Multilevel Coarse-to-Fine PCFG Parsing

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Statistical Parsing Speed

• Lexicalized statistical parsing can be slow.
  – Charniak: 0.7 seconds per sentence.

• Real applications demand more speed!
  – Large corpora, eg. NANTC (McClosky, Charniak and Johnson 2006)
  – More words to consider-- lattices from speech recognition (Hall and Johnson 2004)
  – Costly second stage such as question answering.
**Bottom-up Parsing I**

- Standard probabilistic CKY chart parsing.
  - Computes the inside probability $\beta$ for each constituent.

```
Constit Length | The constituent
---------------|-------------------
 4 wds         | (VP (VBZ plays) (NP (NNP Elianti)))
 3 wds         | S1 S S1 S          
 2 wds         | NP S1 S            
 1 wd          | NP VP              
 1 wd          | NP VP              
 1 wd          | (VBZ plays) NP     
 1 wd          | (NNP Elianti)      
```

Beginning word
Some constituents are **gold constituents** (parts of correct parse).

- These may not be part of the highest probability (Viterbi) parse.
- We can use a reranker to try to pick them out later on.
Pruning

- We want to dispose of the incorrect constituents and retain the gold.

- Initial idea: prune **constituents with low probability** (~ outside α times inside β).
  
  \[ p(n_{i,j}^k | s) = \frac{\alpha(n_{i,j}^k)\beta(n_{i,j}^k)}{p(s)} \]

<table>
<thead>
<tr>
<th>POS</th>
<th>4 wds</th>
<th>3 wds</th>
<th>2 wds</th>
<th>1 wd</th>
<th>POS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1 S</td>
<td>S1 S</td>
<td>S1 S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NNP Ms.</td>
<td></td>
<td>S1 S</td>
<td>S1 S</td>
<td>S VP</td>
<td></td>
</tr>
<tr>
<td>(NNP Haag)</td>
<td>S1 S</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(VBZ plays)</td>
<td>NP</td>
<td>VP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NNP Elianti)</td>
<td>NP</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Outside Probabilities

• We need the full parse of the sentence to get outside probability $\alpha$.
  
  – Estimates how well the constituent contributes to spanning parses for the sentence.

\[
\begin{array}{c}
S1 S \\
\alpha \approx 1 \\
S1 S \\
\alpha \approx 0
\end{array}
\]

• Caraballo and Charniak (1998): agenda reordering method-- proper pruning needs an approximation of $\alpha$.
  
  – Approximated $\alpha$ using ngrams at constituent boundaries.
**Coarse-to-Fine Parsing**

- Parse quickly with a smaller grammar.

<table>
<thead>
<tr>
<th></th>
<th>4 wds</th>
<th>3 wds</th>
<th>2 wds</th>
<th>1 wd</th>
<th>POS</th>
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</thead>
<tbody>
<tr>
<td><strong>S1 P</strong></td>
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<td></td>
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<tr>
<td><strong>S1 P</strong></td>
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<td></td>
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<tr>
<td><strong>P</strong></td>
<td><strong>S1 P</strong></td>
<td><strong>P</strong></td>
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<td></td>
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</tr>
<tr>
<td><strong>P</strong></td>
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<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td></td>
</tr>
<tr>
<td><strong>POS</strong></td>
<td><strong>(NNP Ms.)</strong></td>
<td><strong>(NNP Haag)</strong></td>
<td><strong>(VBZ plays)</strong></td>
<td><strong>(NNP Elianti)</strong></td>
<td></td>
</tr>
</tbody>
</table>

- Now calculate $\alpha$ using the full chart.

<table>
<thead>
<tr>
<th></th>
<th>4 wds</th>
<th>3 wds</th>
<th>2 wds</th>
<th>1 wd</th>
<th>POS</th>
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<tr>
<td><strong>S1 P</strong></td>
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<tr>
<td><strong>S1 P</strong></td>
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<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td><strong>POS</strong></td>
</tr>
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<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td></td>
</tr>
<tr>
<td><strong>P</strong></td>
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<td></td>
<td></td>
<td><strong>POS</strong></td>
</tr>
<tr>
<td><strong>POS</strong></td>
<td><strong>(NNP Ms.)</strong></td>
<td><strong>(NNP Haag)</strong></td>
<td><strong>(VBZ plays)</strong></td>
<td><strong>(NNP Elianti)</strong></td>
<td></td>
</tr>
</tbody>
</table>
Coarse-to-Fine Parsing II

- Prune the chart, then reparse with a more specific grammar.

- Repeat the process until the final grammar is reached.

- Reduces the cost of a high grammar constant.

<table>
<thead>
<tr>
<th>POS</th>
<th>1 wd</th>
<th>2 wds</th>
<th>3 wds</th>
<th>4 wds</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>N_</td>
<td>N_</td>
<td>S</td>
<td>S1 S_</td>
</tr>
<tr>
<td>(NNP)</td>
<td>(NNP</td>
<td>(NNP</td>
<td>(NNP</td>
<td>(NNP</td>
</tr>
<tr>
<td>Ms.)</td>
<td>Haag)</td>
<td>Elianti)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(VBZ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NNP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elianti</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Related Work

• Two-stage parsers:
  – Maxwell and Kaplan (1993); automatically extracted first stage
  – Goodman (1997); first stage uses regular expressions
  – Charniak (2000); first stage is unlexicalized

• Agenda reordering:
  – Klein and Manning (2003); A* search for the best parse using an upper bound on $\alpha$.
  – Tsuruoka and Tsujii (2004); iterative deepening.
Parser Details

- Binarized grammar based on Klein and Manning (2003)
  - Head annotation.
  - Vertical (parent) and horizontal (sibling) Markov context.
Coarse-to-Fine Scheme

S1

S1 S_ N_

S1 S VP UCP SQ SBAR SBARQ NP NAC NX LST X UCP FRAG ADJP QP CONJP ADVP INTJ PRN PRT PP PRT RRC WHADJP WHADVP WHNP WHPP
Examples

Level 0

Level 1

Level 2

Level 3
(Treebank)
Coarse-to-Fine Probabilities

Heuristic probabilities:

\[ P(N_\_ \rightarrow N_\_ P\_) = \text{weighted-avg}(\]
\[ P(NP \rightarrow NP \ PP) \]
\[ P(NP \rightarrow NP \ PRT) \]
\[ ... \]
\[ P(NP \rightarrow NAC \ PP) \]
\[ P(NP \rightarrow NAC \ PRT) \]
\[ ... \]
\[ P(NAC \rightarrow NP \ PP) \]
\[ ... \) \]

Using \textbf{max} instead of \textbf{avg} computes an exact upper bound instead of a heuristic (Geman and Kochanek 2001).

No smoothing needed.
Pruning Thresholds

Pruning threshold vs. probability of pruning a gold constituent

Threshold vs. fraction of incorrect constituents remaining.

![Graph 1: Pruning threshold vs. probability of pruning a gold constituent](image1)

![Graph 2: Threshold vs. fraction of incorrect constituents remaining](image2)
## Pruning Statistics

<table>
<thead>
<tr>
<th>Levels</th>
<th>Constits Produced (millions)</th>
<th>Constits Pruned (millions)</th>
<th>% Pruned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>8.82</td>
<td>7.55</td>
<td>86.5</td>
</tr>
<tr>
<td>Level 1</td>
<td>9.18</td>
<td>6.51</td>
<td>70.8</td>
</tr>
<tr>
<td>Level 2</td>
<td>11.2</td>
<td>9.48</td>
<td>84.4</td>
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<tr>
<td>Level 3</td>
<td>11.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>40.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Level 3 only</td>
<td>392</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
## Timing Statistics

<table>
<thead>
<tr>
<th>Level</th>
<th>Time At Level</th>
<th>Cumulative Time</th>
<th>F-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>1598</td>
<td>1598</td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>2570</td>
<td>4164</td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>4303</td>
<td>8471</td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td>1527</td>
<td><strong>9998</strong></td>
<td>77.9</td>
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<tr>
<td>Level 3 only</td>
<td><strong>114654</strong></td>
<td>-</td>
<td>77.9</td>
</tr>
</tbody>
</table>

10x speed increase from pruning.
Discussion

• No loss in f-score from pruning.

• Each pruning level is useful.
  – Prunes ~80% of constituents produced.

• Pruning at level 0 (only two nonterminals, S1 / P)
  – Preterminals are still useful.
  – Probability of $\textbf{P-IN} \rightarrow \textbf{NN IN}$
    (a constituent ending with a preposition)
    will be very low.
Conclusion

- Multi-level coarse-to-fine parsing allows bottom-up parsing to use top-down information.
  - Deciding on good parent labels.
  - Using the string boundary.
- Can be combined with agenda reordering methods.
  - Use coarser levels to estimate outside probability.
- More stages of parsing can be added.
  - Lexicalization.
Future Work

• The coarse-to-fine scheme we use is hand-generated.

• A coarse-to-fine scheme is just a hierarchical clustering of constituent labels.
  – Hierarchical clustering is a well-understood task.
  – Should be possible to define an objective function and search for the best scheme.
  – Could be used to automatically find useful annotations/lexicalizations.
Acknowledgements

- Class project for CS 241 at Brown University
- Funded by:
  - Darpa GALE
  - Brown University fellowships
  - Parents of undergraduates
- Our thanks to all!