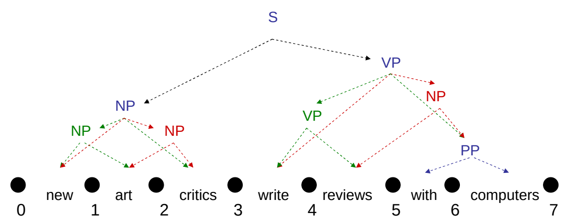
CS 294-5: Statistical Natural Language Processing

PCFG Parsing I

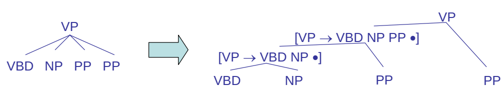
Lecture 15: 10/26/05

The Parsing Problem



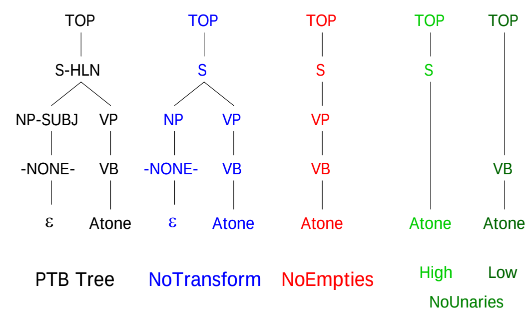
Chomsky Normal Form

- Chomsky normal form:
  - All rules of the form X → Y Z or X → w
  - In principle, this is no limitation on the space of (P)CFGs
    - N-ary rules introduce new non-terminals



    - Unaries / empties are "promoted"
  - In practice it's kind of a pain:
    - Reconstructing n-aries is easy
    - Reconstructing unaries is trickier
    - The straightforward transformations don't preserve tree scores
  - Makes parsing algorithms simpler!

Unaries in Grammars



A Recursive Parser

- Here's a recursive (CNF) parser:

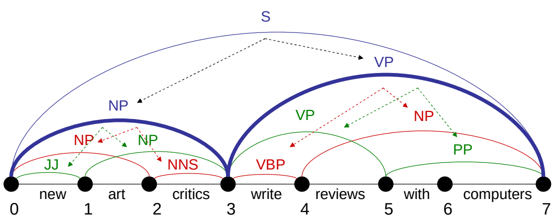
```
bestParse(X,i,j,s)
  if (j = i+1)
     return X -> s[i]
  (X->YZ,k) = argmax score(X->YZ) *
                     bestScore(Y,i,k,s) *
                     bestScore(Z,k,j,s)
  parse.parent = X
  parse.leftChild = bestParse(Y,i,k,s)
  parse.rightChild = bestParse(Z,k,j,s)
  return parse
```

A Recursive Parser

```
bestScore(X,i,j,s)
  if (j = i+1)
     return tagScore(X,s[i])
  else
     return max score(X->YZ) *
                bestScore(Y,i,k) *
                bestScore(Z,k,j)
```

- Will this parser work?
- Why or why not?
- Memory requirements?

An Example



A Memoized Parser

- One small change:

```
bestScore(X,i,j,s)
  if (scores[X][i][j] == null)
    if (j = i+1)
      score = tagScore(X,s[i])
    else
      score = max score(X->YZ) *
                  bestScore(Y,i,k,s) *
                  bestScore(Z,k,j,s)
    scores[X][i][j] = score
  return scores[X][i][j]
```

Memory: Theory

- How much memory does this require?
  - Have to store the score cache
  - Cache size: |symbols|*n^2 doubles
  - For the plain treebank grammar:
    - X ~ 20K, n = 40, double ~ 8 bytes = ~ 256MB
    - Big, but workable.
- What about sparsity?

Time: Theory

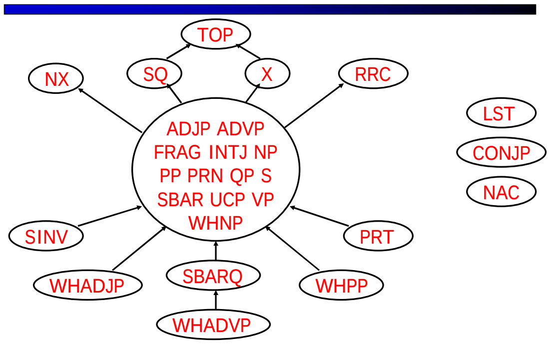
- How much time will it take to parse?
  - Have to fill each cache element (at worst)
  - Each time the cache fails, we have to:
    - Iterate over each rule X $\rightarrow$ Y Z and split point k
    - Do constant work for the recursive calls
  - Total time: |rules|*n^3
  - Cubic time
  - Something like 5 sec for an unoptimized parse of a 20-word sentences

Unary Rules

- Unary rules?

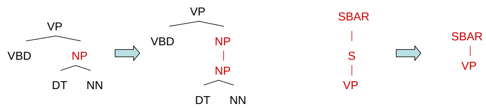
```
bestScore(X,i,j,s)
  if (j = i+1)
    return tagScore(X,s[i])
  else
    return max max score(X->YZ) *
                   bestScore(Y,i,k,s) *
                   bestScore(Z,k,j,s)
               max score(X->Y) *
                   bestScore(Y,i,j,s)
```

Same-Span Reachability



CNF + Unary Closure

- We need unaries to be non-cyclic
  - Can address by pre-calculating the *unary closure*
  - Rather than having zero or more unaries, always have exactly one



  - Alternate unary and binary layers
  - Reconstruct unary chains afterwards

Alternating Layers

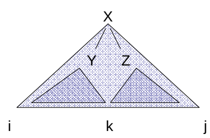
```
bestScoreB(X,i,j,s)
    return max max score(X->YZ) *
                   bestScoreU(Y,i,k,s) *
                   bestScoreU(Z,k,j,s)


bestScoreU(X,i,j,s)
  if (j = i+1)
     return tagScore(X,s[i])
  else
     return max max score(X->Y) *
                   bestScoreB(Y,i,j,s)
```

A Bottom-Up Parser (CKY)

- Can also organize things bottom-up

```
bestScore(s)
  for (i : [0,n-1])
    for (X : tags[s[i]])
      score[X][i][i+1] =
          tagScore(X,s[i])
  for (diff : [2,n])
    for (i : [0,n-diff])
      j = i + diff
      for (X->YZ : rule)
        for (k : [i+1, j-1])
          score[X][i][j] = max score[X][i][j],
                               score(X->YZ) *
                               score[Y][i][k] *
                               score[Z][k][j]
```



Efficient CKY

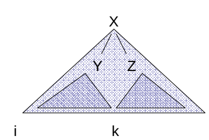
- Lots of tricks to make CKY efficient
  - Most of them are little engineering details:
    - E.g., first choose k, then enumerate through the Y:[i,k] which are non-zero, then loop through rules by left child.
    - Optimal layout of the dynamic program depends on grammar, input, even system details.
  - Another kind is more critical:
    - Many X:[i,j] can be suppressed on the basis of the input string
    - We'll see this next class as figures-of-merit or A* heuristics

Memory: Practice

- Memory:
  - Still requires memory to hold the score table
- Pruning:
  - score[X][i][j] can get too large (when?)
  - can instead keep beams scores[i][j] which only record scores for the top K symbols found to date for the span [i,j]

Time: Theory

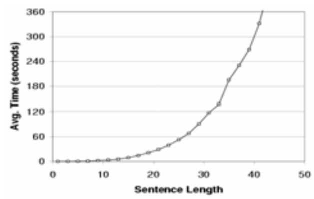
- How much time will it take to parse?
  - For each diff (<= n)
    - For each i (<= n)
      - For each rule $X \rightarrow Y\ Z$
        - For each split point k
          Do constant work



  - Total time: |rules|*n^3

Runtime: Practice

- Parsing with the vanilla treebank grammar:



~ 20K Rules

(not an optimized parser!)

Observed exponent:

3.6

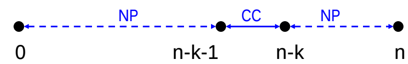
- Why's it worse in practice?
  - Longer sentences "unlock" more of the grammar
  - All kinds of systems issues don't scale

Rule State Reachability

Example: NP CC •

1 Alignment

Example: NP CC NP •

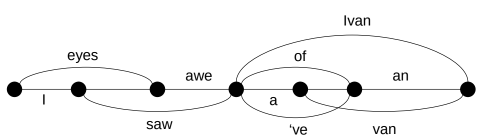


n Alignments

- Many states are more likely to match larger spans!

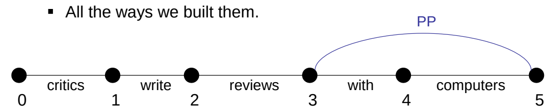
(Speech) Lattices

- There was nothing magical about words spanning exactly one position.
- When working with speech, we generally don't know how many words there are, or where they break.
- We can represent the possibilities as a lattice and parse these just as easily.



A Simple Chart Parser

- Chart parsers are sparse dynamic programs
- Ingredients:
  - Nodes: positions between words
  - Edges: spans of words with labels, represent the set of trees over those words rooted at x
  - A chart: records which edges we've built
  - An agenda: a holding pen for edges (a queue)
- We're going to figure out:
  - What edges can we build?
  - All the ways we built them.



Word Edges

- An edge found for the first time is called discovered. Edges go into the agenda on discovery.
- To initialize, we discover all word edges.

AGENDA

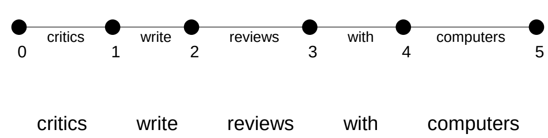
critics[0,1], write[1,2], reviews[2,3], with[3,4], computers[4,5]

CHART [EMPTY]

Unary Projection

- When we pop an word edge off the agenda, we check the lexicon to see what tag edges we can build from it

critics[0,1]	write[1,2]	reviews[2,3]	with[3,4]	computers[4,5]
NNS[0,1]	VBP[1,2]	NNS[2,3]	IN[3,4]	NNS[3,4]



The "Fundamental Rule"

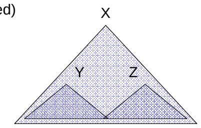
- When we pop edges off of the agenda:
  - Check for unary projections (NNS → critics, NP → NNS)

Y[i,j] with X → Y forms X[i,j]

  - Combine with edges already in our chart (this is sometimes called the fundamental rule)

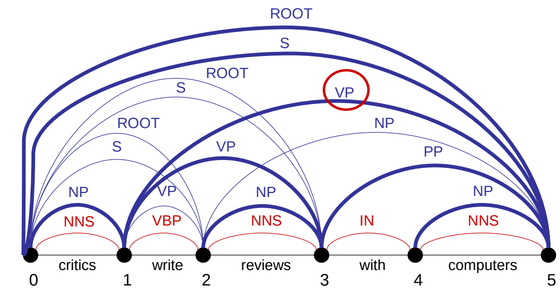
Y[i,j] and Z[j,k] with X → Y Z form X[i,k]

  - Enqueue resulting edges (if newly discovered)
  - Record backtraces (called traversals)
  - Stick the popped edge in the chart
- Queries a chart must support:
  - Is edge X:[i,j] in the chart?
  - What edges with label Y end at position j?
  - What edges with label Z start at position i?



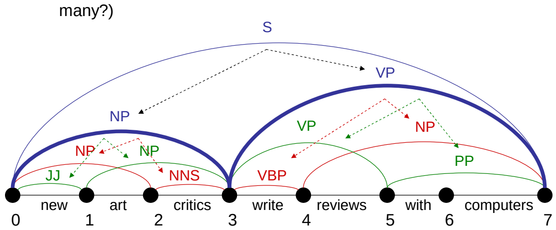
An Example

NNS[0,1] VBP[1,2] NNS[2,3] IN[3,4] NNS[3,4] NP[0,1] VP[1,2] NP[2,3] NP[4,5] S[0,2] VP[1,3] PP[3,5] ROOT[0,2] S[0,3] VP[1,5] NP[2,5] ROOT[0,3] S[0,5] ROOT[0,5]



Exploiting Substructure

- Each edge records all the ways it was built (locally)
  - Can recursively extract trees
  - A chart may represent too many parses to enumerate (how many?)



Order Independence

- A nice property:
  - It doesn't matter what policy we use to order the agenda (FIFO, LIFO, random).
  - Why? Invariant: before popping an edge:
    - Any edge X[i,j] that can be directly built from chart edges and a single grammar rule is either in the chart or in the agenda.
    - Convince yourselves this invariant holds!
  - This will not be true once we get weighted parsers.

Empty Elements

- Sometimes we want to posit nodes in a parse tree that don't contain any pronounced words:

I want John to parse this sentence

I want [ ] to parse this sentence

- These are easy to add to our chart parser!
  - For each position i, add the "word" edge ε:[i,i]
  - Add rules like NP → ε to the grammar
  - That's it!