CS 294-5: Statistical Natural Language Processing

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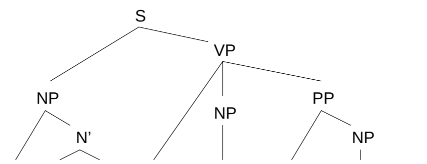
MF 1-2:30pm
Soda Hall 310

The Parsing Task

- Parsing marks how words are syntactically organized
- Decisions we make here affect how we process the text
- Big difference between natural languages and programming languages: rampant ambiguity



Context-Free Grammars

- A context-free grammar is a tuple <*N, T, S, R*>
  - *N* : the set of non-terminals
    - Phrasal categories: S, NP, VP, ADJP, etc.
    - Parts-of-speech (pre-terminals): NN, JJ, DT, VB
  - *T* : the set of terminals (the words)
  - *S* : the start symbol
    - Often written as ROOT or TOP
    - *Not* usually the sentence non-terminal S
  - *R* : the set of rules
    - Of the form $X \rightarrow Y_1 Y_2 \ldots Y_k$, with $X, Y_i \in N$
    - Examples: S → NP VP, VP → VP CC VP
    - Also called rewrites, productions, or local trees

Example CFG

- Can just write the grammar (rules with non-terminal LHSs) and lexicon (rules with pre-terminal LHSs)

Grammar

ROOT → S
S → NP VP
VP → VBP
VP → VBP NP
VP → VP PP
PP → IN NP
NP → NNS
NP → NN
NP → JJ NP
NP → NP NNS
NP → NP PP

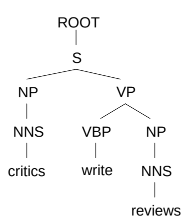
Lexicon

JJ → new
NN → art
NNS → critics
NNS → reviews
NNS → computers
VBP → write
IN → with

Top-Down Generation from CFGs

- A CFG *generates* a language
- Fix an order: apply rules to leftmost non-terminal

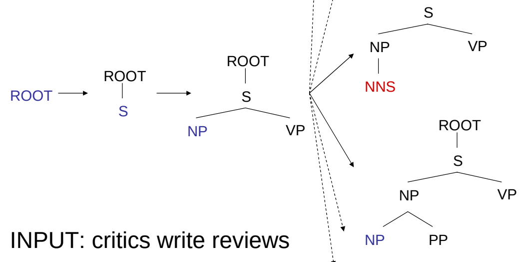
ROOT
S
NP VP
NNS VP
critics VP
critics VBP NP
critics write NP
critics write NNS
critics write reviews



- Gives a *derivation* of a tree using rules of the grammar

Parsing as Search: Top-Down

- Top-down parsing: starts with the root and tries to generate the input



INPUT: critics write reviews

How Top-Down Fails

- Big problem 1: search isn't guided by the input

INPUT: critics write reviews

NP VP → NP PP VP → NP NNS PP VP → JJ NP NNS PP VP

- Big problem 2: separate ambiguities create redundant work

new art critics write reviews with computers

NP VP
[NP] NNS VP → [new art] critics VP → [new art] critics VBP NP
[new art] critics VBP NP PP
[JJ NP] VP → new [art critics] VP → new [art critics] VBP NP
new [art critics] VBP NP PP

Parsing as Search: Bottom-Up

- Bottom-up parsing: input drives the search (shift-reduce parsing)

critics write reviews
NNS write reviews
NP write reviews
NP VBP reviews
NP VBP NNS
NP VBP NP
NP VP
S
ROOT

ROOT
S
NP VP
NNS VBP NP
critics write NNS
reviews

How Bottom-Up Fails

- Big Problem 1: ambiguities still create redundant work

new art critics write reviews with computers

new art critics
write reviews
with computers

[art critics] NP VBP NP PP → NP VBP NP
NP VP PP
[new art] NP VBP NP PP → NP VBP NP
NP VP PP

- Little Problem: partial analyses which can't be completed

art critics write reviews with art computers

[NP][VP] computers

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.

PP

0 critics 1 write 2 reviews 3 with 4 computers 5

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]

0 1 2 3 4 5

critics write reviews with computers

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]

0 critics 1 write 2 reviews 3 with 4 computers 5

critics write reviews with computers

The "Fundamental Rule"

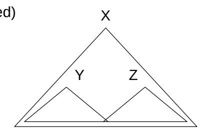
- When we pop edges off of the agenda:
  - Check for unary projections (NNS → critics, NP → NNS)

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]

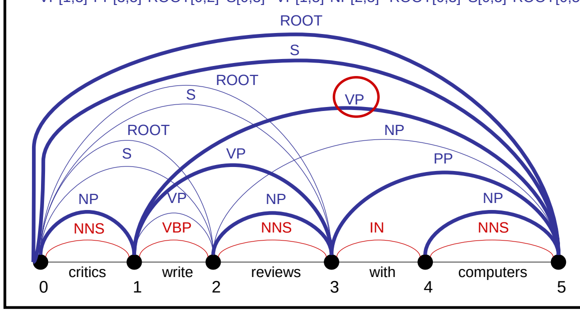
  - Enqueue resulting edges (if newly discovered)
  - Record backtraces (called traversals)
  - Stick the popped edge in the chart



- 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?

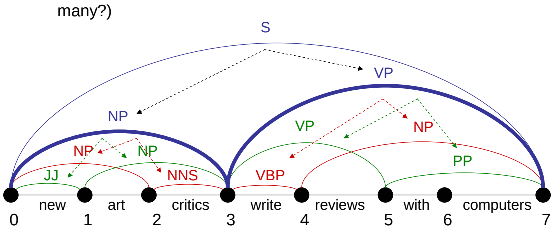
An Example

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.

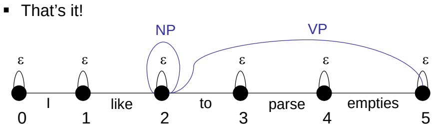
Empty Elements

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

I want John to parse this sentence

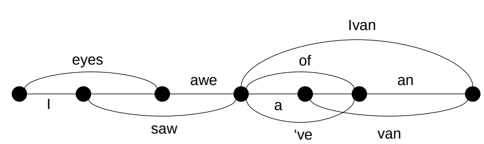
I want [ ] to parse this sentence

- 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!



(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! (cf. HW 1)



N-Ary Rules

- Often we want to write grammar rules like

  VP → VBD NP PP PP

  which are not binary.

- We can work with these rules by introducing new intermediate symbols into our grammar:

  VP

  [VP → VBD NP PP •]

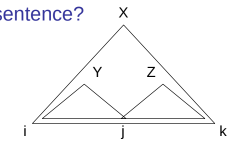
  [VP → VBD NP •]

  VBD NP PP PP

- We'll hear much more about this kind of thing when we talk about grammar representation later in the course.

Runtime: Theory

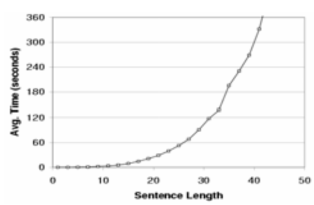
- How long does it take to parse a sentence?
- Depends on:
  - Sentence length
  - Grammar size (and structure)
  - Specific input sentences



- Asymptotically:
  - Do we do constant work per edge pop?
  - No, because one edge may combine with many others.
  - We do constant work per traversal (edge-edge combination).
  - How many traversals?
  - Form of traversal: Y[i,j] + Z[j,k] form Z[i,k].
  - So there are $O(n^3)$ traversals – cubic time.

Runtime: Practice

- Let's take the treebank grammar and go parsing!



~ 20K Rules

(not an optimized parser!)

Observed exponent:

3.6

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

Semantic Interpretation

- Back to meaning!
  - A very basic approach to computational semantics
  - Truth-theoretic notion of semantics (Tarskian)
  - Assign a "meaning" to each word
  - Word meanings combine according to the parse structure
  - People can and do spend entire courses on this topic
  - We'll spend about 15 min!
- Supplemental reading will be on the web page (along with a supplemental syntax reading).
- Question for class: who would attend crash-course linguistics sections if I held them?

Types of Expressions

- Proper names:
  - Refer directly to some entity in the world
  - Have type "e", or entity
  - Alex : alex
- Sentences:
  - Are either true or false (given how the world actually is)
  - Have type "t" for "truth value"
  - Alex sings : sings(alex)
- So what about verbs (and verb phrases)?
  - sings must combine with alex to produce sings(alex)
  - The λ-calculus is a notation for functions whose arguments are not yet filled.
  - sings : λx.sings(x)
  - This is predicate – a function which takes an entity (type e) and produces a truth value (type t). We can write its type as e→t.

S sings(alex)

NP | Alex | alex

VP | sings | λy.sings(y)

Compositional Semantics

- So now we have meanings for the words
- How do we know how to combine words?
- Associate a combination rule with each grammar rule:
  - S : β(α) → NP : α VP : β (function application)
  - VP : λx . α(x) ∧ β(x) → VP : α and : ∅ VP : β (intersection)
- Example:

sings(john) ∧ dances(john)

S [λx.sings(x) ∧ dances(x)](john)

NP | John | john

VP λx.sings(x) ∧ dances(x)

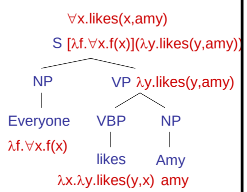
VP | sings | λy.sings(y)

and

VP | dances | λz.dances(z)

Other Cases

- Transitive verbs:
  - likes : λx.λy.likes(y,x)
  - Two-place predicates of type e→(e→t).
  - likes Amy : λy.likes(y,Amy) is just like a one-place predicate.
- Quantifiers:
  - What does "Everyone" mean here?
  - Everyone : λf.∀x.f(x)
  - Mostly works, but some problems
    - Have to change our NP/VP rule.
    - Won't work for "Amy likes everyone."
  - "Everyone like someone."
  - This gets tricky quickly!



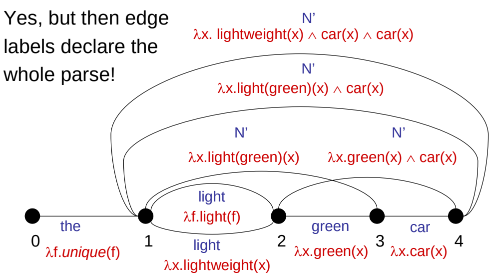
Trickier Stuff

- Non-Intersective Adjectives
  - green ball : λx.[green(x) ∧ ball(x)]
  - fake diamond : λx.[fake(x) ∧ diamond(x)] ? → λx.[fake(diamond(x))]
- Generalized Quantifiers
  - the : λf.[*unique-member*(f)]
- Pronouns
- Plural NPs
- Tense
- Ellipsis
- Propositional Attitudes
- Questions!

- … the list goes on and on!

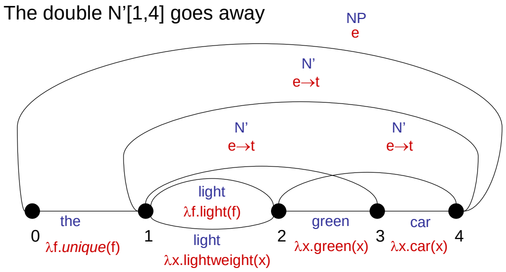
Parsing with Semantics

- Let's say we get that all sorted out…
- Can we augment our parser edges with meanings?
- Yes, but then edge labels declare the whole parse!



Parsing with Semantics

- Instead: augment non-word edges with types
- Assemble meanings the same way we assemble parses
- The double N'[1,4] goes away



What have we accomplished?

- One big unified approach!
  - Sentences in, compact syntactico-semantic representations out
  - Can get parts-of-speech (for, e.g., text-to-speech)
  - Can get phrase structure (for, e.g., translation)
  - Can translate sentences into first-order logic statements (for, e.g., reasoning)
- The Achilles heel:
  - Still now way to decide which analysis is right!
  - Rest of the course focuses on this problem.

Modeling Uncertainty

- Gaping hole warning!
- Big difference between the syntax and semantics models presented here.

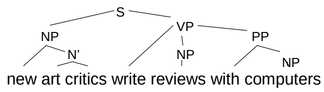
The scout saw the enemy soldiers with night goggles.

- If we get good probabilistic tools, we'll be able to say things like "72% belief that the PP attaches to the NP."
- That means that *probably* the enemy has night vision goggles.
- However, you can't throw a logical assertion into a theorem prover with 72% confidence.
- Not clear humans really extract and process logical statements symbolically anyway.

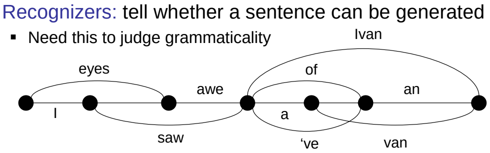
- In short, we need probabilistic reasoning, not just probabilistic disambiguation followed by symbol reasoning!

Parsing vs. Recognition

- Parsers: find the derivations of a sentence in a grammar



- Recognizers: tell whether a sentence can be generated
  - Need this to judge grammaticality



  - Only "I saw a van" and "I saw Ivan" are really grammatical

Who Cares about Recognition?

- Analysis is only a part of NLP!
  - In general we analyze (parse) input language
  - But we have to generate in the output language
  - Translation: Analyze some French, generate some English (or whatever source and target)
  - Speech Recognition: Analyze some acoustic data, generate some English
  - Text Summarization: Read some English, generate less English
  - Need to make sure the results are well formed
- Transduction = Transfer + Fluency

How's our Symbolic Parser at Recognition?

- Using the treebank grammar:

  I saw a van ✓

  I saw of an ✓

  the the the the of ✓

- In fact, it accepts *T** (all terminal strings).
- We'll obviously have to raise our game here!

What's Next?

- Modeling uncertainty from now on!
  - Probabilistic recognition: language modeling
  - Probabilistic parsing: disambiguation
- Next class: building Markov language models
- Readings: Skim M+S 3 4J+M 9,15
- Assignment 0: Try it out – little work, lots of fun.