Chapter 4
Syntax Analysis

Syntax Analysis - Parsing

- **An overview of parsing :**
  - **Functions & Responsibilities**
- **Context Free Grammars**
  - **Concepts & Terminology**
- **Writing and Designing Grammars**
- **Resolving Grammar Problems / Difficulties**
- **Top-Down Parsing**
  - **Recursive Descent & Predictive LL**
- **Bottom-Up Parsing**
  - **LR & LALR**

An Overview of Parsing

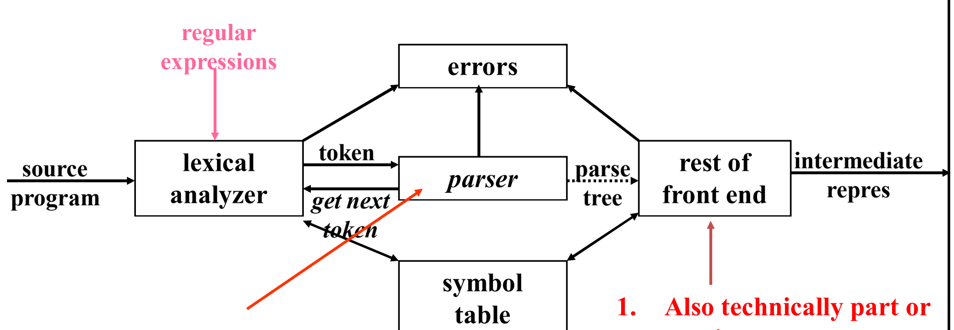
Why are Grammars to formally describe Languages Important ?

1. **Precise, easy-to-understand representations**
2. **Compiler-writing tools can take grammar and generate a compiler**
3. **Allow language to be evolved (new statements, changes to statements, etc.) Languages are not static, but are constantly upgraded to add new features or fix "old" ones**

ADA → ADA9x, C→ C++ , Templates, exceptions,

How do grammars relate to parsing process ?

Parsing During Compilation



1. **Also technically part or parsing**
2. **Includes augmenting info on tokens in source, type checking, semantic analysis**

- **uses a grammar to check structure of tokens**
- **produces a parse tree**
- **syntactic errors and recovery**
- **recognize correct syntax**
- **report errors**

Parsing Responsibilities

Syntax Error Identification / Handling

Recall typical error types:

- **Lexical : Misspellings**
- **Syntactic : Omission, wrong order of tokens**
- **Semantic : Incompatible types**
- **Logical : Infinite loop / recursive call**

Majority of error processing occurs during syntax analysis

NOTE: Not all errors are identifiable !!

Key Issues – Error Processing

1. **Detecting errors**
2. **Finding position at which they occur**
3. **Clear / accurate presentation**
4. **Recover (pass over) to continue and find later errors**
5. **Don't impact compilation of "correct" programs**

Error Recovery Strategies

Panic Mode – Discard tokens until a "synchronous" token is found (end, ";", "}", etc.)

-- Decision of designer

-- Problems:

skip input ⇒miss declaration – causing more errors

⇒miss errors in skipped material

-- Advantages:

simple ⇒suited to 1 error per statement

Phrase Level – Local correction on input

-- "," ⇒";" – Delete "," – insert ";"

-- Also decision of designer

-- Not suited to all situations

-- Used in conjunction with panic mode to allow less input to be skipped

What are some Typical Errors ?

```
#include<stdio.h>
int f1(int v)
{     int i,j=0;
      for (i=1;i<5;i++)
      {  j=v+f2(i) }
      return j; }
int f2(int u)
{     int j;
      j=u+f1(u*u);
      return j; }
int main()
{     int i,j=0;
              for (i=1;i<10;i++)
              {     j=j+i*i  printf("%d\n",i);        }
      printf("%d\n",f1(j));
      return 0;
}
```

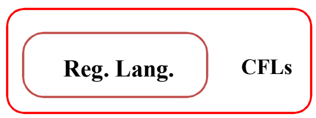
As reported by C Compiler

'f2' undefined;
syntax error : missing ';' before '}'
syntax error : missing ';' before identifier 'printf'

Which are "easy" to recover from?
Which are "hard" ?

Motivating Grammars

- Regular Expressions
  - → Basis of lexical analysis
  - → Represent regular languages
- Context Free Grammars
  - → Basis of parsing
  - → Represent language constructs



Context Free Grammars : Concepts & Terminology

Definition: A Context Free Grammar, CFG, is described by T, NT, S, PR, where:

T: Terminals / tokens of the language

NT: Non-terminals to denote sets of strings generated by the grammar & in the language

S: Start symbol, $S \in NT$, which defines all strings of the language

PR: Production rules to indicate how T and NT are combined to generate valid strings of the language.

PR: $NT \rightarrow (T \mid NT)^*$

Like a Regular Expression / DFA / NFA, a Context Free Grammar is a mathematical model

How does this relate to Languages?

$E \rightarrow E\ A\ E \mid (\ E\ ) \mid -E \mid id$

$A \rightarrow + \mid - \mid * \mid\ /\ \mid \uparrow$

Let G be a CFG with start symbol S. Then $S \overset{+}{\Rightarrow} W$ (where W has no non-terminals) represents the language generated by G, denoted L(G). So $W \in L(G) \Leftrightarrow S \overset{+}{\Rightarrow} W$.

W : is a sentence of G

When $S \Rightarrow \alpha$ (and α may have NTs) it is called a sentential form of G.

EXAMPLE: id * id is a sentence

Here's the derivation:

$E \Rightarrow E\ A\ E \Rightarrow E * E \Rightarrow id * E \Rightarrow id * id$

Sentential forms

$E \overset{*}{\Rightarrow} id * id$

Other Derivation Concepts

Leftmost: Replace the leftmost non-terminal symbol

$E \underset{lm}{\Rightarrow} E\ A\ E \underset{lm}{\Rightarrow} id\ A\ E \underset{lm}{\Rightarrow} id * E \underset{lm}{\Rightarrow} id * id$

Rightmost: Replace the right most non-terminal symbol

$E \underset{rm}{\Rightarrow} E\ A\ E \underset{rm}{\Rightarrow} E\ A\ id \underset{rm}{\Rightarrow} E * id \underset{rm}{\Rightarrow} id * id$

Important Notes: $A \rightarrow \delta$

If $\beta A \gamma \underset{lm}{\Rightarrow} \beta\ \delta\ \gamma$, what's true about β ?

If $\beta A \gamma \underset{rm}{\Rightarrow} \beta\ \delta\ \gamma$, what's true about γ ?

Derivations: Actions to parse input can be represented pictorially in a parse tree.

Examples of LM / RM Derivations

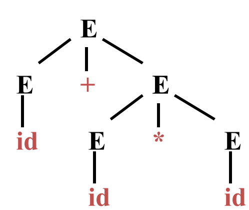
E → E + E | E*E| (E) | -E | id

A leftmost derivation of : id + id * id

A rightmost derivation of : id + id * id

Parse Tree & Derivation

E ⇒ E + E
⇒ id+ E
⇒ id + E * E
⇒ id + id * E
⇒ id + id * id



Alternative Parse Tree & Derivation

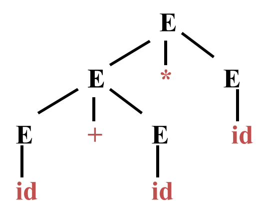
$E \Rightarrow E * E$

$\Rightarrow E + E * E$

$\Rightarrow id + E * E$

$\Rightarrow id + id * E$

$\Rightarrow id + id * id$



WHAT'S THE ISSUE HERE ?

Two distinct leftmost derivations!

Resolving Grammar Problems/Difficulties

Regular Expressions : Basis of Lexical Analysis

Reg. Expr. → generate/represent regular languages

Reg. Languages → smallest, most well defined class of languages

Context Free Grammars: Basis of Parsing

CFGs → represent context free languages

CFLs → contain more powerful languages

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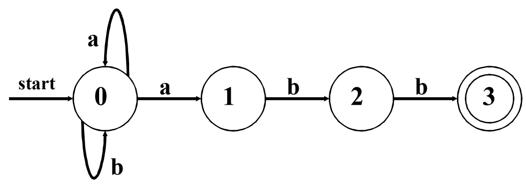
Resolving Problems/Difficulties – (2)

Since Reg. Lang. $\subset$ Context Free Lang., it is possible to go from reg. expr. to CFGs via NFA.

Recall: (a | b)*abb



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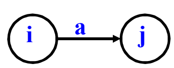
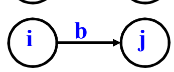
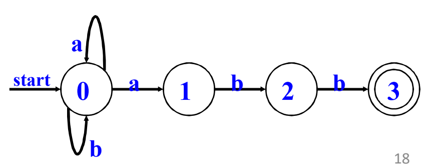
Resolving Problems/Difficulties – (3)

Construct CFG as follows:

1. **Each State I has non-terminal A_i : A_0, A_1, A_2, A_3**
2. **If**  **then $A_i \rightarrow a\, A_j$**
3. **If**  **then $A_i \rightarrow bA_j$**
4. **If I is an accepting state, $A_i \rightarrow \in$: $A_3 \rightarrow \in$**
5. **If I is a starting state, A_i is the start symbol : A_0**

T={a,b}, NT={A_0, A_1, A_2, A_3}, S = A_0
PR ={ $A_0 \rightarrow aA_0 \mid aA_1 \mid bA_0$;
$A_1 \rightarrow bA_2$;
$A_2 \rightarrow bA_3$;
$A_3 \rightarrow \in$ }



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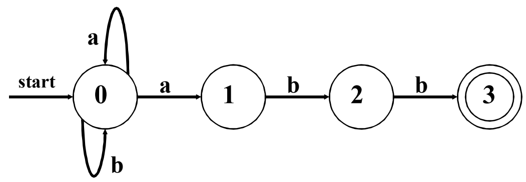
How Does This CFG Derive Strings ?



vs.

$A_0 \rightarrow aA_0$, $A_0 \rightarrow aA_1$

$A_0 \rightarrow bA_0$, $A_1 \rightarrow bA_2$

$A_2 \rightarrow bA_3$, $A_3 \rightarrow \in$

How is abaabb derived in each ?

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Regular Expressions vs. CFGs

Regular expressions for lexical syntax

1. CFGs are overkill, lexical rules are quite simple and straightforward
2. REs – concise / easy to understand
3. More efficient lexical analyzer can be constructed
4. RE for lexical analysis and CFGs for parsing promotes modularity, low coupling & high cohesion.

CFGs : Match tokens "(" ")", begin / end, if-then-else, whiles, proc/func calls, …

Intended for structural associations between tokens !

Are tokens in correct order ?

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Resolving Grammar Difficulties : Motivation

1. **Humans write / develop grammars**
2. **Different parsing approaches have different needs**

Top-Down vs. Bottom-Up

- **For: 1 $\rightarrow$ remove "errors"**
- **For: 2 $\rightarrow$ put / redesign grammar**

Grammar Problems

- **-Removing Non-generating variable**
- **-Removing Non-reachable variable**
- **-ambiguity**
- **- $\in$-moves**
- **- cycles**
- **- left recursion**
- **- left factoring**

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