1. Read Definition 2.8, Theorem 2.9 and Example 2.10 in the textbook (third edition) concerning Chomsky Normal Form and then put the following grammar into Chomsky Normal Form.

\[ S \rightarrow T_a T \]
\[ T \rightarrow a T b | b T a | T T | \varepsilon \]


3. Let \( M \) be the PDA given at the end of class on March 6 that recognizes the language \( \{ w \in \{ a, b \}^* | w \text{ has the same number of } a's \text{ as } b's \} \). (You can find \( M \) in the final frame of the lecture video.)

Show an accepting computation for \( M \) on the string \( aabbbaab \) by giving a chart with the state, tape contents, and stack contents after each step.

4. (a) Following up on a suggestion made by a student in class, give a PDA \( M' \) that recognizes the language of the previous problem, but does so in a non-deterministic way, meaning that whenever \$ \$ comes to the top of the stack, the PDA can either guess that it has reached the end of the input and go to an accepting state which is a sink state, or it can guess that it has not reached the end of the input and read an \( a \) or \( b \) without going to the accept state before reading the next symbol.

(b) Show an accepting computation for \( M' \) on the string \( aabbbaab \) by giving a chart with the state, tape contents, and stack contents after each step.

5. Give PDAs that recognize the following languages:

(a) \( \{ 0^n 1^n 2^n 3^m | n, m \geq 0 \} \).

(b) \( \{ x \# y | x, y \in \{ 0, 1 \}^* \text{ and } |x| = 2|y| \} \).

(c) \( \{ x \# y | x, y \in \{ 0, 1 \}^* \text{ and } |x| \neq 2|y| \} \).

Do not obtain your PDAs by converting context-free grammars for these languages into PDAs.