CMPSC 461: Programming Language Concepts, Fall 2024
Assignment 2 Practice Notes Packet

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September 7, 2025

Problem 1: Context Free Grammar - Creation 1 $[5 + 1.5 + 1.5 = 8$ pts$]$

As a CMPSC 461 student, you wish to write a rudimentary CFG for parsing roman numerals from 1 to 99 (i,ii,iii,iv,v,. . . ,ix,x,. . . ,xl,. . . ,lxxx,. . . ,xc,. . . ,xcix). If you are unfamiliar with roman numerals, please have a look at http://literacy.kent.edu/Minigrants/Cinci/romanchart.htm.).

- Your grammar should comprise of terminals {c, l, x, v, i}.
- c = 100, l = 50, x = 10, v = 5, i = 1.
- Notice that we use lowercase characters here to represent the numerals, to distinguish them from the non-terminals.

1. Define a **context-free grammar** to model this language.
2. What are **terminals** and **nonterminals** in the context of CFGs? Based on your answer for part 1 answer label/describe terminals and non-terminals in your answer.
3. Do context-free grammars represent all regular languages? Do regular languages translate all grammar? Are there any languages CFGs may not be able to represent? (Explain each answer in 10 words)

Problem 2: Context Free Grammar - Creation 2 [8 pts]

Create context free grammars for each of the following languages.

1. The set of strings which contains palindromic binary numbers. The strings can have leading zeros (for example, 101, 010 or 00).
2. The set of strings which have a number of ”a”s followed by twice the number of ”b”s (for example, ”abb”, ”aabbbb” and so on).

Problem 3: Context Free Grammar - Creation 3 [9 pts]

Give context free grammars that generate the following languages.

1. { w $\in \{0,1\}^*$ | w contains at least three **1s**.}
2. { w $\in \{a,b\}^*$ | the length of w is odd and middle symbol is b.}
3. { $a^i b^j c^k$ | $i,j,k \geq 0$ and i = j or i = k }

Problem 4: Context Free Grammar - Creation 4 [12 pts]

Give context free grammars that generate the following languages

1. $\{a^i b^j c^k \mid i, j, k \geq 0 \text{ and i + j = k}\}$
2. $\{ab^n acab^n a \mid n \geq 0\}$

Problem 5: Context Free Grammar - Knowledge Check [10 pts]

For each of the following statements, respond with either "True" or "False" to indicate whether the statement is correct. Provide reasoning for each answer provided.

1. A regular grammar can generate context-free languages.
2. An NFA (Nondeterministic Finite Automaton) can recognize languages that a DFA cannot.
3. When two regular languages are concatenated, the resulting language is still a regular language.
4. An automaton with multiple initial states can be considered a DFA.
5. A NFA (Nondeterministic Finite Automaton) can have epsilon (ε) transitions, allowing it to move to the next state without consuming any input symbol.

Problem 6: BNF-EBNF Conversion [16 pts]

1. Convert the following BNF to an EBNF

```
<goal>      ::= <a>
<goal>      ::= x <b> <a>
<a>         ::= y
<a>         ::= x <a>
<b>         ::= <a>
<b>         ::= <a> <b>
<b>         ::= y <b>
```

2. Convert the following EBNF to a BNF

```
<N> ::= A [B]
<Q> ::= [-] <num>
<P> ::= A { A }
<X> ::= { A }
<blk> ::= begin <cmd> { ; <cmd> } end
<nws> ::= (+|-) <num>
<SN> ::= [(+|-)] <num>
```

Problem 7: Context-Free-Grammar Derivation [16 pts]

Answer the following questions with this following grammar starting with S.

$$
\begin{aligned}
S &\rightarrow S - S \mid P \mid T \\
P &\rightarrow P + P \mid V \mid T \\
V &\rightarrow V * V \mid S \mid T \\
T &\rightarrow 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9
\end{aligned}
$$

1. Give the left-most derivation of the following: $4 - 6 + 1 * 5$
2. Give the right-most derivation of the following: $4 - 6 + 1 * 5$
3. Is there more than one right-most derivation? Explain.

Problem 8: Context-Free-Grammar Parse Tree [16 pts]

Answer the following questions with this following grammar starting with S.

$$
\begin{aligned}
S &\rightarrow S - S \mid P \mid T \\
P &\rightarrow P + P \mid V \mid T \\
V &\rightarrow V * V \mid S \mid T \\
T &\rightarrow 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9
\end{aligned}
$$

1. Draw the parse tree of the left-most derivation for $4 - 6 + 1 * 5$
2. Draw the parse tree of the right-most derivation for $4 - 6 + 1 * 5$

Problem 9: Context-Free-Grammar Ambiguity [16 pts]

The following problems help with some common ambiguity problems. Take the following grammars:

$Grammar1$:

$$S \to S - S \mid T$$
$$T \to 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9$$

$Grammar2$:

$$S \to S - T \mid T - S \mid T$$
$$T \to 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9$$

$Grammar3$:

$$S \to S - P \mid S + P \mid P$$
$$P \to V/P \mid V * P \mid V$$
$$V \to (S) \mid T$$
$$T \to 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9$$

1. Is Grammar 1 Ambiguous? If so, how do you fix it? If not, why?
2. Is Grammar 2 Ambiguous? If so, how do you fix it? If not, why?
3. Is Grammar 3 Ambiguous? If so, how do you fix it? If not, why?

Problem 10: Context-Free-Grammar Parse Tree [16 pts]

Consider the following grammar:

$$S \to TT$$
$$T \to TTT \mid a$$
$$T \to bT \mid Tb$$

1. Give at least four distinct strings generated by derivations of four or fewer steps.
2. Give at least four distinct parse trees to generate the string *babbab*.
3. Is this grammar ambiguous? Explain.

Problem 11: Context-Free-Grammar Parse Tree [16 pts]

Consider the following grammar:

$$S \rightarrow aS \mid aSbS \mid c$$

1. Is this grammar ambiguous? Show by drawing parse trees for the string *aacbc*
2. Design an unambiguous CFG for the language above.

Problem 12: Context-Free-Grammar Parse Tree [10 pts]

Consider the following:

1. What is ambiguity in CFG and what makes a grammar ambiguous?
2. Give a real-world example portraying how ambiguous grammar can be bad.