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Java Programming Tutorial

Custom Graphics

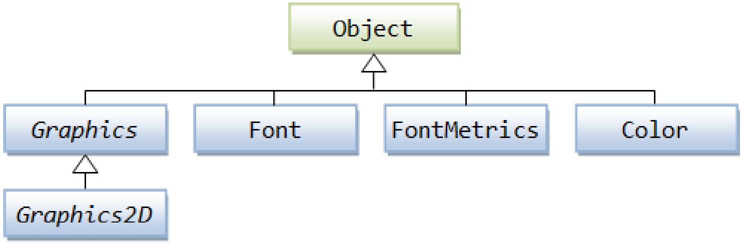
This chapter shows you how you can paint your own custom drawing (such as graphs, charts, drawings and, in particular, computer games) because you cannot find standard GUI components that meets your requirements. I shall stress that you should try to reuse the standard GUI components as far as possible and leave custom graphics as the last resort. Nonetheless, custom graphics is curial in game programming.

Read "Swing Tutorial" trail "Performing Custom Painting".

1. The java.awt.Graphics Class: Graphics Context and Custom Painting

A *graphics context* provides the capabilities of drawing on the screen. The graphics context maintains states such as the color and font used in drawing, as well as interacting with the underlying operating system to perform the drawing. In Java, custom painting is done via the java.awt.Graphics class, which manages a graphics context, and provides a set of *device-independent* methods for drawing texts, figures and images on the screen on different platforms.

The java.awt.Graphics is an abstract class, as the actual act of drawing is system-dependent and device-dependent. Each operating platform will provide a subclass of Graphics to perform the actual drawing under the platform, but conform to the specification defined in Graphics.



1.1 Graphics Class' Drawing Methods

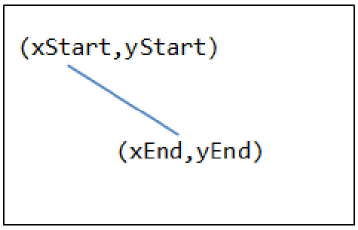
The Graphics class provides methods for drawing three types of graphical objects:

1. Text strings: via the drawString() method. Take note that System.out.println() prints to the system console, not to the graphics screen.
2. Vector-graphic primitives and shapes: via methods drawXxx() and fillXxx(), where Xxx could be Line, Rect, Oval, Arc, PolyLine, RoundRect, or 3DRect.
3. Bitmap images: via the drawImage() method.

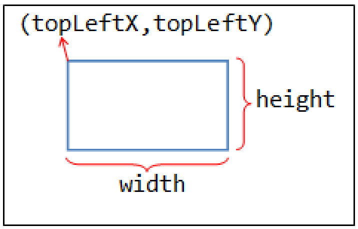
```
// Drawing (or printing) texts on the graphics screen:
drawString(String str, int xBaselineLeft, int yBaselineLeft);

// Drawing lines:
drawLine(int x1, int y1, int x2, int y2);
drawPolyline(int[] xPoints, int[] yPoints, int numPoint);

// Drawing primitive shapes:
drawRect(int xTopLeft, int yTopLeft, int width, int height);
drawOval(int xTopLeft, int yTopLeft, int width, int height);
drawArc(int xTopLeft, int yTopLeft, int width, int height, int startAngle, int arcAngle);
draw3DRect(int xTopLeft, int, yTopLeft, int width, int height, boolean raised);
drawRoundRect(int xTopLeft, int yTopLeft, int width, int height, int arcWidth, int arcHeight)
drawPolygon(int[] xPoints, int[] yPoints, int numPoint);

// Filling primitive shapes:
fillRect(int xTopLeft, int yTopLeft, int width, int height);
fillOval(int xTopLeft, int yTopLeft, int width, int height);
fillArc(int xTopLeft, int yTopLeft, int width, int height, int startAngle, int arcAngle);
fill3DRect(int xTopLeft, int, yTopLeft, int width, int height, boolean raised);
fillRoundRect(int xTopLeft, int yTopLeft, int width, int height, int arcWidth, int arcHeight)
```

```
fillPolygon(int[] xPoints, int[] yPoints, int numPoint);

// Drawing (or Displaying) images:
drawImage(Image img, int xTopLeft, int yTopLeft, ImageObserver obs);  // draw image with its size
drawImage(Image img, int xTopLeft, int yTopLeft, int width, int height, ImageObserver o);  // resize image on screen
```

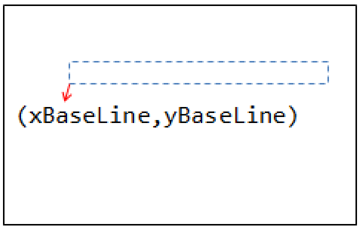
These drawing methods is illustrated below. The `drawXxx()` methods draw the outlines; while `fillXxx()` methods fill the internal. Shapes with negative *`width`* and *`height`* will not be painted. The `drawImage()` will be discussed later.



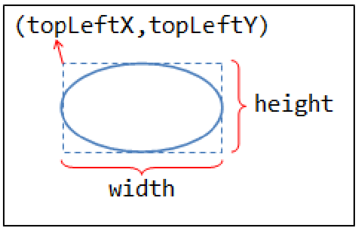
drawLine()



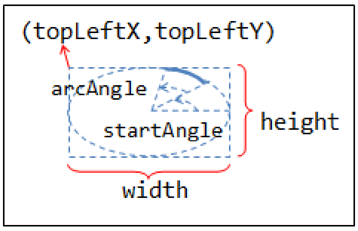
drawRect()



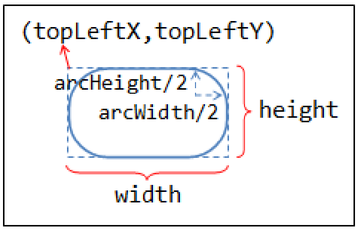
drawString()



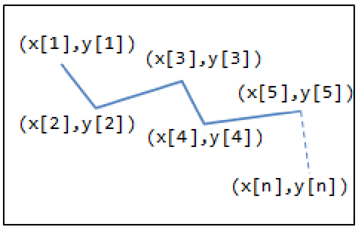
drawOval()



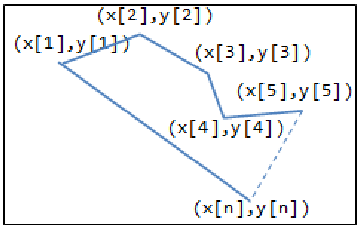
drawArc()



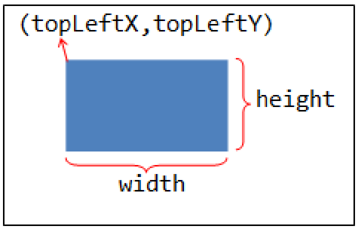
drawRoundRect()



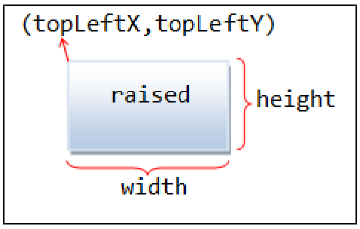
drawPolyline()



drawPolygon()



fillRect()



fill3DRect()

1.2 `Graphics` Class' Methods for Maintaining the Graphics Context

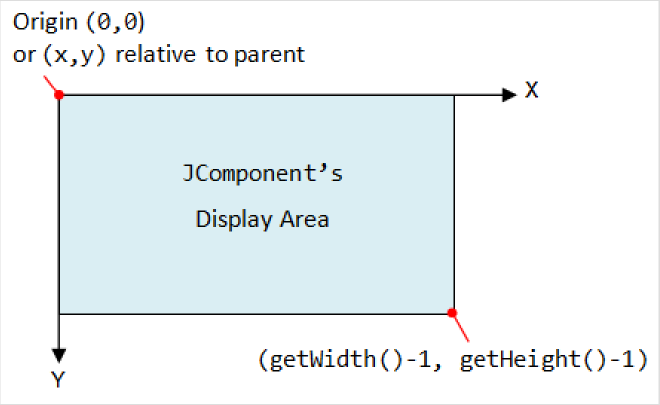
The graphic context maintains *states* (or *attributes*) such as the current painting color, the current font for drawing text strings, and the current painting rectangular area (called *clip*). You can use the methods `getColor()`, `setColor()`, `getFont()`, `setFont()`, `getClipBounds()`, `setClip()` to get or set the color, font, and clip area. Any painting outside the clip area is ignored.

```
// Graphics context's current color.
void setColor(Color c)
Color getColor()

// Graphics context's current font.
void setFont(Font f)
Font getFont()

// Set/Get the current clip area. Clip area shall be rectangular and no rendering is performed outside the clip area.
void setClip(int xTopLeft, int yTopLeft, int width, int height)
void setClip(Shape rect)
public abstract void clipRect(int x, int y, int width, int height) // intersects the current clip with the given rectangle
Rectangle getClipBounds()  // returns an Rectangle
Shape getClip()            // returns an object (typically Rectangle) implements Shape
```

1.3 `Graphics` Class' Other Methods

```
void clearRect(int x, int y, int width, int height)
   // Clear the rectangular area to background
void copyArea(int x, int y, int width, int height, int dx, int dy)
   // Copy the rectangular area to offset (dx, dy).
void translate(int x, int y)
   // Translate the origin of the graphics context to (x, y). Subsequent drawing uses the new origin.
FontMetrics getFontMetrics()
FontMetrics getFontMetrics(Font f)
   // Get the FontMetrics of the current font / the specified font
```

1.4 Graphics Coordinate System



In Java Windowing Subsystem (like most of the 2D Graphics systems), the origin `(0,0)` is located at the top-left corner.

EACH component/container has its own coordinate system, ranging for `(0,0)` to `(width-1, height-1)` as illustrated.

You can use method `getWidth()` and `getHeight()` to retrieve the width and height of a component/container. You can use `getX()` or `getY()` to get the top-left corner `(x,y)` of this component's origin relative to its parent.

2. Custom Painting Template

Under Swing, custom painting is usually performed by extending (i.e., subclassing) a `JPanel` as the drawing canvas and override the `paintComponent(Graphics g)` method to perform your own drawing with the drawing methods provided by the `Graphics` class. The Java Windowing Subsystem invokes (calls back) `paintComponent(g)` to render the `JPanel` by providing the current graphics context `g`, which can be used to invoke the drawing methods. The extended `JPanel` is often programmed as an inner class of a `JFrame` application to facilitate access of private variables/methods. Although we typically draw on the `JPanel`, you can in fact draw on any `JComponent` (such as `JLabel`, `JButton`).

The custom painting code template is as follows:

```
import java.awt.*;
import javax.swing.*;

/** Custom Drawing Code Template */
@SuppressWarnings("serial")
public class CGTemplate extends JFrame {  // Graphics application extends JFrame
   // Named-constants for dimensions
   public static final int CANVAS_WIDTH = 640;
   public static final int CANVAS_HEIGHT = 480;

   private DrawCanvas canvas;  // Declare an instance the drawing canvas (extends JPanel)

   /** Constructor to set up the GUI components */
   public CGTemplate() {
      canvas = new DrawCanvas();    // Construct the drawing canvas
      canvas.setPreferredSize(new Dimension(CANVAS_WIDTH, CANVAS_HEIGHT));
      this.setContentPane(canvas);
         // Set the Drawing JPanel as the content-pane
         // OR
         // Get the JFrame's content-pane and add onto the content-pane as follows:
         //   Container cp = getContentPane();
         //   cp.add(canvas);

      this.setDefaultCloseOperation(EXIT_ON_CLOSE);   // Handle the CLOSE button
      this.pack();              // Either pack() the components; or setSize()
      this.setTitle("......");  // this JFrame sets the title
      this.setVisible(true);    // this JFrame show
   }

   /**
    * DrawCanvas (inner class) is a JPanel used for custom drawing
    */
   private class DrawCanvas extends JPanel {
      // Override paintComponent to perform your own painting
      @Override
      public void paintComponent(Graphics g) {
         super.paintComponent(g);     // paint parent's background
         setBackground(Color.BLACK);  // set background color for this JPanel

         // Your custom painting codes. For example,
         // Drawing primitive shapes
         g.setColor(Color.YELLOW);    // set the drawing color
         g.drawLine(30, 40, 100, 200);
         g.drawOval(150, 180, 10, 10);
         g.drawRect(200, 210, 20, 30);
         g.setColor(Color.RED);       // change the drawing color
         g.fillOval(300, 310, 30, 50);
         g.fillRect(400, 350, 60, 50);
         // Printing texts
         g.setColor(Color.WHITE);
         g.setFont(new Font("Courier New", Font.PLAIN, 12));
         g.drawString("Testing custom drawing ...", 10, 20);
      }
   }

   /** Entry main method */
   public static void main(String[] args) {
      // Run the GUI codes on the Event-Dispatching thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new CGTemplate(); // Let the constructor do the job
         }
      });
   }
}
```

Dissecting the Program

- Custom painting is performed by extending a `JPanel` (called `DrawCanvas`) and overrides the `paintComponent(Graphics g)` method to do your own drawing with the drawing methods provided by the `Graphics` class.
- `DrawCanvas` is designed as an inner class of this `JFrame` application, so as to facilitate access of the private variables/methods.
- Java Windowing Subsystem invokes (calls back) `paintComponent(g)` to render the `JPanel`, with the current graphics context in `g`, whenever there is a need to refresh the display (e.g., during the initial launch, restore, resize, etc). You can use the drawing methods (`g.drawXxx()` and `g.fillXxx()`) on the current graphics context `g` to perform custom painting on the `JPanel`.
- The size of the `JPanel` is set via the `setPreferredSize()`. The `JFrame` does not set its size, but packs the components contained via `pack()`.
- In the `main()`, the constructor is called in the event-dispatch thread via static method `javax.swing.SwingUtilities.invokeLater()` (instead of running in the main thread), to ensure thread-safety and avoid deadlock, as recommended by the Swing developers.

(Advanced) Annoymous Inner Class for Drawing Canvas

Instead of a named-inner class called `DrawCanvas` in the previous example, you can also use an anonymous inner class for the drawing canvas, if the painting code is short. For example,

```
// Create an anonymous inner class extends JPanel
// Construct an instance called canvas
JPanel canvas = new JPanel() {
   @Override
   public void paintComponent(Graphics g) {
      super.paintComponent(g);  // paint parent's background
      ......
   }
};
......
```

(Advanced) Getting the Graphics Context

You can retrieve the `Graphics` context of a `JComponent` via the `getGraphics()` method. This is, however, not commonly used. For example,

```
JPanel panel = new JPanel();
Graphics graphics = panel.getGraphics();
```

Custom Painting in AWT (Obsolete)

Under AWT, you can perform custom painting by extending `java.awt.Canvas`, and override the `paint(Graphics g)` method, in a `java.awt.Frame` application. Similarly, you can explicitly invoke `repaint()` to update the graphics.

2.1 Refreshing the Display via `repaint()`

At times, we need to *explicitly refresh the display* (e.g., in game and animation). We shall NOT invoke `paintComponent(Graphics)` directly. Instead, we invoke the `JComponent`'s `repaint()` method. The Windowing Subsystem will in turn call back the `paintComponent()` with the current `Graphics` context and execute it in the event-dispatching thread for thread safety. You can `repaint()` a particular `JComponent` (such as a `JPanel`) or the entire `JFrame`. The children contained within the `JComponent` will also be repainted.

3. (Optional) Colors and Fonts

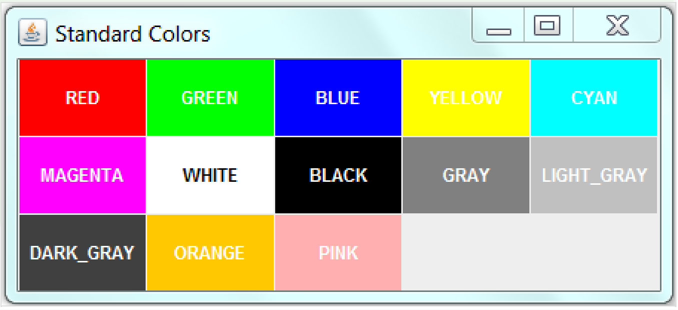
3.1 `java.awt.Color`

The class `java.awt.Color` provides 13 standard colors as named-constants. They are: `Color.RED`, `GREEN`, `BLUE`, `MAGENTA`, `CYAN`, `YELLOW`, `BLACK`, `WHITE`, `GRAY`, `DARK_GRAY`, `LIGHT_GRAY`, `ORANGE`, and `PINK`. (In JDK 1.1, these constant names are in lowercase, e.g., red. This violates the Java naming convention for constants. In JDK 1.2, the uppercase names are added. The lowercase names were not removed for backward compatibility.)

You can use the `toString()` to print the RGB values of these color (e.g., `System.out.println(Color.RED)`):

```
RED        : java.awt.Color[r=255, g=0,   b=0]
GREEN      : java.awt.Color[r=0,   g=255, b=0]
BLUE       : java.awt.Color[r=0,   g=0,   b=255]
YELLOW     : java.awt.Color[r=255, g=255, b=0]
```

```
MAGENTA    : java.awt.Color[r=255, g=0,   b=255]
CYAN       : java.awt.Color[r=0,   g=255, b=255]
WHITE      : java.awt.Color[r=255, g=255, b=255]
BLACK      : java.awt.Color[r=0,   g=0,   b=0]
GRAY       : java.awt.Color[r=128, g=128, b=128]
LIGHT_GRAY: java.awt.Color[r=192, g=192, b=192]
DARK_GRAY : java.awt.Color[r=64,  g=64,  b=64]
PINK       : java.awt.Color[r=255, g=175, b=175]
ORANGE     : java.awt.Color[r=255, g=200, b=0]
```



You can also use the RGB values or RGBA value (A for alpha to specify transparency/opaque) to construct your own color via constructors:

```
Color(int r, int g, int b);                 // between 0 and 255
Color(float r, float g, float b);           // between 0.0f and 1.0f
Color(int r, int g, int b, int alpha);           // between 0 and 255
Color(float r, float g, float b, float alpha); // between 0.0f and 1.0f
   // alpha of 0 for totally transparent, 255 (or 1.0f) for totally opaque
   // The default alpha is 255 (or 1.0f) for totally opaque
```

For example:

```
Color myColor1 = new Color(123, 111, 222);
Color myColor2 = new Color(0.5f, 0.3f, 0.1f);
Color myColor3 = new Color(0.5f, 0.3f, 0.1f, 0.5f);  // semi-transparent
```

To retrieve the individual components, you can use `getRed()`, `getGreen()`, `getBlue()`, `getAlpha()`, etc.

To set the background and foreground (text) color of a component/container, you can invoke:

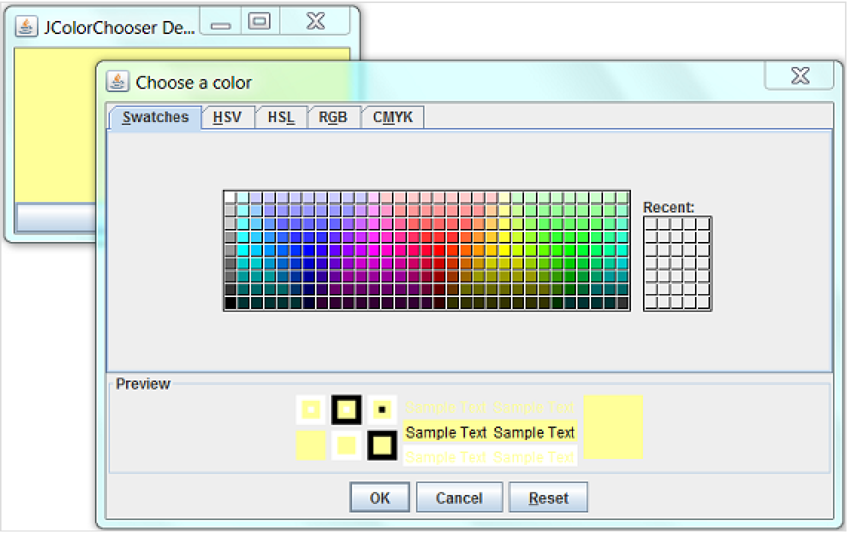
```
JLabel label = new JLabel("Test");
label.setBackground(Color.LIGHT_GRAY);
label.setForeground(Color.RED);
```

To set the color of the `Graphics` context `g` (for drawing lines, shapes, and texts), use `g.setColor(color)`:

```
g.setColor(Color.RED);
g.drawLine(10, 20, 30, 40);   // in Color.RED
Color myColor = new Color(123, 111, 222);
g.setColor(myColor);
g.drawRect(10, 10, 40, 50);   // in myColor
```

(Advanced) `JColorChooser`

This example uses the `javax.swing.JColorChooser` to set the background color of the `JPanel`.



```
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/** Test ColorChooser to set the background */
@SuppressWarnings("serial")
public class JColorChooserDemo extends JFrame {

   JPanel panel;
   Color bgColor = Color.LIGHT_GRAY;  // panel's background color

   /** Constructor to setup the UI components */
   public JColorChooserDemo() {
      panel = new JPanel(new BorderLayout());

      JButton btnColor = new JButton("Change Color");
      panel.add(btnColor, BorderLayout.SOUTH);
      btnColor.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            Color color = JColorChooser.showDialog(JColorChooserDemo.this,
                  "Choose a color", bgColor);
            if (color != null) { // new color selected
               bgColor = color;
            }
            panel.setBackground(bgColor); // change panel's background color
         }
      });

      setContentPane(panel);

      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      setTitle("JColorChooser Demo");
      setSize(300, 200);
      setLocationRelativeTo(null);  // center the application window
      setVisible(true);             // show it
   }

   /** The entry main() method */
   public static void main(String[] args) {
      // Run GUI codes in the Event-Dispatching thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new JColorChooserDemo();  // Let the constructor do the job
         }
      });
   }
}
```

3.2 java.awt.Font

The class `java.awt.Font` represents a specific font face, which can be used for rendering texts. You can use the following constructor to construct a `Font` instance:

```
public Font(String name, int style, int size);
// name:  Family name "Dialog", "DialogInput", "Monospaced", "Serif", or "SansSerif" or
//        Physical font found in this GraphicsEnvironment.
//        You can also use String constants Font.DIALOG, Font.DIALOG_INPUT, Font.MONOSPACED,
//          Font.SERIF, Font.SANS_SERIF (JDK 1.6)
// style: Font.PLAIN, Font.BOLD, Font.ITALIC or Font.BOLD|Font.ITALIC (Bit-OR)
// size:  the point size of the font (in pt) (1 inch has 72 pt).
```

You can use the `setFont()` method to set the current font for the `Graphics` context `g` for rendering texts. For example,

```
Font myFont1 = new Font(Font.MONOSPACED, Font.PLAIN, 12);
Font myFont2 = new Font(Font.SERIF, Font.BOLD | Font.ITALIC, 16);  // bold and italics
JButton btn = new JButton("RESET");
btn.setFont(myFont1);
JLabel lbl = new JLabel("Hello");
lbl.setFont(myFont2);
......
g.drawString("In default Font", 10, 20);     // in default font
Font myFont3 = new Font(Font.SANS_SERIF, Font.ITALIC, 12);
g.setFont(myFont3);
g.drawString("Using the font set", 10, 50);  // in myFont3
```

Font's Family Name vs. Font Name

A font could have many *faces* (or *style*), e.g., plain, bold or italic. All these faces have similar typographic design. The *font face name*, or *font name* for short, is the name of a particular font face, like "Arial", "Arial Bold", "Arial Italic", "Arial Bold Italic". The *font family name* is the name of the font family that determines the typographic design across several faces, like "Arial". For example,

```
java.awt.Font[family=Arial,name=Arial,style=plain,size=1]
java.awt.Font[family=Arial,name=Arial Bold,style=plain,size=1]
java.awt.Font[family=Arial,name=Arial Bold Italic,style=plain,size=1]
java.awt.Font[family=Arial,name=Arial Italic,style=plain,size=1]
```

Logical Font vs. Physical Font

JDK supports these *logical font family* names: "`Dialog`", "`DialogInput`", "`Monospaced`", "`Serif`", or "`SansSerif`". JDK 1.6 provides these `String` constants: `Font.DIALOG`, `Font.DIALOG_INPUT`, `Font.MONOSPACED`, `Font.SERIF`, `Font.SANS_SERIF`.

Physical font names are actual font libraries such as "Arial", "Times New Roman" in the system.

`GraphicsEnvironment`'s `getAvailableFontFamilyNames()` and `getAllFonts()`

You can use `GraphicsEnvironment`'s `getAvailableFontFamilyNames()` to list all the font famiy names; and `getAllFonts()` to construct all `Font` instances (with font size of 1 pt). For example,

```
GraphicsEnvironment env = GraphicsEnvironment.getLocalGraphicsEnvironment();
```

```
// Get all font family name in a String[]
String[] fontNames = env.getAvailableFontFamilyNames();
for (String fontName : fontNames) {
   System.out.println(fontName);
}

// Construct all Font instance (with font size of 1)
Font[] fonts = env.getAllFonts();
for (Font font : fonts) {
   System.out.println(font);
}
```

`Font`'s `deriveFont()`

You can use `Font`'s `deriveFont()` to derive a new `Font` instance from this `Font` with varying size, style and others.

```
public Font deriveFont(float size)
public Font deriveFont(int style)
public Font deriveFont(AffineTransform trans)
public Font deriveFont(int style, float size)
public Font deriveFont(int style, AffineTransform trans)
```

For example,

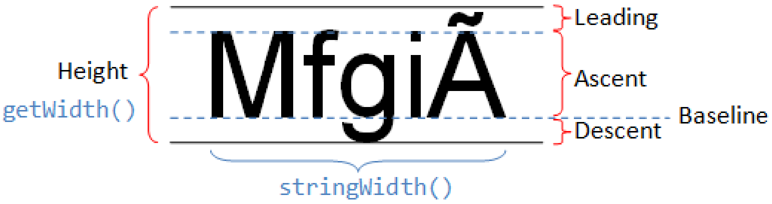
```
Font font = new Font(Font.MONOSPACED, Font.BOLD, 12);
System.out.println(font);
   // java.awt.Font[family=Monospaced,name=Monospaced,style=bold,size=12]
Font fontDerived = font.deriveFont(20);
System.out.println(fontDerived);
   // java.awt.Font[family=Monospaced,name=Monospaced,style=plain,size=12]
```

3.3 `java.awt.FontMetrics`

The `java.awt.FontMetrics` class can be used to measure the exact width and height of the string for a particular font face, so that you can position the string as you desire (such as at the center of the screen).

To create a `FontMetrics`, use `getFontMetrics()` methods of the `Graphics` class, as follows:

```
// In java.awt.Graphics
public abstract FontMetrics getFontMetrics(Font f)
   // Get the FontMetrics of the specified font
public abstract FontMetrics getFontMetrics()
   // Get the FontMetrics of the current font
```



```
// in java.awt.FontMetrics
public int getHeight()
public int getLeading()
public int getAscent()
public int getDescent()
```

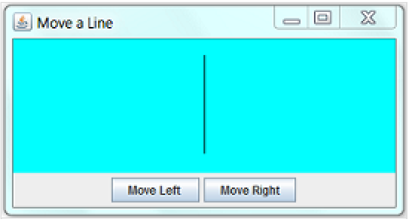
The most commonly-used function for `FontMetrics` is to measure the width of a given `String` displayed in a certain font.

```
public int stringWidth(String str)
   // Returns the total width for showing the specified String in this Font.
```

To centralize a string on the drawing canvas (e.g., JPanel):

```
public void paintComponent(Graphics g) {
   super.paintComponent(g);
   g.setFont(new Font("Arial", Font.BOLD, 30));
   // Get font metrics for the current font
   FontMetrics fm = g.getFontMetrics();
   // Centralize the string
   String msg = "Hello, world!";
   int msgWidth = fm.stringWidth(msg);
   int msgAscent = fm.getAscent();
   // Get the position of the leftmost character in the baseline
   // getWidth() and getHeight() returns the width and height of this component
   int msgX = getWidth() / 2 - msgWidth / 2;
   int msgY = getHeight() / 2 + msgAscent / 2;
   g.drawString(msg, msgX, msgY);
}
```

4. Example 1: Moving an Object via Key/Button Action



This example illustrates how to re-paint the screen in response to a `KeyEvent` or `ActionEvent`.

The display consists of two `JPanel` in a `JFrame`, arranged in `BorderLayout`. The top panel is used for custom painting; the bottom panel holds two `JButton` arranged in `FlowLayout`. Clicking the "Move Right" or "Move Left" buttons moves the line. The `JFrame` listens to the "Left-arrow" and "Right-arrow" keys, and responses by moving the line left or right.

```
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/**
 * Custom Graphics Example: Using key/button to move a line left or right.
 */
@SuppressWarnings("serial")
public class CGMoveALine extends JFrame {
   // Name-constants for the various dimensions
   public static final int CANVAS_WIDTH = 400;
   public static final int CANVAS_HEIGHT = 140;
   public static final Color LINE_COLOR = Color.BLACK;
   public static final Color CANVAS_BACKGROUND = Color.CYAN;

   // The line from (x1, y1) to (x2, y2), initially position at the center
   private int x1 = CANVAS_WIDTH / 2;
   private int y1 = CANVAS_HEIGHT / 8;
   private int x2 = x1;
   private int y2 = CANVAS_HEIGHT / 8 * 7;

   private DrawCanvas canvas; // the custom drawing canvas (extends JPanel)

   /** Constructor to set up the GUI */
   public CGMoveALine() {
      // Set up a panel for the buttons
      JPanel btnPanel = new JPanel(new FlowLayout());
      JButton btnLeft = new JButton("Move Left ");
      btnPanel.add(btnLeft);
      btnLeft.addActionListener(new ActionListener() {
         public void actionPerformed(ActionEvent e) {
            x1 -= 10;
            x2 -= 10;
            canvas.repaint();
            requestFocus(); // change the focus to JFrame to receive KeyEvent
         }
      });
      JButton btnRight = new JButton("Move Right");
      btnPanel.add(btnRight);
      btnRight.addActionListener(new ActionListener() {
         public void actionPerformed(ActionEvent e) {
            x1 += 10;
            x2 += 10;
            canvas.repaint();
            requestFocus(); // change the focus to JFrame to receive KeyEvent
         }
      });

      // Set up a custom drawing JPanel
      canvas = new DrawCanvas();
      canvas.setPreferredSize(new Dimension(CANVAS_WIDTH, CANVAS_HEIGHT));

      // Add both panels to this JFrame
      Container cp = getContentPane();
      cp.setLayout(new BorderLayout());
      cp.add(canvas, BorderLayout.CENTER);
      cp.add(btnPanel, BorderLayout.SOUTH);

      // "this" JFrame fires KeyEvent
      addKeyListener(new KeyAdapter() {
         @Override
         public void keyPressed(KeyEvent evt) {
            switch(evt.getKeyCode()) {
               case KeyEvent.VK_LEFT:
                  x1 -= 10;
                  x2 -= 10;
                  repaint();
                  break;
               case KeyEvent.VK_RIGHT:
                  x1 += 10;
                  x2 += 10;
                  repaint();
                  break;
            }
         }
      });

      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE); // Handle the CLOSE button
      setTitle("Move a Line");
      pack();           // pack all the components in the JFrame
      setVisible(true); // show it
      requestFocus();   // set the focus to JFrame to receive KeyEvent
   }

   /**
    * DrawCanvas (inner class) is a JPanel used for custom drawing
    */
   class DrawCanvas extends JPanel {
      @Override
      public void paintComponent(Graphics g) {
         super.paintComponent(g);
         setBackground(CANVAS_BACKGROUND);
         g.setColor(LINE_COLOR);
         g.drawLine(x1, y1, x2, y2); // draw the line
      }
   }

   /** The entry main() method */
   public static void main(String[] args) {
      // Run GUI codes on the Event-Dispatcher Thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new CGMoveALine(); // Let the constructor do the job
         }
      });
   }
}
```

Dissecting the Program

- To do custom painting, you have to decide which superclass to use. It is recommended that you use a `JPanel` (or a more specialized Swing component such as `JButton` or `JLabel`). In this example, we extend the `JPanel` to do our custom painting, in an inner class, as follows:

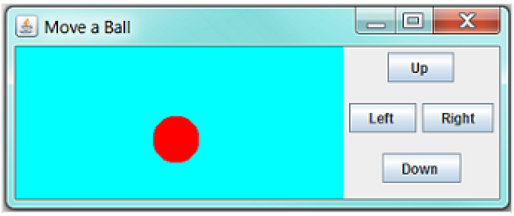
  ```
  class DrawCanvas extends JPanel {
     @Override
     public void paintComponent(Graphics g) {
        super.paintComponent(g);  // paint background
        setBackground(CANVAS_BACKGROUND);
        g.setColor(LINE_COLOR);
        g.drawLine(x1, y1, x2, y2);
     }
  }
  ```

- The `paintComponent()` method is overridden to provide the custom drawing codes. We use the `drawLine()` method to draw a line from `(x1,y1)` to `(x2, y2)`.
- The `paintComponent()` method cannot be called directly from your code, because it requires a `Graphics` object as argument.
- `paintComponent()` is a so-called "*call-back*" method. The Windowing subsystem invokes this method and provides a pre-configured `Graphics` object to represent its state (e.g., current color, font, clip area and etc). There are two kinds of painting: system-triggered painting and application-triggered painting. In a system-trigger painting, the system request a component to render its content when the component is first made visible on the screen, or the component is resized, or the component is damaged that needs to be repaint. In an application-triggered painting, the application invokes a `repaint()` request. Under both cases, the Windowing subsystem will *call-back* the `paintComponent()` to render the contents of the component with a proper `Graphics` object as argument.
- In this example, the application requests for a `repaint()` in the `KeyEvent` and `MouseEvent` handlers, which triggers the `paintComponent()` with an appropriate `Graphics` object as the argument.
- To be precise, when you invoke the `repaint()` method to repaint a `JComponent`, the Windowing subsystem *calls-back* `paint()` method. The `paint()` method then *calls-back* three methods: `paintComponent()`, `paintBorder()` and `paintChilden()`.
- In the overridden `paintComponent()` method, we call `super.paintComponent()` to paint the background of the `JComponent`. If this call is omitted, you must either paint the background yourself (via a `fillRect()` call) or use `setOpaque(false)` to make the `JComponent` transparent. This will inform Swing system to paint those `JComponents` behind the transparent component.
- We choose the `JFrame` as the source of the `KeyEvent`. `JFrame` shall be "*in focus*" when the key is pressed. The `requestFocus()` method (of "`this`" `JFrame`) is invoked to request for the keyboard focus.

[TODO]: may need to revise.

Try

Modifying the program to move a ball in response to up/down/left/right buttons, as well as the 4 arrow and "wasd" keys , as shown:



5. Example 2: Moving Sprites

In game programing, we have moving game objects called *sprites*. Each sprite is usually modelled in its own class, with its own properties, and it can paint itself.

`Sprite.java`

This class models a sprite, with its own properties, and it can paint itself via the `paint()` method provided given a `Graphics` context. A rectangle is used here.

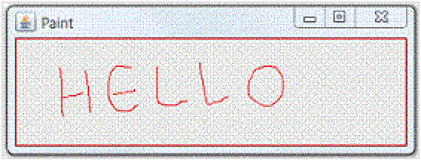
```
import java.awt.*;
/**
 * The class Srite models a moving game object, with its own operations
 *  and can paint itself.
 */
public class Sprite {
   // Variables (package access)
   int x, y, width, height; // rectangle (for illustration)
   Color color = Color.RED; // color of the object

   /** Constructor to setup the GUI */
   public Sprite(int x, int y, int width, int height, Color color) {
      this.x = x;
      this.y = y;
      this.width = width;
      this.height = height;
      this.color = color;
   }

   /** Paint itself (given the Graphics context) */
   public void paint(Graphics g) {
      g.setColor(color);
      g.fillRect(x, y, width, height); // fill a rectangle
   }
}
```

`MoveASprite.java`

Instead of repainting the entire display, we only repaint the affected areas (clips), for efficiency, via the `repaint(x, y, width, height)` method. In `moveLeft()` and `moveRight()`, we save the states, move the object, repaint the saved clip-area with the background color, and repaint the new clip-area occupied by the sprite. Repainting is done by asking the sprite to paint itself at the new location, and erase from the old location.

```
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/**
 * Custom Graphics Example: Using key/button to move a object left or right.
 * The moving object (sprite) is defined in its own class, with its own
 * operations and can paint itself.
 */
public class CGMoveASprite extends JFrame {
   // Name-constants for the various dimensions
   public static final int CANVAS_WIDTH = 400;
   public static final int CANVAS_HEIGHT = 140;
   public static final Color CANVAS_BG_COLOR = Color.CYAN;

   private DrawCanvas canvas; // the custom drawing canvas (extends JPanel)
   private Sprite sprite;     // the moving object

   /** Constructor to set up the GUI */
   public CGMoveASprite() {
      // Construct a sprite given x, y, width, height, color
      sprite = new Sprite(CANVAS_WIDTH / 2 - 5, CANVAS_HEIGHT / 2 - 40,
            10, 80, Color.RED);

      // Set up a panel for the buttons
      JPanel btnPanel = new JPanel(new FlowLayout());
      JButton btnLeft = new JButton("Move Left ");
      btnPanel.add(btnLeft);
      btnLeft.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            moveLeft();
            requestFocus(); // change the focus to JFrame to receive KeyEvent
         }
      });
      JButton btnRight = new JButton("Move Right");
      btnPanel.add(btnRight);
      btnRight.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            moveRight();
            requestFocus(); // change the focus to JFrame to receive KeyEvent
         }
      });

      // Set up the custom drawing canvas (JPanel)
      canvas = new DrawCanvas();
      canvas.setPreferredSize(new Dimension(CANVAS_WIDTH, CANVAS_HEIGHT));

      // Add both panels to this JFrame
      Container cp = getContentPane();
      cp.setLayout(new BorderLayout());
      cp.add(canvas, BorderLayout.CENTER);
      cp.add(btnPanel, BorderLayout.SOUTH);

      // "this" JFrame fires KeyEvent
      addKeyListener(new KeyAdapter() {
         @Override
         public void keyPressed(KeyEvent evt) {
            switch(evt.getKeyCode()) {
               case KeyEvent.VK_LEFT:  moveLeft();  break;
               case KeyEvent.VK_RIGHT: moveRight(); break;
            }
         }
      });

      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      setTitle("Move a Sprite");
      pack();            // pack all the components in the JFrame
      setVisible(true);  // show it
      requestFocus();    // "this" JFrame requests focus to receive KeyEvent
   }

   /** Helper method to move the sprite left */
   private void moveLeft() {
      // Save the current dimensions for repaint to erase the sprite
      int savedX = sprite.x;
      // update sprite
      sprite.x -= 10;
      // Repaint only the affected areas, not the entire JFrame, for efficiency
      canvas.repaint(savedX, sprite.y, sprite.width, sprite.height); // Clear old area to background
      canvas.repaint(sprite.x, sprite.y, sprite.width, sprite.height); // Paint new location
   }

   /** Helper method to move the sprite right */
   private void moveRight() {
      // Save the current dimensions for repaint to erase the sprite
      int savedX = sprite.x;
      // update sprite
      sprite.x += 10;
      // Repaint only the affected areas, not the entire JFrame, for efficiency
      canvas.repaint(savedX, sprite.y, sprite.width, sprite.height); // Clear old area to background
      canvas.repaint(sprite.x, sprite.y, sprite.width, sprite.height); // Paint at new location
   }

   /** DrawCanvas (inner class) is a JPanel used for custom drawing */
   class DrawCanvas extends JPanel {
      @Override
      public void paintComponent(Graphics g) {
         super.paintComponent(g);
         setBackground(CANVAS_BG_COLOR);
         sprite.paint(g);  // the sprite paints itself
      }
   }

   /** The entry main() method */
   public static void main(String[] args) {
      // Run GUI construction on the Event-Dispatching Thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new CGMoveASprite(); // Let the constructor do the job
         }
      });
   }
}
```

6. Example 3: Paint



MyPaint.java

```java
import java.util.List;
import java.util.ArrayList;
import javax.swing.*;
import java.awt.*;
import java.awt.event.*;

/**
 * Custom Graphics Example: Paint
 */
public class MyPaint extends JFrame {
   // Name-constants for the various dimensions
   public static final int CANVAS_WIDTH = 500;
   public static final int CANVAS_HEIGHT = 300;
   public static final Color LINE_COLOR = Color.RED;

   // Lines, consists of a List of PolyLine instances
   private List<PolyLine> lines = new ArrayList<PolyLine>();
   private PolyLine currentLine;  // the current line (for capturing)

   /** Constructor to set up the GUI */
   public MyPaint() {
      DrawCanvas canvas = new DrawCanvas();
      canvas.setPreferredSize(new Dimension(CANVAS_WIDTH, CANVAS_HEIGHT));
      canvas.addMouseListener(new MouseAdapter() {
         @Override
         public void mousePressed(MouseEvent e) {
            // Begin a new line
            currentLine = new PolyLine();
            lines.add(currentLine);
            currentLine.addPoint(e.getX(), e.getY());
         }
      });
      canvas.addMouseMotionListener(new MouseMotionAdapter() {
         @Override
         public void mouseDragged(MouseEvent e) {
            currentLine.addPoint(e.getX(), e.getY());
            repaint();  // invoke paintComponent()
         }
      });

      setContentPane(canvas);
      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      setTitle("Paint");
      pack();
      setVisible(true);
   }

   /** DrawCanvas (inner class) is a JPanel used for custom drawing */
   private class DrawCanvas extends JPanel {
      @Override
      protected void paintComponent(Graphics g) { // called back via repaint()
         super.paintComponent(g);
         g.setColor(LINE_COLOR);
         for (PolyLine line: lines) {
            line.draw(g);
         }
      }
   }

   /** The entry main method */
   public static void main(String[] args) {
      SwingUtilities.invokeLater(new Runnable() {
         // Run the GUI codes on the Event-Dispatching thread for thread safety
         @Override
         public void run() {
            new MyPaint(); // Let the constructor do the job
         }
      });
   }
}
```

PolyLine.java

```java
import java.awt.Graphics;
import java.util.*;
/*
 * The PolyLine class model a line consisting of many points
 */
public class PolyLine {
   private List<Integer> xList;  // List of x-coord
   private List<Integer> yList;  // List of y-coord

   /** Constructor */
   public PolyLine() {
      xList = new ArrayList<Integer>();
      yList = new ArrayList<Integer>();
   }

   /** Add a point to this PolyLine */
   public void addPoint(int x, int y) {
      xList.add(x);
      yList.add(y);
   }

   /** This PolyLine paints itself */
   public void draw(Graphics g) { // draw itself
      for (int i = 0; i < xList.size() - 1; ++i) {
         g.drawLine((int)xList.get(i), (int)yList.get(i), (int)xList.get(i + 1),
               (int)yList.get(i + 1));
      }
   }
}
```

Dissecting the Program

[TODO]

7. Drawing Images

7.1 javax.swing.ImageIcon

The javax.swing.ImageIcon class represents an icon, which is a fixed-size picture, typically small-size and used to decorate components. To create an ImageIcon:

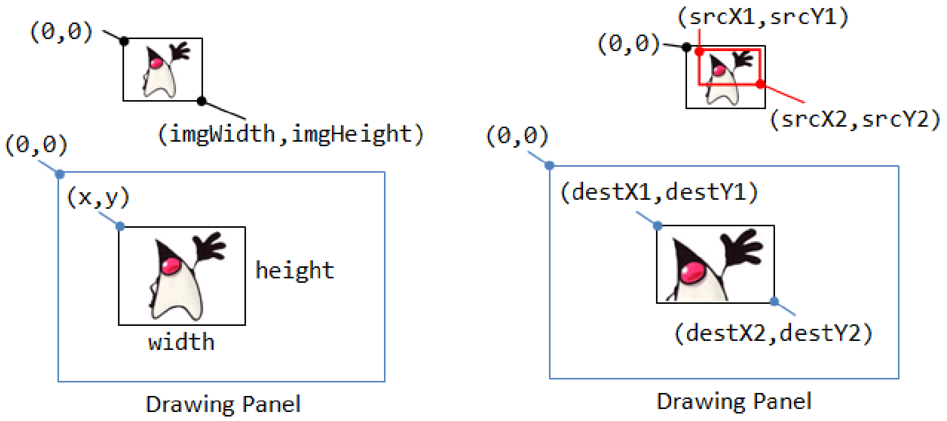
```java
// Prepare an ImageIcons to be used with JComponents or drawImage()
String imgNoughtFilename = "images/nought.gif";
ImageIcon iconNought = null;
URL imgURL = getClass().getClassLoader().getResource(imgNoughtFilename);
if (imgURL != null) {
   iconNought = new ImageIcon(imgURL);
} else {
   System.err.println("Couldn't find file: " + imgNoughtFilename);
}
```

7.2 Graphics Class' drawImage()

ImageIcon is fixed-in-sized and cannot be resized in display. You can use Graphics's drawImage() to resize a source image in display.

The java.awt.Graphics class declares 6 overloaded versions of abstract method drawImage().

```java
public abstract boolean drawImage(Image img, int x, int y, ImageObserver observer)
public abstract boolean drawImage(Image img, int x, int y, int width, int height, ImageObserver observer)
public abstract boolean drawImage(Image img, int x, int y, Color bgcolor, ImageObserver observer)
public abstract boolean drawImage(Image img, int x, int y, int width, int height, Color bgcolor, ImageObserver observer)
   // The img is drawn with its top-left corner at (x, y) scaled to the specified width and height
   //  (default to the image's width and height).
   // The bgColor (background color) is used for "transparent" pixels.

public abstract boolean drawImage(Image img, int destX1, int destY1, int destX2, int destY2,
      int srcX1, int srcY1, int srcX2, int srcY2, ImageObserver observer)
public abstract boolean drawImage(Image img, int destX1, int destY1, int destX2, int destY2,
      int srcX1, int srcY1, int srcX2, int srcY2, Color bgcolor, ImageObserver observer)
   // The img "clip" bounded by (scrX1, scrY2) and (scrX2, srcY2) is scaled and drawn from
   // (destX1, destY1) to (destX2, destY2) on the display.
```



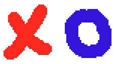
The coordinates involved is shown in the above diagram. The `ImageObserver` receives notification about the `Image` as it is loaded. In most purposes, you can set it to `null` or `this`.

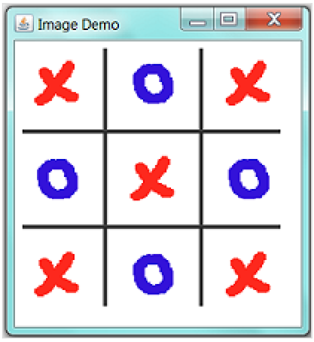
The `drawImage()` method requires an `Image` instance, which can be obtained via `ImageIcon`'s `getImage()` method; or via `static` method `ImageIO.read()` (read "Reading Images into your program"). For example,

```
// Prepare an ImageIcon
ImageIcon icon = null;
String imgFilename = "images/duke.gif";
java.net.URL imgURL = getClass().getClassLoader().getResource(imgFilename);
if (imgURL != null) {
   icon =  new ImageIcon(imgURL);
} else {
   System.err.println("Couldn't find file: " + imgFilename);
}

// Prepare an Image object to be used by drawImage()
final Image img = icon.getImage();
// Extend a JLabel and override paintComponet() to drawImage()
JLabel lbl4 = new JLabel() {
   @Override public void paintComponent(Graphics g) {
      super.paintComponent(g);  // paint background
      g.drawImage(img, 0, 0, 200, 200, null);
   }
};
lbl4.setPreferredSize(new Dimension(200, 200));
cp.add(lbl4);
```

Example

Images:





```
import java.awt.*;
import java.net.URL;
import javax.swing.*;
import java.util.Random;

/** Test drawImage() thru ImageIcon */
@SuppressWarnings("serial")
public class CGDrawImageDemo extends JFrame {
   // Define named-constants for the various dimensions
   public static final int ROWS = 3;
   public static final int COLS = 3;
   public static final int IMAGE_SIZE = 50;
   public static final int PADDING = 20;  // padding from the border
   public static final int CELL_SIZE = IMAGE_SIZE + 2 * PADDING;
   public static final int CANVAS_SIZE = CELL_SIZE * ROWS;

   private DrawCanvas canvas;    // The drawing canvas
   private Random random = new Random(); // for picking images in random

   // Images
   private String imgCrossFilename = "images/cross.gif";
   private String imgNoughtFilename = "images/nought.gif";
   private Image imgCross;   // drawImage() uses an Image object
   private Image imgNought;

   /** Constructor to set up the GUI components */
   public CGDrawImageDemo() {
      // Prepare the ImageIcon and Image objects for drawImage()
      ImageIcon iconCross = null;
      ImageIcon iconNought = null;
      URL imgURL = getClass().getClassLoader().getResource(imgCrossFilename);
      if (imgURL != null) {
         iconCross = new ImageIcon(imgURL);
      } else {
         System.err.println("Couldn't find file: " + imgCrossFilename);
      }
      imgCross = iconCross.getImage();

      imgURL = getClass().getClassLoader().getResource(imgNoughtFilename);
      if (imgURL != null) {
         iconNought = new ImageIcon(imgURL);
      } else {
         System.err.println("Couldn't find file: " + imgNoughtFilename);
      }
      imgNought = iconNought.getImage();

      canvas = new DrawCanvas();
      canvas.setPreferredSize(new Dimension(CANVAS_SIZE, CANVAS_SIZE));
      this.setContentPane(canvas);  // use JPanel as content-pane
      this.setDefaultCloseOperation(EXIT_ON_CLOSE);
      this.pack();  // pack the components of this JFrame
      this.setTitle("Test drawImage()");
      this.setVisible(true);
   }

   /** DrawCanvas (inner class) is a JPanel used for custom drawing */
   private class DrawCanvas extends JPanel {
      @Override
      public void paintComponent(Graphics g) {
         super.paintComponent(g);
         setBackground(Color.WHITE);  // Set background color for this JPanel
         // Drawing Images (picked in random)
         for (int row = 0; row < ROWS; ++row) {
            for (int col = 0; col < COLS; ++col) {
               boolean useCross = random.nextBoolean();
               Image img = useCross ? imgCross : imgNought;
               g.drawImage(img,
                     CELL_SIZE * col + PADDING, CELL_SIZE * row + PADDING,
                     IMAGE_SIZE, IMAGE_SIZE, null);
            }
         }
         // Draw Borders
         g.fill3DRect(CELL_SIZE - 2, 0, 4, CELL_SIZE * 3, true);
         g.fill3DRect(CELL_SIZE * 2 - 2, 0, 4, CELL_SIZE * 3, true);
         g.fill3DRect(0, CELL_SIZE - 2, CELL_SIZE * 3, 4, true);
         g.fill3DRect(0, CELL_SIZE * 2 - 2, CELL_SIZE * 3, 4, true);
      }
   }

   /** The entry main method */
   public static void main(String[] args) {
      // Run the GUI codes on the Event-Dispatching thread for thread-safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new CGDrawImageDemo(); // Let the constructor do the job
         }
      });
   }
}
```

This example places absolute numbers in the draw methods, which is hard to maintain and reuse. You should define name-constants such as `CELL_WIDTH`, `BORDER_WIDTH`, etc, and compute the numbers based on these constants.

8. Animation

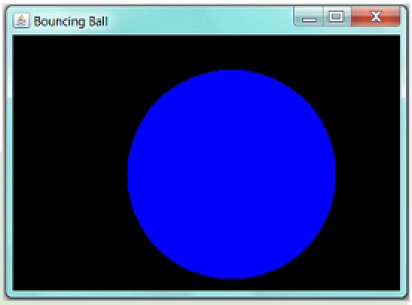
8.1 Animation using `javax.swing.Timer`

Creating an animation (such as a bouncing ball) requires repeatedly running an updating task at a regular interval. Swing provides a `javax.swing.Timer` class which can be used to fire `ActionEvent` to its registered `ActionListeners` at regular interval.

The `Timer` class has one constructor:

```
public Timer(int delay, ActionListener listener)
```

You are required to override the actionPerformed() method of the ActionListener to specify your task's behavior. The Timer fires an ActionEvent to the ActionListener after the (initial) delay, and then at regular interval after delay.



You can start and stop the Timer via the Timer's start() and stop() methods. For example,

```
int delay = 500; // milliseconds
// Create an instance of an anonymous subclass of ActionListener
ActionListener updateTask = new ActionListener() {
   @Override
   public void actionPerformed(ActionEvent evt) {
      // ......
   }
};
// Start and run the task at regular delay
new Timer(delay, updateTask).start();
```

You can use method setRepeats(false) to set the Timer to fire only once, after the delay. You can set the initial delay via setInitialDelay() and regular delay via setDelay().

A Timer can fire the ActionEvent to more than one ActionListeners. You can register more ActionListeners via the addActionListener() method.

The actionPerformed() runs on the event-dispatching thread, just like all the event handlers. You can be relieved of the multi-threading issues.

JDK 1.3 introduced another timer class called java.util.Timer, which is more general, but javax.swing.Timer is sufficient (and easier) to run animation in Swing application.

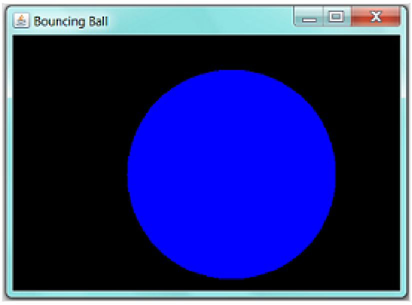
Example: A Bouncing Ball

```
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/** Bouncing Ball (Animation) via Swing Timer */
@SuppressWarnings("serial")
public class CGBouncingBallSwingTimer extends JFrame {
   // Define named-constants
   private static final int CANVAS_WIDTH = 640;
   private static final int CANVAS_HEIGHT = 480;
   private static final int UPDATE_PERIOD = 50; // milliseconds

   private DrawCanvas canvas;  // the drawing canvas (extends JPanel)

   // Attributes of moving object
   private int x = 100, y = 100;  // top-left (x, y)
   private int size = 250;        // width and height
   private int xSpeed = 3, ySpeed = 5; // displacement per step in x, y

   /** Constructor to setup the GUI components */
   public CGBouncingBallSwingTimer() {
      canvas = new DrawCanvas();
      canvas.setPreferredSize(new Dimension(CANVAS_WIDTH, CANVAS_HEIGHT));
      this.setContentPane(canvas);
      this.setDefaultCloseOperation(EXIT_ON_CLOSE);
      this.pack();
      this.setTitle("Bouncing Ball");
      this.setVisible(true);

      // Define an ActionListener to perform update at regular interval
      ActionListener updateTask = new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            update();   // update the (x, y) position
            repaint();  // Refresh the JFrame, callback paintComponent()
         }
      };
      // Allocate a Timer to run updateTask's actionPerformed() after every delay msec
      new Timer(UPDATE_PERIOD, updateTask).start();
   }

   /** Update the (x, y) position of the moving object */
   public void update() {
      x += xSpeed;
      y += ySpeed;
      if (x > CANVAS_WIDTH - size || x < 0) {
         xSpeed = -xSpeed;
      }
      if (y > CANVAS_HEIGHT - size || y < 0) {
         ySpeed = -ySpeed;
      }
   }

   /** DrawCanvas (inner class) is a JPanel used for custom drawing */
   private class DrawCanvas extends JPanel {
      @Override
      public void paintComponent(Graphics g) {
         super.paintComponent(g);  // paint parent's background
         setBackground(Color.BLACK);
         g.setColor(Color.BLUE);
         g.fillOval(x, y, size, size);  // draw a circle
      }
   }

   /** The entry main method */
   public static void main(String[] args) {
      // Run GUI codes in Event-Dispatching thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new CGBouncingBallSwingTimer(); // Let the constructor do the job
         }
      });
   }
}
```

`javax.swing.Timer` does not provide very accurate timing due to the overhead of event-handling. It probaly cannot be used for real-time application such as displaying a clock.

[TODO] Stop the Timer after x steps

8.2 Animation using a new `Thread` (Advanced)



Animation usually involves multi-threading, so that the GUI refreshing operations does not interfere with the programming logic. Multi-threading is an advanced topics. Read "Multithreading & Concurrent Programming"

In the previous example, we use `javax.swing.Timer`, which run the updating task at regular interval on the event-dispatching thread. In this example, we shall create a new thread to run the update.

To create a new thread, define a (anonymous and inner) subclass of `Thread` and override the `run()` method to specify the behavior of the task. Create an instance and start the instance via the `start()` method, which calls back the `run()` defined earlier.

To ensure the new thread does not starve the other threads, in particular the event-dispatching thread, the thread shall yield control via the `sleep(mills)` method, which also provides the necessary delay.

```
import java.awt.*;
import javax.swing.*;

/** Bouncing Ball (Animation) via custom thread */
public class CGBouncingBall extends JFrame {
   // Define named-constants
   private static final int CANVAS_WIDTH = 640;
   private static final int CANVAS_HEIGHT = 480;
   private static final int UPDATE_INTERVAL = 50; // milliseconds

   private DrawCanvas canvas;  // the drawing canvas (extends JPanel)

   // Attributes of moving object
   private int x = 100;     // top-left (x, y)
   private int y = 100;
   private int size = 250;  // width and height
   private int xSpeed = 3;  // moving speed in x and y directions
   private int ySpeed = 5;  // displacement per step in x and y

   /** Constructor to setup the GUI components */
   public CGBouncingBall() {
      canvas = new DrawCanvas();
      canvas.setPreferredSize(new Dimension(CANVAS_WIDTH, CANVAS_HEIGHT));
      this.setContentPane(canvas);
      this.setDefaultCloseOperation(EXIT_ON_CLOSE);
      this.pack();
      this.setTitle("Bouncing Ball");
      this.setVisible(true);

      // Create a new thread to run update at regular interval
      Thread updateThread = new Thread() {
         @Override
         public void run() {
            while (true) {
               update();   // update the (x, y) position
               repaint();  // Refresh the JFrame. Called back paintComponent()
               try {
                  // Delay and give other thread a chance to run
                  Thread.sleep(UPDATE_INTERVAL);  // milliseconds
               } catch (InterruptedException ignore) {}
            }
         }
      };
      updateThread.start(); // called back run()
   }

   /** Update the (x, y) position of the moving object */
   public void update() {
      x += xSpeed;
      y += ySpeed;
      if (x > CANVAS_WIDTH - size || x < 0) {
         xSpeed = -xSpeed;
      }
      if (y > CANVAS_HEIGHT - size || y < 0) {
         ySpeed = -ySpeed;
      }
   }

   /** DrawCanvas (inner class) is a JPanel used for custom drawing */
   class DrawCanvas extends JPanel {
      @Override
      public void paintComponent(Graphics g) {
         super.paintComponent(g);  // paint parent's background
         setBackground(Color.BLACK);
         g.setColor(Color.BLUE);
         g.fillOval(x, y, size, size);  // draw a circle
      }
   }

   /** The entry main method */
   public static void main(String[] args) {
      // Run GUI codes in Event-Dispatching thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new CGBouncingBall(); // Let the constructor do the job
         }
      });
   }
}
```

- To update the display regularly, we explicitly invoke the `repaint()` method of the `JFrame`, which will callback the `paintComponent(g)` of all the components contained in this `JFrame`.
- The display refreshing code is run in its own thread, so as to avoid the infamous unresponsive user interface problem. It is programmed as an anonymous inner class, extends class `Thread`, by overriding the `run()` method to provide the programmed operations (i.e., `repaint()`). The `start()` method is use to start the thread, which will callback the `run()`.
- Inside the overridden `run()`, the `repaint()` is programmed inside an infinite loop, followed by a `Thread.sleep(milliseconds)` method, which suspends the thread for the given milliseconds. This operation provides the necessary delay and also yield control to other thread to perform their intended operations.

[TODO] Stopping the thread after x steps

9. (Advanced) A Closer Look at `repaint()`

Reference: "Painting in AWT and Swing" @ http://www.oracle.com/technetwork/java/painting-140037.html. I summarise some of the important points here.

Heavyweight AWT Components vs. Lightweight Swing Components

The original AWT components are heavyweight components. "Heavyweight" means that the component has it's own opaque native window. Heavyweight components, such as `java.awt.Button`, are mapped to the platform-specific components. It relies on the windowing subsystem in each native platform to take care of details such as damage detection, clip calculation, and z-ordering. On the other hand, the newer Swing `JComponent`s (such as `javax.swing.JButton`) are lightweight components. A "lightweight" component does not own its screen resources but reuses the native window of its closest heavyweight ancestor. Swing `JComponent`s do not rely on the native platform and are written purely in Java, . The top-level containers, such as `JFrame`, `JApplet` and `JDialog`, which are not subclass of `JComponent`, remain heavyweight. It is because the lightweight Swing `JComponent`s need to attach to a heavyweight ancester.

Painting Mechanism

Painting is carried out via a "call-back" mechanism. A program shall put its painting codes in a overridden method (`paint()` for AWT components or `paintComponent()` for Swing component), and the windowing subsystem will call back this method when it's time to paint.

System-triggered vs. Application-triggered Painting Requests

There are two types of paint (or repaint) requests:

1. System-triggered: e.g., the component is first made visible, the componet is resized, etc. The windowing subsystem will schedule `paint()` or `paintComponent()` on the event-dispatching thread.
2. Application-triggered: application has modified the appearance of the component and requested to repaint the component. However, Application

shall not invoke `paint()` or `paintComponent()` directly. Instead, it shall invoke a special method called `repaint()`, which will in turn invoke `paint()` or `paintComponent()`. Multiple `repaint()` requests may be collapsed into a single `paint()` call.

Instead of issuing `repaint()` to paint the entire component, for efficiency, you can selectively repaint a rectangular clip area. You can also specify a maximum time limit for painting to take place.

```
public void repaint()
      // requests to repaint this component
public void repaint(long timeMax)
      // repaint before timeMax msec (for lightweight components)
public void repaint(int x, int y, int width, int height)
      // repaint the specified rectangular area
public void repaint(long timeMax, int x, int y, int width, int height)
      // repaint the specified rectangular area within timeMax msec
```

Painting the Lightweight Swing Components

A lightweight needs a heavyweight somewhere up the containment hierarchy in order to have a place to paint, as only heavyweight components have their own opague window. When this heavyweight ancestor is asked to paint its window, it must also paint all of its lightweight descendents. This is handled by `java.awt.Container`'s `paint()` method, which calls `paint()` on any of its visible, lightweight children which intersect with the rectangle to be painted. Hence, it is crucial for all `Container` subclasses (lightweight or heavyweight) that override `paint()` to place a `super.paint()` call in the `paint()` method. This `super.paint()` call invoke `Container`'s (`super`) `paint()` method, which in turn invoke `paint()` on all its descendents. If the `super.paint()` call is missing, some of the lightweight descendents will be shown up.

Opaque and Transparent

Lightweight components does not own its opaque window and "borrow" the screen real estate of its heavyweight ancestor. As a result, they could be made transparent, by leaving their background pixels unpainted to allow the underlying component to show through.

To improve performance of opaque components, Swing adds a property called `opaque` to all `JComponent`s. If `opaque` is set to `true`, the component agrees to paint all of the pixels contained within its rectangular bounds. In order words, the windowing subsystem does not have to do anything within these bounds such as painting its ancesters. It `opaque` is set to `false`, the component makes no guarantees about painting all the bits within its rectangular bounds, and the windowing subsystem has more work to do.

Swing further factor the `paint()` method into three methods, which are invoked in the following order:

```
protected void paintComponent(Graphics g)
protected void paintBorder(Graphics g)
protected void paintChildren(Graphics g)
```

Swing programs should override `paintComponent()` instead of `paint()`.

Most of the standard Swing components (in particular, `JPanel`) have their look and feel implemented by separate look-and-feel objects (called "UI delegates") for Swing's Pluggable look and feel feature. This means that most or all of the painting for the standard components is delegated to the UI delegate and this occurs in the following way:

1. `paint()` invokes `paintComponent()`.
2. If the `ui` property is non-`null`, `paintComponent()` invokes `ui.update()`.
3. If the component's `opaque` property is `true`, `ui.udpate()` fills the component's background with the background color and invokes `ui.paint()`.
4. `ui.paint()` renders the content of the component.

This means that subclasses of Swing components which have a UI delegate (such as `JPanel`), should invoke `super.paintComponent()` within their overridden `paintComponent()`, so that `ui.update()` fills the background (of the superclass such as `JPanel`) provided `opaque` is `true`.

```
public class MyPanel extends JPanel {
   @Override
   protected void paintComponent(Graphics g) {
      // Let UI delegate paint first
      // (including background filling, if I'm opaque)

      super.paintComponent(g);  // fill the JPanel's background and invoke ui.paint()

      // paint my contents next....
   }
}
```

Try removing the `super.paintComponent()` from a Swing program that does animation (e.g., bouncing ball). The background will not be painted, and the previous screen may not be cleared. You can also paint the background yourself by filling a Rectangle with background color.

```
@Override
protected void paintComponent(Graphics g) {
   g.setColor(backgroundColor);
   g.fillRect(0, 0, getWidth() - 1, getHeight() - 1);
}
```

Furthermore, if you set the `opaque` to `false` (via `setOpaque(false)`) for the subclass of `JPanel`, the `super.paintComponent(g)` does not fill the background.

REFERENCES & RESOURCES

- "The Swing Tutorial" @ http://docs.oracle.com/javase/tutorial/uiswing/, in particular, the section on "Performing Custom Graphics".
- "Painting in AWT and Swing" @ http://www.oracle.com/technetwork/java/painting-140037.html.

Latest version tested: JDK 1.7.0_17
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