CS 536

Introduction to Programming Languages and Compilers

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Recitations

Both sections:

Tuesdays, 2:25 — 3:15

113 Psychology

Java & Object-Oriented Programming

Java is a fairly new and very popular programming language designed to support secure, platform-independent programming.

It is a good alternative to C or C++, trading a bit of efficiency for easier programming, debugging and maintenance.

Java is routinely interpreted (at the byte-code level), making it significantly slower than compiled C or C++. However true Java compilers exist, and are becoming more wide-spread. (IBM's Jalapeno project is a good example). When compiled, Java's execution speed is close to that of C or C++.

Basic Notions

In Java data is either primitive or an object (an instance of some class).

All code is written inside classes, so Java programming consists of writing classes.

Primitive data types are quite close to those of C or C++:

`boolean`	(not a numeric type)
`char`	(Unicode, 16 bits)
`byte`	
`short`	
`int`	
`long`	(64 bits)
`float`	
`double`	

Objects

- All Java objects are instances of classes.
- All objects are heap-allocated, with automatic garbage collection.
- A reference to an object, in a variable, parameter or another object, is actually a pointer to some object allocated within the heap.
- No explicit pointer manipulation operations (like **`*`** or **`->`** or **`++`**) are needed or allowed.
- Example:

```
 class Point {int x,y;}
Point data = new Point();
```

- Declaring an object reference (like class **`Point`**) *does not* automatically allocate space for an object. The reference is initialized to **`null`** unless an explicit initializer is included.
- Fields are accessed just as they are in C: **`data.x`** references field **`x`** in object **`data`**.
- Object references are automatically checked for validity (null or non-null). Hence

```
 data.x = 0;
```

  forces a run-time exception if data contains **`null`** rather than a valid object reference.

- Java makes it *impossible* for an object reference to access an illegal address. A reference is either **`null`** or a pointer to a valid, type-correct object in the heap. (This makes Java programs far more secure and reliable than C or C++ programs).

Class Members

Classes contain members. Class members are either fields (data) or methods (functions).

Example:

```
class Point {
     int x,y;
     void clear() {x=0; y=0;}
 }
 Point d = new Point():
 d.clear();
```

A special method is a *constructor*.

A constructor has no result type. It is used only to define the initialization of an object after the object has been created.

Constructors may be *overloaded*.

```
class Point {
    int x,y;
    Point() {x=0; y=0;}
    Point(int xin, int yin) {
       x = xin; y = yin;
    }
}
```

Static Members

Class members may be *static*.

A static member is allocated only once—for all instances of the class.

Ordinary members (called *instance* members) apply only to a particular class instance (i.e., only one object created from the class definition).

```
class Point {
    int x,y;
    static int howMany = 0;
    Point() {x=0; y=0;
             howMany++;}
    static void reset() {
       howMany = 0;
    }
}
```

Static member functions (methods) may not access non-static data. (Why?)

Static members are accessed using a class name rather than the name of an object reference.

For example,

```
Point.reset();
```

Visibility of Class Members

Class members may be declared as *public*, *private* or *protected*.

Public members may be accessed from outside a class.

Private members of a class may be accessed only from with the class itself.

Protected members may be accessed only from with the class itself or from within one of its subclasses.

Members nor marked public, private or protected are shared at the package level—similar to C++'s friend mechanism.

Example:

```
 class Customer {
   int id;
   private int pinCode;
}
Customer me = new Customer();
me.id = 1234; //OK
me.pinCode = 7777;
 //Compile-time error
```

In a class, a special method, **`main`**, declared as

```
 static public void
    main(String[] args)
```

is automatically executed when a class is run.

`main` is very useful as a “test driver” for auxiliary and library classes.

Final Members

A field may be declared *final* making it effectively a constant.

```
class Point {
    int x,y;
    static final Point origin
         = new Point(0,0);
    Point(int xin, int yin) {
       x = xin; y = yin;
    }
}
```

Final fields may be used to create constants within a class:

```
class Card {
  final static int Clubs = 1;
  final static int Diamonds = 2;
  final static int Hearts = 3;
  final static int Spades = 4;
  int suit = Spades;
}
```

Inside a class suit names are available for use without qualification. E.g.,

```
int suit = Spades;
```

Outside a class, the field names must be qualified using the class name:

```
Card c = new Card();
c.suit = Card.Clubs;
```

Methods may also be marked as final. This forbids redeclaration in a subclass, allowing a more efficient implementation. Security may also be improved if a key method is known to be unchangeable.

Java Arrays

In Java, arrays are implemented as a special kind of class. Arrays of primitive types are implemented as an object that contains a block of values within it. Arrays of objects are implemented as an object that contains a block of object *references* within it. Allocating an array of objects *does not* allocate the objects themselves. Hence within an array of objects, some positions may reference actual objects while other may contain **`null`** (this can be advantageous) if objects are large.

Multi-dimensional arrays are arrays of arrays. Arrays within an array *need not* all have the same size.

Hence we may see

```
int[][] TwoDim = new int[3][];
TwoDim[0] = new int[1];
TwoDim[1] = new int[2];
TwoDim[2] = new int[3];
```

The size of an array is part of its value; not its type.

Thus

```
int [] A = new int[10];
int [] B = new int[5];
A = B;
```

is valid.

Pascal showed that making an array's size part of its type is undesirable. (Why?)

Still, forcing an array to have a fixed size can be necessary (e.g., an array indexed by months). (How do we simulate a fixed-size array?).

Subclassing in Java

When a new class is defined in terms of an existing class, the new class *extends* the existing class. The new class *inherits* all public and protected members of its *parent* (or *base*) class.

The new class may add new methods or fields. It may also redefine inherited methods or fields.

```
class Point {
    int x,y;
     Point(int xin, int yin) {
       x = xin; y = yin;
    }
    static float dist(
      Point P1, Point P2) {
     return (float) Math.sqrt(
      (P1.x-P2.x)*(P1.x-P2.x)+
      (P1.y-P2.y)*(P1.y-P2.y));
    }
}
```

```
class Point3 extends Point {
    int z;
     Point3(int xin, int yin,
            int zin) {
       super(xin,yin); z=zin;
    }
    static float dist(
      Point3 P1, Point3 P2) {
      float d=Point.dist(P1,P2);
     return (float) Math.sqrt(
      (P1.z-P2.z)*(P1.z-P2.z)+
        d*d);
    }
}
```

Note that although **Point3** redefines **dist**, the old definition of **dist** is still available by using the parent class as a qualifier (**Point.dist**).

The same is true for fields that are hidden when a field in a parent is redeclared.

Non-static methods are automatically *virtual*: a redefined method is automatically used in all inherited methods including those defined in parent classes that think they are using an earlier definition of the class.

Example:

```
class C {
  void DoIt()(PrintIt();}
  void PrintIt()
     {println("C rules!");}
}
class D extends C {
  void PrintIt()
      {println("D rules!");}
  void TestIt() {DoIt();}
}
D dvar = new D();
dvar.TestIt();
D rules! is printed.
```

Static methods in Java are *not* virtual (this can make them easier to implement efficiently).

Abstract Classes and Methods

Sometimes a Java class is not meant to be used by itself because it is intentionally incomplete.

Rather, the class is meant to be starting point for the creation (via subclassing) of more complete classes.

Such classes are *abstract*.

Example:

```
abstract class Shape {
  Point location;
}
class Circle extends Shape {
  float radius;
}
```

Methods can also be made abstract to indicate that their actual definition will appear in subclasses:

```
abstract class Shape {
  Point location;
  abstract float area();
}
class Circle extends Shape {
  float radius;
  float area(){
   return Math.pi*radius*radius;
  }
}
```

Subtyping and Inheritance

We can use a subtyping mechanism, as found in C++ or Java, for two different purposes:

- We may wish to inherit the actual implementations of classes and members to use as the basis of a more complete or extended class.
  To inherit an implementation, we say a given class "extends" an existing class:
  ```
  class Derived extends Base
    { ... };
  ```
  Class **`Derived`** contains all of the members of **`Base`** *plus* any others it cares to add.

- We may wish to inherit an *interface*—a set of method names and values that will be available for use.
  To inherit (or claim) an interface, we use a Java interface definition.
  An interface doesn't implement anything; rather, it gives a name to a set of operations or values that may be available within one or more classes.

Why are Interfaces Important?

Many classes, although very different, share a common subset of values or operations. We may be willing to use any such class as long as only interface values or operations are used.

For example, many objects can be ordered (or at least partially-ordered) using a "less than" operation.

If we always implement less than the same way, for example,

```
boolean lessThan(Object o1,
                 Object o2);
```

then we can create an interface that admits all classes that know about the **`lessThan`** function:

```
interface Compare {
 boolean lessThan(Object o1,
                  Object o2);
}
```

Now different classes can each implement the **`Compare`** interface, proclaiming to the world that they know how to compare objects of the class they define:

```
class IntCompare implements Compare {
 public boolean lessThan(Object i1,
                         Object i2){
 return ((Integer)i1).intValue() <
        ((Integer)i2).intValue();}
}
class StringCompare implements
  Compare {
 public boolean lessThan(Object i1,
                         Object i2){
 return
((String)i1).compareTo((String)i2)<0;
}}
```

The advantage of using interfaces is that we can now define a method or class that only depends on the given interface, and which will accept *any* type that implements that interface.

```
class PrintCompare {
  public  static void printAns(
   Object v1, Object v2, Compare c){
    System.out.println(
     v1.toString() + " < " +
     v2.toString() + " is " +
     new Boolean(c.lessThan(v1,v2))
       .toString());
} }
class Test {
  public static void
    main(String args[]){
     Integer i1 = new Integer(2);
     Integer i2 = new Integer(1);
     PrintCompare.printAns(
       i1,i2,new IntCompare());
     String s2 = "abcdef";
     String s1 = "xyzaa";
     PrintCompare.printAns(
      s1,s2,new StringCompare());}}
```

Since classes may have many methods and modes of use or operation, a given class may implement many different interfaces. For example, many classes support the **`Clonable`** interface, which states that objects of the class may be duplicated (cloned).

Exceptions in Java

Java provides a fairly elaborate exception handling mechanism based on the throw-catch model.

All exceptions are objects, required to be a subclass of **`Throwable`**.

Class **`Throwable`** has two subclasses, **`Exception`** and **`Error`**. Class **`Exception`** has a subclass **`RuntimeException`**.

Exceptions may be explicitly thrown (using a **`throw`** statement) or they may be implicitly thrown as the result of a run-time error.

For example, an **`ArithmeticException`** is thrown for certain run-time arithmetic errors, like division by zero.

Unlike other languages, Java divides exceptions into two general classes: *checked* and *unchecked*.

A checked exception *must* either be caught (using a try-catch block) or propagated (by marking a method as throwing the exception).

This means that checked exceptions cannot be ignored—you must be prepared to catch them or you must “advertise” to your callers that you may throw an exception back to them.

Unchecked exceptions need not be caught or marked as potentially thrown. This makes exception handling for such exceptions optional. Unchecked exceptions are typically those that might occur so

often (like **`NullPointerException`** or **`ArithmeticException`**) that forced checks could unnecessarily clutter a program without significant benefit.

How are checked and unchecked exceptions distinguished?

- Any exception that is a member (or subclass) of **`Error`** or **`RuntimeException`** is unchecked.
- All other exceptions must be checked.

Exceptions are propagated dynamically:

- When an exception is thrown (explicitly or implicitly) the innermost try-catch block that can “catch” the exception is selected, and the catch block that matches the exception is executed.

- A catch block “catches” a given exception if the class of the exception is the same as the class used in the catch. An exception that is a subclass of the catch’s exception class will also be caught.
  Thus an catch that handles class **`Throwable`** catches *all* exceptions.
- If no catch can handle the exception in the current method, a return to the method’s caller is forced, and the exception is rethrown from the point of call.
- This process is repeated until a catch that can handle the exception is found or until we force a return from the main method.

- If a return from the main method is forced, no handler exists. A run-time error message is printed (“Uncaught exception”) and execution is terminated.
- One of the limitations of Java’s exception mechanism (and similar mechanisms found in other languages) is that there is no “retry” mechanism. Once an exception is thrown, we never go back to the point where the exception occurred. This is why Scheme’s call/cc mechanism is considered so special and unique.

Example:

```
class badValue extends Exception{
  float value;
  badValue(float f) {value=f;} }

float sqrt(float val)
    throws badValue {
  if (val < 0.0)
     throw new badValue(val);
  else return
       (float) Math.sqrt(val); }

try {
  System.out.println(
    "Ans = " + sqrt(-123.0));
} catch (badValue b) {
  System.out.println(
    "Can't take sqrt of "+b)
}
```

Lex/Flex/JLex

Lex is a well-known Unix scanner generator. It builds a scanner, in C, from a set of regular expressions that define the tokens to be scanned.

Flex is a newer and faster version of Lex.

Jlex is a Java version of Lex. It generates a scanner coded in Java, though its regular expression definitions are very close to those used by Lex and Flex.

Lex, Flex and JLex are largely *non-procedural*. You don’t need to tell the tools *how* to scan. All you need to tell it *what* you want scanned (by giving it definitions of valid tokens).

This approach greatly simplifies building a scanner, since most of the details of scanning (I/O, buffering, character matching, etc.) are automatically handled.

JLex

JLex is coded in Java. To use it, you enter

`java JLex.Main f.jlex`

Your **`CLASSPATH`** should be set to search the directories where JLex's classes are stored.
(The **`CLASSPATH`** we gave you includes JLex's classes).

After JLex runs (assuming there are no errors in your token specifications), the Java source file **`f.jlex.java`** is created. (**`f`** stands for any file name you choose. Thus **`csx.jlex`** might hold token definitions for CSX, and **`csx.jlex.java`** would hold the generated scanner).

You compile **`f.jlex.java`** just like any Java program, using your favorite Java compiler.

After compilation, the class file **`Yylex.class`** is created.

It contains the methods:

- **`Token yylex()`** which is the actual scanner. The constructor for **`Yylex`** takes the file you want scanned, so
  `new Yylex(System.in)`
  will build a scanner that reads from **`System.in`**. **`Token`** is the token class you want returned by the scanner; you can tell JLex what class you want returned.
- **`String yytext()`** returns the character text matched by the last call to **`yylex`**.

A simple example of using JLex is in
`~cs536-1/pubic/jlex`
Just enter
`make test`

Input to JLex

There are three sections, delimited by **`%%`**. The general structure is:

```
User Code
%%
Jlex Directives
%%
Regular Expression rules
```

The User Code section is Java source code to be copied into the generated Java source file. It contains utility classes or return type classes you need. Thus if you want to return a class **`IntlitToken`** (for integer literals that are scanned), you include its definition in the User Code section.

JLex directives are various instructions you can give JLex to customize the scanner you generate.

These are detailed in the JLex manual. The most important are:

- **`%{`**
  `Code copied into the Yylex class (extra fields or methods you may want)`
  `%}`
- **`%eof{`**
  `Java code to be executed when the end of file is reached`
  `%eof}`
- **`%type classname`**
  `classname` is the return type you want for the scanner method, **`yylex()`**

Macro Definitions

In section two you may also define *macros*, that are used in section three. A macro allows you to give a name to a regular expression or character class. This allows you to reuse definitions and make regular expression rule more readable.

Macro definitions are of the form

`name = def`

Macros are defined one per line.

Here are some simple examples:

`Digit=[0-9]`

`AnyLet=[A-Za-z]`

In section 3, you use a macro by placing its name within **`{`** and **`}`**. Thus **`{Digit}`** expands to the character class defining the digits 0 to 9.

Regular Expression Rules

The third section of the JLex input file is a series of token definition rules of the form

`RegExpr    {Java code}`

When a token matching the given **`RegExpr`** is matched, the corresponding Java code (enclosed in "{" and "}") is executed. JLex figures out what **`RegExpr`** applies; you need only say what the token looks like (using **`RegExpr`**) and what you want done when the token is matched (this is usually to return some token object, perhaps with some processing of the token text).

Here are some examples:

```
"+"    {return new Token(sym.Plus);}
(" ")+ {/* skip white space */}
{Digit}+ {return new
  IntToken(sym.Intlit,
  newInteger(yytext().intValue()));}
```

Regular Expressions in JLex

To define a token in JLex, the user to associates a regular expression with commands coded in Java.

When input characters that match a regular expression are read, the corresponding Java code is executed. As a user of JLex you don’t need to tell it *how* to match tokens; you need only say *what* you want done when a particular token is matched.

Tokens like white space are deleted simply by having their associated command not return anything. Scanning continues until a command with a return in it is executed.

The simplest form of regular expression is a single string that matches exactly itself.

For example,

```
if    {return new Token(sym.If);}
```

If you wish, you can quote the string representing the reserved word (`"if"`), but since the string contains no delimiters or operators, quoting it is unnecessary.

For a regular expression operator, like +, quoting is necessary:

```
"+"    {return newToken(sym.Plus);}
```

Character Classes

Our specification of the reserved word if, as shown earlier, is incomplete. We don’t (yet) handle upper or mixed-case.

To extend our definition, we’ll use a very useful feature of Lex and JLex—*character classes*.

Characters often naturally fall into classes, with all characters in a class treated identically in a token definition. In our definition of identifiers all letters form a class since any of them can be used to form an identifier. Similarly, in a number, any of the ten digit characters can be used.

Character classes are delimited by **[** and **]**; individual characters are listed without any quotation or separators. However \, **^**, **]** and **-**, because of their special meaning in character classes, must be escaped. The character class **[xyz]** can match a single **x**, **y**, or **z**.

The character class **[\])]** can match a single **]** or **)**.

(The **]** is escaped so that it isn't misinterpreted as the end of character class.)

Ranges of characters are separated by a **-**; **[x-z]** is the same as **[xyz]**. **[0-9]** is the set of all digits and **[a-zA-Z]** is the set of all letters, upper- and lower-case. \ is the escape character, used to represent

unprintables and to escape special symbols.

Following C and Java conventions, **\n** is the newline (that is, end of line), **\t** is the tab character, \\ is the backslash symbol itself, and **\010** is the character corresponding to octal 10.

The **^** symbol complements a character class (it is JLex's representation of the **Not** operation).

[^xy] is the character class that matches any single character *except* **x** and **y**. The **^** symbol applies to all characters that follow it in a character class definition, so **[^0-9]** is the set of all characters that aren't digits. **[^]** can be used to match all characters.

Here are some examples of character classes:

Character Class	Set of Characters Denoted
[abc]	Three characters: a, b and c
[cba]	Three characters: a, b and c
[a-c]	Three characters: a, b and c
[aabbcc]	Three characters: a, b and c
[^abc]	All characters except a, b and c
[\^\-\]]	Three characters: ^, - and]
[^]	All characters
"[abc]"	Not a character class. This is one five character *string*: `[abc]`

Regular Operators in JLex

JLex provides the standard regular operators, plus some additions.

- Catenation is specified by the juxtaposition of two expressions; no explicit operator is used.
  Outside of character class brackets, individual letters and numbers match themselves; other characters should be quoted (to avoid misinterpretation as regular expression operators).

Regular Expr	Characters Matched
a b cd	Four characters: `abcd`
(a)(b)(cd)	Four characters: `abcd`
[ab][cd]	Four different strings: `ac` or `ad` or `bc` or `bd`
while	Five characters: `while`
"while"	Five characters: `while`
[w][h][i][l][e]	Five characters: `while`

Case *is* significant.

- The alternation operator is **|**.
  Parentheses can be used to control grouping of subexpressions.
  If we wish to match the reserved word **`while`** allowing any mixture of upper- and lowercase, we can use
  `(w|W)(h|H)(i|I)(l|L)(e|E)`
  or
  `[wW][hH][iI][lL][eE]`

Regular Expr	**Characters Matched**
`ab|cd`	Two different strings: `ab` or `cd`
`(ab)|(cd)`	Two different strings: `ab` or `cd`
`[ab]|[cd]`	Four different strings: a or b or c or d

- Postfix operators:
  `*` Kleene closure: 0 or more matches
  `(ab)*` matches λ or **`ab`** or **`abab`** or **`ababab`** ...

  `+` Positive closure: 1 or more matches
  `(ab)+` matches **`ab`** or **`abab`** or **`ababab`** ...

  `?` Optional inclusion:
  `expr?`
  matches **`expr`** zero times or once.
  `expr?` is equivalent to **`(expr) |`** λ and eliminates the need for an explicit λ symbol.
  `[-+]?[0-9]+` defines an optionally signed integer literal.

- Single match:
  The character **"`.`"** matches any single character (other than a newline).
- Start of line:
  The character **`^`** (when used outside a character class) matches the beginning of a line.
- End of line:
  The character **`$`** matches the end of a line. Thus,
  `^A.*e$`
  matches an entire line that begins with **`A`** and ends with **`e`**.

Overlapping Definitions

Regular expressions map overlap (match the same input sequence).

In the case of overlap, two rules determine which regular expression is matched:

- The *longest possible* match is performed. JLex automatically buffers characters while deciding how many characters can be matched.
- If two expressions match *exactly* the same string, the earlier expression (in the JLex specification) is preferred. Reserved words, for example, are often special cases of the pattern used for identifiers. Their definitions are therefore placed before the

expression that defines an identifier token.

Often a “catch all” pattern is placed at the very end of the regular expression rules. It is used to catch characters that don’t match any of the earlier patterns and hence are probably erroneous. Recall that "." matches any single character (other than a newline). It is useful in a catch-all pattern. However, avoid a pattern like .* which will consume all characters up to the next newline.

In JLex an unmatched character will cause a run-time error.

The operators and special symbols most commonly used in JLex are summarized below. Note that a symbol sometimes has one meaning in a regular expression and an *entirely different* meaning in a character class (i.e., within a pair of brackets). If you find JLex behaving unexpectedly, it’s a good idea to check this table to be sure of how the operators and symbols you’ve used behave. Ordinary letters and digits, and symbols not mentioned (like @) represent themselves. If you’re not sure if a character is special or not, you can always escape it or make it part of a quoted string.

Symbol	Meaning in Regular Expressions	Meaning in Character Classes
(	Matches with) to group sub-expressions.	Represents itself.
)	Matches with (to group sub-expressions.	Represents itself.
[	Begins a character class.	Represents itself.
]	Represents itself.	Ends a character class.
{	Matches with } to signal macro-expansion.	Represents itself.
}	Matches with { to signal macro-expansion.	Represents itself.
"	Matches with " to delimit strings (only \ is special within strings).	Represents itself.
\	Escapes individual characters. Also used to specify a character by its octal code.	Escapes individual characters. Also used to specify a character by its octal code.
.	Matches any one character except \n.	Represents itself.

Symbol	Meaning in Regular Expressions	Meaning in Character Classes
|	Alternation (or) operator.	Represents itself.
*	Kleene closure operator (zero or more matches).	Represents itself.
+	Positive closure operator (one or more matches).	Represents itself.
?	Optional choice operator (one or zero matches).	Represents itself.
/	Context sensitive matching operator.	Represents itself.
^	Matches only at beginning of a line.	Complements remaining characters in the class.
$	Matches only at end of a line.	Represents itself.
-	Represents itself.	Range of characters operator.

Potential Problems in Using JLex

The following differences from "standard" Lex notation appear in JLex:

- Escaped characters within quoted strings are not recognized. Hence **"\n"** is *not* a new line character. Escaped characters outside of quoted strings (**\n**) and escaped characters within character classes (**[\n]**) are OK.
- A blank should not be used within a character class (i.e., **[** and **]**). You may use **\040** (which is the character code for a blank).

- A doublequote must be escaped within a character class. Use **[\"]** instead of **["]**.
- Unprintables are defined to be all characters before blank as well as the last ASCII character. These can be represented as: **[\000-\037\177]**

JLex Examples

A JLex scanner that looks for five letter words that begin with "P" and end with "T".

This example is in **~cs536-1/public/jlex**

The JLex specification file is:

```
class Token {
   String text;
   Token(String t){text = t;}
}
%%
Digit=[0-9]
AnyLet=[A-Za-z]
Others=[0-9'&.]
WhiteSp=[\040\n]
// Tell JLex to have yylex() return a
Token
%type Token
// Tell JLex what to return when eof of
file is hit
%eofval{
return new Token(null);
%eofval}
%%
[Pp]{AnyLet}{AnyLet}{AnyLet}[Tt]{WhiteSp}+
     {return new Token(yytext());}

({AnyLet}|{Others})+{WhiteSp}+
     {/*skip*/}
```

The Java program that uses the scanner is:

```
import java.io.*;

class Main {

public static void main(String args[])
   throws java.io.IOException {

 Yylex lex  = new Yylex(System.in);
 Token token = lex.yylex();

 while ( token.text != null ) {
   System.out.print("\t"+token.text);
   token = lex.yylex(); //get next token
 }
}}
```

In case you care, the words that are matched include:

```
Pabst
paint
petit
pilot
pivot
plant
pleat
point
posit
Pratt
print
```

A JLex tester that looks for matches of regular expressions being tested.

This example is in
~cs536-1/public/jlex.tester

The JLex specification file is:

```
class Token {
   String text;
   Token(String t){text = t;}
}
%%
Digit=[0-9]
AnyLet=[A-Za-z]
Others=[0-9’&.]
WhiteSp=[\040\n]
// Tell JLex to have yylex() return a
Token
%type Token
// Tell JLex what to return when eof of
file is hit
%eofval{
return new Token(null);
%eofval}
%%
testRE     {return new Token(yytext());}
{WhiteSp}+ {/*skip*/}
(.)        {System.out.println(
             "Illegal:"+yytext());}
```

The Java program that uses this scanner tester is:

```
import java.io.*;

class Main {

public static void main(String args[])
   throws java.io.IOException {

 Yylex lex  = new Yylex(System.in);
 Token token = lex.yylex();

 while ( token.text != null ) {
   System.out.print("Matched:"+
        token.text);
   token = lex.yylex(); //get next token
 }
}}
```

An example of CSX token specifications. This example is in **~cs536-1/public/proj2/startup**

The JLex specification file is:

```
import java_cup.runtime.*;

/*  Expand this into your solution for
project 2 */

class CSXToken {
 int linenum;
 int colnum;
 CSXToken(int line,int col){
 linenum=line;colnum=col;};
}

class CSXIntLitToken extends CSXToken {
 int intValue;
 CSXIntLitToken(int val,int line,
   int col){
   super(line,col);intValue=val;};
}

class CSXIdentifierToken extends
CSXToken {
String identifierText;
CSXIdentifierToken(String text,int line,
  int col){
  super(line,col);identifierText=text;};
}
```

```
class CSXCharLitToken extends CSXToken {
  char charValue;
CSXCharLitToken(char val,int line,
    int col){
   super(line,col);charValue=val;};
}

class CSXStringLitToken extends CSXToken
{
   String stringText;
   CSXStringLitToken(String text,
     int line,int col){
   super(line,col);
   stringText=text; };
}

// This class is used to track line and
column numbers
// Feel free to change to extend it
class Pos {
static int  linenum = 1;
/* maintain this as line number current
   token was scanned on */
static int  colnum = 1;
  /* maintain this as column number
    current token began at */
static int  line = 1;
/* maintain this as line number after
   scanning current token  */
static int  col = 1;
  /* maintain this as column number
    after scanning current token  */
static void setpos() {
 //set starting pos for current token
   linenum = line;
   colnum = col;}
}

%%
Digit=[0-9]

// Tell JLex to have yylex() return a
 Symbol, as JavaCUP will require
%type Symbol

// Tell JLex what to return when eof of
file is hit
%eofval{
return new Symbol(sym.EOF,
         new  CSXToken(0,0));
%eofval}

%%
"+"   {Pos.setpos(); Pos.col +=1;
        return new Symbol(sym.PLUS,
          new CSXToken(Pos.linenum,
                      Pos.colnum));}
```

```
"!="    {Pos.setpos(); Pos.col +=2;
         return new Symbol(sym.NOTEQ,
           new CSXToken(Pos.linenum,
                        Pos.colnum));}
";"     {Pos.setpos(); Pos.col +=1;
           return new Symbol(sym.SEMI,
             new CSXToken(Pos.linenum,
                          Pos.colnum));}
{Digit}+   {// This def doesn't check
            // for overflow
           Pos.setpos();
           Pos.col += yytext().length();
           return new Symbol(sym.INTLIT,
            new CSXIntLitToken(
       new Integer(yytext()).intValue(),
       Pos.linenum,Pos.colnum));}

\n     {Pos.line +=1; Pos.col = 1;}
" "    {Pos.col +=1;}
```

The Java program that uses this scanner (P2) is:

```
class P2 {
 public static void main(String args[])
    throws java.io.IOException {
  if (args.length != 1) {
    System.out.println(
    "Error: Input file must be named on
command line." );
    System.exit(-1);
  }
  java.io.FileInputStream yyin = null;
  try {
   yyin =
   new java.io.FileInputStream(args[0]);
  } catch (FileNotFoundException
           notFound){
    System.out.println(
   "Error: unable to open input file.");
    System.exit(-1);
  }

 // lex is a JLex-generated scanner that
 // will read from yyin
    Yylex lex = new Yylex(yyin);
```

```
   System.out.println(
      "Begin test of CSX scanner.");

/**********************************
 You should enter code here that
 thoroughly test your scanner.

 Be sure to test extreme cases,
 like very long symbols or lines,
 illegal tokens, unrepresentable
 integers, illegals strings, etc.
 The following is only a starting point.
***********************************/
Symbol token = lex.yylex();

while ( token.sym != sym.EOF ) {
 System.out.print(
   ((CSXToken) token.value).linenum
   + ":"
   + ((CSXToken) token.value).colnum
   + " ");

  switch (token.sym) {
   case sym.INTLIT:
    System.out.println(
     "\tinteger literal(" +
     ((CSXIntLitToken)
     token.value).intValue + ")");
    break;
   case sym.PLUS:
     System.out.println("\t+");
     break;

   case sym.NOTEQ:
     System.out.println("\t!=");
     break;

   default:
     throw new RuntimeException();
  }

  token = lex.yylex(); // get next token
 }

 System.out.println(
    "End test of CSX scanner.");
}}}
```

Java CUP

Java CUP is a parser-generation tool, similar to Yacc.

CUP builds a Java parser for LALR(1) grammars from production rules and associated Java code fragments.

When a particular production is recognized, its associated code fragment is executed (typically to build an AST).

CUP generates a Java source file parser.java. It contains a class parser, with a method
  Symbol parse()

The Symbol returned by the parser is associated with the grammar's start symbol and contains the AST for the whole source program.

The file sym.java is also built for use with a JLex-built scanner (so that both scanner and parser use the same token codes).

If an unrecovered sytntax error occurs, Exception() is thrown by the parser.

CUP and Yacc accept exactly the same class of grammars—all LL(1) grammars, plus many useful non-LL(1) grammars.

CUP is called as

  java java_cup.Main < file.cup

Java CUP Specifications

Java CUP specifications are of the form:

- Package and import specifications
- User code additions
- Terminal and non-terminal declarations
- A context-free grammar, augmented with Java code fragments

Package and Import Specifications

You define a package name as:
 package name ;

You add imports to be used as:

import java_cup.runtime.*;

User Code Additions

You may define Java code to be included within the generated parser:

`action code {: /*java code */ :}`
This code is placed within the generated action class (which holds user-specified production actions).

`parser code {: /*java code */ :}`
This code is placed within the generated parser class .

`init with{: /*java code */ :}`
This code is used to initialize the generated parser.

`scan with{: /*java code */ :}`
This code is used to tell the generated parser how to get tokens from the scanner.

Terminal and Non-terminal Declarations

You define terminal symbols you will use as:

terminal classname name$_1$, name$_2$, ...

`classname` is a class used by the scanner for tokens (**`CSXToken`**, **`CSXIdentifierToken`**, etc.)

You define non-terminal symbols you will use as:

non terminal classname name$_1$, name$_2$, ...

`classname` is the class for the AST node associated with the non-terminal (**`stmtNode`**, **`exprNode`**, etc.)

Production Rules

Production rules are of the form

name ::= name$_1$ name$_2$ ... action ;

or

name ::= name$_1$ name$_2$ ... action$_1$
| name$_3$ name$_4$ ... action$_2$
| ...
;

Names are the names of terminals or non-terminals, as declared earlier.

Actions are Java code fragments, of the form

`{: /*java code */ :}`

The Java object assocated with a symbol (a token or AST node) may be named by adding a **`:id`** suffix to a terminal or non-terminal in a rule.

RESULT names the left-hand side non-terminal.

The Java classes of the symbols are defined in the terminal and non-terminal declaration sections.

For example,

```
prog ::= LBRACE:l stmts:s RBRACE
   {: RESULT=
       new csxLiteNode(s,
         l.linenum,l.colnum); :}
```

This corresponds to the production

prog → { stmts }

The left brace is given the name **`l`**; the stmts non-terminal is called **`s`**.

In the action code, a new **`CSXLiteNode`** is created and assigned to **`prog`**. It is constructed from the AST node associated with **`s`**. Its line and column numbers are those given to the left barce, **`l`** (by the scanner).

To tell CUP what non-terminal to use as the start symbol (**`prog`** in our example), we use the directive:

```
start with prog;
```

Example

Let's look at the CUP specification for CSX-lite. Recall its CFG is

program $\rightarrow$ { stmts }

stmts $\rightarrow$ stmt stmts

| λ

stmt $\rightarrow$ id = expr ;

| if (expr) stmt

expr $\rightarrow$ expr + id

| expr - id

| id

The corresponding CUP specification is:

```
/***
This Is A Java CUP Specification For
CSX-lite, a Small Subset
of The CSX Language,  Used In Cs536
 ***/

/* Preliminaries to set up and use
the scanner.  */

import java_cup.runtime.*;
parser code {:
 public void syntax_error
  (Symbol cur_token){
   report_error(
    "CSX syntax error at line "+
    String.valueOf(((CSXToken)
       cur_token.value).linenum),
    null);}
:};

init with {:              :};
scan with {:
   return Scanner.next_token();
:};
```

```
/* Terminals (tokens returned by the
scanner). */
terminal CSXIdentifierToken
IDENTIFIER;
terminal CSXToken     SEMI, LPAREN,
RPAREN, ASG, LBRACE, RBRACE;
terminal CSXToken     PLUS, MINUS,
rw_IF;

/* Non terminals */
non terminal csxLiteNode prog;
non terminal stmtsNode   stmts;
non terminal stmtNode    stmt;
non terminal exprNode    exp;
non terminal nameNode    ident;



start with prog;

prog::= LBRACE:l stmts:s RBRACE
 {: RESULT=
     new csxLiteNode(s,
          l.linenum,l.colnum); :}
;
```

```
stmts::= stmt:s1  stmts:s2
 {: RESULT=
     new stmtsNode(s1,s2,
       s1.linenum,s1.colnum);
 :}
|
 {: RESULT= stmtsNode.NULL; :}
;
stmt::= ident:id ASG exp:e SEMI
 {: RESULT=
       new asgNode(id,e,
           id.linenum,id.colnum);
 :}

| rw_IF:i LPAREN exp:e RPAREN  stmt:s
 {: RESULT=new ifThenNode(e,s,
            stmtNode.NULL,
            i.linenum,i.colnum); :}
;
exp::=
 exp:leftval PLUS:op ident:rightval
 {: RESULT=new binaryOpNode(leftval,
      sym.PLUS, rightval,
      op.linenum,op.colnum); :}
```

```
| exp:leftval MINUS:op ident:rightval
 {: RESULT=new binaryOpNode(leftval,
           sym.MINUS,rightval,
           op.linenum,op.colnum); :}
| ident:i
 {: RESULT = i; :}
;
ident::= IDENTIFIER:i
 {: RESULT = new nameNode(
   new identNode(i.identifierText,
                i.linenum,i.colnum),
   exprNode.NULL,
   i.linenum,i.colnum); :}
;
```

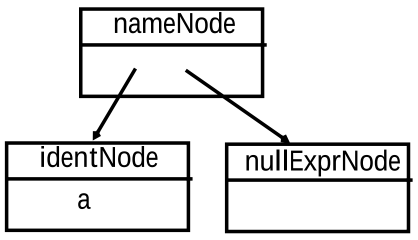
Let’s parse

{ a = b ; }

First, a is parsed using

```
ident::= IDENTIFIER:i
 {: RESULT = new nameNode(
   new identNode(i.identifierText,
                i.linenum,i.colnum),
   exprNode.NULL,
   i.linenum,i.colnum); :}
```

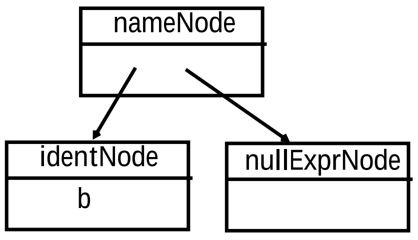
We build



Next, a is parsed using

```
ident::= IDENTIFIER:i
 {: RESULT = new nameNode(
   new identNode(i.identifierText,
                i.linenum,i.colnum),
   exprNode.NULL,
   i.linenum,i.colnum); :}
```

We build



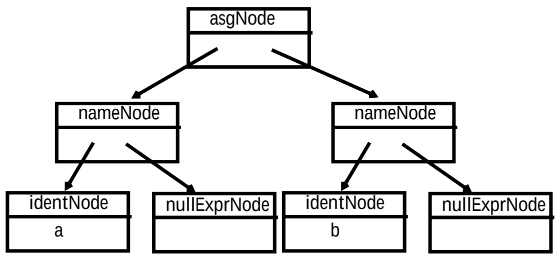
Then b's subtree is recognized as an exp:

```
| ident:i
 {: RESULT = i; :}
```

Now the assignment statement is recognized:

```
stmt::= ident:id ASG exp:e SEMI
 {: RESULT=
       new asgNode(id,e,
           id.linenum,id.colnum);
 :}
```

We build

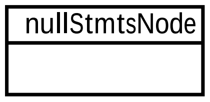


The stmts → λ production is matched (indicating that there are no more statements in the program).

CUP matches

```
stmts::=
 {: RESULT= stmtsNode.NULL; :}
```

and we build



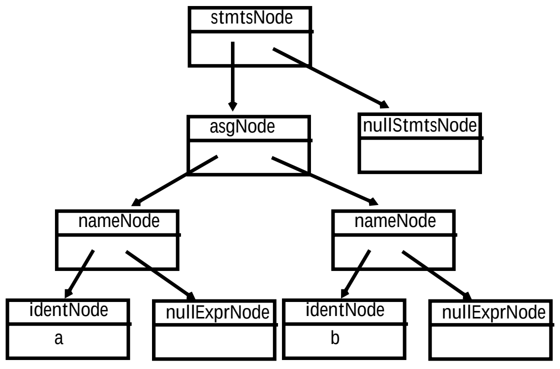
Next,

stmts → stmt stmts

is matched using

```
stmts::= stmt:s1  stmts:s2
 {: RESULT=
     new stmtsNode(s1,s2,
       s1.linenum,s1.colnum);
 :}
```

This builds



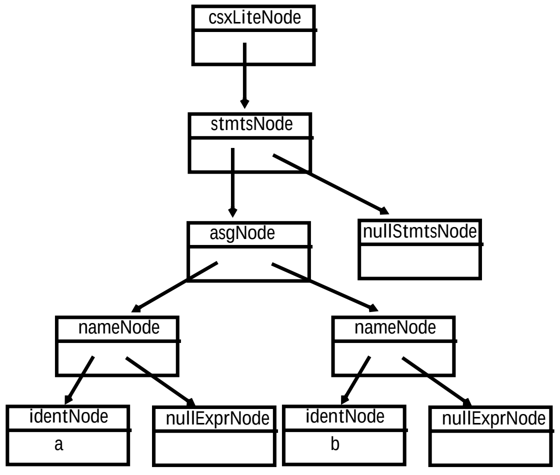
As the last step of the parse, the parser matches

program → { stmts }

using the CUP rule

```
prog::= LBRACE:l stmts:s RBRACE
 {: RESULT=
     new csxLiteNode(s,
          l.linenum,l.colnum); :}
;
```

The final AST reurned by the parser is



Sample Type-Checking Routines for CSX-Lite

```
// abstract superclass; only
subclasses are actually created
abstract class ASTNode {
// Total number of type errors found
static int typeErrors =  0;

static void typeMustBe(int testType,
 int requiredType,String errorMsg) {
 if ((testType != Types.Error) &&
(testType != requiredType)) {
  System.out.println(errorMsg);
  typeErrors++;
  }
}
```

```
static void typesMustBeEqual(
int type1,int type2,String errorMsg)
{
 if ((type1 != Types.Error) &&
     (type2 != Types.Error) &&
     (type1 != type2)) {

System.out.println(errorMsg);
typeErrors++;
}}

String error() {
 return “Error (line “ + linenum +
   “): “;}

public static SymbolTable st =
  new SymbolTable();

void checkTypes(){};
// This will normally need to be
// redefined in a subclass
```

```
// This node is used to root only
// CSX lite programs
class csxLiteNode extends ASTNode {

  void checkTypes(){
    fields.checkTypes();
    progStmts.checkTypes();
  }
  boolean isTypeCorrect() {
        checkTypes();
        return (typeErrors == 0);
  };

  private stmtsNode progStmts;
  private fieldDeclsNode fields;
};
```

```
// Root of all ASTs for CSX
class classNode extends ASTNode {
  // You need to refine this one
  boolean isTypeCorrect() {
    return true;};

  private identNodeclassName;
  private memberDeclsNodemembers;
};



class fieldDeclsNode extends ASTNode
{
  void checkTypes() {
        thisField.checkTypes();
        moreFields.checkTypes();
  };

  private declNodethisField;
  private fieldDeclsNode moreFields;
};
```

```
class nullFieldDeclsNode extends
fieldDeclsNode {
   void checkTypes(){};
};


class varDeclNode extends declNode {
   void checkTypes() {
     SymbolInfo     id;
     id = (SymbolInfo)
     st.localLookup(varName.idname);
     if (id != null) {
       System.out.println(error() +
        id.name()+
        " is already declared.");
        typeErrors++;
        varName.type =
           new Types(Types.Error);
     } else {
      id =
      new SymbolInfo(varName.idname,
         new Kinds(Kinds.Var),
         varType.type);
      varName.type = varType.type;
      try {
        st.insert(id);
```

```
      } catch (DuplicateException d)
           { /* can't happen */ }
        catch (EmptySTException e)
           { /* can't happen */ }
      varName.idinfo=id;
   }
  };
    privateidentNodevarName;
    privatetypeNode varType;
    privateexprNode initValue;
  };


  abstract class typeNode extends
  ASTNode {
  // abstract superclass; only
  // subclasses are actually created
   Types   type;
   // Used for typechecking
   // -- the type of this typeNode
  };
```

```
class intTypeNode extends typeNode {
  intTypeNode(int line, int col){
     super(line,col, new
     Types(Types.Integer));
  }
  void checkTypes() {
   //      No type checking needed
  }
};


class stmtsNode extends ASTNode {
  void checkTypes() {
    thisStmt.checkTypes();
    moreStmts.checkTypes();
  };

  private stmtNodethisStmt;
  private stmtsNode moreStmts;
};
```

```
class nullStmtsNode extends
stmtsNode {
   void checkTypes(){};
};

class asgNode extends stmtNode {
void checkTypes() {
  target.checkTypes();
  source.checkTypes();
  //In CSX-lite all IDs are vars!
  assert(target.kind.val ==
          Kinds.Var);
  typesMustBeEqual(source.type.val,
                   target.type.val,
     error() +
     "Both the left and right" +
" hand sides of an assignment must "
    + "have the same type.");
  }

  private nameNodetarget;
  private exprNode source;
};
```

```
class ifThenNode extends stmtNode {
  void checkTypes() {
    condition.checkTypes();
    typeMustBe(condition.type.val,
               Types.Boolean,
      error() +
      “The control expression of an”
      + “ if must be a bool.”);
     thenPart.checkTypes();
     // No else parts in CSX Lite
  };
  private exprNode condition;
  private stmtNode thenPart;
  private stmtNode elsePart;
};
```

```
class printNode extends stmtNode {
  void checkTypes() {
  outputValue.checkTypes();
  typeMustBe(outputValue.type.val,
             Types.Integer,
     error() +
 “Only int values may be printed.”);
   };
  private exprNode outputValue;
  private printNode morePrints;
};

// abstract superclass;
// only subclasses are actually
//created
abstract class exprNode extends
ASTNode {
  protected Types   type;
  // Used for typechecking:
  //  the type of this node
  protected Kinds   kind;
  // Used for typechecking:
  // the kind of this node
};
```

```
class binaryOpNode extends exprNode
{
  void checkTypes() {
   //Only two bin ops in CSX-lite
   assert(operatorCode== sym.PLUS
    ||operatorCode==sym.MINUS);
   leftOperand.checkTypes();
   rightOperand.checkTypes();
   type = new Types(Types.Integer);

   typeMustBe(leftOperand.type.val,
              Types.Integer,
      error() +
      “Left operand of” +
      toString(operatorCode)
      +  “must be an int.”);

  typeMustBe(rightOperand.type.val,
             Types.Integer,
   error() +  “Right operand of” +
      toString(operatorCode)
   +  “must be an int.”);
  };
  private exprNode leftOperand;
  private exprNode rightOperand;
  private int operatorCode;
};
```

```
class identNode extends exprNode {
  void checkTypes() {
   SymbolInfo    id;
   //In CSX-lite all IDs are vars!
   assert(kind.val == Kinds.Var);

   id = (SymbolInfo)
          st.localLookup(idname);
   if (id == null) {
     System.out.println(error() +
      idname +“ is not declared.”);
     typeErrors++;
     type = new Types(Types.Error);
    } else {
      type = id.type;
      idinfo = id;
      // Save ptr to sym table entry
    }
  }

  publicString idname;
  public  SymbolInfo  idinfo;
  // sym table entry for this ident
  private boolean nullFlag;
};
```

```
class intLitNode extends exprNode {
  void checkTypes() {
  // All intLits are automatically
  // type-correct
  }
  private int intval;
};

class nameNode extends exprNode {
  void checkTypes() {
    varName.checkTypes();
    // Subscripts not in CSX Lite
    type=varName.type;
  };

  private identNode varName;
  private exprNode subscriptVal;
};
}
```