Lexical Analysis – Part I

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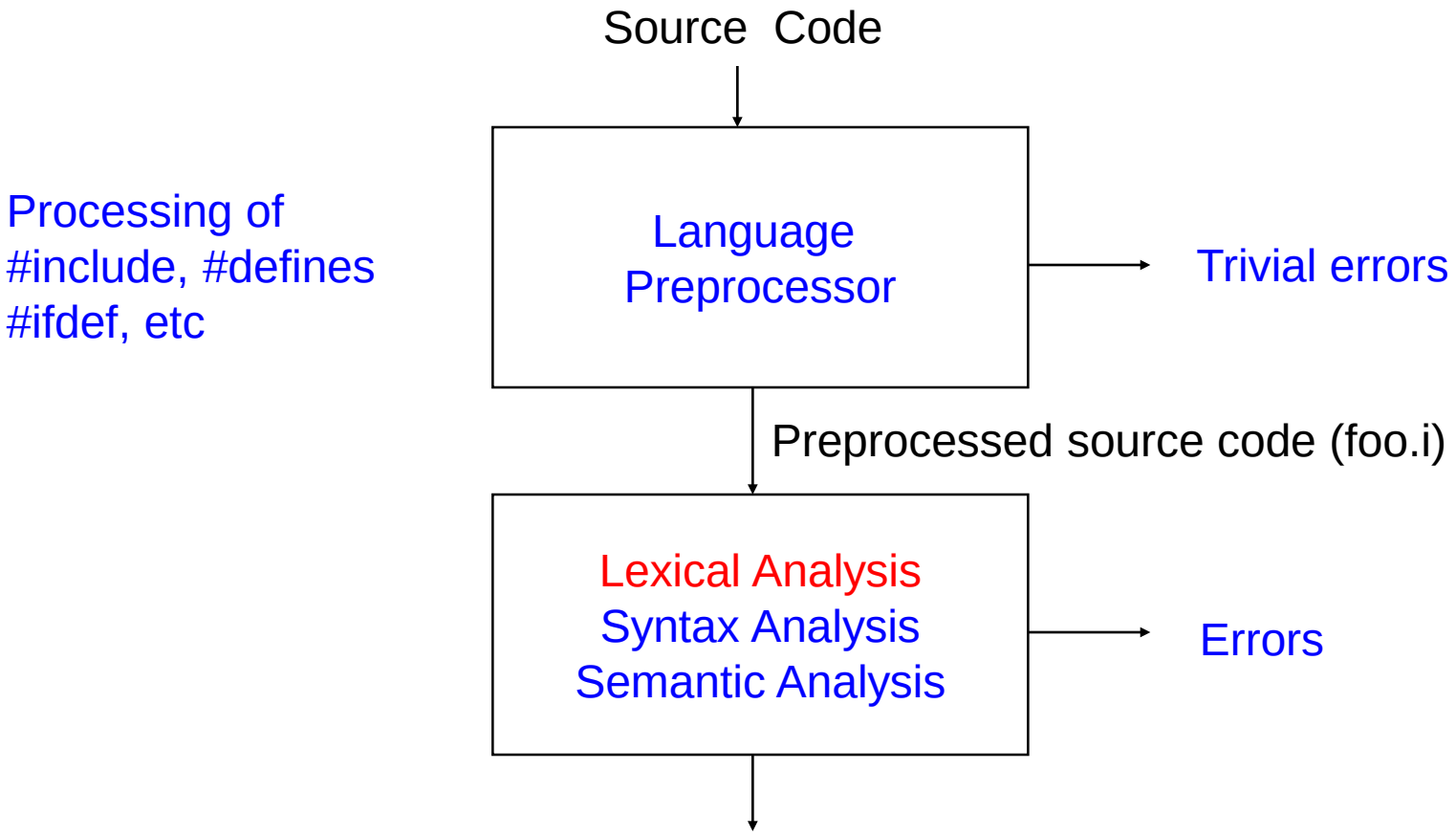
Frontend Structure



Note: gcc –E foo.c –o foo.i
to invoke just the
preprocessor

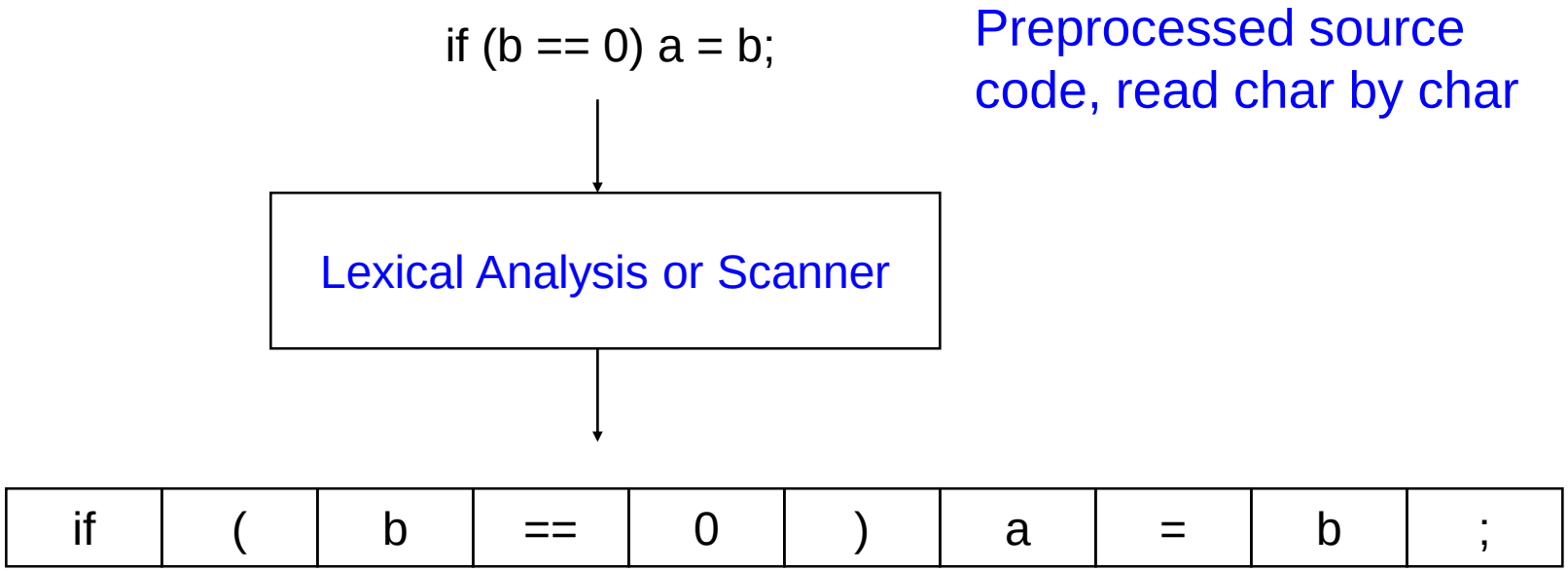
Lexical Analysis: Specification, Recognition, and Automation

- **Specification: how to specify lexical patterns?**
  - In C, identifiers are strings like x, xy, match0, and _abc.
  - Numbers are strings like 3, 12, 0.012, and 3.5E4.
  - → regular expressions

- **Recognition: how to recognize the lexical patterns?**
  - Recognize match0 as an identifier.
  - Recognize 512 as a number.
  - → deterministic finite automata.

- **Automation: how to automatically generate string recognizers from specifications?**
  - → Thompson's construction and subset construction

Lexical Analysis Process



Preprocessed source code, read char by char

Lexical analysis

- Transform multi-character input stream to token stream
- Reduce length of program representation (remove spaces)

Tokens

- Identifiers: x y11 elsex
- Keywords: if else while for break
- Integers: 2 1000 -20
- Floating-point: 2.0 -0.0010 .02 1e5
- Symbols: + * { } ++ << < <= [ ]
- Strings: “x” “He said, \”I luv compiler\””

How to Describe Tokens

- **Use regular expressions to describe programming language tokens!**

- **A regular expression (RE) is defined inductively**
  - a ordinary character stands for itself
  - ε empty string
  - R|S either R or S (alteration), where R,S = RE
  - RS R followed by S (concatenation)
  - R* concatenation of R, 0 or more times (Kleene closure)

Language

- **A regular expression R describes a set of strings of characters denoted L(R)**
- **L(R) = the language defined by R**
  - L(abc) = { abc }
  - L(hello|goodbye) = { hello, goodbye }
  - L(1(0|1)*) = all binary numbers that start with a 1
- **Each token can be defined using a regular expression**

RE Notational Shorthand

- R+ one or more strings of R: R(R*)
- R? optional R: (R|ε)
- [abcd] one of listed characters: (a|b|c|d)
- [a-z] one character from this range: (a|b|c|d...|z)
- [^ab] anything but one of the listed chars
- [^a-z] one character not from this range

Example Regular Expressions

- **Regular Expression, R**
  - a
  - ab
  - a|b
  - (ab)*
  - (a| ε)b
  - digit = [0-9]
  - posint = digit+
  - int = -? posint
  - real = int (ε | (. posint))
    = -?[0-9]+ (ε|(.[0-9]+))

- **Strings in L(R)**
  - “a”
  - “ab”
  - “a”, “b”
  - “”, “ab”, “abab”, ...
  - “ab”, “b”
  - “0”, “1”, “2”, ...
  - “8”, “412”, ...
  - “-23”, “34”, ...
  - “-1.56”, “12”, “1.056”, ...
  - Note, “.45” is not allowed in this definition of real

Class Problem

- **A. What the difference?**
  - [abc] abc

- **Extend the description of real on the previous slide to include numbers in scientific notation**
    - -2.3E+17, -2.3e-17, -2.3E17

How to Break up Text

elsex = 0;

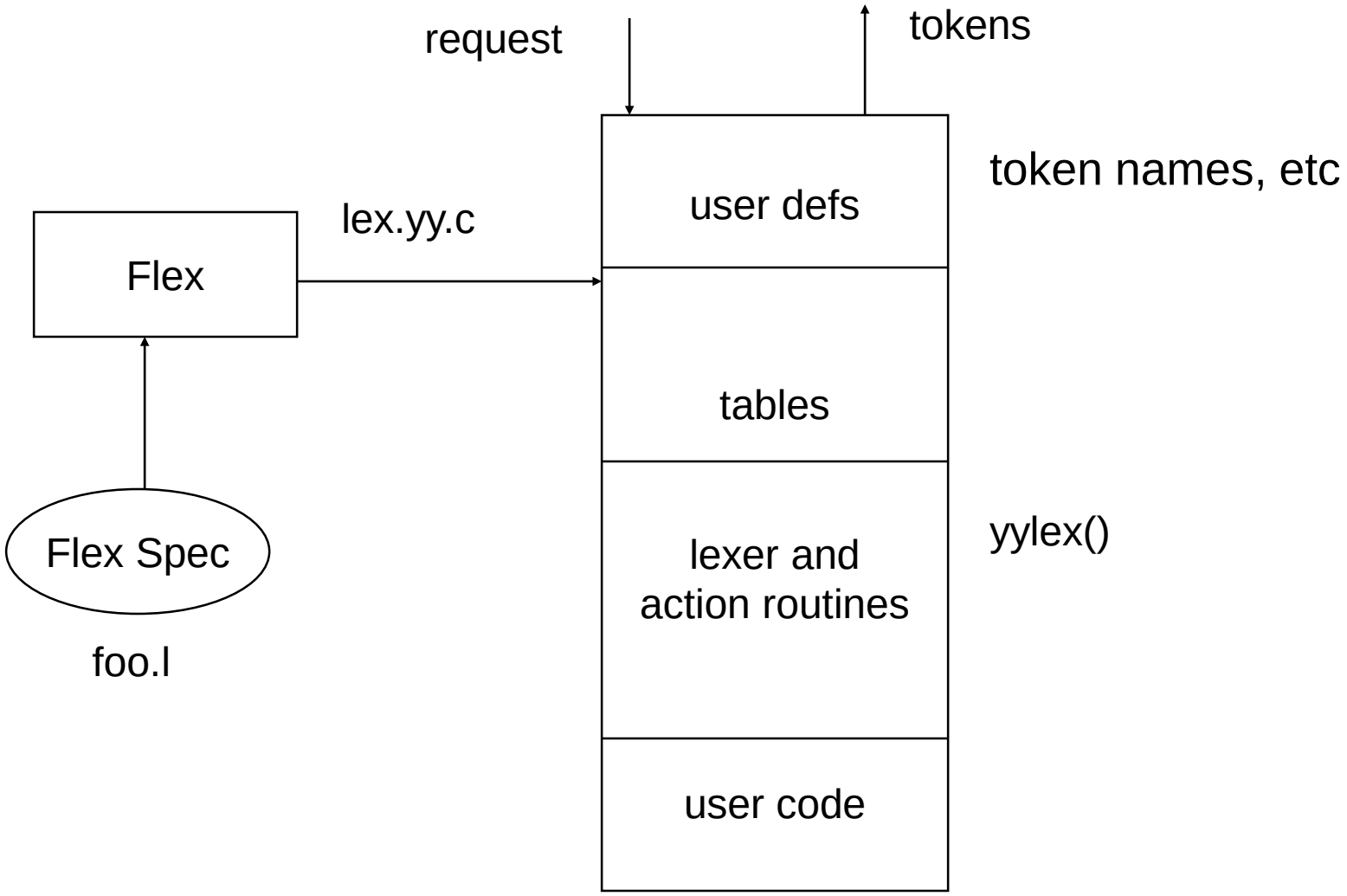
1	else	x	=	0	;
2	elsex	=	0	;	

- **REs alone not enough, need rule for choosing when get multiple matches**
  - Longest matching token wins
  - Ties in length resolved by priorities
    - Token specification order often defines priority
  - RE's + priorities + longest matching token rule = definition of a lexer

Automatic Generation of Lexers

- **2 programs developed at Bell Labs in mid 70's for use with UNIX**
  - Lex – transducer, transforms an input stream into the alphabet of the grammar processed by yacc
    - Flex = fast lex, later developed by Free Software Foundation
  - Yacc/bison – yet another compiler/compiler (next week)
- **Input to lexer generator**
  - List of regular expressions in priority order
  - Associated action with each RE
- **Output**
  - Program that reads input stream and breaks it up into tokens according the the REs

Lex/Flex


request
tokens
user defs
token names, etc
lex.yy.c
Flex
tables
Flex Spec
lexer and
action routines
yylex()
foo.l
user code

Lex Specification

- **Definition section**
  - All code contained within "%{" and "%}" is copied to the resultant program. Usually has token defns established by the parser
  - User can provide names for complex patterns used in rules
  - Any additional lexing states (states prefaced by %s directive)
  - Pattern and state definitions must start in column 1 (All lines with a blank in column 1 are copied to resulting C file)

lex file always has 3 sections:

definition section

%%

rules section

%%

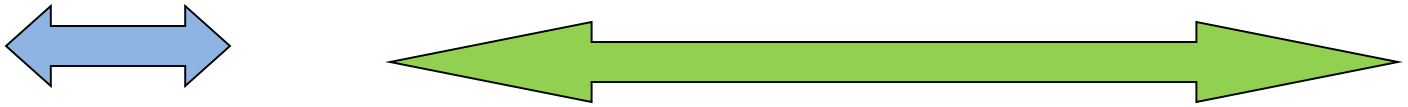
user functions section

Lex Specification (continued)

- **Rules section**
  - Contains lexical patterns and semantic actions to be performed upon a pattern match. Actions should be surrounded by {} (though not always necessary)
  - Again, all lines with a blank in column 1 are copied to the resulting C program
- **User function section**
  - All lines in this section are copied to the final .c file
  - Unless the functions are very immediate support routines, better to put these in a separate file

Partial Flex Program

```
D                   [0-9]
%%
if                  printf ("IF statement\n");
[a-z]+              printf ("tag, value %s\n", yytext);
{D}+                printf ("decimal number %s\n", yytext);
"++"                printf ("unary op\n");
"+"                 printf ("binary op\n");
```



pattern action

Flex Program

```
%{
        #include <stdio.h>
        int num_lines = 0, num_chars = 0;
%}

%%
\n      ++num_lines; ++num_chars;
.       ++num_chars;

%%
main()
{
        yylex();
        printf( "# of lines = %d, # of chars = %d \n",num_lines, num_chars );
}
```

Running the above program:

```
[ 17 ] sandbox -: flex count.l
[ 18 ] sandbox -: gcc lex.yy.c -lfl
[ 19 ] sandbox -: a.out < count.l
# of lines = 16, # of chars = 245
```

Another Flex Program

```
%{
/* recognize articles a, an, the */
#include <stdio.h>
%}

%%
[ \t]+              /* skip white space - action: do nothing */ ;
a |                 /* | indicates do same action as next pattern */
an |
the                 {printf("%s: is an article\n", yytext);}
[a-zA-Z]+           {printf("%s: ???\n", yytext);}

%%
main()
{
        yylex();
}
```

Note: yytext is a pointer to first char of the token
yyleng = length of token

Lex Regular Expression Meta Chars

Meta Char	Meaning
.	match any single char (except \n ?)
*	Kleene closure (0 or more)
[]	Match any character within brackets - in first position matches - ^ in first position inverts set
^	matches beginning of line
$	matches end of line
{a,b}	match count of preceding pattern from a to b times, b optional
\	escape for metacharacters
+	positive closure (1 or more)
?	matches 0 or 1 REs
|	alteration
/	provides lookahead
()	grouping of RE
<>	restricts pattern to matching only in that state

How Does Lex Work?

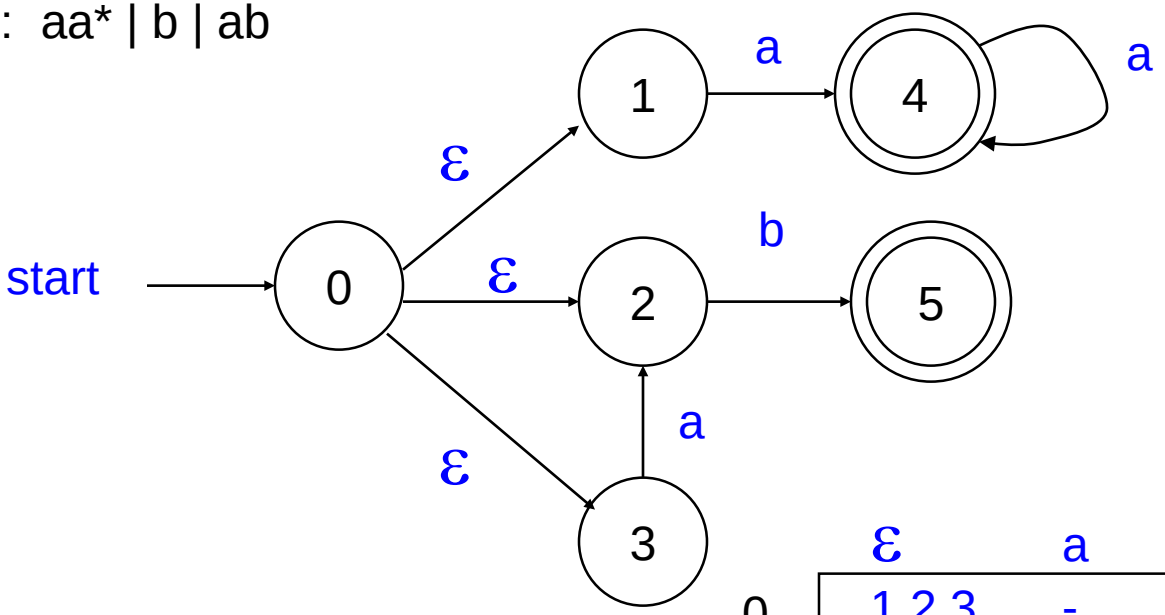
- **Formal basis for lexical analysis is the finite state automaton (FSA)**
  - REs generate regular sets
  - FSAs recognize regular sets
- **FSA – informal defn:**
  - A finite set of states
  - Transitions between states
  - An initial state (start)
  - A set of final states (accepting states)

Two Kinds of FSA

- **Non-deterministic finite automata (NFA)**
  - There may be multiple possible transitions or some transitions that do not require an input (ε)
- **Deterministic finite automata (DFA)**
  - The transition from each state is uniquely determined by the current input character
    - For each state, at most 1 edge labeled ‘a’ leaving state
  - No ε transitions

NFA Example

Recognizes: aa* | b | ab

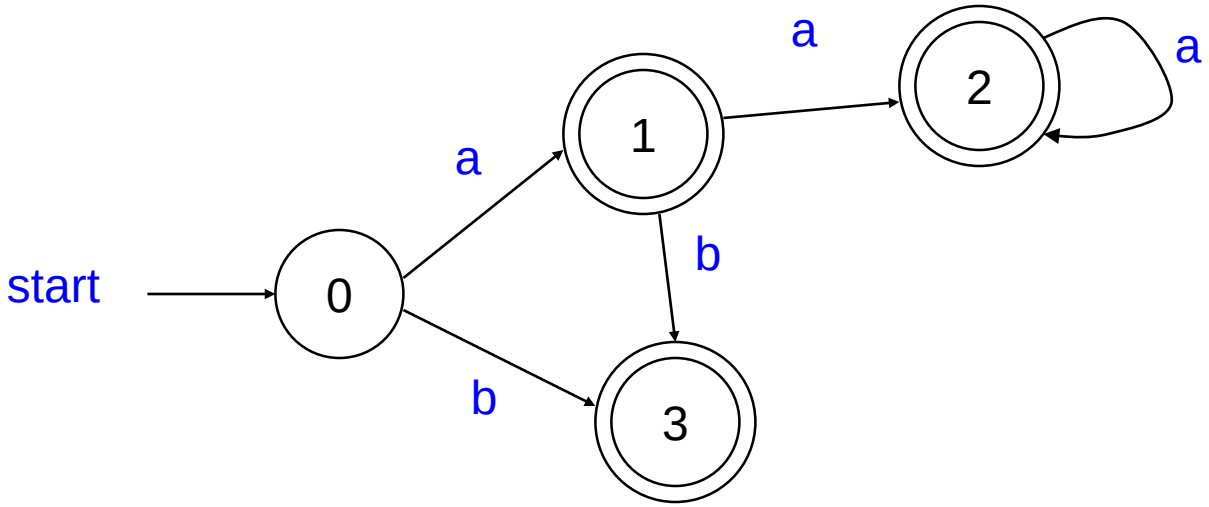


Can represent FA with either graph or transition table

	ε	a	b
0	1,2,3	-	-
1	-	4	Error
2	-	Error	5
3	-	2	Error
4	-	4	Error
5	-	Error	Error

DFA Example

Recognizes: aa* | b | ab



NFA vs DFA

- **DFA**
  - Action on each input is fully determined
  - Implement using table-driven approach
  - More states generally required to implement RE

- **NFA**
  - May have choice at each step
  - Accepts string if there is ANY path to an accepting state
  - Not obvious how to implement this

Class Problem

Is this a DFA or NFA?
What strings does it recognize?