Abstract Classes and Interfaces

EECS2030 B & E: Advanced Object Oriented Programming
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Learning Outcomes

This module is designed to help you learn about:

- What an ***abstract*** method and an ***abstract*** class are
- What an ***interface*** is
- Reinforce: ***Polymorphism*** and ***dynamic binding***
- *When* to use abstract classes vs. interfaces?

Abstract Class (1)

Problem: A polygon may be either a triangle or a rectangle. Given a polygon, we may either

- ***Grow*** its shape by incrementing the size of each of its sides;
- Compute and return its ***perimeter***; or
- Compute and return its ***area***.

- For a rectangle with *length* and *width*, its area is $length \times width$.
- For a triangle with sides a, b, and c, its area, according to Heron's formula, is

$$\sqrt{s(s-a)(s-b)(s-c)}$$

where

$$s = \frac{a+b+c}{2}$$

- How would you solve this problem in Java, while *minimizing code duplicates*?

Abstract Class (2)

```
public abstract class Polygon {
  double[] sides;
  Polygon(double[] sides) { this.sides = sides; }
  void grow() {
    for(int i = 0; i < sides.length; i ++) { sides[i] ++; }
  }
  double getPerimeter() {
    double perimeter = 0;
    for(int i = 0; i < sides.length; i ++) {
      perimeter += sides[i];
    }
    return perimeter;
  }
  abstract double getArea();
}
```

- Method `getArea` not implemented and shown *header* only.
- ∴ `Polygon` cannot be used as a *dynamic type*
- Writing `new Polygon(...)` is forbidden!

Abstract Class (3)

```
public class Rectangle extends Polygon {
  Rectangle(double length, double width) {
    super(new double[4]);
    sides[0] = length; sides[1] = width;
    sides[2] = length; sides[3] = width;
  }
  double getArea() { return sides[0] * sides[1]; }
}
```

- Method `getPerimeter` is inherited from the super-class `Polygon`.
- Method `getArea` is implemented in the sub-class `Rectangle`.
- ∴ `Rectangle` can be used as a *dynamic type*
- Writing `Polygon p = new Rectangle(3, 4)` allowed!

Abstract Class (4)

```
public class Triangle extends Polygon {
  Triangle(double side1, double side2, double side3) {
    super(new double[3]);
    sides[0] = side1; sides[1] = side2; sides[2] = side3;
  }
  double getArea() {
    /* Heron's formula */
    double s = getPerimeter() * 0.5;
    double area = Math.sqrt(
      s * (s - sides[0]) * (s - sides[1]) * (s - sides[2]));
    return area;
  }
}
```

- Method `getPerimeter` is inherited from `Polygon`.
- Method `getArea` is implemented in the sub-class `Triangle`.
- ∴ `Triangle` can be used as a *dynamic type*
- Writing `Polygon p = new Triangle(3, 4, 5)` allowed!

Abstract Class (5)

```
1  public class PolygonCollector {
2    Polygon[] polygons;
3    int numberOfPolygons;
4    PolygonCollector() { polygons = new Polygon[10]; }
5    void addPolygon(Polygon p) {
6      polygons[numberOfPolygons] = p; numberOfPolygons ++;
7    }
8    void growAll() {
9      for(int i = 0; i < numberOfPolygons; i ++) {
10       polygons[i].grow();
11     }
12   }
13 }
```

- **Polymorphism**: **Line 5** may accept as argument any object whose *static type* is `Polygon` or any of its sub-classes.
- **Dynamic Binding**: **Line 10** calls the version of `grow` inherited to the *dynamic type* of `polygons[i]`.

Abstract Class (6)

```
1  public class PolygonConstructor {
2    Polygon getPolygon(double[] sides) {
3      Polygon p = null;
4      if(sides.length == 3) {
5        p = new Triangle(sides[0], sides[1], sides[2]);
6      }
7      else if(sides.length == 4) {
8        p = new Rectangle(sides[0], sides[1]);
9      }
10     return p;
11   }
12   void grow(Polygon p) { p.grow(); }
13 }
```

- **Polymorphism**:
  - **Line 2** may accept as return value any object whose *static type* is `Polygon` or any of its sub-classes.
  - **Line 5** returns an object whose *dynamic type* is `Triangle`; **Line 8** returns an object whose *dynamic type* is `Rectangle`.

Abstract Class (7.1)

```
public class PolygonTester {
 public static void main(String[] args) {
  Polygon p;
  p = new Rectangle(3, 4); /* polymorphism */
  System.out.println(p.getPerimeter()); /* 14.0 */
  System.out.println(p.getArea()); /* 12.0 */
  p = new Triangle(3, 4, 5); /* polymorphism */
  System.out.println(p.getPerimeter()); /* 12.0 */
  System.out.println(p.getArea()); /* 6.0 */

  PolygonCollector col = new PolygonCollector();
  col.addPolygon(new Rectangle(3, 4)); /* polymorphism */
  col.addPolygon(new Triangle(3, 4, 5)); /* polymorphism */
  System.out.println(col.polygons[0].getPerimeter()); /* 14.0 */
  System.out.println(col.polygons[1].getPerimeter()); /* 12.0 */
  col.growAll();
  System.out.println(col.polygons[0].getPerimeter()); /* 18.0 */
  System.out.println(col.polygons[1].getPerimeter()); /* 15.0 */
```


Abstract Class (7.2)

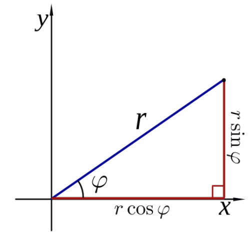
```
  PolygonConstructor con = new PolygonConstructor();
  double[] recSides = {3, 4, 3, 4};  p = con.getPolygon(recSides);
  System.out.println(p instanceof Polygon);   ✓
  System.out.println(p instanceof Rectangle);   ✓
  System.out.println(p instanceof Triangle);   ×
  System.out.println(p.getPerimeter()); /* 14.0 */
  System.out.println(p.getArea()); /* 12.0 */
  con.grow(p);
  System.out.println(p.getPerimeter()); /* 18.0 */
  System.out.println(p.getArea()); /* 20.0 */
  double[] triSides = {3, 4, 5};  p = con.getPolygon(triSides);
  System.out.println(p instanceof Polygon);   ✓
  System.out.println(p instanceof Rectangle);   ×
  System.out.println(p instanceof Triangle);   ✓
  System.out.println(p.getPerimeter()); /* 12.0 */
  System.out.println(p.getArea()); /* 6.0 */
  con.grow(p);
  System.out.println(p.getPerimeter()); /* 15.0 */
  System.out.println(p.getArea()); /* 9.921 */
 } }
```


Abstract Class (8)

- An *abstract class* :
  - Typically has **at least one** method with no implementation body
  - May define common implementations inherited to **sub-classes**.
- Recommended to use an *abstract class* as the ***static type*** of:
  - A *variable*
    e.g., `Polygon p`
  - A *method parameter*
    e.g., `void grow(Polygon p)`
  - A *method return value*
    e.g., `Polygon getPolygon(double[] sides)`
- It is forbidden to use an *abstract class* as a ***dynamic type***
  e.g., `Polygon p = new Polygon(...)` is not allowed!
- Instead, create objects whose ***dynamic types*** are descendant classes of the *abstract class* ⇒ Exploit *dynamic binding* !
  e.g., `Polygon p = con.getPolygon(recSides)`
  This is is as if we did `Polygon p = new Rectangle(...)`

Interface (1.1)

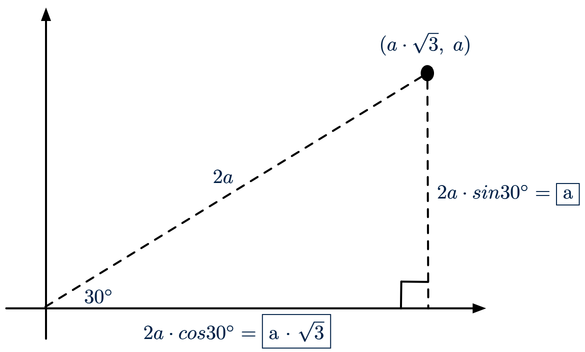
- We may implement `Point` using two representation systems:



  - The *Cartesian system* stores the *absolute* positions of `x` and `y`.
  - The *Polar system* stores the *relative* position: the angle (in radian) `phi` and distance `r` from the origin (0.0).
- As far as users of a `Point` object `p` is concerned, being able to call `p.getX()` and `p.getY()` is what matters.
- How `p.getX()` and `p.getY()` are internally computed, depending on the *dynamic type* of `p`, do not matter to users.

Interface (1.2)

Recall: $sin30° = \frac{1}{2}$ and $cos30° = \frac{1}{2} \cdot \sqrt{3}$



We consider the same point represented differently as:

- $r = 2a$, $\psi = 30°$ [polar system]
- $x = 2a \cdot cos30° = a \cdot \sqrt{3}$, $y = 2a \cdot sin30° = a$ [cartesian system]

Interface (2)

```
public interface Point {
  public double getX();
  public double getY();
}
```

- An interface `Point` defines how users may access a point: either get its *x* coordinate or its *y* coordinate.
- Methods `getX` and `getY` similar to `getArea` in `Polygon`, have no implementations, but *headers* only.
- ∴ `Point` cannot be used as a *dynamic type*
- Writing `new Point(...)` is forbidden!

Interface (3)

```
public class CartesianPoint implements Point {
  private double x;
  private double y;
  public CartesianPoint(double x, double y) {
    this.x = x;
    this.y = y;
  }
  public double getX() { return x; }
  public double getY() { return y; }
}
```

- `CartesianPoint` is a possible implementation of `Point`.
- Attributes `x` and `y` declared according to the *Cartesian system*
- All method from the interface `Point` are implemented in the sub-class `CartesianPoint`.
- ∴ `CartesianPoint` can be used as a *dynamic type*
- `Point p = new CartesianPoint(3, 4)` allowed!

Interface (4)

```
public class PolarPoint implements Point {
  private double phi;
  private double r;
  public PolarPoint(double r, double phi) {
    this.r = r;
    this.phi = phi;
  }
  public double getX() { return Math.cos(phi) * r; }
  public double getY() { return Math.sin(phi) * r; }
}
```

- `PolarPoint` is a possible implementation of `Point`.
- Attributes `phi` and `r` declared according to the *Polar system*
- All method from the interface `Point` are implemented in the sub-class `PolarPoint`.
- ∴ `PolarPoint` can be used as a *dynamic type*
- `Point p = new PolarPoint(3,` $\frac{\pi}{6}$`)` allowed! [$360° = 2\pi$]

Interface (5)

```java
1  public class PointTester {
2   public static void main(String[] args) {
3     double A = 5;
4     double X = A * Math.sqrt(3);
5     double Y = A;
6     Point p;
7     p = new CartisianPoint(X, Y); /* polymorphism */
8     print("(" + p.getX() + ", " + p.getY() + ")"); /* dyn. bin. */
9     p = new PolarPoint(2 * A, Math.toRadians(30)); /* polymorphism */
10    print("(" + p.getX() + ", " + p.getY() + ")"); /* dyn. bin. */
11  }
12 }
```

- **Lines 7 and 9** illustrate *polymorphism*, how?
- **Lines 8 and 10** illustrate *dynamic binding*, how?

Interface (6)

- An *interface*:
  - Has **all** its methods with no implementation bodies.
  - Leaves complete freedom to its ***implementors***.
- Recommended to use an *interface* as the ***static type*** of:
  - A *variable*
    e.g., `Point p`
  - A *method parameter*
    e.g., `void moveUp(Point p)`
  - A *method return value*
    e.g., `Point getPoint(double v1, double v2, boolean isCartesian)`
- It is forbidden to use an *interface* as a ***dynamic type***
  e.g., `Point p = new Point(...)` is not allowed!
- Instead, create objects whose ***dynamic types*** are descendant classes of the *interface* ⇒ Exploit *dynamic binding*!

Abstract Classes vs. Interfaces: When to Use Which?

- Use *interfaces* when:
  - There is a *common set of functionalities* that can be implemented via *a variety of strategies*.
    e.g., Interface `Point` declares headers of `getX()` and `getY()`.
  - Each descendant class represents a different implementation strategy for the same set of functionalities.
  - `CartesianPoint` and `PolarPoinnt` represent different strategies for supporting `getX()` and `getY()`.
- Use *abstract classes* when:
  - *Some (not all) implementations can be shared* by descendants, and *some (not all) implementations cannot be shared*.
    e.g., Abstract class `Polygon`:
    - Defines implementation of `getPerimeter`, to be shared by `Rectangle` and `Triangle`.
    - Declares header of `getArea`, to be implemented by `Rectangle` and `Triangle`.

Beyond this lecture. . .

Study the `ExampleAbstractClasses` and `ExampleInterfaces` source code:

- Draw the ***inheritance hierarchy*** based on the class declarations
- Use the ***debugger*** to step into the various method calls (e.g., `getArea()` of Polygon, `getX()` of Point) to see which version of the method gets executed (i.e., ***dynamic binding***).

Index (1)

Index (2)