POLITECNICO DI TORINO

Formal Languages and Compilers

Laboratory N°1

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Languages?

- Lexicon (Lesson 1)
  - Ask me no questions, I'll tell you no lies!
    - Words should pertain to a known and defined dictionary
  - Sak em on stinqueo, I'll lelt uoy no leis!
  - Scanner **JFlex**: lexical analyzer
- Syntax (Lessons 2,3)
  - Ask me no questions, I'll tell you no lies!
    - Words pattern is important!
  - Me no questions ask, no 'll tell I you lies
  - Parser **Cup**: syntax and semantic analyzer
- Semantic (Lessons 4,5)
  - Switch on the light
  - Int vect[12], myValue=3;
    - Understanding the meaning of expressions

JFlex – a lexical analyzers generator

- Transforming regular expressions in deterministic finite state automata and implementing them is a long, mechanical (and tedious) process; hence, a lexical analyzer (or scanner) automatic generator is often used.
- JFlex is a generator which takes as input a set of regular expressions and associated actions, and produces as output a Java program that matches a given input against them.

Regular expressions in JFlex

- Regular expressions describe sequences of ASCII characters using a set of operators:
  - " \ [ ] ^ - ? . * + | ( ) $ / { } % < >
- Letters and numbers in the input string are described by the characters themselves:
  - the regular expression val1 matches the input sequence 'v' 'a' 'l' '1'
- Non alphabetical characters must be written in quotation marks, to avoid ambiguities with operators:
  - the regular expression xyz"++" matches the input sequence 'x' 'y' 'z' '+' '+'

Regular expressions in JFlex

...continues...

- Non alphabetical characters can be also preceded by the \ character
  - the regular expression xyz\+\+ matches the input sequence 'x' 'y' 'z' '+' '+'.
  - For operators: \" \\ \[\] \^ \- \? \. * \+ \| \(\) \$ \/ \{ \} \% \< \>
- Character classes are identified by square brackets [ ]:
  - the regular expression [0123456789] matches a digit in the input text.
- In character classes, the – character is used to describe a range of characters:
  - the expression [0-9] matches a digit between 0 and 9
  - the expression [a-z] matches any lower case letter
  - the expression [a-zA-Z0-9] matches both lower case and upper case letters, as well as numbers

Regular expressions in JFlex

...continues...

- To include the character – in a character class, it must be either the first or the last character within the brackets:
  - the expression [-+0-9] matches a digit or a +/- sign in the input string.
- The character ^ at the beginning of a character class identifies a "negated character class", i.e. a list of characters to be excluded
  - the expression [^0-9] matches any character except digits.
- The symbol . (dot) identifies any character except newline.

Regular expressions in JFlex

...continues...

- The newline character is described by the following regular expression
  - `\n|\r|\r\n` (\r line feed - \n carrige return)
  - JFlex is written in Java, as a consequence generated scanners must be portable on Windows, Linux and Mac OS operating systems
  - Note:
    - \n | \r | \r\n -> matches one newline
    - [\n\r]+ -> matches one or more newlines: \n\n\n\r\r
- The symbol \t identifies the tabulation character.
- The operator ? Indicates that the preceding expression is optional
  - the expression ab?c matches both ac and abc.

Regular expressions in JFlex

...continues...

- The operator * indicates that the preceding expression can be repeated 0 or more times:
  - the expression ab*c matches all the sequences starting with a, terminating with c and with any number of b's in between.
- The operator + indicates that the preceding expression can be repeated 1 or more times:
  - the expression ab+c matches all the sequences starting with a, terminating with c and with at least 1 b in between.
  - abc, abbc, abbbc : OK
  - ac : NO!!!

Regular expressions in JFlex

...continues...

- The operator {n} represents n repetitions of the precedent regular expression:
  - ab{3}c matches the sequence abbbc
- The operator {n,m} represents a repetition of the precedent regular expression between a minimum of n and a maximum of m times:
  - ab{2,4}c matches the sequences abbc, abbbc and abbbbc
- The operator | represents two alternative expressions:
  - ab|cd matches both the sequences ab and cd.
- Parentheses are used to express or modify operators priority:
  - (ab|cd+)?ef matches sequences such as ef, abef, cdddef.

Regular expressions in JFlex

...continues...

- Unsigned integer
  - [0-9]+
- Unsigned integer without leading zeros
  - [1-9][0-9]*
- Signed integer
  - ("+"|"-")? [0-9]+
- Floating point number
  - ("+"|"-")? ([1-9][0-9]* "." [0-9]*) | ("." [0-9]+) | (0 "." [0-9]*)

Single quotation marks allow to distinguish an input character ("+") from an operator (+).

Structure of a JFlex source file

- A JFlex source file has three distinct sections separated by '%%'.
  - The first section (code section) contains the user code and can be empty.
  - The second section (declarations section) contains option and declarations.
  - The third section (rules section) contains the lexical rules in the form of regular_expression action pairs.

Code section
%%
Declarations section
%%
Rules section

Code Section

- All the code lines present in this section are copied without any modification in the generated scanner.
- Usually, import statement for Java libraries that will be used in the next sections are inserted here.
- Examples:

  `import java.io.*;` (*if one wishes to use the Java I/O library*)

  `import java_cup.runtime.*;` (*for compatibility with the Cup parser generator*)

Declarations section

- To simplify the use of complex or repetitive regular expressions, it is possible to define identifiers for sub-expressions.
- Example: definition of a signed integer:

```
integer    =   [+-]?[1-9][0-9]*
```

- The sub-expression can then be used in the rules section or directly in the declaration section, writing its name between braces:

```
{integer} {
    System.out.print("integer found\n");
}
```

- Java code can be included in the declarations section by writing it between '%{' and '%}'.
  - See also %init{ ... %init} and %eof{ …%eof}

Rules section

- In JFlex, each regular expression is associated to an action, which is executed when the input matches the regular expression.
- Actions are constituted by snippets of Java code, written between braces.
- The simplest action consists in ignoring the matched string and is expressed by an empty action {;}

ACTION:

```
\n | \r | \r\n {
    System.out.println("newline found");
}
```

Scanner methods and fields accessible in actions

- Returns the matched string (that is saved in a internal buffer) :
  - string **yytext**()
- The number of matched character is returned by the method:
  - int **yylength**()
- Returns the character at position pos.
  - char **yycharat**(int pos)
- Contains the current line and column of input file, respectively. Those variables have a meaningful value only if %line and %column directives are declared.
  - int **yyline**
  - int **yycolumn**
- contains the current character count in the input (starting with 0, only active with the %char directive)
  - int **yychar**

Example

```
%%
euro   =   [1-9][0-9]*"."[0-9][0-9] | 0?"."[0-9][0-9]
lire   =   [1-9][0-9]*
%%
{euro} { System.out.println( "Euro: "+ yytext() ); }
{lire}   { System.out.println( "Lire: " + yytext() ); }
```

INPUT	OUTPUT
0.02	Euro: 0.02
.10	Euro: .10
2000.30	Euro: 2000.30
1.50	Euro: 1.50
15000	Lire: 15000

Compiling JFlex source

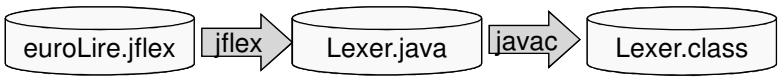
FILE: euroLire.jflex :

```
%%
%class Lexer
%standalone

euro    =   [1-9][0-9]*"."[0-9][0-9] | 0?"."[0-9][0-9]
lire  =   [1-9][0-9]*
%%
{euro}          { System.out.println( "Euro: "+ yytext() ); }
{lire}          { System.out.println( "Lire: " + yytext() ); }
```

- %standalone: generates the main method
  - The main method accepts as input the list of file to be scanned.
  - NB: with %standalone option, the default Jflex behaviour is to print unmatched characters to stdout. Use . (dot) regular expression to manage them.
- %class Lexer: the generated class is named Lexer.java

Compiling JFlex source



- Compiling steps:
  jflex *euroLire.jflex*
  javac *Lexer.java*
  java *Lexer* <nome_file_1> … <nome_file_n>

Ambiguous Source Rules

- JFlex can handle ambiguous specifications.
- There are two main sources of ambiguity:
  - the initial part of character sequences matched by one regular expression is also matched by another regular expression.
  - the same character sequence is matched by two distinct regular expressions.
- The first case is handled by always selecting the regular expression that gives the longest match.
- Among rules which matched the same number of characters, the rule specified first in the source file is preferred.

Example

- Given the source file

```
%%
%%
for             { System.out.println( "FOR_CMD" ); }
format          { System.out.println( "FORMAT_CMD" ); }
[a-z]+          { System.out.println( "GENERIC_ID" ); }
```

- Given the input string "format", the scanner will print FORMAT_CMD,
  - Preferring the second rule to the first, because it gives a longer match
  - Preferring the second rule to the third, because it comes before in the source file

Ambiguous Source Rules

- Given the rules for handling ambiguous specifications, when analyzing a programming language it is necessary to define first the rules for keywords, and then for identifiers.
- The longest match rule can result in unwanted behaviour:

```
\".*\" { System.out.println( "QUOTED_STRING" );}
```

  tries to match the second single quotation mark as far as possible (since longest matches are preferred); hence, given the following input string

```
"first" quoted string here, "second" here
```

  it will match 36 characters instead of 7.

- A better regular expression is the following:

```
\"[^"]+\"        { System.out.println( "QUOTED_STRING" ); }
\" ~ \"          { System.out.println( "QUOTED_STRING" ); }
```

Context

- It could be useful to limit the validity of a regular expression to a determined context.
- There are different mechanisms to specify sensitivity to the left context (i.e., the string that precedes the sequence being matched) and to the right context (i.e., the string that follows the sequence being matched).
- Special techniques are used to handle the beginning and the end of a line.

Beginning and end of line

- The character '^' at the beginning of a regular expression indicates that the sequence must be found at the beginning of the line.
  - This means that either the character sequence is at the beginning of the input stream, or that the last character previously read was a **newline**.
- The character '$' at the end of a regular expression indicates that the sequence must be followed by a newline character.
- By default, the newline is not matched by the regular expression, and thus must be matched by another rule
  - end$ The characters 'e' 'n' 'd' at the end of the line
  - \r | \n | \r\n Matches the newline

Sensitivity to the right context

- The binary operator '/' separates a regular expression from its right context.
- Therefore, the expression

```
ab/cd
```

  matches the string "ab", but if and only if is followed by the string "cd".
- The characters forming the right context are read from the input file, but are not part of the matched string. A suitable buffer is defined by JFlex to hold such characters.
- **NB:** The expression ab$ is equivalent to ab / (\n | \r | \r\n).

Start conditions (inclusive states)

- Rule starting with

  <state>

  are active only when the scanner is in the state *state*.

- Possible states must be declared in the declarations section using the `%state` keyword.

- The default state is `YYINITIAL`.

- The scanner enters a state when the following action is executed:

  yybegin(state);

Start conditions (inclusive states)

...continues...

- When a state is activated, the state rules are added (inclusive or) to the other scanner base rules.

- A state is active until another state is activated. To return to the initial condition, one must activate the initial state by means of the statement

  yybegin(YYINITIAL);

- A rule can be preceded by one or more state names, separated by a comma, to indicate that it is active in each of the states.

Example

- The following program handles pseudo-comments of the form // $*var+*

```
%%
%state comment
%%
<comment>\$[a-zA-Z]+[-+]   {process(yytext());}
"//"                       {yybegin(comment);}
\n|\r|\r\n                 {yybegin(YYINITIAL);}
" "                        {;} /* ignore blanks*/
\t                         {;} /* and tabs */
...  /* other rules */
```

Combining more than one scanner (exclusive states)

- A set of rules can be grouped within an exclusive state as well.
- When the scanner enters an exclusive state:
  - default rules are disabled,
  - only the rules explicitly defined for the state are active.
- In this way, “mini-scanner” that deal with special sections of the input stream, such as comments or strings, can be defined.
- The %xstate keyword defines an exclusive state.

Eliminating comments

- This scanner recognizes and eliminates C comments, while counting the number of lines.

```
%%
%standalone
%xstate comment
%{
public int line_num = 1;
public int line_num_comment = 1;
%}
nl                  =   \n | \r | \r\n
%%
{nl}                              { ++line_num; }
"/*"                              { yybegin(comment); }
<comment>[^*\r\n]*                {;}
<comment>"*"+[^\/\r\n]*           {;}
<comment>{nl}                     { ++line_num_comment; }
<comment>"*"+"/"                  { yybegin(YYINITIAL); }
... other rules
```

End of file rule

- The special rule **<<EOF>>** introduces the action to be performed when the end of file is reached.

```
<<EOF>>
{System.out.println(line_num+" "+line_num_comment);
return YYEOF;}
```

- This rule can be useful, coupled with start conditions, to detect unbalanced parentheses (or braces, brackets, quotation marks, ….) :

```
\"          { yybegin(quote); }
...
<quote><<EOF>> { System.out.println("EOF in string"); }
```

OTHER SLIDES

File switching

- In many cases, a scanner must suspend the analysis of the current file, and open another file:
  - Example: #include directives of C language
- This is handled by JFlex by using a stack; a series of primitives are available for file switching:
  - If one wishes to start scanning another file, the current file is pushed in the stack
  - When the end of the current file is found, the previous file is popped from the stack to resume the analysis

File switching continues

- void yypushStream(java.io.Reader reader)
  - Push the current stream in the stack and start reading the new stream.
- void yypopStream(void)
  - Close the current stream and start reading from the stream on top of the stack
- boolean yymoreStreams()
  - Returns TRUE if the stream stack is not empty

Example:

```
"#include" {FILE} {
yypushStream(new FileReader(getFile(yytext())));
}
...
<<EOF>> {if(yymoreStreams())yypopStream();else return YYEOF;}
```

File inclusion

- Example of a parser that handles nested file inclusion.

```
import java.io.FileReader;

%%

%xstate INCL DELETENR
%standalone

%%
import          {yybegin(INCL);}
.+              {System.out.print(yytext());}

/* Eliminate spaces and tabulations */
<INCL>[ \t]*        {;}
```

```
<INCL>[^ \t\n\r]+ {  /* Push the file in the stack */
  yypushStream(new FileReader(yytext()));
        yybegin(YYINITIAL);
}

<DELETENR>[ \t\n\r]* {yybegin(YYINITIAL);}

<<EOF>>             { /* Pop the file from stack  */
if(yymoreStreams()){
                yypopStream();
                yybegin(DELETENR);
        }else return YYEOF;
}
```