CMPT-413: Computational Linguistics

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Parts of Speech

- We have seen that individual words can be classified into groups or classes that we call **parts of speech**
  - Determiners: *a, the*
  - Verbs: *arrive, attracts, love, sit*
  - Prepositions: *of, by, in, outside, on*
  - Nouns: *he, she, it, San, Diego*
- But these individual words can group together to form larger groups which possess meaning when put together, e.g. *San Diego*, *the man outside the building*

Constituents

- Let's consider the grouping of words into **noun phrases**
  - *three parties from Brooklyn*
  - *a high class spot such as Mindy's*
  - *they*
  - *Harry the Horse*
  - *the fact that he came into the Hot Box*
  - *swimming on a hot day*

Chunking Noun Phrases: Not as easy as it seems

- Finding noun phrases can be treated as finding a sequence of words that is a noun phrase (the **chunking** approach). Finding chunks is not trivial:
  - *(NNP San) (NNP Diego)*
  - *(NNPS Wednesdays)*
  - *(DT the) (NN company) (POS 's) (VBN refocused) (NN direction)*
  - *(DT the) (NN government) (VBZ 's) (VBG dawdling)*
  - $*$ *(DT The) (NNP Dow) (NNP Jones) (VBZ is) (VBG swimming) (IN in) (NN tech) (NNS stocks)*

Recursion in Regular Languages

- Let's attempt to provide a regular expression grammar for a subset of all the possible noun phrases
- Consider the noun phrases: *the man in the park*, *the person with the big head in the park*, *the unicorn in the garden inside the dream with a strange mark on the head*, ...
- These are simple noun phrases that have prepositional phrases (PP, for short) modifying nouns. PPs are another example of a constituent, but now we need to combine them with NPs

Recursion in Regular Languages

- Consider the noun phrases: *the man in the park*, *the person with the big head in the park*, *the unicorn in the garden inside the dream with a strange mark on the head*, ...
- (NP) $(PP)^* \rightarrow$ (Det N) $(PP)* \rightarrow$ (Det N) $(P\ NP)^*$
- (Det N) (P (Det N)) $PP^* \rightarrow$ (Det N) (P (Det N))*
- So, it's possible, but it gets ugly fast, let's widen our view of what can occur inside NPs.

Recursion in Regular Languages

- Let's call (Det N) a **basal** NP and now consider that (Det N) is not the only base NP that is possible: (N) or (A N) or (A^+ N) or even:
  (D A^* N POS N) *the short man 's dream* ...
- So this means that we can now have (P (N)) or (P (A N)) or (P (A^+ N)) or ...
- Each former type of NP can be modified by each latter type of PP
- What is the only way to rescue the regular expression approach?
  combinatorial explosion of combinations

Context-Free Languages

- Clearly, this and other issues with the kind of recursion possible in regular languages is a problem if we want to describe natural languages
  Recall our morphological FSA which over-generated and produced bogus words like *demonizableable* **because** of recursion
- We need to look at a class of formal languages that generalizes regular languages: **Context-Free Languages**

Context-Free Languages

- Here is a simple Context Free Grammar that does word morphology. The CFG is more *elegant* and smaller than the equivalent regular grammar (consider ∗joyable, ∗richment):

$$
\begin{aligned}
V &\rightarrow X \\
A &\rightarrow X \textit{ -able} \mid X \textit{ -ment} \\
X &\rightarrow \textit{en- } NA \\
NA &\rightarrow \textit{joy} \mid \textit{rich}
\end{aligned}
$$

- This is an engineering argument. However, it is related to the problem of describing the human learning process. Certain aspects of language are learned all at once not individually for each case.
  e.g., learning *enjoyment* automatically if *enrichment* was learnt

Context-Free Grammars

- Recall the trinity of regular expressions, finite state automata and regular languages
- Now we generalize to context free grammars, pushdown automata and context-free languages
- Just like before, certain closure properties hold, the union of two CFLs is also a CFL, etc.
  except for one property that is true in RLs but not in CFLs

Context-Free Grammars

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- Just like before, certain closure properties hold, the union of two CFLs is also a CFL, etc.
  except for one property that is true in RLs but not in CFLs
- CFLs are not closed under Intersection

Context-Free Grammars

- Determinization is also not always possible for pushdown automata
  surprising fact about CFGs is that you can construct one that is *inherently* ambiguous
- Particular relevance for natural languages, compare with artificial grammars that we use routinely when we use a programming language (what happens in cases of ambiguity in finite state automata?)
- Deterministic vs. non-deterministic parsing (more on this later)

Context-Free Grammars

- A CFG is a 4-tuple: (N, T, P, S), where
  - N is a set of non-terminal symbols,
  - T is a set of terminal symbols which can include the empty string ϵ. T is analogous to Σ the alphabet in FSAs.
  - P is a set of rules of the form $A \rightarrow \alpha$, where $A \in N$ and $\alpha \in \{N \cup T\}^*$
  - S is a set of start symbols, $S \in N$

Context-Free Grammars

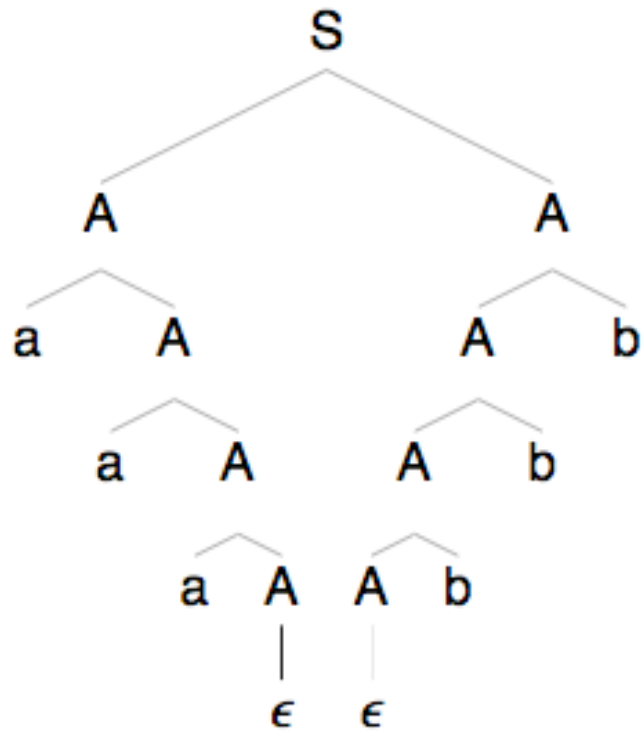
- Here's an example of a CFG, let's call this one G:
  1. $S \rightarrow a\ S\ b$
  2. $S \rightarrow \epsilon$
- What is the language of this grammar, which we will call $L(G)$, the set of strings *generated* by this grammar How? Notice that there cannot be any FSA that corresponds exactly to this set of strings $L(G)$ Why?
- What is the *tree set* or derivations produced by this grammar?

Context-Free Grammars

- This notion of generating both the strings and the trees is an important one for Computational Linguistics
- Consider the trees for the grammar G':
  $P = \{S \rightarrow A\ A, A \rightarrow aA, A \rightarrow A\ b, A \rightarrow \epsilon\}$,
  $\Sigma = \{a, b\}, N = \{S, A\}, T = \{a, b, \epsilon\}, S = \{S\}$
- Why is it called *context-free* grammar?

Context-Free Grammars

- Can the grammar G' produce only trees of the kind shown below?



Context-Free Grammars

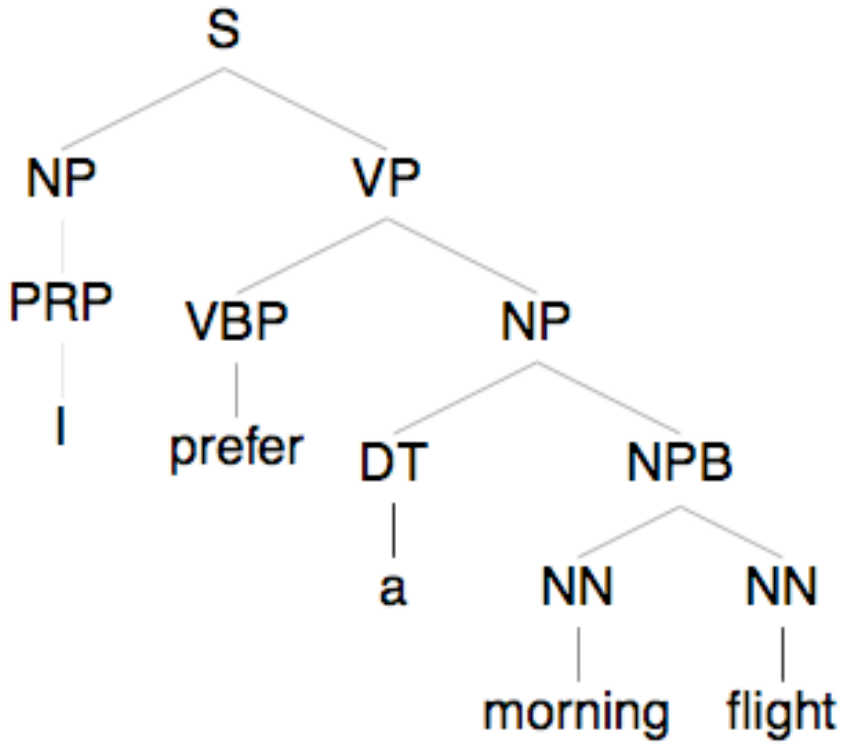
- We will come back to this issue when we try to figure out whether human languages are more powerful than CFLs.
- The distinction between strings and the trees (or any kind of structural description) is called *weak* vs. *strong* generative capacity.

Parse Trees

Consider the grammar with rules:

$$
\begin{aligned}
S &\rightarrow NP\ VP \\
NP &\rightarrow PRP \\
NP &\rightarrow DT\ NPB \\
VP &\rightarrow VBP\ NP \\
NPB &\rightarrow NN\ NN \\
PRP &\rightarrow I \\
VBP &\rightarrow prefer \\
DT &\rightarrow a \\
NN &\rightarrow morning \\
NN &\rightarrow flight
\end{aligned}
$$

Parse Trees



Parse Trees: Equivalent Representations

- (S (NP (PRP I)) (VP (VBP prefer) (NP (DT a) (NPB (NN morning) (NN flight)))))
- [$_S$ [$_{NP}$ [$_{PRP}$ I]] [$_{VP}$ [$_{VBP}$ prefer] [$_{NP}$ [$_{DT}$ a] [$_{NPB}$ [$_{NN}$ morning] [$_{NN}$ flight]]]]]

Ambiguous Grammars

- $S \rightarrow S\ S$
- $S \rightarrow a$
- Given the above rules, consider the input *aaa*, what are the valid parse trees?
- Now consider the input *aaaa*