Lexical Analysis

Textbook:Modern Compiler Design

Chapter 2.1

http://www.cs.tau.ac.il/~msagiv/courses/wcc11-12.html

A motivating example

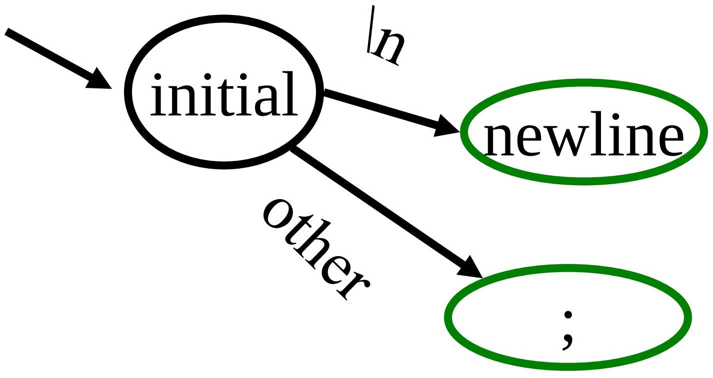
- Create a program that counts the number of lines in a given input text file

Solution (Flex)

```
        int num_lines = 0;
%%
\n      ++num_lines;
.       ;
%%
     main()
          {
          yylex();
          printf( "# of lines = %d\n", num_lines);
          }
```

Solution(Flex)

```
        int num_lines = 0;
%%
\n      ++num_lines;
.       ;
%%
      main()
          {
          yylex();
          printf( "# of lines = %d\n", num_lines);
          }
```



JLex Spec File

User code

– Copied directly to Java file

Possible source of javac errors down the road

%%

JLex directives

– Define macros, state names

DIGIT= [0-9]
LETTER= [a-zA-Z]

YYINITIAL

%%

Lexical analysis rules

– Optional state, regular expression, action

– How to break input to tokens

– Action when token matched

{LETTER}({LETTER}|{DIGIT})*

File: lineCount

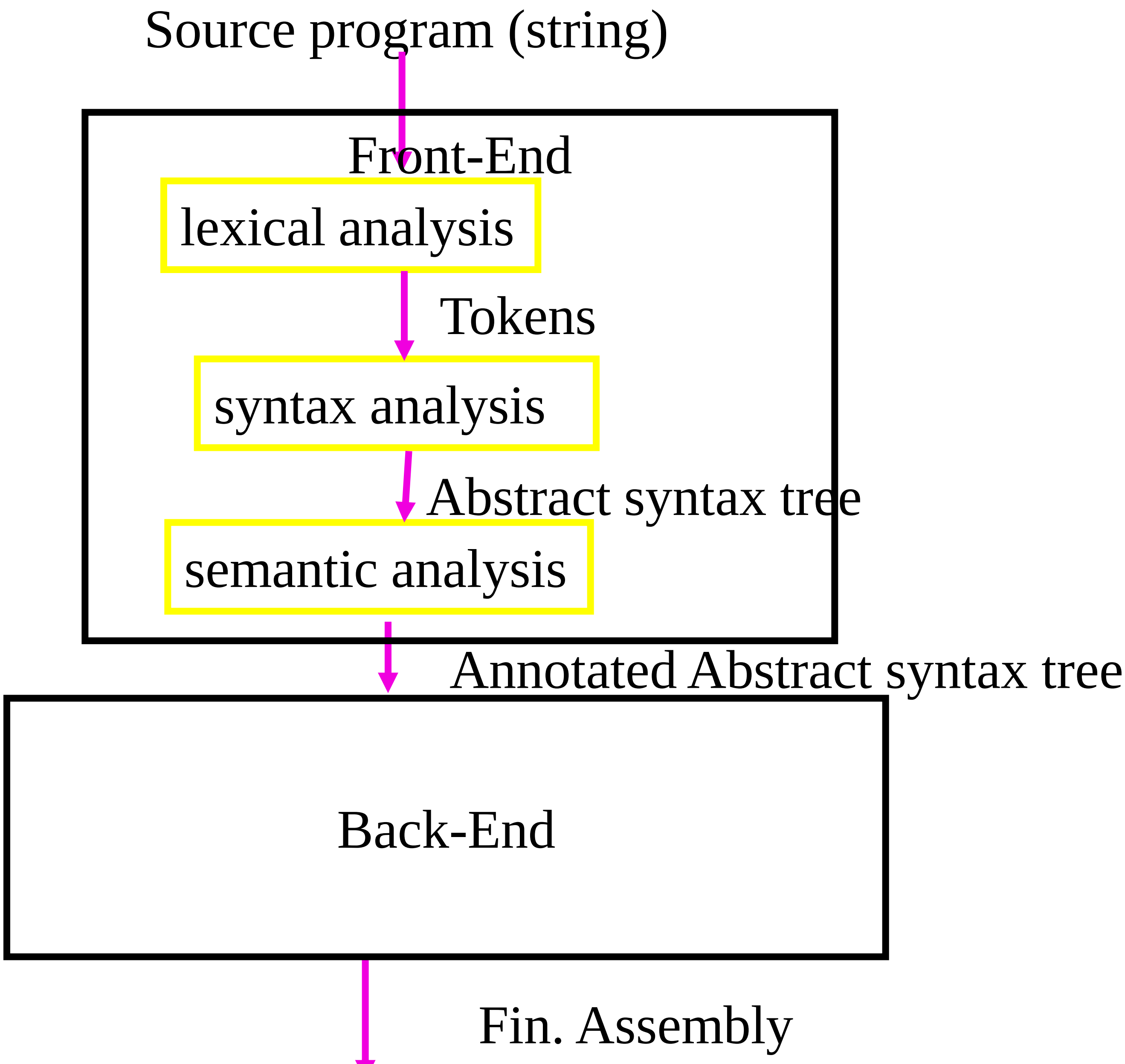
Jlex linecount

```
import java_cup.runtime.*;
%%
%cup
%{
  private int lineCounter = 0;
%}

%eofval{
  System.out.println("line number=" + lineCounter);
  return new Symbol(sym.EOF);
%eofval}

NEWLINE=\n
%%
{NEWLINE} {
       lineCounter++;
}
[^{NEWLINE}] { }
```

Outline

- Roles of lexical analysis
- What is a token
- Regular expressions
- Lexical analysis
- Automatic Creation of Lexical Analysis
- Error Handling

Basic Compiler Phases



Example Tokens

Type	Examples
ID	foo n_14 last
NUM	73 00 517 082
REAL	66.1 .5 10. 1e67 5.5e-10
IF	if
COMMA	,
NOTEQ	!=
LPAREN	(
RPAREN	)

Example Non Tokens

Type	Examples
comment	/* ignored */
preprocessor directive	#include <foo.h>
	#define NUMS 5, 6
macro	NUMS
whitespace	\t \n \b

Example

```
void match0(char *s) /* find a zero */
{
        if (!strncmp(s, “0.0”, 3))
                return 0. ;
}
```

VOID ID(match0) LPAREN CHAR DEREF ID(s)

RPAREN LBRACE IF LPAREN NOT ID(strncmp) LPAREN ID(s) COMMA STRING(0.0) COMMA NUM(3)

RPAREN RPAREN RETURN REAL(0.0) SEMI RBRACE EOF

Lexical Analysis (Scanning)

- input
  - program text (file)
- output
  - sequence of tokens
- Read input file
- Identify language keywords and standard identifiers
- Handle include files and macros
- Count line numbers
- Remove whitespaces
- Report illegal symbols
- [Produce symbol table]

Why Lexical Analysis

- Simplifies the syntax analysis
  - And language definition
- Modularity
- Reusability
- Efficiency

What is a token?

- Defined by the programming language
- Can be separated by spaces
- Smallest units
- Defined by regular expressions

A simplified scanner for C

```
Token nextToken()
{
char c ;
loop: c = getchar();
switch (c){
        case `  `:goto loop ;
        case `;`:  return SemiColumn;
        case `+`:  c = getchar() ;
                switch (c) {
                  case `+': return PlusPlus ;
                  case '='  return PlusEqual;
                  default:  ungetc(c);
                            return Plus;                    }
         case `<`:
        case `w`:
 }
```

Regular Expressions

Basic patterns	Matching
x	The character x
.	Any character expect newline
[xyz]	Any of the characters x, y, z
R?	An optional R
R*	Zero or more occurrences of R
R+	One or more occurrences of R
R_1R_2	R_1 followed by R_2
$R_1 \| R_2$	Either R_1 or R_2
(R)	R itself

Escape characters in regular expressions

- \ converts a single operator into text
  - a\+
  - (a\+*)+
- Double quotes surround text
  - “a+*”+
- Esthetically ugly
- But standard

Ambiguity Resolving

- Find the longest matching token
- Between two tokens with the same length use the one declared first

The Lexical Analysis Problem

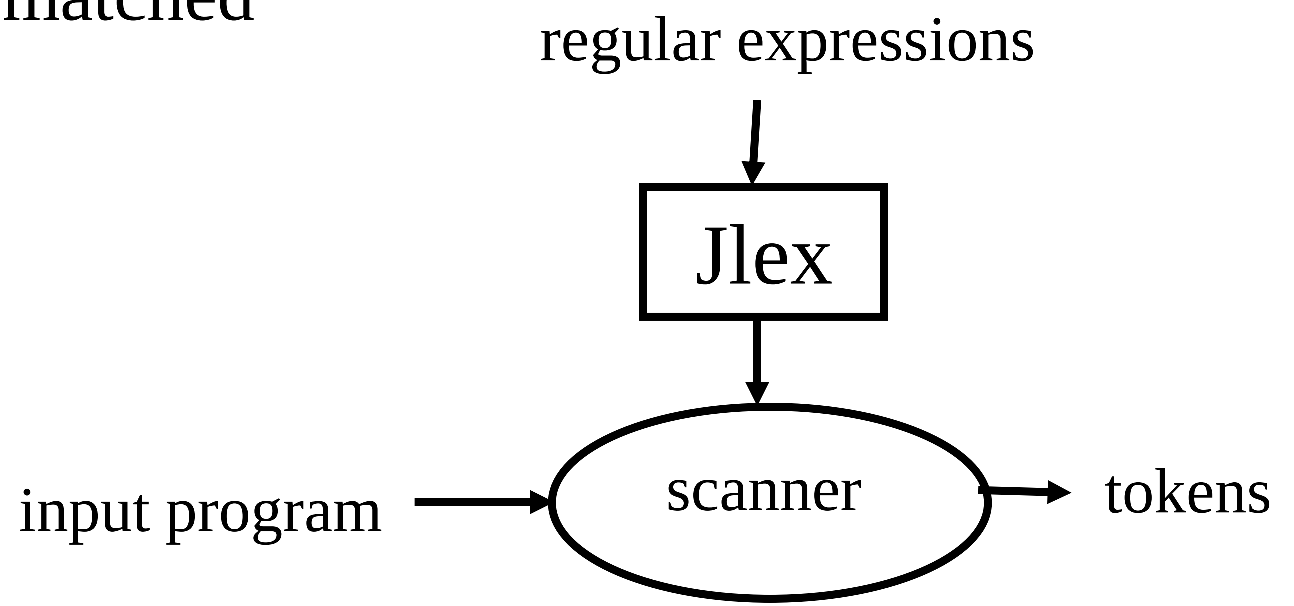
- Given
  - A set of token descriptions
    - Token name
    - Regular expression
  - An input string
- Partition the strings into tokens (class, value)
- Ambiguity resolution
  - The longest matching token
  - Between two equal length tokens select the first

A Jlex specification of C Scanner

```
import java_cup.runtime.*;
%%
%cup
%{
  private int lineCounter = 0;
%}
Letter= [a-zA-Z_]
Digit= [0-9]
%%
"\t" { }
"\n"    { lineCounter++; }
";"      { return new  Symbol(sym.SemiColumn);}
"++"   {return new  Symbol(sym.PlusPlus); }
"+="   {return new  Symbol(sym.PlusEq); }
"+"     {return new  Symbol(sym.Plus); }
"while"  {return new  Symbol(sym.While); }
{Letter}({Letter}|{Digit})*
              {return new  Symbol(sym.Id, yytext() ); }
"<="     {return new  Symbol(sym.LessOrEqual); }
"<"     {return new  Symbol(sym.LessThan); }
```

Jlex

- Input
  - regular expressions and actions (Java code)
- Output
  - A scanner program that reads the input and applies actions when input regular expression is matched



How to Implement Ambiguity Resolving

- Between two tokens with the same length use the one declared first
- Find the longest matching token

Pathological Example

```
if                                   { return IF; }
[a-z][a-z0-9]*                       { return ID; }
[0-9]+                               { return NUM; }
[0-9]"."[0-9]*|[0-9]*"."[0-9]+       { return REAL; }
(\-\-[a-z]*\n)|("  "|\n|\t)          { ; }
.                                    { error(); }
```

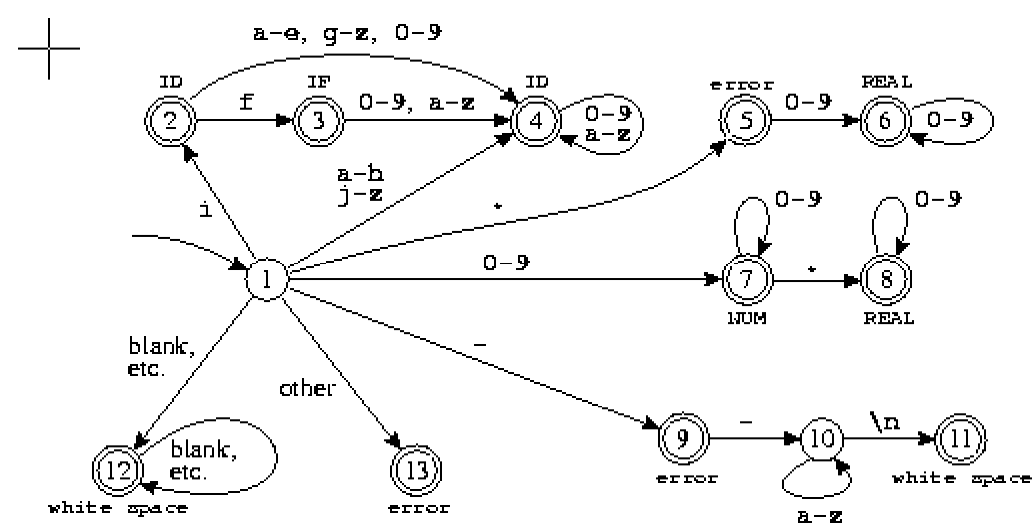
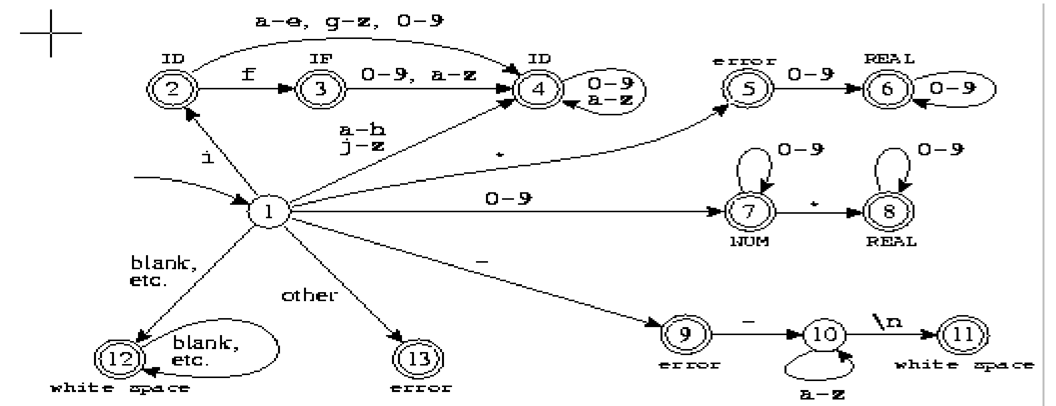


FIGURE 2.4. Combined finite automaton.
From *Modern Compiler Implementation in ML,*
Cambridge University Press, ©1998 Andrew W. Appel



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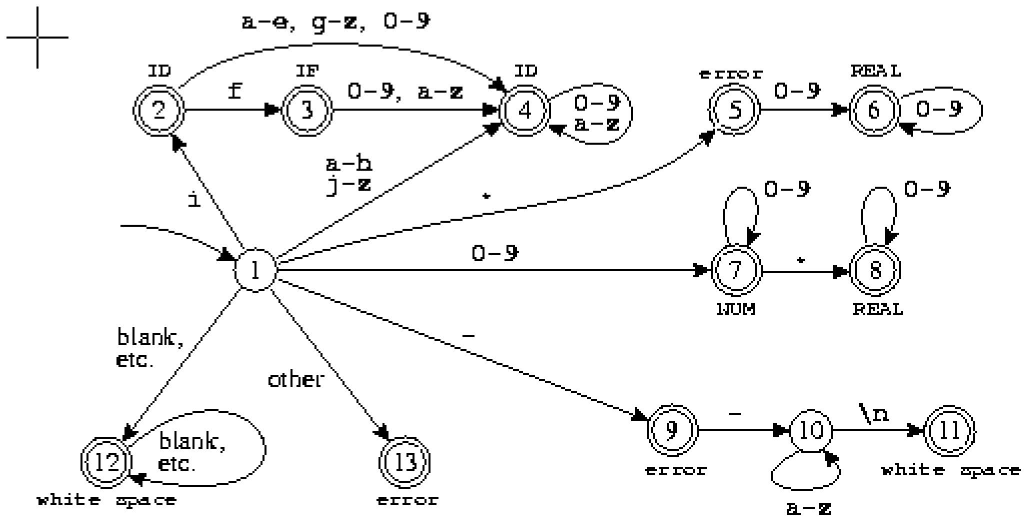
```
int edges[][256] ={ /* …, 0, 1, 2, 3, ..., -, e, f, g, h, i, j,  ... */
/* state 0 */        {0,  ..., 0, 0, …,  0, 0, 0, 0, 0, ..., 0, 0, 0, 0, 0, 0}
/* state 1 */        {13,  ..., 7, 7, 7, 7,  …,  9,  4, 4, 4, 4, 2, 4, ..., 13, 13}
/* state 2 */        {0,  …, 4, 4, 4, 4,  ..., 0,  4, 3, 4, 4, 4, 4, ..., 0, 0}
/* state 3 */        {0, …,  4, 4, 4, 4,  …, 0,  4, 4, 4, 4, 4, 4, , 0, 0}
/* state 4 */        {0, …,  4, 4, 4, 4,   ..., 0,  4, 4, 4, 4, 4, 4, ..., 0, 0}
/* state 5 */        {0, …,  6, 6, 6, 6,   …, 0,  0, 0, 0, 0, 0, 0, …,  0, 0}
/* state 6 */        {0,  …,  6, 6, 6, 6,  …, 0,  0, 0, 0, 0, 0, 0, ..., 0, 0}
/* state 7 */
                             ...
/* state 13 */       {0,  …,  0, 0, 0, 0,  …, 0,  0, 0, 0, 0, 0, 0, …,  0, 0}
```

Pseudo Code for Scanner

```
Token nextToken()
{
lastFinal = 0;
currentState = 1 ;
inputPositionAtLastFinal = input;
currentPosition = input;
while (not(isDead(currentState)))  {
        nextState = edges[currentState][*currentPosition];
        if  (isFinal(nextState)) {
                lastFinal = nextState ;
                inputPositionAtLastFinal = currentPosition; }
        currentState = nextState;
        advance currentPosition;
        }
input = inputPositionAtLastFinal ;
return action[lastFinal];
}
```

Example



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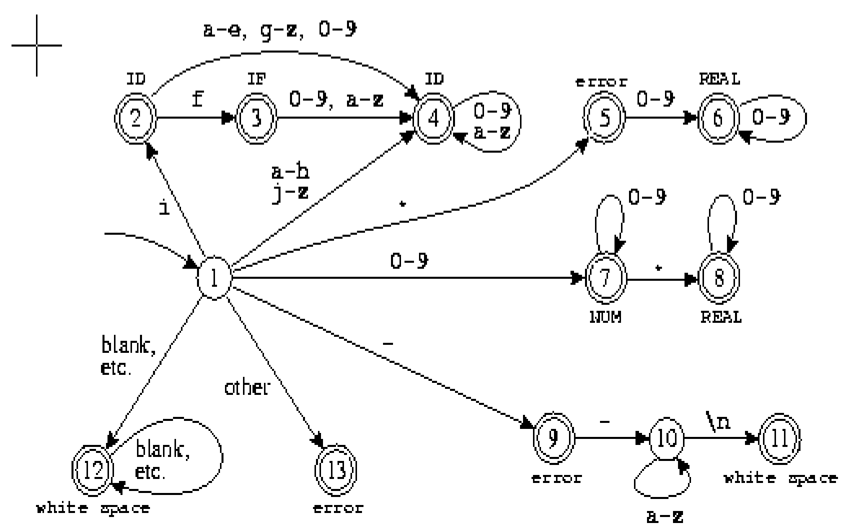
Input: “if --not-a-com”



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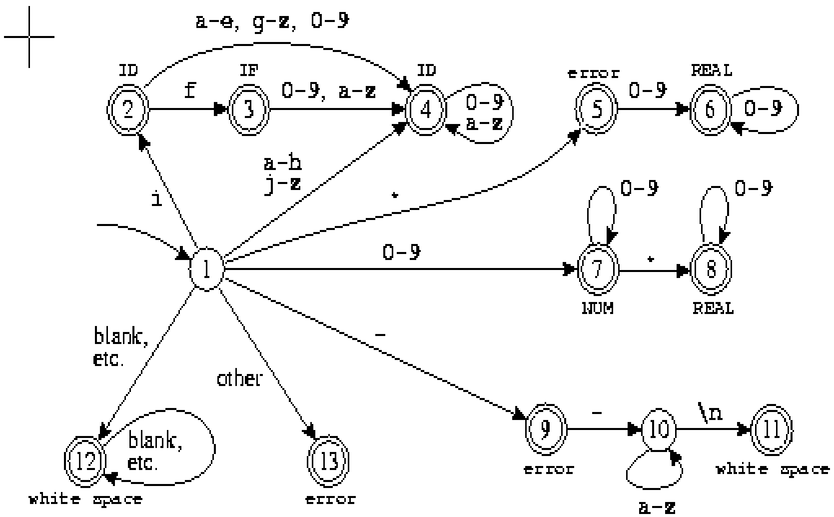
return IF

final	state	input
0	1	if --not-a-com
2	2	if --not-a-com
3	3	if --not-a-com
3	0	if --not-a-com



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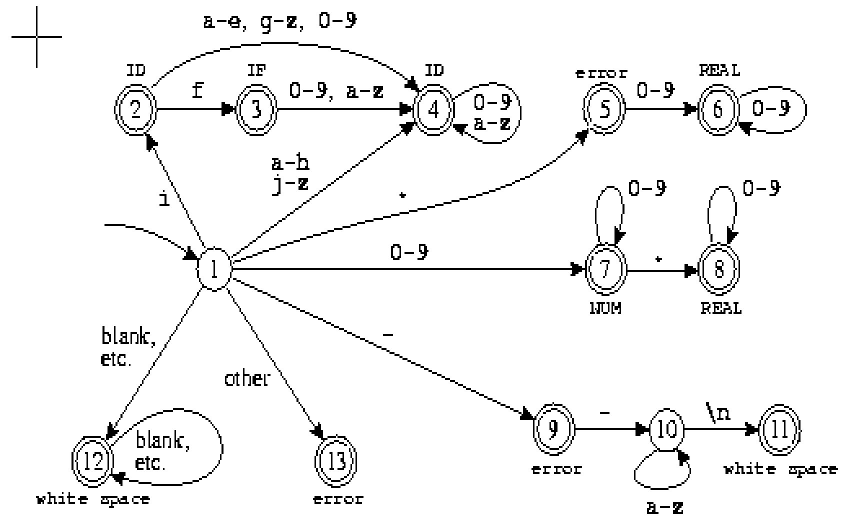
final	state	input
0	1	--not-a-com
12	12	--not-a-com
12	0	--not-a-com

found whitespace



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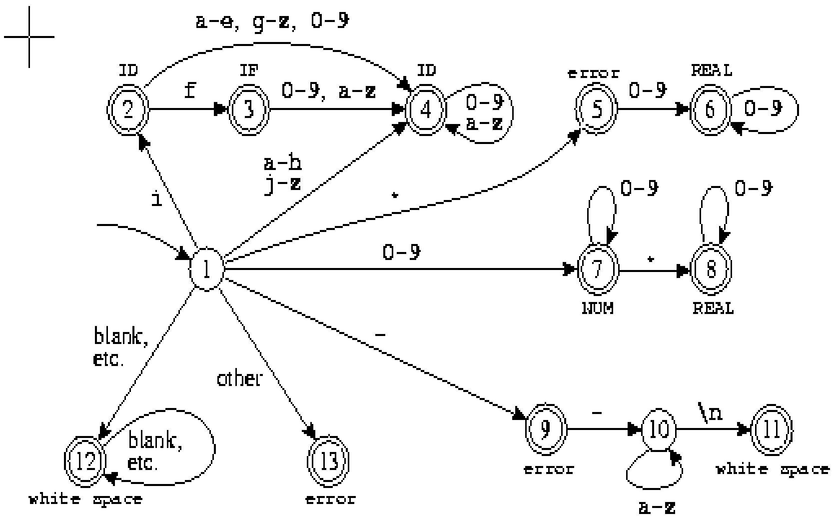
error

final	state	input
0	1	--not-a-com
9	9	--not-a-com
9	10	--not-a-com
9	10	--not-a-com
9	10	--not-a-com
9	0	--not-a-com



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final	state	input
0	1	-not-a-com
9	9	-not-a-com
9	0	-not-a-com

error

Efficient Scanners

- Efficient state representation
- Input buffering
- Using switch and gotos instead of tables

Constructing Automaton from Specification

- Create a non-deterministic automaton (NDFA) from every regular expression
- Merge all the automata using epsilon moves (like the | construction)
- Construct a deterministic finite automaton (DFA)
  - State priority
- Minimize the automaton starting with separate accepting states

NDFA Construction

if	{ return IF; }
[a-z][a-z0-9]*	{ return ID; }
[0-9]+	{ return NUM; }

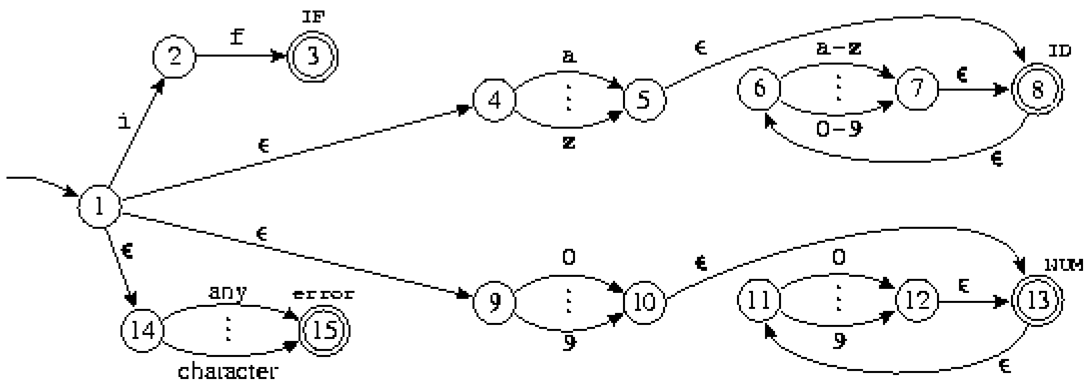

FIGURE 2.7. Four regular expressions translated to an NFA.
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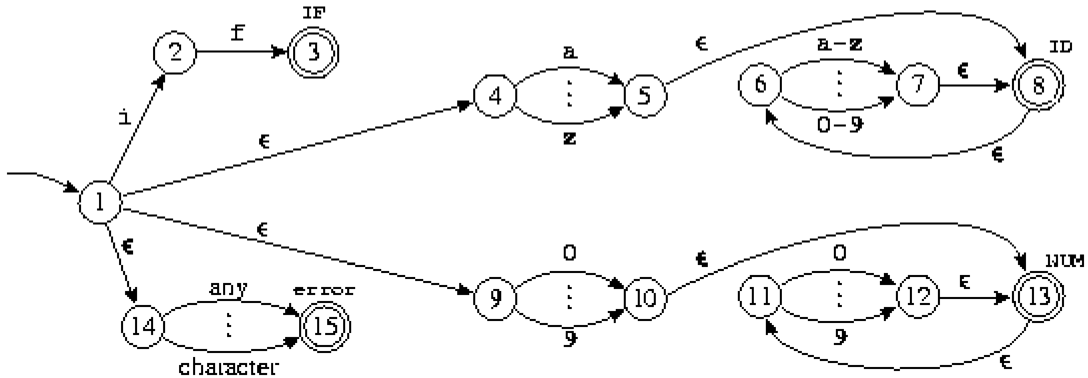

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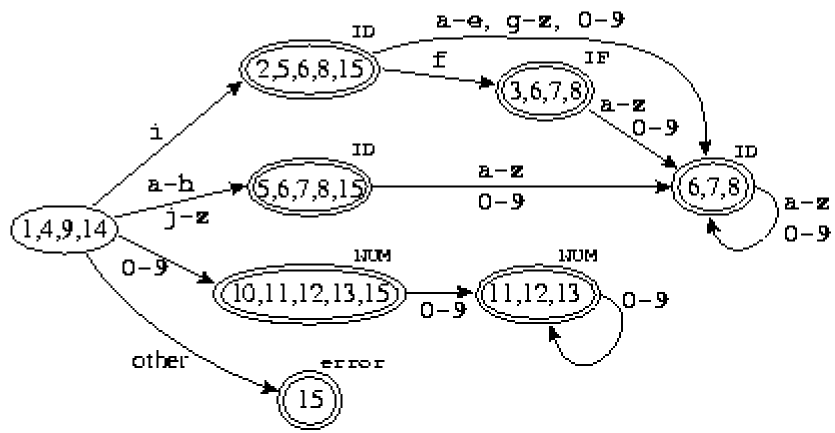

FIGURE 2.8. NFA converted to DFA.
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Minimization

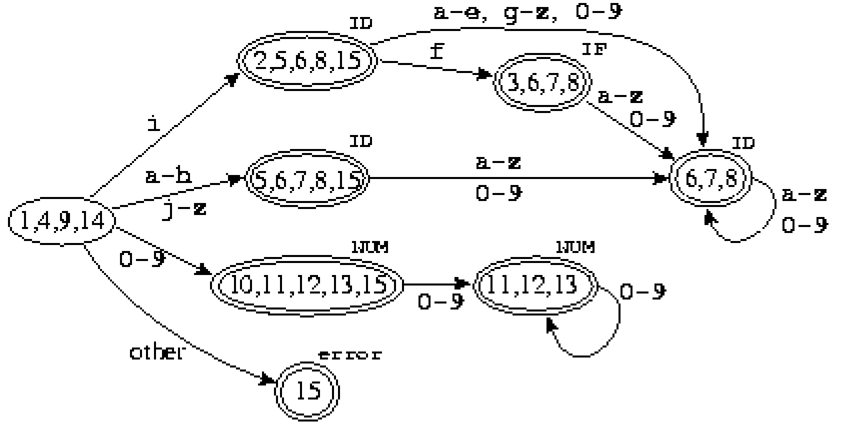

FIGURE 2.8. NFA converted to DFA.
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Start States

- It may be hard to specify regular expressions for certain constructs
  - Examples
    - Strings
    - Comments
- Writing automata may be easier
- Can combine both
- Specify partial automata with regular expressions on the edges
  - No need to specify all states
  - Different actions at different states

Missing

- Creating a lexical analysis by hand
- Table compression
- Symbol Tables
- Nested Comments
- Handling Macros

Summary

- For most programming languages lexical analyzers can be easily constructed automatically
- Exceptions:
  - Fortran
  - PL/1
- Lex/Flex/Jlex are useful beyond compilers