>

\[ \neg \text{dog}(u) \]
\[ \text{owns}(x, u) \]

\[ \Rightarrow \]
\[ \text{love}(z, y) \]

<table>
<thead>
<tr>
<th>w</th>
</tr>
</thead>
<tbody>
<tr>
<td>parakeet(w)</td>
</tr>
<tr>
<td>own(u, w)</td>
</tr>
</tbody>
</table>

\[ \Rightarrow \]
\[ \text{love}(x, v) \]

\[ \text{cat}(v) \]
\[ \text{owns}(y, v) \]

\[ \Rightarrow \]

\[ \text{love}(x, v) \]

\[ x, y, z, w \text{ and } v \text{ are accessible to } \text{love}(x, v) \]
\[ u \text{ isn’t accessible to } \text{love}(x, v) \]
\[ x, y \text{ and } z \text{ are accessible to } \text{love}(z, y) \]
\[ u, w \text{ and } v \text{ are not accessible to } \text{love}(z, y) \]
An Inaccessible Pronoun

*John doesn’t own a car. It is red*

(One of) the DRSs for *John doesn’t own a car*:

<table>
<thead>
<tr>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>john(x)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>car(y)</td>
</tr>
<tr>
<td>own(x,y)</td>
</tr>
</tbody>
</table>

The DRS for *It is red*:

<table>
<thead>
<tr>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>red(z)</td>
</tr>
<tr>
<td>z=?</td>
</tr>
</tbody>
</table>

z=?: an instruction to resolve the equality with something accessible.
The LF of the Discourse: Merge plus resolution

Merge:

\[
\begin{array}{c|c|c}
\text{x} & & \\
\hline
\text{john(x)} & y &  \\
\text{\neg} & \text{car(y)} & \text{own(x,y)} \\
\end{array}
\oplus
\begin{array}{c|c|c}
\text{z} & & \\
\hline
\text{\neg} & \text{red(z)} & z=? \\
\end{array}
= \\
\begin{array}{c|c|c}
\text{x,z} & & \\
\hline
\text{john(x)} & y &  \\
\text{\neg} & \text{car(y)} & \text{own(x,y)} \\
\text{\neg} & \text{red(z)} & z=? \\
\end{array}
\]

Resolving z=?:
\[
x \text{ is accessible, but wrong gender...}
\]
More Discourses that DRT ‘gets right’

(12) Mia ordered a five dollar shake. Vincent tasted it.
(13) Mia didn’t order a five dollar shake. ??Vincent tasted it.
(14) Butch stole a chopper. It belonged to Zed.
(15) Butch stole a chopper or a motor cycle. ??It belonged to Zed.
(16) If a boxer loves a woman she is happy.
(17) Every woman snorts. ??She collapses.
Conclusion

- FOL as a semantic representation of NL discourse is problematic because when dealing with *anaphora*, either:
  - it gets the truth conditions wrong, and/or
  - LF construction would be really complicated
- DRSs potentially fare better, because they:
  - Offer a story about how things like negation and conditionals block things from being antecedents to anaphora
  - Through merging DRSs and making pronouns look for antecedents, LF construction may turn out OK too.
- But we will see how LF construction is done next time.