

Informatique Fondamentale IMA S8

Cours 5 : Lexical and Syntactic Analysis

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April 2011



V - Lexical and syntactic analysis : the compiler front-end in practise

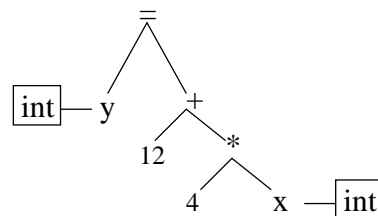
Refreshing memories

Compiler Front-End ► **Abstract Syntax Tree** (AST)

```
int y = 12 + 4*x ;
```

⇒ [TKINT, TKVAR("y"), TKEQ, TKINT(12), TKPLUS, TKINT(4), TKFOIS, TKVAR("x"), TKPVIRG]

⇒



- 1 Lexical Analysis aka Lexing
 - Lexing with C
 - Lexing in Java : JFLEX
 - Producing tokens for Parsing !

- 2 Syntactic Analysis aka Parsing

- 3 Syntactic Analysis and rules

- 4 Towards a methodology for designing front-ends in Java

- 5 Other technologies for the front-end

What for ?

```
int y = 12 + 4*x ;
```

⇒ [TKINT, TKVAR("y"), TKEQ, TKINT(12), TKPLUS, TKINT(4), TKFOIS, TKVAR("x"), TKPVIRG]

► The Lexing produces from a flow of characters a list of tokens.

Algorithm

What's behind ?

From a Regular language, produce an automata (see **course 1**)

A tool for C : LEX - 1

lex : A (standard) tool that produces an automaton that recognises a given language and produces tokens :

- **input** : a set of regular expressions with actions (`toto.lex`).
- **output** : a `.c` that contains the associated automata.

A tool for C : LEX - 2

Demos :

- recognising (simple) arithmetic expressions.
- producing tokens.

.lex format and compilation

.lex construction

```
%{
// Initial C code
}%
// Macro defs
%%
// Rules
%%
// Auxiliary c procedures and (eventually) main
```

Compilation with :

```
lex toto.lex //produces lex.yy.c
gcc -o toto lex.yy.c -ll // links with lex lib
```

.lex example

.lex dummy example

```
%{
// nothing there
}%
// simple macros
CHIFFRE [0-9]
%%
{CHIFFRE}+ ;
[ \t \n] ;
<<EOF>> { printf ("recognized_file !_!\n");
          exit (0);
        }
. {printf ("unrecognized !_!\n"); exit(1) ;}
%%
// nothing
```

► recognise files with numbers, spaces, tab and newlines

.lex syntax

- *"string"* : a string
- *'c'* : a character
- *[A-Z]* : a character between A and Z
- *<<EOF>>* : end of file
- *{DIGIT}+* : a number (one or more digits)
- *[A-Za-z]** : a word (could be empty)
- *[-+]?{DIGIT}+* a signed number (the sign is optional)
- and more

► See the [manual](#)

<http://dinosaur.compilertools.net/lex/index.html>

.lex variables and functions

Variables :

- *yyin* input file (default is stdin)
- *yyout* output file (default is stdout)
- *yytext* : last recognized string
- *yylen* longueur de *yytext*

Functions :

- *yylex()* call to lex, active until the first return
- *yywrap()* useful to deal with several files.

► example.

Lex counts !

Lex is a little more expressive than regular automata :

.lex dummy example

```
%{
  int num_lines = 0;
  int num_chars = 0;
}%
//no macros

%%
\n      { num_lines++; num_chars++;}
.       { num_chars++ ;}
%%

int main() {
  yylex();
  printf("#_of_lines_=%d, #_of_chars_=%d\n",
        num_lines, num_chars );
  return 0;
}
```

Lexing tool for java : JFLEX

The official webpage : jflex.de (GPL)

Lexing in java - 1

A minimal example from the distribution (standalone.flex) :

```
%%

%public          <<<---- generates a public class
%class Subst    <<<---- which name is Subst.java
%standalone     <<<---- standalone use (no cup)

%unicode        <<<---- encoding

%{
  String name;   <<<-- declaration of local var
}%

"name_" [a-zA-Z]+ { name = yytext().substring(5); }
[Hh] "ello"      { System.out.print(yytext()+"_"+name+"!"); }
```

► Demo !

Lexing in java - 2

Commands :

```
flex standalone.flex //produces Subst.java file
javac Subst.java     //produces Subst.class
java Subst totoexample // the lexer in action !
```

So Far ...

Lex/JFlex have been used to produce **acceptors** for (\simeq regular) languages.

\Rightarrow we have to produce tokens (terminal symbols)

Terminal symbols

For instance :

- numbers
- identifiers
- operations
- keywords
- braces, brackets

With C/Lex

Syntax :

```
{CHIFFRE}+          { return TK_INT ; }
```

The tokens must be declared (in yacc file)

With Java/Flex

Syntax (using Symbol from `java_cup.runtime.Symbol`) :

```
"+"                { return symbol(sym.PLUS); }
```

The token `sym.PLUS` must be declared (in cup file)

Terminal symbols - tokens and values

The token may have values :

- TK_INT (+value int)
- TK_ID (+ value string)
- ...

► See later for examples in C and Java.

1 Lexical Analysis aka Lexing

2 Syntactic Analysis aka Parsing

- Parsing ?
- Parsing in C : Yacc (or Bison)
- Parsing in Java : Cup

3 Syntactic Analysis and rules

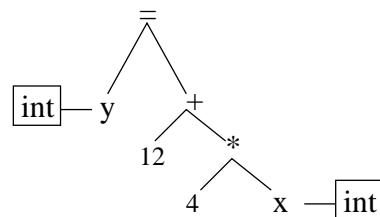
4 Towards a methodology for designing front-ends in Java

5 Other technologies for the front-end

What's Parsing ?

[TKINT, TKVAR("y"), TKEQ, TKINT(12), TKPLUS, TKINT(4), TKFOIS, TKVAR("x"), TKPVIRG]

⇒



or “yes, it belongs to the grammar !”

From the grammar to the parser

The grammar must be a **context-free grammar**

S → aSb

S → ε

In this grammar :

- S is the start symbol
- a and b are **non terminal** tokens (**produced by the lexing phase**)

Recognising $a^n b^n$ - with lex/yacc

example4.lex

```
%{
// inclusion of generated
// .h from yacc
#include "y.tab.h"
#include <stdio.h>
}%
// macros
%%
"a" {return TK_A;}
"b" {return TK_B;}
%%
// nothing
```

example4.y

```
%{ // initial code
#include <stdio.h>
}%
%token TK_A TK_B
%start S
%%
// grammar rules
S : TK_A S TK_B
  |
  ;
%%
int main(void) {
    yyparse();
    printf("end_of_parsing\n");
}
```

► Syntax error on "aaaaab".

A Makefile for lex/yacc

```
NAME=exemple4

all: y.tab.c lex.yy.c
    gcc -o $(NAME) y.tab.c lex.yy.c -ll -ly

lex.yy.c : $(NAME).lex
    lex $(NAME).lex

y.tab.c : $(NAME).y
    yacc -d $(NAME).y

clean:
    rm lex.yy.c y.tab.c y.tab.h *~
```

Recognising $a^n b^n$ - with Flex and Cup -1

anbn.flex

```
import java_cup.runtime.*; // import Symbol class etc
%%
%class Anbn
%unicode
%line
%column
%cup
%{ /* a function to create tokens along with line,col. numbers */
private Symbol symbol(int type) {
    return new Symbol(type, yyline, yycolumn);
}
}%
/* macros */
%%
/* rules */
'a' {return symbol(sym.TKA) ; }
'b' {return symbol(sym.TKB) ; }
```

► flex generates **Anbn.java**

Recognising $a^n b^n$ - with Flex and Cup -2

anbn.cup

```
import java_cup.runtime.*;
parser code {
    public void report_fatal_error( String message, Object info)
    throws Exception {report_error (message, info );
    throw new Exception("Syntax_Error");
    }
};

terminal TKA,TKB;
non terminal S;

S ::= TKA S TKB | ;
```

► cup generates two classes : **parser.java** and **sym.java**

Recognising $a^n b^n$ - with Flex and Cup -3

The main class :

Analyseur.java

```
import java.io.*;

public class Analyseur {
    static public void main ( String argv[] ){

    try {
        parser p = new parser(new Anbn(new FileReader(argv[0]))) ;
        Object result = p.parse();
        System.out.println("\n_file_ OK" ) ;
    } catch ( Exception e ) {
        System.out.println("\n_Syntax_Error" ) ;
    }
    }
}
```

► Compiled with all **.java**. ► **warning**, to run, java-cup-11a.jar must be in the classpath (or used with the -cp option)

A Makefile for flex/cup

```
JFLEX=/home/laure/analyseurs/jflex-1.4.3/bin/jflex
CUPJAR=/home/laure/analyseurs/jflex-1.4.3/java-cup-11a.jar

# directory/package containing your sources
CUPFILE=anbn.cup # the cup file containing your grammar
LEXFILE=anbn.flex # the flex file containing your lexical analyzer

CPATH=./$(CUPJAR)
SOURCES=*.java

all: cup flex
javac -cp $(CPATH) $(SOURCES)

cup: $(CUPFILE)
java -jar $(CUPJAR) $(CUPFILE)

flex: $(LEXFILE)
$(JFLEX) $(LEXFILE)

clean:
rm *.class parser.java sym.java *~ Anbn.java
```

So Far ...

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Lex/Yacc and JFlex/Cup have been used to produce **acceptors** for context-free languages

⇒ the abstract syntax tree remains to be constructed (then used !)

Semantic actions

Semantic actions : code that are performed each time a grammar rule is matched.

Example in C/Yacc

```
S : TK_A S TK_B { printf("rule_1\n");};
```

Example in Java/Cup

```
S ::= TKA S TKB { :System.out.println("rule1");};
```

► We can do more than pretty print!

Semantic actions and implicit AST in C - 1

Example : evaluation of an arithmetic expression in C (12+5*6).

example5.lex

```
#include "y.tab.h"
#include <stdio.h>
%}
DIGIT      [0-9]
%%
{DIGIT}+  { yylval=atoi(yytext);
           return TK_INT; }
"+"       { return TK_PLUS; }
"*"       { return TK_TIMES; }
";"       { return TK_SEMICOL; }
[ \t \n] ;
%%
```

Semantic actions and implicit AST in C - 2

Example : example5.y

```
%{ // code initial
#include <stdio.h>
%}
%token TK_INT TK_PLUS TK_TIMES TK_SEMICOL
%left TK_PLUS
%left TK_TIMES
%start S
%%
// rules
S: E TK_SEMICOL { printf("result_:_%d\n", $1); }
;
E: TK_INT      { $$=$1; }
  | E TK_PLUS E { $$=$1+$3; }
  | E TK_TIMES E { $$=$1*$3; }
;
%%
int main(void) {
  yyparse();
  printf("end_of_parsing\n");
}
```

Semantic actions and implicit AST in Java

a part of expr.flex

```
{integer} { return symbol(sym.TKINT, new Integer(yytext())); }
"+"       { return symbol(sym.TKPLUS); }
```

a part of expr.cup

```
E ::= TKINT:n
   | E: e1 TKPLUS E: e2
   { : RESULT = new Integer(n.intValue()); ; }
   { : RESULT = new Integer(e1.intValue() + e2.intValue()); ; }
```

Do not forget to declare that * > +

Explicit AST, why ?

Why not program our compilers entirely using semantic actions ?

- Because manipulating a tree is easier.
- Because the semantics actions are not really easy to read
- Because of **the separation of concerns**

http:

[//en.wikipedia.org/wiki/Separation_of_concerns](http://en.wikipedia.org/wiki/Separation_of_concerns)

► Parse, **then** evaluate/print/construct another internal representation, ...

Semantic actions and explicit AST in Java - 1

The class ASTExpr.java : The Tree !

```
public class ASTExpr {
    final static int INT=0, ADD=1, MUL=2 ;
    int tag ;
    int asInt ; // value used if tag = INT
    ASTExpr e1, e2 ; // used if ADD or MUL
    //Constructors
    ASTExpr(int i) { tag = INT ; asInt = i ; }
    ASTExpr(ASTExpr e1, int op, ASTExpr e2) {
        tag = op; this.e1 = e1; this.e2 = e2; }
    //evaluation of an expression
    int eval() {
        switch (this.tag) {
            case ASTExpr.INT: return this.asInt;
            case ASTExpr.ADD: return this.e1.eval()+this.e2.eval();
            case ASTExpr.MUL: return this.e1.eval()*this.e2.eval();
        }
        throw new Error("incorrect_tag");
    }
}
```

Semantic actions and explicit AST in Java - 2

a part of expr.cup

```
non terminal ASTExpr E;

S ::= E:e TKSEMICOL { :System.out.println(e.eval()); : }
;

E ::= TKINT:n
    { : RESULT = new ASTExpr(n.intValue()); : }
    |
    E:e1 TKPLUS E:e2
    { : RESULT = new ASTExpr(e1,ASTExpr.ADD,e2); : }
;
```

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The running example

```
vars x,y,z;
y:=13;
z:=80;
x:=y+z;
z:=x*12;
print(x);
```

- ▶ Parse and evaluate expressions in Java !

Questions

- What is the grammar ? (and keywords, and end symbols ...)
- Write the lex and cup files.
- Construct the intermediate representation in Java **But How ?**

A class hierarchy as intermediate representation

A quick look at **the grammar** :

```
program ::= instruction_l
instruction_l ::= instruction instruction_l
instruction ::= declaration | assignment | print
```

Then

- Each non-terminal is a class.
- `Instruction` will be an abstract class
- `class Declaration` extends `Instruction`
- the class `Program` will have an `interpret()` function.

Last (?) problem

We have to store the variables and their (current) values, **the context**

- ▶ Use a hashmap !

```
HashMap<String,Integer> currentContext
```

- ▶ Evaluating an expression requires this context !

Front-end more recent technologies

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- 5 Other technologies for the front-end
 - XML parsers (java, . . .) : more for data languages
 - ANTLR (multi languages)
 - ROSE (C/C++ frontend) : source to source translator, provides high level functions in C++
 - LLVM, (C/C++) more for code optimisation, still in research domain.