Lex: A Lexical Analyser Generator

Compiler-Construction Tools

The compiler writer uses specialised tools (in addition to those normally used for software development) that produce components that can easily be integrated in the compiler and help implement various phases of a compiler.

- Scanner generators
- Parser generators
- Syntax-directed translation
- Code-generator generators
- Data-flow analysis: key part of code optimisation

Constructing a Lexical Analyser

- Problem:
- Write a piece of code that examines the input string and find a prefix that is a *lexeme* matching one of the *patterns* for all the needed *tokens*.

A Simple Example

Example

Consider the following grammar:

$$
\begin{array}{lcl}
\mathit{stmt} & \rightarrow & \textbf{if}\ \mathit{expr}\ \textbf{then}\ \mathit{stmt} \\
 & | & \textbf{if}\ \mathit{expr}\ \textbf{then}\ \mathit{stmt}\ \textbf{else}\ \mathit{stmt} \\
 & | & \epsilon \\
\mathit{expr} & \rightarrow & \mathit{term}\ \textbf{relop}\ \mathit{term} \\
 & | & \mathit{term} \\
\mathit{term} & \rightarrow & \textbf{id} \\
 & | & \textbf{number}
\end{array}
$$

Figure 3.10: A grammar for branching statements

<table>
<tr><th>EXPRESSION</th><th>MATCHES</th><th>EXAMPLE</th></tr>
<tr><td>c</td><td>the one non-operator character c</td><td><code>a</code></td></tr>
<tr><td>$\backslash c$</td><td>character c literally</td><td><code>*</code></td></tr>
<tr><td>"s"</td><td>string s literally</td><td><code>"**"</code></td></tr>
<tr><td>.</td><td>any character but newline</td><td><code>a.*b</code></td></tr>
<tr><td>^</td><td>beginning of a line</td><td><code>^abc</code></td></tr>
<tr><td>$</td><td>end of a line</td><td><code>abc$</code></td></tr>
<tr><td>[s]</td><td>any one of the characters in string s</td><td><code>[abc]</code></td></tr>
<tr><td>[^s]</td><td>any one character not in string s</td><td><code>[^abc]</code></td></tr>
<tr><td>$r*$</td><td>zero or more strings matching r</td><td><code>a*</code></td></tr>
<tr><td>$r+$</td><td>one or more strings matching r</td><td><code>a+</code></td></tr>
<tr><td>$r?$</td><td>zero or one r</td><td><code>a?</code></td></tr>
<tr><td>$r\{m,n\}$</td><td>between m and n occurrences of r</td><td><code>a{1,5}</code></td></tr>
<tr><td>$r_1 r_2$</td><td>an r_1 followed by an r_2</td><td><code>ab</code></td></tr>
<tr><td>$r_1 \mid r_2$</td><td>an r_1 or an r_2</td><td><code>a|b</code></td></tr>
<tr><td>(r)</td><td>same as r</td><td><code>(a|b)</code></td></tr>
<tr><td>r_1/r_2</td><td>r_1 when followed by r_2</td><td><code>abc/123</code></td></tr>
</table>

Figure 3.8: Lex regular expressions

Regular Definitions for the Language Tokens

$$
\begin{array}{rcl}
\mathit{digit} & \to & [\texttt{0-9}] \\
\mathit{digits} & \to & \mathit{digit}^{+} \\
\mathit{number} & \to & \mathit{digits}\ (\texttt{.}\ \mathit{digits})?\ (\ \texttt{E}\ [\texttt{+-}]?\ \mathit{digits}\ )? \\
\mathit{letter} & \to & [\texttt{A-Za-z}] \\
\mathit{id} & \to & \mathit{letter}\ (\ \mathit{letter} \mid \mathit{digit}\ )^{*} \\
\mathit{if} & \to & \texttt{if} \\
\mathit{then} & \to & \texttt{then} \\
\mathit{else} & \to & \texttt{else} \\
\mathit{relop} & \to & \texttt{<} \mid \texttt{>} \mid \texttt{<=} \mid \texttt{>=} \mid \texttt{=} \mid \texttt{<>}
\end{array}
$$

Figure 3.11: Patterns for tokens of Example 3.8

Note that keywords **if**, **then**, **else**, also match the patterns for *relop*, *id* and *number*.
Assumption: consider keywords as ‘reserved words’.

Tokens Table

LEXEMES	TOKEN NAME	ATTRIBUTE VALUE
Any *ws*	–	–
if	**if**	–
then	**then**	–
else	**else**	–
Any *id*	**id**	Pointer to table entry
Any *number*	**number**	Pointer to table entry
<	**relop**	LT
<=	**relop**	LE
=	**relop**	EQ
<>	**relop**	NE
>	**relop**	GT
>=	**relop**	GE

Figure 3.12: Tokens, their patterns, and attribute values

Whitespace

The LA also recognises the 'token' *ws* defined by:

$$ws \rightarrow (\textbf{blank}|\textbf{tab}|\textbf{newline})$$

This token will not be returned to the parser; the LA will restart from the next character.

Recogniser for **relop**

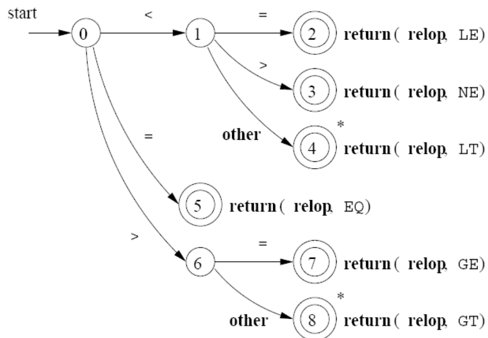


Figure 3.13: Transition diagram for **relop**

An Implementation

```
TOKEN getRelop()
{
    TOKEN retToken = new(RELOP);
    while(1) { /* repeat character processing until a return
                  or failure occurs */
        switch(state) {
            case 0: c = nextChar();
                    if ( c == '<' ) state = 1;
                    else if ( c == '=' ) state = 5;
                    else if ( c == '>' ) state = 6;
                    else fail(); /* lexeme is not a relop */
                    break;
            case 1: ...
            ...
            case 8: retract();
                    retToken.attribute = GT;
                    return(retToken);
        }
    }
}
```

Figure 3.18: Sketch of implementation of **relop** transition diagram

Recogniser for **id**

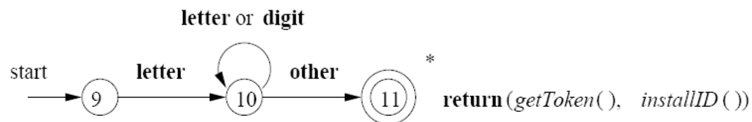


Figure 3.14: A transition diagram for **id**'s and keywords

Recogniser for **number**

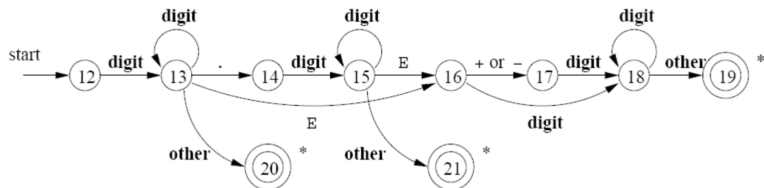


Figure 3.16: A transition diagram for unsigned numbers

Recogniser for whitespace

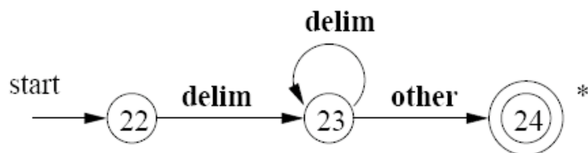


Figure 3.17: A transition diagram for whitespace

Lex

The *Lex compiler* is a tool that allows one to specify a lexical analyser from regular expressions.
Inputs are specified in the *Lex language*.

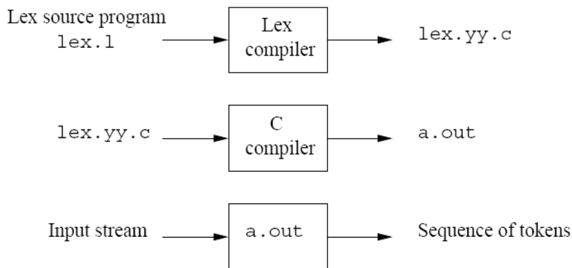


Figure 3.22: Creating a lexical analyzer with Lex

A *Lex program* consists of *declarations %% translation rules %% auxiliary functions*.

Example

```
%{
    /* definitions of manifest constants
    LT, LE, EQ, NE, GT, GE,
    IF, THEN, ELSE, ID, NUMBER, RELOP */
%}

/* regular definitions */
delim     [ \t\n]
ws        {delim}+
letter    [A-Za-z]
digit     [0-9]
id        {letter}({letter}|{digit})*
number    {digit}+(\.{digit}+)?(E[+-]?{digit}+)?

%%

{ws}      {/* no action and no return */}
if        {return(IF);}
then      {return(THEN);}
else      {return(ELSE);}
{id}      {yylval = (int) installID(); return(ID);}
{number}  {yylval = (int) installNum(); return(NUMBER);}
"<"       {yylval = LT; return(RELOP);}
"<="      {yylval = LE; return(RELOP);}
"="       {yylval = EQ; return(RELOP);}
"<>"      {yylval = NE; return(RELOP);}
">"       {yylval = GT; return(RELOP);}
">="      {yylval = GE; return(RELOP);}
```

Example (ctd.)

```
%%

int installID() {/* function to install the lexeme, whose
                    first character is pointed to by yytext,
                    and whose length is yyleng, into the
                    symbol table and return a pointer
                    thereto */
}

int installNum() {/* similar to installID, but puts numer-
                     ical constants into a separate table */
}
```

Figure 3.23: Lex program for the tokens of Fig. 3.12

Design of a LA Generator

Two approaches:

- NFA-based
- DFA-based

The *Lex compiler* is implemented using the second approach.

Generated LA

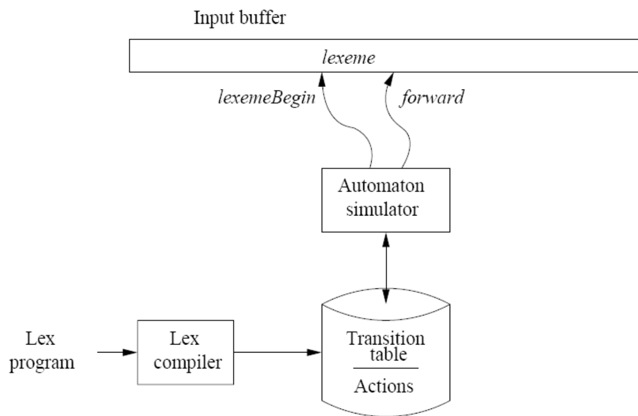


Figure 3.49: A Lex program is turned into a transition table and actions, which are used by a finite-automaton simulator

We show how o convert regular expressions to NFA's and a conversion of NFA's into DFA's. The NFA produced can then be transformed into a DFA by meanns of the latter construction if desired. It can also be used directly via a simulation following the subset construction translation alorithm.

Constructing the Automaton

For each regular expression in the *Lex program* construct a NFA.

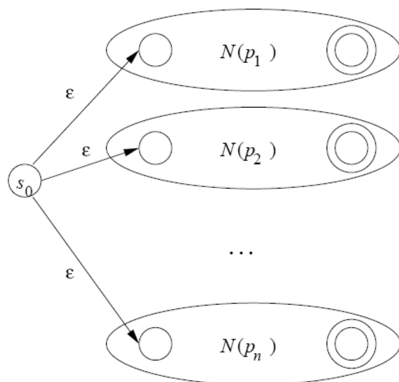
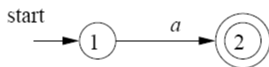
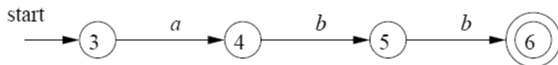


Figure 3.50: An NFA constructed from a Lex program

Simulating NFA's

Example:





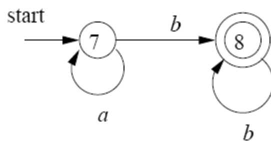


Figure 3.51: NFA's for $\mathbf{a}$, $\mathbf{abb}$, and $\mathbf{a}^*\mathbf{b}^+$

Pattern Matching

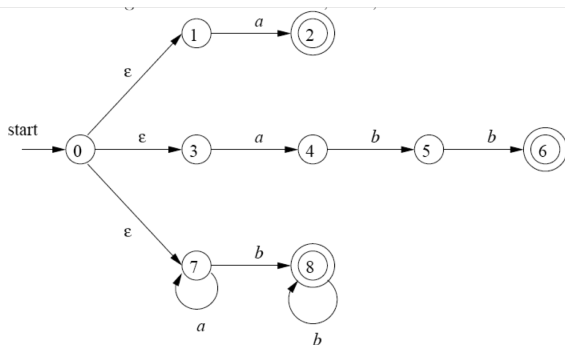


Figure 3.52: Combined NFA

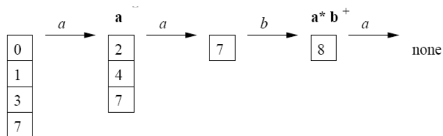


Figure 3.53: Sequence of sets of states entered when processing input *aaba*

LA Based on DFA's

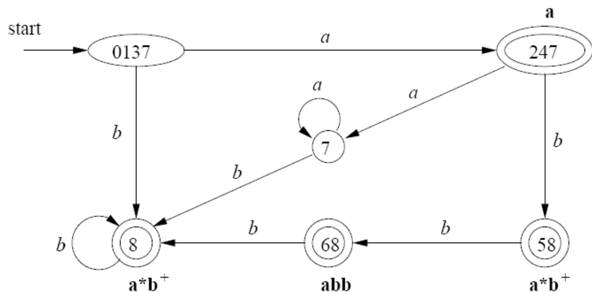


Figure 3.54: Transition graph for DFA handling the patterns **a**, **abb**, and $\mathbf{a}^*\mathbf{b}^+$