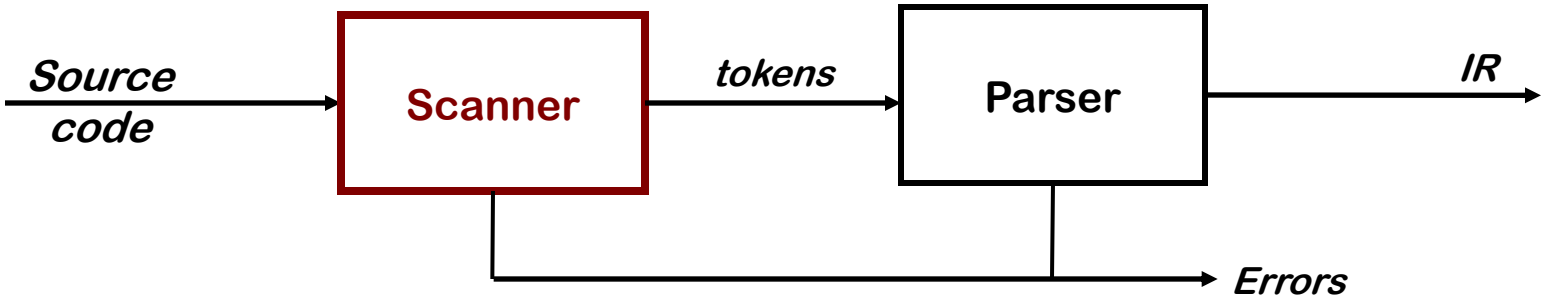
Lexical Analysis

Implementing Scanners & LEX: A Lexical Analyzer Tool

Scanners and Parsers



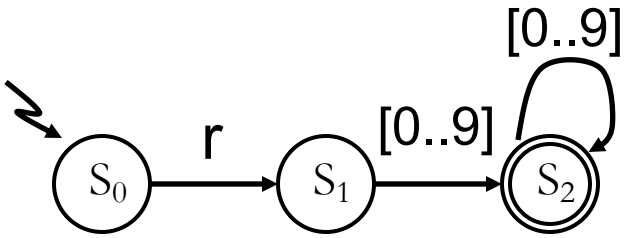
Scanner

- Maps stream of characters into words
  - Basic unit of syntax
  - x = x + y ; *becomes*
    <id,x> <eq,=> <id,x> <pl,+> <id,y> <sc,; >
- Characters that form a word are its ***lexeme***
- Its *part of speech* (or *syntactic category*) is called its ***token type***
- Scanner discards white space & (often) comments

Scanners Construction

- Straightforward Implementation
  - Input: REs
  - Construct an NFA for each RE
  - Combine NFAs using ε-transitions (alternation in Thompson's construction)
  - Create a DFA using the subset construction
  - Minimize the resulting DFA
  - Create an executable code for the DFA

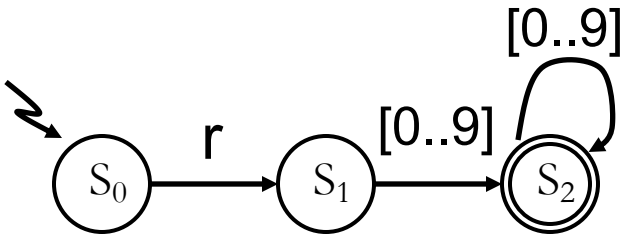
Table-driven Scanners




```
char ← nextChar()
state ← s0
while (char ≠ eof)
    state ← δ(state,char)
    char ← nextChar()
end while
 if state ∈ SF
    then report acceptance
    else report failure
```

δ	r	0..9	Other
s_0	s_1	s_e	s_e
s_1	s_e	s_2	s_e
s_2	s_e	s_2	s_e
s_e	s_e	s_e	s_e

Direct-Coded Scanners



goto s_0

s_0: char ← nextChar()
  if(char = 'r')
    then goto s_1
    else goto s_e

s_1: char ← nextChar()
  if('0' ≤ char ≤ '9')
    then goto s_2
    else goto s_e

s_2: char ← nextChar()
  if('0' ≤ char ≤ '9')
    then goto s_2
    elseif (char = eof)
      then report acceptance
      else goto s_e

s_e: report failure

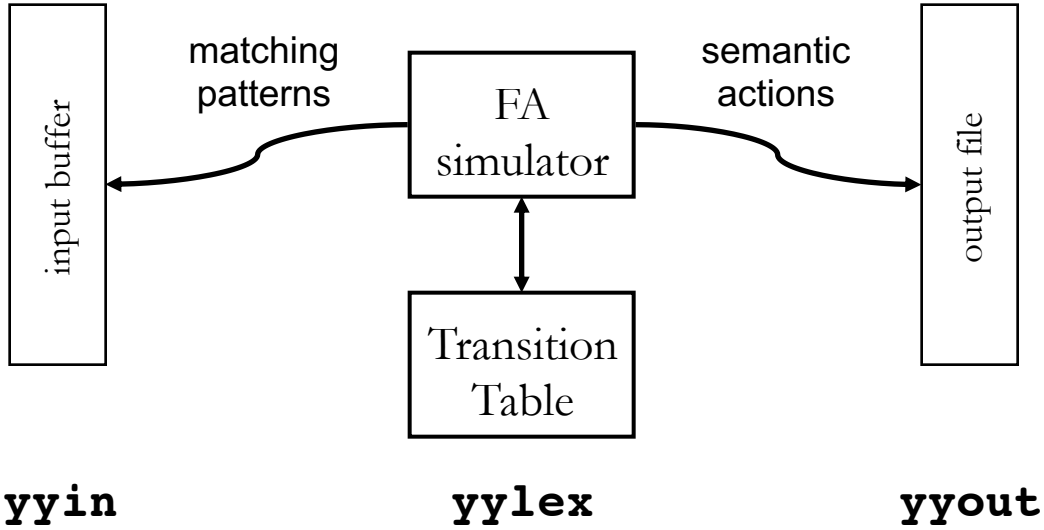
Scanners in Practice

- Uses automated tools to construct a Lexical Analyzer
  - Given a set of tokens defined using regular expressions
  - Tools will generate a character stream tokenizer by constructing a DFA
- Common Scanner Generator Tools
  - lex in C
  - JLex in java

LEX: A Lexical Analyzer Tool

- Input:
  - File with suffix .l
  - Three (3) regions delimited by the marker ´%%´ corresponding to:
    - **Declarations**: macros and language declaration between ‘%{‘ e ‘%}‘
    - **Rules**: regular expression and corresponding action between brackets { } to be executed when the analyzer matches the regular expression.
    - **Code**: support functions
- Output:
  - Generates a C function named **`yylex`** in the file **`lex.yy.c`**, with the command **`lex file.l`** and compiled using -ll switch
  - **`flex`** uses the library -lfl

LEX: A Lexical Analyzer Tool



LEX: Regular Expressions

x	the character x
"x"	the character x, even if it is a special character
\x	the character x, even if it is a special character
x$	the character x at the end of a line
^x	the character x at the beginning of a line
x?	Zero or one occurrence of x
x+	One or more occurrences of x
x*	Zero or more occurrences of x
xy	the character x followed by the character y
x|y	the character x or the character y
[az]	the character a or the character z
[a-z]	from character a to character z
[^a-z]	Any character except from a to z
x{n}	n occurrences of x
x{m,n}	between m and n occurrences of x
x/y	x if followed by y (only x is part of the pattern)
.	Any character except \n
(x)	same as x, parentheses change operator priority
<<EOF>>	end of file

LEX: Regular Expression Short-hands

- Allow Regular Expressions Simplification
- In the declaration region; consists of an identifier followed by a regular expression
- Use between brackets [ ] in subsequent regular expressions

```
DIGIT[0-9]
INT         {DIGIT}+
EXP         [Ee][+-]?{INT}
REAL        {INT}"."{INT}({EXP})?
```

LEX: Example lex.l

```
%{
  /* definitions of constants */
#define LT          128
#define LE          129
#define EQ          130
#define NE          131
#define GT          132
#define GE          133
#define IF          134
#define THEN        135
#define ELSE        136
#define ID          137
#define NUM         138
#define RELOP       139

void install_id()  { printf(" Installing an identifier %s\n", yytext); }
void install_num()  { printf(" Installing a number %s\n", yytext); }

%}
/* 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}        { install_id(); return(ID); }
{number}    { install_num(); return(NUM); }
“<“         { return(LT); }
“<=“        { return(LE); }
“=“         { return(EQ); }
“<>”        { return(NE); }
“>”         { return(GT); }
“>=“        {return(GE); }
%%

int yywrap() {  return 1; }

int main(){
  int n, tok;
   n = 0;
  while(1) {
    tok = yylex();
    if(tok == 0) break;
    printf(" token matched is %d\n",tok);
    n++;
  }
  printf(" number of tokens matched is %d\n",n);
  return 0;
}
```

LEX: Executing yylex

```
%> more in.txt
a = 4
b = 12.5
if a <> 0 then a = 1
```

```
%> ./a.out < in.txt
Installing an identifier a
 token matched is 137
 token matched is 130
 Installing a number 4
 token matched is 138
 Installing an identifier b
 token matched is 137
 token matched is 130
 Installing a number 12.5
 token matched is 138
 token matched is 134
 Installing an identifier a
 token matched is 137
 token matched is 131
 Installing a number 0
 token matched is 138
 token matched is 135
 Installing an identifier a
 token matched is 137
 token matched is 130
 Installing a number 1
 token matched is 138
 number of tokens matched is 14
```

LEX: Handling of Regular Expressions

- Disambiguating in case of multiple regular expression matching:
  - Longest input sequence is selected
  - If same length, first in specification is selected

- Note: Input sequence length not length of regular expression length:

```
%%
dependent       printf(Found 'dependent'\n");
[a-z]+          ECHO;
```

LEX: Context Sensitive Rules

- Set of regular expressions *activated* by a '**BEGIN**' command and identified by '**%s**' in the declaration region

- The regular expression in each set are preceded by the identifier between < and >. The '**INITIAL**' identifier indicates the global rules permanently active.

- At any given time only the global rules and at most one of the set of context sensitive rules can be active by the invocation of the '**BEGIN**' command.

LEX: Global Variables (C lang.)

- **char yytext[]**, string containing matched input text
- **int yyleng**, length of string containing matched input text
- **int yylineno**, line number of input file where the last character of the macthed input text lies. With flex use the option -l or include **%option yylineno** or **%option lex-compat** in input file .l
- **FILE *yyin**, file pointer where from the input characters are read
- **FILE *yyout**, file pointer where to the output text is written using the **ECHO** macro or other programmer defined functions
- **YYSTYPE yylval**, internal variable used to carry over the values between the lexical analyzer and other tools, namely YACC

LEX: Auxiliary Functions (C lang.)

- **int yylex(void),** lex generated function that implements the lexical analysis. Returns a numeric value identifying the matched lexical element (i.e. as identified by **y.tab.h**) or 0 (zero) when EOF is reached

- **int yywrap(void),** programmer defined function invoked when the EOF of the current input file is reached. In the absence of more additional input files this function returns 1 (one). It returns 0 (zero) otherwise and the **yyin** variable should be pointing to the new input file

- **void yymore(void),** function invoked in a semantic action allowing the matched text to be saved and concatenated to the following matched text

- **void yyless(int n),** function invoked in a semantic action allowing the **n** characters of **yytext** to be reconsidered for processing.

LEX: Predefined Macros (C lang.)

- **ECHO**: outputs the matched text, that is **yytext**, for a given regular expression, or when aggregated using other rules by the invocation of the yymore() function
  - Is defined as #define ECHO fwrite(yytext, yyleng, 1, yyout)

- **REJECT**: after processing of the semantic action that includes a **REJECT** invocation, the processing restarts at the beginning of the matched text but this time ignoring it.
  - What is the point?!

Lex and Flex

- Lex compatible mode: use flex -l or include ‘%option lex-compat’ in declaration region of the input specification
- Access to yylineno: use lex compatibility mode or include “%option yylineno” in the declaration region
- Context Sensitive Rules: only the currently active context sensitive rules are active in addition to the global rules using “%x’ instead of ‘%s”
- Debug mode: use flex -d and set the yy_flex_debug to 1

Lex: Processing Efficiency

- Processing time of FA proportional to the size of the input file and not on the number of regular expressions used (although the number of expressions may impact number of internal states and therefore in space)

- Use as much as possible regular expressions and as little as possible action processing in C

- Use regular expressions more specific at the beginning of the LEX file specification (keyword for example) and more generic regular expressions at the end (identifiers, for example)

Lex: Example lex.l with Context Rules

```
%{
   #include <stdio.h>
   #include <string.h>
   int nest = 0;
%}
%s COMMENT ACTION
HREF    [Hh][Rr][Ee][Ff][ \t\n]*=[ \t\n]*
%%
"<!--"                  {nest++; BEGIN COMMENT; printf(" begin comment\n"); }
<COMMENT>"<"        ;
<COMMENT>"-->"      {if(--nest==0) BEGIN INITIAL; printf(" end comment\n"); }
"<"                     { BEGIN ACTION; printf(" begin action\n"); }
<ACTION>{HREF}\"(\"\"|[^\"])*\" { printf("(%s)\n",index(yytext,"")); }
<ACTION>">"             { BEGIN INITIAL; printf(" end action\n"); }
.|\n            ;
%%
int yywrap(){
  return 1;
}

int main(int argc, char **argv){
  int tok;
  int n;
  n = 0;
  while(1) {
    tok = yylex();
    if(tok == 0)
      break;
    printf(" token matched is %d\n",tok);
    n++;
  }
  printf(" number of tokens matched is %d\n",n);
  return 0;
}
```

```
more test1.txt
<!-- sdsdswdsdsdsdssds -->
  <HREF="string4">
<!--
  <HREF="string5">
  sdsdswdsdsdsdssds
-->
< HREF="string3">
<HREF="string2">
<HREF = "string1">

./a.out < test1.txt
 begin comment
 end comment
 begin action
("string4")
 end action
 begin comment
 end comment
 begin action
("string3")
 end action
 begin action
("string2")
 end action
 begin action
("string1")
 end action
```

Summary

- Scanner Construction
  - Table-driven
  - Direct-coded
- Lex: A Lexical Analyzer Tool