Natural Language Processing

Lecture 15—10/15/2015
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Today

- Start on Parsing
  - Parsing frameworks
  - CKY

Treebanks

- Treebanks are corpora in which each sentence has been paired with a parse tree (presumably the right one).
- These are generally created
  1. By first parsing the collection with an automatic parser
  2. And then having human annotators hand correct each parse as necessary.
- This generally requires detailed annotation guidelines that provide a POS tagset, a grammar, and instructions for how to deal with particular grammatical constructions.

Penn Treebank

- Penn TreeBank is a widely used treebank.

Most well known part is the Wall Street Journal section of the Penn TreeBank.

- 1 M words from the 1987-1989 Wall Street Journal.

```
( (S (`` ``)
    (S-TPC-2
      (NP-SBJ-1 (PRP We) )
      (VP (MD would)
        (VP (VB have)
          (S
            (NP-SBJ (-NONE- *-1) )
            (VP (TO to)
              (VP (VB wait)
                (SBAR-TMP (IN until)
                  (S
                    (NP-SBJ (PRP we) )
                    (VP (VBP have)
                      (VP (VBN collected)
                        (PP-CLR (IN on)
                          (NP (DT those)(NNS assets))))))))))))
    (, ,) (`` ``)
    (NP-SBJ (PRP he) )
    (VP (VBD said)
      (S (-NONE- *T*-2) ))
    (. .) ))
```


Treebank Grammars

- Treebanks implicitly define a grammar for the language covered in the treebank.
- Simply take the local rules that make up the sub-trees in all the trees in the collection and you have a grammar
  - The WSJ section gives us about 12k rules if you do this
- Not complete, but if you have decent size corpus, you will have a grammar with decent coverage.

Treebank Grammars

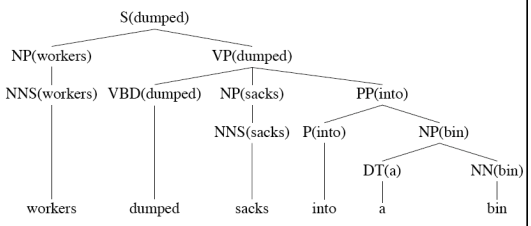
- Such grammars tend to be very flat due to the fact that they tend to avoid recursion.
  - To ease the annotators burden, among things
- For example, the Penn Treebank has ~4500 different rules for VPs. Among them...

```
VP → VBD PP
VP → VBD PP PP
VP → VBD PP PP PP
VP → VBD PP PP PP PP
```

Head Finding

- Finding heads in treebank trees is a task that arises frequently in many applications.
  - As we'll see it is particularly important in statistical parsing
- We can visualize this task by annotating the nodes of a parse tree with the heads of each corresponding node.

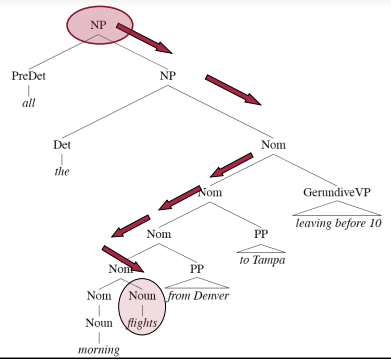
Lexically Decorated Tree



Head Finding

- Given a tree, the standard way to do head finding is to use a simple set of tree traversal rules specific to each non-terminal in the grammar.

Noun Phrases



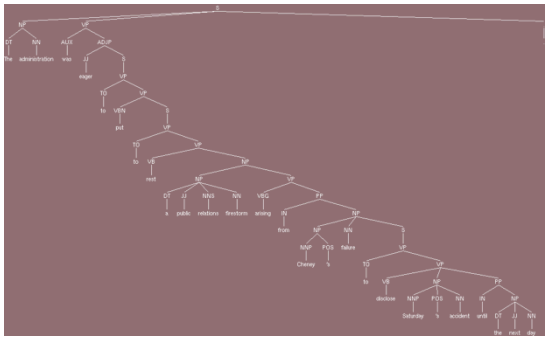
Treebank Uses

- Treebanks (and head-finding) are particularly critical to the development of statistical parsers
  - Chapter 14
- Also valuable to *Corpus Linguistics*
  - Investigating the empirical details of various constructions in a given language

Parsing

- Parsing with CFGs refers to the task of assigning proper trees to input strings
- Proper here means a tree that covers all and only the elements of the input and has an S at the top
- It doesn't mean that the system can select the correct tree from among all the possible trees

Automatic Syntactic Parse



For Now

- Let's assume…
  - You have all the words for a sentence already in some buffer
  - The input is not POS tagged prior to parsing
  - We won't worry about morphological analysis
  - All the words are known
- These are all problematic in various ways, and would have to be addressed in real applications.

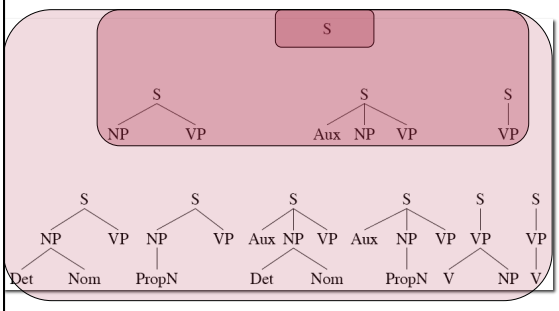
Search Framework

- It's productive to think about parsing as a form of search…
  - A search through the space of possible trees given an input sentence and grammar
  - This framework suggests that heuristic search methods and/or dynamic programming methods might be applicable
  - It also suggests that notions such as the direction of the search might be useful

Top-Down Search

- Since we're trying to find trees rooted with an *S* (Sentences), why not start with the rules that give us an *S*.
- Then we can work our way down from there to the words.

Top Down Space



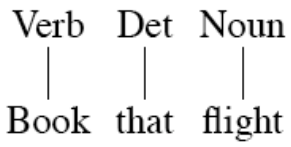
Bottom-Up Parsing

- Of course, we also want trees that cover the input words. So we might also start with trees that link up with the words in the right way.
- Then work your way up from there to larger and larger trees.

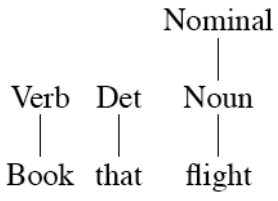
Bottom-Up Search

Book that flight

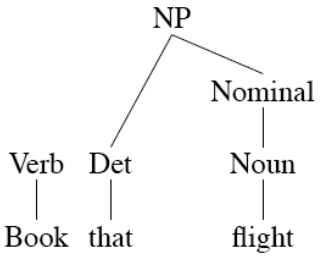
Bottom-Up Search



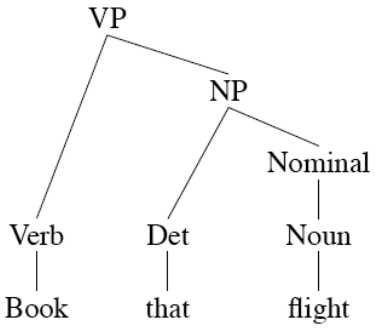
Bottom-Up Search



Bottom-Up Search



Bottom-Up Search



Top-Down and Bottom-Up

- Top-down
  - Only searches for trees that can be answers (i.e. S's)
  - But also suggests trees that are not consistent with any of the words
- Bottom-up
  - Only forms trees consistent with the words
  - But suggests trees that make no sense globally

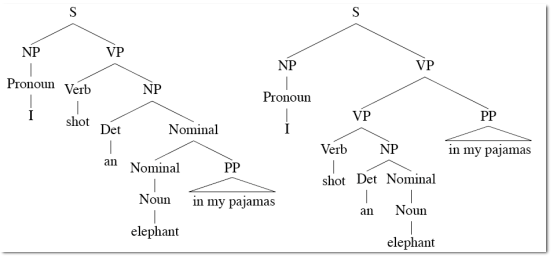
Control

- Of course, in both cases we left out how to keep track of the search space and how to make choices
  - Which node to try to expand next
  - Which grammar rule to use to expand a node
- One approach is called backtracking.
  - Make a choice, if it works out then fine
  - If not then back up and make a different choice
    - Same as with ND-Recognize

Problems

- Even with the best filtering, backtracking methods are doomed because of two inter-related problems
  - Ambiguity and search control (choice)
  - Shared subproblems

Ambiguity

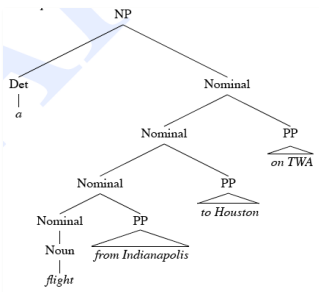


Shared Sub-Problems

- No matter what kind of search (top-down or bottom-up or mixed) that we choose...
  - We can't afford to redo work we've already done.
  - Without some help naïve backtracking will lead to such duplicated work.

Shared Sub-Problems

- Consider
  - *A flight from Indianapolis to Houston on TWA*



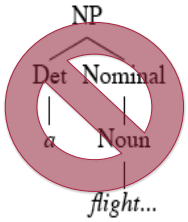
Sample L1 Grammar

Grammar	Lexicon
$S \rightarrow NP\ VP$	$Det \rightarrow that \mid this \mid a$
$S \rightarrow Aux\ NP\ VP$	$Noun \rightarrow book \mid flight \mid meal \mid money$
$S \rightarrow VP$	$Verb \rightarrow book \mid include \mid prefer$
$NP \rightarrow Pronoun$	$Pronoun \rightarrow I \mid she \mid me$
$NP \rightarrow Proper\text{-}Noun$	$Proper\text{-}Noun \rightarrow Houston \mid NWA$
$NP \rightarrow Det\ Nominal$	$Aux \rightarrow does$
$Nominal \rightarrow Noun$	$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Nominal \rightarrow Nominal\ Noun$	
$Nominal \rightarrow Nominal\ PP$	
$VP \rightarrow Verb$	
$VP \rightarrow Verb\ NP$	
$VP \rightarrow Verb\ NP\ PP$	
$VP \rightarrow Verb\ PP$	
$VP \rightarrow VP\ PP$	
$PP \rightarrow Preposition\ NP$	

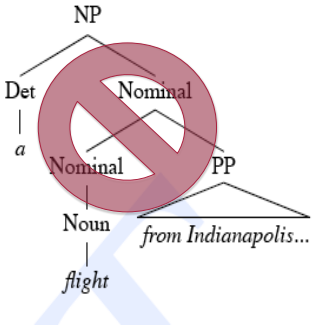
Shared Sub-Problems

- Assume a top-down parse that has already expanded the *NP* rule (dealing with the Det)
- Now its making choices among the various *Nominal* rules
- In particular, between these two
  - *Nominal -> Noun*
  - *Nominal -> Nominal PP*
- Statically choosing the rules in this order leads to the following bad behavior...

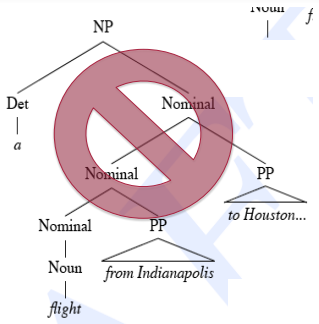
Shared Sub-Problems



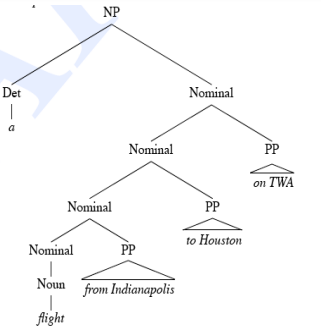
Shared Sub-Problems



Shared Sub-Problems



Shared Sub-Problems



Dynamic Programming

- DP search methods fill tables with partial results and thereby
  - Avoid doing avoidable repeated work
  - Solve exponential problems in polynomial time (ok, not really)
  - Efficiently store ambiguous structures with shared sub-parts.
- We'll cover one approach that corresponds to a bottom-up strategy
  - CKY

CKY Parsing

- First we'll limit our grammar to epsilon-free, binary rules (more on this later)
- Consider the rule *A* → *BC*
  - If there is an A somewhere in the input generated by this rule then there must be a B followed by a C in the input.
  - If the A spans from i to j in the input then there must be some k st. i<k<j
    - In other words, the B splits from the C someplace after the i and before the j.

CKY

- Let's build *a table* so that an *A* spanning from i to j in the input is placed in cell [i,j] in the table.
  - So a non-terminal spanning an entire string will sit in cell [0, n]
    - Hopefully it will be an *S*
- Now we know that the parts of the A must go from i to k and from k to j, for some k

CKY

- Meaning that for a rule like A → B C we should look for a B in [i,k] and a C in [k,j].
- In other words, if we think there might be an A spanning i,j in the input… AND

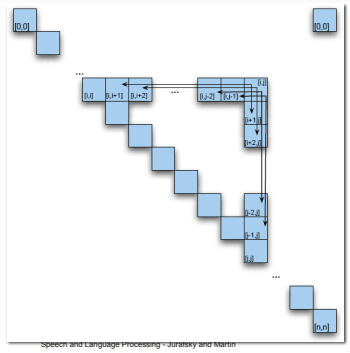
  A → B C is a rule in the grammar THEN
- There must be a B in [i,k] and a C in [k,j] for some k such that i<k<j

What about the B and the C?

CKY

- So to fill the table loop over the cells [i,j] values in some systematic way
  - Then for each cell, loop over the appropriate k values to search for things to add.
  - Add all the derivations that are possible for each [i,j] for each k

CKY Table



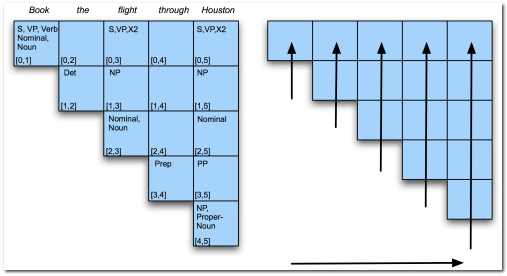
CKY Algorithm

function CKY-PARSE(*words*, *grammar*) **returns** *table*

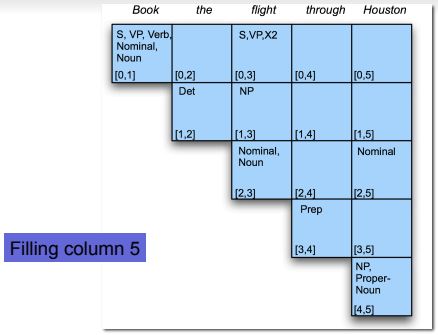
for $j \leftarrow$ **from** 1 **to** LENGTH(*words*) **do**
  $table[j-1, j] \leftarrow \{A \mid A \rightarrow words[j] \in grammar\}$
  for $i \leftarrow$ **from** $j-2$ **downto** 0 **do**
    for $k \leftarrow i+1$ **to** $j-1$ **do**
      $table[i,j] \leftarrow table[i,j] \cup$
        $\{A \mid A \rightarrow BC \in grammar,$
          $B \in table[i,k],$
          $C \in table[k,j]\}$

What's the complexity of this?

Example



Example



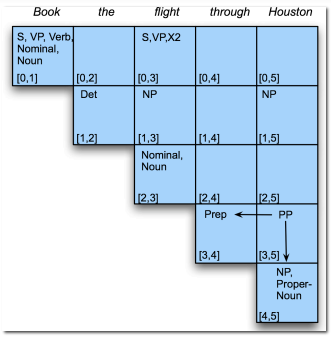
Example

- Filling column 5 corresponds to processing word 5, which is *Houston*.
  - So *j* is 5.
  - So *i* goes from 3 to 0 (3,2,1,0)

```
function CKY-PARSE(words, grammar) returns table

for j ← from 1 to LENGTH(words) do
    table[j − 1, j] ← {A | A → words[j] ∈ grammar}
    for i ← from j − 2 downto 0 do
        for k ← i + 1 to j − 1 do
            table[i,j] ← table[i,j] ∪
                         {A | A → BC ∈ grammar,
                              B ∈ table[i,k],
                              C ∈ table[k, j]}
```

Example



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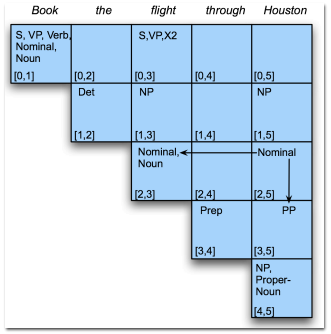
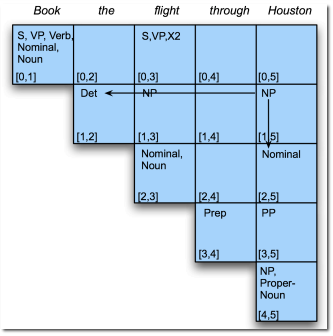
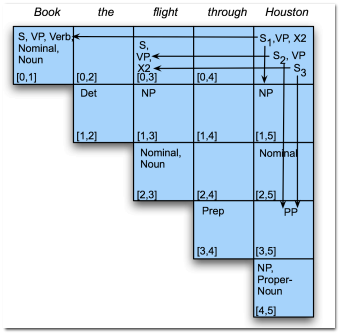


Example



Example



Example

- Since there's an *S* in [0,5] we have a valid parse.
- Are we done? We we sort of left something out of the algorithm

```
function CKY-PARSE(words, grammar) returns table

for j ← from 1 to LENGTH(words) do
    table[j − 1, j] ← {A | A → words[j] ∈ grammar}
    for i ← from j − 2 downto 0 do
        for k ← i + 1 to j − 1 do
            table[i,j] ← table[i,j] ∪
                        {A | A → BC ∈ grammar,
                             B ∈ table[i,k],
                             C ∈ table[k, j]}
```


CKY Notes

- Since it's bottom up, CKY hallucinates a lot of silly constituents.
  - Segments that by themselves are constituents but cannot really occur in the context in which they are being suggested.
  - To avoid this we can switch to a top-down control strategy
  - Or we can add some kind of filtering that blocks constituents where they can not happen in a final analysis.

CKY Notes

- We arranged the loops to fill the table a column at a time, from left to right, bottom to top.
  - This assures us that whenever we're filling a cell, the parts needed to fill it are already in the table (to the left and below)
  - It's somewhat natural in that it processes the input a left to right a word at a time
    - Known as online
  - Can you think of an alternative strategy?