Computer Science III
Semester 2025-I
Workshop No. 1 — Theory of the Computation

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Welcome to the first workshop of the *Computer Science III* course! This workshop focuses on **theory of the computation** for: an *finite-state machines*. By exploring the principles of *regular expressions*, *context-free grammars*, and *Turing machines*, you will gain a deeper understanding of the theoretical foundations of computer science.

Workshop Scope and Objectives:

- **Finite-State Machines:** You will learn how to define finite-state machines for specific languages, and how to derive regular expressions from them.
- **Regular Expressions:** You will explore the relationship between regular expressions and finite-state machines, and how to construct generative grammars from regular expressions.
- **Context-Free Grammars:** You will learn how to define context-free grammars for specific languages, and how to derive derivation trees from them.
- **Derivation Trees:** You will practice constructing derivation trees for specific strings generated by context-free grammars.
- **Real Numbers and Identifiers:** You will explore the grammar for real numbers and identifiers.

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1. For each of the following `languages`, define the corresponding **finite-state machine**:

   (i) $\Sigma = \{0, 1, 2\}$. $L = (01^{*}2 \cup 2102)^{*}101(01 \cup 12 \cup 20)^{*}$.

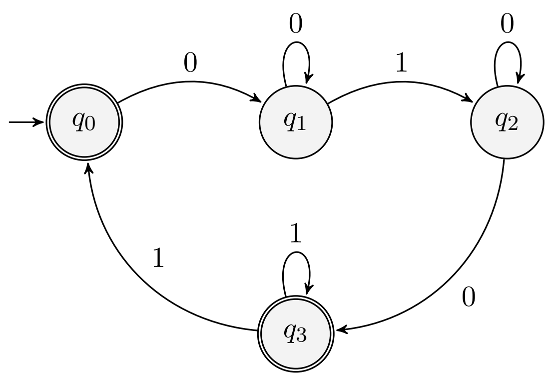
   (ii) $\Sigma = \{a, b, c\}$. $L = (abc \cup bca \cup cab)(abc \cup bca \cup cab)^{*}$.

   (iii) $\Sigma = \{a, b, c\}$. $L = (abc \cup bca \cup cab)^{*}(abc \cup bca \cup cab)$.

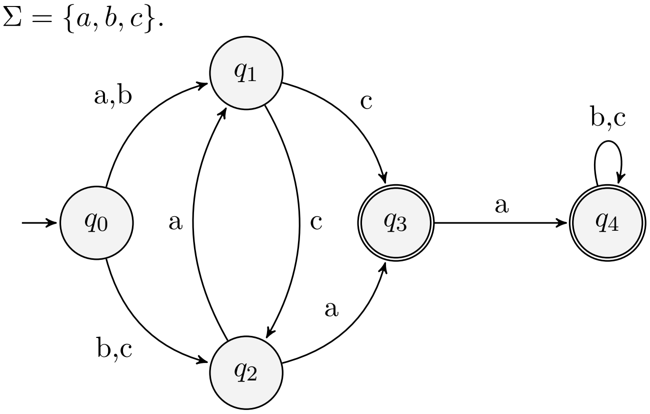
   (iv) $\Sigma = \{0, 1, 2\}$. $L = (01^{*}2 \cup 10^{*}2 \cup 21^{*}0)^{*}(01 \cup 12 \cup 20)^{*}101$.

2. For each one of the following `finite-state machines`, define the corresponding **regular expression** and a `generative grammar`:

   (i) $\Sigma = \{0, 1\}$.



   (ii) $\Sigma = \{a, b, c\}$.



3. For each of the following `regular expressions`, define the corresponding **generative grammar** (all over the alphabet $\Sigma = \{a, b, c, d\}$):

   (i) $\{a^i b^j c^j d^i : i, j \geq 1\}$.

   (ii) $\{a^i b^i c^j d^j : i, j \geq 1\}$.

   (iii) $\{a^i b^j c^j d^i : i, j \geq 1\} \cup \{a^i b^i c^j d^j : i, j \geq 1\}$.

   (iv) $\{a^i b^j c^{i+j} : i \geq 0, j \geq 1\}$.

4. Let G a `context-free grammar` with the following productions:

$$G = \begin{cases} S \to ABC \mid BaC \mid aB \\ A \to Aa \mid a \\ B \to BAB \mid bab \\ C \to cC \mid \lambda \end{cases}$$

   Find derivation trees for the following strings:

   (i) $w_1 = abab$.
   (ii) $w_2 = babacc$.
   (iii) $w_3 = abababababc$.

5. As follows there is a `context-free grammar` to generate **real numbers** without sign, the alphabet is $\Sigma = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, ., +, -, E\}$:

`<real>`	$\to$	`<digits> <decimal> <exp>`
`<digits>`	$\to$	`<digit> <digits>` | `<digit>`
`<digit>`	$\to$	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
`<decimal>`	$\to$	`. <digits>` | λ
`<exp>`	$\to$	E`<digits>` | E+`<digits>` | E-`<digits>` | λ

   Define the derivation tree for the following strings:

   (i) $w_1 = 47.236$
   (ii) $w_2 = 321.25E + 35$
   (iii) $w_3 = 0.8E9$
   (iv) $w_4 = 0.8E + 9$

6. The following is a `context-free grammar` to generate **identifiers**, identifiers are strings of letters and digits, starting with a letter:

`<identifier>`	$\to$	`<letter> <lsds>`
`<lsds>`	$\to$	`<letter> <lsds>` | `<digit> <lsds>` | λ
`<letter>`	$\to$	a | b | c | ... | x | y | z | A | B | C | ... | X | Y | Z
`<digit>`	$\to$	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

   Draw the derivation tree for the following names:

   (i) $w_1 = MyVariable$
   (ii) $w_2 = temp2$
   (iii) $w_3 = string2int$
   (iv) $w_4 = 2NotAVariable$

7. For each of the following cases, define a regular expression as used in a compiler based on the Python `re` library:

    (i) **Identifier:** A regular expression to match valid identifiers (variable names, function names, etc.).
    (ii) **Integer Literal:** A regular expression to match integer literals.
    (iii) **Floating Point Literal:** A regular expression to match floating-point literals.
    (iv) **String Literal:** A regular expression to match string literals enclosed in double quotes.
    (v) **Single-line Comment:** A regular expression to match single-line comments starting with '//'.
    (vi) **Multi-line Comment:** A regular expression to match multi-line comments enclosed in '/* */'.
    (vii) **Whitespace:** A regular expression to match whitespace characters (spaces, tabs, newlines).
    (viii) **Operators:** A regular expression to match common operators (e.g., '+', '-', '*', '/', '==', '!=').
    (ix) **Keywords:** A regular expression to match reserved keywords (e.g., 'if', 'else', 'while', 'return').
    (x) **Hexadecimal Literal:** A regular expression to match hexadecimal literals.

8. Let G a `context-free grammar` with the following productions:

```
S -> Prog
Prog -> StatL
StatL -> Statement StatL | <lambda>
Statement -> Assignment | IfStat | WhileStat | ReturnStat
Assignment -> Ident "=" Exp ";"
IfStat -> "if" "(" Exp ")" "{" StatL "}" ElsePart
ElsePart -> "else" "{" StatL "}" | <lambda>
WhileStat -> "while" "(" Exp")" "{" StatL "}"
ReturnStat -> "return" Exp ";"
Exp -> Term OperLog
OperLog -> "&&" Exp | "||" Exp | <lambda>
Oper -> "+" | "-" | "*" | "/" | ">" | "<" | ">=" | "<=" | "==" | "!="
Term -> Factor Oper Factor
Factor -> "(" Exp ")" | Ident | Number
Ident -> [a-zA-Z_][a-zA-Z0-9_]*
Number -> [0-9]+
```

Explanation:

- **S** is the start symbol.
- **Prog** consists of a list of statements.
- **StaL** is a sequence of statements or an empty sequence ($< lambda >$).
- **Statement** can be an assignment, an if statement, a while statement, or a return statement.
- **Assignment** assigns an expression to an identifier.
- **IfStat** includes an optional else part.
- **WhileStat** represents a while loop.
- **ReturnStat** returns an expression.
- **Exp** consists of terms combined with addition or subtraction.
- **Term** consists of factors combined with multiplication or division.
- **Factor** can be an expression in parentheses, an identifier, or a number.
- **Ident** matches typical variable names.
- **Number** matches sequences of digits.

Based on the provided context-free grammar, create derivation trees for the following statements:

(a) **Exercise 1:**

```
x = 5 + 3 * 2;
```

(b) **Exercise 2:**

```
if (x > 0) {
    y = x - 1;
} else {
    y = 0;
}
```

(c) **Exercise 3:**

```
while (x < 10) {
    x = x + 1;
}
```

(d) **Exercise 4:**

```
return (a + b) * c;
```

Deadline: Wednesday, May 14th, 2025, 6:00. Submissions after this deadline may incur penalties in accordance with course policies.

Good luck, and remember: this workshop is your starting point for conceptualizing and designing a compiler.