

# COMPILER CONSTRUCTION

## Lex

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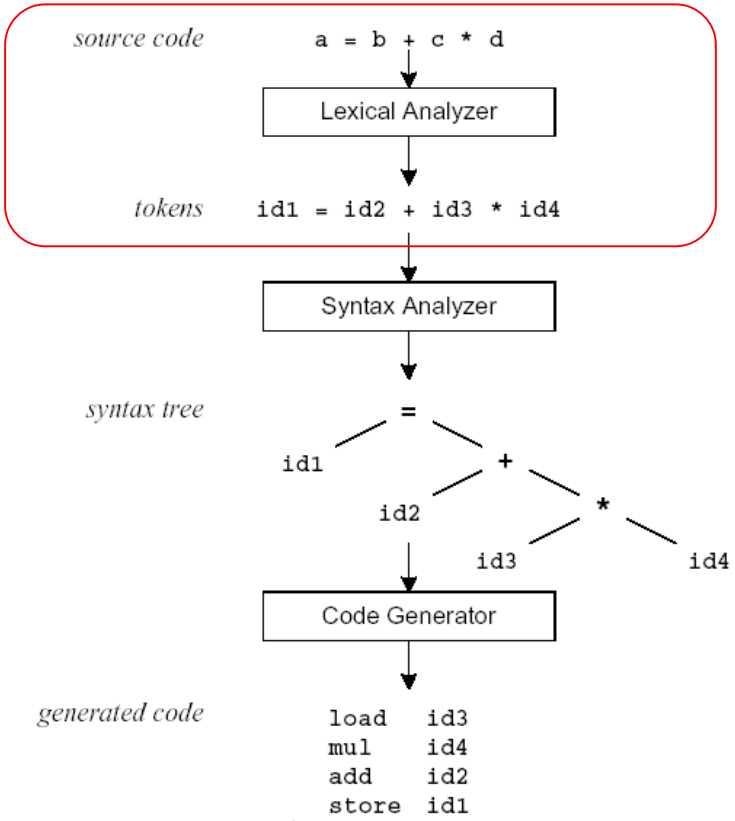
# Where are we?

- Lex and Yacc are able to do the following
- Now, our target is Lex





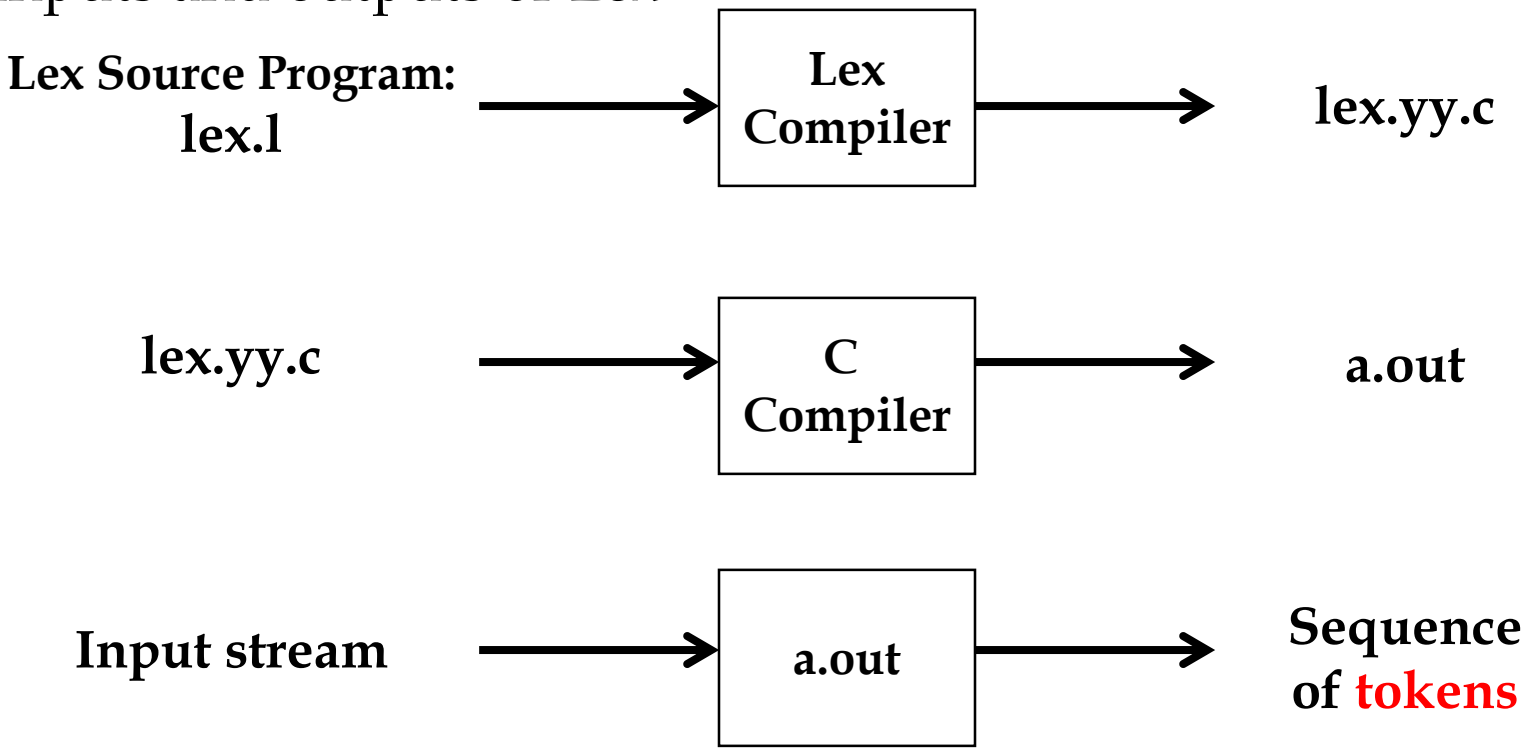
# Lex and Yacc

- Two compiler writing tools:
  - Lexical Tokens and their Order of Processing (**Lex**)
  - Context Free Grammar for LALR(1) (**Yacc**)
- Both Lex and Yacc have Long History in Computing
  - Lex and Yacc – Earliest Days of Unix Minicomputers
  - Flex and Bison – From GNU
  - JFlex - Fast Scanner Generator for Java
  - BYacc/J – Berkeley
  - PCLEX and PCYACC from Abacus
  - **ANTLR**, CUP, PCYACC



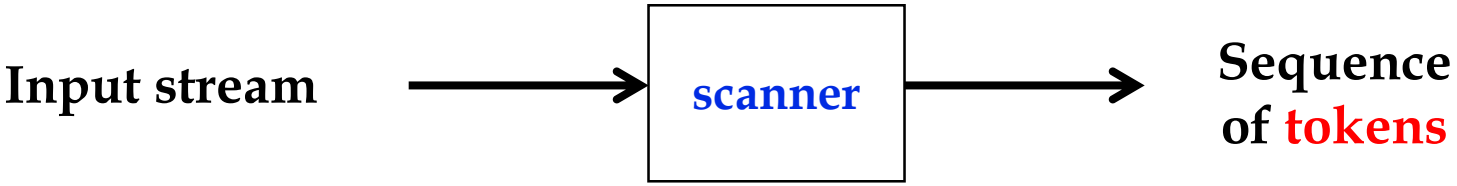
# Lex – A Lexical Analyzer Generator

- A Unix Utility from early 1970s
- A Compiler that takes as source a specification for:
  - Tokens/Patterns of a Language
  - Generates a "C" Lexical Analyzer Program
- Inputs and outputs of Lex





# Lex




- The main job of a *lexical analyzer (scanner)* is to break up an input stream into more usable elements (*tokens*)

```
a = b + c * d;
```
← **Input stream**

ID ASSIGN ID PLUS ID MULT ID SEMI ← **Tokens**

- Lex is an utility to help you rapidly generate your scanners



# Lex (Cont'd)

- Lexical analyzers **tokenize** input streams
- Tokens are the **terminals** of a language
  - English
    - words, punctuation marks, …
  - Programming language
    - Identifiers, operators, keywords, …
- **Regular expressions define terminals/tokens**



# Lex Source to C Program

- The input (.l) is translated to a C program (lex.yy.c) which
  - reads an input stream,
  - partitions the input into strings which match the given expressions, and
  - copies it to an output stream if necessary



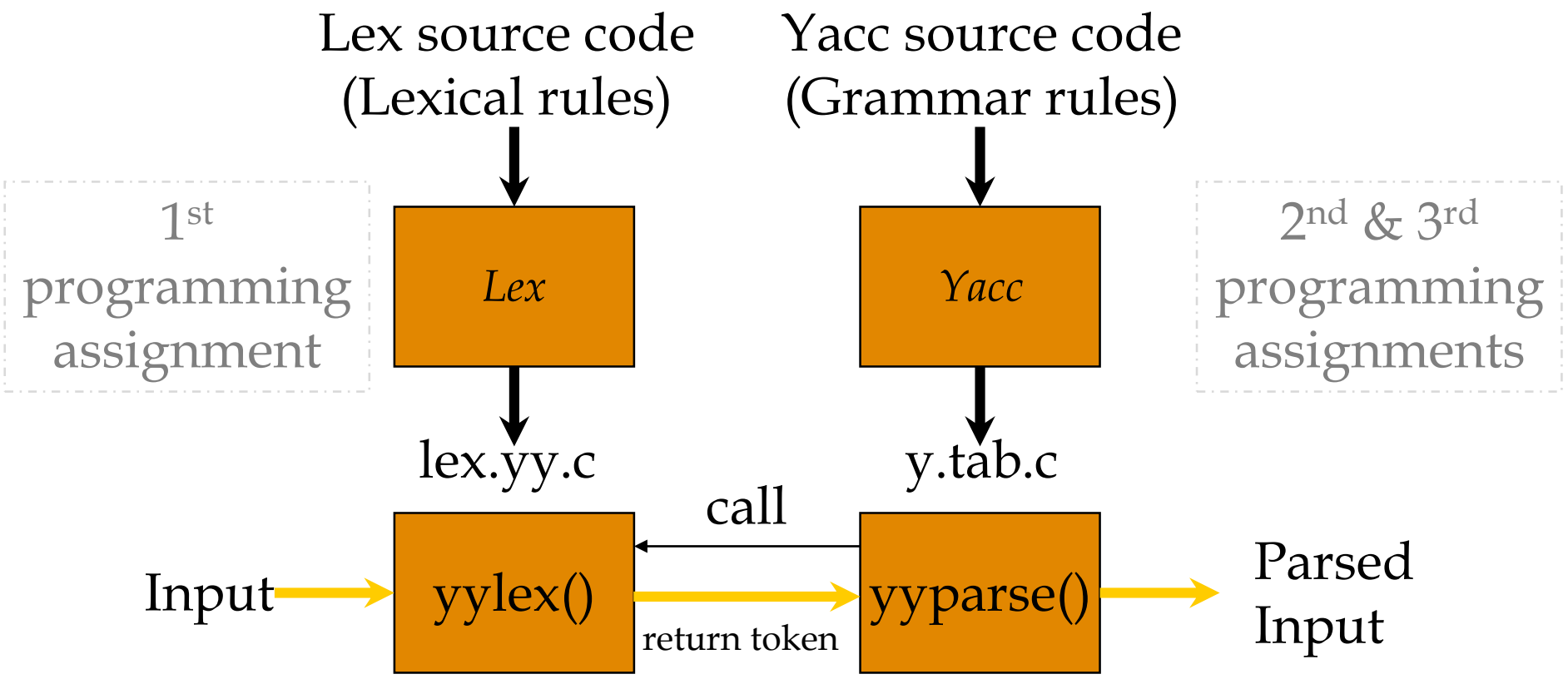
# Lex vs. Yacc

- Lex
  - Generates C code for a lexical analyzer, or scanner
  - Uses **patterns** that match strings in the input and converts the strings to **tokens**

- Yacc
  - Generates C code for syntax analyzer, or parser
  - Uses **grammar rules** that allow it to analyze tokens from Lex and create a **syntax tree**

- **Together they form a compiler**

# Lex & Yacc


Lex source code
(Lexical rules)
Yacc source code
(Grammar rules)
1st programming assignment
Lex
Yacc
2nd & 3rd programming assignments
lex.yy.c
y.tab.c
call
Input
yylex()
yyparse()
Parsed Input
return token



# Format of a Lexical Specification

- lex.l is divided into 3 parts:

1. Declarations:
   - Defs, Constants, Types, #includes, etc. that can occur in **a C Program**
   - Regular Definitions (expressions)
2. Translation rules:
   - Pairs of (**Regular Expression**, **Action**)
   - Informs lexical analyzer of action when pattern is recognized
3. Auxiliary procedures:
   - Designer Defined **C Code**
   - E.g., symbol table codes

**lex.l file format:**

DECLARATIONS
%%
TRANSLATION RULES
%%
AUXILIARY PROCEDURES

# lex.l Example



```
%{
#define  T_IDENTIFIER  300
#define  T_INTEGER     301
#define  T_REAL        302
#define  T_STRING      303
#define  T_ASSIGN      304
#define  T_ELSE        305
#define  T_IF          306
#define  T_THEN        307
#define  T_EQ          308
#define  T_LT          309
#define  T_NE          310
#define  T_GE          311
#define  T_GT          312
%}

letter          [a-zA-Z]
digit           [0-9]
ws              [ \t\n]+
id              [A-Za-z][A-Za-z0-9]*
comment         "(*"([^*]|\n|"*"+[^)])*"*"+")"
integer         [0-9]+/([^0-9]|"..")
real            [0-9]+"."[0-9]*([0-9]|"E"[+-]?[0-9]+)
string          \'([^']|\'\')*\'
%%

":="            {printf(" %s ", yytext);return(T_ASSIGN);}
"else"          {printf(" %s ", yytext);return(T_ELSE);}
```

User defined values to each token (else lex will assign)

Regular expression rules for later token definitions

Token definitions and action

# lex.l Example (Cont'd)

```
"then"          {#ifdef PRNTFLG
                 printf(" %s ", yytext);
                 #endif
                 return(T_THEN);
                }
"<="            {printf(" %s ", yytext);return(T_EQ);}
"<"             {printf(" %s ", yytext);return(T_LT);}
"<>"            {printf(" %s ", yytext);return(T_NE);}
">="            {printf(" %s ", yytext);return(T_GE);}
">"             {printf(" %s ", yytext);return(T_GT);}

{id}            {printf(" %s ", yytext);return(T_IDENTIFIER);}
{integer}       {printf(" %s ", yytext);return(T_INTEGER);}
{real}          {printf(" %s ", yytext);return(T_REAL);}
{string}        {printf(" %s ", yytext);return(T_STRING);}
{comment}       {/* T_COMMENT */}
{ws}            {/* spaces, tabs, newlines */}
%%

yywrap()        {return 0;}

main()
{
  int i;
  do {
    i = yylex();
  } while (i!=0);
}
```

Conditional compilation action

Token definitions and action

Discard

EOF for input

Three variables shared by Lex&Yacc:

1. **yytext** = "currenttoken"
2. **yylen** = 12
3. **yylval** = 300



# Internal Variables in Lex

- You may find the variables useful when writing translation rules
- char ***yytext**;
  - Pointer to current lexeme terminated by '\0'
- int **yylen**;
  - Number of chacters in yytex but not '\0'
- **yylval**:
  - Global variable through which the token value can be returned to Yacc
  - Parser (Yacc) can access yylval, yylen, and yytext
- How are these used?

  Consider **integer tokens**:

  yylval = ascii_to_integer (yytext);

  → Conversion from *string* to actual *integer value*



# Internal Variables in Lex (Cont'd)

- FILE ***yyin**
  - The input of the lex, pointing to the current file position
  - Default is set to stdin
- FILE ***yyout**
  - The output of the lex program
  - Default is set to stdout
- **yylineno**
  - The current line number of yyin



# Lex Library Routines

- **yylex()**
  - The default main() contains a call of yylex()
- **yymore()**
  - return the next token
- **yyless(n)**
  - retain the first n characters in yytext
- **yywarp()**
  - is called whenever Lex reaches an end-of-file
  - The default yywarp() always returns 1



# Lex Regular Expressions (Extended Regular Expressions)

- A regular expression matches a set of strings
- Regular expression
  - Operators
  - Character classes
  - Arbitrary character
  - Optional expressions
  - Alternation and grouping
  - Context sensitivity
  - Repetitions and definitions



# Operators

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

- Considered as the meta-character of the regular expressions used in Lex
- If they are to be used as **text characters**, an escape should be used

  \$ = “$”

  \\ = “\”
- Every character is always a text character, except *blank*, *tab* (\t), *newline* (\n) and the list above



# Character Classes [ ]

- `[abc]`
  - matches **a single character**, which may be `a`, `b`, **or** `c`
- Every operator meaning is ignored
  - except `\` `-` **and** `^`
- Examples:

| | |
|---|---|
| `[ab]` | => `a` or `b` |
| `[a-z]` | => `a` or `b` or `c` or … or `z` |
| `[-+0-9]` | => all the digits and the two signs |
| `[^a-zA-Z]` | => any character which is not a letter |



# Arbitrary Character .

- The operator character .
  - is the class of all characters, except newline

An escape character example:

- [\40-\176]
  - matches all printable characters in the ASCII character set, from $40_{octal}$ (space) to $176_{octal}$ (tilde~)



# Optional & Repeated Expressions

- a?  => zero or one instance of a
- a*  => zero or more instances of a
- a+  => one or more instances of a

- Examples:

  ab?c  => ac or abc

  [a-z]+  => all strings of lower case letters

  [a-zA-Z][a-zA-Z0-9]*

  => all alphanumeric strings with a leading alphabetic character



# Precedence of Operators

- Level of precedence
  1. Kleene closure (*), ?, +
  2. concatenation
  3. alternation (|)
- All operators are **left associative**
- Ex: `a*b|cd*` = `((a*)b)|(c(d*))`



# Pattern Matching Primitives

| Metacharacter | Matches |
|---|---|
| . | any character except newline |
| \n | newline |
| * | zero or more copies of the preceding expression |
| + | one or more copies of the preceding expression |
| ? | zero or one copy of the preceding expression |
| ^ | beginning of line / complement |
| $ | end of line |
| a\|b | a or b |
| (ab)+ | one or more copies of ab (grouping) |
| [ab] | a or b |
| a{3} | 3 instances of a |
| “a+b” | literal “a+b” (C escapes still work) |



# Regular Expression and its Action

```
// Input stream
a = b + c;
```

```
// Input stream
a = b + c;

// Output
a operator: ASSIGNMENT b + c;
```

```
…
%%
<regexp> <action>
<regexp> <action>
…
%%
```

```
%%
[abcd]          {printf("%s ", yytext);}
"="             {printf("operator: ASSIGNMENT");}
…
```



# Transition Rules

- regexp <one or more blanks> action (C code);
- regexp <one or more blanks> { actions (C code) }

- A null statement ; will ignore the input (no actions)
  - Example:

    [ \t\n]  ;

    Causes the three spacing characters to be ignored

```
// Input stream
a = b + c;
d = b * c;
↓ ↓
// Corresponding output for the rule
a=b+c;d=b*c;
```



# Transition Rules (cont'd)

- Four special options for actions:
  |, **ECHO;, BEGIN**, and **REJECT;**
- | indicates that the action for this rule is from the action for the next rule
  - [ \t\n] ;
  - " " |
    "\t" |
    "\n" ; ← **the three applies the same rule**
- The **unmatched token** is using a default action: **ECHO** from the input to the output



# Transition Rules (cont'd)

- **REJECT**
  - Go do the next alternative rule
  - It causes whatever rule was second choice after the current rule to be executed

- The **matching rules** depend on the tool you use:
  - Matching rules for Flex:
  1. Match the longest possible token
  2. Of the tokens with the same length, prefer the pattern **earlier** in the source file



# Transition Rules (cont'd)

- **BEGIN**
  - For conditional rules

**BEGIN name1;**

- Executing the action statement enters a start condition, which changes the start condition to **name1**

**BEGIN 0;**

- Executing the action statement resets the initial condition of the Lex automaton interpreter

Example:

```
%START AA BB CC
%%
^a              {ECHO; BEGIN AA;}
^b              {ECHO; BEGIN BB;}
^c              {ECHO; BEGIN CC;}
\n              {ECHO; BEGIN 0;}
<AA>magic       printf("first");
<BB>magic       printf("second");
<CC>magic       printf("third");
```

- (**AA**) Copy the input to the output, except change the word magic to the word first on every line that begins with the letter a.
- (**BB**) Change magic to second on every line that begins with b.
- (**CC**) Change magic to third on every line that begins with c. Here is how the problem might be handled with a flag.



# Usage

- To run Lex on a source file, type

  **lex scanner.l**

  - It produces a file named lex.yy.c which is a C program for the lexical analyzer

- To compile lex.yy.c, type

  **cc lex.yy.c –ll**

- To run the lexical analyzer program, type

  **./a.out < inputfile**



# Versions of Lex

- Versions:
  - AT&T Lex
    http://www.combo.org/lex_yacc_page/lex.html
  - GNU Flex
    https://github.com/westes/flex
  - Win32 version of Flex:
    http://gnuwin32.sourceforge.net/packages/flex.htm
  - Lex on Cygwin :
    https://www.cygwin.com/
- Each Lex implementation may has its own **character**
  - Please refer to the online manual for Lex on The Lex & Yacc Page



# QUESTIONS?



# A lex.l example for tokens in **Pascal**

# A Pascal lex.l



```
%{
#include "y.tab.h"
%}

letter                  [a-zA-Z]
digit                   [0-9]

ws                      [ \t\n]+
id                      [A-Za-z][A-Za-z0-9]*
comment                 "(*"([^*]|\n|"*"+[^)])*"*"+")"
integer                 [0-9]+/([^0-9]|"..")
real                    [0-9]+"."[0-9]*([0-9]|"E"[+-]?[0-9]+)
string                  \'([^']|\'\')*\'

%%

":="                    {return(T_ASSIGN);}
":"                     {return(T_COLON);}
"array"                 {return(T_ARRAY);}
"begin"                 {return(T_BEGIN);}
"case"                  {return(T_CASE);}
"const"                 {return(T_CONST);}
"downto"  {return(T_DOWNTO);}
"do"                    {return(T_DO);}
"else"                  {return(T_ELSE);}
"end"                   {return(T_END);}
"file"                  {return(T_FILE);}
"for"                   {return(T_FOR);}
```

# A Pascal lex.l (Cont'd)



```
"function" {return(T_FUNCTION);}
/*  "goto"          {return(T_GOTO);} */
"if"                {return(T_IF);}
"label"             {return(T_LABEL);}
"nil"               {return(T_NIL);}
"not"               {return(T_NOT);}
"of"                {return(T_OF);}
/* "packed"         {return(T_PACKED);} */
"procedure"         {return(T_PROCEDURE);}
"end"               {return(T_END);}
"program" {return(T_PROGRAM);}
"record"  {return(T_RECORD);}
"repeat"  {return(T_REPEAT);}
"set"               {return(T_SET);}
"then"              {return(T_THEN);}
"to"                {return(T_TO);}
"type"              {return(T_TYPE);}
"until"             {return(T_UNTIL);}
"var"               {return(T_VAR);}
"while"             {return(T_WHILE);}
/* "with"   {return(T_WITH);} */
"+"                 {return(T_PLUS);}
"-"                 {return(T_MINUS);}
"or"                {return(T_OR);}
"and"               {return(T_AND);}
"div"               {return(T_DIV);}
"mod"               {return(T_MOD);}
"/"                 {return(T_RDIV);}
```

# A Pascal lex.l (Cont'd)



```
"*"                 {return(T_MULT);}
"("                 {return(T_LPAREN);}
")"                 {return(T_RPAREN);}
"="                 {return(T_EQ);}
","                 {return(T_COMMA);}
".."                {return(T_RANGE);}
"."                 {return(T_PERIOD);}
"["                 {return(T_LBRACK);}
"]"                 {return(T_RBRACK);}
"<="                {return(T_EQ);}
"<"                 {return(T_LT);}
"<>"                {return(T_NE);}
">="                {return(T_GE);}
">"                 {return(T_GT);}
"in"                {return(T_IN);}
"^"                 {return(T_UPARROW);}
";"                 {return(T_SEMI);}

{id}                {return(T_IDENTIFIER);}
{integer}   {return(T_INTEGER);}
{real}              {return(T_REAL);}
{string}    {return(T_STRING);}
{comment}           {/* T_COMMENT */}
{ws}                {/* spaces, tabs, newlines */}
```