CM1210

Object Oriented Java Programming

SERIES 4

Object Oriented Programming with Composition & Inheritance and Polymorphism

Class Re-Use

- Lets look again at how **reusing existing** classes, brings a very important dimension to the Java language.
- Namely, the ability to utilise its **Object Oriented Programming (OOP)** approach.
- There are TWO ways in which existing classes can be re-used:

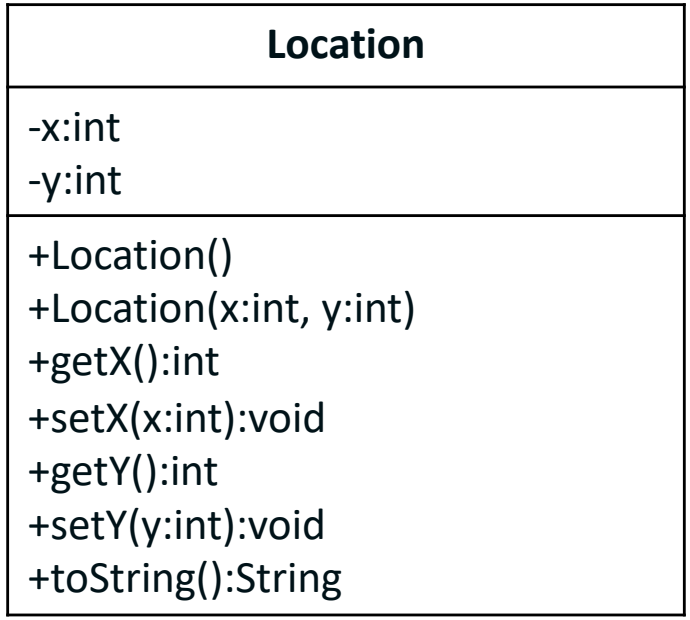
Composition

Inheritance

Composition

Composition (aka aggregation)

- We've seen this one already ☺
- You define a **new** class, composed of **existing** classes.
- Consider an example:
  - Suppose we had written a class called `Location`
  - Its class diagram is as follows:



Composition

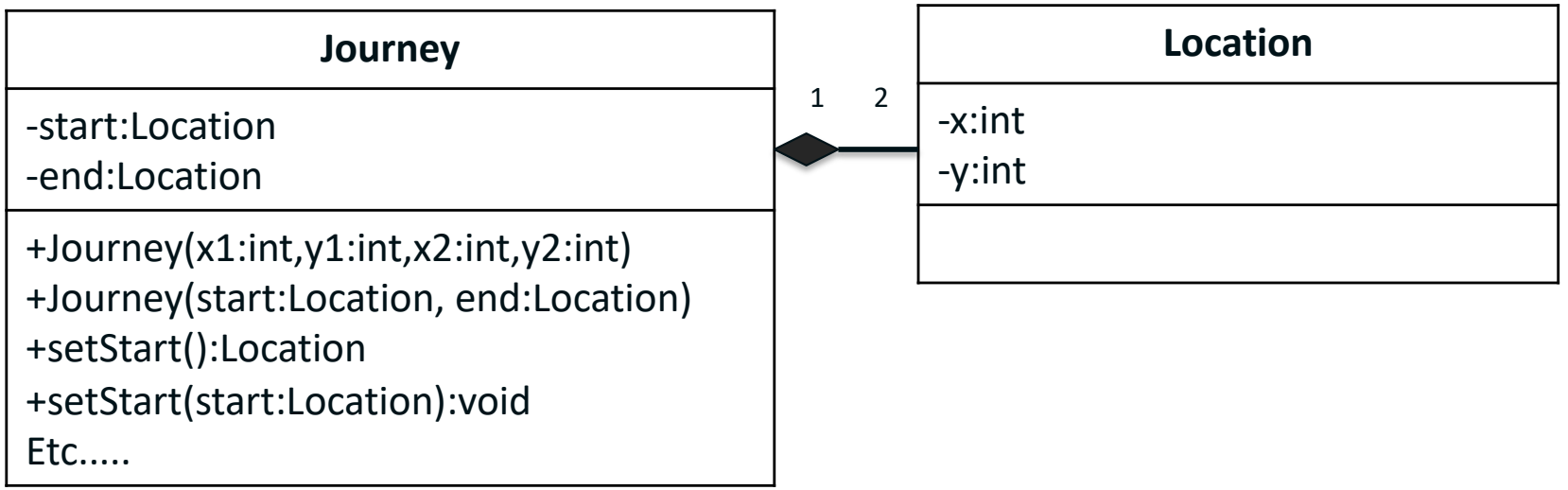
Composition (aka aggregation)

An example

- Suppose we decide to write a **class** called **Journey**.
- We could now use our Location class via **composition**.
- We can say:
  - "A Journey is composed of two locations"
  - Or "Journey has two locations"
- **Composition** exhibits a **"has-a"** relationship.
- The following slide shows this using UML notation.
  - Composition is represented as a diamond head pointing to its constituent class(es).

Composition

Composition (aka aggregation)

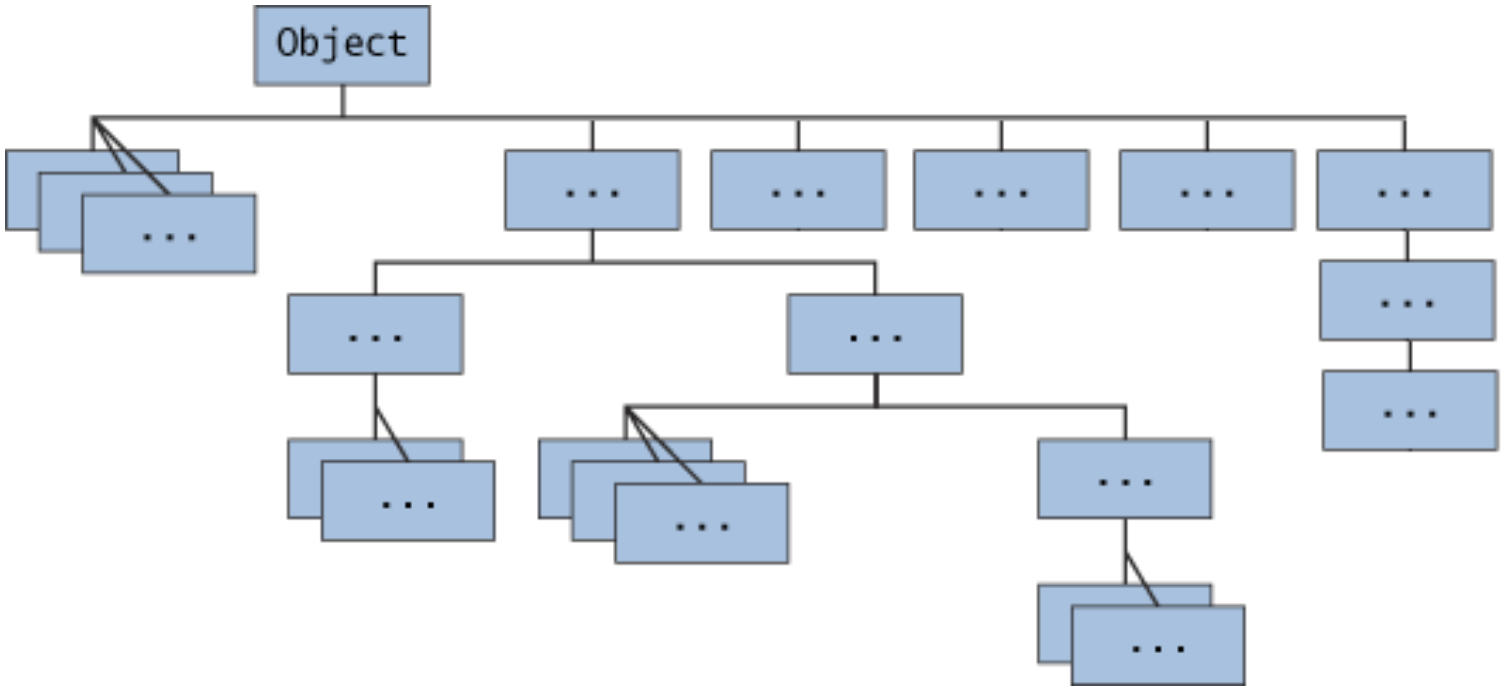


Inheritance

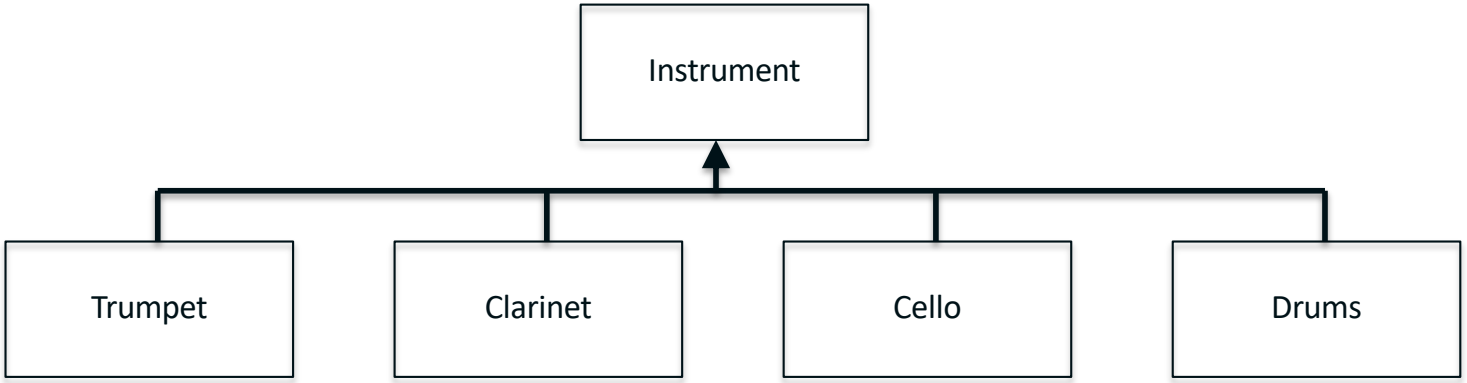
- In OOP, we can organise classes **hierarchically**, in attempt to **avoid duplication** and **reduce redundancy**.
- The notion of inheritance is simple but powerful.
- When you create new classes, if there is an existing class that includes some of the code your want, you can **derive** your **new class** from the **existing one**.
- This allows you to **reuse** the variables and methods of the existing class, without the need to write (and debug!) new code.
- **Inheritance** exhibits a **“is-a”** relationship

Java Platform Class Hierarchy

- The `Object` class in the java.lang package, defines and implements behaviour common to ALL classes (including any you write).
- Many classes derive directly from Object, other classes from those to form a hierarchy of classes:



Hierarchy



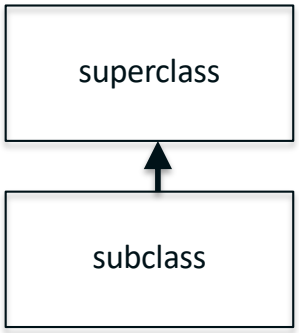
- Classes in the lower hierarchy **inherit** all the **variables** (static attributes) and **methods** (dynamic behaviours) from the higher hierarchies.
- A class in the lower hierarchy is called a **subclass** (or derived, child, extended class).
- A class in the upper hierarchy is called a **superclass** (or base, parent class).
- Separating out all the common variables and methods into the **superclasses**, and leaving the specialised variables and methods in the **subclasses**, allows **redundancy** to be greatly **reduced** or even **eliminated**.
- The common variables do **not** need to be **repeated** in every subclass.

Hierarchy

- Each subclass **inherits ALL** variables and methods from its superclasses, including its immediate parent and any ancestors.
- But please note: a subclass is **NOT** a “subset” of a superclass.
- In fact, subclass is a “superset” of a superclass.
- It is because a subclass inherits all the variables and methods of the superclass; but also, it extends the superclass by providing **MORE** variables and methods.

Defining a subclass

- In Java, you define a subclass using the keyword "**extends**", e.g:
  - Class Trumpet **extends** Instrument {.....}
  - Class Teenager **extends** Human {....}



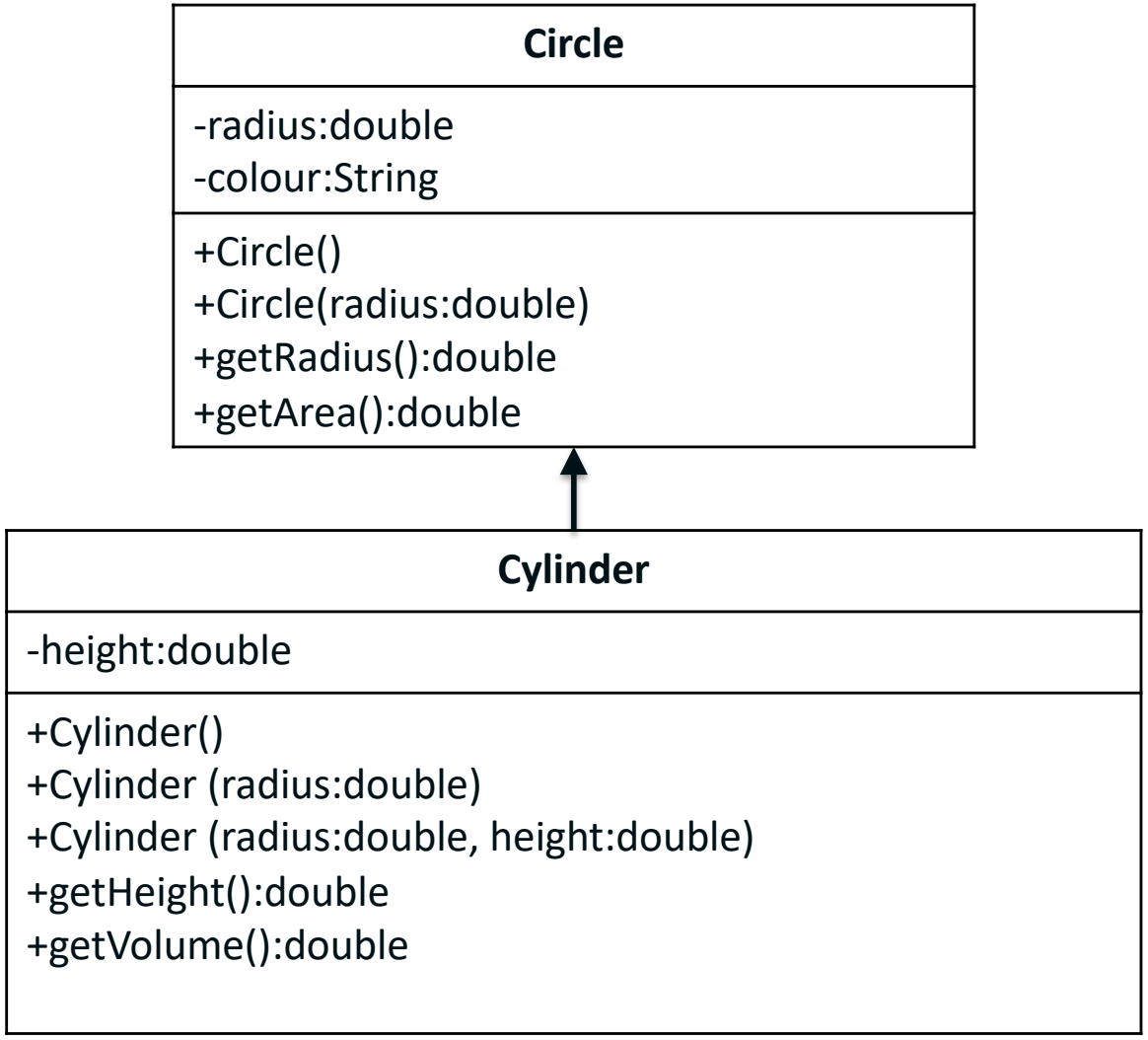
  - Excepting `Object`, which has no superclass, every class has **ONE** and **ONLY ONE** direct superclass (single inheritance).
  - In the absence of any other explicit superclass, every class is implicitly a subclass of `Object`.

Inheritance Example

Worked example

- Assuming we have a class called **Circle** (our **superclass**), lets derive a **subclass** called **Cylinder**.
- The Cylinder class will **inherit all member variables** (radius and colour) and **methods** (getRadius(), getArea(), etc..) **from** the **superclass** Circle
- The Cylinder class will further define a **new variable** for **height**, and two public **methods** called **getHeight()** and **getVolume()** and its own **constructors**.
- Code re-use like this is one of the most important properties of OOP. (Why write it again, if it already exists!!).

Inheritance Example



Inheritance Example

- You can use keyword "this" to refer to ***this*** instance inside a class definition.
- One of the main usage of keyword this is to resolve ambiguity.

```
public class Circle {
   double radius;  // Member variable called "radius"
   public Circle(double radius) { // Method's argument also called "radius"
      this.radius = radius;
         // "this.radius" refers to this instance's member variable
         // "radius" resolved to the method's argument.
   }
   ...
}
```

- In the above codes, there are two identifiers called radius - a member variable of the class and the method's argument. This causes **naming conflict**.
- To avoid the naming conflict, you could name the method's argument r instead of radius. However, radius is more approximate and meaningful in this context. Java provides a keyword called ***this*** to **resolve** this **naming conflict**. "this.radius" refers to the member variable; while "radius" resolves to the method's argument.

Using keyword "this"

- this.*varName* refers to *varName* of this instance; this.*methodName*(...) invokes *methodName*(...) of this instance.
- In a constructor, we can use this(...) to call another constructor of this class.
- Inside a method, we can use the statement "return this" to return this instance to the caller.

Keyword "super"

- As we have seen, inside a class definition, you can use the keyword **this** to refer to ***this instance***.
- Similarly, the keyword **super** refers to the **superclass**, which could be the immediate parent or its ancestor.
- The **keyword super** allows the subclass to access superclass' methods and variables within the subclass' definition.
- For example, super() and super(*argumentList*) can be used invoke the superclass' constructor.
- If the subclass overrides a method inherited from its superclass, says getArea(), you can use super.getArea() to invoke the superclass' version within the subclass definition.
- Similarly, if your subclass hides one of the superclass' variable, you can use super.*variableName* to refer to the hidden variable within the subclass definition.

Constructors and Inheritance

- The subclass inherits all the **variables** and **methods** from its superclasses.
- Importantly, the subclass does **NOT inherit** the **constructors** of its superclasses.
- Each class in Java defines its **OWN constructors**.
- In the body of a constructor, you can use super(*args*) to invoke a constructor of its immediate superclass.
- Note that super(*args*), if it is used, must be the *first statement* in the subclass' constructor.
- If it is not used in the constructor, Java compiler automatically insert a super() statement to invoke the no-arg constructor of its immediate superclass. This follows the fact that the parent must be born before the child can be born. You need to properly construct the superclasses before you can construct the subclass.

Default no-arg constructor

- If no constructor is defined in a class, Java compiler automatically create a *no-argument (no-arg) constructor*, that simply issues a super() call, as follows:

```
// If no constructor is defined in a class, compiler inserts this no-arg
constructor
public ClassName () {
   super(); // call the superclass' no-arg constructor
}
```

- The default no-arg constructor will not be automatically generated, if one (or more) constructor was defined. In other words, you need to define no-arg constructor explicitly if other constructors were defined.
- If the immediate superclass does not have the default constructor (it defines some constructors but does not define a no-arg constructor), you will get a compilation error in doing a super() call. Note that Java compiler inserts a super() as the first statement in a constructor if there is no super(args).

Polymorphism

- The word "*polymorphism*" means "*many forms*".
- It comes from Greek word "*poly*" (means *many*) and "*morphos*" (means *form*).
- E.g. carbon exhibits polymorphism because it can be found in more than one form:
  - Graphite
  - Diamond
- Each of the forms has it own distinct properties.

Substitutability

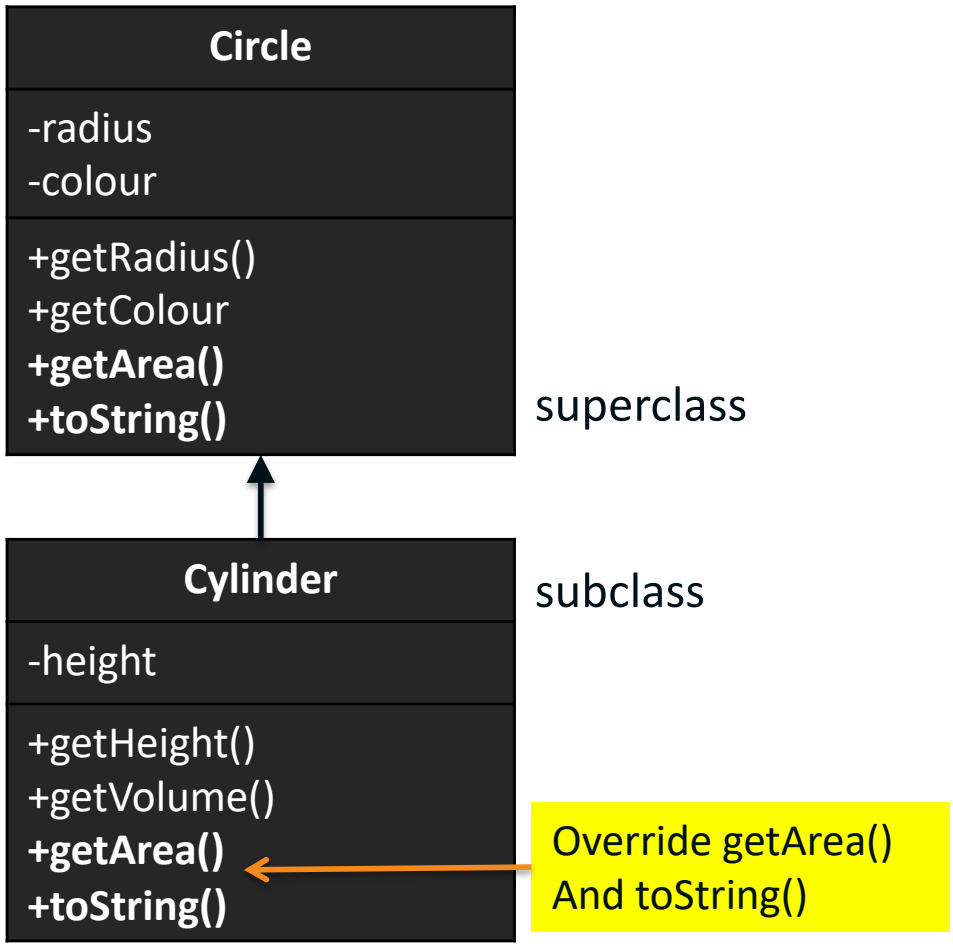
- A subclass possesses all the attributes and operations of its superclass (because a subclass inherited all attributes and operations from its superclass).
- This means that a subclass object can do whatever its superclass can do. As a result, we can *substitute* a subclass instance when a superclass instance is expected, and everything shall work fine. This is called *substitutability*.
- In last lectures example of Circle and Cylinder: Cylinder is a subclass of Circle. We can say that Cylinder "*is-a*" Circle (actually, it "*is-more-than-a*" Circle). Subclass-superclass exhibits a so called "*is-a*" relationship.

Substitutability

- Via *substitutability*, we can create an instance of Cylinder, and assign it to a Circle (its superclass) reference, as follows:

```
// Substitute a subclass instance to its superclass reference
Circle c1 = new Cylinder(5.0);
```

- You can invoke all the methods defined in the Circle class for the reference c1, (which is actually holding a Cylinder object), e.g. c1.getRadius() and c1.getColor(). This is because a subclass instance possesses all the properties of its superclass.



Substitutability

- However, you cannot invoke methods defined in the Cylinder class for the reference c1, e.g. c1.getHeight() and c1.getVolume(). This is because c1 is a reference to the Circle class, which does not know about methods defined in the subclass Cylinder.
- c1 is a reference to the Circle class, but holds an object of its subclass Cylinder. The reference c1, however, *retains its internal identity*. In our example, the subclass Cylinder overrides methods getArea() and toString(). c1.getArea() or c1.toString() invokes the *overridden* version defined in the subclass Cylinder, instead of the version defined in Circle. This is because c1 is in fact holding a Cylinder object internally.

Substitutability Summary

1. A subclass instance can be assigned (substituted) to a superclass' reference.
2. Once substituted:
   - we can invoke methods defined in the superclass
   - we cannot invoke methods defined in the subclass.
3. However, if the subclass overrides inherited methods from the superclass, the subclass (overridden) versions will be invoked.

Upcasting

Upcasting a Subclass Instance to a Superclass Reference

- Substituting a subclass instance for its superclass is called "*upcasting*".
- This is because, in a UML class diagram, subclass is often drawn below its superclass.
- Upcasting is *always safe* because a subclass instance possesses all the properties of its superclass and can do whatever its superclass can do.
- The compiler checks for valid upcasting and issues error "incompatible types" otherwise.

Upcasting Example

Example

```
// Compiler checks to ensure that R-value is a
subclass of L-value
Circle c1 = new Cylinder();

// Compilation error: incompatible types
Circle c2 = new String();
```

Downcasting

Downcasting a Substituted Reference to Its Original Class

- You can revert a substituted instance back to a subclass reference.
- This is called "*downcasting*".

Example

```
// upcast is safe
Circle c1 = new Cylinder(5.0);

// downcast needs the casting operator
Cylinder aCylinder = (Cylinder) c1;
```

Downcasting

- Downcasting requires *explicit type casting operator* in the form of prefix operator (*new-type*).
- Downcasting is not always safe, and throws a runtime ClassCastException if the instance to be downcasted does not belong to the correct subclass.
- A subclass object can be substituted for its superclass, but the reverse is not true.

Downcasting

- Compiler may not be able to detect error in explicit cast, which will be detected only at runtime.

Example

```
Circle c1 = new Circle(5);
Point p1 = new Point();

c1 = p1; // compilation error: incompatible types (Point is not
a subclass of Circle)

c1 = (Circle)p1; // runtime error:
java.lang.ClassCastException: Point cannot be casted to Circle
```

instanceOf Operator

- Java provides a binary operator called instanceof which returns true if an object is an instance of a particular class.

Syntax

<Object> **instanceof** *<Class>*

Example

```
Circle c1 = new Circle();
System.out.println(c1 instanceof Circle);  // true

if (c1 instanceof Circle) { ..... }
```

instanceOf Operator

Note

- An instance of subclass is also an instance of its superclass.

Example

```
Circle c1 = new Circle(5);
Cylinder cy1 = new Cylinder(5, 2);
System.out.println(c1 instanceof Circle);    // true
System.out.println(c1 instanceof Cylinder);  // false
System.out.println(cy1 instanceof Cylinder); // true
System.out.println(cy1 instanceof Circle);   // true

Circle c2 = new Cylinder(5, 2);
System.out.println(c2 instanceof Circle);    // true
System.out.println(c2 instanceof Cylinder);  // true
```

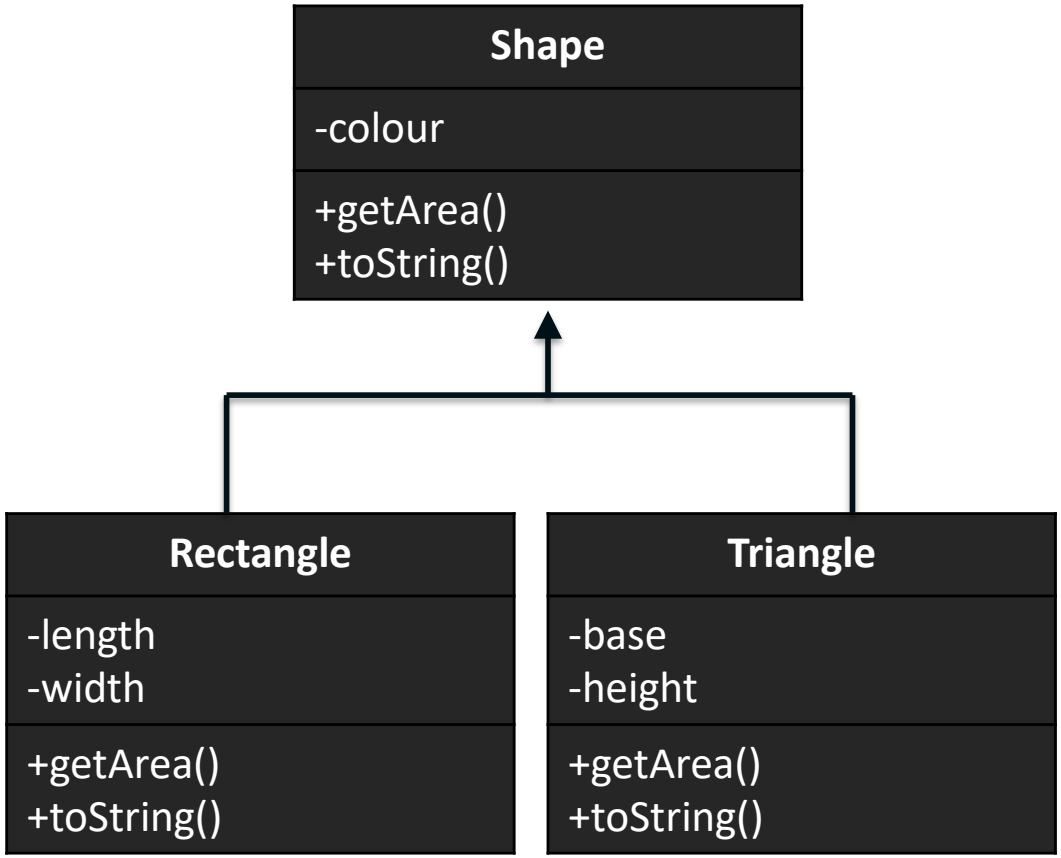
Polymorphism Summary

1. A subclass instance processes all the attributes and operations of its superclass. When a superclass instance is expected, it can be substituted by a subclass instance. In other words, a reference to a class may hold an instance of that class or an instance of one of its subclasses - it is called substitutability.
2. If a subclass instance is assigned to a superclass reference, you can invoke the methods defined in the superclass only. You cannot invoke methods defined in the subclass.
3. However, the substituted instance retains its own identity in terms of overridden methods and hiding variables. If the subclass overrides methods in the superclass, the subclass's version will be executed, instead of the superclass's version.

Polymorphism Example

- Polymorphism is very powerful in OOP to *separate the interface and implementation* so as to allow the programmer to *program at the interface* in the design of a *complex system*.
- Lets go back to our shape example. Suppose that our program uses many kinds of shapes, such as triangle, rectangle and so on. We should design a superclass called Shape, which defines the public interface (or behaviors) of all the shapes.
- E.g., we would like all the shapes to have a method called getArea(), which returns the area of that particular shape.

Polymorphism Example



Polymorphism Example – Shape.java

```
// Define superclass Shape
public class Shape {
   // Private member variable
   private String colour;

   // Constructor
   public Shape (String colour) {
      this.colour = colour;
   }

   @Override
   public String toString() {
      return "Shape of colour=\"" + colour + "\"";
   }

   // Problem - all shapes must have a method called getArea()
   public double getArea() {
      System.err.println("Shape unknown! Cannot compute area!");
      return 0;   // Need a return to compile the program
   }
}
```

Polymorphism Example

- NOTE: we have a problem on writing the getArea() method in the Shape class.
- The area obviously cannot be computed unless the actual shape is known.
- For now, we shall print an error message. We will come back in a few slides to see how this problem can be resolved.
- Moving on with our example:
  - We can now derive subclasses, such as Triangle and Rectangle, from the superclass Shape.

Polymorphism Example

Polymorphism Example – Rectangle.java

```
// Define Rectangle, subclass of Shape
public class Rectangle extends Shape {
   // Private member variables
   private int length;
   private int width;

   // Constructor
   public Rectangle(String colour, int length, int width) {
      super(colour);
      this.length = length;
      this.width = width;
   }

   @Override
   public String toString() {
      return "Rectangle of length=" + length + " and width=" + width + ",
           subclass of " + super.toString();
   }

   @Override
   public double getArea() {
      return length*width;
   }
}
```

Polymorphism Example – Triangle.java

```
// Define Triangle, subclass of Shape
public class Triangle extends Shape {
   // Private member variables
   private int base;
   private int height;

   // Constructor
   public Triangle(String colour, int base, int height) {
      super(colour);
      this.base = base;
      this.height = height;
   }

   @Override
   public String toString() {
      return "Triangle of base=" + base + " and height=" + height + ",
           subclass of " + super.toString();
   }

   @Override
   public double getArea() {
      return 0.5*base*height;
   }
}
```

Polymorphism Example

Polymorphism Example – TestShape.java

- We can now create references of Shape, and assign them instances of subclasses:

```
// Test program for Shape and its subclasses
public class TestShape {
   public static void main(String[] args) {
      Shape s1 = new Rectangle("red", 4, 5);
      System.out.println(s1);
      System.out.println("Area is " + s1.getArea());

      Shape s2 = new Triangle("blue", 4, 5);
      System.out.println(s2);
      System.out.println("Area is " + s2.getArea());
   }
}
```

- The beauty of this code is that *all the references are from the superclass* (i.e., *programming at the interface level*). You could instantiate a different subclass instance, and the code still works.
- You could easily extend your program by adding in more subclasses, such as Circle, Square, etc...

Polymorphism Example

Shape – Back To The Problem – getArea()

- We know the definition of the Shape class has a problem.
- If someone instantiates a Shape object and invokes its getArea() method, our program breaks:

```
public class TestShape {
   public static void main(String[] args) {
      // Constructing a Shape instance poses problem!
      Shape s3 = new Shape("green");
      System.out.println(s3);
      System.out.println("Area is " + s3.getArea());
   }
}
```

- This is because the Shape class is meant to provide a common interface to all its subclasses, which are supposed to provide the actual implementation.
- We do not want anyone to instantiate a Shape instance.
- **Solution** -> using the so-called abstract class.

Abstract Classes

- An abstract method is a method with only a signature (i.e., the method name, the list of arguments and the return type) without implementation (i.e., the method's body). You use the keyword abstract to declare an abstract method.
- For example, in the Shape class, we can declare three abstract methods getArea(), draw(), as follows::

```
abstract public class Shape {
   ......
   public abstract double getArea();
   public abstract void draw();
}
```

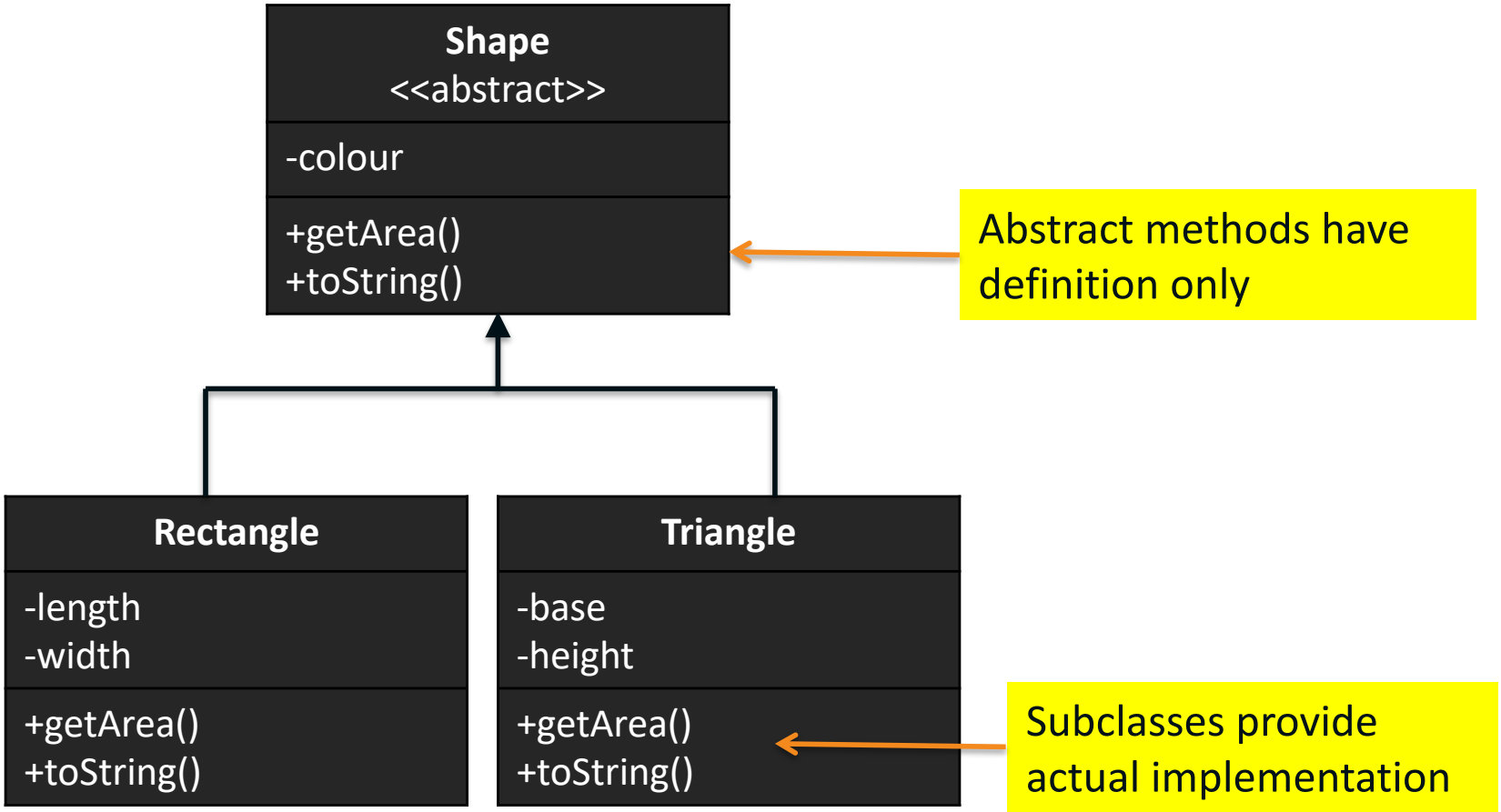
- Implementation of these methods is not possible in the Shape class, as the actual shape is not yet known. (How to compute the area if the shape is not known?).
- Implementation of these abstract methods will be provided later once the actual shape is known.
- These abstract methods cannot be invoked because they have no implementation.

Abstract Classes

- A class containing one or more abstract methods is called an abstract class.
- An abstract class must be declared with a class-modifier abstract.
- Lets now go back to our Shape class and rewrite it as an abstract class, containing an abstract method for getArea().

Abstract Classes

Shape Example – Abstract Class



Abstract Classes

Abstract Class – Shape.java

```
abstract public class Shape {
  // Private member variable
  private String color;

  // Constructor
  public Shape (String color) {
    this.color = color;
  }

  @Override
  public String toString() {
    return "Shape of color=\"" + color + "\"";
  }

  // All Shape subclasses must implement a method called getArea()
  abstract public double getArea();
}
```

Abstract Classes

- Our abstract class is *incomplete* in its definition, since the implementation of its abstract methods are missing. Therefore, our abstract class *cannot be instantiated*. In other words, we cannot create instances from our abstract class (otherwise, you will have an incomplete instance with missing method's body).
- To use our abstract class, we have to derive a subclass from the abstract class. In the derived subclass, we have to override the abstract methods and provide implementation to all the abstract methods. The subclass derived is then complete, and can be instantiated. (If a subclass does not provide implementation to all the abstract methods of the superclass, the subclass remains abstract.)
- This property of the abstract class solves our earlier problem. In other words, you can create instances of the subclasses such as Triangle and Rectangle, and upcast them to Shape (so as to program and operate at the interface level), but you cannot create instances of Shape, which avoids the pitfall that we faced.

Abstract Classes Summary

- In summary, an abstract class provides *a template for further development*.
- The purpose of an abstract class is to provide a common interface (or protocol, or contract, or understanding, or naming convention) to all its subclasses.
- E.g., in the abstract class Shape, you can define abstract methods such as getArea() and draw(). No implementation is possible because the actual shape is not known. However, by specifying the signature of the abstract methods, all the subclasses are *forced* to use these methods' signature. The subclasses should provide the proper implementations.
- Coupled with polymorphism, you can upcast subclass instances to Shape, and program at the Shape level, i,e., program at the interface.
- The separation of interface and implementation enables better software design, and ease in expansion.
- E.g., Shape defines a method called getArea(), which all the subclasses must provide the correct implementation. You can ask for a getArea() from any subclasses of Shape, the correct area will be computed.
- Furthermore, you application can be extended easily to accommodate new shapes (such as Circle or Square) by deriving more subclasses.

Abstract Classes Summary

- **Rule of Thumb:** Program at the interface, not at the implementation. (That is, make references at the superclass; substitute with subclass instances; and invoke methods defined in the superclass only.)

Notes:

- An abstract method cannot be declared final, as a final method cannot be overridden. An abstract method, on the other hand, must be overridden in a descendent before it can be used.
- An abstract method cannot be private (which generates a compilation error). This is because private methods are not visible to the subclass and thus cannot be overridden.

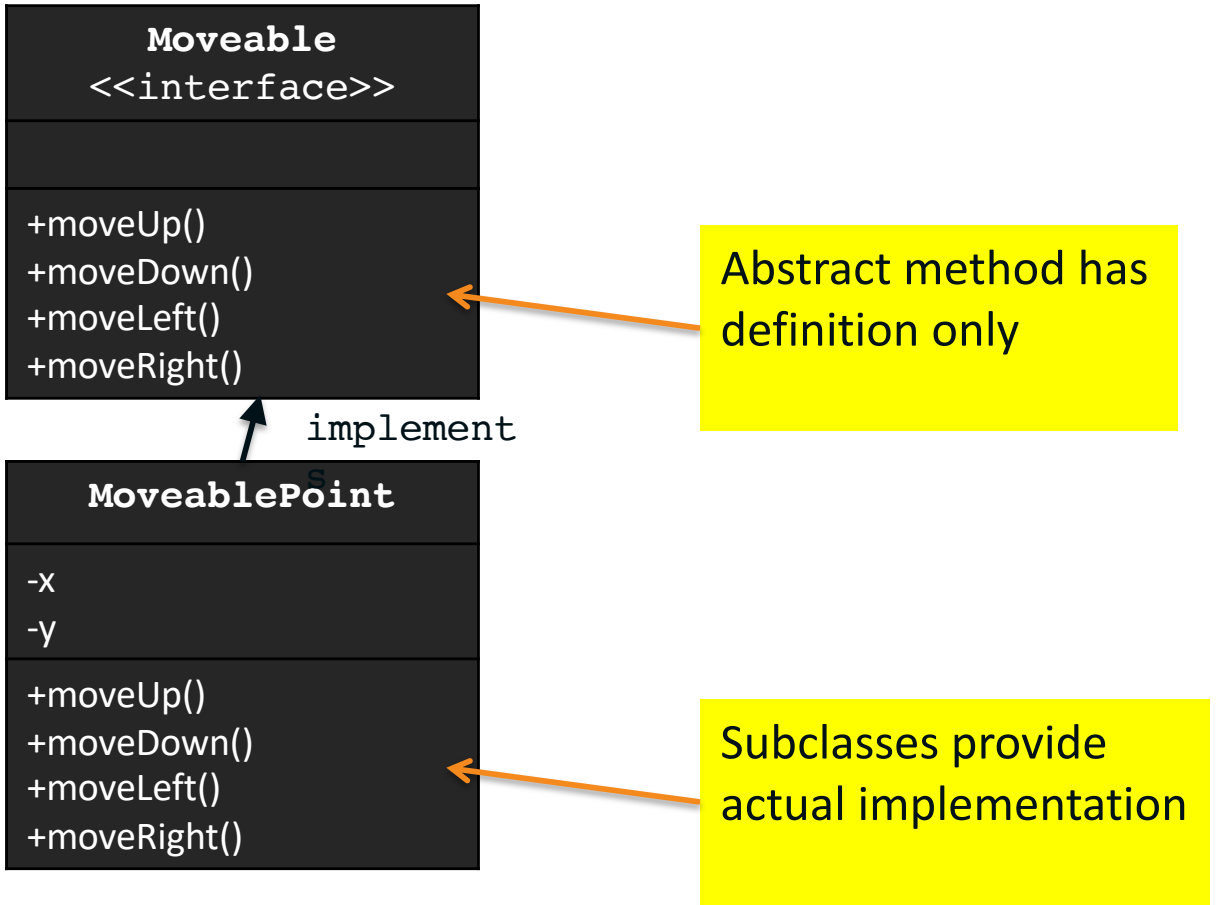
The Interface

The `interface`

- A Java interface is a *100% abstract superclass* which defines a set of methods that its subclasses must support.
- An interface only contains public *abstract methods* (methods with signature and no implementation) and possibly *constants* (public static final variables).
- You have to use the keyword "interface" to define an interface (instead of keyword "class" for normal classes).
- The keyword public and abstract are not needed for its abstract methods as they are mandatory.
- An interface is a *contract* for what the classes can do.
- It, however, does not specify how the classes should do it.
- **Interface Naming Convention:** Use an adjective (typically ends with "able") consisting of one or more words. Each word shall be initial capitalised (camel-case). For example, Serialisable, Extenalisable, Movable, Clonable, Runnable, etc.

Interface Example

- Suppose that our application involves many objects that can move.
- We could define an interface called movable, containing the signatures of the various movement methods.



Interface Moveable

```
public interface Movable {
    // abstract methods to be implemented by the subclasses
    public void moveUp();
    public void moveDown();
    public void moveLeft();
    public void moveRight();
}
```

- Similar to an abstract class, an interface cannot be instantiated; because it is incomplete (the abstract methods' body is missing).
- To use an interface, again, you must derive subclasses and provide implementation to all the abstract methods declared in the interface.
- The subclasses are only then complete and can be instantiated.

Keyword “implements”

- To derive subclasses from an interface, a new keywords "implements”.
- This is instead of "extends" for deriving subclasses from an ordinary class or an abstract class.
- It is important to note that the subclass implementing an interface needs to override ALL the abstract methods defined in the interface; otherwise, the subclass cannot be compiled

Example

Implementing Moveable – MovablePoint.java

```
public class MovablePoint implements Movable {
   // Private member variables
   private int x, y;   // (x, y) coordinates of the point

   // Constructor
   public MovablePoint(int x, int y) {
      this.x = x;
      this.y = y;
   }

   @Override
   public String toString() {
      return "Point at (" + x + "," + y + ")";
   }

   // Implement abstract methods defined in the interface Movable
   @Override
   public void moveUp() {
      y--;
   }
```

Example

Implementing Moveable – MovablePoint.java

```
    @Override
    public void moveDown() {
        y++;
    }

    @Override
    public void moveLeft() {
        x--;
    }

    @Override
    public void moveRight() {
        x++;
    }
}
```

- Other classes in the application can similarly implement the Movable interface and provide their own implementation to the abstract methods defined in the interface Movable.

Example

Testing – TestMovable.java

- We can also upcast subclass instances to the Movable interface, via polymorphism, similar to an `abstract` class.

```
public class TestMovable {
   public static void main(String[] args) {
      Movable m1 = new MovablePoint(5, 5);  // upcast
      System.out.println(m1);
      m1.moveDown();
      System.out.println(m1);
      m1.moveRight();
      System.out.println(m1);
   }
}
```

Multiple Interfaces

Implementing Multiple `interfaces`

- As already mentioned, Java supports only *single inheritance*.
- That is, a subclass can be derived from one and only one superclass.
- Java does not support *multiple inheritance* to avoid inheriting conflicting properties from multiple superclasses.
- A subclass, however, can implement more than one interfaces. This is permitted in Java as an interface merely defines the abstract methods without the actual implementations and less likely leads to inheriting conflicting properties from multiple interfaces.
- In other words, Java indirectly supports multiple inheritances via implementing multiple interfaces.

```
// One superclass but implement multiple interfaces
public class Circle extends Shape implements Movable, Displayable {
   .......
}
```

Interface Syntax

`interface` Syntax

```
[public|protected|package] interface interfaceName
[extends superInterfaceName] {
   // constants
   static final ...;

   // abstract methods' signature
   ...
}
```

- All methods in an interface are public and abstract (default). You cannot use any other access modifier such as private, protected and default, or modifiers such as static or final.
- All variables should be public, static and final (default).
- An interface may "extend" from a super-interface.

Summary

- An interface is a *contract* (or a protocol, or a common understanding) of what the classes can do.
- When a class implements a certain interface, it promises to provide implementation to all the abstract methods declared in the interface.
  - The interface defines a set of common behaviors.
  - The classes implement the interface agree to these behaviors and provide their own implementation to the behaviors.
- This allows you to program at the interface, instead of the actual implementation.
- One of the main uses of an interface is provide a *communication contract* between two Objects.
- If you know a class implements an interface, then you know that class contains concrete implementations of the methods declared in that interface, and you are guaranteed to be able to invoke these methods safely.
- In other words, two Objects can communicate based on the contract defined in the interface, instead of their specific implementation.