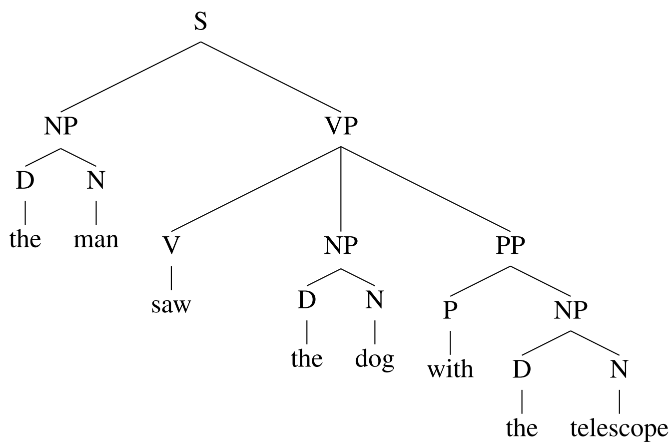
# Questions for Flipped Classroom Session of COMS 4705 Week 6, Fall 2014. (Michael Collins)

**Question 1** Consider the following parse tree:




Now assume that we add head-words to the non-terminals in the parse tree. We do this by specifying the following rules for finding the heads of context-free rules (note that these rules don't necessarily make sense from a linguistic standpoint):

- For the rule `S -> NP VP`, the `VP` is the head of the rule.
- For the rule `NP -> D N`, the `N` is the head of the rule.
- For the rule `PP -> P NP`, the `NP` is the head of the rule.
- For the rule `VP -> V NP PP`, the `NP` is the head of the rule.
- As is usual with head-finding rules, for any rule of the form `X -> w` where `X` is a non-terminal, and `w` is a word, we take `w` to be the head of the rule (and `X` then has `w` as its head-word).

**Question:** Draw a new version of the parse tree, where head-words have been added to the non-terminals in the tree using the rules we have specified.

**Question 2** Consider the following lexicalized grammar:

S(likes) $\rightarrow_2$ NP(Bob) VP(likes)
VP(likes) $\rightarrow_1$ VB(likes) NP(parks)
NP(parks) $\rightarrow_1$ NP(parks) PP(in)
NP(parks) $\rightarrow_1$ NP(parks) NP-CC(London)
NP(Paris) $\rightarrow_1$ NP(Paris) NP-CC(London)
PP(in) $\rightarrow_1$ IN(in) NP(Paris)
NP-CC(London) $\rightarrow_2$ CC(and) NP(London)
NP(Bob) $\rightarrow$ Bob
NP(parks) $\rightarrow$ parks
NP(London) $\rightarrow$ London
NP(Paris) $\rightarrow$ Paris
VB(likes) $\rightarrow$ likes

Show all parse trees under this grammar for the sentence

*Bob likes parks in Paris and London*

If we add probabilities to the above rules, how will this model perform compare to a conventional PCFG with rules `S` $\rightarrow$ `NP VP`, `NP` $\rightarrow$ `NP PP` etc.?

**Question 3** We define the following type of "lexicalized" grammar:

- $N$ is a set of non-terminal symbols
- $\Sigma$ is a set of terminal symbols
- $R$ is a set of rules which take one of two forms:
  - $X(h) \rightarrow Y_1(h)\ Y_2(w)$ for $X \in N$, and $Y_1, Y_2 \in N$, and $h, w \in \Sigma$
  - $X(h) \rightarrow h$ for $X \in N$, and $h \in \Sigma$
- $S \in N$ is a distinguished start symbol

Note that this is similar to the "lexicalized Chomsky normal form" grammar we introduced in lecture, **except** that we do not allow rules of the following form:

$$X(h) \rightarrow Y_1(w)\ Y_2(h) \text{ for } X \in N, \text{ and } Y_1, Y_2 \in N, \text{ and } h, w \in \Sigma.$$

**Question:** Define a grammar in the above form that gives at least one valid parse tree for the sentence *the man saw the man with the man*. Draw a parse tree under your grammar for this sentence. Make sure to show the head words in your parse tree.

**Question:** Now assume we have a probabilistic lexicalized context-free grammar with rules that take the above form. Give pseudo-code for an efficient dynamic programming algorithm that returns the highest probability parse tree for a given input sentence $w_1, w_2, \ldots, w_n$. Your algorithm should run in at most $O(n^3|N|^3)$ time where $n$ is the length of the sentence, and $|N|$ is the number of non-terminals in the grammar.

**Question 4** Consider a language model with a vocabulary $\mathcal{V} = \{a, b\}$ and the following parameters:

$$\begin{aligned}
q(a|*) &= 0.3 \\
q(b|*) &= 0.7 \\
q(a|a) &= 0.2 \\
q(b|a) &= 0.7 \\
q(STOP|a) &= 0.1 \\
q(a|b) &= 0.8 \\
q(b|b) &= 0.1 \\
q(STOP|b) &= 0.1
\end{aligned}$$

Now write down a lexicalized PCFG with the same distribution over sentences as this grammar (write down both the rules in the lexicalized PCFG, and their probabilities). For any string $s$, if $\mathcal{T}(s)$ is the set of possible parse trees for $s$, and $p(t)$ is the probability for any tree, then the probability distribution over strings is

$$p(s) = \sum_{t \in \mathcal{T}(s)} p(t)$$

Note that you can assume that the strings $s$ always end in the STOP symbol, so for example the string

*a b STOP*

should have probability

$$q(a|*) \times q(b|a) \times q(STOP|b)$$

under the lexicalized PCFG.