

**St. Francis Xavier University**  
**Department of Computer Science**  
**CSCI 356: Theory of Computing**  
**Assignment 2**  
**Due October 22, 2021 at 11:15am**

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**Assignment Regulations.**

- This assignment may be completed individually or in a group of up to four people. If you are collaborating on an assignment as a group, your group must submit exactly one joint set of answers.
  - Please include your full name and email address on your submission. For groups, every member must include their full name and email address on the joint submission.
  - You may either handwrite or typeset your submission. If your submission is handwritten, please ensure that the handwriting is neat and legible.
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- [6 marks] 1. Let  $\Sigma = \{ (, ) \}$ . Recall that a word  $w$  over  $\Sigma$  contains balanced parentheses if every opening parenthesis is matched by a closing parenthesis and each pair of parentheses is correctly nested. Thus, the words  $()$ ,  $()()$ , and  $((())())$  all contain balanced parentheses, but the words  $((())()$  and  $((()))((()))$  do not.

Using the pumping lemma for regular languages, prove that the following language is not regular:

$$L_{()} = \{w \mid w \text{ contains balanced parentheses}\}.$$

- [8 marks] 2. Let  $\Sigma = \{a, b, c, d\}$ . In part (a), construct a *pushdown automaton* recognizing  $L_1$ . In part (b), give a *context-free grammar* generating the language  $L_2$ .

(a)  $L_1 = \{wdw^R \mid w \in \{a, b, c\}^*\}$ . (The notation  $w^R$  denotes the reversal of the word  $w$ .)

(b)  $L_2 = \{a^{2i+1}b^{k+1}c^{2k+1}d^{m+1} \mid i \geq 1, k \geq 1, m \geq 1\}$

- [4 marks] 3. Consider the following grammar:

$$\begin{aligned} S &\rightarrow I \mid E \mid A \\ I &\rightarrow \text{if condition then } S \\ E &\rightarrow \text{if condition then } S \text{ else } S \\ A &\rightarrow a := 1 \end{aligned}$$

This grammar models the part of a generic programming language that handles if-then-else statements.

An example of a code fragment generated by this grammar is `if condition then a := 1`.

Give one example of an ambiguous code fragment generated by this grammar. Show that it is ambiguous by illustrating two different parse trees for the code fragment.

- [7 marks] 4. Consider the following grammar:

$$\begin{aligned} S &\rightarrow ASA \mid aB \\ A &\rightarrow B \mid S \\ B &\rightarrow b \mid \epsilon \end{aligned}$$

Convert this grammar to an equivalent grammar in Chomsky normal form.