COMPILER CONSTRUCTION

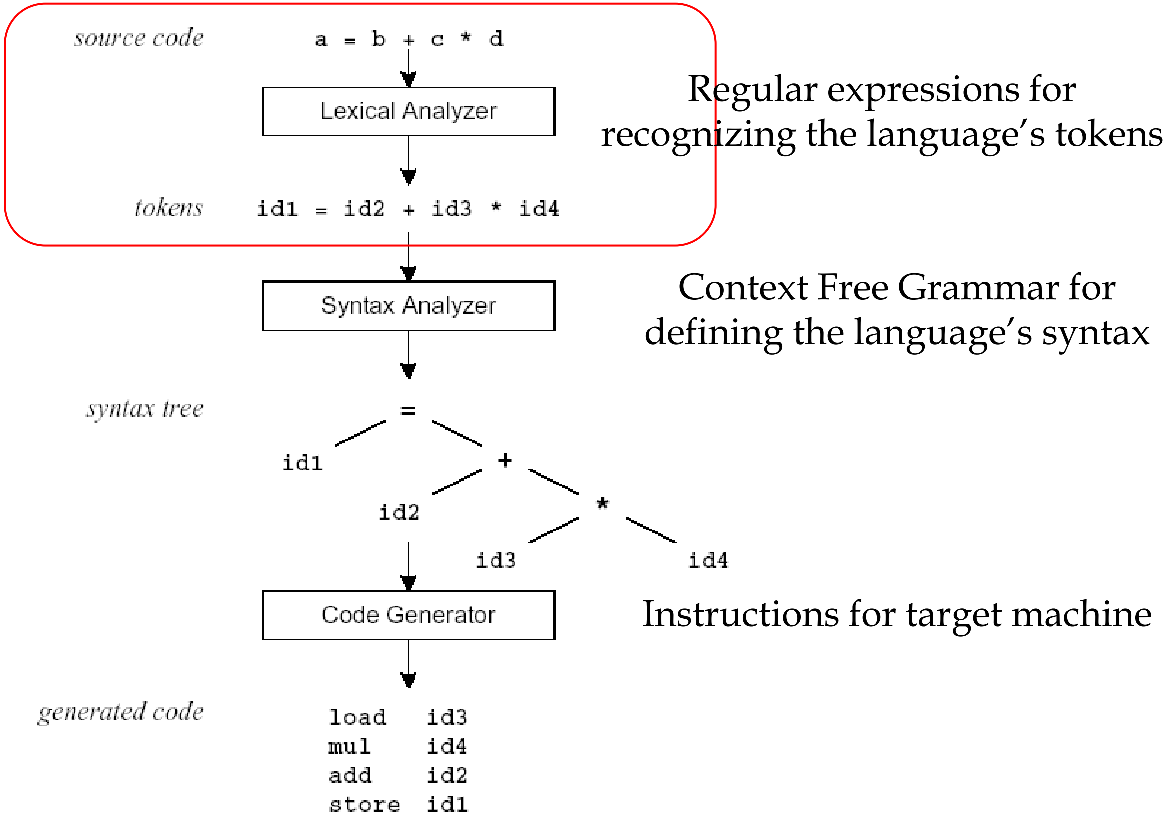
Lex

Chia-Heng Tu
Dept. of Computer Science and Information Engineering
National Cheng Kung University
Spring 2022

Courtesy of CSE4100, Lex and Yacc, CSE, University of Connecticut. Prof. Steven A. Demurjian; Lex Yacc tutorial, PLLAB, CS, NTHU. Dr. Kun-Yuan Hsieh.

Where are we?

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



Regular expressions for recognizing the language's tokens

Context Free Grammar for defining the language's syntax

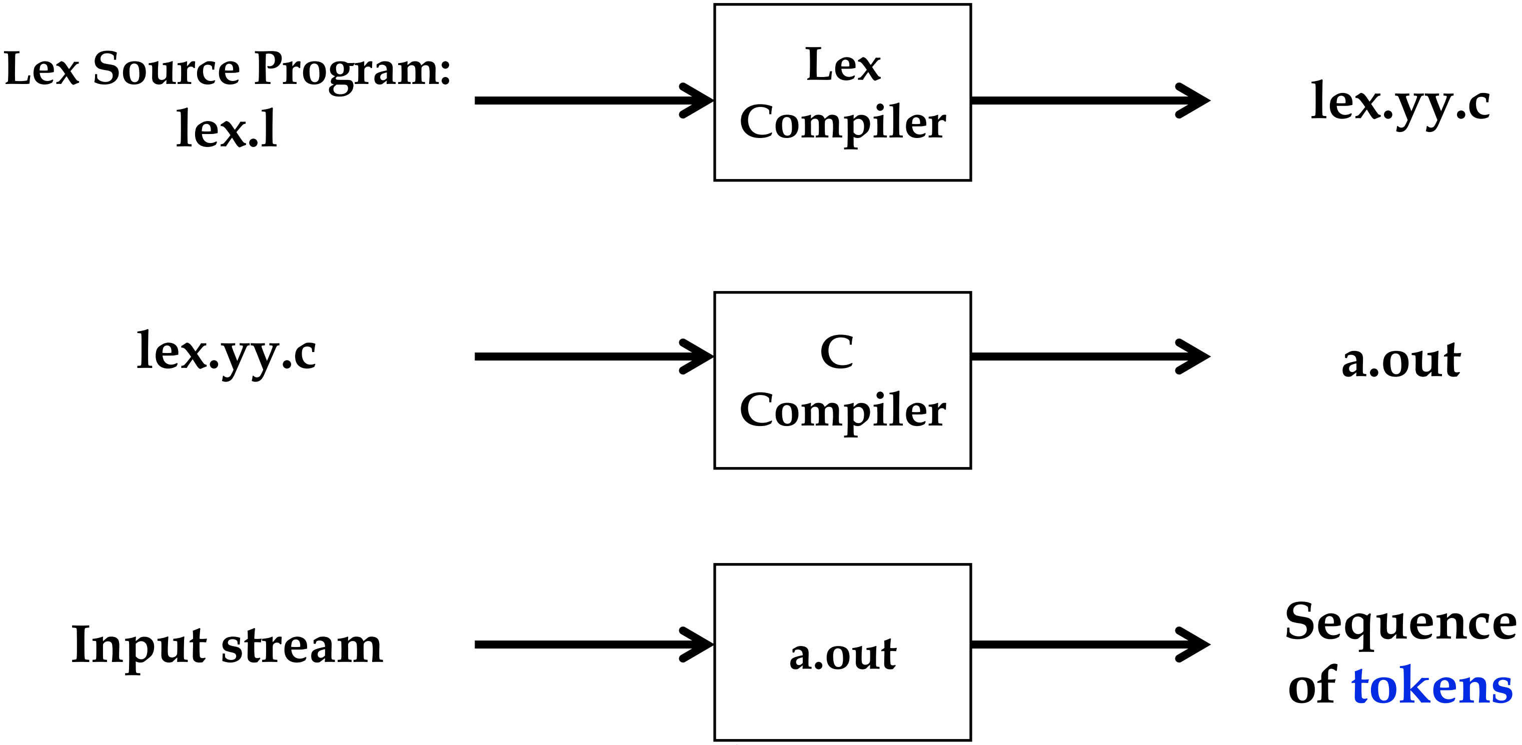
Instructions for target machine

Lex and Yacc

- Two compiler generation 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

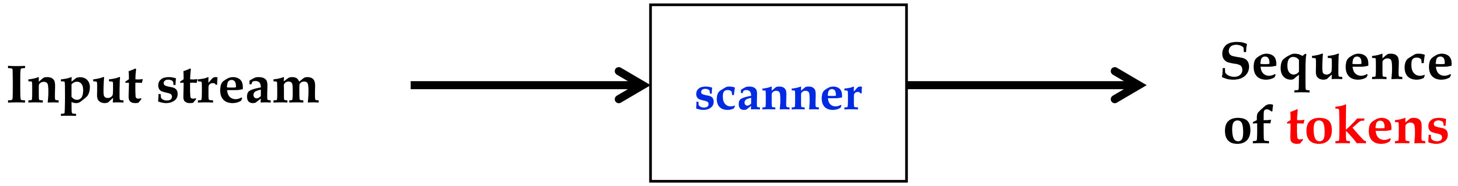


Lex Source Program:
lex.l → Lex Compiler → lex.yy.c

lex.yy.c → C Compiler → a.out

Input stream → a.out → Sequence of **tokens**

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**

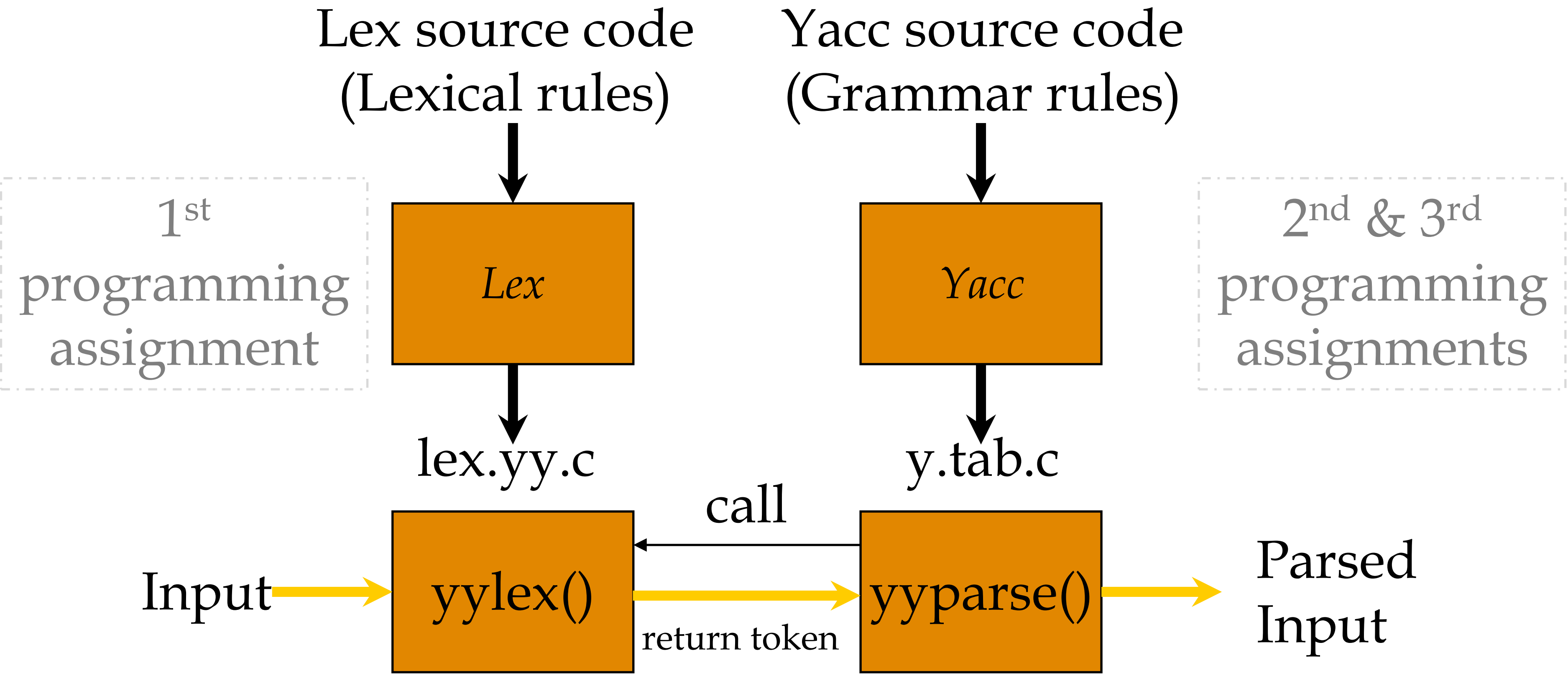
Lex Source to C Program

- 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 the basis of 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
%}
```

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

```
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          \'([^']|\'\')*\'
%%
```

Regular expression rules for later token definitions

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

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

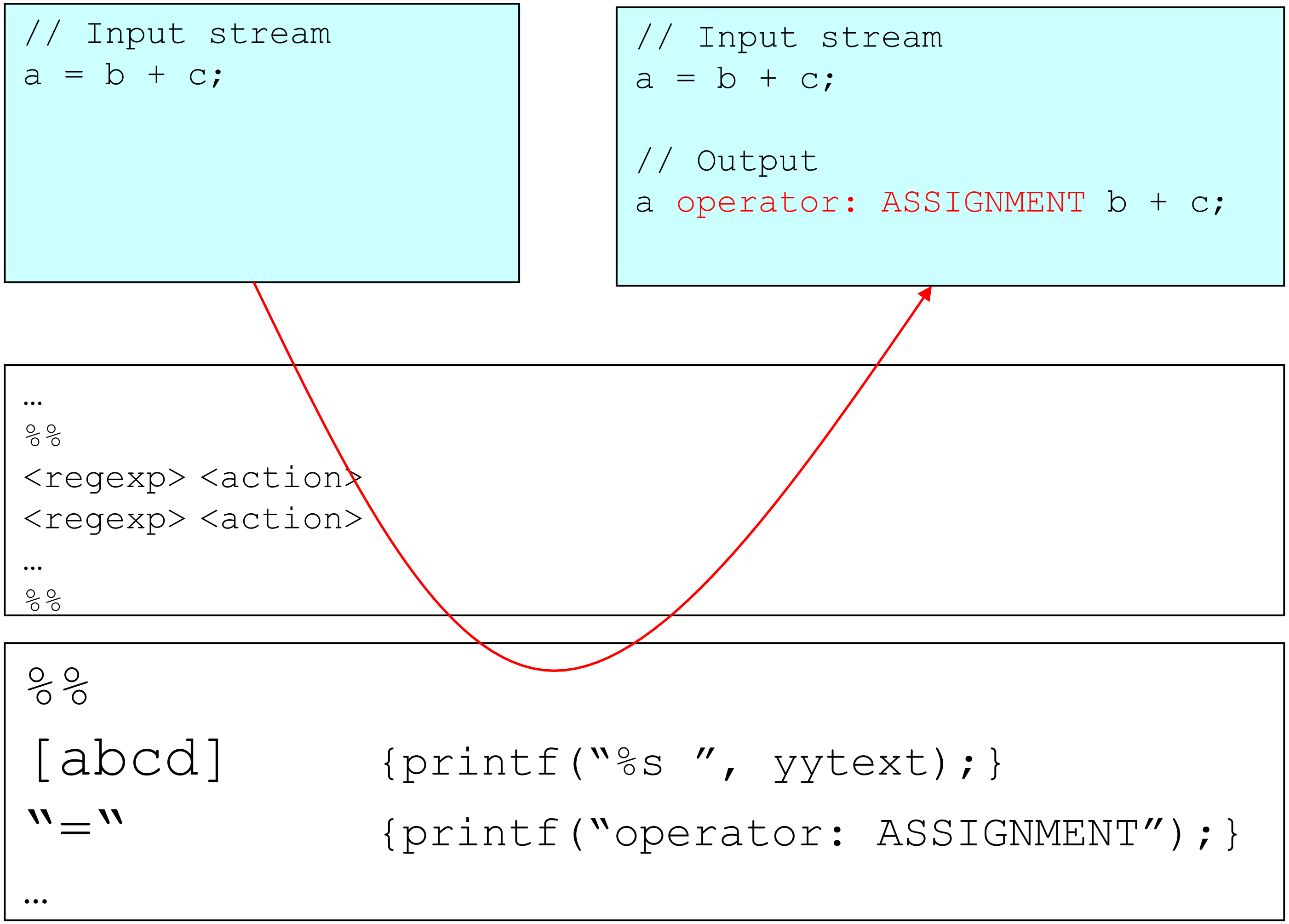
Precedence of Operators

- 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 */}
```