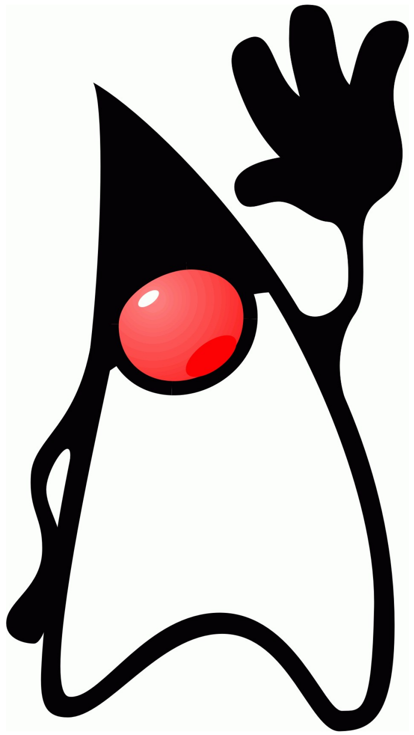
MSc Introduction to Java



Dr Timothy Kimber
Department of Computing
Imperial College London

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Based on notes by William Knottenbelt , Reuben Rowe, Alastair Donaldson and Maria Valera Espina

Course Overview

- Lectures:
  - Wednesday 13th January 1000-1200
    - The Java Framework (An Overview)
    - Language specification (A more detailed look at the language)
    - Input/Output
  - Thursday 14th January 1200-1300
    - Generics
  - Friday 15th January 1100-1300
    - Collections
    - Exceptions
    - GUIs, Threads and Basic Networking
- Labs:
  - Thursday 14th January 1600-1800
  - Friday 15th January 1500-1800

Reference Materials

- **The Java Tutorial** online at:
  `http://docs.oracle.com/javase/tutorial/`

- **Java API Documentation**
  `http://docs.oracle.com/javase/7/docs/`

- **Java – The Complete Reference (8th ed.)** (McGraw-Hill)
  by Herbert Schildt
- **Developing Java Software** (Wiley)
  by Russel Winder and Graham Roberts
- **Thinking in Java** (Prentice-Hall)
  by Bruce Eckel, also online:
  `http://www.mindview.net/Books/TIJ/`

The Java Framework

(An Overview)

What is Java?

- Programming based on objects; no global functions or variables
- Uses C++-style syntax, statements and expressions
- Developed by Sun (now Oracle)
  - Java is, first and foremost, a *specification*
    - so it is much more standardised than C++
  - Sun also developed a (reference) implementation
    - but so have others (OpenJDK, caffe, jikes)
- Java programs are compiled to bytecode, which is interpreted by a virtual machine

What is Java?

- Java is both language and platform
  - Language (specification)
    - Core syntax and features
    - Class declarations (API)
  - Platform (implementation)
    - Java Virtual Machine (JVM) interprets bytecodes
    - Libraries contain class implementations
    - Together = Java Runtime Environment (JRE)
- Development tools
  - **`javac`** compiler, **`jdb`** debugger, **`javadoc`**, etc.
  - Together with runtime = JDK/SDK (java development kit)

Java: The Pros

- Portability
  - Java Virtual Machine implementations widely available (write once, run everywhere)
  - Bytecode/JIT compilation provides efficiency
  - Swing classes interface to X (Unix), Windows, Mac, etc.
- Mobility
  - Bytecodes can be downloaded (or uploaded) for execution
  - Web browsers can execute Java code - *applets*.
- Security
  - Java bytecodes can be verified and sandboxed
  - SecurityManager class provides fine control over permissions

Java: The Cons(?)

- Sometimes not completely portable
  - (Write once, debug everywhere)

- Less efficient than native code
  - But JIT (Just In Time) compilation is very sophisticated now
  - If necessary, can compile to native code or make external calls to native code

Some Features of Java

- No explicit pointers; only references and garbage collection
- Single inheritance; multiple inheritance through Interfaces
- Error handling using exceptions
- Standard class library (API), with abstractions for:
    - Networking
    - Graphical User Interfaces
    - Concurrency support (threads and monitors)
- Reflection (programmatic access to class structure at runtime)
- Permits remote invocation method (RMI) and Java native Interface (JNI) calls
- Automatic HTML documenting (javadoc)
- International character set support (Unicode)

Hello World

```
class Hello {

  public static void main(String[] args) {
    System.out.println("Our first Java program");
  }
}
```

- Each class must live in a `.java` file with the same name
- e.g. the **`Hello`** class must live in `Hello.java`
- Java does not have separate header files
- Java does not have standalone functions (only methods)
  - We implement the main function using a static method

Hello World

```
class Hello {

  public static void main(String[] args) {
    System.out.println("Our first Java program");
  }
}
```

- We compile the program using `javac`:

```
% javac Hello.java
```

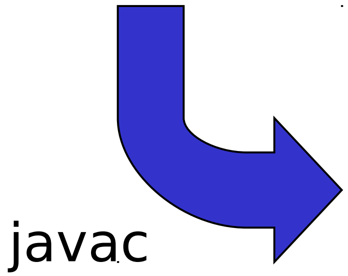
- This produces a *bytecode* file `Hello.class`
- This is run using `java` which executes the static main method of the specified class:

```
% java Hello
Hello World!
```

Compiling Java Programs

Hello.java

```
class Hello {
  public static void main(String[] args) {
    System.out.println( "Hello World" );
}
```

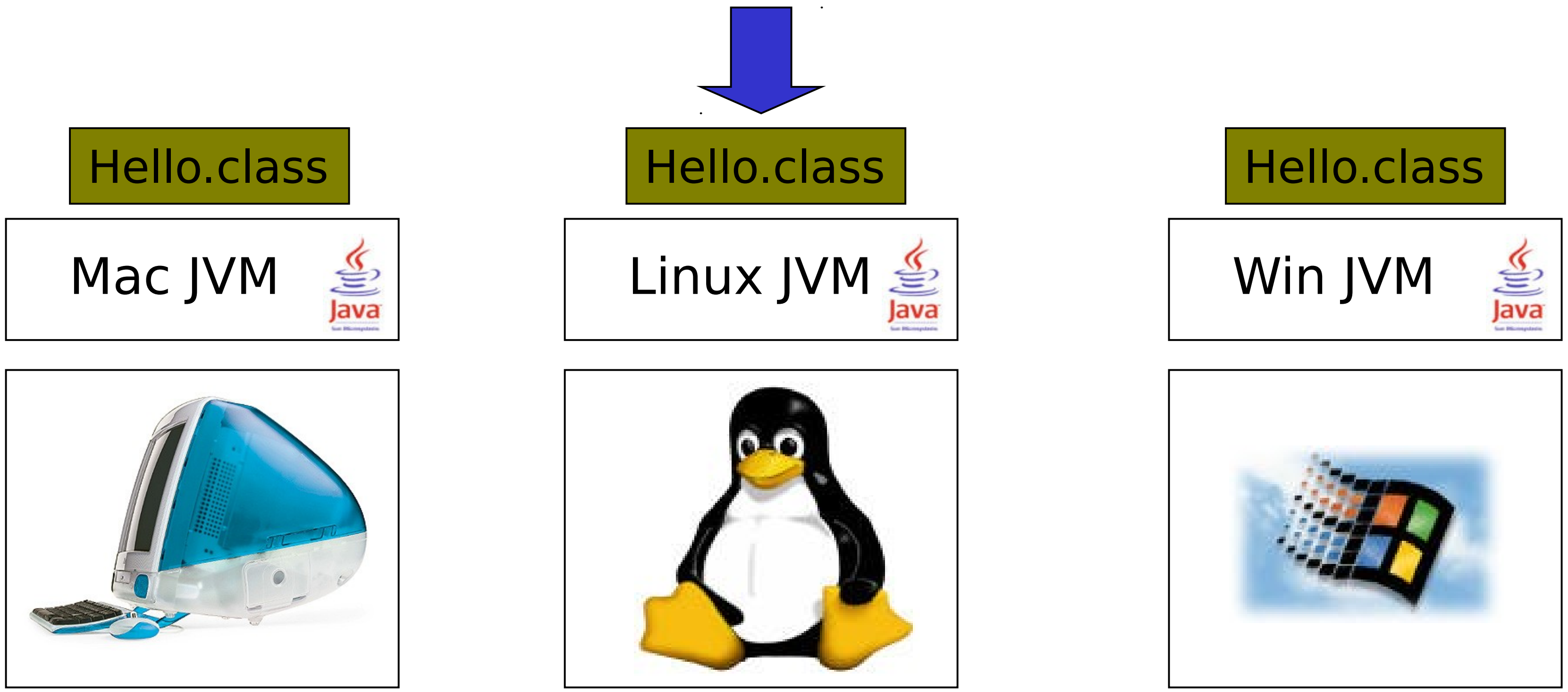


Hello.class

```
…
Method Hello()
    0 aload_0
    1 invokespecial #1 <Method java.lang.Object()>
    4 return
Method void main(java.lang.String[])
    0 getstatic #2 <Field java.io.PrintStream out>
    3 ldc #3 <String "Hello World!">
    5 invokevirtual #4 <Method void println(String)>
    8 return
```

The Java Virtual Machine

```
class Hello {
  public static void main() {
  // do something
}
```



Classpath: Where's My Code?

- The JVM knows where to find the standard library classes
  - but what about 3rd party code (our own, or others')?
- We can tell the JVM where to look for such classes using the *classpath*
  - Can be given to `java` directly using a flag
  - Can be stored in the CLASSPATH environment variable

```
~/proj1% java -cp ~/lib/lib_foo ProjMain

~/proj2% export CLASSPATH=~/lib/lib_bar
~/proj2% java ProjMain
```

Language specification

- References
- Encapsulation
- Polymorphism and Interfaces
- Inheritance and abstract classes
- Inputs/Outputs

A Class Definition

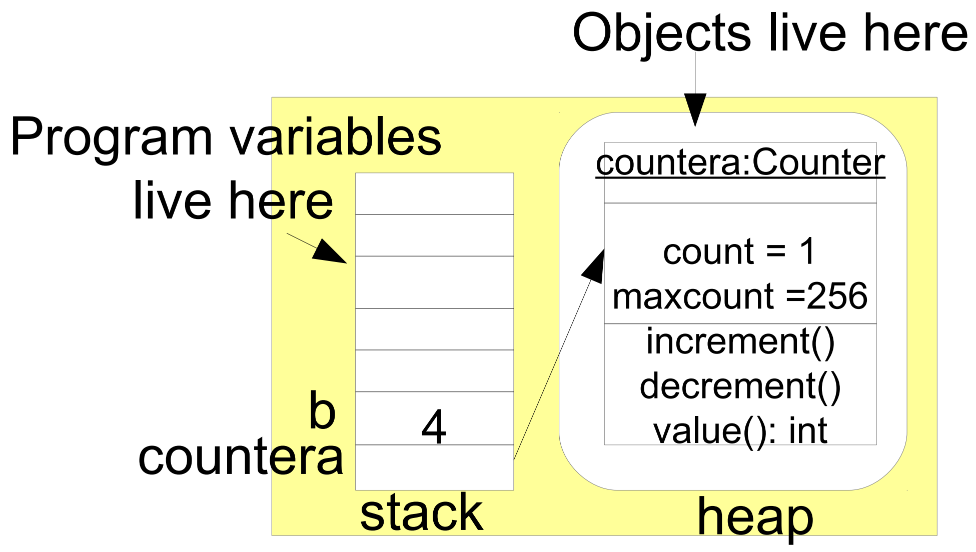
```
class Counter {
      private int count = 0;
      private static int maxcount = 256;
      public Counter(int i) /* no initialiser list */ {
         count = (i < 0) ? 0 :
            ((i > maxcount) ? maxcount : i); }
      public Counter(String s) {
         count = Integer.ParseInt(s);
      }
      public void increment() {
            if (count < maxcount) count++; }
      public void decrement() { if (count > 0) count--; }
      public int value()   { return count; }

}
```

References to Objects

- A reference to an object is the position in the heap where the object is stored
- Interaction is always through a reference to the object
- `this` keyword returns a reference object to itself
- `new` keyword returns a reference which is stored in a reference variable in the declaration of the object:

```
Counter countera ; //reference variable
countera = new Counter(1);
int b = 4;
```



Datatypes in Java

- In Java all variables are **typed** and stored in the program stack.
- Primitive types- Values reside in Stack
  - `boolean`, `char`, `byte`, `short`, `int`, `long`, `float`, `double`

1. Reserves memory in the heap for an object
2. Creates an object using the class
3. Runs a constructor method defined within the class
4. Returns a reference to the object

- Reference types – objects reside in Heap
  - for objects (including arrays)
    - always declared using the `new` keyword and passed by reference
  - but they can be null, and re-assigned
  - wrapper classes for primitive types: `Integer`, `Long`, etc.

Declaring and Using Objects

Declaring objects:

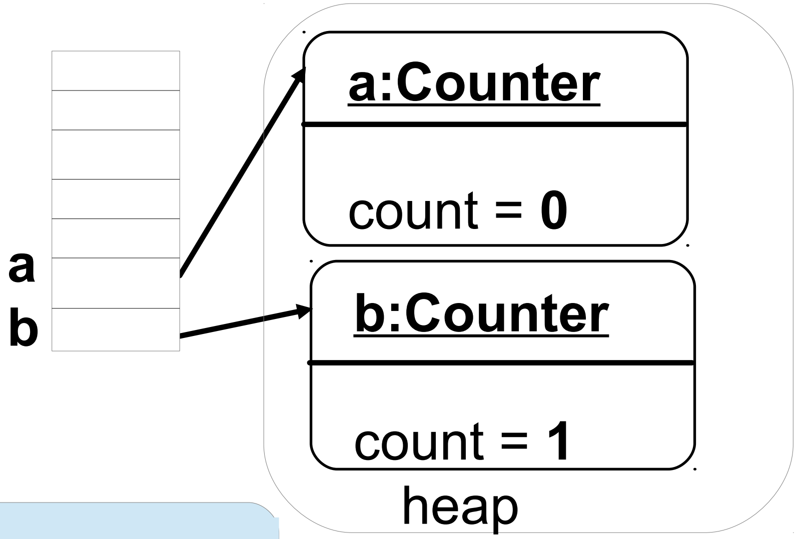
```
Counter a = new Counter(0);
Counter b = new Counter(1);
```

Method invocation:

```
a.increment();
b.decrement();
```

Passing as argument:

```
foo(a);
a.decrement();
```



All references to objects in Java are implicit pointers!

Assignment:

```
a = b;          // makes a and b point at the same object
```

Careful with assignment "=" operator → aliasing

Testing for equality:

```
a == b          // tests if a and b point at the same object
```

Automatic garbage collection:

```
a = null;       // may be garbage-collected if no more references left
```

Garbage Collection

- The separation of objects and references can lead to:
  - Reference variables pointing to no object (**null pointers**)
  - Object with many references to them (**aliasing**)
  - Objects with no references to them (called **inaccessible objects**)

- Java has a garbage collection process
  - Runs automatically
  - Frees up memory by removing objects that are inaccessible
  - You do not have to worry about “destruction”; leave objects in the heap, the garbage collector will remove them for you

Operators and Control Flow

- Java has all (nearly all) the familiar operators from C++
  - `++`, `–`, `*=`, `?:`, `&&`, etc.
  - (obviously) no pointer derefencing operators `*`, `->`
  - no user-defined operator overloading, however
- All the usual C++ statements can be used
  - `while`, `do`, `for`, `switch`, etc.
- Enhance loop; designed for iteration through *Arrays* or *Collections:*

```
int[] numbers = {1,2,3,4,5};
 for(int item : numbers){
     System.out.println("The number is: " + item);
 }
```

- Labelled break and continue

```
loop: for (int i = 0; i < 10; i++) {
          for (int j = 0; j < 10; j++) {
           if (...){ break loop;}
        }
    }
```

Arrays in Java

- Arrays are special kinds of object, created using
  - the `new` keyword

    ```
    int[] table  = new int[128];
    Object[] objects = new Object[10];
    ```

  - an array literal

    ```
    int[] lookup = { 1,2,4,8,16,32,64,128 };
    Object[] objs = { new A(), new B(), new C()};
    ```

- Array access is as expected

  ```
  table[i] = 0;
  int i = lookup[3];
  ```

- But remember, no pointers!

  ```
  // Object o = objects + 2;
  // lookup++;
  ```

Arrays in Java

- All array objects have a **`length`** field:

```
for (int i = 0; i < table.length; i++)
    table[i] = 0;
```

- The **`System`** class has a method for efficiently copying arrays

```
System.arraycopy(lookup, 0, table, 3, 8);
```

  copies elements 0-7 from **`lookup`** to indexes 3-10 in **`table`**

- The **`Arrays`** class has methods for manipulating arrays
  - `Sort`, `binarySearch`, `equals`, `fill`, etc.

Strings in Java

- Strings are objects, not null-terminated arrays of characters:

```
String a = "Hello";
String b = "World";
```

- String concatenation is achieved using the + operator

```
String message = a + ", " + b;
```

- The `String` class has methods for (non-destructively) manipulating strings:
  - `length`, `charAt`, `indexOf`, `compareTo`, `startsWith`, `substring` and many more
- Never use `==` or `!=` to compare **`String`** references, always use **`equals()`**
- **`StringBuffer`** and **`StringBuilder`** are classes for efficiently dealing with *mutable* strings
  - `append`, `insert`, `delete`, `replace`, `reverse`, `setCharAt`

Packages

In Java, packages:

- Are collections of related classes
- Create *namespaces*
    - different classes in separate packages can have the same name (CAREFUL!)
- A package can contain other packages; can be nested to create hierarchies

To place a class in a particular package, include a **`package`** directive, which must be the first declaration in the file

```
package JCool.Server.Database;
public class DataManager { ... }
```

If we want the class to be visible to code in other packages, we must declare the class `public`

Packages

Java enforces file organization in directory tree, where classpath points to root:

```
H:/Java/                         ←———   CLASSPATH
      Jcool/
         Client/
              Gui/
         Server/
              Database/          ←———   Package
         Engine/
```

Class `JCool.Server.Database.DataManager` must live in the file **`JCool/Server/Database/DataManager.java`**

Using Library Classes

- C++ has the `using` keyword, Java's version is `import`

```
import javax.swing.JPanel;
...
JPanel panel = new Jpanel();
panel.setVisible(true);
    ...
```

- The `JPanel` class actually lives in the package `javax.swing`
- We can import all the classes in a package in one go

```
import javax.swing.*;
```

- Notice that this does not import classes from e.g.

  `javax.swing.text`

- The Java compiler automatically imports all the classes from the `java.lang` and the parent package of the current class

Comments and `javadoc`

```
/**
 * The base class for all graphics contexts
 * @author
 */
public abstract class Graphics {
    /**
     * Draws an image
     * @param img    the image to be drawn
     * @return       <i>true</i> if successful
     */
    public abstract boolean drawImage(Image img);
}
```

Constants

- Java does not have a `const` keyword
- Constant values are indicated with the **`final`** keyword

```
final int i = 3;
i++; // cannot assign a value to final
 variable i
```

- However there is no way to specify an object must not change

```
class ConstDemo {
    public int i = 0;
    public ConstDemo() {}
    public static void main(String[] args) {
        final ConstDemo d = new ConstDemo();
        d.i++; // OK
        d = new ConstDemo(); // cannot assign a value to
                                      final variable d
    }
}
```

Static Fields and Methods

- They are declared using the `static` keyword
- Static Fields (**class variables**) are treated as Global Variables and Static Methods as Global Methods (**class methods**)

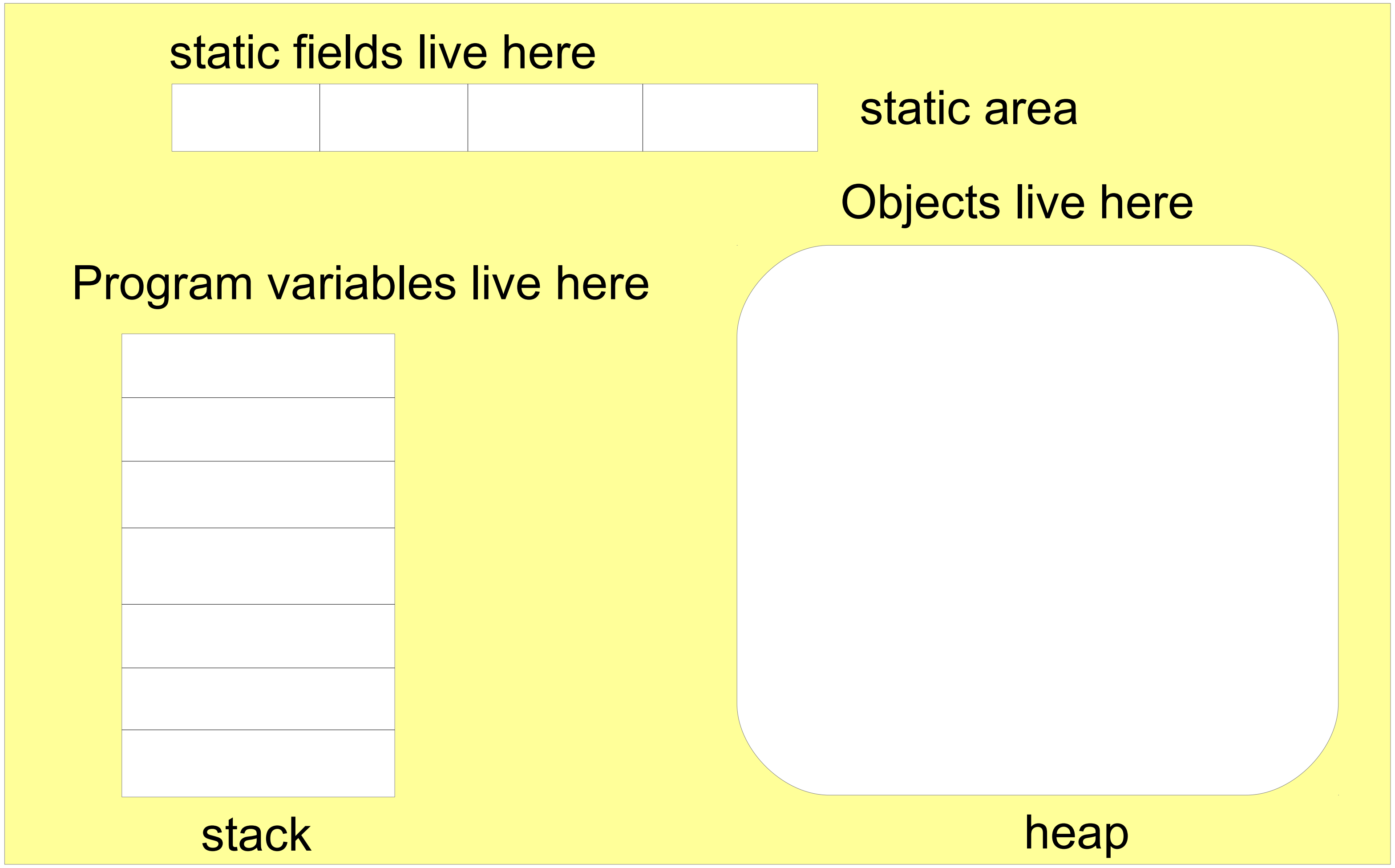
```
class A {
    public static int oneAndOnly;
    public int someMethod(){ ...}
    public static int staticMethod(){....}
}

class B {
    void foo() { System.out.println("A.foo()"); }
    public static void main(String[] args) {
        A.oneAndOnly = 2;
        A myA = new A();
        int x = A.staticMethod();
        int y = myA.someMethod();
        foo(); Compile error: non-static method foo()
        //     cannot be referenced from a static context
    }
}
```

Only one static field is created per class not one per object

You do not invoke globalMethod() on an instance of A

Static Fields and Methods- view of memory



Encapsulation and Visibility

encapsulation

- Classes should:
  - Give access to well-defined behaviours (methods)
  - Hide internal data representation (fields)
  - Hide algorithmic implementation details
- Classes should allow **changing internal representation without affecting users**
- **Visibility** explains who can access methods, fields and classes. It is a mechanism for implementing **encapsulation**.
- Methods and fields can be declared:
  - `public`: anyone can access
  - `package`: (the default) anyone from within the package
  - `private`: accessible only within the class
  - `protected`: related to inheritance

Immutable objects (value objects)

Declaring fields `final` the values cannot changes after the construction of this object

```
public class Rectangle {
    private final int width, height;

    public Rectangle(int width, int height) {
         this.width = width; // one and only
         this.height = height; // assignment to fields
    }

    public int getWidth() { return width; }

    public Rectangle rectangleBySettingWidth(int width) {
         return new Rectangle(width, getHeight());
     } // similar for height
 }
```

Interfaces- Case study

- Imagine we design a document management application that manages at start various kind of page elements:

  - Text box- has width, height, unique label and maximum number of characters
  - Menu - has width,height, unique label and list of options

- How can we find the height of the tallest page element?

- Let's add another page element...
  - Image – has width, height, unique label and filename associate to

Interfaces- Case study

- Problems with this design:
  - Duplicate code everywhere
  - `DocumentManager` has to be explicitly aware of all the different sorts of page elements that exist
  - If we introduce a new page element, we need to change `DocumentManager`
  - Makes third parties difficult to contribute
  - If another actions such as determine one page element is taller than another, one approach we would have to overload 'tallerThan' for each pair of types N kinds of page element-> N^2 'tallerThan' methods

Interfaces

```
public interface PageElement {
    public int getWidth();
    public int getHeight();
    public String getId();
}
```

- Interfaces define a group of methods to be implemented
- Methods are declared without bodies
- Interfaces, like classes, induce named types
- Interfaces do not contain fields, however
  - Interfaces may contain constants
  - They are implicitly `public static final` when the interface is implemented
- Interfaces can extend each other

Implementing Interfaces

```
public class TextBox implements PageElement {
  …//Fields declaration and constructor
  public int getWidth() {     public String getId() {
    return width;                 return id;
  }                             }

  public int getHeight() {      public int getMaxChars() {
    return height;                return maxChars;
  }                             }
}
```

Implementation required by the interface specification

Method specific to TextBox

- Methods in a class that implement interface must be public
- Interfaces **decouple**(separate) the specification from the implementation
- A class can use any class that implements the interface through the interface type (**polymorphism**)

Multiple Interfaces

```
public interface AlarmClock{
…
}
public interface Clock{
…
}
```

```
public class SmartPhone
implements Clock, AlarmClock{
…//Implements at least
specified methods in both
interfaces
}
```

- Classes are allowed to implement multiple interfaces
- Multiple methods with the same name (**Name conflict**):
  - Different signatures:overloading
  - Same signatures and same return type: same method!
  - Same signature and different return type: //compile error

Apparent and actual types

- The **apparent type** of an object is what the compiler statically can infer
- The **actual type** of an object is what the object really is
- RULES:
  - Interfaces or classes can be apparent type
  - Only classes can be actual type
  - Methods and fields available according to apparent type
  - In inheritance **apparent type** must be a super type of **actual type**
- Java checks these rules at compile time
  - Java is a **strongly typed** language
  - It does static type checking

Using interfaces: late binding and polymorphism

- If a reference variable has interface type, we can use the same way as a class, however:
    - Only call to methods that are specified by the interface
    - Cannot access fields through an interface: the classes that implements the interface
- When we call a method on an interface, the actual method invoke is decided at runtime through **late binding**

Inheritance in Java

- Java has **single** inheritance only (for multiple inheritance use interfaces as classes are allowed to implement multiple interfaces)
- Inheritance is indicated by the `extends` keyword

```
class Foo extends Bar { ... }
```

- Derived objects:
  - **extend** their superclass
  - **Inherit** all members of superclass (including private)
  - Can **override** methods of superclass
  - Can **access** public/protected fields of superclass
  - Can **call** public/protected methods of superclass
- Classes inherit from `Object` by default

```
class Counter /* extends Object */ { ... }
```

  - The `Object` class contains a set of 'standard' methods
    - e.g. `clone()`, `equals(Object obj)`, `toString()`

Super

```
public Circle(int radius) {
        super();
        this.radius = radius;
}
```

- Used to call superclass' constructor
- Must be the first line
- Can have different signatures (`super()`, `super(arg1, arg2)`,)
- `super()` is called implicitly if no other constructor is called
- Used to call an overridden method for a superclass

```
super.superclassmethod();
```

Visibility

	public	protected	package (default)	private
Within class	**Yes**	**Yes**	**Yes**	**Yes**
Within package	**Yes**	**Yes**	**Yes**	**No**
Within subclass	**Yes**	**Yes**	**No** (unless in same package)	**No**
Anywhere	**Yes**	**No**	**No**	**No**

Abstract Classes

- *Pure* (virtual) methods are declared using the `abstract` keyword
- Unlike classes, they cannot be instantiated
- No object can have as **actual type** the type of abstract class
- Why to use them?
  - ➢ We want to prevent users from handling objects that are too generic (**`BasicPageElement`**)
  - – We cannot give full implementation for the class (**`Shape`**)

Rules - Abstract Classes

```
public abstract class A {
    public abstract void foo();
}
public class B extends A {
 //Compile-error. Class B must
 //implement abstract method foo
}
public abstract class B extends A {
 //ok. Subclasses of B must implement
 //foo (or declared abstract)
}
public abstract class B extends A {
 //ok. Subclasses of B must implement
 //foo and bar(or declared abstract)
    abstract void bar();}
```

Rules - Abstract Classes

```
public  class A {

}
public abstract class B extends A {
 //ok, but uncommon
 }
 public abstract final class A {
 //Compile-error class cannot
  // be abstract and final
 }
```

Input/Output

Input/Output in Java

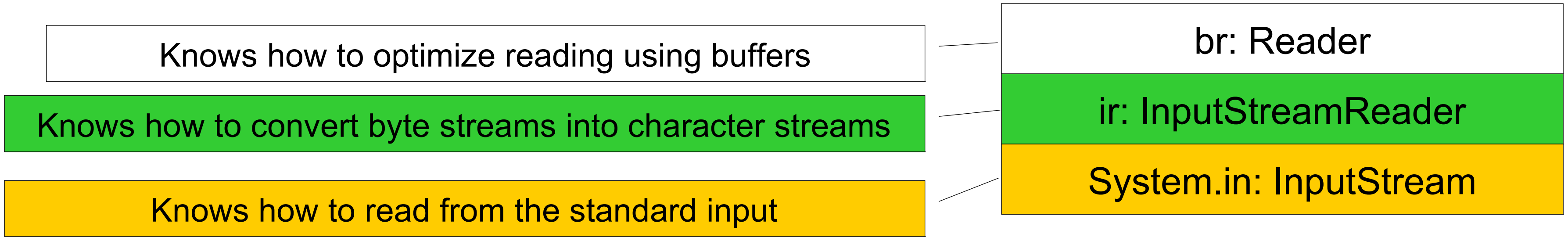
- Interacting with the user
  - `System.out` is a global PrintStream object: outputs to the screen

    ```
    System.out.println("Hello");
    ```

  - `System.in` is a global InputStream object: reads from the keyboard
- The `java.io` package or `java.util.Scanner` contains library classes for performing input and output actions
- How to read a line from keyboard?
  - **`BufferedReader`** class can read characters and lines
  - How can we build a **`BufferedReader`**? We need an **`InputStreamReader`**
  - How can we build an **`InputStreamReader`**? We need an **`InputStream`**
  - How can we build an **`InputStream`**? We have one **`System.in`**

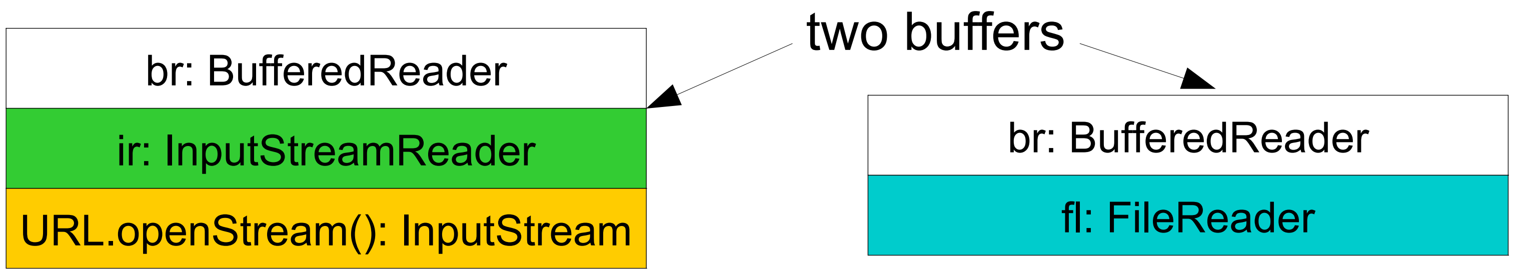
Input/Output in Java

- The Java I/O classes are designed to build on top of one another to provide:
  - Separation of concerns
  - Efficiency
  - Flexibility- we can use different input streams to read from:
    - The web
    - A file
    - Other complex devices

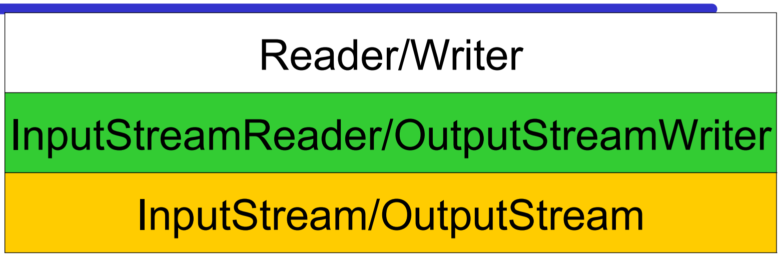

Knows how to optimize reading using buffers
Knows how to convert byte streams into character streams
Knows how to read from the standard input
br: Reader
ir: InputStreamReader
System.in: InputStream

Input/Output in Java

- We can have multiple objects of a same class with different state
  - Several files being read simultaneously
  - Several URL being read simultaneously
- Objects encapsulate their state and behaviour: we can have multiple objects performing radically different tasks
  - Several BufferedReader objects reading from files, URLs and the standard input simultaneously
- Example: a program that checks if a web page is up to date by comparing it with its local copy of the html file



Input/Output in Java



- Input/OutputStream classes:
  - System.in
  - System.out
  - DataInputStream: reads primitive datatypes from its source
  - DataOutStream: writes primitive datatypes in a portable way
  - ObjectInputStream: reads "serializable" objects from an InputStream
  - ObjectOutStream: writes "serializable" objects to an OutputStream
- InputStreamReader/OutStreamWriter classes:
  - FileReader: file as source
  - FileWriter: file as a sink
- Reader/Writer classes:
  - CharArrayReader: byte[] as source
  - CharArrayWriter: accumulates writes and provides data as a byte array
  - BufferedReader: will read enough data to fill an internal buffer
  - BufferedWriter
  - StringWriter
  - PrintWriter

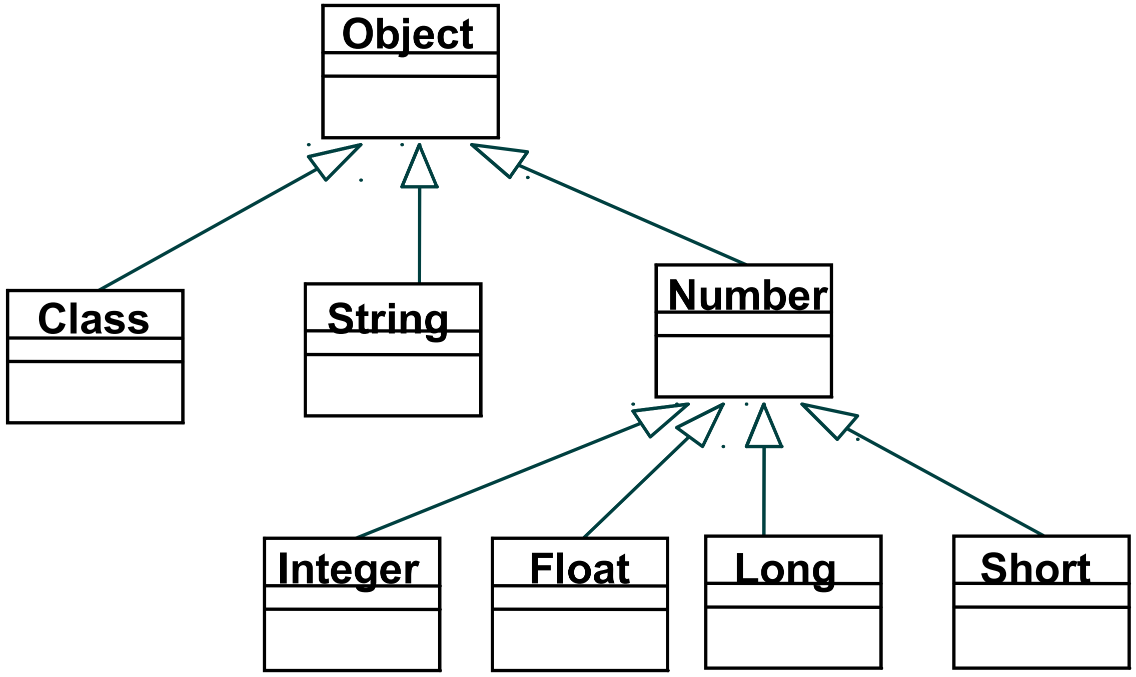
Generics and Collections

(http://docs.oracle.com/javase/tutorial/extra/generics)

- Casting and Object equality
- Generics methods
- Generics and subtyping
- Wilcards
- Inheritance and generics
- Collections

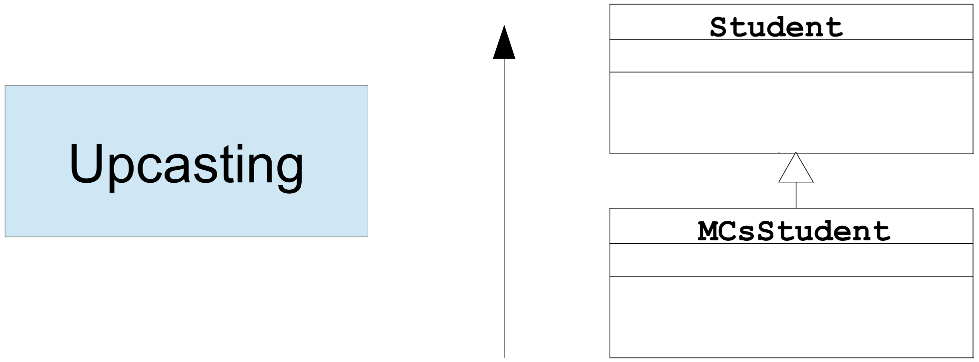
Casting

- Looking at Java Development Kit Documentation:
  - Every Java class is a subclass of Object
  - Object is the superclass
  - Being a subclass of Object is not declared explicitly



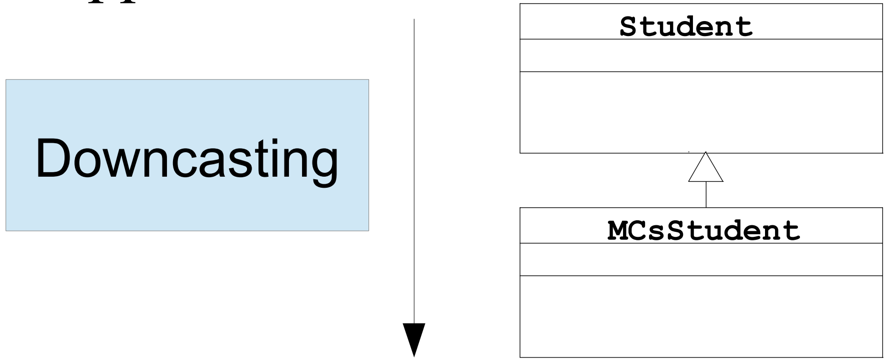
Casting

- **Upcasting** or widening type: the process of treating an object of type subclass as if it was of type superclass.
  - **Upcasting** is done automatically, it cannot fail.



```
Student c2 = new
    MScStudent(1455, "ret",
    "law");
```

- **Downcasting** or narrowing type: to reduce the type of the apparent class to be able to call certain methods.



```
MCsStudent c3 = (MScStudent) c2;
```

Casting

- Downcasting is an explicit type conversion
- Some downcasts cannot be verified at compile time, may produce run-time errors: ClassCastException
- To avoid ClassCastException use `instanceof` to discover the actual type of an object (it takes care of null `instanceof` T)

```
if (c1 instanceof MScStudent){
   MScStudent c3 = (MscStudent) c1;
}
```

- However, sometimes to use `instanceof` may indicate poor design, better to use subclassing

Object equality

- As discussed class Object provides equals method:

```
public boolean equals(Object obj);
```

- The equals method must be:
  - Reflexive: for any object, o.equals(o) must be true
  - Symmetric: for any two objects, o1.equals(o2) holds if and only if o2.equals(o1)
  - Transitive: for any three objects, if o1.equals(o2) and o2.equals(o3), it must be the case that o1.equals(o3)
  - Consistent: if we keep asking whether o1.equals(o2) and neither o1 nor o2 changes, the result should stay the same
  - o.equals(null) must be false
- o1.equals(o2) if and only if o1.hashCode() == o2.hashCode()
- Therefore, if you override equals() you must override hashCode()

Object equality- Override annotation

- Writing a basic equals method:
  - Check incoming object has appropriate type
  - Downcast incoming object
  - Compare fields
- Good practice – specify the intention of override a superclass method by typing "@Override" on top of the method to override
- If you define a method with `final` keyword the method cannot be overridden
- If you define a class with `final` keyword the class cannot be subclassed (**immutable** classes)
- Private methods cannot be overridden

Generics

- It is the Java version of C++ Templates with some differences. In Java:
  - Only type parameters (no constant or function parameters)
  - Generics allow for **subtyping**
- Constructor declarations do not use parameter specification
  - public Pair<S, T>(S first, T second){...} // WRONG
  - public Pair(S first, T second){...} //CORRECT
- Constructor calls and reference variable declarations **do** use parameter specification
  - Pair p; //WRONG
  - Pair<`String`, `Integer`> p; //CORRECT
  - **`new`** Pair(); //WRONG
  - **`new`** Pair<`String`, `Integer`>(); //CORRECT

Generics

- Actual parameter of a generic must be a **reference type**
  - Pair<int, int > //WRONG
  - Pair<Integer, Integer > //CORRECT
- Illegal statement with formal type parameters:
  - `new` T(); //WRONG: generic parameter cannot denote a constructor
  - `new` T[2]; //WRONG: generic parameter cannot denote an array constructor
- Arrays of generic classes are not allowed
  - Pair<`String`, `String`> values = **`new`** Pair<`String`, `String`> [2];//WRONG
  - Pair<`String`, `String`> values = **`new`** Pair<`String`,`String`>{("one","two"), ("three", "four")};//WRONG
  - However, you can write the following, although you will get a warning while compiling:
    - Pair<`String`, `String`>[] values = **`new`** Pair[]{ **`new`** Pair<`String`,`String`>("one","two"), **`new`** Pair<`String`,`String`>("3","4"

Generic Classes

```
public class Pair<S, T> {

    private S first;
    private T second;

    public Pair(S first, T second){
        this.first = first;
        this.second = second;
    }
    public S getFirst() {
        return first;
    }
    public void setFirst(S first) {
        this.first = first;
    }
    public T getSecond() {
        return second;
    }
    public void setSecond(T second) {
        this.second = second;
    }
}
```

Generic methods

- Add <S,T,...> before **return type** (int, void,...) of the method to indicate that the method should work for arbitrary types S,T,etc
- Then use freely the types S,T inside the method:

```
public static <S,T> Pair<S,T> makePair(S first, T second){
    return new Pair<S,T>(first,second);
}
public static <S> Pair<S,S> makeHomogeneousPair(S first, S
    second){
    return new Pair<S,S>(first,second);
}
public static <S,T> T lookPair(S key,Pair<S,T>[] elems, T
    generic){
    for( Pair<S,T> elem : elems){
        if(key.equals(elem.getFirst())){
            return elem.getSecond();
        }
    }
    return generic;
}
```

return type

Generics and subtyping

- If String extends Object, is Set<String> a subtype of Set<Object>? Can we swap safely Set<String> for Set<Object>?

```
static double maxArea(Set<Shape> shapes) { ... }

public static void main(String[] args) {

Set<Circle> circles = new HashSet<Circle>();

...

double d = maxArea(circles); // Seems OK, but gives
compile error

Shape rectangle = new Rectangle(...);

addOne(circles, rectangle); // Certainly not OK

}
```

Generics and subtyping

- Our intuition say Yes, but in general the answer is NO!

- The general rule is:

If C is a generic class, and B extends A, then C<B> is **NOT** a subtype of C<A>

- We can also say that C<A> and C<B> are not **covariant**

Wildcards

- Suppose we wish to print an arbitrary set of objects

```
public class WithoutWildcards {

  public static void printSet(Set<Object> s) {
    for (Object o : s) {
      System.out.println(o);
    }
  }

  public static void main(String[] args) {
    Set<Shape> shapes = new HashSet<Shape>();
    ...
    printSet(shapes);
  }
}
```

Too specific – only accepts values with exactly type `Set<Object>`

Does not compile – `Set<Shape>` is **not** a subtype of `Set<Object>`

Wildcards

`Set<?>` vs `Set<Object>`

- We can add a `String` to a `Set<Object>` because `String` is a subtype of `Object`
- We *cannot* add a `String` to a `Set<?>` because `?` could denote *anything* (e.g. we might really have a `Set<Integer>`)
    - `Set<?>` is **not** a subtype of `Set<T>` for any `T`
- Is there anything that we can add to a `Set<?>`?
- Is there any type we can guarantee for elements retrieved from a `Set<?>`?

Wildcards

- Suppose we want to find the maximum area over a set of shapes

Too specific – only accepts values with exactly type `Set<Object>`

```
public class WithoutBoundedWildcards {
  public static void printColourShape(Set<Shape> shapes) {
        for (Shape s : shapes) {
            System.out.println(s.getColour());
        }
  public static void main(String[] args) {
    Set<Circle> circles = new HashSet<Circle>();
    ...
    printColourShape(circles);
  }
}
```

Does not compile – Set<Circle> is **not** a subtype of Set<Shape>

Bounded wildcard

- Does a wildcard help?

Does not compile – we cannot retrieve Shape objects from a Set<?>

```
public class WithoutBoundedWildcards {
  public static void printColourShape(Set<?> shapes) {
        for (Shape s : shapes) {
            System.out.println(s.getColour());
        }
  public static void main(String[] args) {
    Set<Circle> circles = new HashSet<Circle>();
    ...
    printColourShape(circles);
  }
}
```

However, OK – Set<Circle> is a subtype of Set<?>

Bounded wildcard

- We use a bound on the type parameter
  - `Set<? extends Shape>` is a set whose elements are some (unknown) subclass of `Shape`

```
public class WithBoundedWildcards {
  public static void printColourShape(Set<? extends Shape> shapes) {
        for (Shape s : shapes) {
            System.out.println(s.getColour());
        }
  public static void main(String[] args) {
    Set<Circle> circles = new HashSet<Circle>();
    ...
    printColourShape(circles);
  }
}
```

Fine – elements of `shapes` are guaranteed to be `Shape` objects

OK – `Set<Circle>` is a subtype of `Set<? extends Shape>`

Wildcards

`Set<? extends Shape>` vs `Set<Shape>`

- We can add a `Circle` to a `Set<Shape>` because `Circle` is a subtype of `Shape`
- We *cannot* add a `Circle` to a `Set<? extends Shape>` because `?` could denote *anything* (e.g. we might really have a `Set<Rectangle>`)
- Is there anything that we can add to a `Set<? extends Shape>`?
- Is there any type we can guarantee for elements retrieved from a `Set<? extends Shape>`?

Bounds for Generic Type Parameters

- We make the method generic, placing a (named) bound on the return type
  - The method can only be instantiated by types `T` that extend `Shape`

```
public class BoundedGenerics {
  public static <T extends Shape> T largest(Set<T> shapes) {
    T result = null; boolean first = true;
    for (T s : shapes) {
      if (first) { result = s; first = false; }
      else if (s.area() > result.area()) result = s;
    }
    return result;
  }
  public static void main(String[] args) {
    Set<Circle> circles = new HashSet<Circle>();
    ...
    Circle largestCircle = largest(circles);
  }
}
```

OK – Circle extends Shape

OK – return type of largest is T, which in this invocation is Circle

Bounds for Generic Type Parameters

- Suppose we want to *return the element* with the largest area

```
public class BoundedWildcardsNotGoodEnough {
  public static Shape largest(Set<? extends Shape> shapes) {
    Shape result = null; boolean first = true;
    for (Shape s : shapes) {
      if (first) { result = s; first = false; }
      else if (s.area() > result.area()) result = s;
    }
    return result;
  }
  public static void main(String[] args) {
    Set<Circle> circles = new HashSet<Circle>();
    ...
    Circle largestCircle = largest(circles);
  }
}
```

Does not compile – largest returns a Shape, **not** a Circle

Bounds for Generic Type Parameters

- We make the method generic, placing a (named) bound on the return type
  - The method can only be instantiated by types `T` that extend `Shape`

```
public class BoundedGenerics {
  public static <T extends Shape> T largest(Set<T> shapes) {
    T result = null; boolean first = true;
    for (T s : shapes) {
      if (first) { result = s; first = false; }
      else if (s.area() > result.area()) result = s;
    }
    return result;
  }
  public static void main(String[] args) {
    Set<Circle> circles = new HashSet<Circle>();
    ...
    Circle largestCircle = largest(circles);
  }
}
```

OK – Circle extends Shape

OK – return type of largest is T, which in this invocation is Circle

Inheritance and Generics

- Common for a class to extend a generic class or implement a generic interface, reminding generic (Java documentation)

```
public abstract class AbstractSet<E> implements Set<T>{
 //Provides abstract implementation of various 'set' algorithms

}
```

```
public class HashSet<E> extends AbstractSet<E>{
 //Implements Set using a hashtable

}
```

```
public class LinkedHashSet<E> extends HashSet<E> {
 //Unlike plain HashSet<E>, provides guaranteed
 //iteration order
}
```

Inheritance and Generics

- Also useful for extending/implementing class to be specific

```
public interface Comparable<T>{
    int compareTo(T Obj);
}
```

```
public class UniDegrees implements Comparable<UniDegrees>{
    public int compareTo(T Obj){...};
}
```

```
public static void main(String[] args) {
    UniDegrees<UniDegrees> dg; //WRONG
    UniDegrees dg; // CORRECT- this class is not generic
}
```

The Collections Framework

- Java has a large library of container classes and interfaces
- A container allows objects to be stored and retrieved
- All elements of the framework are *generic*
- There are different types of collections according to the additional services and behaviour implemented

	Ordered	Duplicates
Sets	NO	NO
Lists	YES	YES
Maps	NO	*(key, value) pairs* *No duplicate keys*

Container class hierarchy

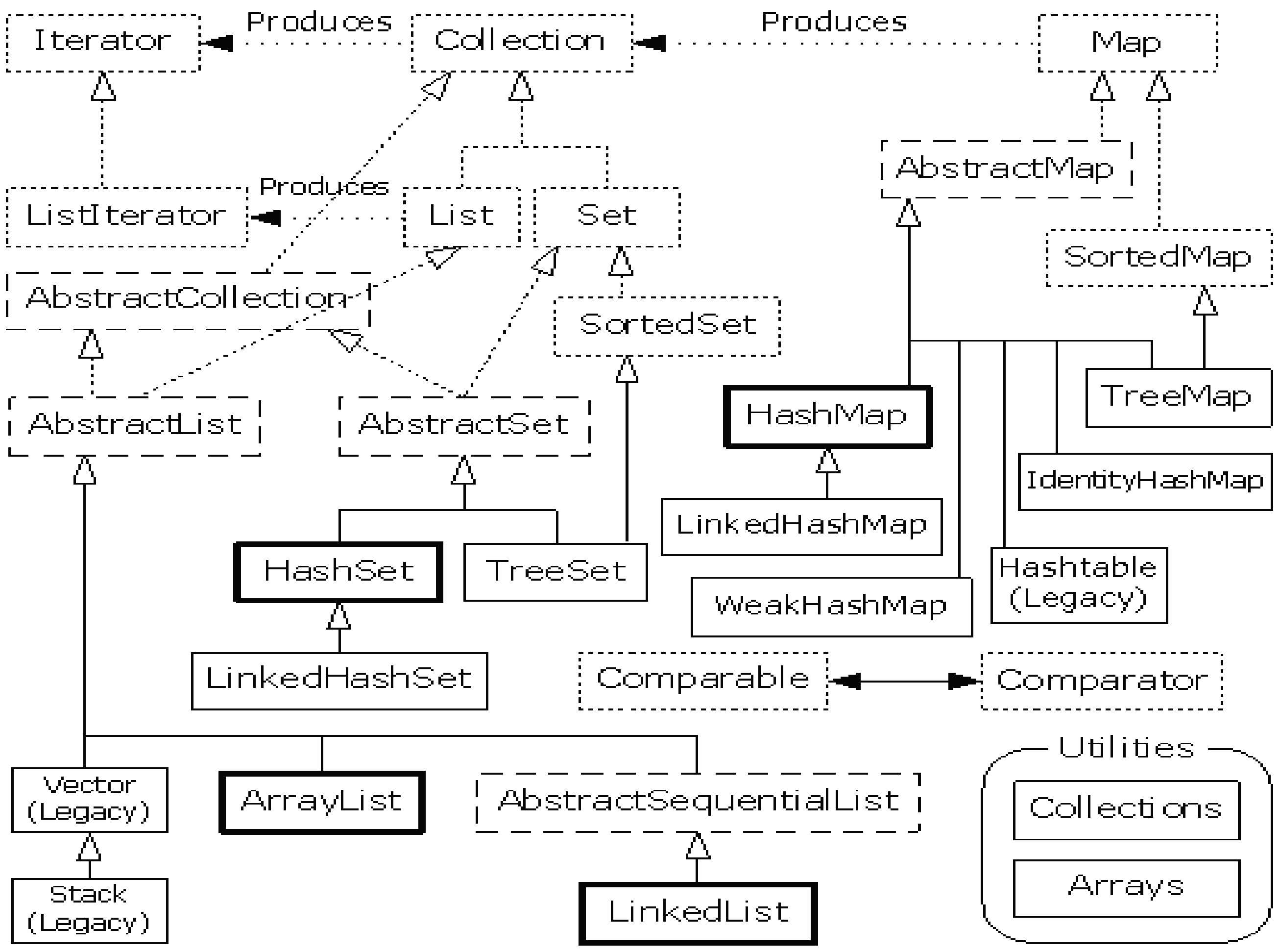


Image extracted from www.cs.duke.edu

Java.util.Collection (Interface)

```
public interface Collection<E> {

   boolean add(E o);
   boolean remove(Object o); // Why object and not E?
   boolean contains(Object o);
   boolean addAll(Collection<? extends E> c)
   boolean isEmpty();
   Iterator<E> iterator();
   int size();

   // … many other methods
}
```

```
public interface Iterator<E> {
  boolean hasNext();
  E next() ;
  void remove();

}
```

- All collection classes also implement Iterable<E>
  - Defines an iterator() method which returns an Iterator<E>

Iterating Through Collections

```
List<String> stringList = new ArrayList()
...
Iterator<String> it = stringList.iterator();
while (it.hasNext()) {
    System.out.println(it.next());
}
```

- However, you could also use the Enhance For loop (for-each syntax) with any class that implement Iterable

```
List<String> stringList = new ArrayList()
...
for (String s : stringList) {
    System.out.println(s);
}
```

More Specialised Kinds of Collection

- `List<E>` allows fine control over the position of elements
  - Provides search operations
  - May contain duplicate elements
- `Set<E>` does not allow duplicate elements
  - uses the `equals(Object o)` method to determine equality
  - Allows a null element
- `Map<K,V>` stores pairs<*key*,*value*>
  - Not a Collection subclass
  - Keys are unique
  - `V put(K key, V value)`
  - `V get(Object key)`
  - `Set<K> keySet()`
  - `Collectiob<v> values()`

More Specialised Kinds of Collection

- `SortedSet<E>` and `SortedMap<K,V>` maintain (total) orderings on their elements
- `Queue<E>` and `Deque<E>` provide methods for processing elements in FIFO (first in first out) manner
  - `E peek()`
  - `E poll()`

Some Concrete Collection Classes

- Java provides some default implementations for each of the interfaces in the Collections Framework, e.g.
  - `ArrayList<E>` implements `List<E>` as a resizable array
  - `LinkedList<E>` implements `List<E>` as a (doubly) linked list
  - `HashSet<E>` and `HashMap<K,V>` implement `Set<E>` and `Map<K,V>` respectively using hash tables
  - `TreeSet<E>` and `TreeMap<K,V>` implement `Set<E>` and `Map<K,V>` respectively using red-black trees
  - `LinkedHashSet<E>` and `LinkedHashMap<K,V>` implement `Set<E>` and `Map<K,V>` respectively using hash tables, and also maintain a linked list so the elements can be iterated through in insertion order

Sorted Collections

- In C++, sorted collections maintain an order on their elements
  - By using an overloaded version of the < (less than) operator
  - By taking a comparison function as a template parameter

- In Java, we cannot overload operators, and there are no function parameters, so
  - Elements of the sorted container must implement the `Comparable<E>` interface
    - `int compareTo(E e)`
  - We can provide an object to the constructor which implements the `Comparator<E>` interface
    - `int compare(E e1, E e2)`

Sorted Collections

- Alternativelly, we can pass the constructor a **`Comparator`** object of an appropriate type

```
SortedSet<SetIntPair> s = new
TreeSet<IntPair>(new Comparator<IntPair>() {
public int compare(IntPair p1, IntPair p2) {
return p1.fst() < p2.fst() ? -1 :
(p1.fst() > p2.fst() ? 1 :
p1.snd() - p2.snd());
}
});
```

Anonymous class: it is an expression (does not have a name), i.e. you define the class in another expression. In this case, it implements the `Comparator<IntPair>` interface. It is necessarily an ***inner*** class, which is a class declared inside another class

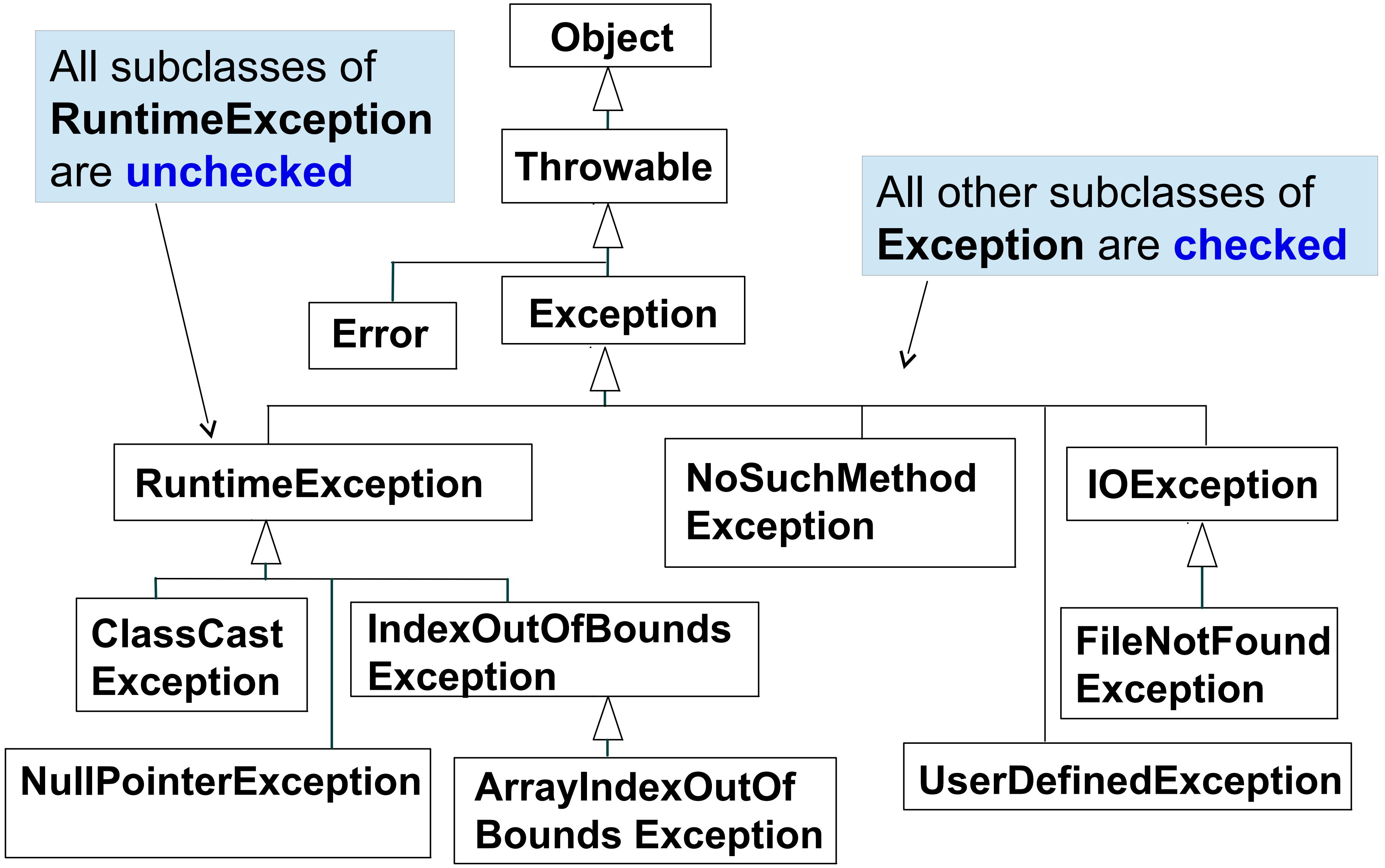
Exceptions

(Dealing with Abnormal Execution)

Exceptions

- Exceptions and exception handling support the development of ***robust*** programs
  - Report and detect unexpected, erroneous situations
    - File not found / inaccessible
    - Run out of memory
    - Network unavailable
  - We can recover from the error, or exit the program safely
- Exceptions are objects; they have type and are instantiated using **`new`**.
- Exceptions can be defined with custom structure, operations, constructors by extending any predefined exception type.
- **Exception** class extends the **Throwable** class
  - **Exception** is the parent class of all exceptions
  - **Throwable** is also extended by **Error** and its subclasses

Java exception class hierarchy


All subclasses of **RuntimeException** are **unchecked**
All other subclasses of **Exception** are **checked**
Object
Throwable
Error
Exception
RuntimeException
NoSuchMethod Exception
IOException
ClassCast Exception
IndexOutOfBounds Exception
FileNotFound Exception
NullPointerException
ArrayIndexOutOf Bounds Exception
UserDefinedException

Checked and unchecked exceptions and errors

- Checked exceptions are declared explicitly in `throws` part of method signature.
  - The compiler verifies that such exceptions are either caught or thrown by all calling methods
- Unchecked exceptions do not need to be declared in signature method that throws them
  - You can catch them, but it is not compulsory
  - If not caught, these exceptions are automatically propagated up to call stack
  - If never caught: program terminates
- The Error throwable class represent serious errors
  - Exceptions that application should not try to catch such as error in the JVM
    - StackOverflowError
    - OutOfMemoryError
  - Rarely used. Mostly to terminate programs with customised failure modes

Exceptions methods

- `Throwable` class specifies basic operations for all exceptions and errors:
  - `String getMessage()` : Exceptions may contain human-readable information
  - `Throwable getCause()` : Exceptions may be caused by other exceptions and chained together
  - `void printStackTrace()` : We can see information about the chain of method calls that led to this exception being thrown. This method prints standard error output the stack of the method calls at point of creation

Exceptions and throwing Exceptions: Java syntax

- For the provider method

```
<return-type> methodName(<arguments>) throws <exception list>{...}

<exception list> = exceptiontype1,...,exceptiontypeN
```

- When calling a method (catching exceptions)

```
try{
//call the method
}catch(ExceptionType1 name){
…
}catch(ExceptionTypeN name){
…
}finally{
//code here always gets executed regardless
}
```

- Throwing exceptions is easy. Use the `throw` keyword follow the `new` object Exception instance.
- You can `throw` anything that extends **Throwable**

Writing Exception classes

- If we want to create and Exception class
  - This new exception overrides **`getMessage()`** method

```
public class UnknownStudentException extends Exception {
    @Override
    public String getMessage() {
        return "Invalid Student login ("
                + super.getMessage() + ")";
    }

}
```

Try/catch and inheritance

- `catch (Exception e) {…}` catches any exception which derives from(and including) SomeException

```
try {
   ...
}
catch (Exception e) {
   //any (non-Error) exception will be caught here
}catch(IOException e){
//unreachable, because an IOException is an Exception!
}
```

Method overriding: narrowing exception types

- This is allowed in Java:

```
public class AException extends Exception{...}
```

```
public class BException extends AException{...}
```

```
public class C{
    public void foo() throws AException {...}
}
```

```
public class D extends C{
    @Override
    public void foo() throws BException {...}
}
```

- In order words, Java supports covariance with respect to `throws`

Graphical User Interfaces, Threads and Networking

- Java Swing library
- Threads
- Sockets

Swing: The Java GUI Framework

- Java has an extensive library, called Swing, for creating GUI applications
    - Oracle has recently developed JavaFX, but this builds on top of Swing and so it will be useful to learn Swing first
- It is very quick to build applications with:
    - Windows
    - Buttons
    - Menus
    - Customisable layouts
    - And many more features …
- We will look at how to program some basic features in Swing
    - And on the way introduce Java's functionality for programming *concurrency*

JFrame: Creating Windows

- The basic class for implementing windows is `JFrame`
  - We can create instances of `JFrame` and set its properties
  - Or we can create a subclass of it if we want more specialised behaviour

```
JFrame myFrame = new JFrame("This is my window");
```

This goes in the title bar

```
myFrame.setSize(1024, 768);
```

What size the window should be

```
myFrame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
```

What should happen when the window is closed – we can exit the application, hide the window, or even do nothing!

```
myFrame.setVisible(true);
```

Make the window visible

A Basic Application

- An application can be implemented as any ordinary class with a main method that creates a window

```
public class MyApp implements Runnable {
   public MyApp() {}
   public void run() {
      JFrame frame = new Jframe(“A Basic GUI”);
      myFrame.setSize(1024, 768);
      myFrame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      myFrame.setVisible(true);
   }
   public static void main(String[] args) {
      javax.swing.SwingUtilities.invokeLater(new MyApp());
   }
}
```

A Basic Application

- An application can be implemented as any ordinary class with a main method that creates a window

```
public class MyApp implements Runnable
    public MyApp() {}
    public void run() {
        JFrame frame = new Jframe("A Basic GUI");
        myFrame.setSize(1024, 768);
        myFrame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        myFrame.setVisible(true);
    }
    public static void main(String[] args) {
        javax.swing.SwingUtilities.invokeLater(new MyApp());
    }
}
```

This method will create the window for the application and display it

Because the GUI needs to run independently alongside the main application, Swing runs it using its own *Thread*, which is created using the `Runnable` object passed as the argument to the `invokeLater` method.

Components

- Windows contain various different *components*
- The basic superclass of components in Swing is `JComponent`
- Many useful GUI classes are subclasses of `JComponent`
  - `JLabel`
  - `JButton`
  - `JMenu`, `JMenuBar`, `JMenuItem`
  - `JPanel`
  - `JFileChooser`
- Some components may contain others (e.g. `JPanel`, `JMenu`)
- Other components are basic entities (e.g. `JLabel`)

Displaying A Label

```
JFrame myFrame = new JFrame(“This is my window”);
myFrame.setSize(1024, 768);
myFrame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

JLabel myLabel
   = new JLabel(“My Label”, SwingConstants.CENTER);
```

The text of the label

The horizontal alignment of the text

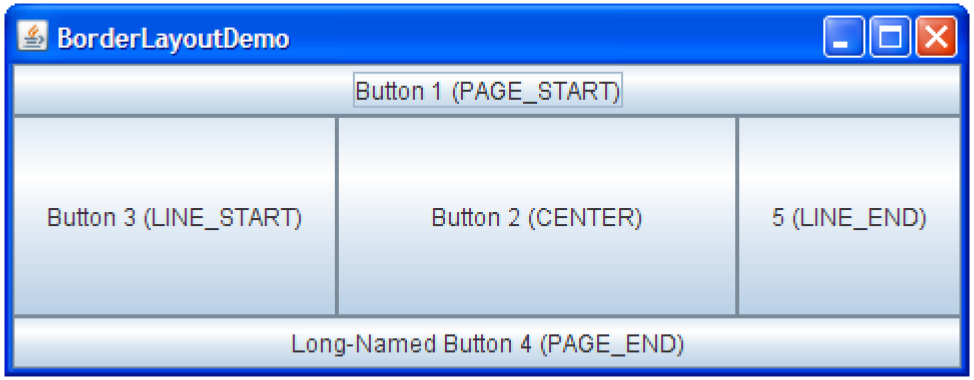
```
mMyFrame.add(myLabel);
```

Adding the `JLabel` component to the window

```
myFrame.setVisible(true);
```

Layout Managers

- A `LayoutManager` takes care of positioning sub-components in a particular way
  - `BorderLayout`, `FlowLayout`, `GridLayout` etc.
- The `BorderLayout`, for example, divides the component into five areas: `NORTH`, `EAST`, `SOUTH`, `WEST`, and `CENTER`



```
myFrame.add(myLabel, BorderLayout.CENTER);
```

Layout Managers

- A `BoxLayout` lays components out either horizontally or vertically

```
JFrame myFrame = new JFrame(“This is my window”);
myFrame.setSize(1024, 768);
myFrame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
myFrame.getContentPane().setLayout(new BoxLayout(
myFrame.getContentPane(),BoxLayout.PAGE_AXIS));
myFrame.add(new JLabel(“Label 1”));
myFrame.add(Box.createVerticalGlue());
myFrame.add(new JLabel(“Label 2”));
myFrame.setVisible(true);
```

Layout Managers

- There are many other kinds of layout managers:
  - `CardLayout`
  - `GridBagLayout`
  - `GridLayout`
  - `FlowLayout`
  - `GroupLayout`
  - `SpringLayout`

Buttons

- Buttons are created using the `JButton` class
  - They can display text and/or an icon
    - We can set the alignment of the text/icon
  - They can be enabled and disabled

```
JButton myButton = new JButton("A Button");
myButton.setVerticalTextPosition(AbstractButton.BOTTOM);
myButton.setHorizontalTextPosition(AbstractButton.CENTER);
myButton.setEnabled(false);
```

Buttons

- We can make buttons do something by adding an object that implements the `ActionListener` interface
  - When the button is pressed, the `actionPerformed` method of the object is invoked

```
JButton myButton = new JButton(“Click Me”);
myButton.addActionListener(new ActionListener() {
public void actionPerformed(ActionEvent e) {
// Respond to the button click
}
});
```

Buttons

- We can also associate an action command string with the button
  - This is available via the `ActionEvent` parameter
  - Can be useful for handling multiple buttons using a single `ActionListener` object

```
JButton myButton = new JButton(“Click Me”);
myButton.setActionCommand(“Click”);
myButton.addActionListener(new ActionListener() {
public void actionPerformed(ActionEvent e) {
   System.out.println(e.getActionCommand());
}
});
```

Putting it together...

- Let's look at an example which brings all these features together
  - An application with a button and a label
    - When we press the button, the label text will change

```
public class SimpleDemo implements Runnable {
   private JLabel theLabel;
   public void run () {
      ...
   }
public static void main(String[] args){
 javax.swing.SwingUtilities.invokeLater(new SimpleDemo());
}
}
```

Putting it together...

```
public void run() {
JFrame myFrame = new JFrame("Our Simple Demo");
myFrame.setSize(512, 384);
myFrame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
theLabel = new JLabel(); // setting the field: a label with
no text
myFrame.add(theLabel, BorderLayout.CENTER);
JButton theButton = new JButton("Click Me");
theButton.addActionListener(new ActionListener() {
public void actionPerformed(ActionEvent e) {
SimpleDemo.this.theLabel.setText("We pressed the button!");
}
});

myFrame.add(theButton, BorderLayout.SOUTH);
myFrame.setVisible(true);
}
```

A reference to the instance of the class that contains the anonymous inner class object

Introducing Threads

- Q: What would happen if were to run a very time-consuming calculation in our button's action listener?

```
theButton.addActionListener(new ActionListener() {
public void actionPerformed(ActionEvent e) {
      BigInteger i = ...
      // Calculate a prime number with 10,000,000
        digits
      theLabel.setText(i);
      }
});
```

- A: Our GUI would freeze up!

Threads

- The Thread class is the programming abstraction that Java uses to represent a thread of execution
- We can create new threads by:
  - Subclassing the Thread class
  - Instantiating a new Thread object using a Runnable
- Threads are started by calling the start method
- We can make the current thread wait until another thread has finished executing by calling the join method
- The static sleep method makes the current thread suspend for a set period of time (given in milliseconds)

Threads

- Spawn a new thread to perform the calculation

```
theButton.addActionListener(new ActionListener() {
   public void actionPerformed(ActionEvent e) {
      Thread t = new Thread(new Runnable() {
         public void run() {
            BigInteger i = ... // Calculate prime
            theLabel.setText(i);
         }
      });
      t.start();
   }
});
```

- The `actionPerformed` method will return immediately (and our GUI will remain responsive) and the thread will run concurrently

Networking in Java

- The `java.net` package contains classes for performing networking functions
- `URL`, provides a flexible high level abstraction for accessing resources over a network
- There are also classes for doing more low-level network access, e.g. TCP/UDP sockets
  - Client uses `Socket` class to connect and communicate with server
  - Server uses `ServerSocket` to listen for clients

Client/server networking

- Client uses **`Socket`** object to connect to server

```
// connect to server
Socket s = new Socket(serverAddress, port);

// send data
OutputStream os = s.getOutputStream();
PrintStream ps = new PrintStream(os);
ps.println("Hi there!");
```

Client/server networking (cont'd)

- Server uses **`ServerSocket`** object to listen for clients

```
// listen for client
ServerSocket ss = new ServerSocket(port);
Socket s = ss.accept();      // waits for connection

// receive data
InputStream is = s.getInputStream();
InputStreamReader isr = new InputStreamReader(is);
BufferedReader br = new BufferedReader(isr);
input = br.readLine();
```