Java GUI Programming

*Adapted from a lecture by Vangelis Metsis

CS 3354
Spring 2017

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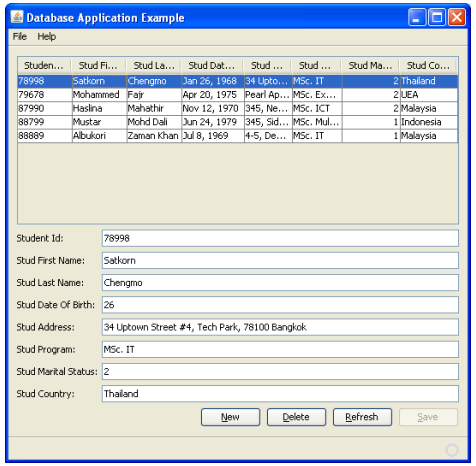
Why study GUIs?

- Learn about event-driven programming techniques
- Practice learning and using a large, complex API
- A chance to see how it is designed and learn from it
- Because GUIs are neat!



Java GUI example

Java GUI libraries

- **Swing: the main Java GUI library**
  - Benefits: Features; cross-platform compatibility; OO design – Paints GUI controls itself pixel-by-pixel
  - Does not delegate to OS's window system
- **Abstract Windowing Toolkit (AWT): Sun's initial GUI library**
  - Maps Java code to each operating system's real GUI system
  - Problems: Limited to lowest common denominator (limited set of UI widgets); clunky to use.
- SWT + JFace
  - Mixture of native widgets and Java rendering; created for Eclipse for faster performance
- Others
  - Apache Pivot, SwingX, JavaFX, ...
- **Advice:** Use Swing. You occasionally have to use AWT (Swing is built on top of AWT). Beware: it's easy to get them mixed up.

GUI terminology

- **window**: A first-class citizen of the graphical desktop
  - Also called a top-level container
  - Examples: frame, dialog box, applet
- **component**: A GUI widget that resides in a window
  - Also called controls in many other languages
  - Examples: button, text box, label
- **container**: A component that hosts (holds) components
  - Examples: panel, box

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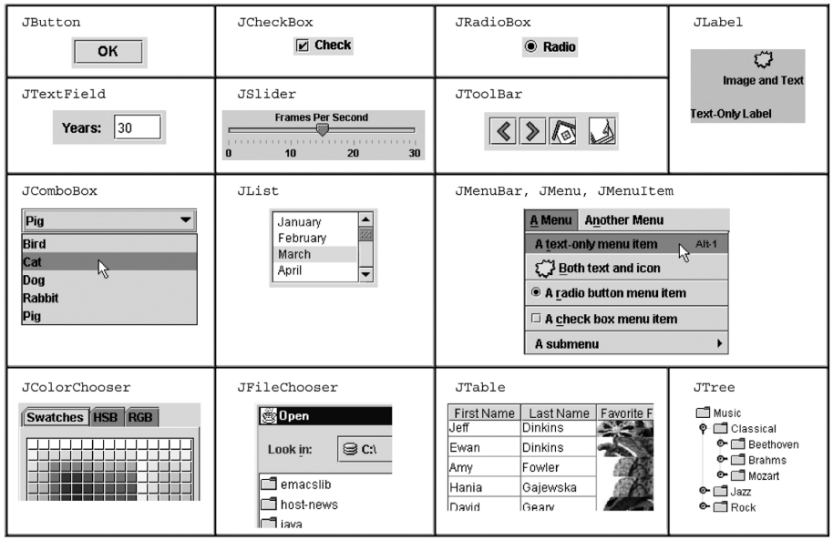
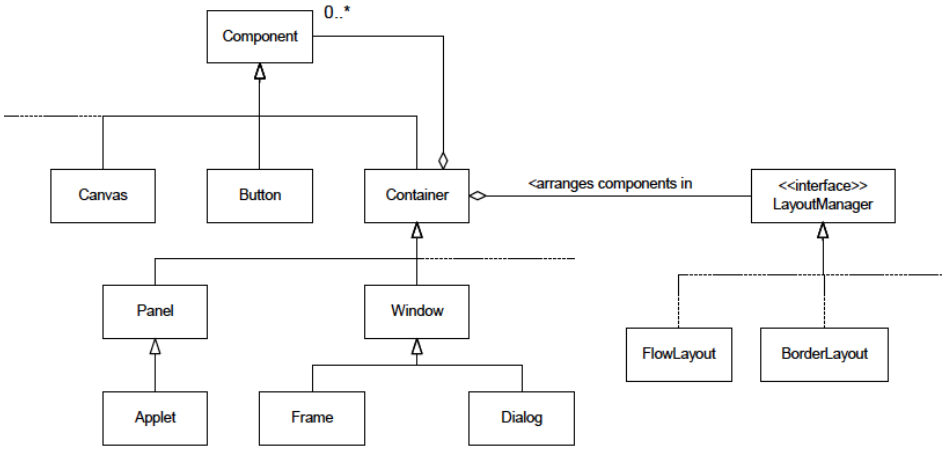
Basic Elements

- Components:
  - Button / List / Checkbox / Choice / TextField / Etc.
- Containers (subclass of Component):
  - Panel / Window / Dialog / Applet / Frame / Etc.
- Menu Components
  - Menu / Menu bar / Etc.
- Layout Managers
  - BorderLayout / GridLayout / Etc.
- Events
  - MouseEvent / MouseMotionEvent / ItemEvent / Etc.
- Graphics
  - Graphics / Image / Color / Font / FontMetrics / Etc.

Components



AWT Components, Containers, and Layout Managers



Swing/AWT inheritance hierarchy

```
Component   (AWT)
   Window
      Frame
         JFrame   (Swing)
         JDialog
   Container
      Jcomponent  (Swing)
         JButton          JColorChooser     JFileChooser
         JComboBox        JLabel            JList
         JMenuBar         JOptionPane       JPanel
         JPopupMenu       JProgressBar      JScrollbar
         JScrollPane      JSlider           JSpinner
         JSplitPane       JTabbedPane       JTable
         JToolbar         JTree             JTextArea
         JTextField       ...
```

Component fields/properties

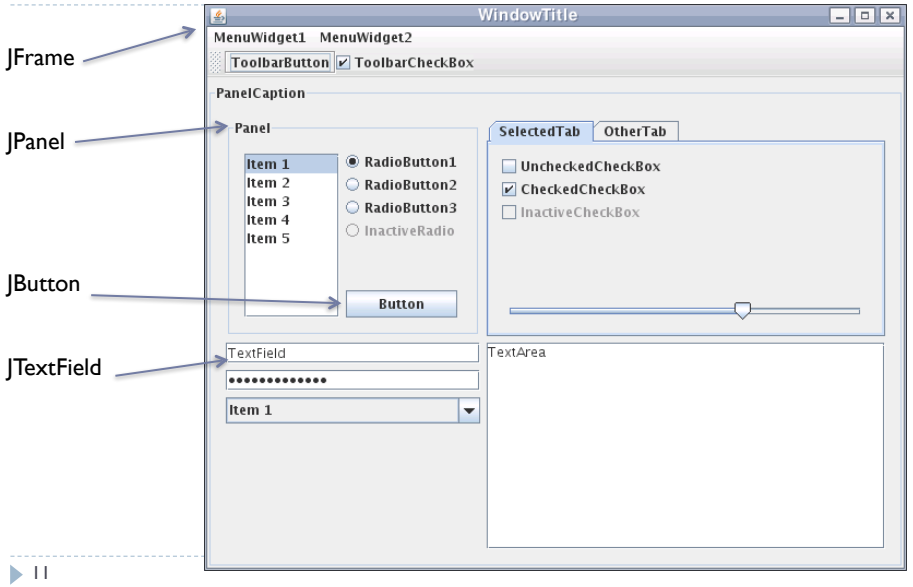
- Each has a `get` (or is) accessor and a `set` modifier.
  - Examples: `getColor`, `setFont`, `isVisible`, …

name	description
background	background color behind component
border	border line around component
enabled	whether it can be interacted with
focusable	whether key text can be typed on it
font	font used for text in component
foreground	foreground color of component
height, width	component's current size in pixels
visible	whether component can be seen
tooltip text	text shown when hovering mouse
size, minimum / maximum / preferred size	various sizes, size limits, or desired sizes that the component may take

Types of containers

- Top-level containers: JFrame, JDialog, …
  - Often correspond to OS windows
  - Can be used by themselves, but usually as a host for other components
  - Live at top of UI hierarchy, not nested in anything else
- Mid-level containers: panels, scroll panes, tool bars
  - Sometimes contain other containers, sometimes not
  - JPanel is a general-purpose component for drawing or hosting other UI elements (buttons, etc.)
- Specialized containers: menus, list boxes, …
- Technically, all J-components are containers

Swing window example



JFrame – top-level window

- Graphical window on the screen
- Typically holds (hosts) other components
- Common methods:
  - `JFrame(String title)` – constructor, title optional
  - `setSize(int width, int height)` – set size
  - `add(Component c)` – add component to window
  - `setVisible(boolean v)` – make window visible or not. Don't forget this!

JFrame

- Frame window has *decorations*
  - title bar
  - close box
  - provided by windowing system

- Basic code to create a frame:

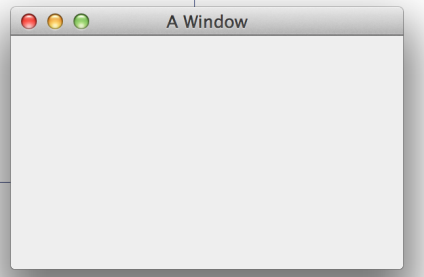
```
JFrame frame = new JFrame();
frame.pack();   // Fit frame to its contents
frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
frame.setVisible(true);
```


Example: SimpleFrameMain

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

public class SimpleFrameMain {
  public static void main(String[] args) {
    SimpleFrame frame = new SimpleFrame("A Window");
    // frame.pack();
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    frame.setVisible(true);
  }
}

class SimpleFrame extends JFrame {
  public SimpleFrame(String title) {
    super(title);
    setSize(300,200);
  }
}
```



More JFrame

- `public void setDefaultCloseOperation(int op)`
  Makes the frame perform the given action when it closes.
  - Common value passed: `JFrame.EXIT_ON_CLOSE`
    - Other possible values:
      `DO_NOTHING_ON_CLOSE`
      `HIDE_ON_CLOSE`
      `DISPOSE_ON_CLOSE`
  - If not set, the program will never exit even if the frame is closed.

- `public void setSize(int width, int height)`
  Gives the frame a fixed size in pixels.

- `public void pack()`
  Resizes the frame to fit the components inside it snugly.

JPanel – a general-purpose container

- Commonly used as a place for graphics, or to hold a collection of button, labels, etc.

- Needs to be added to a window or other container
  `frame.add(new Jpanel(…))`

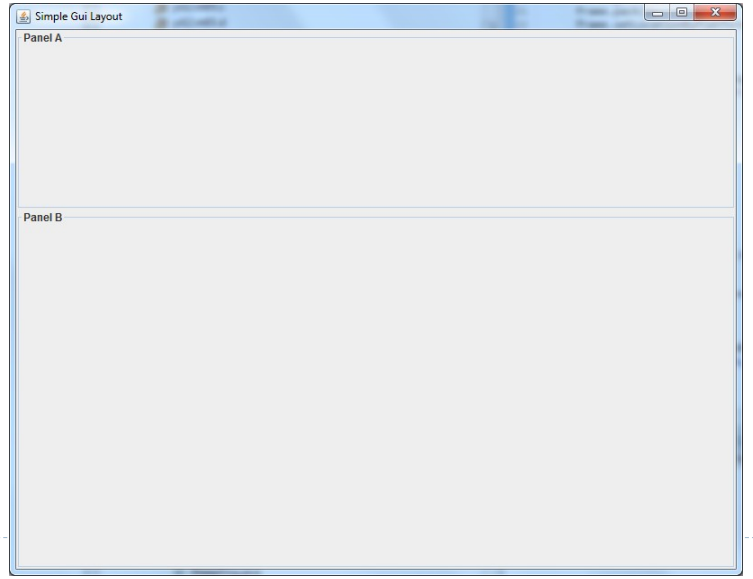
- JPanels can be nested to any depth

- Many methods/fields in common with JFrame (since both inherit from Component)

- Advice: can't find a method/field? Check the superclass(es)

- Some new methods. Particularly useful:
  - setPreferredSize(Dimension d)

JPanel – a general-purpose container



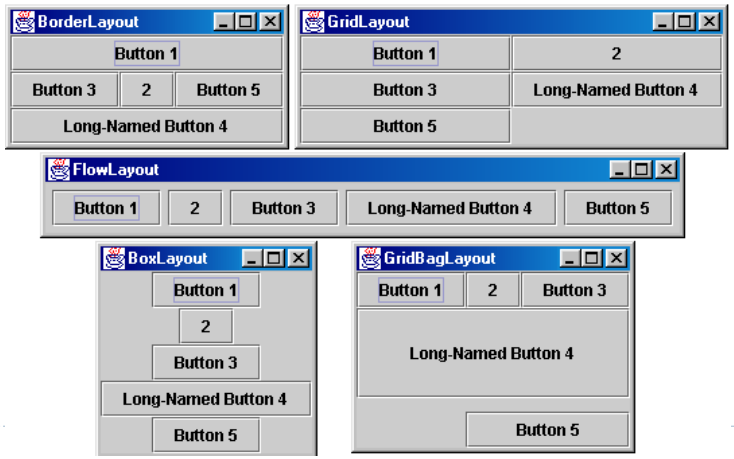
Sizing and positioning

How does the programmer specify where each component appears, how big each component should be, and what the component should do if the window is resized / moved / maximized / etc.?

- Absolute positioning (C++, C#, others):
  - Programmer specifies exact pixel coordinates of every component.
    - "Put this button at (x=15, y=75) and make it 70x31 px in size."
- Layout managers (Java):
  - Objects that decide where to position each component based on some general rules or criteria.
    - "Put these four buttons into a 2x2 grid and put these text boxes in a horizontal flow in the south part of the frame."

Containers and layout

- What if we add several components to a container? How are they positioned relative to each other?
- Answer: each container has a **layout manger**.



Layout managers

- Kinds:
  - FlowLayout (left to right, top to bottom) – default for Jpanel
  - BorderLayout ("center", "north", "south", "east", "west") – default for Jframe
  - GridLayout (regular 2-D grid)
  - others... (some are incredibly complex)
- The first two should be good enough for now.
  - E.g.: `contentPane.setLayout(new BorderLayout(0,0));`

JFrame as container

A `JFrame` is a container. Containers have these methods:

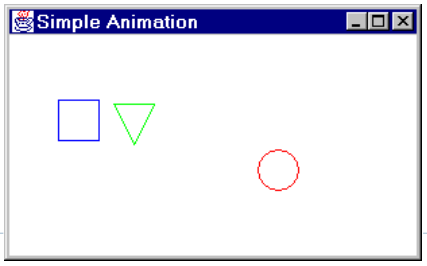
- `public void add(Component comp)`
- `public void add(Component comp, Object info)`
  Adds a component to the container, possibly giving extra information about where to place it.
- `public void remove(Component comp)`
- `public void setLayout(LayoutManager mgr)`
  Uses the given layout manager to position components.
- `public void validate()`
  Refreshes the layout (if it changes after the container is onscreen).

Preferred sizes

- Swing component objects each have a certain size they would "like" to be: Just large enough to fit their contents (text, icons, etc.).
  - This is called the preferred size of the component.
  - Some types of layout managers (e.g. FlowLayout) choose to size the components inside them to the preferred size.
  - Others (e.g. BorderLayout, GridLayout) disregard the preferred size and use some other scheme to size the components.

Graphics and drawing

- What if we want to actually draw something? A map, an image, a path, ...?
- Answer: Override method `paintComponent`
  - Method in `JComponent` that draws the component
  - In `JLabel`'s case, it draws the label text.



Graphics vs Graphics2D

- Class `Graphics` was part of the original Java AWT
  - Has a procedural interface: `g.drawRect(…)`, `g.fillOval(…)`
- Swing introduced `Graphics2D`
  - Added a object interface – create instances of `Shape` like `Line2D`, `Rectangle2D`, etc., and add these to the Graphics2D object
- Parameter to `paintComponent` is always Graphics2D.
- Can always cast it to that class. Graphics2D supports both sets of graphics methods.

Who calls paintComponent? And when??

- Answer: the window manager calls `paintComponent` *whenever it wants*!!!
  - When the window is first made visible, and whenever after that it is needed.
- Corollary: `paintComponent` must always be ready to repaint – regardless of what else is going on
  - You have no control over when or how often – must store enough information to repaint on demand
- If you want to redraw a window, call `repaint()` from the program (not from `paintComponent`)
  - Tells the window manager to schedule repainting
  - Window manager will call `paintComponent` when it decides to redraw (soon, but maybe not right away)

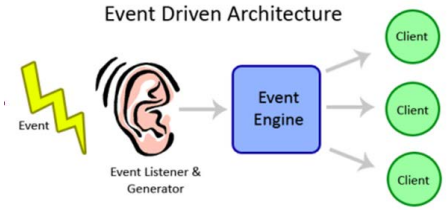
Rules for painting

- Always override `paintComponent(g)` if you want to draw on a component.
- Always call `super.paintComponent(g)` first.
- **NEVER** call `paintComponent` yourself.
- Always paint the entire picture, from scratch.
- Use paintComponent's Graphics parameter to do all the drawing. **ONLY** use it for that. Don't copy it, try to replace it, permanently side-effect it, etc. It is quick to anger.
- **DON'T** create new Graphics or Graphics2D objects
- Fine print: Once you are a certified™ wizard, you may find reasons to do things differently, but you aren't there yet.

Event-driven programming

A style of coding where a program's overall flow of execution is dictated by events.

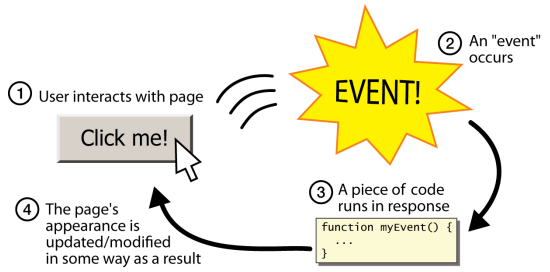
- The program loads, then waits for user input events.
- As each event occurs, the program runs particular code to respond.
- The overall flow of what code is executed is determined by the series of events that occur
- Contrast with application- or algorithm-driven control where program expects input data in a pre-determined order and timing
  - Typical of large non-GUI applications like web crawling, payroll, batch simulation



Event-driven programming

- The main body of the program is an event loop. Abstractly:

```
do {
      e = getNextEvent();
      process event e;
} while (e != quit);
```



Graphical events

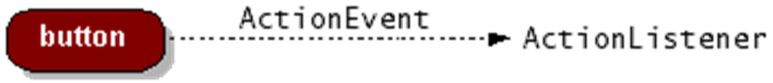
- **event**: An object that represents a user's interaction with a GUI component; can be "handled" to create interactive components.
- **listener**: An object that waits for events and responds to them.
  - To handle an event, attach a listener to a component.
  - The listener will be notified when the event occurs (e.g. button click).

Kinds of GUI events

- ***Mouse*** move/drag/click, mouse button press/release
- ***Keyboard***: key press/release, sometimes with modifiers like shift/ control/alt/…
- ***Touchscreen*** finger tap/drag
- ***Joystick***, drawing tablet, other device inputs
- ***Window*** resize/minimize/restore/close
- ***Network*** activity or file I/O (start, done, error)
- ***Timer*** interrupt (including animations)

Action events

- **action event**: An action that has occurred on a GUI component.
  - The most common, general event type in Swing. Caused by:
    - button or menu clicks,
    - check box checking / unchecking,
    - pressing Enter in a text field, ...
  - Represented by a class named `ActionEvent`
  - Handled by objects that implement interface `ActionListener`



Implementing a Listener (Observer)

```
public class MyClass implements ActionListener {
    public void actionPerformed(ActionEvent event) {
        code to handle the event;
    }
}
```

`JButton` and other graphical components have this method:

```
/** Attaches the given listener to be notified of clicks and
events that occur on this component. */
public void addActionListener(ActionListener al)
```

e.g.

```
button.addActionListener(new MyClass());
```

Example: button

- Create a JButton and add it to a window
  - `public JButton(String text)` Creates a new button with the given string as its text.
  - `public String getText()` Returns the text showing on the button.
  - `public void setText(String text)` Sets button's text to be the given string.
- Create an object that implements `ActionListener` (containing an `actionPerformed` method)
- Add the listener object to the button's listeners


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

public class ButtonDemo1 {
  // inner class to handle button events
  private static class ButtonListener implements ActionListener {
    private int nEvents = 0;

    public void actionPerformed(ActionEvent e) {
      nEvents++;
      System.out.println(e.getActionCommand() + " " + nEvents);
    }
  }

  public static void main(String[] args) {
    JFrame frame = new JFrame("Button Demo");
    frame.setDefaultCloseOperation(WindowConstants.EXIT_ON_CLOSE);

    // create a new button with label "Hit me" and string "OUCH!" to be
    // returned as part of each action event
    JButton button = new JButton("Hit me");
    button.setActionCommand("OUCH!");
    button.addActionListener(new ButtonListener());

    // Add button to the window and make it visible
    frame.add(button); frame.pack(); frame.setVisible(true);
  }
}
```



```
import java.awt.*;          // basic awt classes
import java.awt.event.*;    // event classes
import javax.swing.*;       // swing classes

public class ButtonDemo2 {

  public static void main(String[] args) {
    JFrame frame = new JFrame("Button Demo");
    frame.setDefaultCloseOperation(WindowConstants.EXIT_ON_CLOSE);

    // create a new button with label "Hit me" and string "OUCH!" to be
    // returned as part of each action event
    JButton button = new JButton("Hit me");
    button.setActionCommand("OUCH!");

    // Create and register a new button listener to handle clicks
    button.addActionListener(new ActionListener () {
      int nEvents = 0; // number of events handled
      public void actionPerformed(ActionEvent e) {
        nEvents++;
        System.out.println(e.getActionCommand() + " " + nEvents);
      }
    });

    // Add button to the window and make it visible
    frame.add(button);
    frame.pack();
    frame.setVisible(true);
  }
}
```


Program thread and UI thread

- The program and user interface run in concurrent threads.
- All UI actions happen in the UI thread – even when they execute callbacks to code like `actionListener`, etc. defined in your program.
  - Any updates to the user interface must happen on the **event dispatch thread**.
- Event handlers usually should not do a lot of work.
- If the event handler does a lot of computing, the user interface will appear to freeze up.

Program thread and UI thread

- If there's lots to do, the event handler should start a new thread or set a bit that the program thread will notice.
- Do the heavy work back in the program thread.
- When the heavy work finishes, the UI is notified to update the view.

Suppose we have a button that launches a series of database queries. We dutifully start up a new thread so that our queries won't block the user interface:

```
JButton b = new JButton("Run query");
b.addActionListener(new ActionListener() {
  public void actionPerformed(ActionEvent e) {
    Thread queryThread = new Thread() {
      public void run() {
        runQueries();
      }
    };
    queryThread.start();
  }
});
```


Program thread and UI thread

- But now, from our query thread, we want to update a progress bar or some other component showing the current progress to the user.
- How can we do this if we're no longer in the event dispatch thread? Well, the `SwingUtilities` class, which provides various useful little calls, includes a method called `invokeLater()`.
  - This method allows us to post a "job" to Swing, which it will then run on the event dispatch thread at its next convenience.

So here is how to use `SwingUtilities.invokeLater()` from our `runQueries` method:

```
// Called from non-UI thread
private void runQueries() {
  for (int i = 0; i < noQueries; i++) {
    runDatabaseQuery(i);
    updateProgress(i);
  }
}

private void updateProgress(final int queryNo) {
  SwingUtilities.invokeLater(new Runnable() {
    public void run() {
      // Here, we can safely update the GUI
      //because we'll be called from the
      // event dispatch thread
      statusLabel.setText("Query: " + queryNo);
    }
  });
}
```


Application startup code

- There's one place where it's very easy to forget that we need `SwingUtilities.invokeLater()`, and that's on application startup.
- Our applications `main()` method will always be called by the main program thread that the VM starts up for us.
- If we have code to update the GUI there, it may interfere with the UI thread.
- The **code that *initializes* our GUI must also take place in an `invokeLater()`.**

```
public class MyApplication extends JFrame {

  public static void main(String[] args) {
    SwingUtilities.invokeLater(new Runnable() {
      public void run() {
        MyApplication app = new MyApplication();
        app.setVisible(true);
      }
    });
  }

  private MyApplication() {
    // create UI here: add buttons, actions etc
  }
}
```


Better implementation of ButtonDemo

```
public class ButtonDemo3 extends JFrame {

  private ButtonDemo3(String title) { //
    super(title);
    this.setDefaultCloseOperation(WindowConstants.EXIT_ON_CLOSE);
    Component c = this;

    JButton button = new JButton("Hit me");
    button.setActionCommand("OUCH!");

    button.addActionListener(new ActionListener () {
      int nEvents = 0; // number of events handled
      public void actionPerformed(ActionEvent e) {
        nEvents++;
        JOptionPane.showMessageDialog(c, e.getActionCommand() + " " + nEvents);
      }
    });
    this.add(button); this.pack(); this.setVisible(true);
  }

  public static void main(String[] args) {
    SwingUtilities.invokeLater(new Runnable() {
      public void run() {
        ButtonDemo3 app = new ButtonDemo3("Button Demo");
        app.setVisible(true);
      }
    });
  }
}
```