Module 02

Pralay Mitra
Partha Pratim
Das

Objectives & Outline

Lexical Analysis Outline

Flex Specification

Sample

Regular Expressions

Common Errors

Line Count Example

Interactive Flex

Flex-Bison Flow

Start Conditions

Summary

Module 02: CS31003: Compilers:

Lexical Analyzer Generator: Flex / Lex

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Module Objectives

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- Understand Flex Specification
- Understand Lexical Analysis

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- Lexical Analysis Outline
- Flex Specification
  - Sample
  - Regular Expressions
  - Common Errors in Flex
  - Line Count Example
- Interactive Flex
- Flex–Bison Flow
- Start Condition in Flex

Lexical Analysis Algorithm

- RE[1] for every Token Class
- Convert Regular Expression to an NFA[2]
- Convert NFA to DFA[3]
- Lexical Action for every final state of DFA

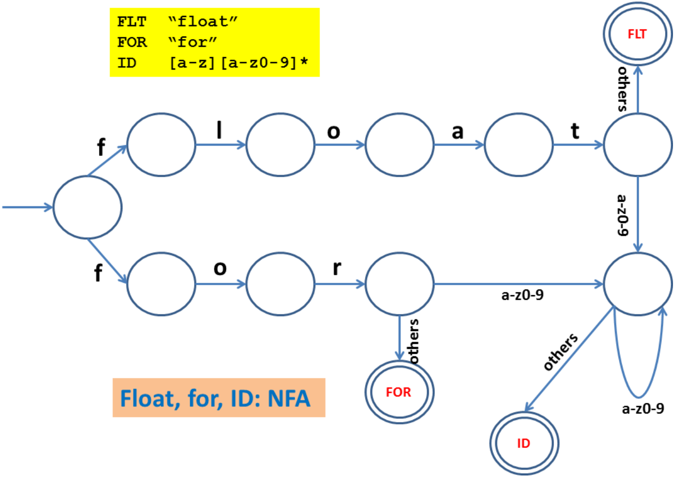
[1] Regular Expression

[2] Non-deterministic Finite Automata

[3] Deterministic Finite Automata

Lexical Analysis Algorithm

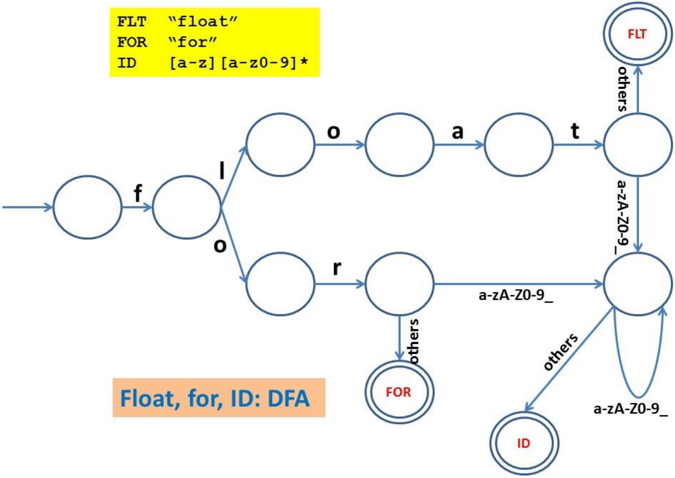
```
FLT   "float"
FOR   "for"
ID    [a-z][a-z0-9]*
```



Float, for, ID: NFA

Lexical Analysis Algorithm

```
FLT   "float"
FOR   "for"
ID    [a-z][a-z0-9]*
```



Float, for, ID: DFA

Lexical Analysis Rules

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number → digits optFrac optExp
digit → 0 | 1 | 2 | …| 9
digits → digit digit*
optFrac → . digit | ε
optExp → (E (+ | - | ε) digit) | ε

integer and float constants

id → letter (letter | digit)*
letter → A | B | C … | Z | a | b | c … | z
digit → 0 | 1 | 2 | … | 9

Character class

FSM for Integer and Floating Point Constants

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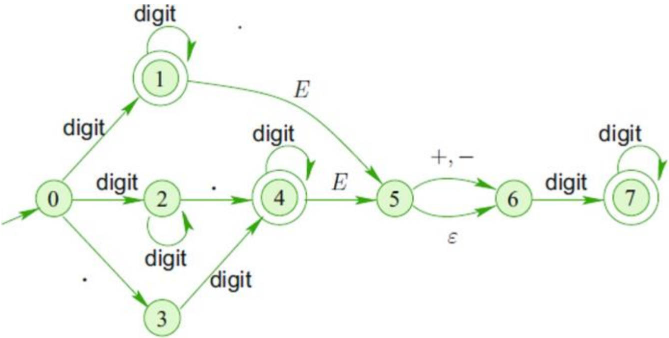

Token Representation

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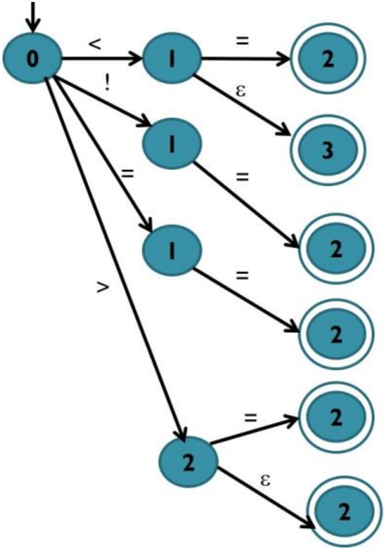
Summary

Lexemes	Token Name	Attribute Value
Any ws	-	-
if	**if**	-
then	**then**	-
else	**else**	-
Any id	**id**	Pointer to ST
Any number	**number**	Pointer to ST
<	**relop**	LT
<=	**relop**	LE
==	**relop**	EQ
!=	**relop**	NE
>	**relop**	GT
>=	**relop**	GE

FSM for Logical Operators



return (relop, LE)

return (relop, LT)

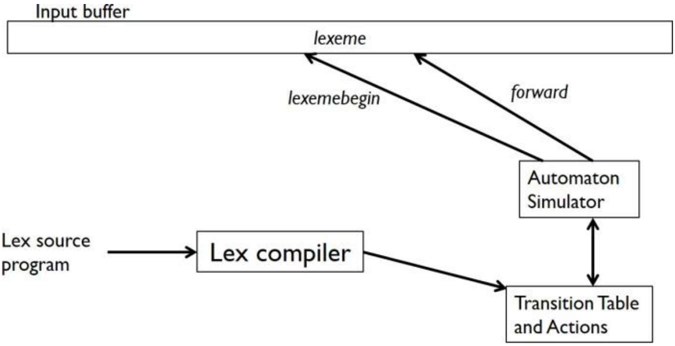
return (relop, NE)

return (relop, EQ)

return (relop, GE)

return (relop, GT)

Flex Flow



Lex program → Transition table and actions → FA simulator

Our Sample for Flex

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Summary

- This is a simple block with declaration and expression statements
- We shall use this as a running example

```
{
    int x;
    int y;
    x = 2;
    y = 3;
    x = 5 + y * 4;
}
```

Structure of Flex Specs

```
Declarations
%%
Translation rule
%%
Auxiliary functions
```

Flex Specs for our sample

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Start Conditions

Summary

- C Declarations and definitions
- Definitions of Regular Expressions
- Definitions of Rules & Actions
- C functions

```
%{
/* C Declarations and Definitions */
%}
 /* Regular Expression Definitions */
INT         "int"
ID          [a-z][a-z0-9]*
PUNC        [;]
CONST       [0-9]+
WS          [ \t\n]
/* Definitions of Rules \& Actions */
%%
{INT}       { printf("<KEYWORD, int>\n"); /* Keyword Rule */ }
{ID}        { printf("<ID, %s>\n", yytext); /* Identifier Rule */}
"+"         { printf("<OPERATOR, +>\n"); /* Operator Rule */ }
"*"         { printf("<OPERATOR, *>\n"); /* Operator Rule */ }
"="         { printf("<OPERATOR, =>\n"); /* Operator Rule */ }
"{"         { printf("<SPECIAL SYMBOL, {>\n"); /* Scope Rule */ }
"}"         { printf("<SPECIAL SYMBOL, }>\n"); /* Scope Rule */ }
{PUNC}      { printf("<PUNCTUATION, ;>\n"); /* Statement Rule */ }
{CONST}     { printf("<INTEGER CONSTANT, %s>\n",yytext); /* Literal Rule */ }
{WS}        /* White-space Rule */ ;
%%
/* C functions */
main() { yylex(); /* Flex Engine */ }
```

Flex I/O for our sample

I/P Character Stream

```
{
    int x;
    int y;
    x = 2;
    y = 3;
    x = 5 + y * 4;
}
```

O/P Token Stream

- <SPECIAL SYMBOL, {>
- <KEYWORD, int> <ID, x> <PUNCTUATION, ;>
- <KEYWORD, int> <ID, y> <PUNCTUATION, ;>
- <ID, x> <OPERATOR, => <INTEGER CONSTANT, 2> <PUNCTUATION, ;>
- <ID, y> <OPERATOR, => <INTEGER CONSTANT, 3> <PUNCTUATION, ;>
- <ID, x> <OPERATOR, => <INTEGER CONSTANT, 5> <OPERATOR, +>
- <ID, y> <OPERATOR, *> <INTEGER CONSTANT, 4> <PUNCTUATION, ;>
- <SPECIAL SYMBOL, }>

- Every token is a doublet showing the token class and the specific token information
- The output is generated as one token per line. It has been rearranged here for better readability

Variables in Flex

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Summary

yylex	Flex generated lexer driver
yyin	File pointer to Flex input
yyout	File pointer to Flex output
yytext	Pointer to Lexeme
yyleng	Length of the Lexeme

Regular Expressions – Basic

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Summary

Expr.	Meaning
x	Character x
.	Any character except newline
[xyz]	Any characters amongst x, y or z.
[a-z]	Denotes any letter from a through z
[ˆ0-9]	Stands for any character which is not a decimal digit, including new-line
\x	If x is an a, b, f, n, r, t, or v, then the ANSI-C interpretation of \x. Otherwise, a literal x (used to escape operators such as *)
\0	A NULL character
\num	Character with octal value num
\xnum	Character with hexadecimal value num
”string”	Match the literal string. For instance ”/*” denotes the character / and then the character *, as opposed to /* denoting any number of slashes
<<EOF>>	Match the end-of-file

Regular Expressions - Operators

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Summary

Expr.	**Meaning**
(r)	Match an r; parentheses are used to override precedence
rs	Match the regular expression r followed by the regular expression s. This is called *concatenation*
r|s	Match either an r or an s. This is called *alternation*
{abbreviation}	Match the expansion of the abbreviation definition. Instead of: %% [a-zA-Z_][a-zA-Z0-9_]* return IDENTIFIER; %% Use id [a-zA-Z_][a-zA-Z0-9_]* %% {id} return IDENTIFIER; %%

Regular Expressions - Operators

Expr.	Meaning
	quantifiers
r*	zero or more r's
r+	one or more r's
r?	zero or one r's
r{[num]}	num times r
r{min,[max]}	Anywhere from min to max (defaulting to no bound) r's
r/s	Match an r but only if it is followed by an s. This type of pattern is called *trailing context*. For example: Distinguish DO1J=1,5 (a for loop where I runs from 1 to 5) from DO1J=1.5 (a definition/assignment of the floating variable DO1J to 1.5) in FORTRAN. Use DO/[A-Z0-9]*=[A-Z0-9]*
ˆr	Match an r at the beginning of a line
r$	Match an r at the end of a line

Wrong Flex Specs for our sample

- Rules for ID and INT have been swapped.
- No keyword can be tokenized as keyword now.

```
%{
/* C Declarations and Definitions */
%}
 /* Regular Expression Definitions */
INT          "int"
ID           [a-z][a-z0-9]*
PUNC         [;]
CONST        [0-9]+
WS           [ \t\n]

%%
{ID}         { printf("<ID, %s>\n", yytext); /* Identifier Rule */}
{INT}        { printf("<KEYWORD, "int">\n"); /* Keyword Rule */ }
"+"          { printf("<OPERATOR, +>\n"); /* Operator Rule */ }
"*"          { printf("<OPERATOR, *>\n"); /* Operator Rule */ }
"="          { printf("<OPERATOR, =>\n"); /* Operator Rule */ }
"{"          { printf("<SPECIAL SYMBOL, {>\n"); /* Scope Rule */ }
"}"          { printf("<SPECIAL SYMBOL, }>\n"); /* Scope Rule */ }
{PUNC}       { printf("<PUNCTUATION, ;>\n"); /* Statement Rule */ }
{CONST}      { printf("<INTEGER CONSTANT, %s>\n",yytext); /* Literal Rule */ }
{WS}         /* White-space Rule */ ;
%%

main() {
    yylex(); /* Flex Engine */
}
```

Wrong Flex I/O for our sample

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I/P Character Stream

```
{
    int x;
    int y;
    x = 2;
    y = 3;
    x = 5 + y * 4;
}
```

O/P Token Stream

- <SPECIAL SYMBOL, {>
- <ID, int> <ID, x> <PUNCTUATION, ;>
- <ID, int> <ID, y> <PUNCTUATION, ;>
- <ID, x> <OPERATOR, => <INTEGER CONSTANT, 2> <PUNCTUATION, ;>
- <ID, y> <OPERATOR, => <INTEGER CONSTANT, 3> <PUNCTUATION, ;>
- <ID, x> <OPERATOR, => <INTEGER CONSTANT, 5> <OPERATOR, +>
- <ID, y> <OPERATOR, *> <INTEGER CONSTANT, 4> <PUNCTUATION, ;>
- <SPECIAL SYMBOL, }>

- Both `int`'s have been taken as `ID`!

Count Number of Lines – Flex Specs

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```
/* C Declarations and definitions */
%{
    int charCount = 0, wordCount = 0, lineCount = 0;
%}

/* Definitions of Regular Expressions */
word   [^ \t\n]+

/* Definitions of Rules \& Actions */
%%
{word}     { wordCount++; charCount += yyleng; }
[\n]       { charCount++; lineCount++; }
.          { charCount++; }
%%

/* C functions */
main() {
    yylex();
    printf("Characters: %d Words: %d Lines %d\n",charCount, wordCount, lineCount);
}
```

Count Number of Lines – lex.yy.c

```
char *yytext;
int charCount = 0, wordCount = 0, lineCount = 0; /* C Declarations and definitions */
/* Definitions of Regular Expressions & Definitions of Rules & Actions */
int yylex (void) { /** The main scanner function which does all the work. */
// ...
    if ( ! (yy_start) ) (yy_start) = 1;     /* first start state */
    if ( ! yyin ) yyin = stdin;
    if ( ! yyout ) yyout = stdout;
// ...
    while ( 1 ) {         /* loops until end-of-file is reached */
// ..
     yy_current_state = (yy_start);
yy_match: // ...
yy_find_action: // ...
do_action:
        switch ( yy_act ) { /* beginning of action switch */
            case 0: /* must back up */ // ...
            case 1: { wordCount++; charCount += yyleng; } YY_BREAK
            case 2: { charCount++; lineCount++; } YY_BREAK
            case 3: { charCount++; } YY_BREAK
            case 4: ECHO; YY_BREAK
            case YY_STATE_EOF(INITIAL): yyterminate();
            case YY_END_OF_BUFFER:
            default: YY_FATAL_ERROR("fatal flex scanner internal error--no action found" );
         } /* end of action switch */
     } /* end of scanning one token */
} /* end of yylex */
main() { /* C functions */
    yylex();
    printf("Characters: %d Words: %d Lines %d\n",charCount, wordCount, lineCount);
}
```

Modes of Flex Operations

Flex can be used in two modes:

- **Non-interactive**: Call `yylex()` only once. It keeps spitting the tokens till the end-of-file is reached. So the actions on the rules do not have `return` and falls through in the `switch` in `lex.yy.c`.
  This is convenient for small specifications. But does not work well for large programs because:
  - Long stream of spitted tokens may need a further tokenization while processed by the parser
  - At times tokenization itself, or at least the information update in the actions for the rules, may need information from the parser (like pointer to the correctly scoped symbol table)
- **Interactive**: Repeatedly call `yylex()`. Every call returns one token (after taking the actions for the rule matched) that is consumed by the parser and `yylex()` is again called for the next token. This lets parser and lexer work hand-in-hand and also eases information interchange between the two.

Flex Specs (non-interactive) for our sample

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- C Declarations and definitions
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```
%{
/* C Declarations and Definitions */
%}
 /* Regular Expression Definitions */
INT          "int"
ID           [a-z][a-z0-9]*
PUNC         [;]
CONST        [0-9]+
WS           [ \t\n]
/* Definitions of Rules \& Actions */
%%
{INT}        { printf("<KEYWORD, int>\n"); /* Keyword Rule */ }
{ID}         { printf("<ID, %s>\n", yytext); /* Identifier Rule */}
"+"          { printf("<OPERATOR, +>\n"); /* Operator Rule */ }
"*"          { printf("<OPERATOR, *>\n"); /* Operator Rule */ }
"="          { printf("<OPERATOR, =>\n"); /* Operator Rule */ }
"{"          { printf("<SPECIAL SYMBOL, {>\n"); /* Scope Rule */ }
"}"          { printf("<SPECIAL SYMBOL, }>\n"); /* Scope Rule */ }
{PUNC}       { printf("<PUNCTUATION, ;>\n"); /* Statement Rule */ }
{CONST}      { printf("<INTEGER CONSTANT, %s>\n",yytext); /* Literal Rule */ }
{WS}         /* White-space Rule */ ;
%%
/* C functions */
main() { yylex(); /* Flex Engine */ }
```

Flex Specs (interactive) for our sample

```
%{
#define     INT         10
#define     ID          11
#define     PLUS        12
#define     MULT        13
#define     ASSIGN      14
#define     LBRACE      15
#define     RBRACE      16
#define     CONST       17
#define     SEMICOLON   18
%}

INT         "int"
ID          [a-z][a-z0-9]*
PUNC        [;]
CONST       [0-9]+
WS          [ \t\n]

%%
{INT}     { return INT; }
{ID}      { return ID; }
"+"       { return PLUS; }
"*"       { return MULT; }
"="       { return ASSIGN; }
"{"       { return LBRACE; }
"}"       { return RBRACE; }
{PUNC}    { return SEMICOLON; }
{CONST}   { return CONST; }
{WS}      {/* Ignore
                whitespace */}
%%
```

```
main() { int token;
    while (token = yylex()) {
        switch (token) {
            case INT: printf("<KEYWORD, %d, %s>\n",
                token, yytext); break;
            case ID: printf("<IDENTIFIER, %d, %s>\n",
                token, yytext); break;
            case PLUS: printf("<OPERATOR, %d, %s>\n",
                token, yytext); break;
            case MULT: printf("<OPERATOR, %d, %s>\n",
                token, yytext); break;
            case ASSIGN: printf("<OPERATOR, %d, %s>\n",
                token, yytext); break;
            case LBRACE: printf("<SPECIAL SYMBOL, %d, %s>\n",
                token, yytext); break;
            case RBRACE: printf("<SPECIAL SYMBOL, %d, %s>\n",
                token, yytext); break;
            case SEMICOLON: printf("<PUNCTUATION, %d, %s>\n",
                token, yytext); break;
            case CONST: printf("<INTEGER CONSTANT, %d, %s>\n",
                token, yytext); break;
        }
    }
}
```

– Input is taken from `stdin`. It can be changed by opening the file in `main()` and setting the file pointer to `yyin`.
– When the lexer will be integrated with the YACC generated parser, the `yyparse()` therein will call `yylex()` and the `main()` will call `yyparse()`.

Flex I/O (interactive) for our sample

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I/P Character Stream

```
{
     int x;
     int y;
     x = 2;
     y = 3;
     x = 5 + y * 4;
}
```

```
#define     INT          10
#define     ID           11
#define     PLUS         12
#define     MULT         13
#define     ASSIGN       14
#define     LBRACE       15
#define     RBRACE       16
#define     CONST        17
#define     SEMICOLON    18
```

O/P Token Stream

```
<SPECIAL SYMBOL, 15, {>
<KEYWORD, 10, int>
<IDENTIFIER, 11, x>
<PUNCTUATION, 18, ;>
<KEYWORD, 10, int>
<IDENTIFIER, 11, y>
<PUNCTUATION, 18, ;>
<IDENTIFIER, 11, x>
<OPERATOR, 14, =>
<INTEGER CONSTANT, 17, 2>
<PUNCTUATION, 18, ;>
<IDENTIFIER, 11, y>
<OPERATOR, 14, =>
<INTEGER CONSTANT, 17, 3>
<PUNCTUATION, 18, ;>
<IDENTIFIER, 11, x>
<OPERATOR, 14, =>
<INTEGER CONSTANT, 17, 5>
<OPERATOR, 12, +>
<IDENTIFIER, 11, y>
<OPERATOR, 13, *>
<INTEGER CONSTANT, 17, 4>
<PUNCTUATION, 18, ;>
<SPECIAL SYMBOL, 16, }>
```

- Every token is a triplet showing the token class, token manifest constant and the specific token information.

Managing Symbol Table

```
%{
    struct symbol {
        char *name;
        struct ref *reflist;
    };
    struct ref {
        struct ref *next;
        char *filename;
        int flags;
        int lineno;
   };

   #define NHASH 100
   struct symbol symtab[NHASH];
   struct symbol *lookup(char *);
   void addref(int, char*, char*, int);
%}
```

First Flex Program

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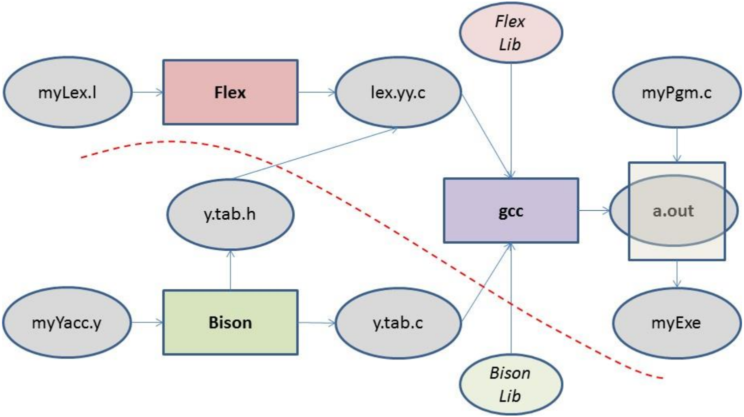
```
$ flex myLex.l
$ cc lex.yy.c -lfl
$ ./a.out
...
$
```

Flex-Bison Flow



Start Condition in Flex

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Start Conditions

Summary

Flex provides a mechanism for conditionally activating rules. Any rule whose pattern is prefixed with <sc> will only be active when the scanner is in the start condition named sc. For example,

```
<STRING>[^"]*        { /* eat up the string body ... */
                     ...
                     }
```

will be active only when the scanner is in the STRING start condition, and

```
<INITIAL,STRING,QUOTE>\.  { /* handle an escape ... */
                          ...
                          }
```

will be active only when the current start condition is either INITIAL, STRING, or QUOTE.

Source: http://flex.sourceforge.net/manual/Start-Conditions.html

Start Condition in Flex - Specs

- *Declaration*: Declared in the definitions section of the input
- BEGIN *Action*: A start condition is activated using the BEGIN action. Until the next BEGIN action is executed, rules with the given start condition will be active and rules with other start conditions will be inactive.
- *Inclusive Start Conditions*: Use unindented lines beginning with '%s' followed by a list of names. If the start condition is inclusive, then rules with no start conditions at all will also be active.
- *Exclusive Start Conditions*: Use unindented lines beginning with '%x' followed by a list of names. If it is exclusive, then only rules qualified with the start condition will be active.

  A set of rules contingent on the same exclusive start condition describe a scanner which is independent of any of the other rules in the flex input. Because of this, exclusive start conditions make it easy to specify mini-scanners which scan portions of the input that are syntactically different from the rest (for example, comments).

Source: http://flex.sourceforge.net/manual/Start-Conditions.html

Start Condition in Flex - Example

The set of rules:

```
%s example
%%
<example>foo      do_something();
bar               something_else();
```

is equivalent to

```
%x example
%%
<example>foo              do_something();
<INITIAL,example>bar      something_else();
```

Without the <INITIAL,example> qualifier, the bar pattern in the second example wouldn't be active (that is, couldn't match) when in start condition example. If we just used <example> to qualify bar, though, then it would only be active in example and not in INITIAL, while in the first example it's active in both, because in the first example the example start condition is an inclusive (%s) start condition.

Source: http://flex.sourceforge.net/manual/Start-Conditions.html

Handling Comments

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```
%x comment
%%
int line_num = 1;

"/*"                     BEGIN(comment);

<comment>[^*\n]*         /* eat anything that’s not a ’*’ */
<comment>"*"+[^*/\n]*    /* eat up ’*’s not followed by ’/’s */
<comment>\n              ++line_num;
<comment>"*"+"/"         BEGIN(INITIAL);
```

Source: http://flex.sourceforge.net/manual/Start-Conditions.html

Start Condition in Flex - Specs

Module 02

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Objectives & Outline

Lexical Analysis Outline

Flex Specification

Sample
Regular Expressions
Common Errors
Line Count Example

Interactive Flex

Flex-Bison Flow

Start Conditions

Summary

- *Declaration*: Declared in the definitions section of the input
- BEGIN *Action*: A start condition is activated using the BEGIN action. Until the next BEGIN action is executed, rules with the given start condition will be active and rules with other start conditions will be inactive.
- *Inclusive Start Conditions*: Use unintended lines beginning with '%s' followed by a list of names. If the start condition is inclusive, then rules with no start conditions at all will also be active.
- *Exclusive Start Conditions*: Use unintended lines beginning with '%x' followed by a list of names. If it is exclusive, then only rules qualified with the start condition will be active.

  A set of rules contingent on the same exclusive start condition describe a scanner which is independent of any of the other rules in the flex input. Because of this, exclusive start conditions make it easy to specify mini-scanners which scan portions of the input that are syntactically different from the rest (for example, comments).

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Module Summary

- Lexical Analysis process is introduced
- Flex specification for Lexical Analyzer generation is discussed in depth
- Flow of Flex and Bison explained
- Special Flex feature of Start Condition discussed