Course: Compiler Construction

Week 4: Compiler Design Phases – Syntax Analysis

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Learning outcomes Week 4: Compiler Design Phases – Syntax Analysis

At the end of the lecture, you will be able to:

(i) Define Parser, Grammar and Ambiguity

(ii) Describe Context Free Grammar (CFG)

(iii) Derive strings using parse trees

1. Introduction to Syntax Analysis

- ✓ Another term for Syntax Analysis is **Parsing**
- ✓ This is the process of analyzing a sequence of tokens to determine their g**rammatical structure** with respect to a **given formal grammar**[1].
- ✓ It is the most important phase of a compiler.
- ✓ A **syntax analyzer (parser)** checks for the correct syntax and builds a data structure (**parse tree**) implicit in the input tokens i.e. it considers the sequence of tokens for possible valid constructs of the programming language[2].

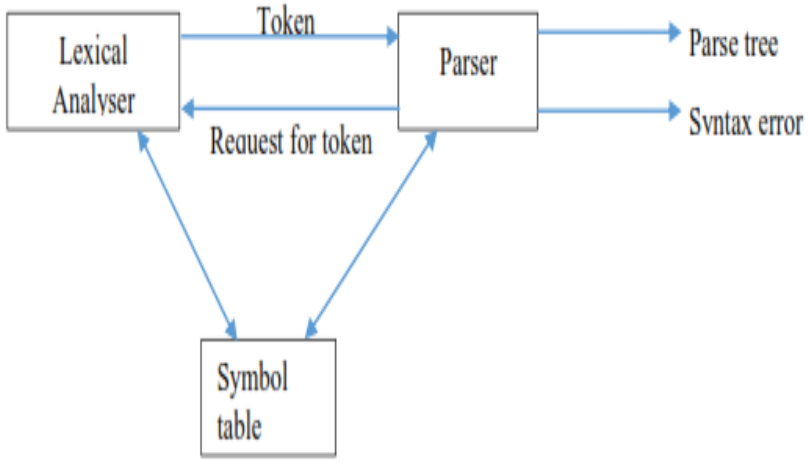
[1] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 216

[2] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 217

1.1. Two Roles of a Parser[3]

1. To identify language constructs that are present in a given input program. If the parser determines input to be **valid**, it outputs the presentation of the input in form of a **parse tree**
2. If the input is grammatically **incorrect**, the parser declares the detection of **syntax error** in the input. In this case, a parse tree is **not produced.**

Parser Roles Illustration[4]



2. Grammar

A grammar **G** is defined as a **four-tuple** with **<V_N, V_T, P, S>**[5] where: -

I. **V_N** is the set of **non-terminal** symbols used to write the grammar.

II. **V_T** is the set of **terminals** (set of words of the language, lexicon or dictionary of words).

III. **P** is the set of **production rules** that define how a sequence of terminal and non-terminal symbols can be replaced by some other sequence

IV. **S: - S Є V_N** is a special non-terminal called the **start symbol** of the grammar.

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[3] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 217

[4] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 217

[5] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 222

The language of the grammar **G= <V_N, V_T, P, S>** denoted by **L(G)** is defined as all those strings over $\mathbf{V_T}$ that can be generated by starting with the start symbol **S** then applying the production rules in **P** *until no more non-terminal symbols are present*.

- ✓ ***Example:*** Consider the grammar to generate arithmetic expressions consisting of **numbers** and operator symbols i.e. **+, -, *, /.**
- ✓ Rules of the grammar can be written as follows[6]: -
  - ✓ $E \rightarrow EAE$
  - ✓ $E \rightarrow (E)$
  - ✓ $E \rightarrow number$
  - ✓ $A \rightarrow +$
  - ✓ $A \rightarrow -$
  - ✓ $A \rightarrow *$
  - ✓ $A \rightarrow /$
- ✓ We can apply these rules to derive the expression $2 * (3 + 5 * 4)$ as follows: -

  $E \rightarrow EAE \rightarrow EA(E) \rightarrow EA(EAE) \rightarrow EA(EAEAE) \rightarrow EA(EAEA\ 4) \rightarrow EA(EAE * 4) \rightarrow EA(EA\ 5 * 4) \rightarrow EA(E + 5 * 4) \rightarrow EA(3 + 5 * 4) \rightarrow E * (3 + 5 * 4) \rightarrow 2 * (3 + 5 * 4)$
- ✓ In the grammar, ***E*** and ***A*** are **non-terminals** while the rest are **terminals**.

2.1. Context Free Grammar (CFG)

- ✓ This is grammar that **defines** Context Free Languages and consist of production rules in which: -
  - (i) the Left-Hand Side (LHS) contains only a single non-terminal and no terminals;
  - (ii) the Right-Hand Side (RHS) consists of terminals, non-terminals or both.
- ✓ **Note:** Most programming language constructs belong to Context Free Languages (CFL)[7]

[6] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 193

[7] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 193

2.2. Notational Conventions[8]

The following is the notational convention that would be used when defining grammars:

1. The following will be taken as **terminals**:
    - ✓ all operator symbols
    - ✓ punctuation symbols including parenthesis '()'
    - ✓ digits
    - ✓ lower case letters of the alphabet such as a, b, c
    - ✓ Lexemes such as id, number, while, etc.
2. The following will represent **non-terminals**:
    - ✓ Upper case letters of the alphabet such as A, B, C.
    - ✓ The letter S will represent the start symbol
    - ✓ Lowercase names such as expr, stmt etc
3. A set of productions with the same Left-Hand Side (LHS) such as: $A \rightarrow \alpha_1$, $A \rightarrow \alpha_2 \ldots A \rightarrow \alpha_n$ will be written as $A \rightarrow \alpha_1 \mid \alpha_2 \mid \ldots \mid \alpha_n$.
4. If no start symbol is represented, then the non-terminal appearing on the Left-Hand Side of the production rule will be considered as the **start symbol**

2.3. Derivation

- ✓ This is the process of generating a sequence of intermediary strings to expand the start symbol of the grammar to the desired string of terminals.
- ✓ The graphical depiction of a derivation is a **parse tree**.
- ✓ Each step of the derivation modifies an intermediary string to a new one by replacing a substring of it that matches the left-hand side of the production rule by a string on the right-hand side of the rule[9].

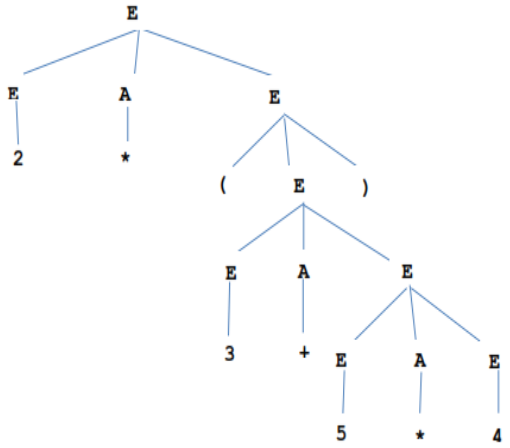
[8] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 223

[9] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 225

In a parse tree

- ✓ The start symbol of the derivation becomes the root.
- ✓ All leaf nodes are terminals
- ✓ All interior nodes are non-terminals
- ✓ In-order traversal gives original input string
- ✓ A parse tree depicts associativity and precedence of operators

Example: The following is the derivation of the string $2*(3+5*4)$ [10]



2.4. Associativity & Precedence[11]

A. Associativity

If an operand has operators on both sides, left associativity dictates that the operand be taken by the left operator. If the operation is right-associative, the right operator will take the operand

B. Precedence

To decrease the chances of ambiguity in a language or its grammar, operands in brackets have the highest precedence, followed by division, multiplication, addition and subtraction comes last.

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[10] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 227

[11] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 218

2.5. Types of Derivation

There are two types of derivation: -

i. Left-Most Derivation

- ✓ Here, the left-most non-terminal is replaced at each step.
- ✓ The intermediate strings are called left-sentential forms. They consist of grammar symbols (both terminal & non-terminals)

ii. Right-Most Derivation

- ✓ In this derivation the right-most non-terminal is replaced at each step.
- ✓ The intermediary strings are called right-sentential forms.
- ✓ Right-most derivation is often referred to as canonical representation[12].

2.6. Ambiguity

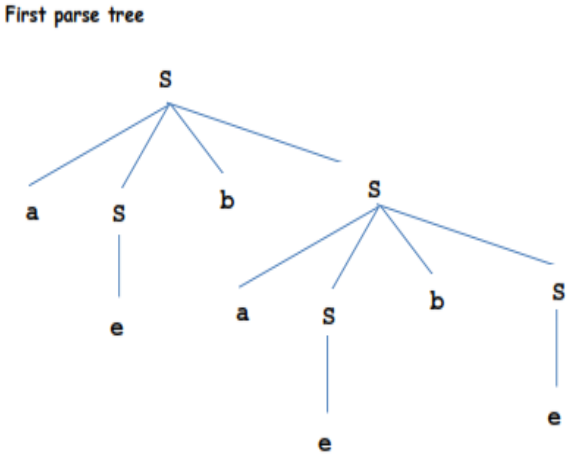
- ✓ A grammar is said to be ambiguous if there exists more than one parse tree for the same sentence

Example: - Consider the following grammar: $S \rightarrow aSbS|bSaS|e$

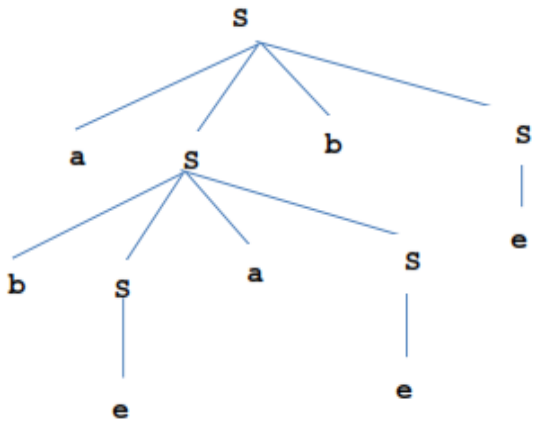
- ✓ To show that the grammar is ambiguous, we present two different parse trees for the string "$abab$".

[12] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 201

1. First Parse Tree for the string "$abab^{13}$"



2. Second Parse Tree for the string "$abab^{14}$"



Dangling Else Ambiguity

✓ Most programing languages have both if… then and if… then … else versions of the statement. The grammar rules are as follows: -

stmt → if condition then stmt else stmt

|if condition then stmt[15]

[13] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 204

[14] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 204

[15] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 235

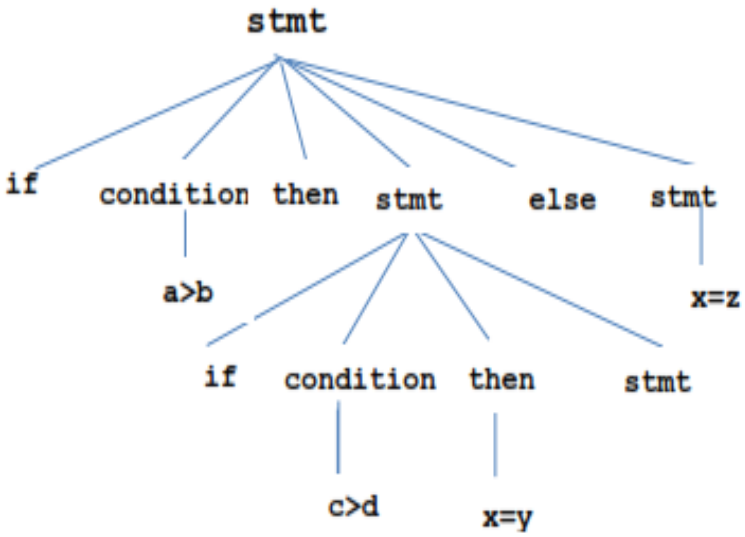
Consider the following code segment

$$if\ a > b\ then$$
$$if\ c > d\ then\ x = y$$
$$else\ x = z$$

✓ Two parse trees can be generated by the grammar as shown below:

(i) the else is taken with the outer if statement[16].

$$if\ a > b\ then$$
$$if\ c > d\ then\ x = y$$
$$else\ x = z$$

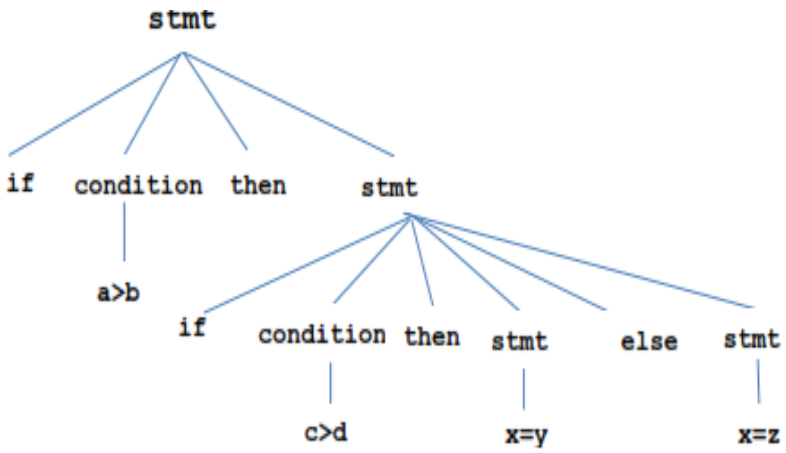


(ii) the else is taken with the inner if statement[17].

$$if\ a > b\ then$$
$$if\ c > d\ then\ x = y$$
$$else\ x = z$$

[16] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 236

[17] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 237



✓ **Note:** most programming languages accept this second parse tree as the correct syntax.

Eliminating Ambiguity[18]

Ambiguity may be eliminated by: -

i. Rewriting the grammar

ii. Modifying the grammar e.g. Many programming languages require that "if" should have a matching 'end if" as shown below: -

$stmt \rightarrow if\ condition\ then\ stmt\ else\ stmt\ endif$

$| if\ condition\ then\ stmt\ endif$

[18] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 235

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Course Text Books

1. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007))

2. Compiler Construction: Principles and practices; Kenneth C. Louden; Cengage Learning; 1st edition, ISBN-10: 0534939724 (1997)

3. Basics of Compiler Design: Torben Mogensen; DIKU University of Copenhagen Universitetsparken 1 DK-2100 Copenhagen DENMARK (2007)

4. Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; Morgan Kaufmann Publishers ISBN: 978-0-12-088478-0 (2003)

5. Compiler Design: Santanu Chattopadhyay; PHI Learning Publishers, ISBN 812032725X, 9788120327252 (2005)