Preliminaries II

Agenda

Objects and classes

- Encapsulation and information hiding
- Documentation
- Packages

Inheritance

- Polymorphism
- Implementation of inheritance in Java
- Abstract classes
- Interfaces
- Generics

Desirable qualities of software systems

- Usefulness
- Timeliness
- Reliability
- Maintainability
- Reusability
- User friendliness
- Efficiency

Not all these qualities are attainable at the same time, nor are they of equal importance.

Object-oriented programming

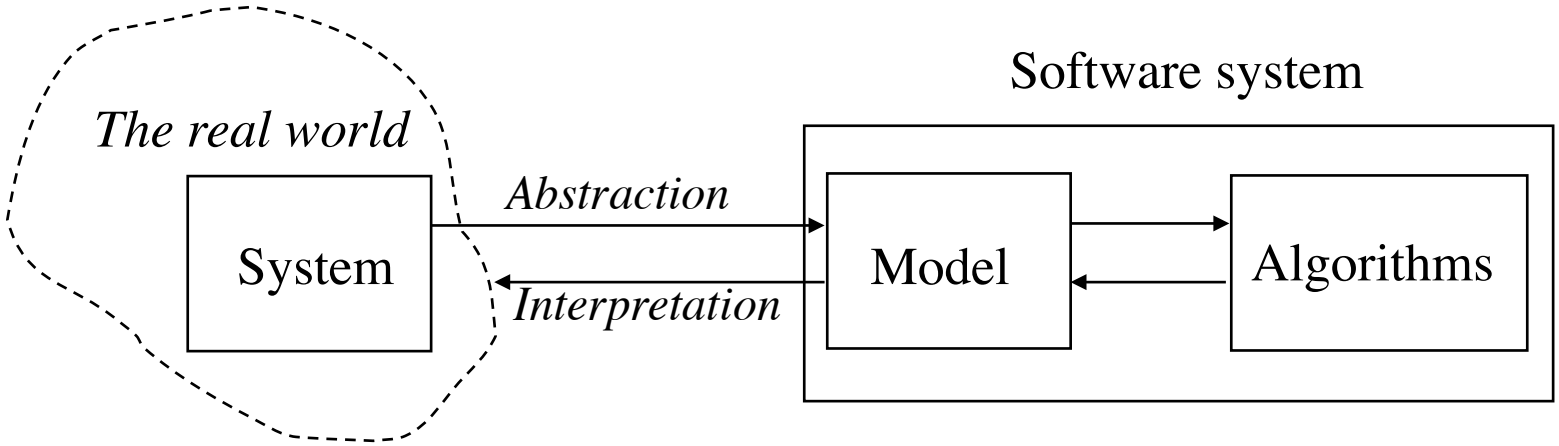
Focuses primarily on

- Reusability
- Maintainability

Maintainability is simplified by

- Flexibility (aspects are easily changeable)
- Simplicity
- Readability

Software development



Abstraction: only essential and relevant parts are captured, others are ignored

Basic concepts in object-oriented programming

Object:

Interpretation in the real world:

An object represents anything in the real world that can be distinctly identified

Representation in the model:

An object has an *identity*, a *state*, and a *behavior*

State and behavior

The **state** of an object is composed of a set of *fields*, or *attributes*. Each field has has a name, a type, and a value.

The **behavior** of an object is defined by a set of *methods* that may operate on the object. In other words, a method may access or manipulate the state of the object.

The **features** of an object refer to the combination of the state and the behavior of the object.

Classes

Class:

Interpretation in the real world:

A *class* represents a set of objects with similar characteristics and behavior. These objects are called *instances* of the class.

Representation in the model:

A *class* characterizes the structure of states and behaviors that are shared by all its instances.

Noun-verb analysis in object oriented design

Noun-verb analysis is a means of identifying classes and their methods.

If you look in the "problem statement" for *nouns*, they will often wind up as *classes*.

If you look for *verbs*, they will be *methods* of those classes.

An example of a class

```
class Point {    // Class name
    int x, y;    // Fields

    void move(int dx, int dy) {   // Method
        x += dx;
        y += dy;
    }
}
```

A class is a template, blueprint, that defines what an object's fields and methods will be.

A simple example

figure 3.1

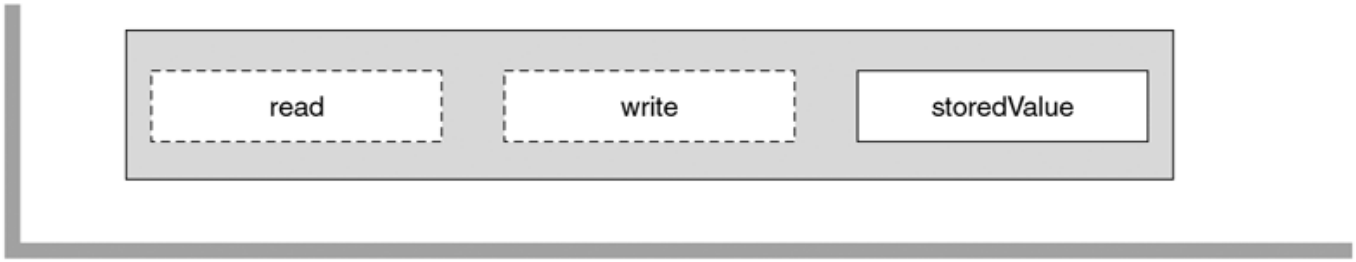
A complete declaration of an `IntCell` class

```
1  // IntCell class
2  //  int read( )         -->  Returns the stored value
3  //  void write( int x ) -->  x is stored
4
5  public class IntCell
6  {
7        // Public methods
8      public int read( )         { return storedValue; }
9      public void write( int x ) { storedValue = x; }
10
11       // Private internal data representation
12     private int storedValue;
13 }
```

A view of the accessibility

figure 3.2

`IntCell` members: `read` and `write` are accessible, but `storedValue` is hidden.



Using the class

```
1  // Exercise the IntCell class
2
3  public class TestIntCell
4  {
5      public static void main( String [ ] args )
6      {
7          IntCell m = new IntCell( );
8
9          m.write( 5 );
10         System.out.println( "Cell contents: " + m.read( ) );
11
12         // The next line would be illegal if uncommented
13         // because storedValue is a private member
14     //  m.storedValue = 0;
15     }
16 }
```

figure 3.3

A simple test routine to show how `IntCell` objects are accessed

javadoc for the class

figure 3.4

The `IntCell` declaration with *javadoc* comments

```
1  /**
2   * A class for simulating an integer memory cell
3   * @author Mark A. Weiss
4   */
5
6  public class IntCell
7  {
8      /**
9       * Get the stored value.
10      * @return the stored value.
11      */
12     public int read( )
13     {
14         return storedValue;
15     }
16
17     /**
18      * Store a value.
19      * @param x the number to store.
20      */
21     public void write( int x )
22     {
23         storedValue = x;
24     }
25
26     private int storedValue;
27 }
```

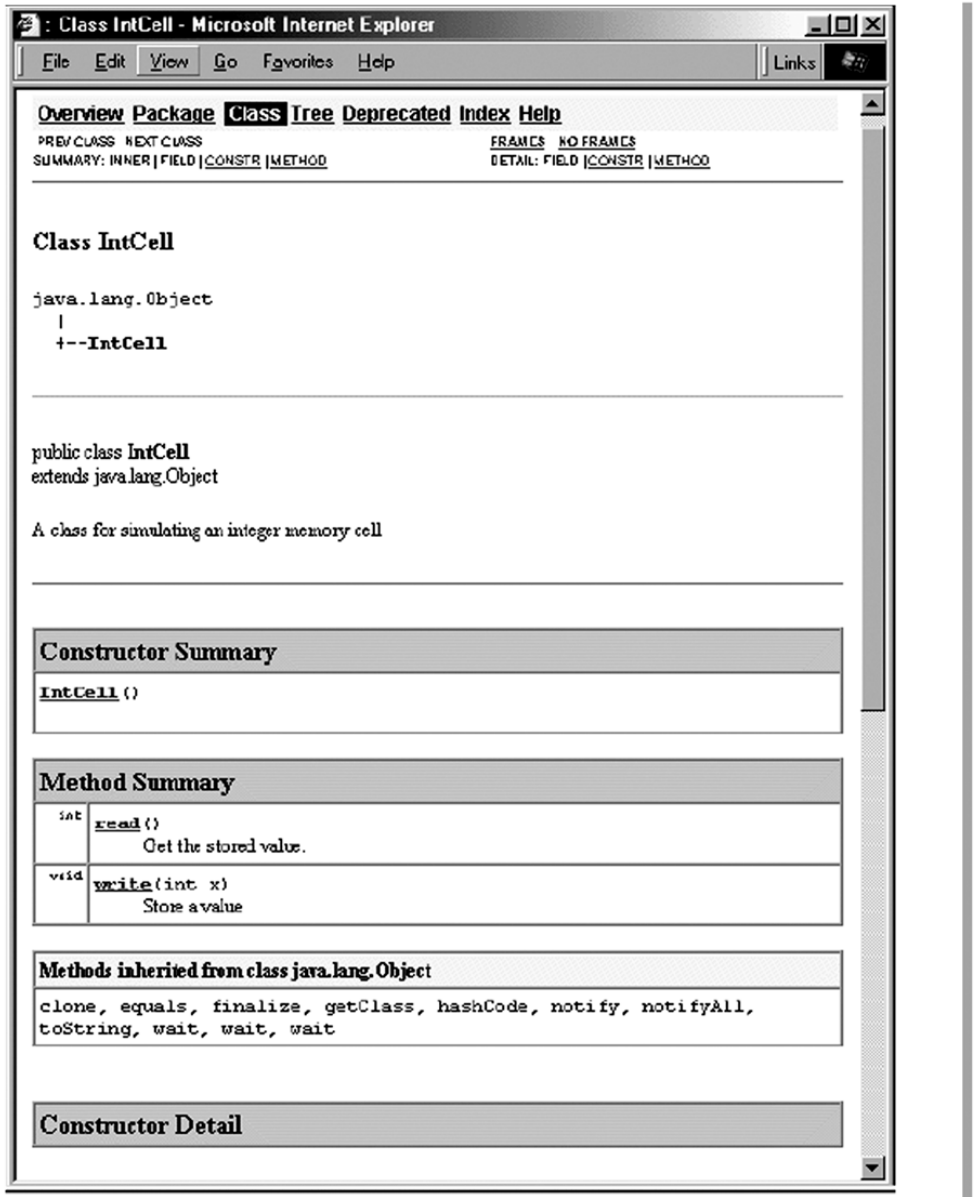


figure 3.5

javadoc output for Figure 3.4 (partial output)

Constructors

```
public class Point {
    int x, y;

    public Point() {   // no-arg constructor
        x = 0; y = 0;
    }

    public Point(int x0, int y0) {
        x = x0; y = y0;
    }
}
```

Constructors may be **overloaded**:
A class may have several constructors, if only they have a different number of parameters, or their types differ.

Creation of `Point` objects

```
Point p1 = new Point();

Point p2 = new Point(13, 17);
```

If no constructor is provided for a class, a default no-arg constructor with an empty body is provided implicitly.

```
1  // Minimal Date class that illustrates some Java features
2  // No error checks or javadoc comments
3
4  public class Date
5  {
6          // Zero-parameter constructor
7      public Date( )
8      {
9          month = 1;
10         day = 1;
11         year = 2010;
12     }
13
14         // Three-parameter constructor
15     public Date( int theMonth, int theDay, int theYear )
16     {
17         month = theMonth;
18         day   = theDay;
19         year  = theYear;
20     }
21
22         // Return true if two equal values
23     public boolean equals( Object rhs )
24     {
25         if( ! ( rhs instanceof Date ) )
26             return false;
27         Date rhDate = ( Date ) rhs;
28         return rhDate.month == month && rhDate.day == day &&
29                rhDate.year == year;
30     }
31
32         // Conversion to String
33     public String toString( )
34     {
35         return month + "/" + day + "/" + year;
36     }
37
38         // Fields
39     private int month;
40     private int day;
41     private int year;
42 }
```

figure 3.6

A minimal Date class that illustrates constructors and the equals and toString methods

The `this` reference

The keyword `this` may be used inside an instance method or constructor to denote the receiving instance of the call.

Example of use:

```
public class Point {
    int x, y;

    public Point(int x, int y) {
        this.x = x; this.y = y;
    }
}
```

Allows access to fields “shadowed” (hidden) by parameters.

Passing `this` as a parameter

```
class Line {
    Point p1, p2;

    public Line(Point p1, Point p2) {
        this.p1 = p1; this.p2 = p2;
    }
}

public class Point {
    int x, y;

    public Line connect(Point otherPoint) {
        return new Line(this, otherPoint);
    }
}
```

Dealing with aliasing

```
public class Point {
    public Line connect(Point otherPoint) {
        if (this == otherPoint)
            return null;
        return new Line(this, otherPoint);
    }
}
```

The `this` shorthand for constructors

Many classes have multiple constructors that behave similarly.

We can use `this` inside a constructor to call one of the other constructors.

Example:

```
public Date() {
    this(1, 1, 2010);
}
```

The call to `this` must be the first statement in the constructor.

The `instanceof` operator

The `instanceof` operator performs a runtime test of class membership.

The result of

```
exp instanceof ClassName
```

is `true` if exp is an instance of `ClassName`, and `false` otherwise.

If `exp` is `null`, the result is always `false`.

Static fields and methods

A **static field** is used when we have a variable that all the instances of the same class need to *share*. Typically, this is a symbolic constant, but need not be.

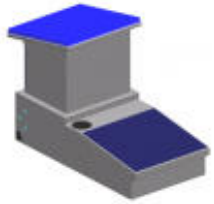
A **static method** is a method that does not need a controlling object, and thus is typically called by supplying the class name in stead of the controlling object.

Static fields and methods are called **class fields** and **class methods**, respectively.
Non-static fields and methods are called **instance fields** and **instance methods**, respectively.

```
1  class Ticket
2  {
3      public Ticket( )
4      {
5          System.out.println( "Calling constructor" );
6          serialNumber = ++ticketCount;
7      }
8
9      public int getSerial( )
10     {
11         return serialNumber;
12     }
13
14     public String toString( )
15     {
16         return "Ticket #" + getSerial( );
17     }
18
19     public static int getTicketCount( )
20     {
21         return ticketCount;
22     }
23
24     private int serialNumber;
25     private static int ticketCount = 0;
26 }
27
```

figure 3.9

The Ticket class: an example of static fields and methods



Static initializers

Static fields are initialized when the class is loaded. Occasionally, we need a complex initialization.

Such an initialization may be performed in a block preceded by the keyword `static`. The block must follow the declaration of the static field.

figure 3.10

An example of a static initializer

```
1  public class Squares
2  {
3      private static double [ ] squareRoots = new double[ 100 ];
4
5      static
6      {
7          for( int i = 0; i < squareRoots.length; i++ )
8              squareRoots[ i ] = Math.sqrt( ( double ) i );
9      }
10     // Rest of class
11 }
```

Packages

Packages are used to organize similar classes. A package is a collection of related classes, interfaces, or other packages.

Package declaration is file based; that is, all classes in the same source file belong to the same package. The name of the package may be given in the beginning of the source file:

```
package PackageName;
```

An example package

The source file Point.java:

```
package geometry;

public class Point {
    int x, y;
    // ...
}
```

The source file Line.java:

```
package geometry;

public class Line {
    Point p1, p2;
}
```

Examples of application of the package

(1) Using the fully qualified name:

```
import geometry;
geometry.Point p = new geometry.Point(3, 4);
```

(2) Importing the class and using the simple class name:

```
import geometry.Point;
Point p = new Point(3, 4);
```

(3) Importing all classes:

```
import geometry.*;
Point p1 = new Point(3, 4),
      p2 = new Point(6, 9);
Line l = new Line(p1, p2);
```

Packages and directory structure

Use of a package requires a directory structure that corresponds to the name of the package.

Example:

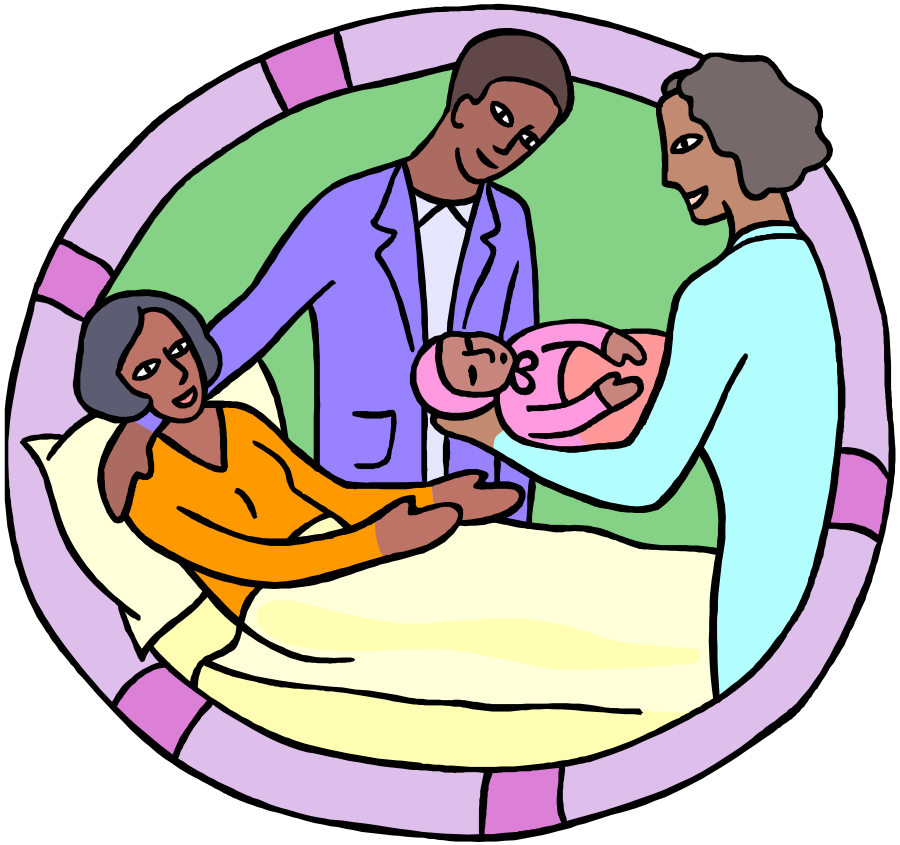
The package

```
dk.ruc.jDisco
```

must be placed in the directory

```
dk/ruc/jDisco
```

Inheritance



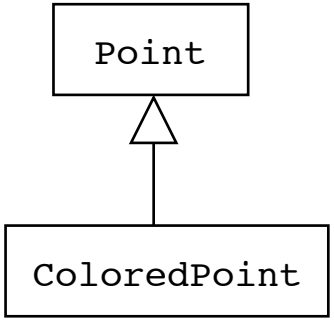
Inheritance

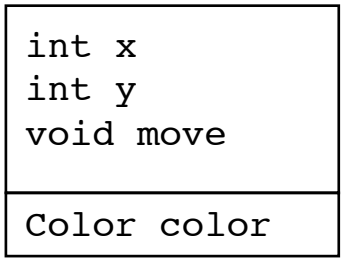
Inheritance is the fundamental object-oriented principle that is used to reuse code among related classes.

Inheritance models the **IS-A relation**.

Example:

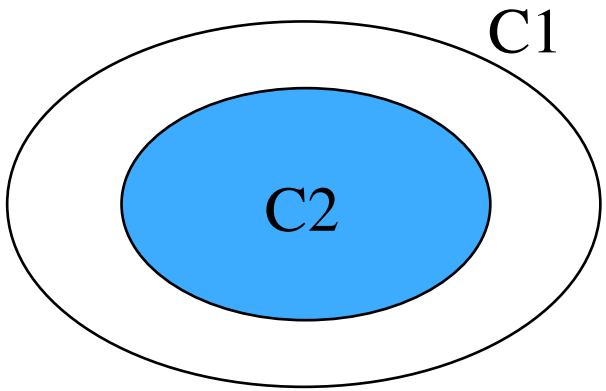
```
class ColoredPoint extends Point {
    Color color;
}
```



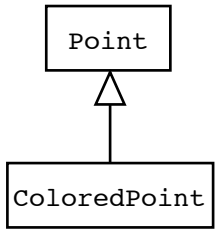


Inherence terminology

A class C2 is said to *inherit* from another class C1, if all instances of C2 are also instances of C1.



C2 is said to be a *subclass* of C1.
C1 is said to be a *superclass* of C2.



Interpretations of inheritance

A subclass is an *extension* of its superclass.

A subclass is a *specialization* of its superclass.

A superclass is a *generalization* of its subclasses.

```
1  class Person
2  {
3      public Person( String n, int ag, String ad, String p )
4        { name = n; age = ag; address = ad; phone = p; }
5
6      public String toString( )
7        { return getName( ) + " " + getAge( ) + " "
8                            + getPhoneNumber( ); }
9
10     public String getName( )
11       { return name; }
12
13     public int getAge( )
14       { return age; }
15
16     public String getAddress( )
17       { return address; }
18
19     public String getPhoneNumber( )
20       { return phone; }
21
22     public void setAddress( String newAddress )
23       { address = newAddress; }
24
25     public void setPhoneNumber( String newPhone )
26       { phone = newPhone; }
27
28     private String name;
29     private int    age;
30     private String address;
31     private String phone;
32 }
```

figure 4.1

The `Person` class stores name, age, address, and phone number.

figure 4.2

The `Student` class stores name, age, address, phone number, and gpa via copy-and-paste.

```
1  class Student
2  {
3      public Student( String n, int ag, String ad, String p,
4                      double g )
5        { name = n; age = ag; address = ad; phone = p; gpa = g; }
6
7      public String toString( )
8        { return getName( ) + " " + getAge( ) + " "
9              + getPhoneNumber( ) + " " + getGPA( ); }
10
11     public String getName( )
12       { return name; }
13
14     public int getAge( )
15       { return age; }
16
17     public String getAddress( )
18       { return address; }
19
20     public String getPhoneNumber( )
21       { return phone; }
22
23     public void setAddress( String newAddress )
24       { address = newAddress; }
25
26     public void setPhoneNumber( String newPhone )
27       { phone = newPhone; }
28
29     public double getGPA( )
30       { return gpa; }
31
32     private String name;
33     private int    age;
34     private String address;
35     private String phone;
36     private double gpa                  // grade point average
37 }
```

```
1  class Student extends Person
2  {
3      public Student( String n, int ag, String ad, String p,
4                      double g )
5        {
6          /* OOPS! Need some syntax; see Section 4.1.6 */
7           gpa = g; }
8
9      public String toString( )
10       { return getName( ) + " " + getAge( ) + " "
11             + getPhoneNumber( ) + " " + getGPA( ); }
12
13     public double getGPA( )
14       { return gpa; }
15
16     private double gpa;
17 }
```

figure 4.3

Inheritance used to create `Student` class

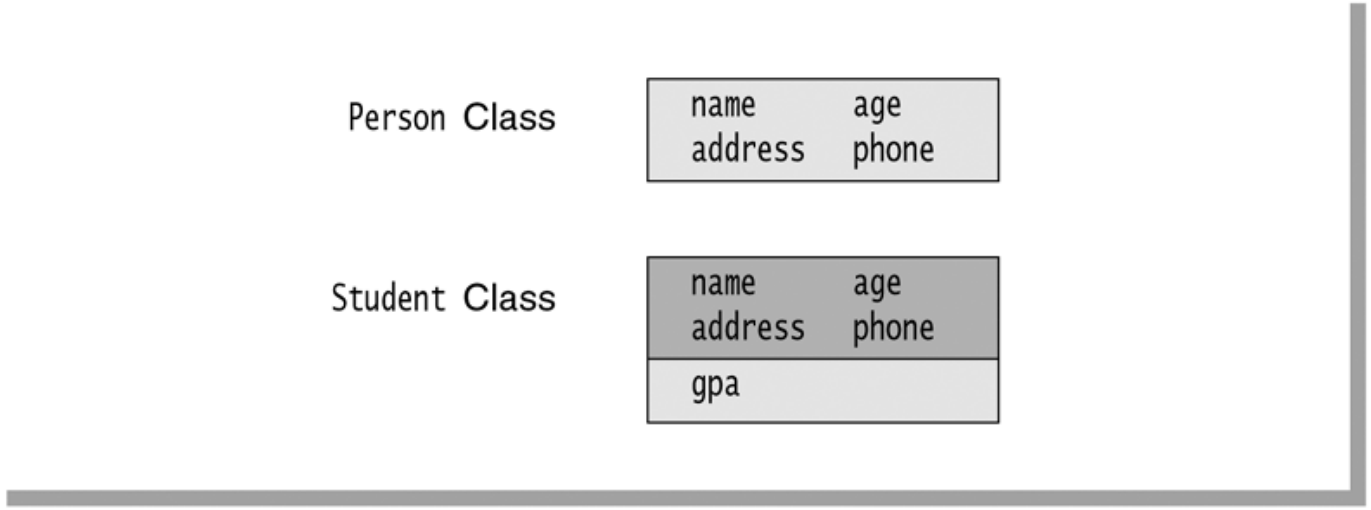


figure 4.4

Memory layout with inheritance. Light shading indicates fields that are private, and accessible only by methods of the class. Dark shading in the `Student` class indicates fields that are not accessible in the `Student` class but are nonetheless present.

figure 4.5

The general layout of inheritance

```
1  public class Derived extends Base
2  {
3      // Any members that are not listed are inherited unchanged
4      // except for constructor.
5
6          // public members
7      // Constructor(s) if default is not acceptable
8      // Base methods whose definitions are to change in Derived
9      // Additional public methods
10
11         // private members
12     // Additional data fields (generally private)
13     // Additional private methods
14 }
```

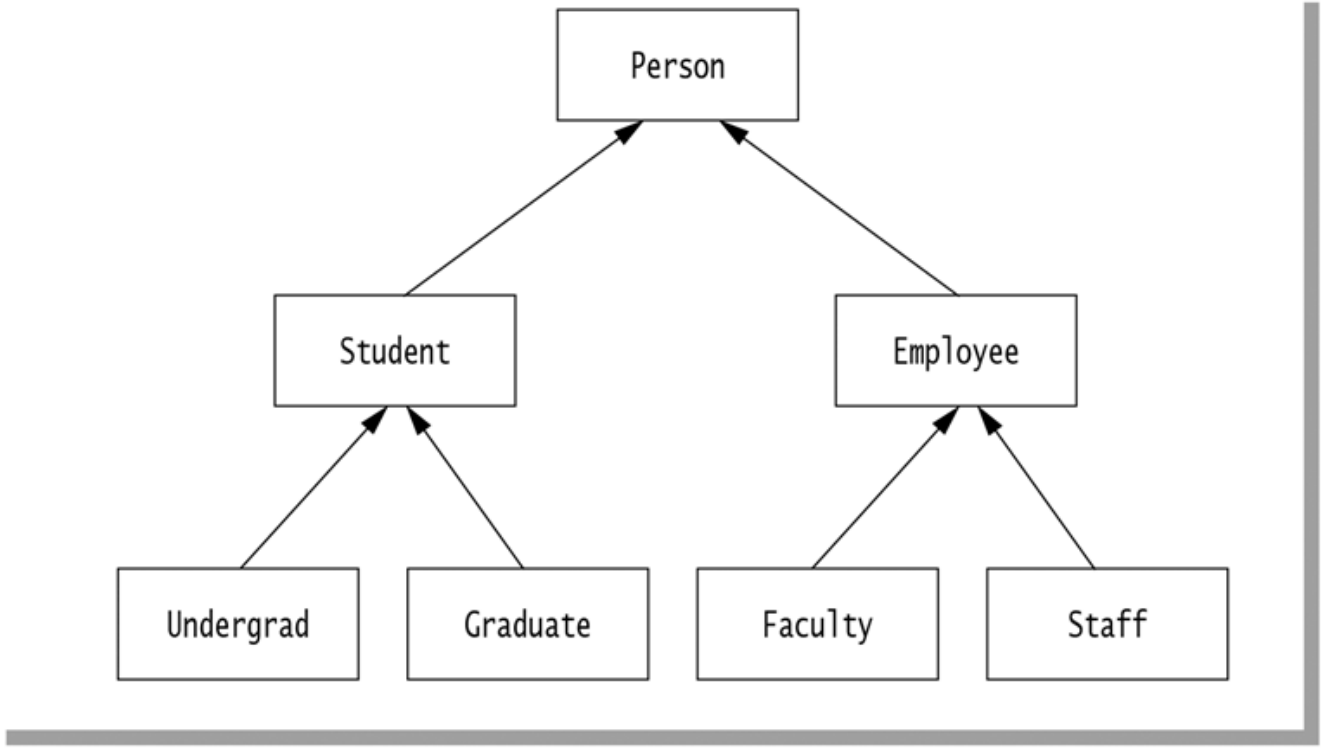


figure 4.6

The `Person` hierarchy

Constructors for subclasses

```
import java.awt.Color;

public class ColoredPoint extends Point {
    public Color color;

    public ColoredPoint(int x, int y, Color color) {
          super(x, y);              // must be the first statement
          this.color = color;
    }

    public ColoredPoint(int x, int y) {    // black point
        this(x, y, Color.black); // must be the first statement
    }

    public ColoredPoint() {
        color = Color.black;     // invokes super() implicitly
    }
}
```

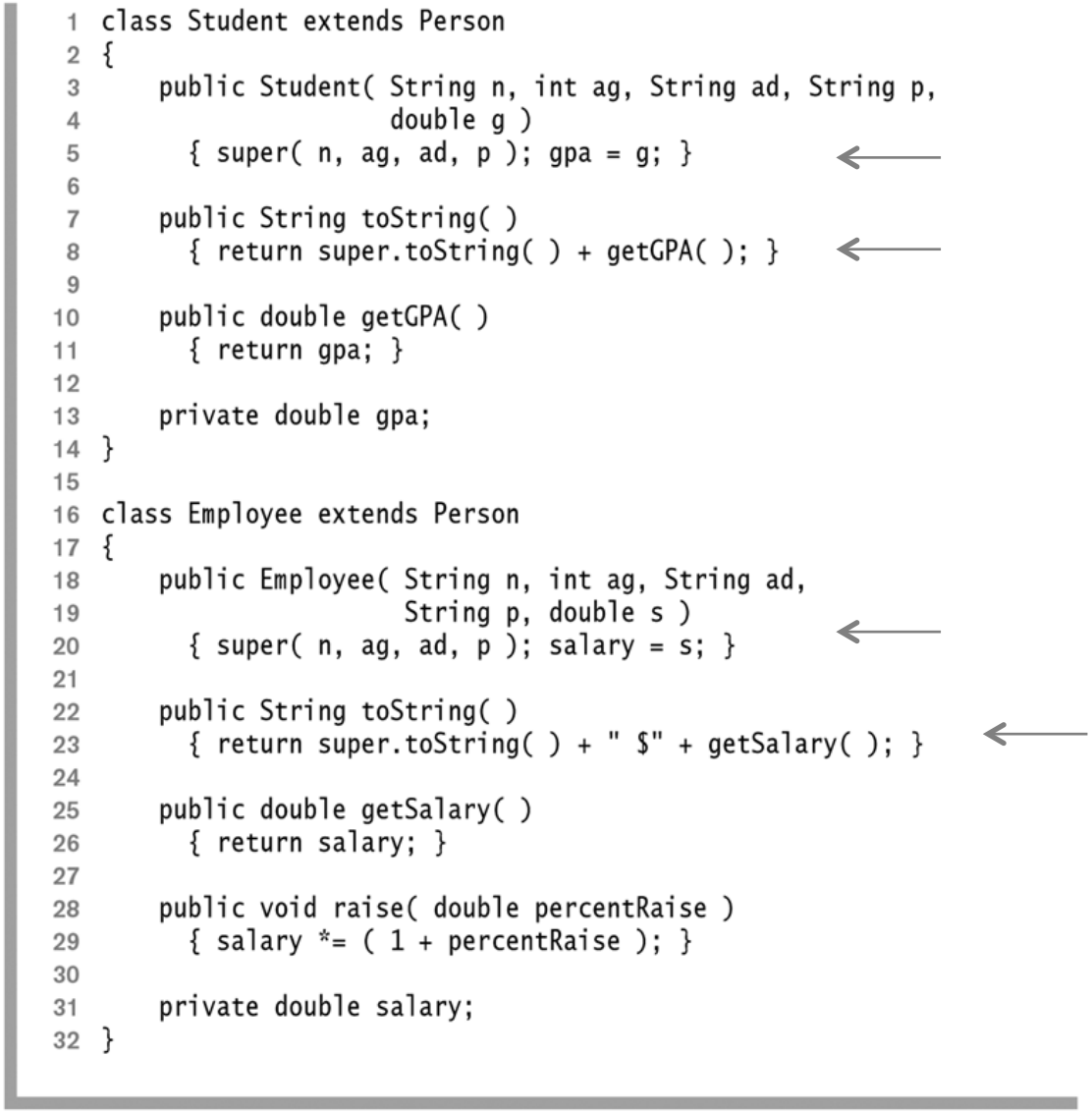
```
1  class Student extends Person
2  {
3      public Student( String n, int ag, String ad, String p,
4                      double g )
5        { super( n, ag, ad, p );  gpa = g; }
6
7      // toString and getAge omitted
8
9      private double gpa;
10 }
```

figure 4.7

A constructor for new class `Student`; uses `super`

figure 4.8

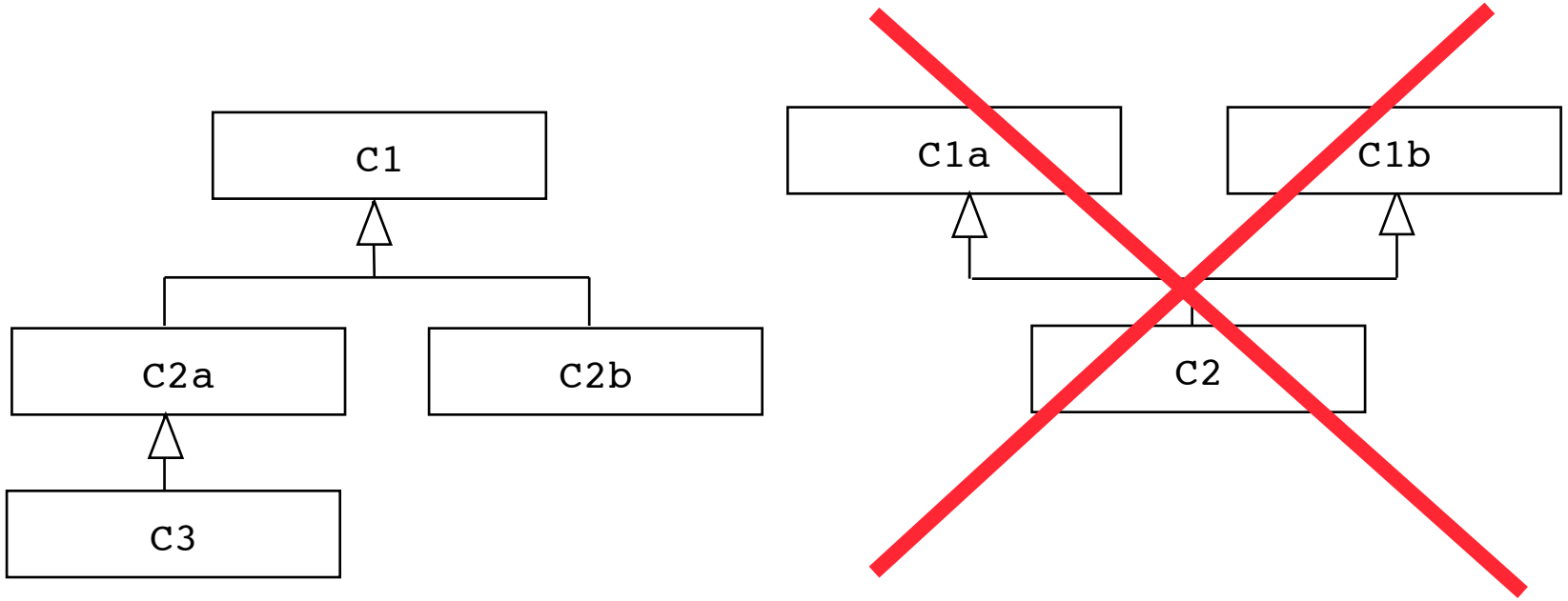
The complete `Student` and `Employee` classes, using both forms of `super`



```
1  class Student extends Person
2  {
3      public Student( String n, int ag, String ad, String p,
4                      double g )
5        { super( n, ag, ad, p ); gpa = g; }
6
7      public String toString( )
8        { return super.toString( ) + getGPA( ); }
9
10     public double getGPA( )
11       { return gpa; }
12
13     private double gpa;
14 }
15
16 class Employee extends Person
17 {
18     public Employee( String n, int ag, String ad,
19                      String p, double s )
20       { super( n, ag, ad, p ); salary = s; }
21
22     public String toString( )
23       { return super.toString( ) + " $" + getSalary( ); }
24
25     public double getSalary( )
26       { return salary; }
27
28     public void raise( double percentRaise )
29       { salary *= ( 1 + percentRaise ); }
30
31     private double salary;
32 }
```

Single inheritance

In Java, a class may inherit from at most one superclass.



Class `Object`

In Java, all classes are organized in a hierarchy (tree) that has the class `Object` as root.

All classes, except `Object`, has a unique superclass.

If no superclass is specified for a class, then `Object` is its superclass.

Class `Object`

```
public class Object {
    public String toString();
    public boolean equals(Object obj);
    public int hashCode();
    protected Object clone();

    ...
}
```

Polymorphic assignment

Rule of assignment: The type of the expression at the right-hand side of an assignment must be a subtype of the type at the left-hand side of the assignment.

```
Person p = new Person(...);
Student s = new Student(...);
Employee e = new Employee(...);

p = s;        // ok

p = p;        // ok

s = e;        // compilation error

e = p;        // compilation error
```

Polymorphic (from Greek): having many forms

Type conversion
(casting)

The rule of assignment is checked at **compile time**.

```
e = p;     // compilation error
```

The rule may be satisfied by narrowing the type at the right-hand side of the assignment:

```
e = (Employee) p;     // explicit cast, ok
```

The validity of an explicit cast is always checked at **run time**.

If the cast is invalid, a `ClassCastException` is thrown.

Overriding methods

Methods in a superclass may be *overridden* by methods defined in a subclass. *Overriding* refers to the introduction of an instance method in a subclass that has the same name, same signature, and a type-compatible return type of a method in the superclass. Implementation of the methods in the subclass *replaces* the implementation in the superclass.

```
class Shape {
    public String toString() {
        return "Shape";
    }
}

class Line extends Shape {
    Point p1, p2;

    public String toString() {
        return "Line from " + p1 + " to " + p2;
    }
}
```

@Override

In Java 5, the annotation `@Override` forces the compiler to check that a method is overridden.

```
class Line extends Shape {
    @Override
    public String toSting() {
        ...
    }
}
```

Misspelling

The compiler prints out the error message

```
method does not override a method from its superclass
    @Override
     ^
```

Polymorphic method invocation

Which implementation of a overridden method will be invoked depends on the actual class of the object referenced by the variable at **run time**, not the declared type of the variable. This is known as *dynamic binding*.

Example:

```
Person p;
p = Math.random() > 0.5 ? new Student(...)
                        : new Employee(...);
System.out.println(p.toString());
```

```
1  class PersonDemo
2  {
3      public static void printAll( Person [ ] arr )
4      {
5          for( int i = 0; i < arr.length; i++ )
6          {
7              if( arr[ i ] != null )
8              {
9                  System.out.print( "[" + i + "] " );
10                 System.out.println( arr[ i ].toString( ) );
11             }
12         }
13     }
14
15     public static void main( String [ ] args )
16     {
17     Person [ ] p = new Person[ 4 ];
18
19         p[0] = new Person( "joe", 25, "New York",
20                            "212-555-1212" );
21         p[1] = new Student( "jill", 27, "Chicago",
22                             "312-555-1212", 4.0 );
23         p[3] = new Employee( "bob", 29, "Boston",
24                              "617-555-1212", 100000.0 );
25
26         printAll( p );
27     }
28 }
```

figure 4.9

An illustration of polymorphism with arrays

Field and method modifiers

`public`
The feature is accessible to any class.

`private`
The feature is only accessible by the class itself.

`protected`
The feature is accessible by the class itself, all its subclasses, and all the classes within the same package.

Neither **`public`**, **`private`**, nor **`protected`**
The feature is accessible by all the classes in the same package.

`final`
A **`final`** field has a constant value, which may not be changed.
A **`final`** method may not be overridden in subclasses.

`static`
A **`static`** field is shared by all instances of the class.
A **`static`** method accesses only static fields.

Design of hierarchies

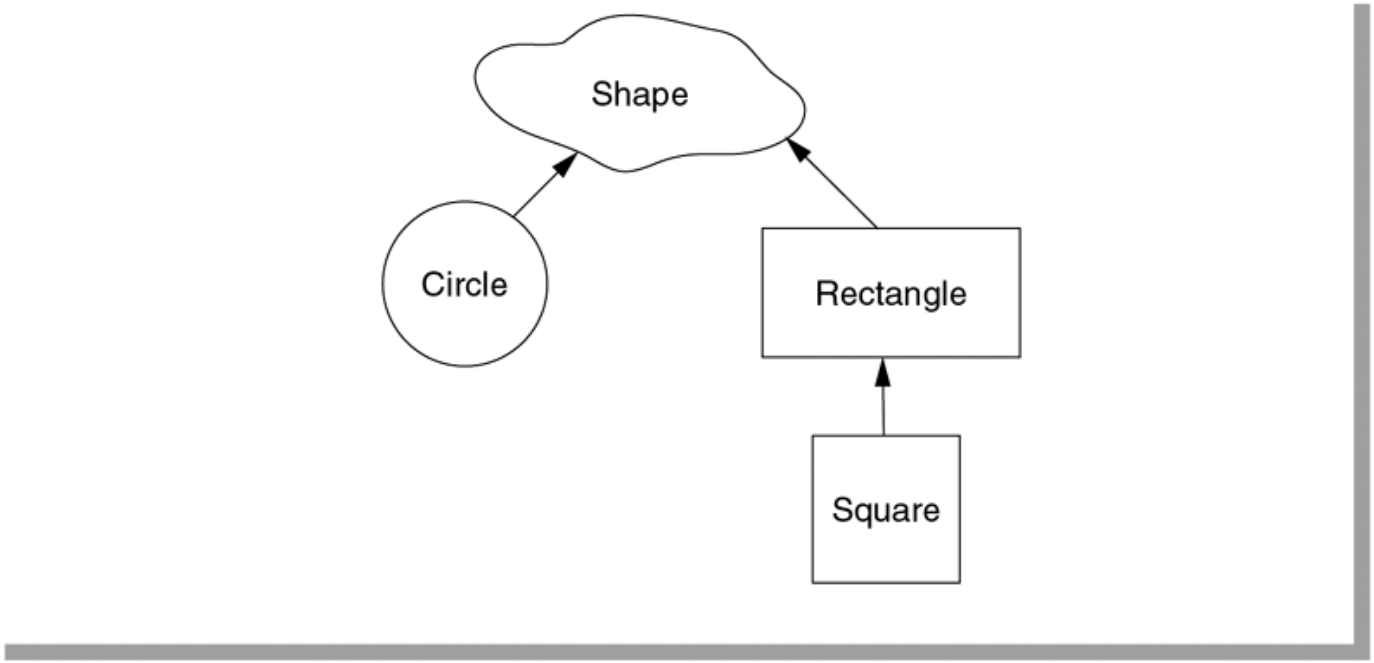


figure 4.10

The hierarchy of shapes used in an inheritance example

figure 4.11

A possible `Shape` class

```
1 public class Shape
2 {
3     public double area( )
4     {
5         return -1;
6     }
7 }
```

```
1  public class Circle extends Shape
2  {
3      public Circle( double rad )
4        { radius = rad; }
5
6      public double area( )
7        { return Math.PI * radius * radius; }
8
9      public double perimeter( )
10       { return 2 * Math.PI * radius; }
11
12     public String toString( )
13       { return "Circle: " + radius; }
14
15     private double radius;
16 }
17
18 public class Rectangle extends Shape
19 {
20     public Rectangle( double len, double wid )
21       { length = len; width = wid; }
22
23     public double area( )
24       { return length * width; }
25
26     public double perimeter( )
27       { return 2 * ( length + width ); }
28
29     public String toString( )
30       { return "Rectangle: " + length + " " + width; }
31
32     public double getLength( )
33       { return length; }
34
35     public double getWidth( )
36       { return width; }
37
38     private double length;
39     private double width;
40 }
41
42 public class Square extends Rectangle
43 {
44     public Square( double side )
45       { super( side, side ); }
46
47     public String toString( )
48       { return "Square: " + getLength( ); }
49 }
```

figure 4.12

`Circle`, `Rectangle`, and `Square` classes

figure 4.13

A sample program that uses the shape hierarchy

```
1  class ShapeDemo
2  {
3      public static double totalArea( Shape [ ] arr )
4      {
5          double total = 0;
6
7          for( Shape s : arr )
8              if( s != null )
9                  total += s.area( );
10
11         return total;
12     }
13
14     public static void printAll( Shape [ ] arr )
15     {
16         for( Shape s : arr )
17             System.out.println( s );
18     }
19
20     public static void main( String [ ] args )
21     {
22         Shape [ ] a = { new Circle( 2.0 ),
23                         new Rectangle( 1.0, 3.0 ),
24                         null, new Square( 2.0 ) };
25
26         System.out.println( "Total area = " + totalArea( a ) );
27         printAll( a );
28     }
29 }
```

Abstract methods and classes

An **abstract method** is a method that declares functionality that all derived class objects must eventually implement. In other words, it says what these objects *can do*. However, it does not provide a default implementation.

A class that has a least one abstract method is an **abstract** class. Java requires that abstract classes explicitly be declared as such (using the keyword `abstract`).

Any attempt to construct an instance of an abstract class is illegal.

```
1 public abstract class Shape
2 {
3     public abstract double area( );
4     public abstract double perimeter( );
5
6     public double semiperimeter( )
7       { return perimeter( ) / 2; }
8 }
```

figure 4.14

An abstract `Shape` class. Figures 4.12 and 4.13 are unchanged.

Interfaces

An **interface** can be thought of as a special form of class, which declares only the *features to be supported* by the class.
Java interfaces provide no implementation. Implementation is deferred to classes that implement the interfaces.

Interface features can be either abstract methods or constants (that is, static and final fields). All features are public.

Like abstract classes, an interface may not have instances.

Implementation of interfaces

A class that *implements* an interface provides implementation for the abstract methods declared in interface by overriding those methods.

```
interface Drawable {
    void draw(Graphics g);
}


public class Line implements Drawable {
    Point p1, p2;

    public void draw(Graphics g) {
        g.drawLine(p1.x, p1.y, p2.x, p2.y);
    }
}
```

Extending and implementing interfaces

Classes that implement an interface must provide implementations of all methods of the interface (unless the class itself should be abstract).

An interface may inherit from one or more interfaces but not from a class.

Java allows only single inheritance for class extension but *multiple inheritance* for interface extension and implementation.

Multiple interface implementations

```
interface Movable {
    void move(int dx, int dy);
}


public class Line implements Drawable, Movable {
    Point p1, p2;

    public void move(int dx, int dy) {
        p1.move(dx, dy);
        p2.move(dx, dy);
    }

    public void draw(Graphics g) {
        g.drawLine(p1.x, p1.y, p2.x, p2.y);
    }
}
```

figure 4.15

The `Comparable` interface (pre-Java 5)

```
1 package java.lang;
2
3 public interface Comparable
4 {
5     int compareTo( Object other );
6 }
```

Contract of the method `compareTo`:

Result < 0,	if `this` precedes `other`;
Result = 0,	if neither `this` precedes `other`, nor `other` precedes `this`;
Result > 0,	if `other` precedes `this`.

```
1  public abstract class Shape implements Comparable
2  {
3      public abstract double area( );
4      public abstract double perimeter( );
5
6      public int compareTo( Object rhs )
7      {
8          Shape other = (Shape) rhs;
9          double diff = area( ) - other.area( );
10
11         if( diff == 0 )
12             return 0;
13         else if( diff < 0 )
14             return -1;
15         else
16             return 1;
17     }
18
19     public double semiperimeter( )
20       { return perimeter( ) / 2; }
21 }
```

figure 4.16

The `Shape` class (final version), which implements the `Comparable` interface

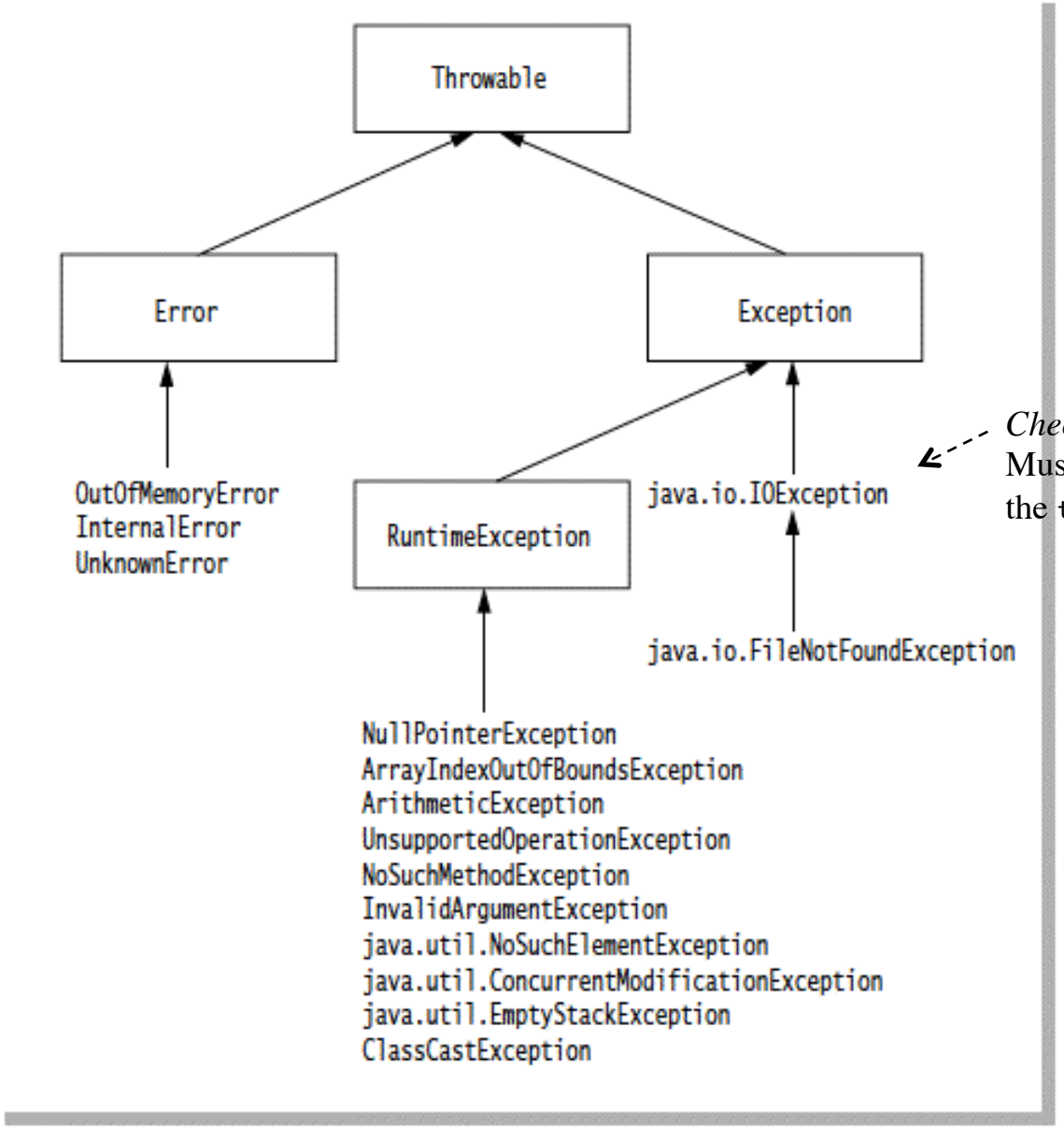


figure 4.18

The hierarchy of exceptions (partial list)

Checked exception:
Must be caught or declared in the `throws` clause

figure 4.19

NoSuchElementException, implemented in weiss.util

```
1  package weiss.util;
2
3  public class NoSuchElementException extends RuntimeException
4  {
5      /**
6       * Constructs a NoSuchElementException with
7       * no detail message.
8       */
9      public NoSuchElementException( )
10     {
11     }
12
13     /*
14      * Constructs a NoSuchElementException with
15      * a detail message.
16      * @param msg the detail message.
17      */
18     public NoSuchElementException( String msg )
19     {
20         super( msg );
21     }
22 }
```

Generics

Using `Object` for genericity

```
1  // MemoryCell class
2  //  Object read( )         -->  Returns the stored value
3  //  void write( Object x ) -->  x is stored
4
5  public class MemoryCell
6  {
7          // Public methods
8      public Object read( )         { return storedValue; }
9      public void write( Object x ) { storedValue = x; }
10
11         // Private internal data representation
12     private Object storedValue;
13 }
```

figure 4.22

A generic `MemoryCell` class (pre-Java 5)

Generic: broadly covering

```
1  public class TestMemoryCell
2  {
3      public static void main( String [ ] args )
4      {
5          MemoryCell m = new MemoryCell( );
6
7          m.write( "37" );
8          String val = (String) m.read( );
9          System.out.println( "Contents are: " + val );
10     }
11 }
```

figure 4.23

Using the generic `MemoryCell` class (pre-Java 5)

figure 4.24

A simplified ArrayList, with add, get, and size (pre-Java 5)

```
1  /**
2   * The SimpleArrayList implements a growable array of Object.
3   * Insertions are always done at the end.
4   */
5  public class SimpleArrayList
6  {
7      /**
8       * Returns the number of items in this collection.
9       * @return the number of items in this collection.
10      */
11     public int size( )
12     {
13         return theSize;
14     }
15
16     /**
17      * Returns the item at position idx.
18      * @param idx the index to search in.
19      * @throws ArrayIndexOutOfBoundsException if index is bad.
20      */
21     public Object get( int idx )
22     {
23         if( idx < 0 || idx >= size( ) )
24             throw new ArrayIndexOutOfBoundsException( );
25         return theItems[ idx ];
26     }
27
28     /**
29      * Adds an item at the end of this collection.
30      * @param x any object.
31      * @return true (as per java.util.ArrayList).
32      */
33     public boolean add( Object x )
34     {
35         if( theItems.length == size( ) )
36         {
37             Object [ ] old = theItems;
38             theItems = new Object[ theItems.length * 2 + 1 ];
39             for( int i = 0; i < size( ); i++ )
40                 theItems[ i ] = old[ i ];
41         }
42
43         theItems[ theSize++ ] = x;
44         return true;
45     }
46
47     private static final int INIT_CAPACITY = 10;
48
49     private int         theSize = 0;
50     private Object [ ] theItems = new Object[ INIT_CAPACITY ];
51 }
```

Wrapper classes

Because in Java primitive types are not objects, *wrapper* classes are provided to "wrap" the values of primitive types into objects when needed. Each primitive type has a corresponding wrapper class.

Primitive type	Wrapper class
`boolean`	`Boolean`
`byte`	`Byte`
`char`	**`Character`**
`double`	`Double`
`float`	`Float`
`int`	**`Integer`**
`long`	`Long`
`short`	`Short`

Each wrapper object is *immutable* (meaning its state can never change), and stores one primitive value that is set when the object is constructed.

Boxing conversions

Automatic conversion of a value of a primitive type to an instance of a wrapper class is called **auto-boxing**.

```
Integer val = 7;
```
is equivalent to
```
Integer val = new Integer(7);
```

Automatic conversion of an instance of a wrapper class to a value of a primitive type is called **auto-unboxing**.

```
int x = val;
```
is equivalent to
```
int x = val.intValue();
```

```
1  import java.util.ArrayList;
2
3  public class BoxingDemo
4  {
5      public static void main( String [ ] args )
6      {
7          ArrayList<Integer> arr = new ArrayList<Integer>( );
8
9          arr.add( new Integer( 46 ) );
10         Integer wrapperVal = arr.get( 0 );
11         int val = wrapperVal.intValue( );
12         System.out.println( "Position 0: " + val );
13     }
14 }
```

figure 4.25

An illustration of the `Integer` wrapper class using Java 5 generic `ArrayList`

Without automatic conversion

figure 4.26

Autoboxing and unboxing

```
1  import java.util.ArrayList;
2
3  public class BoxingDemo
4  {
5      public static void main( String [ ] args )
6      {
7          ArrayList<Integer> arr = new ArrayList<Integer>( );
8
9          arr.add( 46 );
10         int val = arr.get( 0 );
11         System.out.println( "Position 0: " + val );
12     }
13 }
```

```
1  import java.math.BigInteger;
2
3  class FindMaxDemo
4  {
5      /**
6       * Return max item in a.
7       * Precondition: a.length > 0
8       */
9      public static Comparable findMax( Comparable [ ] a )
10     {
11         int maxIndex = 0;
12
13         for( int i = 1; i < a.length; i++ )
14             if( a[ i ].compareTo( a[ maxIndex ] ) > 0 )
15                 maxIndex = i;
16
17         return a[ maxIndex ];
18     }
19
20     /**
21      * Test findMax on BigInteger and String objects.
22      */
23     public static void main( String [ ] args )
24     {
25         BigInteger [ ] bi1 = { new BigInteger( "8764" ),
26                                new BigInteger( "29345" ),
27                                new BigInteger( "1818" ) };
28
29         String [ ] st1 = { "Joe", "Bob", "Bill", "Zeke" };
30
31         System.out.println( findMax( bi1 ) );
32         System.out.println( findMax( st1 ) );
33     }
34 }
```

figure 4.29

A generic `findMax` routine, with demo using shapes and strings (pre-Java 5)

Generics in Java 5

Generics allow a type or method to operate on objects of various types while providing compile-time type safety.

In Java 5, classes, interfaces and methods may be declared with one or more *type parameters*.

Benefits:

- Compile-time type safety
- Greater readability (unnecessary casting is avoided)

A generic `ArrayList`

```
public class ArrayList<E> implements List {
    public boolean add(E o);
    public E get(int i);
    public boolean addAll(Collection<? extends E> c);
    ...
}
```

The name of the type parameter, here `E`, may be chosen freely. Alternative: `ElementType`.

The notation `<? extends E>` denotes an arbitrary subtype of `E` (or `E` itself). The wildcard character `?` stands for an unknown type.

Example of application

```
ArrayList<String> names = new ArrayList<String>();

names.add("Barack Obama");     // OK
names.add(new Integer(21));    // Compile-time error

String name = names.get(0);    // OK without cast

for (String name : names)
    System.out.println(name.toUpperCase());
```

figure 4.30

Generic implementation of the `MemoryCell` class

```
1 public class GenericMemoryCell<AnyType>
2 {
3     public AnyType read( )
4       { return storedValue; }
5     public void write( AnyType x )
6       { storedValue = x; }
7
8     private AnyType storedValue;
9 }
```

Generic `Comparable` interface

```
1 package java.lang;
2
3 public interface Comparable<AnyType>
4 {
5     public int compareTo( AnyType other );
6 }
```

figure 4.31

`Comparable` interface, Java 5 version which is generic

Generic collections are not covariant

```
1  public static double totalArea( ArrayList<Shape> arr )
2  {
3      double total = 0;
4
5      for( Shape s : arr )
6          if( s != null )
7              total += s.area( );
8
9      return total;
10 }
```

figure 4.32

totalArea method that does not work if passed an ArrayList<Square>

Covariance: Type compatibility

`ArrayList<Square>` is not type compatible with `ArrayList<Shape>`.
(In contrast, `Square[]` is type compatible with `Shape[]`. Arrays are covariant.)

Use of wildcards with bound

figure 4.33

totalArea method revised with wildcards that works if passed an ArrayList<Square>

```
1  public static double totalArea( ArrayList<? extends Shape> arr )
2  {
3      double total = 0;
4
5      for( Shape s : arr )
6          if( s != null )
7              total += s.area( );
8
9      return total;
10 }
```

Generic static method

```
1 public static <AnyType>
2 boolean contains( AnyType [ ] arr, AnyType x )
3 {
4     for( AnyType val : arr )
5         if( x.equals( val ) )
6             return true;
7
8     return false;
9 }
```

figure 4.34

Generic static method to search an array

The type parameters in a generic method precede the return type.

```
1  public static <AnyType> AnyType findMax( AnyType [ ] a )
2  {
3      int maxIndex = 0;
4
5      for( int i = 1; i < a.length; i++ )
6          if( a[ i ].compareTo( a[ maxIndex ] ) > 0 )
7              maxIndex = i;
8
9      return a[ maxIndex ];
10 }
```

figure 4.35

Generic static method to find largest element in an array that does not work

The compiler cannot prove that the call to `compareTo` at line 6 is valid.

Using type bounds

figure 4.36

Generic static method to find largest element in an array. Illustrates a bounds on the type parameter

```
1  public static <AnyType extends Comparable<? super AnyType>>
2  AnyType findMax( AnyType [ ] a )
3  {
4      int maxIndex = 0;
5
6      for( int i = 1; i < a.length; i++ )
7          if( a[ i ].compareTo( a[ maxIndex ] ) > 0 )
8              maxIndex = i;
9
10     return a[ maxIndex ];
11 }
```

The notation `<? extends AnyType>` denotes an arbitrary supertype of `AnyType` (or `AnyType` itself).

figure 4.37

SimpleArrayList class using generics

```
1  /**
2   * The GenericSimpleArrayList implements a growable array.
3   * Insertions are always done at the end.
4   */
5  public class GenericSimpleArrayList<AnyType>
6  {
7      /**
8       * Returns the number of items in this collection.
9       * @return the number of items in this collection.
10      */
11     public int size( )
12     {
13         return theSize;
14     }
15
16     /**
17      * Returns the item at position idx.
18      * @param idx the index to search in.
19      * @throws ArrayIndexOutOfBoundsException if index is bad.
20      */
21     public AnyType get( int idx )
22     {
23         if( idx < 0 || idx >= size( ) )
24             throw new ArrayIndexOutOfBoundsException( );
25         return theItems[ idx ];
26     }
27
28     /**
29      * Adds an item at the end of this collection.
30      * @param x any object.
31      * @return true.
32      */
33     public boolean add( AnyType x )
34     {
35         if( theItems.length == size( ) )
36         {
37             AnyType [ ] old = theItems;
38               theItems = (AnyType [])new Object[size( )*2 + 1];
39             for( int i = 0; i < size( ); i++ )
40                 theItems[ i ] = old[ i ];
41         }
42
43         theItems[ theSize++ ] = x;
44         return true;
45     }
46
47     private static final int INIT_CAPACITY = 10;
48
49     private int theSize;
50     private AnyType [ ] theItems;
51 }
```

Because we cannot generate arrays of generic objects, we must create an array of `Object` and use a typecast.

figure 4.38

The SimpleRectangle class, which does not implement the Comparable interface

```
1  // A simple rectangle class.
2  public class SimpleRectangle
3  {
4      public SimpleRectangle( int len, int wid )
5        { length = len; width = wid; }
6
7      public int getLength( )
8        { return length; }
9
10     public int getWidth( )
11       { return width; }
12
13     public String toString( )
14       { return "Rectangle " + getLength( ) + " by "
15                             + getWidth( ); }
16
17     private int length;
18     private int width;
19 }
```

The `Comparator` interface

```
1  package weiss.util;
2
3  /**
4   * Comparator function object interface.
5   */
6  public interface Comparator<AnyType>
7  {
8      /**
9       * Return the result of comparing lhs and rhs.
10      * @param lhs first object.
11      * @param rhs second object.
12      * @return < 0 if lhs is less than rhs,
13      *           0 if lhs is equal to rhs,
14      *         > 0 if lhs is greater than rhs.
15      */
16     int compare( AnyType lhs, AnyType rhs );
17 }
```

figure 4.39

The `Comparator` interface, originally defined in `java.util` and rewritten for the `weiss.util` package

figure 4.40

The generic `findMax` algorithm, using a function object

```
1  public class Utils
2  {
3      // Generic findMax with a function object.
4      // Precondition: a.length > 0.
5      public static <AnyType> AnyType
6      findMax( AnyType [ ] a, Comparator<? super AnyType> cmp )
7      {
8          int maxIndex = 0;
9
10         for( int i = 1; i < a.length; i++ )
11             if( cmp.compare( a[ i ], a[ maxIndex ] ) > 0 )
12                 maxIndex = i;
13
14         return a[ maxIndex ];
15     }
16 }
```

figure 4.41

An example of a function object

```
1  class OrderRectByWidth implements Comparator<SimpleRectangle>
2  {
3      public int compare( SimpleRectangle r1, SimpleRectangle r2 )
4        { return( r1.getWidth() - r2.getWidth() ); }
5  }
6
7  public class CompareTest
8  {
9      public static void main( String [ ] args )
10     {
11         SimpleRectangle [ ] rects = new SimpleRectangle[ 4 ];
12         rects[ 0 ] = new SimpleRectangle( 1, 10 );
13         rects[ 1 ] = new SimpleRectangle( 20, 1 );
14         rects[ 2 ] = new SimpleRectangle( 4, 6 );
15         rects[ 3 ] = new SimpleRectangle( 5, 5 );
16
17         System.out.println( "MAX WIDTH: " +
18             Utils.findMax( rects, new OrderRectByWidth( ) ) );
19     }
20 }
```

Static nested class

```
1  import java.util.Comparator;
2
3  class CompareTestInner1
4  {
5      private static class OrderRectByWidth implements Comparator<SimpleRectangle>
6      {
7          public int compare( SimpleRectangle r1, SimpleRectangle r2 )
8            { return r1.getWidth( ) - r2.getWidth( ); }
9      }
10
11     public static void main( String [ ] args )
12     {
13         SimpleRectangle [ ] rects = new SimpleRectangle[ 4 ];
14         rects[ 0 ] = new SimpleRectangle( 1, 10 );
15         rects[ 1 ] = new SimpleRectangle( 20, 1 );
16         rects[ 2 ] = new SimpleRectangle( 4, 6 );
17         rects[ 3 ] = new SimpleRectangle( 5, 5 );
18
19         System.out.println( "MAX WIDTH: " +
20              Utils.findMax( rects, new OrderRectByWidth( ) ) );
21     }
22 }
```

figure 4.42

Using a nested class to hide the `OrderRectByWidth` class declaration

Local inner class

```
1  class CompareTestInner2
2  {
3      public static void main( String [ ] args )
4      {
5          SimpleRectangle [ ] rects = new SimpleRectangle[ 4 ];
6          rects[ 0 ] = new SimpleRectangle( 1, 10 );
7          rects[ 1 ] = new SimpleRectangle( 20, 1 );
8          rects[ 2 ] = new SimpleRectangle( 4, 6 );
9          rects[ 3 ] = new SimpleRectangle( 5, 5 );
10
11         class OrderRectByWidth implements Comparator<SimpleRectangle>
12         {
13             public int compare( SimpleRectangle r1, SimpleRectangle r2 )
14               { return r1.getWidth( ) - r2.getWidth( ); }
15         }
16
17         System.out.println( "MAX WIDTH: " +
18              Utils.findMax( rects, new OrderRectByWidth( ) ) );
19     }
20 }
```

figure 4.43

Using a local class to hide the `OrderRectByWidth` class declaration further

Non-static nested classes are called *inner classes*.

Anonymous inner class

```
1  class CompareTestInner3
2  {
3      public static void main( String [ ] args )
4      {
5          SimpleRectangle [ ] rects = new SimpleRectangle[ 4 ];
6          rects[ 0 ] = new SimpleRectangle( 1, 10 );
7          rects[ 1 ] = new SimpleRectangle( 20, 1 );
8          rects[ 2 ] = new SimpleRectangle( 4, 6 );
9          rects[ 3 ] = new SimpleRectangle( 5, 5 );
10
11         System.out.println( "MAX WIDTH: " +
12             Utils.findMax( rects, new Comparator<SimpleRectangle>( )
13             {
14                 public int compare( SimpleRectangle r1, SimpleRectangle r2 )
15                   { return r1.getWidth( ) - r2.getWidth( ); }
16             }
17         ) );
18     }
19 }
```

figure 4.44

Using an anonymous class to implement the function object

```
1  final class SomeClass
2  {
3      public SomeClass( int i )
4        { id = i; }
5
6      public boolean sameVal( Object other )
7        { return other instanceof SomeClass && equals( other ); }
8
9      /**
10      * This is a bad implementation!
11      * other has the wrong type, so this does
12      * not override Object's equals.
13      */
14     public boolean equals( SomeClass other )
15       { return other != null && id == other.id; }
16
17     private int id;
18 }
19
20 class BadEqualsDemo
21 {
22     public static void main( String [ ] args )
23     {
24         SomeClass obj1 = new SomeClass( 4 );
25         SomeClass obj2 = new SomeClass( 4 );
26
27         System.out.println( obj1.equals( obj2 ) );   // true
28         System.out.println( obj1.sameVal( obj2 ) );  // false
29     }
30 }
```

figure 4.46

An illustration of overloading `equals` instead of overriding `equals`. Here, the call to the `sameVal` returns false!