CS395T: Structured Models for NLP
Lecture 9: Trees 3

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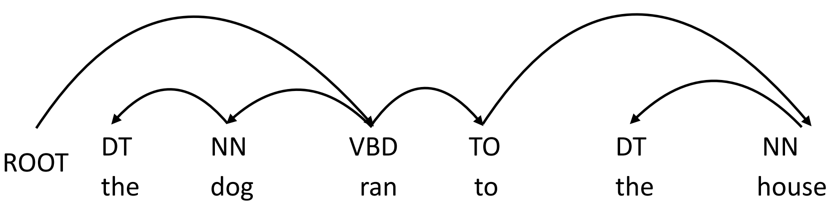
Administrivia

- Project 1 due at *5pm* today
- Project 2 will be out by tonight. Due October 17
  - Shift-reduce parser: greedy model, beam search model, extension

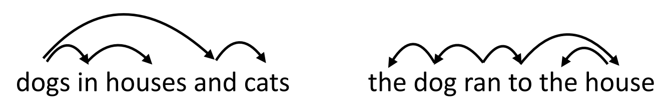
Recall: Dependencies

- Dependency syntax: syntactic structure is defined by dependencies
  - Head (parent, governor) connected to dependent (child, modifier)
  - Each word has exactly one parent except for the ROOT symbol
  - Dependencies must form a directed acyclic graph

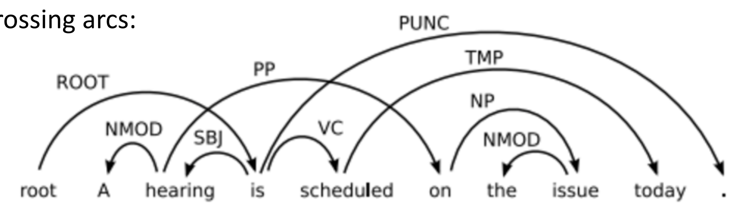


Recall: Projectivity

- Projective <-> no "crossing" arcs



- Crossing arcs:



- Today: algorithms for projective parsing

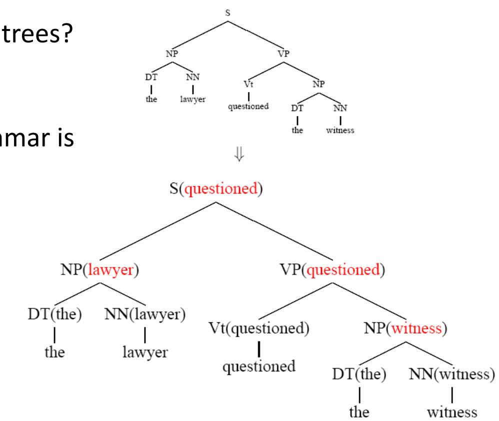
credit: Language Log

This Lecture

- Graph-based dependency parsing
  - Dynamic programs for exact inference — look a lot like sequential CRFs
- Transition-based (shift-reduce) dependency parsing
  - Approximate, greedy inference — fast, but a little bit weird!

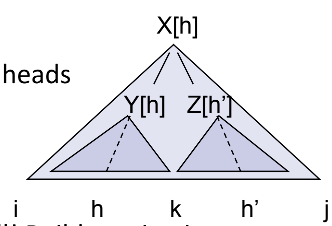
Graph-based Dependency Parsing

- How did we parse lexicalized trees?
- Normal CKY is too slow: grammar is too large if it includes words



Graph-based Dependency Parsing

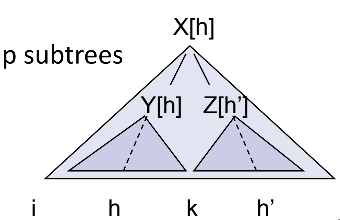
- Naive algorithm: $O(n^5)$
  - Combine spans like CKY and look at their heads
  - Five indices to loop over
  - Features can look at spans and heads

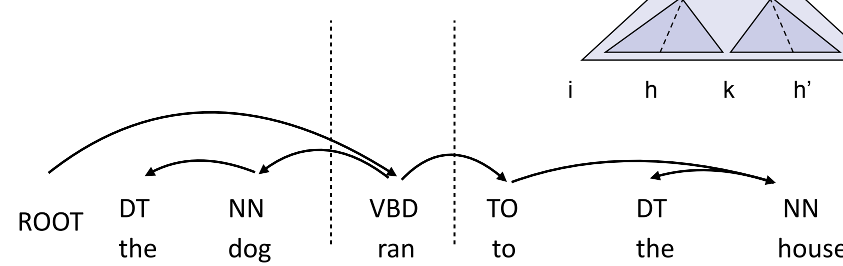


- Can be applied to dependency parses as well! Builds projective trees
- What do our scores look like? For now, assume features on edge (head, child) pair with some weights

Why is this inefficient?

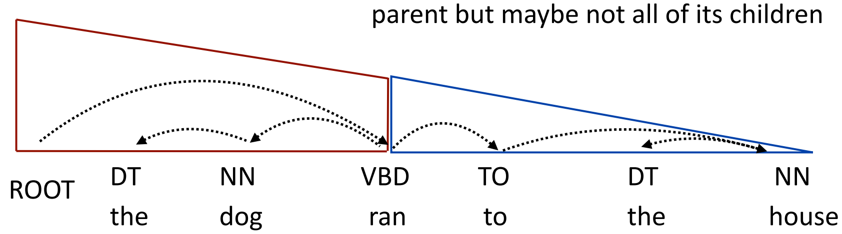
- Lots of spurious ambiguity — many ways to derive the right parses
- Can split at either point and we can build up subtrees





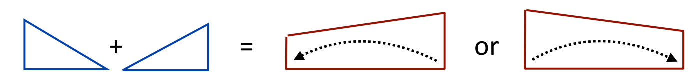
Eisner’s Algorithm: $O(n^3)$

- Cubic-time algorithm like CKY
- Maintain two charts with dimension [n, n, 2]:
  - Complete items: all children are attached, head is at the “tall end”
  - Incomplete items: arc from “tall” to “short” end, word on short end has parent but maybe not all of its children

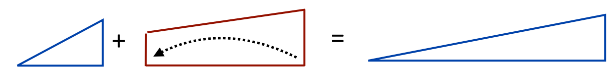


Eisner’s Algorithm: $O(n^3)$

- Complete item: all children are attached, head is at the “tall end”
- Incomplete item: arc from “tall end” to “short end”, may still expect children
- Take two adjacent complete items, add arc and build incomplete item



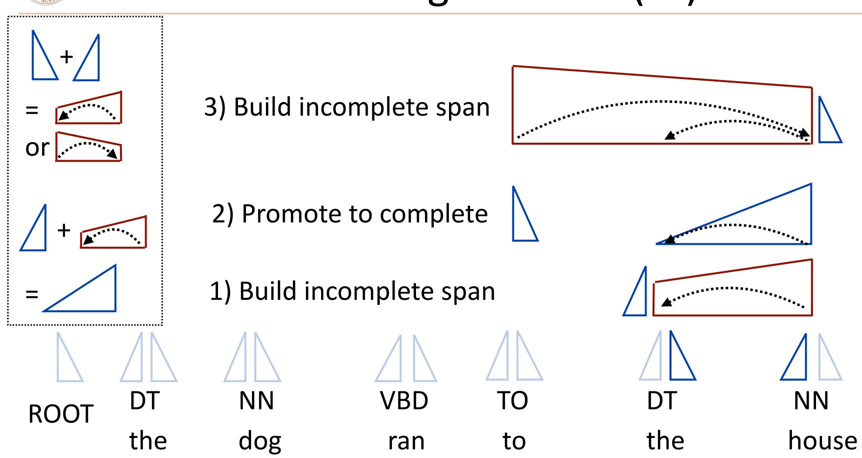
- Take an incomplete item, complete it



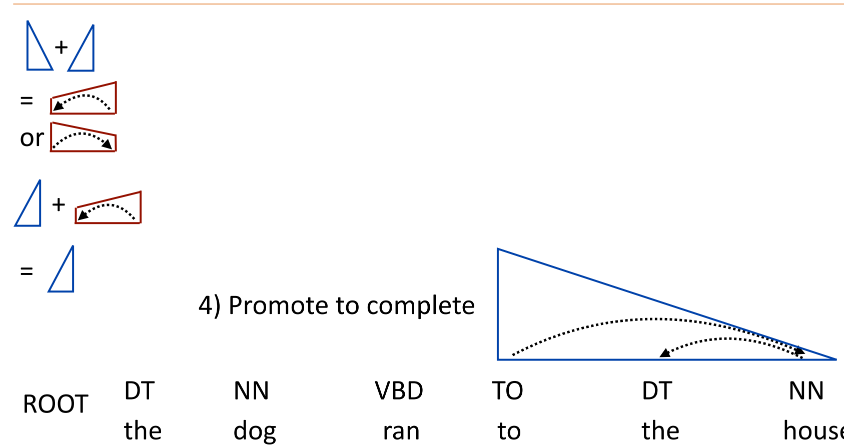
(other case is symmetric)

ROOT DT the NN dog VBD ran TO to DT the NN house

Eisner’s Algorithm: $O(n^3)$

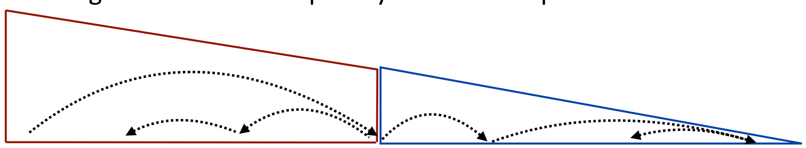


Eisner’s Algorithm: $O(n^3)$

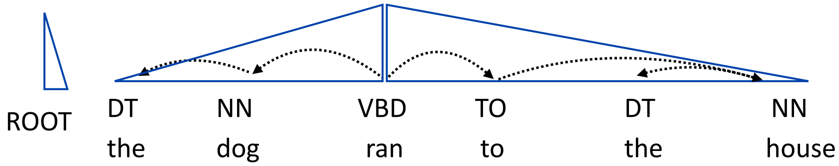


Eisner's Algorithm: $O(n^3)$

- Attaching to ROOT makes an incomplete item with left children, attaches with right children subsequently to finish the parse

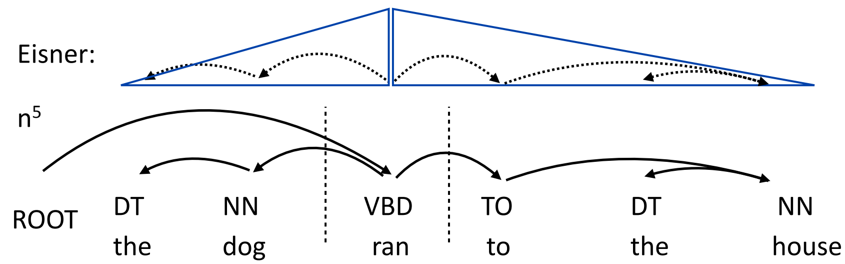


- We've built left children and right children of *ran* as complete items



Eisner's Algorithm

- Eisner's algorithm doesn't have split point ambiguities like this
- Left and right children are built independently, heads are edges of spans
- Charts are n x n x 2 because we need to track arc direction / left vs right



MST Parser

- View dependency parsing as finding a maximum direct spanning tree — space of all spanning trees, so we find nonprojective trees too!
- Chu-Liu-Edmonds algorithm to find the best MST in $O(n^2)$
- This only computes maxes, but there is an algorithm for summing over all trees as well (matrix-tree theorem)
- Ironically, the software artifact called MST Parser has an implementation of Eisner's algorithm, which is what most people use

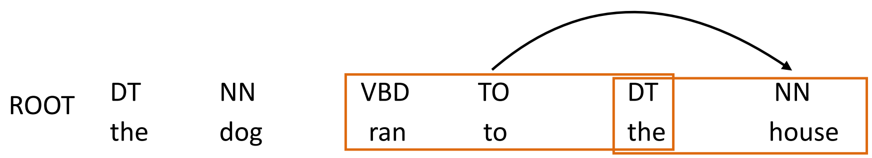
McDonald et al. (2005)

Building Systems

- Can implement Viterbi decoding and marginal computation using Eisner's algorithm or MST to max/sum over projective/nonprojective trees
- Same concept as sequential CRFs for NER, can also use margin-based methods — you know how to implement these!
- Features are over dependency edges

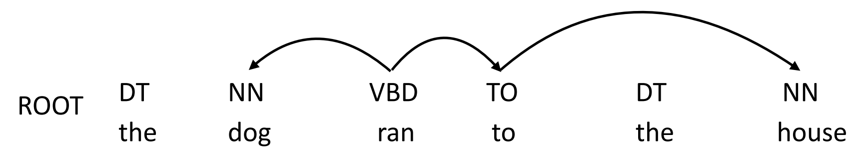
Features in Graph-Based Parsing

- Dynamic program exposes the parent and child indices



- McDonald et al. (2005) — conjunctions of parent and child words + POS, POS of words in between, POS of surrounding words. ~91 UAS
  - HEAD=TO & MOD=NN
  - HEAD=TO & MOD=house
  - HEAD=TO & MOD-1=the
  - HEAD=TO & MOD=DT
- Lei et al. (2014) — ways of learning conjunctions of these

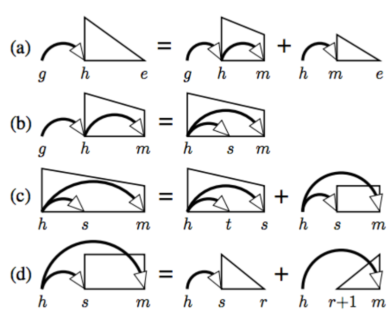
Features in Graph-Based Parsing



- Ideally would use features on more arcs
- Grandparents: ran -> to -> house
- Siblings: dog <- ran -> to

Higher-Order Parsing

- Terry Koo (2010)
- Track additional state during parsing so we can look at grandparents and siblings, $O(n^4)$
- Additional indicator features based on this information, ~93 UAS (up from 91 UAS)
- Turns out you can just use beam search and forget this crazy dynamic program…

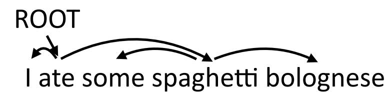


Shift-Reduce Parsing

Shift-Reduce Parsing

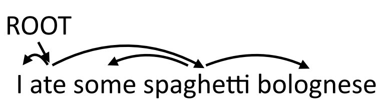
- Similar to deterministic parsers for compilers
- Also called transition-based parsing
- A tree is built from a sequence of incremental decisions moving left to right through the sentence
- Stack containing partially-built tree, buffer containing rest of sentence
- Shifts consume the buffer, reduces build a tree on the stack

Shift-Reduce Parsing



- Initial state: Stack: [ROOT] Buffer: [I ate some spaghetti bolognese]
- Shift: top of buffer -> top of stack
  - Shift 1: Stack: [ROOT I] Buffer: [ate some spaghetti bolognese]
  - Shift 2: Stack: [ROOT I ate] Buffer: [some spaghetti bolognese]

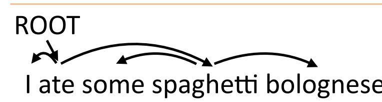
Shift-Reduce Parsing



- State: Stack: [ROOT I ate] Buffer: [some spaghetti bolognese]
- Left-arc (reduce operation): Let σ denote the stack
  - "Pop two elements, add an arc, put them back on the stack"
  - $\sigma|w_{-2}, w_{-1} \rightarrow \sigma|w_{-1}$, w_{-2} is now a child of w_{-1}
- State: Stack: [ROOT ate] Buffer: [some spaghetti bolognese]

  ↓
  I

Arc-Standard Parsing



- Start: stack contains [ROOT], buffer contains [I ate some spaghetti bolognese]
- Arc-standard system: three operations
  - Shift: top of buffer -> top of stack
  - Left-Arc: $\sigma|w_{-2}, w_{-1} \rightarrow \sigma|w_{-1}$, w_{-2} is now a child of w_{-1}
  - Right-Arc $\sigma|w_{-2}, w_{-1} \rightarrow \sigma|w_{-2}$, w_{-1} is now a child of w_{-2}
- End: stack contains [ROOT], buffer is empty []
- Must take 2*n* steps for *n* words (*n* shifts, *n* LA/RA)

Arc-Standard Parsing

ROOT

I ate some spaghetti bolognese

S	top of buffer -> top of stack
LA	pop two, left arc between them
RA	pop two, right arc between them

[ROOT] S [I ate some spaghetti bolognese]

[ROOT I] S [I some spaghetti bolognese]

[ROOT I ate] L [some spaghetti bolognese]

[ROOT ate] [some spaghetti bolognese]

I

- Could do the left arc later! But no reason to wait
- Can't attach ROOT <- ate yet even though this is a correct dependency!

Arc-Standard Parsing

ROOT

I ate some spaghetti bolognese

S	top of buffer -> top of stack
LA	pop two, left arc between them
RA	pop two, right arc between them

[ROOT ate] [some spaghetti bolognese]

I

S

S

[ROOT ate some spaghetti] [bolognese]

I

L

[ROOT ate spaghetti] [bolognese]

I some

S

Arc-Standard Parsing

ROOT

I ate some spaghetti bolognese

S	top of buffer -> top of stack
LA	pop two, left arc between them
RA	pop two, right arc between them

[ROOT ate spaghetti bolognese] []

I some

R

[ROOT ate spaghetti] []

I some bolognese

R

[ROOT ate] []

spaghetti

I

some bolognese

- Stack consists of all words that are still waiting for right children, end with a bunch of right-arc ops

Final state:

[ROOT] []

ate

spaghetti

I

some bolognese

Other Systems

- Arc-eager (Nivre, 2004): lets you add right arcs sooner and keeps items on stack, separate reduce action that clears out the stack
- Arc-swift (Qi and Manning, 2017): explicitly choose a parent from what's on the stack
- Many ways to decompose these, which one works best depends on the language and features

Building Shift-Reduce Parsers

[ROOT] [I ate some spaghetti bolognese]

- How do we make the right decision in this case?
- Only one legal move (shift)

[ROOT ate some spaghetti] [bolognese]

I

- How do we make the right decision in this case? (all three actions legal)
- Correct action is left-arc
- Multi-way classification problem: shift, left-arc, or right-arc?

Features for Shift-Reduce Parsing

[ROOT ate some spaghetti] [bolognese]

I

- Features to know this should left-arc?
- One of the harder feature design tasks!
- In this case: the stack tag sequence VBD - DT - NN is pretty informative — looks like a verb taking a direct object which has a determiner in it
- Things to look at: top words/POS of buffer, top words/POS of stack, leftmost and rightmost children of top items on the stack

Training a Greedy Model

[ROOT ate some spaghetti] [bolognese]

I

- The algorithm we've developed so far is an *oracle*, tells us the correct state transition sequence for each tree
- Use our oracle to extract parser states + correct decisions
- Train a classifier to predict the right decision using these as training data
- Problem: no look ahead
  - No lookahead
  - Training data is extracted assuming everything is correct

Dynamic Oracle

[ROOT ate some spaghetti] [bolognese]

I

- Extract training data based on the oracle but also an execution trace of a trained parser
- Need a *dynamic oracle* to determine what's the optimal thing to do even if mistakes have already been made (so we know how to supervise it)
- We'll see similar ideas in neural net contexts as well

Goldberg and Nivre (2012)

Speed Tradeoffs

	Parser	Dev UAS	Dev LAS	Test UAS	Test LAS	Speed (sent/s)
Unoptimized S-R	standard	89.9	88.7	89.7	88.3	51
	eager	90.3	89.2	89.9	88.6	63
Optimized S-R	Malt:sp	90.0	88.8	89.9	88.5	560
	Malt:eager	90.1	88.9	90.1	88.7	535
Graph-based	MSTParser	92.1	90.8	**92.0**	90.5	12
Neural S-R	Our parser	**92.2**	**91.0**	**92.0**	**90.7**	**1013**

- Optimized constituency parsers are ~5 sentences/sec
- Using S-R used to mean taking a performance hit compared to graph-based, that's no longer true

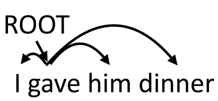
Chen and Manning (2014)

Global Decoding

[ROOT ate some spaghetti] [bolognese]
↓
I

- Try to find the highest-scoring sequence of decisions
- Global search problem, requires approximate search

Global Decoding



[ROOT gave him] [dinner]
↓
I

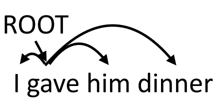
- Correct: Right-arc, Shift, Right-arc, Right-arc

[ROOT gave] [dinner]
↓ ↘
I him

[ROOT gave dinner] []
↓ ↘
I him

[ROOT gave] []
↓ ↘ ↘
I him dinner

Global Decoding: A Cartoon



[ROOT gave him] [dinner]
↓
I

S / LA / RA

[ROOT gave him dinner] []
↓
I

LA / RA

- Both wrong! Also both probably low scoring!

[ROOT gave] [dinner] — S
↓ ↘
I him

- Correct, high scoring option

Global Decoding: A Cartoon

- Lookahead can help us avoid getting stuck in bad spots
- Global model: maximize sum of scores over all decisions
- Similar to how Viterbi works: we maintain uncertainty over the current state so that if another one looks more optimal going forward, we can use that one

Recap

- Eisner's algorithm for graph-based parsing
- Arc-standard system for transition-based parsing
- Run a classifier and do it greedily for now, we'll see global systems next time