The CKY Algorithm

1. Determine the potential parses of the sentence “The women fish with bait” according to the PCFG below, using the CKY algorithm (see Lecture 15). Number the symbols you put in the chart in the order they would be computed. For each chart item, assume that candidate grammar rules are searched in the order they are listed below. Use these numbers to construct backpointers in the chart. For example, when constructing the 6th symbol NP out of a determiner with symbol number 2 and a noun with symbol number 3, you could indicate that by putting ‘6: NP (2, 3)’. (This is not a widely used custom, but a useful one when doing CKY on paper for the context of this tutorial.)

2. What are the probabilities of the parse trees?

\[
\begin{align*}
S & \rightarrow NP \ VP \ (1) \\
NP & \rightarrow DT \ N \ (0.5) \\
NP & \rightarrow N \ N \ (0.4) \\
NP & \rightarrow N \ (0.3) \\
VP & \rightarrow V \ PP \ (1) \\
PP & \rightarrow P \ NP \ (1) \\
DT & \rightarrow the \ (1) \\
P & \rightarrow with \ (1) \\
v & \rightarrow fish \ (1) \\
N & \rightarrow women \ (0.5) \ | \ fish \ (0.3) \ | \ bait \ (0.2)
\end{align*}
\]

2 Dependency Parsing

Consider the following sentence: “Red squirrels and mice eat tree nuts.”

1. This sentence contains an ambiguity: point out that ambiguity by giving paraphrases of the different meanings. Which interpretation is the most salient, and why?

2. Assume that when creating dependency trees we treat conjunction as described here (https://universaldependencies.org/u/dep/conj.html). The assumption that is crucial to the usage of dependency trees (relations between words are asymmetric and binary) is violated when we construct a dependency tree for a sentence with a conjunction: explain why.

3. Provide the dependency tree for the sentence. You can use the following labels to mark the arcs: amod, compound, conj, cc, nsubj, dobj, root. J&M, Figure 14.2, 3rd edition provides explanations per label.

4. Using this way of representing conjunction, could we represent both interpretations discussed in (1) above?
5. If you could change the way conjunction is represented in any way you would like, you would be able to represent the least salient interpretation of the sentence: provide that dependency tree.

3 Compositional Semantics

Consider the following sentence: “Some student ate every apple with a fork.”

1. Explain why this sentence is ambiguous.

2. Provide paraphrases that express the different interpretations that are possible due to the ambiguity.

3. Give the FOL representation of those interpretations. Use Davidsonian semantics as introduced in Lecture 21 (March 11th).

4. Finally, provide the lambda calculus derivation of “A student eats a green apple” using the grammar below. Adjectives were not included in the lecture. Which of the following captures the role of “green” best? Use that representation in your derivation.

(a) \( \lambda x.\text{green}(x) \)
(b) \( \lambda P.\lambda x. (\text{green}(x) \land P(x)) \)
(c) \( \lambda P.\lambda Q. \lambda x. (P(x) \land \text{green}(x) \land Q(x)) \)

5. Adjectives were not included in the lecture because they are not always straightforward. If we treated all adjectives analogously to “green”, we could make invalid inferences. Can you think of two adjectives where this would be the case?

\[
\begin{align*}
S & \rightarrow \text{NP VP} & \text{NP.Sem(VP.Sem)} \\
\text{NP} & \rightarrow \text{Det N’} & \text{Det.Sem(N.Sem)} \\
\text{VP} & \rightarrow \text{Vt NP} & \text{Vt.Sem(NP.Sem)} \\
\text{N’} & \rightarrow \text{A N’} & \text{A.Sem(N’.Sem)} \\
\text{N’} & \rightarrow \text{N} & \text{N.Sem} \\
\text{N} & \rightarrow \text{student} & \lambda x.\text{student}(x) \\
\text{N} & \rightarrow \text{apple} & \lambda x.\text{apple}(x) \\
\text{Vt} & \rightarrow \text{eat} & \lambda R.\lambda z. R(\lambda y.\text{eat}(z, y)) \\
\text{Det} & \rightarrow \text{a} & \lambda P.\lambda Q. \exists x. (P(x) \land Q(x)) \\
\text{A} & \rightarrow \text{green} & ??? \\
\end{align*}
\]