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

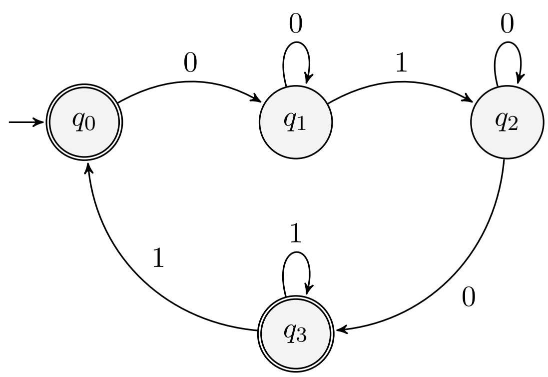
   (ii) $\Sigma = \{a,b,c\}$. $L = (abc \cup bca \cup cab)(abc \cup bca \cup cab)^*$.

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

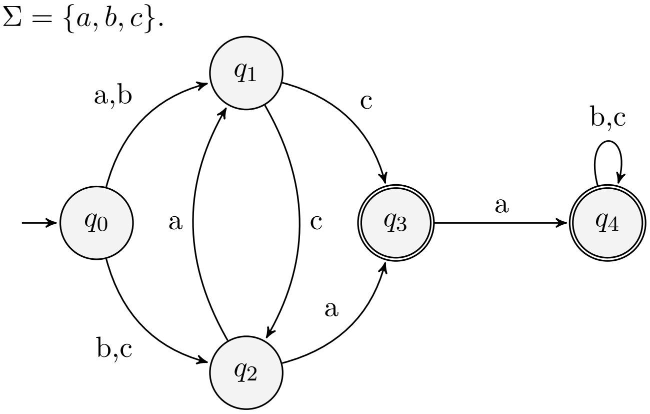
   (iv) $\Sigma = \{0,1,2\}$. $L = (01^*2 \cup 10^*2 \cup 21^*0)^*(01 \cup 12 \cup 20)^*101$.

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) $w_3 = abababab c$.

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 -> Program
Program -> StatementList
StatementList -> Statement StatementList | <lambda>
Statement -> Assignment | IfStatement | WhileStatement | ReturnStatement
Assignment -> Identifier "=" Expression ";"
IfStatement -> "if" "(" Expression ")" "{" StatementList "}" ElsePart
ElsePart -> "else" "{" StatementList "}" | <lambda>
WhileStatement -> "while" "(" Expression ")" "{" StatementList "}"
ReturnStatement -> "return" Expression ";"
Expression -> Term Expression'
Expression' -> "+" Term Expression' | "-" Term Expression' |
<lambda>
Term -> Factor Term'
Term' -> "*" Factor Term' | "/" Factor Term' | <lambda>
Factor -> "(" Expression ")" | Identifier | Number
Identifier -> [a-zA-Z_][a-zA-Z0-9_]*
Number -> [0-9]+
```

Explanation:

- **S** is the start symbol.

- **Program** consists of a list of statements.
- **StatementList** 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.
- **IfStatement** includes an optional else part.
- **WhileStatement** represents a while loop.
- **ReturnStatement** returns an expression.
- **Expression** 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.
- **Identifier** 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.