Graphical Structures

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CS 106A
January 29, 2010

The **GPolygon** Class

- The **GPolygon** class is used to represent graphical objects bound by line segments. In mathematics, such figures are called *polygons* and consist of a set of *vertices* connected by *edges*. The following figures are examples of polygons:

  - diamond
  - regular hexagon
  - five-pointed star

- Unlike the other shape classes, that location of a polygon is not fixed at the upper left corner. What you do instead is pick a *reference point* that is convenient for that particular shape and then position the vertices relative to that reference point.
- The most convenient reference point is often the geometric center of the object.

Constructing a **GPolygon** Object

- The **GPolygon** constructor creates an empty polygon. Once you have the empty polygon, you then add each vertex to the polygon, one at a time, until the entire polygon is complete.
- The most straightforward way to create a **GPolygon** is to use the method `addVertex(x, y)`, which adds a new vertex to the polygon. The `x` and `y` values are measured relative to the reference point for the polygon rather than the origin.
- When you start to build up the polygon, it always makes sense to use `addVertex(x, y)` to add the first vertex. Once you have added the first vertex, you can call any of the following methods to add the remaining ones:
  - `addVertex(x, y)` adds a new vertex relative to the reference point
  - `addEdge(dx, dy)` adds a new vertex relative to the preceding one
  - `addPolarEdge(r, theta)` adds a new vertex using polar coordinates

Each of these strategies is illustrated in a subsequent slide.

Using **addVertex** and **addEdge**

- The **addVertex** and **addEdge** methods each add one new vertex to a **GPolygon** object. The only difference is in how you specify the coordinates. The **addVertex** method uses coordinates relative to the reference point, while the **addEdge** method indicates displacements from the previous vertex.
- Your decision about which of these methods to use is based on what information you have readily at hand. If you can easily calculate the coordinates of the vertices, **addVertex** is probably the right choice. If, however, it is much easier to describe each edge, **addEdge** is probably a better strategy.
- No matter which of these methods you use, the **GPolygon** class closes the polygon before displaying it by adding an edge from the last vertex back to the first one, if necessary.
- The next two slides show how to construct a diamond-shaped polygon using the **addVertex** and the **addEdge** strategies.

Drawing a Diamond (**addVertex**)

The following program draws a diamond using **addVertex**:

```java
public void run() {
    GPolygon diamond = createDiamond(100, 75);
    diamond.setFilled(true);
    diamond.setFillColor(Color.MAGENTA);
    add(diamond, getWidth() / 2, getHeight() / 2);
}

private GPolygon createDiamond(double width, double height) {
    GPolygon diamond = new GPolygon();
    diamond.addVertex(-width / 2, 0);
    diamond.addVertex(0, -height / 2);
    diamond.addVertex(width / 2, 0);
    diamond.addVertex(0, height / 2);
    return diamond;
}
```

Drawing a Diamond (**addEdge**)

This program draws the same diamond using **addEdge**:

```java
public void run() {
    GPolygon diamond = createDiamond(100, 75);
    diamond.setFilled(true);
    diamond.setFillColor(Color.MAGENTA);
    add(diamond, getWidth() / 2, getHeight() / 2);
}

private GPolygon createDiamond(double width, double height) {
    GPolygon diamond = new GPolygon();
    diamond.addVertex(-width / 2, 0);
    diamond.addEdge(width / 2, -height / 2);
    diamond.addVertex(width / 2, height / 2);
    diamond.addEdge(-width / 2, height / 2);
    diamond.addEdge(-width / 2, -height / 2);
    return diamond;
}
```
Using addPolarEdge

- In many cases, you can determine the length and direction of a polygon edge more easily than you can compute its x and y coordinates. In such situations, the best strategy for building up the polygon outline is to call addPolarEdge(r, theta), which adds an edge of length r at an angle that extends theta degrees counterclockwise from the +x axis, as illustrated by the following diagram:

- The name of the method reflects the fact that addPolarEdge uses what mathematicians call polar coordinates.

Drawing a Hexagon

This program draws a regular hexagon using addPolarEdge:

```
public void run() {
    GPolygon hexagon = createHexagon(50);
    add(hexagon, getWidth() / 2, getHeight() / 2);
}
```

private GPolygon createHexagon(double side) {
    GPolygon hex = new GPolygon();
    hex.addVertex(-side, 0);
    int angle = 60;
    for (int i = 0; i < 6; i++) {
        hex.addPolarEdge(side, angle);
        angle -= 60;
    }
    return hex;
}
```

Defining GPolygon Subclasses

- The GPolygon class can also serve as the superclass for new types of graphical objects. For example, instead of calling a method like the createHexagon method from the preceding slide, you could also define a GHexagon class like this:

```
public class GHexagon extends GPolygon {
    public GHexagon(double side) {
        addVertex(-side, 0);
        int angle = 60;
        for (int i = 0; i < 6; i++) {
            addPolarEdge(side, angle);
            angle -= 60;
        }
    }
}
```

- The addVertex and addPolarEdge calls in the GHexagon constructor operate on the object being created, which is set to an empty GPolygon by the superclass constructor.

Exercise: Using the GPolygon Class

Define a class GCross that represents a cross-shaped figure. The constructor should take a single parameter size that indicates both the width and height of the cross. Your definition should make it possible to execute the following program to produce the diagram at the bottom of the slide:

```
public void run() {
    GCross cross = new GCross(100);
    cross.setFilled(true);
    cross.setColor(Color.RED);
    add(cross, getWidth() / 2, getHeight() / 2);
}
```

Creating Compound Objects

- The GCompound class in the acm.graphics package makes it possible to combine several graphical objects so that the resulting structure behaves as a single GObject.

- The easiest way to think about the GCompound class is as a combination of a GCanvas and a GObject. A GCompound is like a GCanvas in that you can add objects to it, but it is also like a GObject in that you can add it to a canvas.

- As was true in the case of the GPolygon class, a GCompound object has its own coordinate system that is expressed relative to a reference point. When you add new objects to the GCompound, you use the local coordinate system based on the reference point. When you add the GCompound to the canvas as a whole, all you have to do is set the location of the reference point; the individual components will automatically appear in the right locations relative to that point.

Creating a Face Object

- The first example of the GCompound class is the DrawFace program, which is illustrated at the bottom of this slide.

- The figure consists of a GOval for the face and each of the eyes, a GPolygon for the nose, and a GRect for the mouth. These objects, however, are not added directly to the canvas but to a GCompound that represents the face as a whole.

- This primary advantage of using the GCompound strategy is that doing so allows you to manipulate the face as a unit.
The GFace Class

```java
import acm.graphics.*;
/** Defines a compound GFace class */
public class GFace extends GCompound {

/** Creates a new GFace object with the specified dimensions */
public GFace(double width, double height) {
    head = new GOval(width, height);
    leftEye = new GOval(EYE_WIDTH * width, EYE_HEIGHT * height);
    rightEye = new GOval(EYE_WIDTH * width, EYE_HEIGHT * height);
    nose = createNose(NOSE_WIDTH * width, NOSE_HEIGHT * height);
    mouth = new GRect(MOUTH_WIDTH * width, MOUTH_HEIGHT * height);
    add(head, 0, 0);
    add(leftEye, 0.25 * width - EYE_WIDTH * width / 2,
        0.25 * height - EYE_HEIGHT * height / 2);
    add(rightEye, 0.75 * width - EYE_WIDTH * width / 2,
        0.25 * height - EYE_HEIGHT * height / 2);
    add(nose, 0.50 * width - NOSE_WIDTH * width / 2,
        0.75 * height - NOSE_HEIGHT * height / 2);
    add(mouth, 0.50 * width - MOUTH_WIDTH * width / 2,
        0.75 * height - MOUTH_HEIGHT * height / 2);
}

/* Creates a triangle for the nose */
private GPolygon createNose(double width, double height) {
    GPolygon poly = new GPolygon();
    poly.addVertex(0, -height / 2);
    poly.addVertex(width / 2, height / 2);
    poly.addVertex(-width / 2, height / 2);
    return poly;
}

/* Constants specifying feature size as a fraction of the head size */
private static final double EYE_WIDTH = 0.15;
private static final double EYE_HEIGHT = 0.15;
private static final double NOSE_WIDTH = 0.15;
private static final double NOSE_HEIGHT = 0.10;
private static final double MOUTH_WIDTH = 0.50;
private static final double MOUTH_HEIGHT = 0.03;
/* Private instance variables */
private GOval head;
private GOval leftEye, rightEye;
private GPolygon nose;
private GRect mouth;
}
```

Exercise: Labeled Rectangles

Define a class GLabeledRect that consists of an outlined rectangle with a label centered inside. Your class should include constructors that are similar to those for GRect but include an extra argument for the label. It should also export setLabel, getLabel, and setFont methods. The following run method illustrates the use of the class:

```java
public void run() {
    GLabeledRect rect = new GLabeledRect(100, 50, "hello");
    rect.setFont("SansSerif-18");
    add(rect, 150, 50);
}
```

Graphical Object Decomposition

- The most important advantage of using the GCompound class is that doing so makes it possible to apply the strategy of decomposition in the domain of graphical objects. Just as you use stepwise refinement to break a problem down into smaller and smaller pieces, you can use it to decompose a graphical display into successively simpler pieces.
- The text illustrates this technique by returning to the example of train cars from Chapter 5, where the goal is to produce the picture at the bottom of this slide.
- In Chapter 5, the decomposition strategy led to a hierarchy of methods. The goal now is to produce a hierarchy of classes.

The TrainCar Hierarchy

- The critical insight in designing an object-oriented solution to the train problem is that the cars form a hierarchy in which the individual classes Engine, Boxcar, and Caboose are all subclasses of a more general class called TrainCar:

```
import acm.graphics.*;
import java.awt.*;
/** This abstract class defines what is common to all train cars */
public abstract class TrainCar extends GCompound {

/** Creates the frame of the car using the specified color. */
    rect.setFont("SansSerif-18");
    rect.setFill(Color.black);
    rect.addLabel("Train Car");
}
```

- The TrainCar class itself is a GCompound, which means that it is a graphical object. The constructor at the TrainCar level adds the common elements, and the constructors for the individual subclasses add any remaining details.
The **TrainCar** Class

```java
/* Adds a wheel centered at (x, y) */
private void addWheel(double x, double y) {
    GOval wheel = new GOval(x - WHEEL_RADIUS, y - WHEEL_RADIUS,
        2 * WHEEL_RADIUS, 2 * WHEEL_RADIUS);
    wheel.setFilled(true);
    wheel.setFillColor(Color.GRAY);
    add(wheel);
}
/* Private constants */
protected static final double CAR_WIDTH = 75;
protected static final double CAR_HEIGHT = 36;
protected static final double CAR_BASELINE = 10;
protected static final double CONNECTOR = 6;
protected static final double WHEEL_RADIUS = 8;
protected static final double WHEEL_INSET = 16;
}
```

The **Boxcar** Class

```java
/**
 * This class represents a boxcar. Like all TrainCar subclasses,
 * a Boxcar is a graphical object that you can add to a GCanvas.
 */
public class Boxcar extends TrainCar {
    /**
     * Creates a new boxcar with the specified color.
     * @param color The color of the new boxcar
     */
    public Boxcar(Color color) {
        super(color);
        double xRightDoor = CONNECTOR + CAR_WIDTH / 2;
        double xLeftDoor = xRightDoor - DOOR_WIDTH;
        double yDoor = -CAR_BASELINE - DOOR_HEIGHT;
        add(new GRect(xLeftDoor, yDoor, DOOR_WIDTH, DOOR_HEIGHT));
        add(new GRect(xRightDoor, yDoor, DOOR_WIDTH, DOOR_HEIGHT));
    }
    /* Dimensions of the door panels on the boxcar */
    private static final double DOOR_WIDTH = 18;
    private static final double DOOR_HEIGHT = 32;
}
```

Nesting Compound Objects

- Given that a `GCompound` is also a `GObject`, you can add a `GCompound` to another `GCompound`.
- The `Train` class on the next slide illustrates this technique by defining an entire train as a compound to which you can append new cars. You can create a three-car train like this:

```java
Train train = new Train();
train.append(new Engine());
train.append(new Boxcar(Color.GREEN));
train.append(new Caboose());
```

One tremendous advantage of making the train a single object is that you can then animate the train as a whole.

The **Train** Class

```java
import acm.graphics.*;
/**
 * This class defines a GCompound that represents a train.
 */
public class Train extends GCompound {
    /**
     * Creates a new train that contains no cars. Clients can add
     * cars at the end by calling append.
     */
    public Train() {
        /* No operations necessary */
    }
    /**
     * Adds a new car to the end of the train.
     * @param car The new train car
     */
    public void append(TrainCar car) {
        double width = getWidth();
        double a = (width == 0) ? 0 : width - TrainCar.CONNECTOR;
        add(car, a, 0);
    }
}
```