COMP9414: Artificial Intelligence

Lecture 7a: Grammars and Parsing

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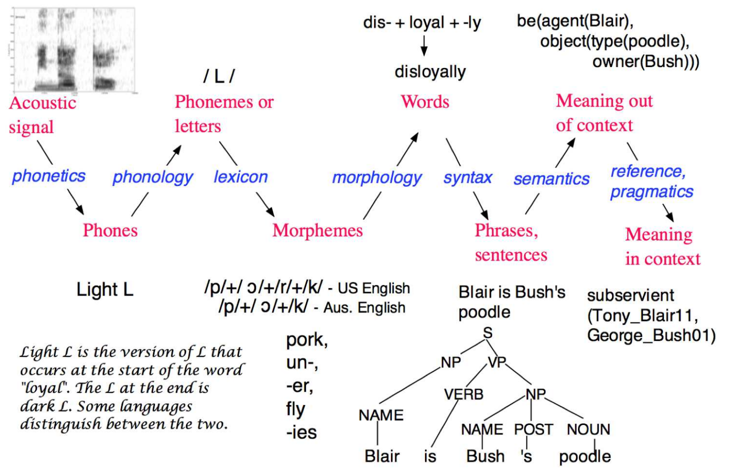
This Lecture

- Overview of Natural Languages
- Syntax and Grammar for Natural Languages
- (Simple) Semantics for Natural Languages
- Pragmatics for Natural Languages

Linguistics Landscape



Natural Language Processing

- Syntax
  - Linguistic Knowledge
  - Grammars and Parsing
  - Probabilistic Parsing
- Semantics
  - Semantic Interpretation and Logical Form
- Pragmatics
  - Discourse Processing
  - Speech Act Theory
  - (Spoken) Dialogue Systems

Related Disciplines

- Linguistics
  - Study of language in the abstract and particular languages
- Psycholinguistics
  - Psychological models of human language processing
- Neurolinguistics
  - Neural models of human language processing
- Logic
  - Study of formal reasoning

NLP Applications

- Chatbots
  - Customer service, e.g. CBA, Amtrak, Lyft, Spotify, Whole Foods
- Personal Assistants
  - Siri, Alexa, Google Assistant
- Information Extraction
  - Financial reports, news articles
- Machine (Assisted) Translation
  - Weather reports, EU contracts, Canada Hansard
- Social Robotics
  - Home care robots

Central Problem – Ambiguity

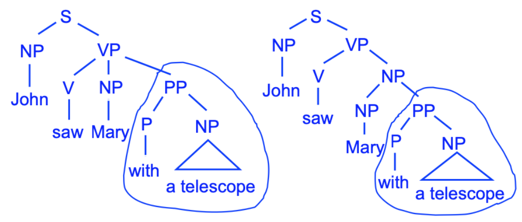
- Natural languages exhibit ambiguity

  "The fisherman went to the bank" (lexical)
  "The boy saw a girl with a telescope" (structural)
  "Every student took an exam" (semantic)
  "The table won't fit through the doorway because it is too [wide/narrow]" (pragmatic)

- Ambiguity makes it difficult to interpret meaning of phrases/sentences
  - But also makes inference harder to define and compute
- Resolve ambiguity by mapping to unambiguous representation

Structural Ambiguity

"John saw Mary with a telescope"



- Different interpretation $\rightarrow$ different representation

"John sold a car to Mary" and "Mary was sold a car by John"

- Same interpretation $\rightarrow$ same representation

Syntax

- Linguistic Knowledge and Grammars
- Context Free Grammars
- Parsing
  - Top Down Parsing
  - Bottom Up Parsing
  - Chart Parsing
  - Deterministic Parsing
  - Probabilistic Parsing

Framework (Chomsky)

- descriptive vs prescriptive
  - Goal not to dictate use of language, but describe how language, especially spoken language, is actually used
- sentence vs utterance
  - Consider sentences (as an abstraction over utterances)
- competence vs performance
  - Focus on underlying linguistic knowledge
- descriptive vs explanatory adequacy
  - Aim to explain how linguistic knowledge is acquired

Methodology

- Autonomy of Syntax

  John promised to work
  *John persuaded to work

  vs

  *John was promised to work (by someone else)
  John was persuaded to work (by someone else)
- Shows 'promise' and 'persuade' have different properties

* means ungrammatical

Lexical Items (Basic Words)

- Open class
  - Nouns: denote objects (e.g. cat, John, justice)
  - Verbs: denote actions, events (e.g. buy, break, believe)
  - Adjectives: denote properties of objects (e.g. red, large)
  - Adverbs: denote properties of events (e.g. quickly)
- Closed class (function words)
  - Prepositions: at, in, of, on, . . .
  - Articles: the, a, an
  - Conjunctions: and, or, if, then, than, . . .

Sentence Forms

- Declarative (indicative)
  - Bart is listening.
- Yes/No question (interrogative)
  - Is Bart listening?
- Wh-question (interrogative)
  - When is Bart listening?
- Imperative
  - Listen, Bart!
- Subjunctive
  - If Bart were listening, he might hear something useful.

Noun Phrases

- Distribution over sentences
  - Noun phrases: occur as "subject" with a range of "predicates"
    - ⟨noun phrase⟩ ate the bone
    - ⟨noun phrase⟩ saw the bird in the sky
    - ⟨noun phrase⟩ believes that 2 + 2 = 4
  - Examples

    John, The dog, The big ugly dog,
    The man in the red car,
    The oldest man in the world with a beard,
    The oldest man who lives in China, . . .
- Sentences need not "make sense"

Verb Phrases

- Distribution over sentences
  - Verb phrases: occur as "predicate" with a range of "subjects"

    John ⟨verb phrase⟩
    The dog ⟨verb phrase⟩
    Any noun phrase ⟨verb phrase⟩
  - Examples

    . . .
- Notice ⟨verb phrase⟩ depends on ⟨noun phrase⟩

Inside Noun Phrases

- Within noun phrase
  - Main item (the head of the phrase): noun
  - Optional specifiers
    - Determiners (articles, demonstratives, quantifiers)
    - Adjectives and other nouns
  - Mandatory arguments
    - Depend on head (e.g. capital ⟨of France⟩)
  - Optional modifiers
    - Adjectival phrases (e.g. larger than Spain)
    - Prepositional phrases (e.g. in the park)
    - Relative clauses (e.g. who likes beer)
  - Order specifiers, head, modifiers in English

Inside Verb Phrases

- Within verb phrase
  - Main item (the head of the phrase): verb
  - Optional specifiers
    - Auxiliary verbs (e.g. do, does, will, might, . . .)
    - Adverbs (e.g. quickly)
  - Mandatory arguments
    - depend on head (e.g. bought ⟨Henry⟩ ⟨a book⟩)
  - Optional modifiers
    - Adverbial phrases (e.g. more quickly than Henry)
  - Notice similar structure to noun phrases

Prepositional Phrases

- Within prepositional phrase
  - Main item (the head of the phrase): preposition
  - Mandatory arguments
    - ⟨noun phrase⟩ (e.g. in the park)
- Nouns, verbs, etc. are just the heads of phrases

Context Free Grammars

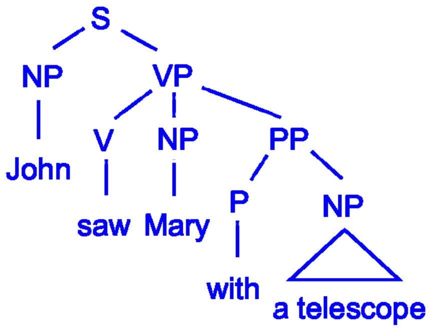
- Nonterminal symbols (grammatical categories)
- Terminal symbols (lexical items)
- Start symbol (a nonterminal) e.g. ⟨sentence⟩
- Rewrite rules
  - nonterminal → sequence of nonterminals, terminals
    e.g. ⟨sentence⟩ → ⟨noun phrase⟩ ⟨verb phrase⟩
- Open question: is English context free?

Typical (Small) Grammar

S → NP VP
NP → [Det] Adj* N [AP | PP | Rel Clause]*
VP → V [NP] [NP] PP*
AP → Adj PP
PP → P NP
Det → a | an | the | . . .
N → John | park | telescope | . . .
V → saw | likes | believes | . . .
Adj → hot | hotter | . . .
P → in | . . .

Special notation: * is “0 or more”; [. .] is “optional”

Syntactic Structure



Syntactically ambiguous = more than one parse tree

(Leftmost) Derivation of Example

S
⇒ NP VP
⇒ N VP
⇒ John VP
⇒ John V NP PP
⇒ John saw NP PP
⇒ John saw N PP
⇒ John saw Mary PP
⇒ John saw Mary P NP
⇒ John saw Mary with NP
⇒ John saw Mary with Det N
⇒ John saw Mary with a N
⇒ John saw Mary with a telescope

⇒ means “rewrites as”

Rightmost Derivation

S
⇒ NP VP
⇒ NP V NP PP
⇒ NP V NP P NP
⇒ NP V NP P Det N
⇒ NP V NP P Det telescope
⇒ NP V NP P a telescope
⇒ . . .
⇒ . . .
⇒ . . .

Parsing

- Aim is to compute a derivation of a sentence (hence tree)
- Methods
  - Top down
    - Start with S, apply rewrite rules until sentence reached
  - Bottom up
    - Start with sentence, apply rewrite rules “in reverse” until S is reached
  - Chart parsing
    - Chart records parsed fragments and hypotheses
    - Can mix top down and bottom up strategies

Top Down Parsing

- Use a stack to record working hypothesis
- Start with S as only symbol on stack
- At each step
  - Rewrite top of stack T using grammar rule T $\rightarrow$ RHS i.e. replace T by RHS (in reverse order), OR
  - Match word on top of stack to next word in sentence
- Apply backtracking on failure
- Accept sentence when stack is empty and all words in sentence matched; reject sentence when no rules to try
- Produces leftmost derivation

Example

STACK	INPUT
S	John saw Mary with a telescope
VP NP	John saw Mary with a telescope
VP N	John saw Mary with a telescope
VP John	John saw Mary with a telescope
VP	saw Mary with a telescope
PP NP V	saw Mary with a telescope
PP NP saw	saw Mary with a telescope
PP NP	Mary with a telescope
...	...
...	...

Bottom Up Parsing

- Use a stack to record parsed (left-right) fragment
- Start with stack empty
- At each step
  - Rewrite sequence at top of stack using rule T $\rightarrow$ RHS i.e. replace RHS (in reverse) by T, OR
  - Move word from input to stack
- Apply backtracking on failure
- Accept sentence when input empty and stack contains S; reject sentence when no more rules to try
- Produces rightmost derivation (in reverse)

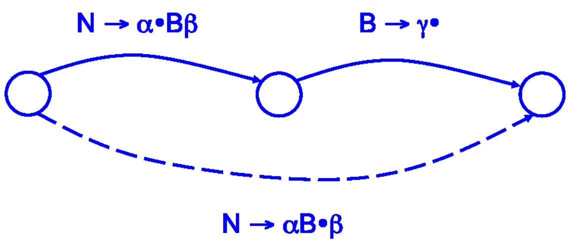
Example

STACK	INPUT
	John saw Mary with a telescope
John	saw Mary with a telescope
N	saw Mary with a telescope
NP	saw Mary with a telescope
NP saw	Mary with a telescope
NP V	Mary with a telescope
NP V Mary	with a telescope
NP V N	with a telescope
...	...
...	...

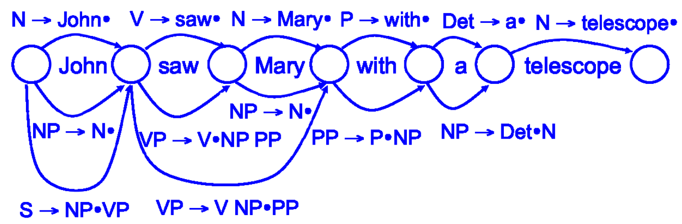
Chart Parsing

- Use a chart to record parsed fragments and hypotheses
- Hypotheses $\mathrm{N} \rightarrow \alpha \bullet \beta$ where $\mathrm{N} \rightarrow \alpha\beta$ is a grammar rule means "trying to parse N as $\alpha\beta$ and have so far parsed α"
- One node in chart for each word gap, start and end
- One arc in chart for each hypothesis
- At each step, apply fundamental rule
  - If chart has $\mathrm{N} \rightarrow \alpha \bullet \mathrm{B}\beta$ from n_1 to n_2 and $\mathrm{B} \rightarrow \gamma\bullet$ from n_2 to n_3 add $\mathrm{N} \rightarrow \alpha\mathrm{B} \bullet \beta$ from n_1 to n_3
- Accept sentence when $\mathrm{S} \rightarrow \alpha\bullet$ is added from start to end
- Can produce any sort of derivation

Fundamental Rule



Example Chart



Top Down Chart Parsing

- Start with $\mathrm{S} \rightarrow \bullet\alpha$ from start node to start node for all rules $\mathrm{S} \rightarrow \alpha$ where S is start symbol
- When adding $\mathrm{N} \rightarrow \alpha \bullet \mathrm{B}\gamma$ from n_1 to n_2
  - Also add $\mathrm{B} \rightarrow \bullet\beta$ from n_2 to n_2 for each rule $\mathrm{B} \rightarrow \beta$
  - Including the special case when α is empty and $n_1 = n_2$
- Exercise: Trace top down chart parser on example

Bottom Up Chart Parsing

- Start with arcs for each lexical item
- When adding C $\rightarrow \alpha\bullet$ from n_1 to n_2
  - Also add B $\rightarrow \bullet C\gamma$ from n_1 to n_1 for each rule B $\rightarrow C\gamma$
- Exercise: Trace bottom up down chart parser on example

Compare and Contrast

- Top Down Parsing
  - Simple, Memory efficient
  - Much repeated work, may loop infinitely
- Bottom Up Parsing
  - Less repeated work, harder to control
- Chart Parsing
  - Memory inefficient (especially with features)
  - No repeated work, difficult to control

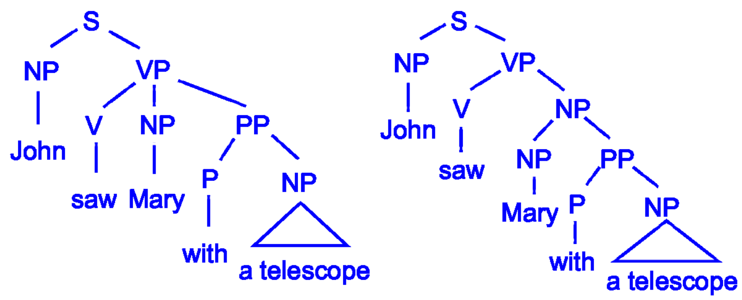
Deterministic Parsing

- Motivation
  - People don't notice ambiguity . . .
  - But sometimes have trouble

    "The horse raced past the barn fell"
    "We painted all the walls with cracks"
    "The man kept the dog in the house"
- Can we do what the "human parser" does?

Heuristics

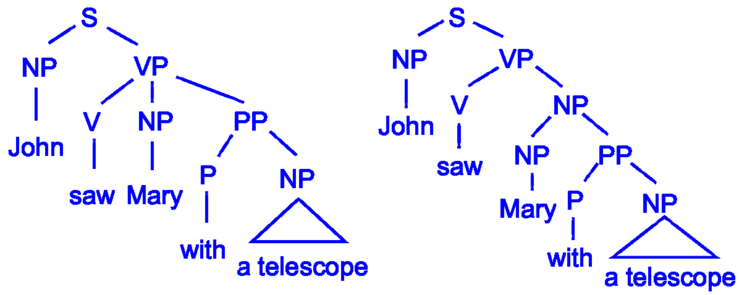
Minimal Attachment



- Minimize size of parse tree

Heuristics

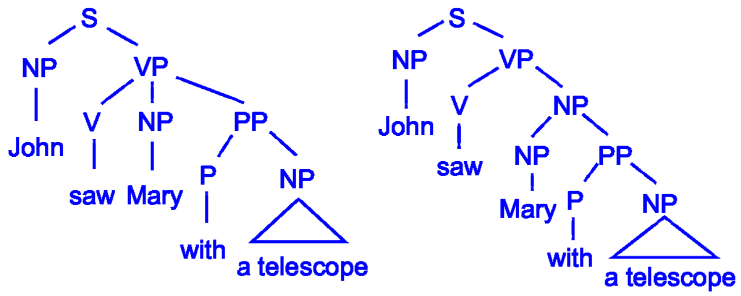
Right Association



- Always attach to rightmost (lower) nodes

Heuristics

Lexical Preference



- Try to fill most common subcategorization frame

Probabilistic Context Free Grammars

- Associate probabilities with grammar rules
  - Requires parsed corpus (e.g. Penn Treebank)
  - Count number of times rule used in parsing corpus sentences
- Probability of parse tree
  - Π_r probability rule r * Π_w probability of word w given category
  - Assuming independence (again)

Probabilistic Chart Parsing

- Start with probabilities calculated by part of speech tagger
- Multiply probabilities when applying fundamental rule
- Best-First Chart Parsing
  - Examine most likely constituents first (priority queue)
    - Various ways to estimate these probabilities!
  - When adding $A \rightarrow \alpha B \bullet \beta$, try to extend to $A \rightarrow \alpha B \beta^1 \bullet \beta^2$
  - Never constructs constituents with lower probability than parse

Summary

- Syntactic Knowledge
  - Grammatical categories defined by distribution
  - Much determined by properties of lexical items
- Context Free Grammars
  - Useful and powerful formalism
  - Relatively efficient parsers
  - Limited when dealing with complex phenomena
- Parsing
  - Top down method is easy to understand, but not efficient
  - Bottom up method is more efficient