AI Programming

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Natural Language Processing

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12-0: Speech Acts

- Since the 1950s (Wittgenstein), communication has been seen as a set of *speech acts*.
  - Communication as a form of action.
- Acts include: query, inform, request, acknowledge, promise
- An agent has a goal that it needs to accomplish, and selects speech acts that help it to acomplish that goal.

12-1: Speech Acts

- An agent has a speech act it wants to achieve
- It must convert this, plus some internal knowledge, into an *utterance* in a particular *language*.
- This utterance is then transmitted to a *hearer* or receiver.
- The hearer must then translate this back into an internal representation and reason about this new knowledge.

12-2: Language

- A language consists of a (possibly infinite) set of strings.
- These strings are constructed through the concatenation of *terminal symbols*.
- We'll distinguish between *formal languages* and *natural languages*
- Formal languages have strict mathematical definitions.
- We can say unambiguously whether a string is a legal utterance in that language.
  - SQL, first-order logic, Java, and Python are all formal languages.

12-3: Natural Language

- Natural languages do not have a strict mathematical definition.
- They have evolved through a community of usage.
  - English, Chinese, Japanese, Spanish, French, etc.
- Structure can be specified:
  - Prescriptively: What are the “correct” rules of the language.
  - Descriptively: How is the language actually used in practice?
- We’ll attempt to treat natural languages as formal languages, even though the match is inexact.

12-4: Grammars

- A *grammar* is a set of rules that specifies the legal structure of a language.
- Each rule specifies how one or more symbols can be *rewritten*.
  - Languages consist of *terminal symbols*, such as “cat”, “the”, “ran”
    - These are our *lexicon*
  - and *nonterminal symbols*, such as NP, VP, or S.

12-5: Example Lexicon

```
Noun -> cat | dog | bunny | fish
InTansVerb -> sit | sleep | eat
TransVerb -> is
Adjective -> happy | sad | tired
Adverb -> happily | quietly
Gerund -> sleeping
Article -> the | a | an
Conjunction -> and | or | but
```

12-6: Example Grammar

```
S -> NP VP | S -> S Conjunction S
NP -> Noun | Article Noun
VP -> InTransVerb | TransVerb Adjective | InTra
InTransVerb Gerund
```

12-7: Syntax and Semantics

- The grammar of a language forms its *syntax*.
  - This describes the structure of a sentence, and defines legal sentences.
- The *semantics* of a sentence describes its actual meaning.
  - This might be expressed in some sort of internal representation, such as SQL, logic, or a data structure.
- The *pragmatics* of a sentence describes its meaning in the context of a given situation.
  - “Class starts at 5:30” might have different meanings depending on the context.

12-8: Classes of languages

- We can characterize languages (and grammars) in terms of the strings that can be constructed from them.
- Regular languages contain rules of the form $A \rightarrow b | A \rightarrow Bb$
  - Equivalent to regular expressions or finite state automata
  - Can’t represent (for example) balanced opening and closing parentheses.
- Context-free languages contain rules of the form $A \rightarrow b | A \rightarrow XY$ (one nonterminal on left, anything on righthand side)
  - All programming languages are context free.

12-9: Classes of languages

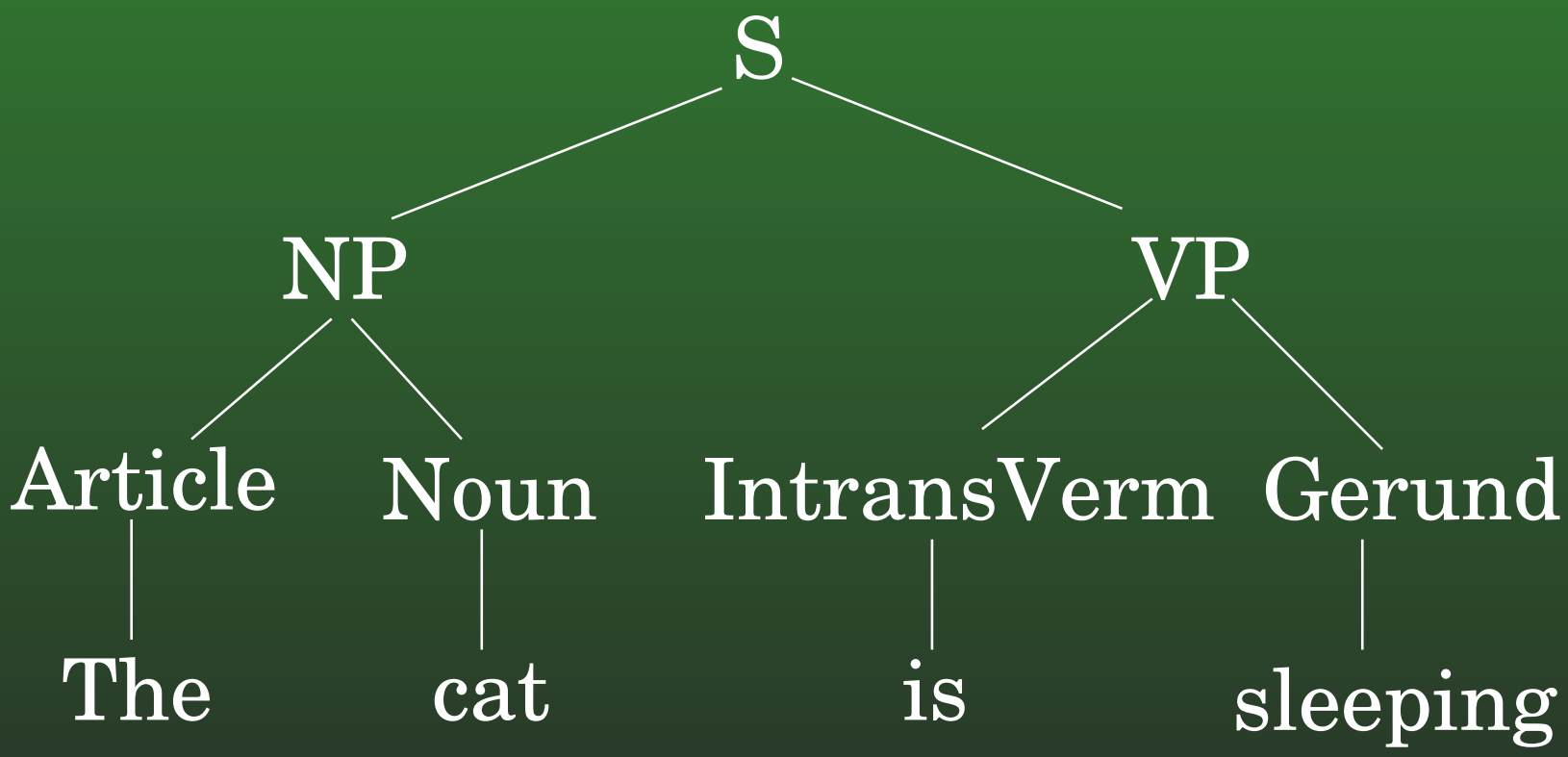
- Context-sensitive languages contain rules of the form $ABC \rightarrow AQC$ (righthand side must contain at least as many symbols as left)
  - Some natural languages have context-sensitive constructs
- Recursively enumerable languages allow unrestricted rules.
  - They are equivalent to Turing machines.
- We'll focus on context-free grammars.

12-10: Parsing

- The first step in processing an utterance is *parsing*.
- Parsing is determining the syntactic structure of a sentence.
  - Parts of speech and sentence structure
- This allows us to then try to assign meaning to components.
- Typically, parsing produces a *parse tree*.

12-11: Example

- "The cat is sleeping"



12-12: Parsing as Search

- Parsing can be thought of as search
  - Our search space is the space of all possible parse trees
- We can either start with the top of the tree and build down, or with the leaves and build up.

12-13: Top-down parsing

- Initial state: Tree consisting only of S.
- Successor function: Returns all trees that can be constructed by matching a rule in the grammar with the leftmost nonterminal node.
- Goal test: Leaves of tree correspond to input, no uncovered nonterminals.

12-14: Example

[S: ?]
[S: [NP:?] [VP :?]]
[S: [Noun : ?] [VP : ?]] - dead end - backtrack.
[S: [[Article: ?] [Noun: ?]] [VP : ?]]
[S:[[Article: The] [Noun: ?]] [VP : ?]]
[S:[[Article: The] [Noun: cat]] [VP : ?]]
[S:[[Article: The] [Noun: cat]] [VP : [Verb : ?]] - dead end,backtrack.
[S:[[Article: The] [Noun: cat]] [VP : [[TransVerb: ?] [Adv: ?]]] -dead end, backtrack.
[S:[[Article: The] [Noun: cat]] [VP : [[IntransVerb: ?] [Gerund: ?]]]
[S:[[Article: The] [Noun: cat]] [VP : [[IntransVerb: is] [Gerund: ?]]]
[S:[[Article: The] [Noun: cat]] [VP : [[IntransVerb: ?] [Gerund: sleeping]]]

12-15: Top-down parsing

- Top-down parsing has two significant weaknesses:
  - Doesn't exploit sentence structure at upper levels of the parse tree
    - Don't look at the input at all until we've made several choices
    - Can wind up doing unnecessary search
  - Can't easily deal with left-recursive rules, such as $S \rightarrow S\ Conj\ S$
  - Can wind up infinitely re-expanding this rule, as in DFS.

12-16: Bottom-up parsing

- Bottom-up parsing takes the opposite approach:
  - Start with leaves of the tree.
  - Try to find right-hand sides of rules that match leaves.
  - Work upward.
- Start state: A tree with leaves filled in.
- Successors: for each position in the tree, examine each rule, and return new trees by substituting right-hand sides for left-hand sides.
- Goal test: a tree with the root S.

12-17: Example

Init: 'The cat is sleeping' Succ: [[Art 'cat is sleeping'] , ['the' Noun 'is sleeping'] ['the cat' InTransVerb 'sleeping']]

S1: [Art 'cat is sleeping'] Succ: [[Art Noun 'is sleeping'] [Art 'cat' InTransVerb 'sleeping'] [Art 'cat is' Gerund]]

S2: [[Art Noun 'is sleeping'] Succ: [[NP 'is sleeping'] [Art Noun IntransVerb 'sleeping'] [Art Noun 'is' Gerund]]

S3: [NP 'is sleeping'] Succ: [[NP InTransVerb 'sleeping'] [NP 'is' Gerund]]

S4: [NP InTransVerb 'sleeping'] Succ: [NP IntransVerb Gerund]

S5: [NP IntransVerb Gerund] Succ: [NP VP]

S6: [NP VP] Succ: [S]

12-18: Bottom-up parsing

- While everything went fine in this simple example, there can be problems:
  - Words might match multiple parts of speech
  - The same right-hand side can match many left-hand sides
  - Partial parses that could never lead to a complete sentence get expanded.

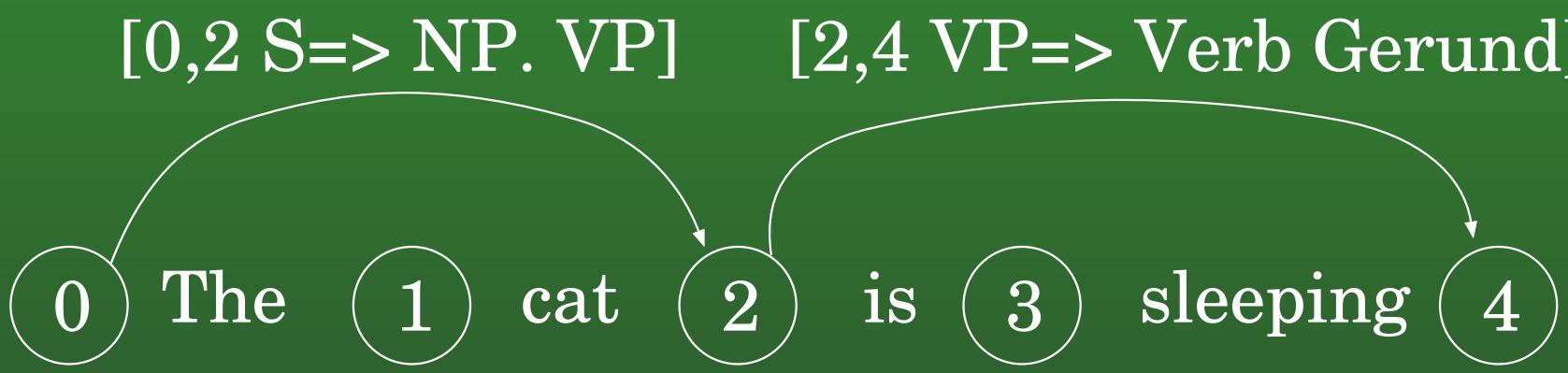
12-19: Efficient Parsing

- Consider the following sentences from R & N:
  - “Have the students in section 2 of CS 662 take the exam”
  - “Have the students in section 2 of CS 662 taken the exam?”
- If we parse this left-to-right (in a depth-first fashion) we can’t tell whether it’s a command or a question until we get to “take/taken”.
- We might then backtrack and have to rediscover that “the students in section 2 of CS662” is an NP in either sentence.
- We need to keep track of partial results so that we don’t have to regenerate them each time.

12-20: Chart Parsing

- We keep track of the partial results of our parse in a data structure called a *chart*.
- The chart is represented as a graph. An n-word sentence produces a graph with $n + 1$ vertices representing each gap before, between, or after a word.
- Edges are added to the chart as parses are discovered for substrings.
- Edges are denoted with the starting and ending vertex, the parse discovered so far, and the parse needed to complete the string.

12-21: Example



- The edge from 0 to 2 is denoted with [S -> NP . VP]. This says that this edge matches an NP, and if you could find a VP, the sentence would be parsed.
- The edge from 2 to 4 is denoted with [VP -> Verb Gerund .] This says that this substring contains a successful parse of a VP as Verb and Gerund.

12-22: Chart Parsing

- Chart parsing uses the best of both top-down and bottom-up methods:
- It starts top-down so as to take advantage of global structure
- It uses bottom-up only to extend existing partial parses
- It uses the chart to avoid repeated search

12-23: Chart Parsing

- (Note: this algorithm differs a little from the one presented in R&N. It scans the text first, rather than interleaving.)
- There are three basic methods:
  - AddEdge - this adds an edge to the chart and then either tries to predict what will come next (if there's more after the dot) or to extend the edge (if there's not)
  - Predictor - adds an edge for each rule that could yield the first token after the dot.
  - Extender - finds other edges that can be extended with a completed edge.

12-24: Chart Parsing

```
chart(words) :
  for word in words :
     scanner(word)
  addEdge([0,0,S'-> .S])

  scanner(word) :
    foreach rule with word on the rhs :
      add an edge

  addEdge(edge) :
     if edge not in chart :
        append edge to chart
        if dot is at rhs :
           extender(edge)
        else :
           predictor(edge)
```

12-25: Chart Parsing

```
predictor([i,j, X -> a . B c]) :
    foreach rule that can predict B :
        addEdge(rule)

extender(rule) :
    foreach rule' with rule as part of the rhs
        replace rule' with rule
```

12-26: Example

- “The cat is sleeping”
- To begin, add edges mapping each word to all parts of speech that produce them.
- Add an edge [0,0,S’->.S]
- Since the . is not at the end, addEdge calls predictor to find a rule with S on the LHS.
- Predictor adds the edge [0,0,S -> . NP VP]
- AddEdge calls predictor again to find a match for NP.
- Predictor adds edges [0,0,NP -> . Noun] and [0,0, NP -> . Article Noun]
- addEdge then calls extender, which adds the edge

12-27: Example

- addEdge then calls extender, which adds the edge [0,2, NP -> Article Noun .]
- addEdge then calls extender to add the edge [0,2, S -> NP . VP]
- addEdge then calls predictor to add the edges [2,2, VP -> . InTransVerb], [2,2,VP -> . TransVerb Adjective], [2,2,VP -> . InTransVerb Adverb], [2,2,VP-> . InTransVerb Gerund]

12-28: Example

- Extended adds the edge [2,3 VP -> IntransVerb . Adverb] and [2,3 VP -> IntransVerb . Gerund]
- Extender is called to add the edge [2,4, VP -> InTransVerb Gerund .]
- Extender is called to add the edge [S -> NP VP .] We have a successful parse.

12-29: Example II

```
Noun -> cat | dog | bunny | fish
InTansVerb -> sits | sleeps | eats
TransVerb -> is
Adjective -> happy | sad | tired
Adverb -> happily | quietly
Gerund -> sleeping
Article -> the | a | an
Conjunction -> and | or | but
```

a dog sleeps quietly

12-30: Example II

```
S -> NP VP | S -> S Conjunction S
NP -> Noun | Article Noun
VP -> InTransVerb |
      TransVerb Adjective |
      InTransVerb Adverb |
      InTransVerb Gerund
```

a dog sleeps quietly

12-31: Parsing is this hard?

- Wait a minute ... is parsing really this hard?
  - Parsing is a key component of compiler design
  - Thousand-line programs are parsed quite quickly
  - No searching required

12-32: Parsing is this hard?

- Computer languages are very restricted
  - No ambiguity
  - Each “language fragment” always means the same thing
- We can create LL(1) grammars for most programming languages
  - Possible to look at the first token, and know which rule to apply
  - Take one of Prof Parr’s language classes, or Compilers for much, much, more on parsing computer languages

12-33: Parsing is this hard?

- Natural Languages are *not* restricted at all
- No set way to encode any specific meaning
- Tremendously ambiguous
  - Even with unambiguous statements, often can't parse the first part of a sentence without seeing all the tokens
  - Context matters, too! (that's why people are pretty good at functional parsing)

12-34: Why are we doing this?

- So why go to all this effort?
- We want to determine the *meaning* (or semantics) of the sentence.
- Constructing a parse tree allows us to transform it into an internal representation that an agent can work with.

12-35: Challenges with NLP

- This is still a hard problem
  - A sentence may have multiple parses
    - “Squad helps dog bite victim.”
    - “Children cook and serve grandparents”
  - We need a complete lexicon for our language.
  - Figures of speech, such as analogy, metaphor, and metonymy.
    - “Apple announced a new iPhone this morning.”
    - “The White House supports the bill”

12-36: Next time …

- We'll combine the statistical ideas from information theory with the structured approach of NLP.
  - What's the probability of a given parse?
  - Speeding up parsing
  - Dealing with incorrect grammar
  - What meaning is the most likely?
  - How should a phrase be segmented?