Syntax Analysis

1

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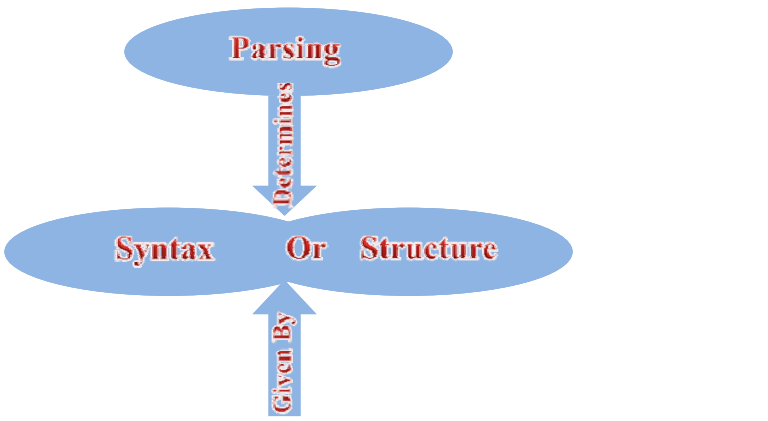

2

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Chomsky Hierarchy of Grammars

- Type 0: Unrestricted Grammar (Equivalent to Turing Machines).
- Type 1: Context Sensitive Grammar (Linear Bound Automata).
- Type 2: Context Free Grammar (Push down Automata).
- Type 3: Regular Grammar (RE).

3

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Context Free Grammars (CFG)

Provides the syntactic structure:
A grammar is quadruple (V_T, V_N, S, R)

- A set of finite terminals "V_T": Basic symbols from which sentences are formed.
- A set of finite non-terminals "V_N": Syntactic variables denoting sets of sentences.
- A set of productions "R": Rules specifying how the terminals and non-terminals can be combined to form sentences. (Å → Æ)
- A unique start symbol "S": A distinguished non-terminal denoting the language (S € N).

4

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Must Conditions for CFG

Three conditions are to be full filled:

1. $V_T \cap V_N = \emptyset$; V_T, V_N are not allowed to have symbol in common. Meaning we must be able to tell terminals and non-terminals apart.
2. $S \in V_N$; S is an element of non-terminal.
3. $R \subseteq \{(N, \alpha) \mid N \in V_N , \alpha \in (V_N \cup V_T)^*\}$ Which means the left side of each production must be non-terminal and right hand side may consists of both (terminals and non-terminals) and is not allowed to include any other symbol.

5

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Example

Grammar Rules:

exp ⟶ exp op exp
op ⟶ + | - | * | /

First rule defines an expression structure (with name exp) consists of expression followed by an operator and another expression.
Second rule defines an operator (name op) consists of add, subtract, multiply and division.

(This notation was given by John Backus and adopted by Peter Naur, so called *Backus Naur form*, BNF)

Terminals: id, +, -, *, /
Non-terminals: exp, op
Start symbol: exp

6

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Specifications for CFG

- CFG uses similar naming conventions and operations as RE, the difference is; rules are recursive, so no symbol is required for repetition.

7

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Specifications for CFG

- Given an alphabet a CFG rule in BNF consists of a string of symbols, first symbol is the name of the structure, followed by meta symbol $\longrightarrow$.
- After the meta symbol, there are symbols either from alphabet or structure name or meta-symbol $|$.

8

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Specifications for CFG

- Informally, a BNF rule defines a structure whose name is on the left side of the arrow.
- Structure consists of one of the choices separated by |.
- The sequence of symbols and structures within each choice defines the layout of the structure.

9

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Specifications for CFG

- Meta-symbol alternatives: (No universal Standard)

  “→“ , “=“, “:”, “::=“

- For text files structure names are written in angle brackets.
- Example: <exp> ::= <exp> <op> <exp>

10

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Derivations

$E \rightarrow E + E \mid E * E \mid (E) \mid -E \mid id$

- A derivation step is an application of a production as a rewriting rule. (E drives in -E)

$$E \Rightarrow -E$$

- A sequence of derivation steps

$$E \Rightarrow -E \Rightarrow -(E) \Rightarrow -(id)$$

is called a derivation of -(id) from E.

- The symbol $\Rightarrow^*$ denotes, derives in zero or more steps and symbol $\Rightarrow^+$ denotes, derives in one or more steps.

11

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Language Determined by Grammar Rules

How ?

- Grammar rules determine the legal strings of token symbols by means of derivation.
- Derivation is a sequence of replacements of structure name by choice on the right hand side of the grammar rule.
- Derivation begins with a single structure name and end with a string of token symbols.

String: (43 - 63) * 100 [exp → exp op exp | (exp) | number]
[op → + | - | *]

exp ⇒ exp op exp
⇒ exp * number
⇒ (exp op exp) * number
⇒ (exp - number) * number
⇒ exp op number
⇒ (exp) * number
⇒ (exp op number) * number
⇒ (number - number) * number

12

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Example of CFG

String: (())((()))()()

Rule: S → SS | (S) | ()

S ⇒ SS
⇒ SSS
⇒ (S)SS
⇒ (())SS
⇒ (())(S)S
⇒ (())(SS)S
⇒ (())((S)S)S
⇒ (())((())S)S
⇒ (())(()())()S
⇒ (())(()())()()

13

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Example: ((a))

L(G) = {a, (a), ((a)), (((a))), ...}

E → (E) | a

E → (E)
(E) → ((E))
((E)) → ((a))

L(G) = {a, a+a, a+a+a, ...}

E → E + a | a

E → E + a
E + a → E + a + a
E + a + a → E + a + a + a
E + ... → .....

E → (E)
L(G) = { }

14

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Non-Context Free Grammar

String: xxxxbbbbcccc

Rules:

S ⟶ xSBC
S ⟶ xbC
CB ⟶ BC
bB ⟶ bb
bC ⟶ bc
cC ⟶ cc

S ⟶ xSBC
xxSBCBC
xxxSBCBCBC
xxxxbCBCBCBC
xxxxbBCCBCBC
xxxxbbBCCCBC
xxxxbbbCBCCC
xxxxbbbbCCCC
xxxxbbbbcCCC
xxxxbbbbccCC
xxxxbbbbcccC
xxxxbbbbcccc

xxxxbbCCBCBC
xxxxbbbCCCBC
xxxxbbbBCCCC
xxxxbbbbccCC

xxxxbbCBCCBC
xxxxbbbCCBCC
xxxxbbbbCCCC
xxxxbbbbcccC

15

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Leftmost & Rightmost Derivation

A leftmost derivation always chooses the leftmost non-terminal to rewrite:

Rules:

E ⟶ E + E
E ⟶ E - E
E ⟶ E * E
E ⟶ E / E
E ⟶ (E)
E ⟶ id

String: (x + y)/(x - y)

Leftmost:

E ⇒ E / E
⇒ (E) / E
⇒ (E + E) / E
⇒ (id + E) / E
⇒ (id + id) / E
⇒ (id + id) / (E)
⇒ (id + id) / (E - E)
⇒ (id + id) / (id - E)
⇒ (id + id) / (id - id)

Rightmost:

E ⇒ E / E
⇒ E / (E)
⇒ E / (E - E)
⇒ E / (E - id)
⇒ E / (id - id)
⇒ (E) / (id - id)
⇒ (E + E) / (id - id)
⇒ (E + id) / (id - id)
⇒ (id + id) / (id - id)

16

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Example: ["(34-3)*42"]

LMD

(1) exp	⇒ exp op exp	[exp → exp op exp]
(2)	⇒ (exp) op exp	[exp → (exp)]
(3)	⇒ (exp op exp) op exp	[exp → exp op exp]
(4)	⇒ (number op exp) op exp	[exp → number]
(5)	⇒ (number - exp) op exp	[op → -]
(6)	⇒ (number - number) op exp	[exp → number]
(7)	⇒ (number - number) * exp	[op → *]
(8)	⇒ (number - number) * number	[exp → number]

RMD

(1) exp	⇒ exp op exp	[exp → exp op exp]
(2)	⇒ exp op number	[exp → number]
(3)	⇒ exp * number	[op → *]
(4)	⇒ (exp) * number	[exp → (exp)]
(5)	⇒ (exp op exp) * number	[exp → exp op exp]
(6)	⇒ (exp op number) * number	[exp → number]
(7)	⇒ (exp - number) * number	[op → - [
(8)	⇒ (number - number)*number	[exp → number]

17

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Difference

- A leftmost derivation corresponds to a pre-order traversal of the parse tree.
- A rightmost derivation corresponds to a post-order traversal of the parse tree in reverse order.

  - Both of these construct different types of parsers.

    - LMD: Top-down Parser
    - RMD: Bottom-up Parser

Top-down parsers construct leftmost derivations.

- Left-to-right traversal of input, constructing a Leftmost derivation

Bottom-up parsers construct rightmost derivations.

- Left-to-right traversal of input, constructing a Rightmost derivation

18

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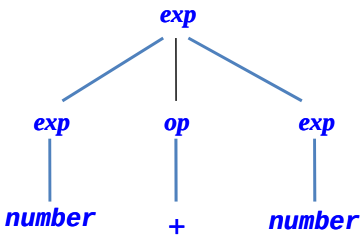
Parse Tree

exp ⇒ exp op exp
⇒ number op exp
⇒ number + exp
⇒ number + number



19

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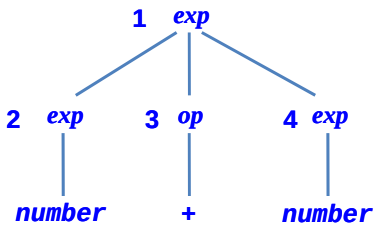
Parse Tree (pre-order numbering)

(1) exp ⇒ exp op exp
(2) ⇒ number op exp
(3) ⇒ number + exp
(4) ⇒ number + number



20

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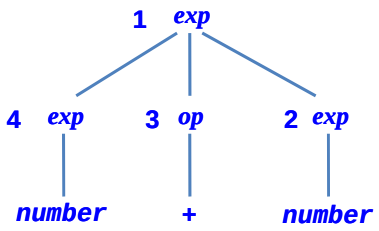
Parse Tree (post-order numbering)

(1) exp ⇒ exp op exp
(2) ⇒ exp op number
(3) ⇒ exp + number
(4) ⇒ number + number



21

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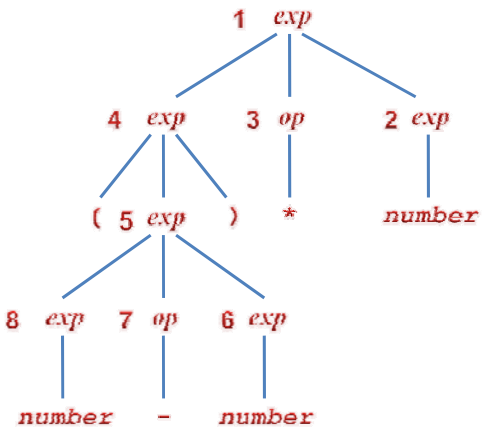
Parse Tree (100 – 200) * 300



22

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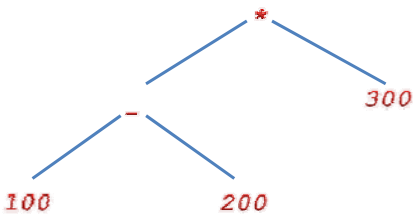
Abstract Syntax Tree (100 – 200) * 300



23

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Example

statement → *if-stmt* | `other`
if-stmt → `if (` *exp* `)` *statement*
| `if (` *exp* `)` *statement* `else` *statement*
exp → `0` | `1`

Possible strings:

```
other
if(0) other
if(1) other
if(0) other else other
if(1) other else other
if(0) if(0) other
if(0) if(1) other else other
if(1) other else if(0) other else other
.....
```

24

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ε- Productions

- *Grammar generating sequences of one or more statements separated by a semicolon.*
- *stmt-seq → stmt ; stmt-seq | stmt*
  stmt → s
- *L(G) = {s, s;s, s;s;s, ……..}*

To include ε

- *stmt-seq → stmt ; stmt-seq | ε*
  stmt → s
- *L(G) = {ε, s;, s;s;, s;s;s;, ……..}*

In this case ";" has become the statement terminator instead of statement separator.

(zero or more stmts terminated by a ";")

To fix the problem:

- *stmt-seq → non-stmt-seq | ε*
  non-stmt-seq → stmt; non-stmt-seq | stmt
  stmt → s

25

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Dangling else Problem

statement → if-stmt | other
if-stmt → if (exp) statement
| if (exp)statement else statement
exp → 0 | 1

Consider the following string:

if(0) if(1) other else other

It will produce the following two trees:

26

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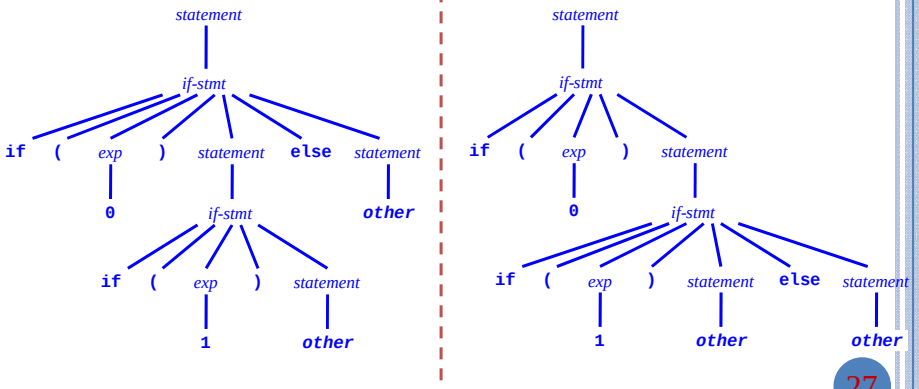
Parse trees for Dangling Else Problem



27

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Solutions for Dangling Problems

- ***Most-closely nested rule*** are easy to state, but hard to put into the grammar itself. Two Possibilities to deal with dangling:
  - **Always associate else part** with the nearest if-statement that does not yet have an associated else-part.
  - Use a "**Bracketing Keyword**" to remove the ambiguity:

Bracketing keyword

if-stmt → `if ( exp ) stmt end`
| `if ( exp ) stmt else stmt end`

28

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EBNF

- Standard Backus-Naur Form (BNF)
  - Meta-symbols are | → ε
- Extended BNF (EBNF):
  - New meta-symbols [...] and {...}
  - ε largely eliminated by these new symbols
- Brackets [...] mean optional like "?"
  - *exp* → *term* '|' *exp* | *term* becomes: *exp* → *term* ['|' *exp*]
  - *if-stmt* → `if` (*exp*) *stmt* | `if` (*exp*) *stmt* `else` *stmt* becomes: *if-stmt* → `if` (*exp*) *stmt* [`else` *stmt*]

29

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EBNF continued

- Braces {...} mean repetition
  - *exp* → *exp* + *term* | *term* becomes: *exp* → *term* { + *term* }
- Choices:
  - *exp* → *exp* + *term* | *exp* − *term* | *term*

    are they same ?

    exp → *term* { + *term* } | *term* { − *term* }

30

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EBNF expression example

exp → *term* { *addop term* }
addop → + | -
term → *factor* { *mulop factor* }
mulop → *
factor → (*exp*) | number

31

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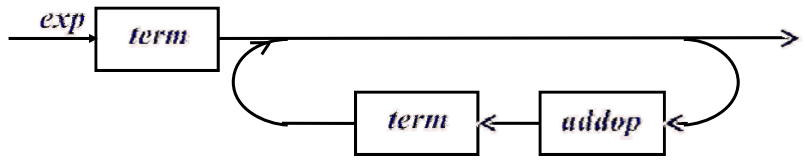
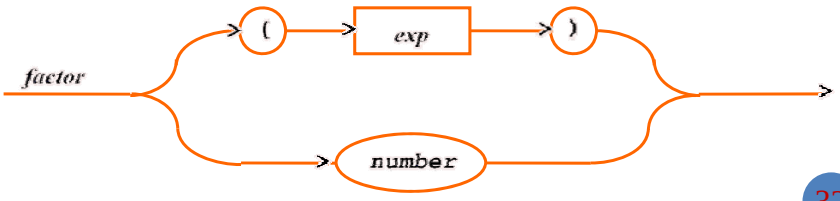
Syntax Diagram for EBNF





32

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