Lexical Analysis - Part 3

Y.N. Srikant

Department of Computer Science and Automation
Indian Institute of Science
Bangalore 560 012

NPTEL Course on Principles of Compiler Design

Outline of the Lecture

- What is lexical analysis? (covered in part 1)
- Why should LA be separated from syntax analysis? (covered in part 1)
- Tokens, patterns, and lexemes (covered in part 1)
- Difficulties in lexical analysis (covered in part 1)
- Recognition of tokens - finite automata and transition diagrams (covered in part 2)
- Specification of tokens - regular expressions and regular definitions (covered in part 2)
- LEX - A Lexical Analyzer Generator

Transition Diagrams

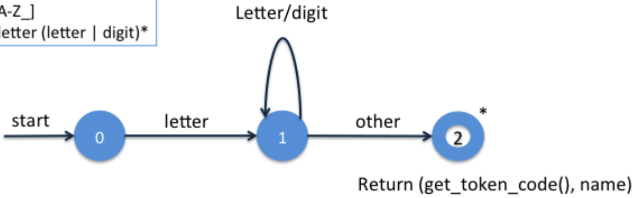
- Transition diagrams are generalized DFAs with the following differences
  - Edges may be labelled by a symbol, a set of symbols, or a regular definition
  - Some accepting states may be indicated as *retracting states*, indicating that the lexeme does not include the symbol that brought us to the accepting state
  - Each accepting state has an action attached to it, which is executed when that state is reached. Typically, such an action returns a token and its attribute value
- Transition diagrams are not meant for machine translation but only for manual translation

Lexical Analyzer Implementation from Trans. Diagrams

```
TOKEN gettoken() {
   TOKEN mytoken; char c;
   while(1) { switch (state) {
     /* recognize reserved words and identifiers */
       case 0: c = nextchar(); if (letter(c))
               state = 1; else state = failure();
               break;
       case 1: c = nextchar();
               if (letter(c) || digit(c))
               state = 1; else state = 2; break;
       case 2: retract(1);
               mytoken.token = search_token();
               if (mytoken.token == IDENTIFIER)
               mytoken.value = get_id_string();
               return(mytoken);
```

Transition Diagram for Identifiers and Reserved Words

letter = [a-zA-Z_]
Identifier = letter (letter | digit)*

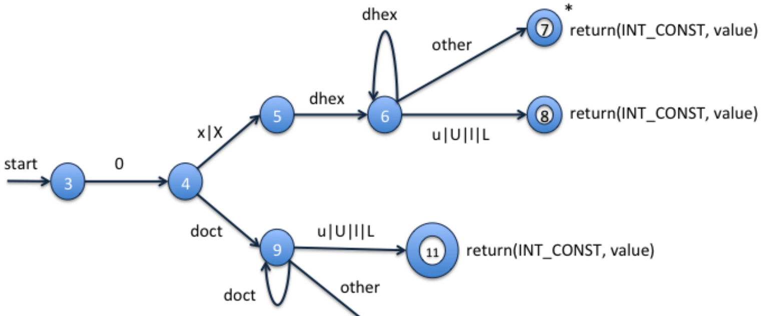


- '*' indicates retraction state
- get_token_code() searches a table to check if the name is a reserved word and returns its integer code, if so
- Otherwise, it returns the integer code of IDENTIFIER token, with name containing the string of characters forming the token (name is not relevant for reserved words)

Lexical Analyzer Implementation from Trans. Diagrams

```
/* recognize hexa and octal constants */
  case 3: c = nextchar();
          if (c == '0') state = 4; break;
          else state = failure();
  case 4: c = nextchar();
          if ((c == 'x') || (c == 'X'))
          state = 5; else if (digitoct(c))
          state = 9; else state = failure();
          break;
  case 5: c = nextchar(); if (digithex(c))
          state = 6; else state = failure();
          break;
```

Transition Diagrams for Hex and Oct Constants



hex_const = 0 (x | X) dhex $^+$ (qualifier | ε)
oct_const = 0 doct $^+$ (qualifier | ε)
qualifier = u | U | l | L
dhex = [0-9A-F]
doct = [0-7]

Lexical Analyzer Implementation from Trans. Diagrams

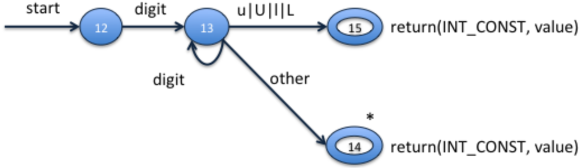
```
    case 6: c = nextchar(); if (digithex(c))
            state = 6; else if ((c == 'u')||
            (c == 'U')||(c == 'l')||
            (c == 'L')) state = 8;
            else state = 7; break;
    case 7: retract(1);
/* fall through to case 8, to save coding */
    case 8: mytoken.token = INT_CONST;
            mytoken.value = eval_hex_num();
            return(mytoken);
    case 9: c = nextchar(); if (digitoct(c))
            state = 9; else if ((c == 'u')||
            (c == 'U')||(c == 'l')||(c == 'L'))
            state = 11; else state = 10; break;
```

Lexical Analyzer Implementation from Trans. Diagrams

```
    case 10: retract(1);
/* fall through to case 11, to save coding */
    case 11: mytoken.token = INT_CONST;
             mytoken.value = eval_oct_num();
             return(mytoken);
```

Transition Diagrams for Integer Constants

int_const = digit $^+$ (qualifier | ε)
qualifier = u | U | l | L
digit = [0-9]

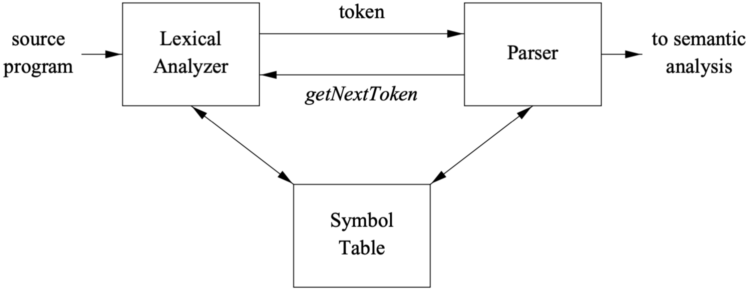


Lexical Analyzer Implementation from Trans. Diagrams

```
    /* recognize integer constants */
        case 12: c = nextchar(); if (digit(c))
                 state = 13; else state = failure();
        case 13: c = nextchar(); if (digit(c))
                 state = 13;else if ((c == 'u')||
                 (c == 'U')||(c == 'l')||(c == 'L'))
                 state = 15; else state = 14; break;
        case 14: retract(1);
    /* fall through to case 15, to save coding */
        case 15: mytoken.token = INT_CONST;
                 mytoken.value = eval_int_num();
                 return(mytoken);
        default: recover();
        }
    }
}
```

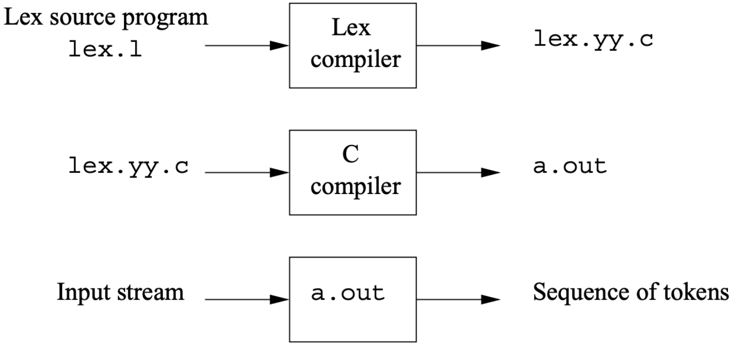
Combining Transition Diagrams to form LA

- Different transition diagrams must be combined appropriately to yield an LA
    - Combining TDs is not trivial
    - It is possible to try different transition diagrams one after another
    - For example, TDs for reserved words, constants, identifiers, and operators could be tried in that order
    - However, this does not use the “longest match" characteristic (*thenext* would be an identifier, and not reserved word *then* followed by identifier *ext*)
    - To find the longest match, all TDs must be tried and the longest match must be used
- Using LEX to generate a lexical analyzer makes it easy for the compiler writer


source program
Lexical Analyzer
token
getNextToken
Parser
to semantic analysis
Symbol Table

LEX - A Lexical Analyzer Generator

- LEX has a language for describing regular expressions
- It generates a pattern matcher for the regular expression specifications provided to it as input
- General structure of a LEX program
  {definitions} – Optional
  %%
  {rules} – Essential
  %%
  {user subroutines} – Essential
- Commands to create an LA
  - lex ex.l – creates a C-program *lex.yy.c*
  - gcc -o ex.o lex.yy.c – produces ex.o
  - ex.o is a *lexical analyzer*, that carves tokens from its input


Lex source program
lex.l
Lex compiler
lex.yy.c
lex.yy.c
C compiler
a.out
Input stream
a.out
Sequence of tokens

```
declarations
%%
translation rules
%%
auxiliary functions
```

The translation rules each have the form

$$\text{Pattern} \quad \{ \text{ Action } \}$$

LEX Example

```
/* LEX specification for the Example */
%%
[A-Z]+   {ECHO; printf("\n");}
.|\n       ;
%%
yywrap(){}
main(){yylex();}
```

```
/* Input */
wewevWEUFWIGhHkkH
sdcwehSDWEhTkFLksewT
```

```
/* Output */
WEUFWIG
H
H
SDWE
T
FL
T
```

Definitions Section

- Definitions Section contains definitions and included code
  - Definitions are like macros and have the following form: **name translation**

    ```
    digit  [0-9]
    number {digit} {digit}*
    ```

  - Included code is all code included between **%{** and **%}**

    ```
    %{
        float number; int count=0;
    %}
    ```

Rules Section

- Contains patterns and C-code
- A line starting with white space or material enclosed in %{ and %} is C-code
- A line starting with anything else is a pattern line
- Pattern lines contain a pattern followed by some white space and C-code
  $\{pattern\} \quad \{action\ (C - code)\}$
- C-code lines are copied verbatim to the the generated C-file
- Patterns are translated into NFA which are then converted into DFA, optimized, and stored in the form of a table and a driver routine
- The action associated with a pattern is executed when the DFA recognizes a string corresponding to that pattern and reaches a final state

Strings and Operators

- **Examples of strings**: integer a57d hello
- **Operators**:

  ```
  " \ [] ^ - ? . * + | () $ {} % <>
  ```

  \ can be used as an escape character as in C
- **Character classes**: enclosed in [and]
  Only \, -, and ^ are special inside [ ]. All other operators are irrelevant inside [ ]
  Examples:

  ```
  [-+][0-9]+    ---> (-|+)(0|1|2|3|4|5|6|7|8|9)+
  [a-d][0-4][A-C]    ---> a|b|c|d|0|1|2|3|4|A|B|C
  [^abc]  ---> all char except a,b, or c,
               including special and control char
  [+\-][0-5]+  ---> (+|-)(0|1|2|3|4|5)+
  [^a-zA-Z]  ---> all char which are not letters
  ```

Operators - Details

- **. operator**: matches any character except newline
- **? operator**: used to implement ϵ option
  $ab?c$ stands for $a(b \mid \epsilon)c$
- **Repetition, alternation, and grouping**:
  $(ab \mid cd+)?(ef)* \longrightarrow (ab \mid c(d)^+ \mid \epsilon)(ef)^*$
- **Context sensitivity**: `/`,`^`,`$`, are context-sensitive operators
  - `^`: If the first char of an expression is `^`, then that expression is matched only at the beginning of a line. Holds only outside [ ] operator
  - $: If the last char of an expression is $, then that expression is matched only at the end of a line
  - /: Look ahead operator, indicates trailing context

```
^ab  ---> line beginning with ab
ab$  ---> line ending with ab (same as ab/\n)
DO/({letter}|{digit})* = ({letter}|{digit})*,
```

LEX Actions

- Default action is to copy input to output, those characters which are unmatched
- We need to provide patterns to **catch** characters
- **yytext**: contains the text matched against a pattern copying **yytext** can be done by the action **ECHO**
- **yyleng**: provides the number of characters matched
- LEX always tries the rules in the order written down and the *longest match* is preferred

```
integer    action1;
[a-z]+     action2;
```

The input *integers* will match the second pattern

LEX Example 1: EX-1.lex

```
%%
[A-Z]+     {ECHO; printf("\n";}
.|\n       ;
%%
yywrap(){}
main(){yylex();}
```

```
/* Input */                    /* Output */
wewevWEUFWIGhHkkH              WEUFWIG
sdcwehSDWEhTkFLksewT           H
                               H
                               SDWE
                               T
                               FL
                               T
```

LEX Example 2: EX-2.lex

```
%%
^[ ]*\n
\n    {ECHO; yylineno++;}
.*    {printf("%d\t%s",yylineno,yytext);}
%%

yywrap(){}
main(){ yylineno = 1; yylex(); }
```

LEX Example 2 (contd.)

```
/* Input and Output */
========================
kurtrtotr
dvure

     123456789

euhoyo854
shacg345845nkfg
========================
1 kurtrtotr
2 dvure
3      123456789
4 euhoyo854
5 shacg345845nkfg
```

LEX Example 3: EX-3.lex

```
%{
FILE *declfile;
%}

blanks [ \t]*
letter  [a-z]
digit [0-9]
id    ({letter}|_)({letter}|{digit}|_)*
number {digit}+
arraydeclpart {id}"["{number}"]"
declpart ({arraydeclpart}|{id})
decllist ({declpart}{blanks}","{blanks})*
                 {blanks}{declpart}{blanks}
declaration (("int")|("float")){blanks}
                 {decllist}{blanks};
```

LEX Example 3 (contd.)

```
%%
{declaration} fprintf(declfile,"%s\n",yytext);
%%

yywrap(){
fclose(declfile);
}
main(){
declfile = fopen("declfile","w");
yylex();
}
```

LEX Example 3: Input, Output, Rejection

```
wjwkfblwebg2; int ab, float cd, ef;
ewl2efo24hg2jhrto;ty;
int ght,asjhew[37],fuir,gj[45]; sdkvbwrkb;
float ire,dehj[80];
sdvjkjkw
==========================================
float cd, ef;
int ght,asjhew[37],fuir,gj[45];
float ire,dehj[80];
==========================================
wjwkfblwebg2; int ab,
ewl2efo24hg2jhrto;ty;
 sdkvbwrkb;
sdvjkjkw
```

LEX Example 4: Identifiers, Reserved Words, and Constants (id-hex-oct-int-1.lex)

```
%{
int hex = 0; int oct = 0; int regular =0;
%}
letter                [a-zA-Z_]
digit                 [0-9]
digits                {digit}+
digit_oct             [0-7]
digit_hex             [0-9A-F]
int_qualifier         [uUlL]
blanks               [ \t]+
identifier            {letter}({letter}|{digit})*
integer              {digits}{int_qualifier}?
hex_const            0[xX]{digit_hex}+{int_qualifier}?
oct_const            0{digit_oct}+{int_qualifier}?
```

LEX Example 4: (contd.)

```
%%
if            {printf("reserved word:%s\n",yytext);}
else          {printf("reserved word:%s\n",yytext);}
while         {printf("reserved word:%s\n",yytext);}
switch        {printf("reserved word:%s\n",yytext);}
{identifier} {printf("identifier :%s\n",yytext);}
{hex_const}  {sscanf(yytext,"%i",&hex);
     printf("hex constant: %s = %i\n",yytext,hex);}
{oct_const}  {sscanf(yytext,"%i",&oct);
     printf("oct constant: %s = %i\n",yytext,oct);}
{integer}    {sscanf(yytext,"%i",&regular);
    printf("integer : %s = %i\n",yytext, regular);}
.|\n ;
%%
yywrap(){}
int main(){yylex();}
```

LEX Example 4: Input and Output

```
uorme while
0345LA 456UB 0x786lHABC
b0x34
========================
identifier :uorme
reserved word:while
oct constant: 0345L = 229
identifier :A
integer : 456U = 456
identifier :B
hex constant: 0x786l = 1926
identifier :HABC
identifier :b0x34
```

LEX Example 5: Floats in C (C-floats.lex)

```
digits          [0-9]+
exp             ([Ee](\+|\-)?{digits})
blanks          [ \t\n]+
float_qual      [fFlL]
%%
{digits}{exp}{float_qual}?/{blanks}
        {printf("float no fraction:%s\n",yytext);}
[0-9]*\.{digits}{exp}?{float_qual}?/{blanks}
        {printf("float with optional
                 integer part :%s\n",yytext);}
{digits}\.[0-9]*{exp}?{float_qual}?/{blanks}
        {printf("float with
                 optional fraction:%s\n",yytext);}
.|\n            ;
%%
yywrap(){} int main(){yylex();}
```

LEX Example 5: Input and Output

```
123 345.. 4565.3 675e-5 523.4e+2 98.1e5  234.3.4
345.   .234E+09L  987E-6F  5432.E7l
=====================================================
float with optional integer part : 4565.3
float no fraction: 675e-5
float with optional integer part : 523.4e+2
float with optional integer part : 98.1e5
float with optional integer part : 3.4
float with optional fraction: 345.
float with optional integer part : .234E+09L
float no fraction: 987E-6F
float with optional fraction: 5432.E7l
```

LEX Example 6: LA for Desk Calculator

```
number [0-9]+\.?|[0-9]*\.[0-9]+
name [A-Za-z][A-Za-z0-9]*
%%
[ ] {/* skip blanks */}
{number} {sscanf(yytext,"%lf",&yylval.dval);
            return NUMBER;}
{name} {struct symtab *sp =symlook(yytext);
             yylval.symp = sp; return NAME;}
"++" {return POSTPLUS;}
"--" {return POSTMINUS;}
"$" {return 0;}
\n|. {return yytext[0];}
```