

This is a review of context-free grammars from the lecture on Tuesday; in each example, the grammar itself is on the left; the explanation for each non-terminal is on the right.

- Properly nested strings of parentheses.

$S \rightarrow \epsilon \mid S(S)$ properly nested parentheses

Here is a different grammar for the same language:

$S \rightarrow \epsilon \mid (S) \mid SS$ properly nested parentheses

- $\{0^m 1^n \mid m \neq n\}$. This is the set of all binary strings composed of some number of 0s followed by a different number of 1s.

$S \rightarrow A \mid B$	$\{0^m 1^n \mid m \neq n\}$
$A \rightarrow 0A \mid 0C$	$\{0^m 1^n \mid m > n\}$
$B \rightarrow B1 \mid C1$	$\{0^m 1^n \mid m < n\}$
$C \rightarrow \epsilon \mid 0C1$	$\{0^m 1^n \mid m = n\}$

Give context-free grammars for each of the following languages. For each grammar, describe *in English* the language for each non-terminal, and in the examples above. As usual, we won't get to all of these in section.

1. $\{0^{2n} 1^n \mid n \geq 0\}$

2. $\{0^m 1^n \mid m \neq 2n\}$

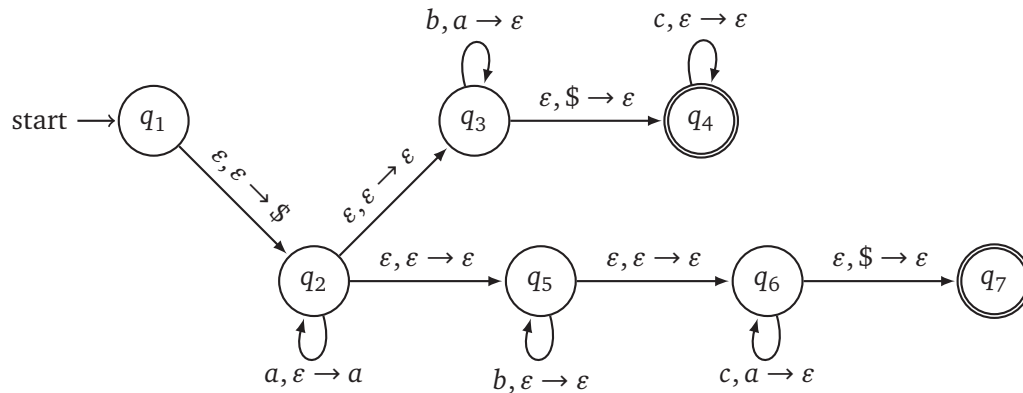
[Hint: If $m \neq 2n$, then either $m < 2n$ or $m > 2n$. Extend the previous grammar, but pay attention to parity. This language contains the string 01.]

3. $\{0, 1\}^* \setminus \{0^{2n} 1^n \mid n \geq 0\}$

[Hint: Extend the previous grammar. What is missing?]

The next few problems deal with push-down automata (PDA). The goal of these problems is to simply gain an understanding of PDAs which are the machines needed to recognize a context-free language:

4. What language does the following push-down automata recognize (Hint: This is a non-deterministic automata as most PDAs are)?



5. Develop the PDA for the language:

$$L = \{w \text{ is a palidrome and } w \in \{0, 1\}^*\} \quad (1)$$

Work on these later:

4. $\{w \in \{0, 1\}^* \mid \#(0, w) = 2 \cdot \#(1, w)\}$ – Binary strings where the number of 0s is exactly twice the number of 1s.
5. $\{0, 1\}^* \setminus \{ww \mid w \in \{0, 1\}^*\}$.

[Anti-hint: The language $\{ww \mid w \in \{0, 1\}^*\}$ is **not** context-free. Thus, the complement of a context-free language is not necessarily context-free!]

6. Convert the following CFG into a PDA:

$$S \rightarrow aBc \mid ab$$

$$B \rightarrow SB \mid \varepsilon$$