CS224N/Ling280

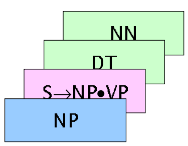
Statistical parsing: Search

General Problem

- Someone gives you a PCFG *G*
- For any given sentence, you might want to:
  - Find the best parse according to *G*
  - Find a bunch of reasonably good parses
  - Find the total probability of all parses licensed by *G*
- Techniques:
  - CKY (for best; can extend to *k*-best (at high space and time cost – k^2 time cost or all parses – the inside algorithm)
  - Beam search
  - Agenda/chart-based search

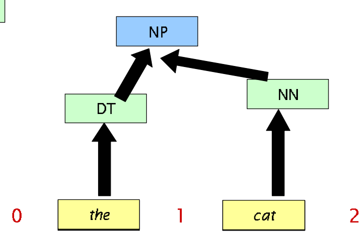
Parsing as Search

Grammar symbols:



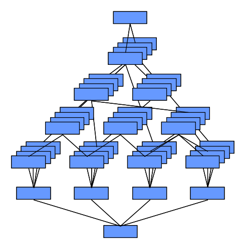
Cards in the same stack represent different symbols over the same span.

Parse triangle:



CKY Parsing

- In CKY parsing, we visit edges tier by tier:



- Guarantees correctness by working inside-out.
- Build all small bits before any larger bits that could possibly require them.
- Exhaustive: the goal is in the last tier!

Beam Search

- State space search
- States are partial parses with an associated probability
  - Keep only the top scoring elements at each stage of the beam search
- Find a way to ensure that all parses of a sentence have the same number *N* steps
  - Leftmost top-down CFG derivations in *true* CNF
  - Shift-reduce derivations in *true* CNF
    - (Use a binary grammar or binarize what you've got, and remove unaries.)

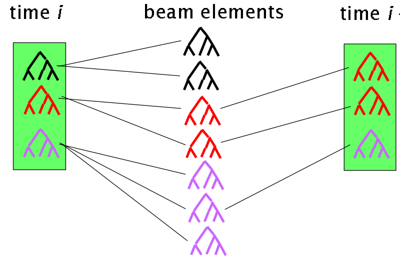
Beam Search

- Time-synchronous beam search

Beam at time *i*

Successors of beam elements

Beam at time *i* + 1



Kinds of beam search

- Constant beam size *k*
- Constant beam width relative to best item
  - Defined either additively or multiplicatively
- Sometimes combination of the above two
- Sometimes do fancier stuff like trying to keep the beam elements diverse
- Beam search can be made very fast
- No measure of how often you find model optimal answer
  - But can track correct answer to see how often/far gold standard optimal answer remains in the beam

Beam search for assignment?

- Would probably want to do bottom up parsing (shift-reduce parsing or a version of left-corner parsing)
  - For treebank grammars, not much grammar constraint, so want to use data-driven constraint
- Don't actually want to store states as partial parses
  - Store them as the last rule applied, with backpointers to the previous states that built those constituents (and a probability)

Agenda-Based Parsing

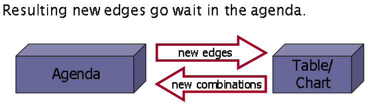
- For general grammars
- Start with a table recording δ(X,i,j)
  - Records the best score of a parse of X over [i,j]
    - If the scores are negative log probabilities, then entries start at ∞, and small is good
    - This can be a sparse or a dense map
    - Again, you may want to record backtraces as well like CKY
- Step 1: Initialize with the sentence and lexicon:
  - For each word w and each tag t
    - Set δ(X,i,j) = lex.score(w,t)

Agenda-based parsing

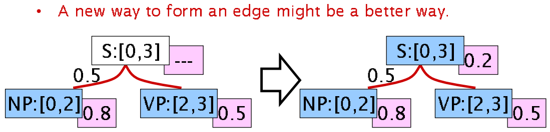
- Keep a list of edges called an agenda
  - Edges are triples [X,i,j]
  - The agenda is a priority queue
- Every time the score of some δ(X,i,j) improves (i.e. gets lower):
  - Stick the edge [X,i,j]-score into the agenda
  - (Update the backtrace for δ(X,i,j)

Agenda-Based Parsing

- The agenda is a holding zone for edges.
- Visit edges by some ordering policy.
  - Combined edge with already-visited edges.
  - Resulting new edges go wait in the agenda.



- A new way to form an edge might be a better way.



Agenda-based parsing

- Step II: While agenda not empty
  - Get the “next” edge [X,i,j] from the agenda
  - Fetch all compatible neighbors [Y,j,k] or [Z,k,i]
    - Compatible means that there are rules A→X Y or B→X Z
  - Build all parent edges [A,i,k] or [B,k,j] found
    - δ(A,i,k) ≤ δ(X,i,j) + δ(Y,j,k) + P(A→X Y)
    - If we've improved δ(A,i,k), then stick it on the agenda
  - Also project unary rules:
    - Fetch all unary rules A→X, score [A,i,j] built from this rule on [X,i,j] and put on agenda if you've improved δ(A,i,k)
- When do we know we have a parse for the root?

Agenda-based parsing

- Open questions:
  - Agenda priority: What did "next" mean?
  - Efficiency: how do we do as little work as possible?
  - Optimality: how do we know when we find the best parse of a sentence?
- If we use $\delta(X,i,j)$ as the priority:
  - Each edge goes on the agenda at most once
  - When an edge pops off the agenda, its best parse is known (why?)
  - This is basically uniform cost search (i.e., Dijkstra's algorithm)

What can go wrong?

- We can build too many edges.
  - Most edges that can be built, shouldn't.
  - CKY builds them all!

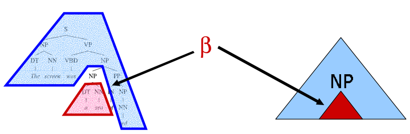
Speed: build promising edges first.

- We can build in an bad order.
  - Might find bad parses before good parses.
  - Will trigger best-first propagation.

Correctness: keep edges on the agenda until you're sure you've seen their best parse.

Uniform-Cost Parsing

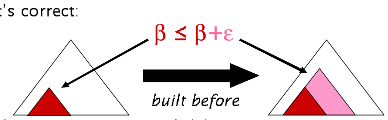
- Let β be the score of an edge's Viterbi parse.



- "Distance" or "cost" is the negative log probability of the rules in a tree structure.
- Uniform-cost parsing: visit edges in order of increasing β (rather than increasing span)

Uniform-Cost Parsing

- We want to work on good parses inside-out.
  - CKY does this synchronously, by tiers.
  - Uniform-cost does it asynchronously, ordering edges by their best known parse score.
- Why it's correct:

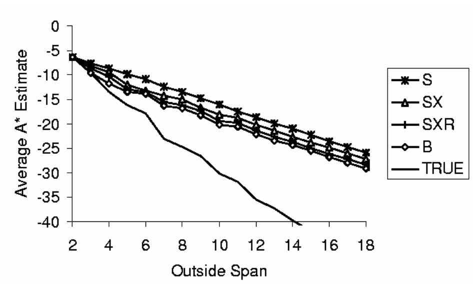


  - Adding structure incurs probability cost.
  - Trees have lower probability than their sub-parts.
  - The best-scored edge in the agenda cannot be waiting on any of its sub-edges.

Speeding up agenda-based parsers

- Two options for doing less work
  - The optimal way: A* parsing
    - Klein and Manning (2003)
  - The ugly but practical way: "best-first" parsing
    - Caraballo and Charniak (1998)
    - Charniak, Johnson, and Goldwater (1998)

A* Estimate Sharpness



Modern statistical parsers

- Klein and Manning (2003) do optimal A* search
  - Done in a restricted space of lexicalized PCFGs that "factors", allowing very efficient A* search
- Collins (1999) exploits both the ideas of beams and agenda based parsing
  - He places a separate beam over each span (and then, roughly, doing uniform cost search
- Charniak (2000) uses inadmissable heuristics to guide search
  - He uses very good (but inadmissable) heuristics – dub "best first search" to find good parses quickly
  - Perhaps unsurprisingly this is the fastest of the 3.