CMPT-825
Natural Language Processing

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Prepositional Phrases

- noun attach: *I bought the shirt with pockets*
- verb attach: *I washed the shirt with soap*
- As in the case of other attachment decisions in parsing: it depends on the meaning of the entire sentence – needs world knowledge, etc.
- Maybe there is a simpler solution: we can attempt to solve it using heuristics or associations between words
Right association: a constituent (NP or PP) tends to attach to another constituent immediately to its right (Kimball 1973)

Minimal attachment: a constituent tends to attach to an existing non-terminal using the fewest additional syntactic nodes (Frazier 1978)

These two principles make opposite predictions for prepositional phrase attachment

Consider the grammar:

\[
\begin{align*}
VP & \rightarrow V \ NP \ PP \\
NP & \rightarrow NP \ PP
\end{align*}
\]

for input: *I [VP saw [NP the man ... [PP with the telescope ]]*, RA predicts that the PP attaches to the NP, i.e. use rule (2), and MA predicts V attachment, i.e. use rule (1)
Structure Based Ambiguity Resolution

- Garden-paths look structural:
  *The emergency crews hate most is domestic violence*

- Neither MA or RA account for more than 55% of the cases in real text

- Psycholinguistic experiments using eyetracking show that humans resolve ambiguities as soon as possible in the left to right sequence using the words to disambiguate

- Garden-paths are caused by a combination of lexical and structural effects:
  *The flowers delivered for the patient arrived*
Learning Prepositional Phrase Attachment: Annotated Data

<table>
<thead>
<tr>
<th>v</th>
<th>n1</th>
<th>p</th>
<th>n2</th>
<th>Attachment</th>
</tr>
</thead>
<tbody>
<tr>
<td>join</td>
<td>board</td>
<td>as</td>
<td>director</td>
<td>V</td>
</tr>
<tr>
<td>is</td>
<td>chairman</td>
<td>of</td>
<td>N.V.</td>
<td>N</td>
</tr>
<tr>
<td>using</td>
<td>crocidolite</td>
<td>in</td>
<td>filters</td>
<td>V</td>
</tr>
<tr>
<td>bring</td>
<td>attention</td>
<td>to</td>
<td>problem</td>
<td>V</td>
</tr>
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<td>is</td>
<td>asbestos</td>
<td>in</td>
<td>products</td>
<td>N</td>
</tr>
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<td>paper</td>
<td>for</td>
<td>filters</td>
<td>N</td>
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<tr>
<td>including</td>
<td>three</td>
<td>with</td>
<td>cancer</td>
<td>N</td>
</tr>
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</table>

... ... ... ... ...

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## Prepositional Phrase Attachment

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always noun attachment</td>
<td>59.0</td>
</tr>
<tr>
<td>Most likely for each preposition</td>
<td>72.2</td>
</tr>
<tr>
<td>Average Human (4 head words only)</td>
<td>88.2</td>
</tr>
<tr>
<td>Average Human (whole sentence)</td>
<td>93.2</td>
</tr>
</tbody>
</table>
Let 1 represent noun attachment.

We want to compute probability of noun attachment:
\[ p(1 \mid v, n1, p, n2). \]

Probability of verb attachment is \( 1 - p(1 \mid v, n1, p, n2). \)
Back-off Smoothing

1. If $f(v, n1, p, n2) > 0$ and $\hat{p} \neq 0.5$
   \[
   \hat{p}(1 \mid v, n1, p, n2) = \frac{f(1, v, n1, p, n2)}{f(v, n1, p, n2)}
   \]

2. Else if $f(v, n1, p) + f(v, p, n2) + f(n1, p, n2) > 0$ and $\hat{p} \neq 0.5$
   \[
   \hat{p}(1 \mid v, n1, p, n2) = \frac{f(1, v, n1, p) + f(1, v, p, n2) + f(1, n1, p, n2)}{f(v, n1, p) + f(v, p, n2) + f(n1, p, n2)}
   \]

3. Else if $f(v, p) + f(n1, p) + f(p, n2) > 0$
   \[
   \hat{p}(1 \mid v, n1, p, n2) = \frac{f(1, v, p) + f(1, n1, p) + f(1, p, n2)}{f(v, p) + f(n1, p) + f(p, n2)}
   \]

4. Else if $f(p) > 0$
   \[
   \hat{p}(1 \mid v, n1, p, n2) = \frac{f(1, p)}{f(p)}
   \]

5. Else $\hat{p}(1 \mid v, n1, p, n2) = 1.0$
Prepositional Phrase Attachment: (Collins and Brooks 1995)

- **Results:** 84.5% accuracy with the use of some limited word classes for dates, numbers, etc.
- Using complex word classes taken from WordNet (which we shall be looking at later in this course) increases accuracy to 88% (Stetina and Nagao 1998)
- We can improve on parsing performance with Probabilistic CFGs by using the insights taken from PP attachment.
- Modify the PCFG model to be sensitive to words and other context-sensitive features of the input.
- And generalizing to other kinds of attachment problems, like coordination or deciding which constituent is an argument of a verb.
Some other studies

- **Toutanova, Manning, and Ng, 2004:** use sophisticated smoothing model for PP attachment
  86.18% with words & stems; with word classes: 87.54%

- **Merlo, Crocker and Berthouzoz, 1997:** test on multiple PPs, generalize disambiguation of 1 PP to 2-3 PPs
  14 structures possible for 3PPs assuming a single verb: all 14 are attested in the Treebank
  same model as CB95; but generalized to dealing with upto 3PPs
  1PP: 84.3%  2PP: 69.6%  3PP: 43.6%

Note that this is still not the real problem faced in parsing natural language