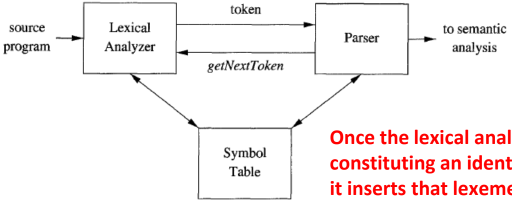
Lexical Analysis

Lexical Analysis

- The main task of the lexical analyzer is to
  - **read the input characters** of the source program,
  - **group** them into **lexemes**, and
  - produce as **output a sequence of tokens** for the source program.
  - **stripping out comments and whitespace** (blank, newline, tab etc), that are used to separate tokens in the input.
- Parser invokes the lexical analyzer by ***getNextToken*** command
- Lexical analyzer reads the characters from input until it finds the next lexeme and produce token



Once the lexical analyzer discovers a lexeme constituting an identifier,
it inserts that lexeme into the symbol table.

Tokens, Patterns and Lexemes

- **Lexeme** : It is a **sequence of characters** in the source program that matches the **pattern**.

  It is identified by the lexical analyzer as an instance of that token

- **Pattern**: Description of the form that the lexemes may take.
  - In the case of a **keyword**, the pattern is just the **sequence of characters** that form the keyword.
  - For **identifiers** and some other tokens, the pattern is a more complex structure that is matched by many strings.

- **Token** : It is a pair consisting of a token name and an optional attribute value.

$$\langle \textit{token-name}, \textit{attribute-value} \rangle$$

  - The token name as an **abstract symbol** represents the kind of **lexical unit/lexeme** (keyword/identifier, operator symbol etc)
  - Processed by parser

```c
#include <stdio.h>
int main() {
    int number1, number2, sum;

    printf("Enter First Number: ");
    scanf("%d", &number1);

    printf("Enter Second Number: ");
    scanf("%d", &number2);

    // calculating sum
    sum = number1 + number2;

    printf("\nAddition of %d and %d is %d", number1, number2, sum);
    return 0;
}
```

Example of tokens

Pattern

	TOKEN	INFORMAL DESCRIPTION	SAMPLE LEXEMES
	if	characters i, f	if
	else	characters e, l, s, e	else
relop	**comparison**	< or > or <= or >= or == or !=	<=, !=
	id	letter followed by letters and digits	pi, score, D2
	number	any numeric constant	3.14159, 0, 6.02e23
	literal	anything but ", surrounded by "'s	"core dumped"

1. One token for each keyword. The pattern for a keyword is the same as the keyword itself.
2. Tokens for the operators, either individually or in classes such as the token `comparison`
3. One token representing all identifiers.
4. One or more tokens representing constants, such as numbers and literal strings.
5. Tokens for each punctuation symbol, such as left and right parentheses, comma, and semicolon.

Example of tokens

Pattern

	Token	Informal Description	Sample Lexemes
	if	characters `i`, `f`	`if`
	else	characters `e`, `l`, `s`, `e`	`else`
relop	**comparison**	`<` or `>` or `<=` or `>=` or `==` or `!=`	`<=`, `!=`
	id	letter followed by letters and digits	`pi`, `score`, `D2`
	number	any numeric constant	`3.14159`, `0`, `6.02e23`
	literal	anything but `"`, surrounded by `"`'s	`"core dumped"`

Find the tokens

```
printf("Total = %d\n", score);
```

Attribute for tokens

$\langle \textit{token-name}, \textit{attribute-value} \rangle$

- **Attribute** provides **additional piece of information** about a **lexeme**
  - Important for the code generator to know which lexeme was found in the source program
- Example: For the token **identifier id**, we need to associate with
  - its lexeme, its type, and the location at which it is first found
  - Attribute value for an identifier **id** is essentially a **pointer to the symbol-table** entry for that identifier
- Example: For the token **number,** attributes can be the respective numbers (1.3, 0 etc)

```
position = initial + rate * 60
```

$\langle \mathbf{id}, 1\rangle \ \langle = \rangle \ \langle \mathbf{id}, 2\rangle \ \langle + \rangle \ \langle \mathbf{id}, 3\rangle \ \langle * \rangle \ \langle 60 \rangle$

(number, 60)

1	position	...
2	initial	...
3	rate	...

Attribute for tokens

$\langle \textit{token-name}, \textit{attribute-value} \rangle$

- Attribute provides additional piece of information about a lexeme
  - Important for the code generator to know which lexeme was found in the source program

The token names and associated attribute values

```
E = M * C ** 2
```

<**id**, pointer to symbol-table entry for `E`>
<**assign_op**>
<**id**, pointer to symbol-table entry for `M`>
<**mult_op**>
<**id**, pointer to symbol-table entry for `C`>
<**exp_op**>
<**number**, integer value 2>

Scanning input from the source file

- Fast reading of the source program from disk
- **Challenge** to find lexemes
    - We often have to look one or more characters beyond the next lexeme
    - To ensure we have the right lexeme.

$-$, $=$, or $<$

Note the challenge!

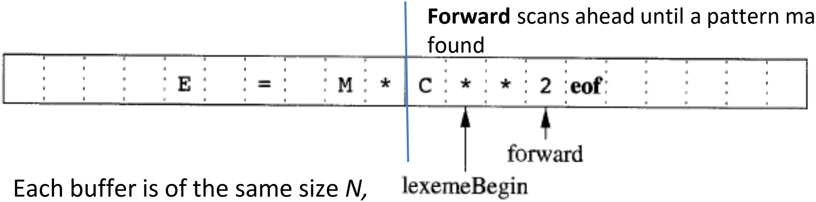
$->$, $==$, or $<=$.

Scanning input from the source file

Two buffer solution

lexemeBegin: marks the beginning of the current lexeme

Forward scans ahead until a pattern match is found



- Each buffer is of the same size *N*,
- *N* is usually the size of a disk block (4KB).
- If fewer than N characters remain in the input file, then a special character, represented by **eof**

Advancing **forward** requires that

(a) we first **test** whether we have reached the **end of one of the buffers**,

(b) if so, we must **reload the other buffer** from the input, and move forward to the beginning of the newly loaded buffer.

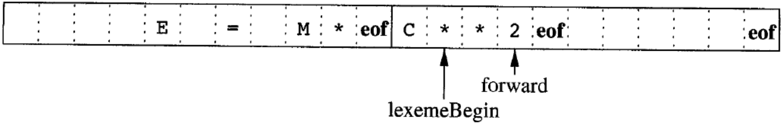
```c
#include <stdio.h>
int main() {
    int number1, number2, sum;

    printf("Enter First Number: ");
    scanf("%d", &number1);

    printf("Enter Second Number: ");
    scanf("%d", &number2);

    // calculating sum
    sum = number1 + number2;

    printf("\nAddition of %d and %d is %d", number1, number2, sum);
    return 0;
}
```

Scanning input from the source file
Sentinels (eof)

Each time we advance **forward**, we make two tests:

(a) if we reached at the **end of the buffer**, and

(b) determine what character is read----**test if the next lexeme** is determined;



(a) We extend each buffer to hold a *sentinel* **eof** character at the end

(b) **eof** retains its use as a marker for the end of the entire input.

Scanning input from the source file

Sentinels

```
switch ( *forward++ ) {
      case eof:
            if (forward is at end of first buffer ) {
                  reload second buffer;
                  forward = beginning of second buffer;
            }
            else if (forward is at end of second buffer ) {
                  reload first buffer;
                  forward = beginning of first buffer;
            }
            else /* eof within a buffer marks the end of input */
                  terminate lexical analysis;
            break;
      Cases for the other characters
}
```

Specification of Tokens – Patterns

- **Regular expressions** are an important notation for specifying **lexeme patterns**.
  - A ***string*** over an **alphabet** is a finite sequence of symbols drawn from that alphabet
  - Represent all the **valid strings** with **Regular expressions**
- Suppose we wanted to describe the set of **valid C identifiers**
- **letter_** stands for any letter or the underscore $\{\mathtt{A}, \mathtt{B}, \ldots, \mathtt{Z}, \mathtt{a}, \mathtt{b}, \ldots, \mathtt{z}\}$
- **digit** stands for any digit $\{0, 1, \ldots 9\}$
- the language/**RE** of **C identifiers** $\mathit{letter\_}\ (\ \mathit{letter\_} \mid \mathit{digit}\ )^*$

OPERATION	DEFINITION AND NOTATION
Union of L and M	$L \cup M = \{s \mid s \text{ is in } L \text{ or } s \text{ is in } M\}$
Concatenation of L and M	$LM = \{st \mid s \text{ is in } L \text{ and } t \text{ is in } M\}$
Kleene closure of L	$L^* = \cup_{i=0}^{\infty} L^i$
Positive closure of L	$L^+ = \cup_{i=1}^{\infty} L^i$

Specification of Tokens

Regular Definitions

Regular expressions

$$\begin{array}{ccc} d_1 & \rightarrow & r_1 \\ d_2 & \rightarrow & r_2 \\ & \cdots & \\ d_n & \rightarrow & r_n \end{array}$$

1. Each d_i is a new symbol, not in Σ and not the same as any other of the d's, and
2. Each r_i is a regular expression over the alphabet $\Sigma \cup \{d_1, d_2, \ldots, d_{i-1}\}$.

Regular definition for the language of C identifiers

$$\begin{array}{rcl} letter\_ & \rightarrow & \mathtt{A} \mid \mathtt{B} \mid \cdots \mid \mathtt{Z} \mid \mathtt{a} \mid \mathtt{b} \mid \cdots \mid \mathtt{z} \mid \_ \\ digit & \rightarrow & \mathtt{0} \mid \mathtt{1} \mid \cdots \mid \mathtt{9} \\ id & \rightarrow & letter\_ \; (\; letter\_ \mid digit \;)^* \end{array}$$

Specification of Tokens

Regular Definitions

Unsigned numbers (integer or floating point)

5280, 0.01234, 6.336E4, or 1.89E-4.

$$
\begin{array}{rcl}
\mathit{digit} & \rightarrow & \texttt{0} \mid \texttt{1} \mid \cdots \mid \texttt{9} \\
\mathit{digits} & \rightarrow & \mathit{digit}\ \mathit{digit}^* \\
\mathit{optionalFraction} & \rightarrow & \texttt{.}\ \mathit{digits} \mid \epsilon \\
\mathit{optionalExponent} & \rightarrow & (\ \texttt{E}\ (\ \texttt{+} \mid \texttt{-} \mid \epsilon\ )\ \mathit{digits}\ ) \mid \epsilon \\
\mathit{number} & \rightarrow & \mathit{digits}\ \mathit{optionalFraction}\ \mathit{optionalExponent}
\end{array}
$$

Specification of Tokens

Notational extensions

One or more instances. The unary, postfix operator $^+$

$$r^* = r^+|\epsilon \text{ and } r^+ = rr^*$$

Zero or one instance. The unary postfix operator ?

$$r? \text{ is equivalent to } r|\epsilon.$$

Character classes.

A regular expression $a_1|a_2|\cdots|a_n$ $\Rightarrow$ $[a_1a_2\cdots a_n]$ $\Rightarrow$ a_1-a_n

$$
\begin{array}{rcl}
\mathit{letter\_} & \rightarrow & \mathtt{A} \mid \mathtt{B} \mid \cdots \mid \mathtt{Z} \mid \mathtt{a} \mid \mathtt{b} \mid \cdots \mid \mathtt{z} \mid \mathtt{\_} \\
\mathit{digit} & \rightarrow & \mathtt{0} \mid \mathtt{1} \mid \cdots \mid \mathtt{9} \\
\mathit{id} & \rightarrow & \mathit{letter\_}\ (\ \mathit{letter\_} \mid \mathit{digit}\ )^*
\end{array}
$$

$$
\begin{array}{rcl}
\mathit{letter\_} & \rightarrow & \mathtt{[A\text{-}Za\text{-}z\_]} \\
\mathit{digit} & \rightarrow & \mathtt{[0\text{-}9]} \\
\mathit{id} & \rightarrow & \mathit{letter\_}\ (\ \mathit{letter} \mid \mathit{digit}\ )^*
\end{array}
$$

$$
\begin{array}{rcl}
\mathit{digit} & \rightarrow & \mathtt{0} \mid \mathtt{1} \mid \cdots \mid \mathtt{9} \\
\mathit{digits} & \rightarrow & \mathit{digit}\ \mathit{digit}^* \\
\mathit{optionalFraction} & \rightarrow & .\ \mathit{digits} \mid \epsilon \\
\mathit{optionalExponent} & \rightarrow & (\ \mathtt{E}\ (\ + \mid - \mid \epsilon\ )\ \mathit{digits}\ ) \mid \epsilon \\
\mathit{number} & \rightarrow & \mathit{digits}\ \mathit{optionalFraction}\ \mathit{optionalExponent}
\end{array}
$$

$$
\begin{array}{rcl}
\mathit{digit} & \rightarrow & \mathtt{[0\text{-}9]} \\
\mathit{digits} & \rightarrow & \mathit{digit}^+ \\
\mathit{number} & \rightarrow & \mathit{digits}\ (.\ \mathit{digits})?\ (\ \mathtt{E}\ [+-]?\ \mathit{digits}\ )?
\end{array}
$$

Recognition of Tokens

Objective:

- Take the **patterns** for **all** the needed **tokens**
- Build a **tool** that examines the **input string** and **finds the lexeme** matching one of the **patterns**

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

- The **terminals** of the grammar, --- **if, then, else, relop, id**, **number**,
  - lexical analyzer recognizes the terminals – Tokens

```c
#include <stdio.h>
int main() {
    int number1, number2, sum;

    printf("Enter First Number: ");
    scanf("%d", &number1);

    printf("Enter Second Number: ");
    scanf("%d", &number2);

    // calculating sum
    sum = number1 + number2;

    printf("\nAddition of %d and %d is %d", number1, number2, sum);
    return 0;
}
```

Recognition of Tokens

Regular Definitions for terminals

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

stripping out whitespace, by recognizing the "token" ***ws***

$$ws \rightarrow (\ \textbf{blank} \mid \textbf{tab} \mid \textbf{newline}\ )^{+}$$

ASCII chars

- Token **ws** is different from the other tokens in that,
    - Once we recognize it, we **do not return it to the parser**,
- Rather **restart the lexical analysis** from the character that follows the whitespace. It is the following token that gets returned to the parser.

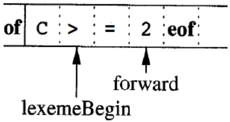
The goal for the lexical analyzer

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`

Construction of the lexical analyzer

We first **convert patterns** into "transition diagrams" --- **Finite Automata**

Scanning the input looking for a lexeme

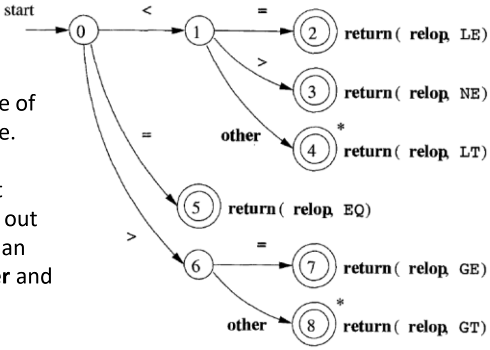


Finite Automata

Collection of nodes, called **states**

Edges are directed links from one state of the transition diagram to another state.

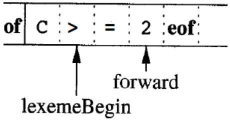
If we are in some **state S**, and the next input symbol is **a**, we look for an **edge** out of state **S** labeled by **a**. If we find such an edge, we **advance the forward pointer** and enter the next state **T**



Construction of the lexical analyzer

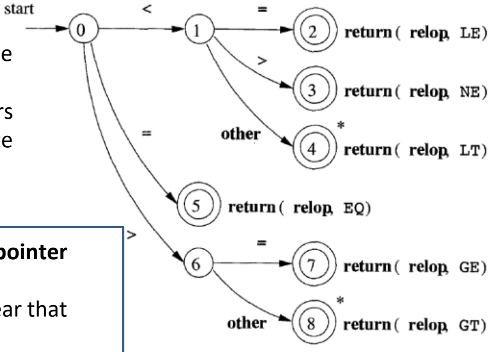
We first convert patterns into "transition diagrams" --- **Finite Automata**

Scanning the input looking for a lexeme



Finite Automata

- Certain states are said to be **accepting**
- These states indicate that a lexeme has been found between the **lexemeBegin** and **forward** pointers
- **Returning a token** and an attribute value to the parser

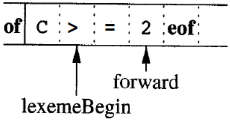


- If necessary, **retract** the **forward pointer** one position
  - additionally place a * near that accepting state

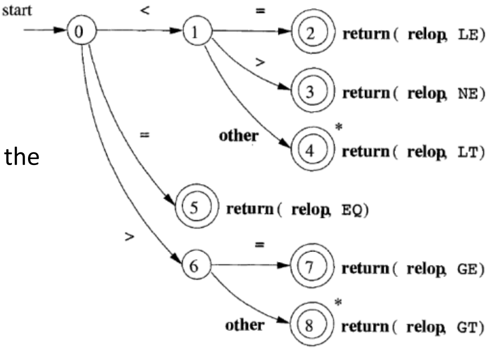
Construction of the lexical analyzer: **token relop**

We first convert patterns into "transition diagrams" --- **Finite Automata**

Scanning the input looking for a lexeme



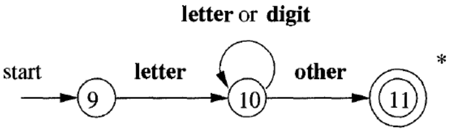
$$relop \rightarrow < \mid > \mid <= \mid >= \mid = \mid <>$$



transition diagram that recognizes the lexemes matching the **token relop**

Construction of the lexical analyzer: **Keywords and Identifiers**

Challenge: Discriminate between **Keywords and Identifiers**



$$letter\_ \ (\ letter\_ \mid digit \ )^*$$

return (*getToken*( ), *installID* ( ))

Lexeme	Token	Attrb
if	IF	
else	ELSE	
count	ID	float, ..

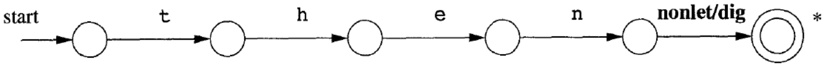
Install the **keywords** in the symbol table initially, with **tokens**

- Once we find an **identifier**, we invoke **installID** to insert it in the symbol table if it is not already in symbol table
- returns a pointer to the symbol-table entry

The function **getToken** examines the symbol table entry for the **lexeme found**, and returns whatever token name — either **ID** or one of the **keyword** tokens

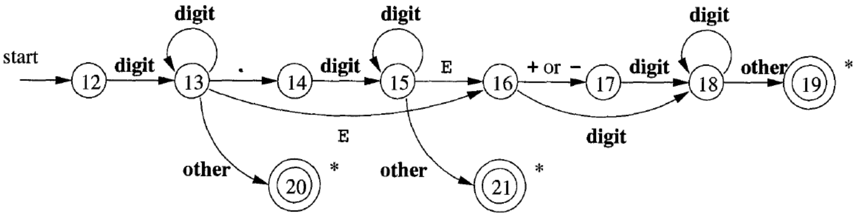
Construction of the lexical analyzer: **Keywords and Identifiers**

Create separate transition diagrams for each keyword



Differentates **then** and **then_value**

Construction of the lexical analyzer:
: **Unsigned numbers**



$$
\begin{aligned}
\textit{letter\_} &\rightarrow \texttt{A} \mid \texttt{B} \mid \cdots \mid \texttt{Z} \mid \texttt{a} \mid \texttt{b} \mid \cdots \mid \texttt{z} \mid \texttt{\_} \\
\textit{digit} &\rightarrow \texttt{0} \mid \texttt{1} \mid \cdots \mid \texttt{9} \\
\textit{id} &\rightarrow \textit{letter\_} \; (\; \textit{letter\_} \mid \textit{digit} \;)^*
\end{aligned}
$$

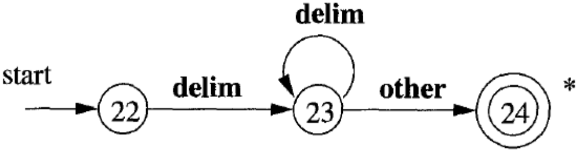
$$
\begin{aligned}
\textit{letter\_} &\rightarrow \texttt{[A-Za-z\_]} \\
\textit{digit} &\rightarrow \texttt{[0-9]} \\
\textit{id} &\rightarrow \textit{letter\_} \; (\; \textit{letter} \mid \textit{digit} \;)^*
\end{aligned}
$$

$$
\begin{aligned}
\textit{digit} &\rightarrow \texttt{0} \mid \texttt{1} \mid \cdots \mid \texttt{9} \\
\textit{digits} &\rightarrow \textit{digit} \; \textit{digit}^* \\
\textit{optionalFraction} &\rightarrow \texttt{.} \; \textit{digits} \mid \epsilon \\
\textit{optionalExponent} &\rightarrow (\; \texttt{E} \; (\; \texttt{+} \mid \texttt{-} \mid \epsilon \;) \; \textit{digits} \;) \mid \epsilon \\
\textit{number} &\rightarrow \textit{digits} \; \textit{optionalFraction} \; \textit{optionalExponent}
\end{aligned}
$$

$$
\begin{aligned}
\textit{digit} &\rightarrow \texttt{[0-9]} \\
\textit{digits} &\rightarrow \textit{digit}^+ \\
\textit{number} &\rightarrow \textit{digits} \; (\texttt{.} \; \textit{digits})? \; (\; \texttt{E} \; \texttt{[+-]}? \; \textit{digits} \;)?
\end{aligned}
$$

Construction of the lexical analyzer:
: **whitespace**

$$ws \rightarrow (\ \textbf{blank} \mid \textbf{tab} \mid \textbf{newline}\ )^+$$



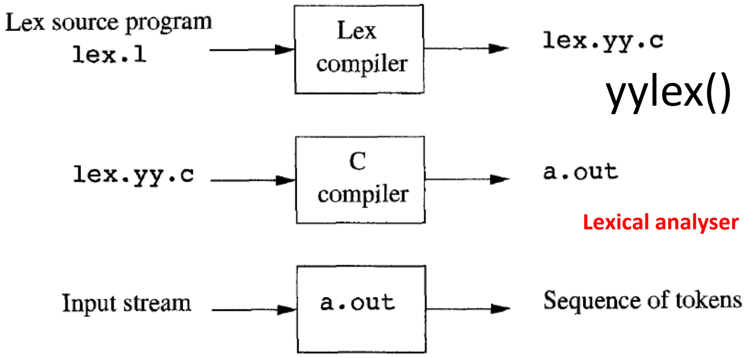
- When we **recognize ws**, we **do not return it to the parser**, but rather **restart the lexical analysis** from the character that follows the whitespace.
- It is the following token that gets returned to the parser.

Lex or flex

- Allows one to **construct a lexical analyzer** by
    - Specifying **regular expressions** to describe **patterns for tokens**.
- The **input notation** for the Lex tool is referred to as the **Lex language**
    - Tool itself is the **Lex compiler**

- Lex compiler **transforms** the **input patterns** into a **transition diagram**

    - Generates **code**, in a file called **lex.yy.c**, that simulates this transition diagram.


Lex source program
lex.l
Lex compiler
lex.yy.c
yylex()
lex.yy.c
C compiler
a.out
Lexical analyser
Input stream
a.out
Sequence of tokens

Structure of Lex Programs

A Lex program has the following form:

(a) auxiliary declarations

(b) regular definitions

declarations
%%
translation rules
%%
auxiliary functions

yylex()

Pattern { Action }

Additional functions --- say main()
etc

Structure of Lex Programs

A Lex program has the following form:

(a) auxiliary declarations
(i)declaration of variable, functions
(ii) inclusion of header file,
(iii)Defining macro

- Enclosed within %{ and %}

- Auxiliary declarations are copied as such by LEX to the output lex.yy.c file.
    - Not processed by the LEX tool.

(b) regular definitions

declarations **Optional**
%%
translation rules
%%
auxiliary functions

Structure of Lex Programs

A Lex program has the following form:

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

Lex.yy.c
yylex()

Pattern { Action }

Additional functions --- say main() etc

(a) Each pattern is a **regular expression**, which may use the **regular definitions** of the **declaration section**.
(b) The **actions** are **fragments of C code**

- yylex() function **checks the input stream** for the **first match to one of the patterns**
- **Executes code** in the **action part** corresponding to the pattern.

Input file

if + 78 else 0

Tokens: if, else, op (+,-), number, other

Lex – example

```
%{
#include<stdio.h>
#define IF 1
#define ELSE 2
#define NUM 3
#define OP 4
#define ERR 5

%}
```

Auxiliary declarations

```
/* Declarations*/
%%
if       return (IF);
else     return (ELSE);
[0-9]+   return(NUM);
[+-]     return(OP);
.        return(ERR);
%%
```

Regular expressions

Actions

Any char

Generates yylex()

Recognition of Tokens

Regular Definitions for terminals

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

stripping out whitespace, by recognizing the "token" ***ws***

$$ws \to (\ \textbf{blank} \mid \textbf{tab} \mid \textbf{newline}\ )^{+}$$

ASCII chars

- Token **ws** is different from the other tokens in that,
    - Once we recognize it, we **do not return it to the parser**,
- Rather **restart the lexical analysis** from the character that follows the whitespace. It is the following token that gets returned to the parser.

Specification of Tokens

Notational extensions

One or more instances. The unary, postfix operator $^+$

$$r^* = r^+|\epsilon \text{ and } r^+ = rr^*$$

Zero or one instance. The unary postfix operator ?

$r?$ is equivalent to $r|\epsilon$.

Character classes.

A regular expression $a_1|a_2|\cdots|a_n$ ⇒ $[a_1a_2\cdots a_n]$ ⇒ $a_1\text{-}a_n$

Structure of Lex Programs

A Lex program has the following form:

(a) auxiliary declarations

(b) regular definitions

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

yylex()

Pattern { Action }

Additional functions --- say main() etc

- **LEX generates C code** for the rules specified in the **Rules section** and places this code into a single function called **yylex()**.
- **In addition** to this LEX generated code, the programmer may wish to add **his own code** to the lex.yy.c file.
- The **auxiliary functions section** allows the programmer to achieve this.

Lex – example

```
%{
#include<stdio.h>
%}



/* Declarations*/
%%
if      printf("if\n");
else    printf("else\n");
[0-9]+  printf("number %s\n",yytext);
[+-]    printf("operator %s\n",yytext);
.       printf("other\n");
```

Any char

```
%%
/* Auxiliary functions */


int main()
{
    yylex();

        return 1;
}

int yywrap(void)
{
        return(1);
}
```

Auxiliary functions

yylex()

```
%{
#include<stdio.h>
%}


/* Declarations*/
%%
if      printf("if\n");
else    printf("else\n");
[0-9]+  printf("number %s\n",yytext);
[+-]    printf("operator %s\n",yytext);
.       printf("other\n");


%%
/* Auxiliary functions */


int main()
{
    yylex();

        return 1;
}

int yywrap(void)
{
        return(1);
}
```

yylex()

- When **yylex() is invoked**, it **reads the input file** and scans through the input looking for a **matching pattern**.
- When the **input or a part of the input matches** one of the given **patterns**, yylex() **executes the corresponding action** associated with the pattern as specified in the Rules section.
- yylex() **continues scanning** the input
  (a) till one of the actions corresponding to a matched pattern **executes a return statement** or
  (b) till the **end of input** has been encountered.
- Note that **if none of the actions** in the Rules section executes a return statement, yylex() **continues scanning for more matching patterns** in the input file **till the end of the file**.

Lex – example-1

Input file – **input_first**

if + 78 else 0

Tokens: if, else, op (+,-), number, other

Lex – example-1

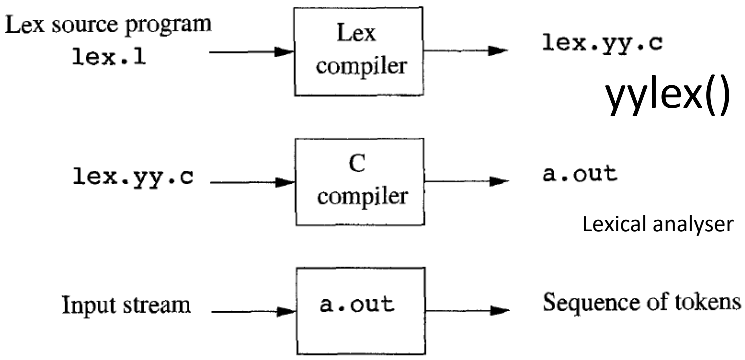
```
%{
#include<stdio.h>
%}


/* Declarations*/
%%
if      printf("if\n");
else    printf("else\n");
[0-9]+  printf("number %s\n",yytext);
[+-]    printf("operator %s\n",yytext);
.       printf("other\n");


%%
/* Auxiliary functions */


int main()
{
    yylex();

        return 1;
}

int yywrap(void)
{
        return(1);
}
```

yytext is the string (of type *char*) indicating the **lexeme*** currently found. [like **LexemeBegin**]

Each invocation of the function ***yylex()*** results in ***yytext*** carrying a pointer to the **lexeme** found in the input stream by *yylex()*

yyleng is a variable of the type **int** and
it stores the length of the lexeme pointed to by
yytext.

lex_first.l


Lex source program
lex.l
Lex compiler
lex.yy.c
yylex()
lex.yy.c
C compiler
a.out
Lexical analyser
Input stream
a.out
Sequence of tokens

bivasm@cpusrv-gpu-108: ~/lex

```
bivasm@cpusrv-gpu-108:~/lex$ lex lex_first.l
bivasm@cpusrv-gpu-108:~/lex$ gcc lex.yy.c
bivasm@cpusrv-gpu-108:~/lex$ ./a.out<input_first
if
other
other
operator +
other
number 78
other
else
other
other
number 0

bivasm@cpusrv-gpu-108:~/lex$
```

Lex – example-1
Input file – **input_first**

if + 78 else 0

Tokens: if, else, op (+,-), number, other

Lex – example-2

```
%{#include<stdio.h>
#define IF 1
#define ELSE 2
#define NUM 3
#define OP 4
#define ERR 5%}
/* Declarations*/

%%
if              return (IF);
Else            return (ELSE);
[0-9]+          return(NUM);
[+-]            return(OP);
.               return(ERR);
%%
```

lex_first_v1.l

```
%%
/* Auxiliary functions */


int main()
{
   int ntoken;
   do{
        ntoken=yylex();

        if(ntoken==0)
                break;

        if(ntoken==IF)
            printf("The IF token is %s\n",yytext);

        else if(ntoken==ELSE)
            printf("The ELSE token is %s\n",yytext);

        else if(ntoken==NUM)
            printf("The NUM token is %s\n",yytext);
        else if(ntoken==OP)
            printf("The OP token is %s\n",yytext);
        else
            printf("The ERR token is %s\n",yytext);
        }
  while(1);
return 1;
}

int yywrap(void)
{
        return(1);
}
```

Input file – **input_first**

if + 78 else 0

bivasm@cpusrv-gpu-108: ~/lex

```
bivasm@cpusrv-gpu-108:~/lex$ lex lex_first_v1.l
bivasm@cpusrv-gpu-108:~/lex$ ls
a.out  head.h  input_f  input_first  le  lex_check.l
bivasm@cpusrv-gpu-108:~/lex$ gcc lex.yy.c
bivasm@cpusrv-gpu-108:~/lex$ ./a.out<input_first
The IF token is if
The ERR token is
The ERR token is
The OP token is +
The ERR token is
The NUM token is 78
The ERR token is
The ELSE token is else
The ERR token is
The ERR token is
The NUM token is 0

bivasm@cpusrv-gpu-108:~/lex$
```

Lex – example-3

lex_first_v2 - Notepad

File Edit Format View Help

```
%{
#include<stdio.h>
#define IF 1
#define ELSE 2
#define NUM 3
#define OP 4
#define ERR 5

%}



/* Declarations*/
%%
if       return (IF);
else     return (ELSE);
[0-9]+   return(NUM);
[+-]     return(OP);
.        printf("The error token is %s\n",yytext);


%%
```

lex_first_v2.l

```
int main()
{
   int ntoken;
   do{
        ntoken=yylex();

        if(ntoken==0)
                break;

        if(ntoken==IF)
            printf("The IF token is %s\n",yytext);

        else if(ntoken==ELSE)
            printf("The ELSE token is %s\n",yytext);

        else if(ntoken==NUM)
            printf("The NUM token is %s\n",yytext);
        else if(ntoken==OP)
            printf("The OP token is %s\n",yytext);
        else
                printf("I don't know\n");
        }
  while(1);
return 1;
}

int yywrap(void)
{
        return(1);
}
```

bivasm@cpusrv-gpu-108: ~/lex

```
bivasm@cpusrv-gpu-108:~/lex$ lex lex_first_v2.l
bivasm@cpusrv-gpu-108:~/lex$ gcc lex.yy.c
bivasm@cpusrv-gpu-108:~/lex$ ./a.out<input_first
The IF token is if
The error token is
The error token is
The OP token is +
The error token is
The NUM token is 78
The error token is
The ELSE token is else
The error token is
The error token is
The NUM token is 0

bivasm@cpusrv-gpu-108:~/lex$ 
```

Lex – example-4

File Edit Format View Help

```
%{
#include<stdio.h>
#define IF 1
#define ELSE 2
#define NUM 3
#define OP 4
#define ERR 5

%}



/* Declarations*/
%%
if      return (IF);
else    return (ELSE);
[0-9]+  return(NUM);
[+-]    return(OP);
.       printf("The error token is %s\n",yytext);


%%
/* Auxiliary functions */


int yywrap(void)
{
        return(1);
}
```

lex_first_v3.l

Note: main() is missing

File Edit Format View Help

```c
#include<stdio.h>
#define IF 1
#define ELSE 2
#define NUM 3
#define OP 4
#define ERR 5

extern int yylex();
extern char* yytext;

int main()
{
   int ntoken;
   do{
        ntoken=yylex();

        if(ntoken==0)
                break;

        if(ntoken==IF)
            printf("The IF token is %s\n",yytext);

        else if(ntoken==ELSE)
            printf("The ELSE token is %s\n",yytext);

        else if(ntoken==NUM)
            printf("The NUM token is %s\n",yytext);
        else if(ntoken==OP)
            printf("The OP token is %s\n",yytext);
        else
                printf("I don't know\n");
        }
  while(1);
return 1;
}
```

scanner_v1.c

bivasm@cpusrv-gpu-108: ~/lex

```
bivasm@cpusrv-gpu-108:~/lex$ lex lex_first_v3.l
bivasm@cpusrv-gpu-108:~/lex$ gcc lex.yy.c scanner_v1.c
bivasm@cpusrv-gpu-108:~/lex$ ./a.out<input_first
The IF token is if
The error token is
The error token is
The OP token is +
The error token is
The NUM token is 78
The error token is
The ELSE token is else
The error token is
The error token is
The NUM token is 0

bivasm@cpusrv-gpu-108:~/lex$
```

Input file – **input_first**

if + 78 else 0

Lex – example-5

Input file – **input_f**

```
db_type: mysql
db_name: testdata
db_table_prefix: test_
db_port: 1091
```

Lex – example-5

lex_check.l

```
%{
#include "head.h"
%}

%%

:        return COLON;
"db_type"        return TYPE;
"db_name"        return NAME;
"db_table_prefix"        return TABLE_PREFIX ;
"db_port"        return PORT;
[a-zA-Z][_a-zA-Z0-9]*    return IDENTIFIER;

[0-9][0-9]*      return INTEGER;
[ \t\n]          ;
.        printf("unexpeced\n");

%%
int yywrap(void)
{
        return 1;
}
```

Recognition of Tokens

Regular Definitions for terminals

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

stripping out whitespace, by recognizing the "token" ***ws***

$$ws \to (\ \textbf{blank} \mid \textbf{tab} \mid \textbf{newline}\ )^{+}$$

ASCII chars

- Token **ws** is different from the other tokens in that,
    - Once we recognize it, we **do not return it to the parser**,
- Rather **restart the lexical analysis** from the character that follows the whitespace. It is the following token that gets returned to the parser.

```c
#define TYPE 1
#define NAME 2
#define TABLE_PREFIX 3
#define PORT 4
#define COLON 5
#define IDENTIFIER 6
#define INTEGER 7
```

head.h

scanner.c

```c
#include <stdio.h>
#include "head.h"
extern int yylex();
extern int yylineno;
extern char* yytext;
char *names[] = {NULL, "db_type", "db_name", "db_table_prefix", "db_port"};
int main(void)
{
	int ntoken, vtoken;
	ntoken = yylex();
	while(ntoken) {
		printf("%d\n", ntoken);
		if(yylex() != COLON) {
			printf("Syntax error in line %d, Expected a ':' but found %s\n", yylineno, yytext);
			return 1;
		}
		vtoken = yylex();
		switch (ntoken) {
		case TYPE:
		case NAME:
		case TABLE_PREFIX:
			if(vtoken != IDENTIFIER) {
				printf("Syntax error in line %d, Expected an identifier but found %s\n", yylineno, yytext);
				return 1;
			}
			printf("%s is set to %s\n", names[ntoken], yytext);
			break;
		case PORT:
			if(vtoken != INTEGER) {
				printf("Syntax error in line %d, Expected an integer but found %s\n", yylineno, yytext);
				return 1;
			}
			printf("%s is set to %s\n", names[ntoken], yytext);
			break;
		default:
			printf("Syntax error in line %d\n",yylineno);
```

```
                break;
            default:
                printf("Syntax error in line %d\n",yylineno);
            }
            ntoken = yylex();
        }
        return 0;
}
```

Input file – **input_f**

```
db_type mysql
db_name: testdata
db_table_prefix: test_
db_port: 1091
```

```
bivasm@cpusrv-gpu-108:~/lex$ lex lex_check.l
bivasm@cpusrv-gpu-108:~/lex$ gcc lex.yy.c scanner.c
bivasm@cpusrv-gpu-108:~/lex$ ./a.out<input_f
1
Syntax error in line 1, Expected a ':' but found mysql
bivasm@cpusrv-gpu-108:~/lex$ vi input_f
bivasm@cpusrv-gpu-108:~/lex$
```

Input file – **input_f**

```
db_type: mysql
db_name: testdata
db_table_prefix: test_
db_port: 1091
```

```
bivasm@cpusrv-gpu-108:~/lex$ ./a.out<input_f
1
db_type is set to mysql
2
db_name is set to testdata
3
db_table_prefix is set to test_
4
db_port is set to 1091
bivasm@cpusrv-gpu-108:~/lex$
```

Lexical analyzer to recognize the following tokens

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

```
%{
    /* 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);}

%%
```

macros

(a) auxiliary declarations

(b) regular definitions

Symbols

{} for symbols usage

\ for meta-symbols (., * etc)

Regular definitions {} are used to define the RE of Rules

Seq. is important

Pattern { Action }

yylval: attributes

Recognition of Tokens

Regular Definitions for terminals

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

stripping out whitespace, by recognizing the "token" ***ws***

$$ws \rightarrow (\ \textbf{blank} \mid \textbf{tab} \mid \textbf{newline}\ )^{+}$$

ASCII chars

- Token **ws** is different from the other tokens in that,
    - Once we recognize it, we **do not return it to the parser**,
- Rather **restart the lexical analysis** from the character that follows the whitespace. It is the following token that gets returned to the parser.

Auxiliary section

```
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 */
}
```

Conflict Resolution in Lex

We have alluded to the two rules that Lex uses to decide on the proper lexeme to select, when several prefixes of the input match one or more patterns:

1. Always prefer a longer prefix to a shorter prefix.
2. If the longest possible prefix matches two or more patterns, prefer the pattern listed first in the Lex program.

yyin variable

yyin is a variable of the type FILE* and points to the input file.

- Defacto -- LEX assigns yyin to stdin(console input)

```
if( ! yyin )
yyin = stdin;
```

- If the programmer assigns an input file to yyin in the auxiliary functions section, then yyin is set to point to that file..

```

    /* Declarations */
%%
    /* Rules */
%%

main(int argc, char* argv[])
{
        if(argc > 1)
        {
                FILE *fp = fopen(argv[1], "r");
                if(fp)
                        yyin = fp;
        }
        yylex();
        return 1;
}
```

$./a.out input_file

yywrap()

- LEX **declares** the function yywrap() of return-type int in the file **lex.yy.c** .
- LEX **does not provide any definition** for yywrap().
- yylex() makes a **call to yywrap()** when it encounters the **end of input**.
- If **yywrap() returns zero** (indicating false) yylex() assumes **there is more input** and it **continues scanning** from the location **pointed to by yyin**.
- If **yywrap() returns a non-zero** value (indicating true), **yylex() terminates the scanning** process and **returns 0** (i.e. “wraps up”). [you define, you specify the return type of yywrap()!!]
- If the programmer wishes to **scan more than one input file** using the generated lexical analyzer, it can be simply done by **setting yyin to a new input file in yywrap()** and **return 0**.
- As LEX does not define yywrap() in lex.yy.c file but **makes a call to it under yylex()**, the programmer **must define it** in the Auxiliary functions section **OR**
- provide **%option noyywrap** in the declarations section.
    - This options removes the call to yywrap() in the lex.yy.c file.

Homework

```
{
        int x;
        int y;
        x = 2;
        y = 3;
        x = 5 + y * 4;
}
```

I/P Character Stream	O/P Token Stream
{	<SPECIAL SYMBOL, {>
int x;	<KEYWORD, int> <ID, x> <PUNCTUATION, ;>
int y;	<KEYWORD, int> <ID, y> <PUNCTUATION, ;>
x = 2;	<ID, x> <OPERATOR, => <INTEGER CONSTANT, 2> <PUNCTUATION, ;>
y = 3;	<ID, y> <OPERATOR, => <INTEGER CONSTANT, 3> <PUNCTUATION, ;>
x = 5 + y * 4;	<ID, x> <OPERATOR, => <INTEGER CONSTANT, 5> <OPERATOR, +>
}	<ID, y> <OPERATOR, *> <INTEGER CONSTANT, 4> <PUNCTUATION, ;>
	<SPECIAL SYMBOL, }>

```
%{
/* C Declarations and Definitions */
%}
 /* Regular Expression Definitions */
INT          "int"
ID           [a-z][a-z0-9]*
PUNC         [;]
CONST        [0-9]+
WS           [ \t\n]

%%
{INT}        { printf("<KEYWORD, int>\n); /* Keyword Rule */ }
{ID}         { printf("<ID, %s>\n", yytext); /* Identifier Rule */}
"+"          { printf("<OPERATOR, +>\n"); /* Operator Rule */ }
"*"          { printf("<OPERATOR, *>\n"); /* Operator Rule */ }
"="          { printf("<OPERATOR, =>\n"); /* Operator Rule */ }
"{"          { printf("<SPECIAL SYMBOL, {>\n"); /* Scope Rule */ }
"}"          { printf("<SPECIAL SYMBOL, }>\n"); /* Scope Rule */ }
{PUNC}       { printf("<PUNCTUATION, ;>\n"); /* Statement Rule */ }
{CONST}      { printf("<INTEGER CONSTANT, %s>\n",yytext); /* Literal Rule */ }
{WS}         /* White-space Rule */ ;
%%
```

Complete example

```
%{
#define INT        10
#define ID         11
#define PLUS       12
#define MULT       13
#define ASSIGN     14
#define LBRACE     15
#define RBRACE     16
#define CONST      17
#define SEMICOLON  18
%}

INT       "int"
ID        [a-z][a-z0-9]*
PUNC      [;]
CONST     [0-9]+
WS        [ \t\n]

%%
{INT}    { return INT; }
{ID}     { return ID; }
"+"      { return PLUS; }
"*"      { return MULT; }
"="      { return ASSIGN; }
"{"      { return LBRACE; }
"}"      { return RBRACE; }
{PUNC}   { return SEMICOLON; }
{CONST}  { return CONST; }
{WS}     {/* Ignore
             whitespace */}
%%
```

```
main() { int token;
    while (token = yylex()) {
        switch (token) {
            case INT: printf("<KEYWORD, %d, %s>\n",
                token, yytext); break;
            case ID: printf("<IDENTIFIER, %d, %s>\n",
                token, yytext); break;
            case PLUS: printf("<OPERATOR, %d, %s>\n",
                token, yytext); break;
            case MULT: printf("<OPERATOR, %d, %s>\n",
                token, yytext); break;
            case ASSIGN: printf("<OPERATOR, %d, %s>\n",
                token, yytext); break;
            case LBRACE: printf("<SPECIAL SYMBOL, %d, %s>\n",
                token, yytext); break;
            case RBRACE: printf("<SPECIAL SYMBOL, %d, %s>\n",
                token, yytext); break;
            case SEMICOLON: printf("<PUNCTUATION, %d, %s>\n",
                token, yytext); break;
            case CONST: printf("<INTEGER CONSTANT, %d, %s>\n",
                token, yytext); break;
        }
    }
}
```