Principles of Software Construction: Objects, Design, and Concurrency
(Part 3: Design Case Studies)

Introduction to GUIs

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Administrivia

- Homework 4a due tonight
- Homework 4b due Thursday, October 22

Key concepts from Tuesday

Key concepts from Tuesday

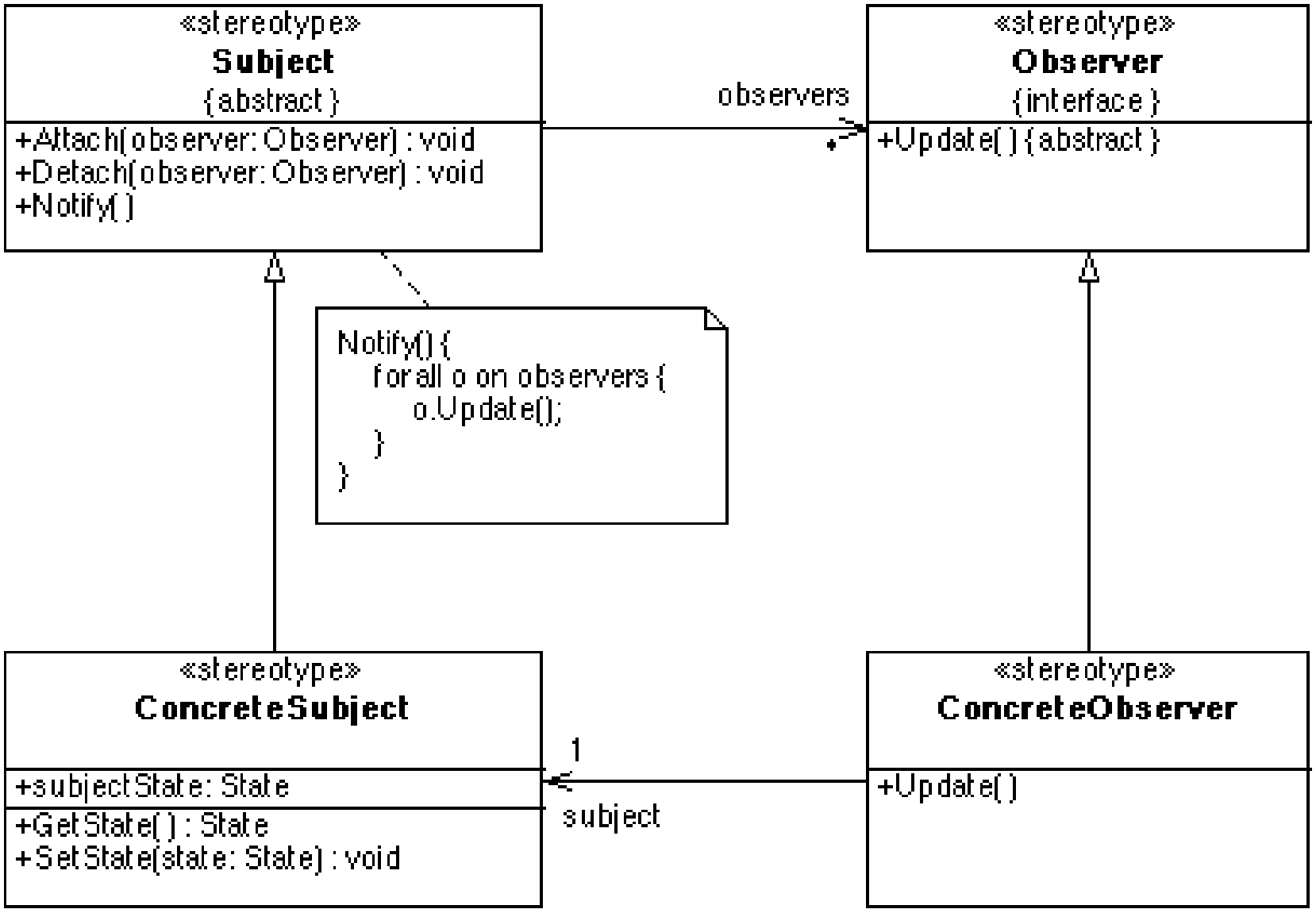
- Formal verification
- Testing
  - Coverage metrics
  - Black-box vs. white-box testing
- Static analysis

Key concepts from recitation yesterday

Key concepts from yesterday's recitation

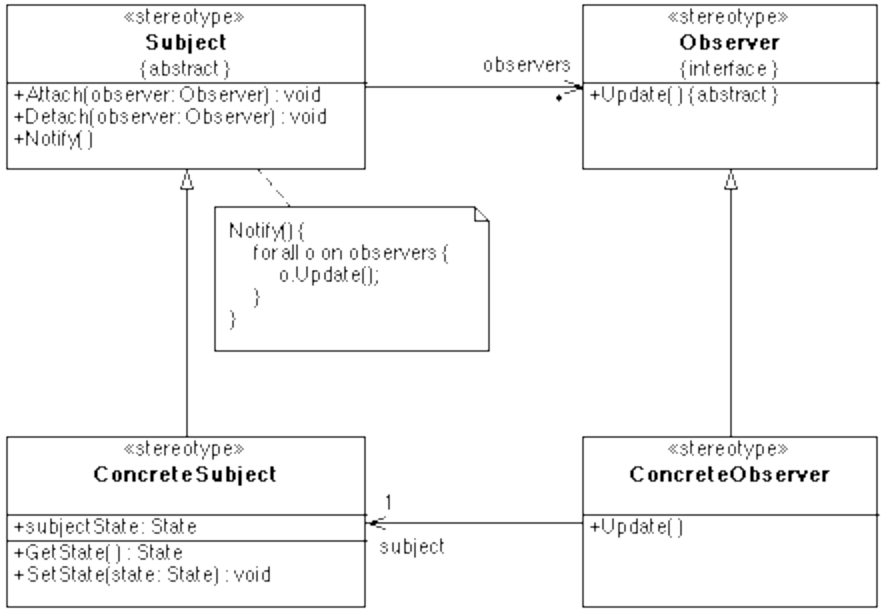
- Discovering design patterns
- The Observer pattern

The Observer design pattern



The Observer design pattern

- Applicability
  - When an abstraction has two interdependent aspects and you want to reuse both
  - When state change to one object requires notifying others, without becoming dependent on them
- Consequences
  - Loose coupling between subject and observer, enhancing reuse
  - Support for broadcast communication
  - Notification can lead to further updates, causing a cascade effect



Learning goals for today

- Understand the design challenges and common solutions for Graphical User Interfaces (GUIs)
- Understand event-based programming
- Understand and recognize the design patterns used and how those design patterns achieve design goals.
  - Observer pattern
  - Strategy pattern
  - Template method pattern
  - Composite pattern
  - Model-view-controller
  - Other common GUI design patterns not discussed here: Decorator, Façade, Adapter, Command, …
- Diagnose problems caused by computation in the GUI threads

Aside: Anonymous inner classes in Java

- You can implement an interface without naming the implementing class
  - E.g.,

```
public interface Runnable {
    public void run();
}

public static void main(String[] args) {
    Runnable greeter = new Runnable() {
        public void run() {
            System.out.println("Hi mom!");
        }
    };

    greeter.run();
}
```

Scope within an anonymous inner class

- An anonymous inner class can access final (or effectively final) variables in the scope where it is defined

```
public interface Runnable {
    public void run();
}

public static void main(String[] args) {
    final String name = "Charlie"; // final variable
    Runnable greeter = new Runnable() {
        public void run() {
            System.out.println("Hi " + name);
        }
    };

    greeter.run();
}
```

OK

Scope within an anonymous inner class

- An anonymous inner class can access final (or effectively final) variables in the scope where it is defined

```
public interface Runnable {
    public void run();
}

public static void main(String[] args) {
    String name = "Charlie"; // not final, but could be
    Runnable greeter = new Runnable() {
        public void run() {
            System.out.println("Hi " + name);
        }
    };

    greeter.run();
}
```

OK

Scope within an anonymous inner class

- An anonymous inner class can access final (or effectively final) variables in the scope where it is defined

```
public interface Runnable {
    public void run();
}

public static void main(String[] args) {
    String name = "Charlie"; // not final; assigned later
    Runnable greeter = new Runnable() {
        public void run() {
            System.out.println("Hi " + name);
        }
    };
    name = “Jonathan”;
    greeter.run();
}
```

Compile-time error

Today: Introduction to Graphical User Interfaces (GUIs)

- Event-based programming
- Building a GUI using Java Swing
- Event-handling and decoupling with the Observer pattern
- GUI design challenges
  - Design patterns that solve them
- Practical advice: Threading architecture of a typical GUI

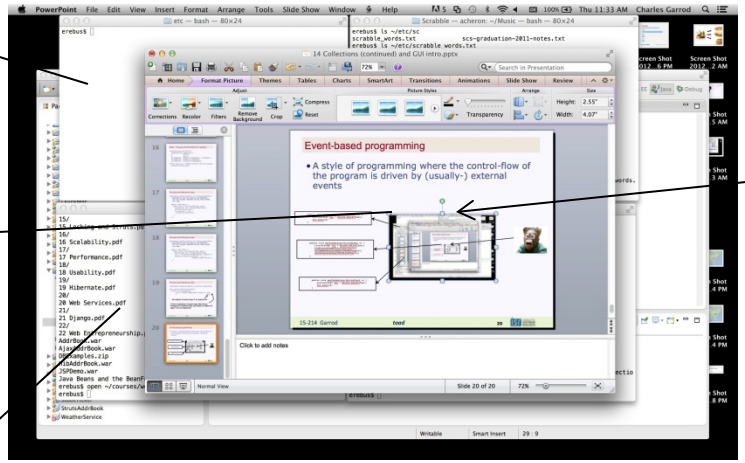
Event-based programming

- Style of programming where control-flow is driven by (usually external) events

```
public void performAction(ActionEvent e) {
    List<String> lst = Arrays.asList(bar);
    foo.peek(42)
}
```

```
public void performAction(ActionEvent e) {
    bigBloatedPowerPointFunction(e);
    withANameSoLongIMadeItTwoMethods(e);
    yesIKnowJavaDoesntWorkLikeThat(e);
}
```

```
public void performAction(ActionEvent e) {
    List<String> lst = Arrays.asList(bar);
    foo.peek(40)
}
```



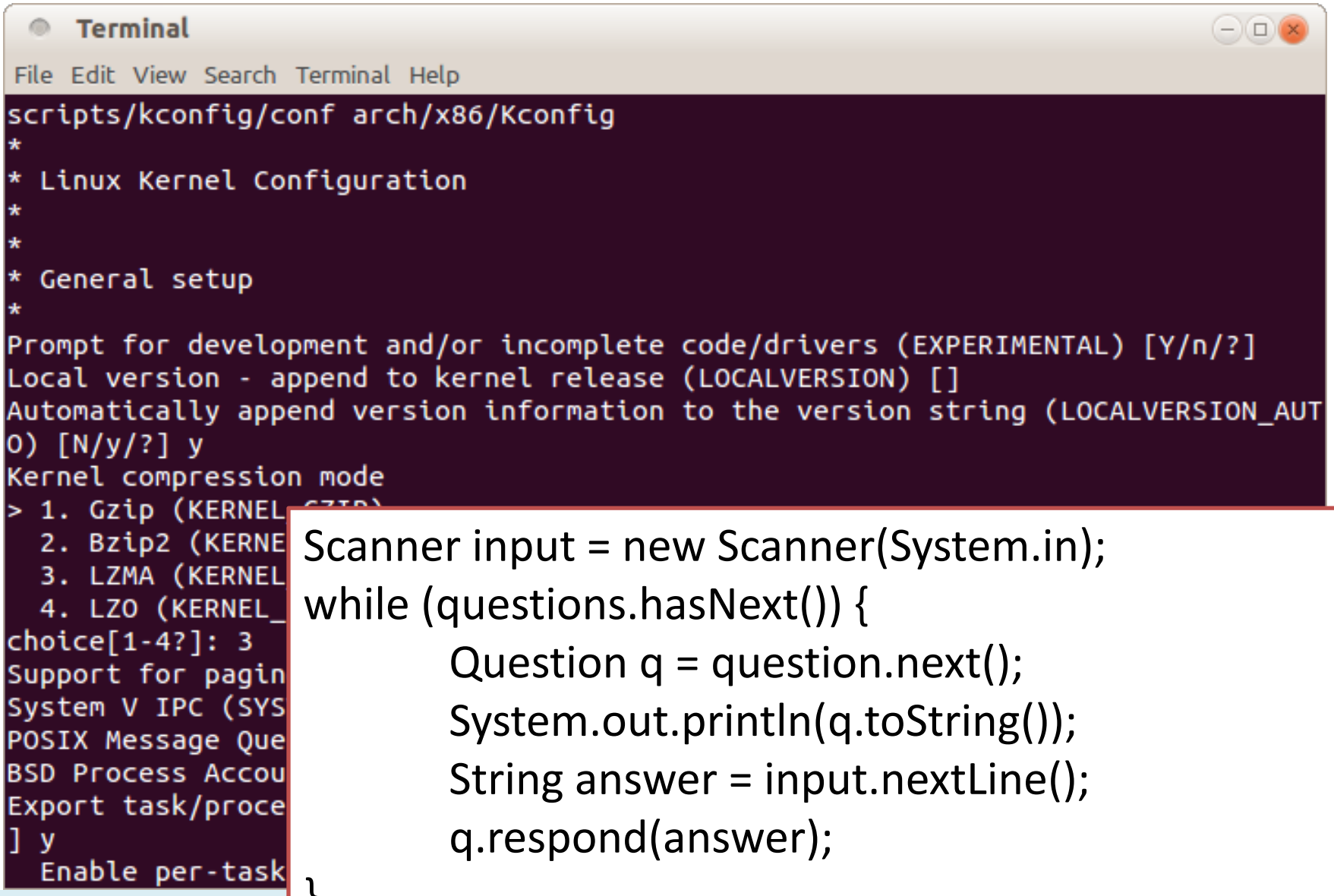
Examples of events in GUIs

Examples of events in GUIs

- User clicks a button, presses a key
- User selects an item from a list, an item from a menu, expands a tree
- Mouse hovers over a widget, focus changes
- Scrolling, mouse wheel turned
- Resizing a window, hiding a window
- Drag and drop

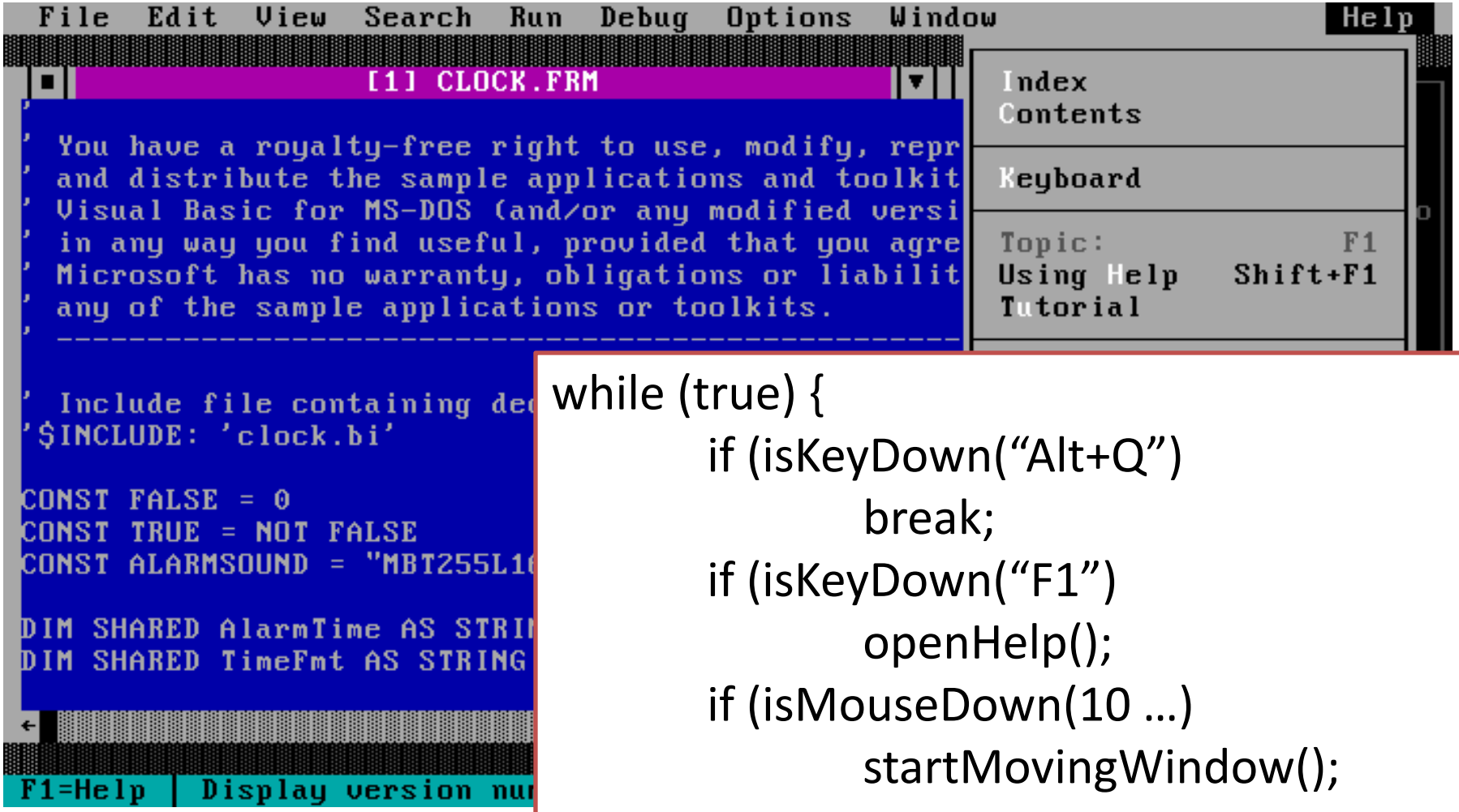
- A package arrives from a web service, connection drops, …
- System shutdown, …

Interaction with command-line interfaces



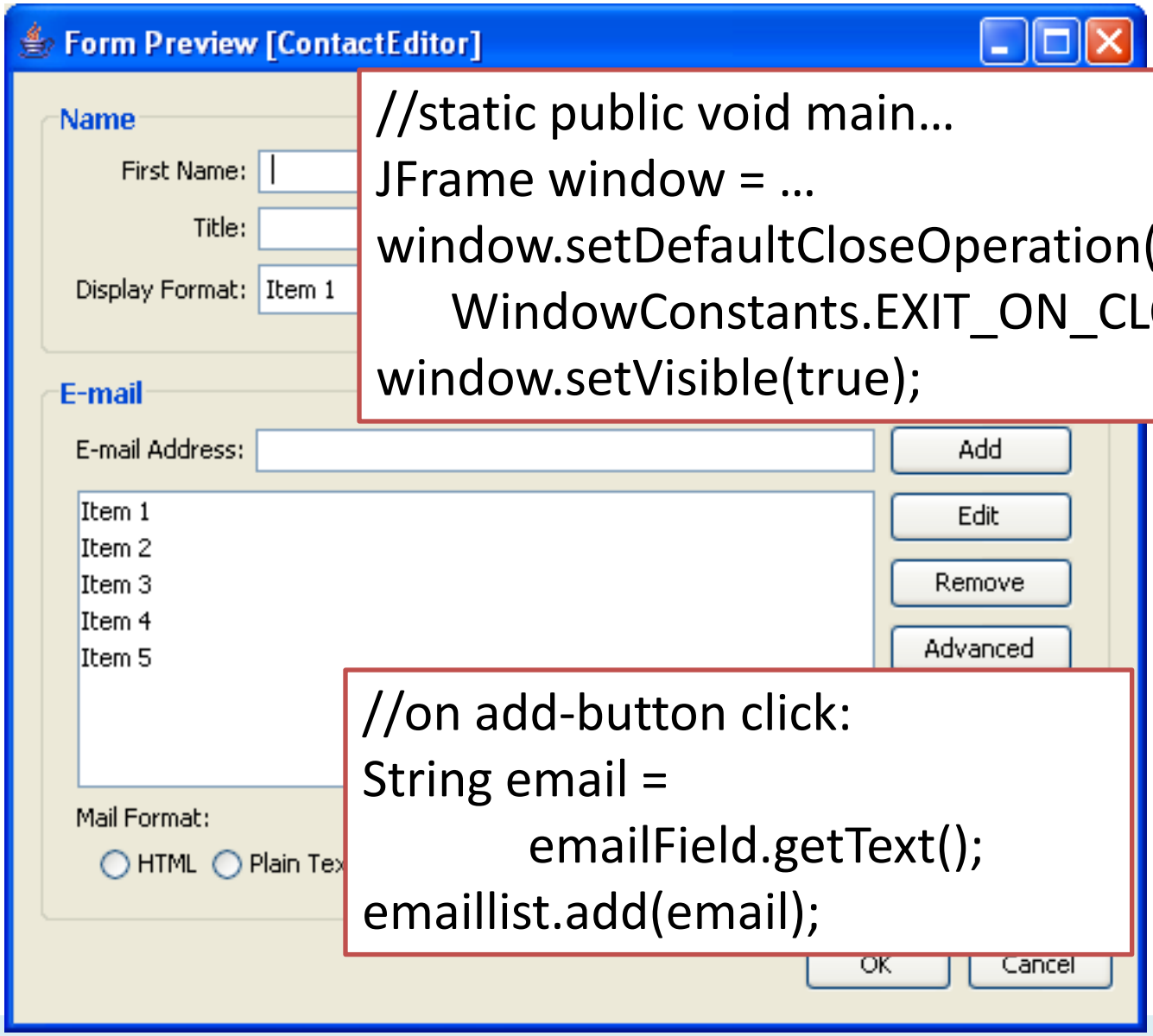

```
Scanner input = new Scanner(System.in);
while (questions.hasNext()) {
        Question q = question.next();
        System.out.println(q.toString());
        String answer = input.nextLine();
        q.respond(answer);
}
```

GUIs without event-based programming




```
while (true) {
        if (isKeyDown("Alt+Q")
                break;
        if (isKeyDown("F1")
                openHelp();
        if (isMouseDown(10 …)
                startMovingWindow();
        …
}
```

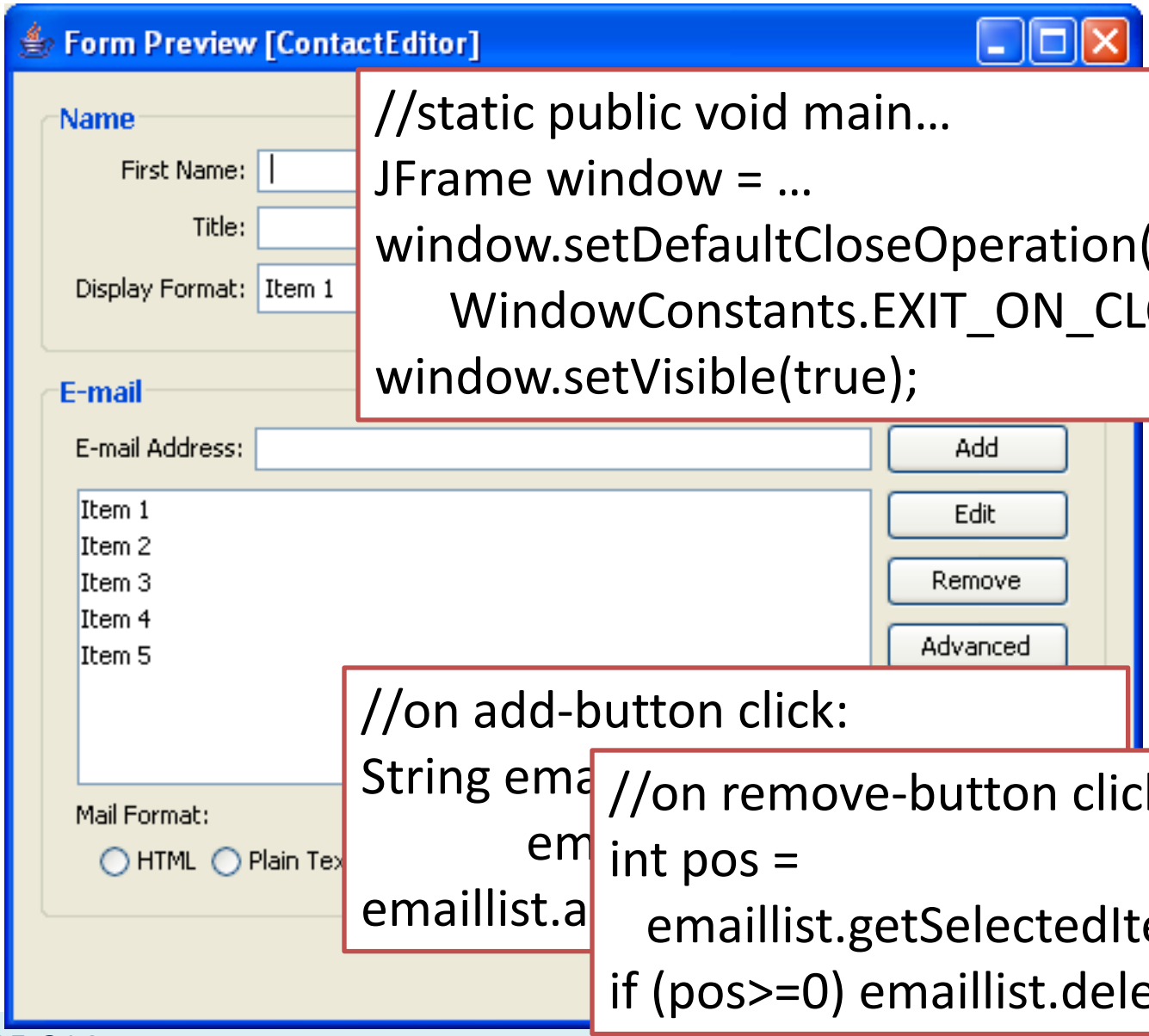
Event-based GUIs




```
//static public void main…
JFrame window = …
window.setDefaultCloseOperation(
      WindowConstants.EXIT_ON_CLOSE);
window.setVisible(true);
```

```
//on add-button click:
String email =
            emailField.getText();
emaillist.add(email);
```

Event-based GUIs

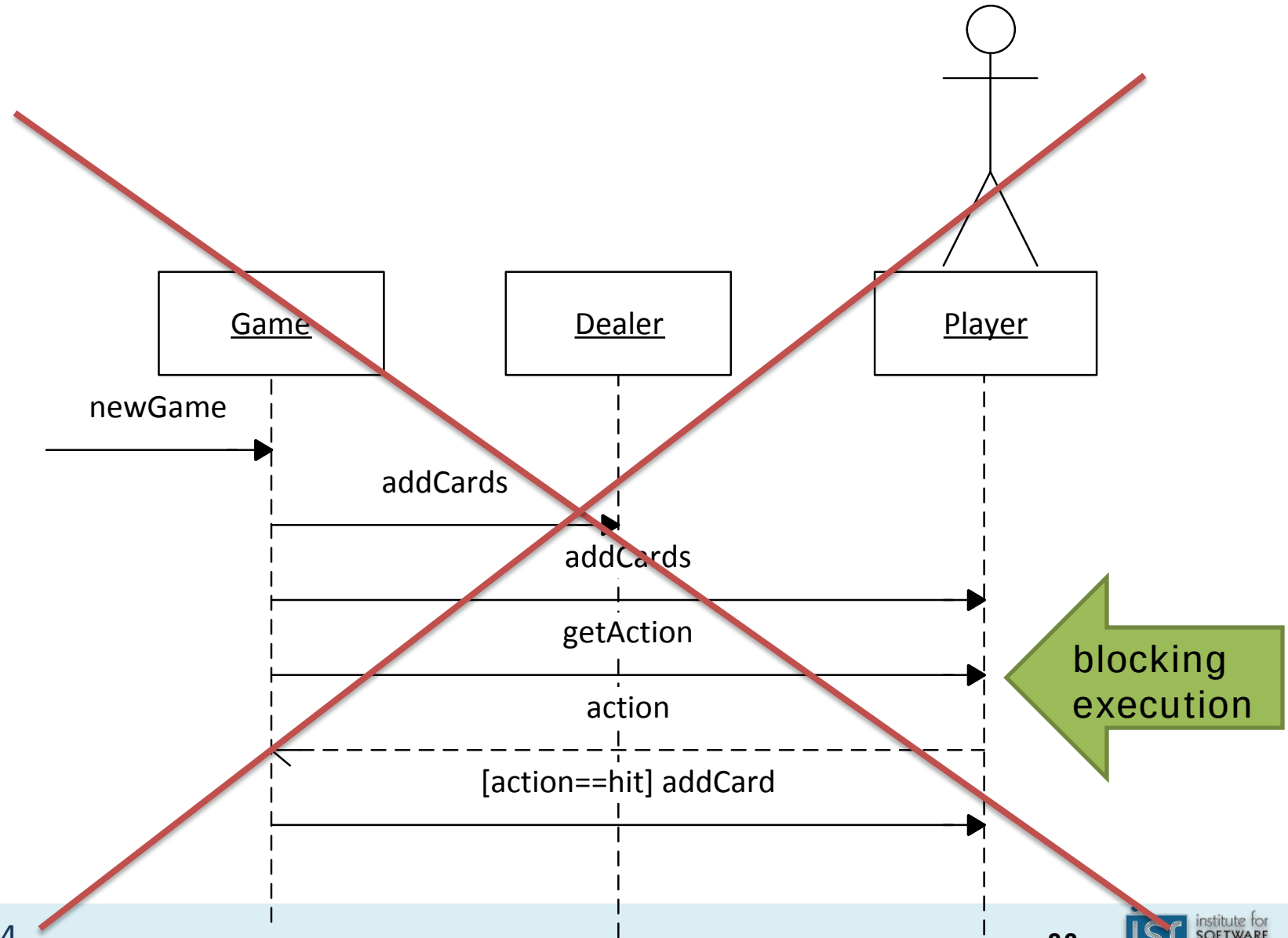



```
//static public void main…
JFrame window = …
window.setDefaultCloseOperation(
    WindowConstants.EXIT_ON_CLOSE);
window.setVisible(true);
```

```
//on add-button click:
String ema
          em
emaillist.a
```

```
//on remove-button click:
int pos =
  emaillist.getSelectedItem();
if (pos>=0) emaillist.delete(pos);
```

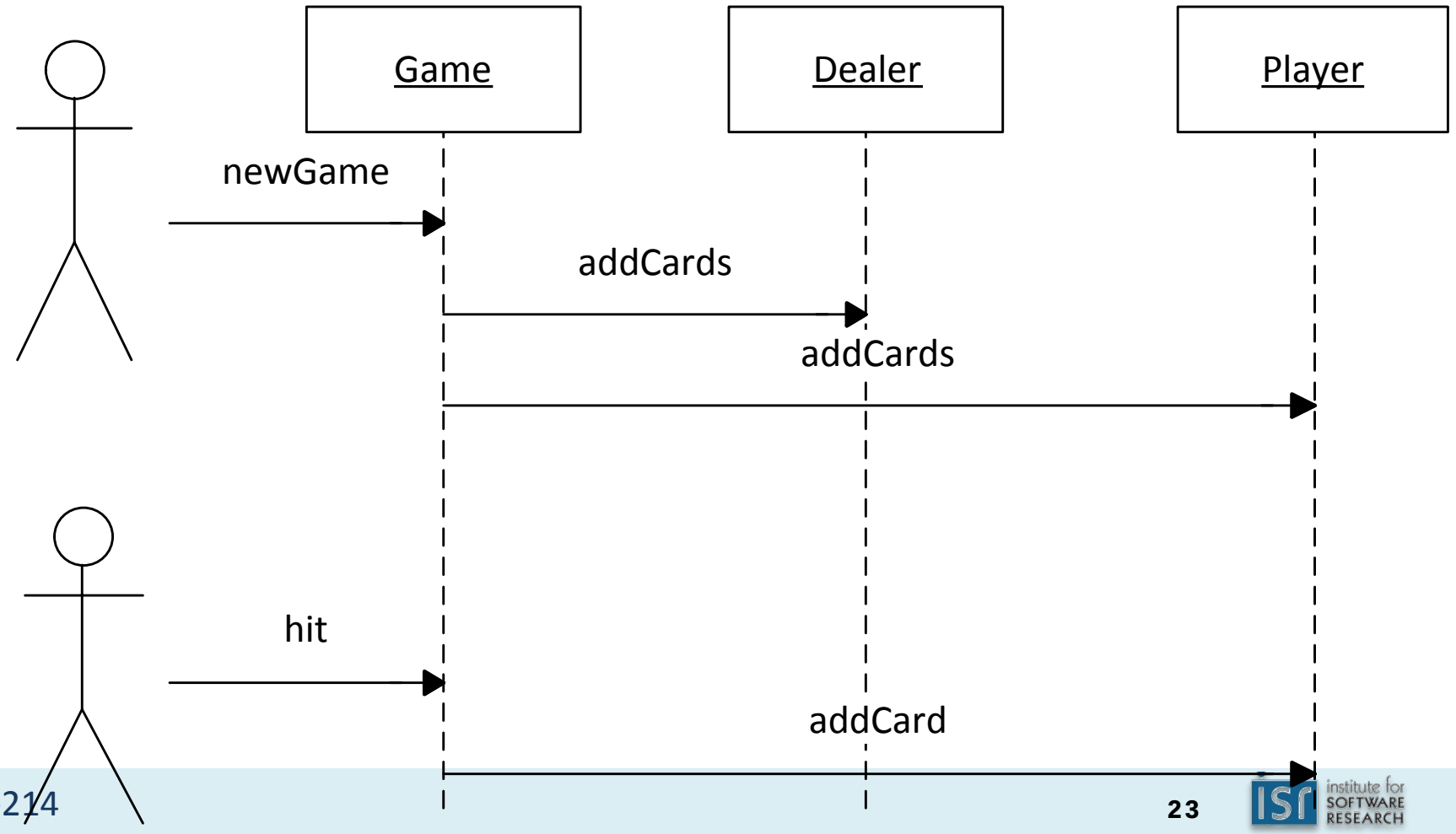
(Blocking) Interactions with users



Interactions with users through events

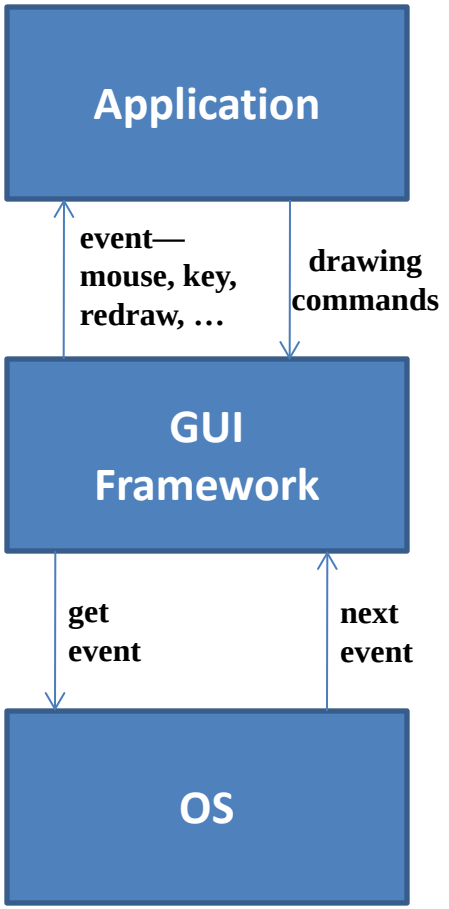
- Do not block waiting for user response
- Instead, react to user events

e.g.:



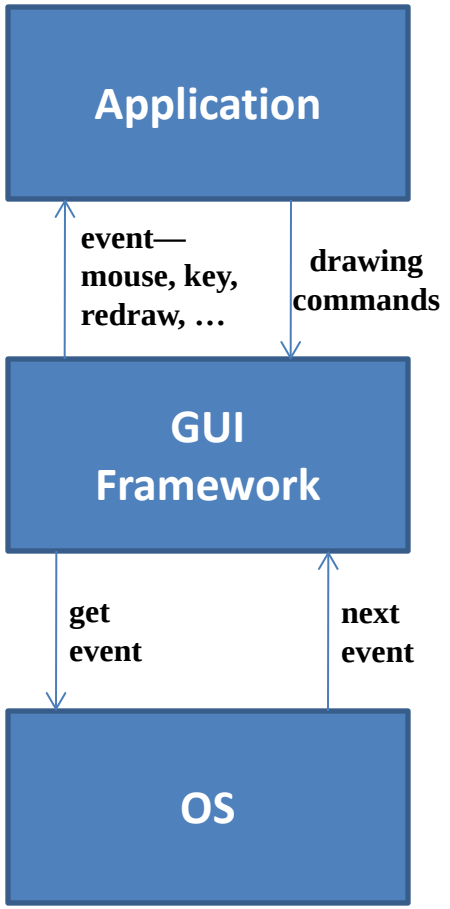
Programming an event-based GUI

- Typically use a GUI *framework*
  - Register code (a.k.a. *callbacks*) to handle different events
  - Operating system / GUI framework detects events
    - Determines which components are registered to handle the event and calls the event handlers
    - Your code is idle until called to handle events
  - Program exits by calling some exit method



Programming an event-based GUI

- Setup phase
  - Describe how the GUI window should look
  - Use libraries for windows, widgets, and layout
  - Embed specialized code for later use
  - Register callbacks
- Execution
  - Framework gets events from OS
    - Raw events: mouse clicks, key presses, window becomes visible, etc.
  - Framework processes events
    - Click at 10,40: which widget?
    - Resize window: what to re-layout and redraw?
  - Triggers callback functions of corresponding widgets (if registered)



Example: The AlarmWindow

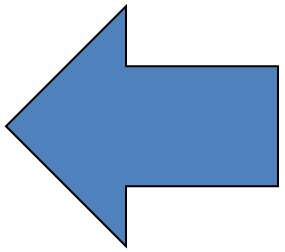
- …edu.cmu.cs.cs214.rec06.alarmclock.AlarmWindow
  - Creates a JFrame with a JPanel to go in it
  - Creates a text label and a button
  - Makes the window (and its contents) visible when the alarm goes off
- When the dismiss button is clicked, its event handler hides the window

Example: The CustomerManagementUI

- …rec06.customerlist.gui.CustomerManagementUI
  - Creates a JFrame with a JPanel to go in it
  - Makes the window (and its contents) visible
- ...rec06.customerlist.gui.CustomerManagementPanel
  - Creates numerous labels and text fields, a customerAddButton
  - Registers an event handler for the customerAddButton
- When the customerAddButton is clicked, its event handler gets the text from the text fields and adds a customer to the list

GUI frameworks in Java

- AWT
  - Native widgets, only basic components, dated
- Swing
  - Java rendering, rich components
- SWT + JFace
  - Mixture of native widgets and Java rendering; created for Eclipse for faster performance



- Others
  - Apache Pivot, SwingX, JavaFX, …

- Different in their specific designs, but similar overall strategies and concepts

Swing

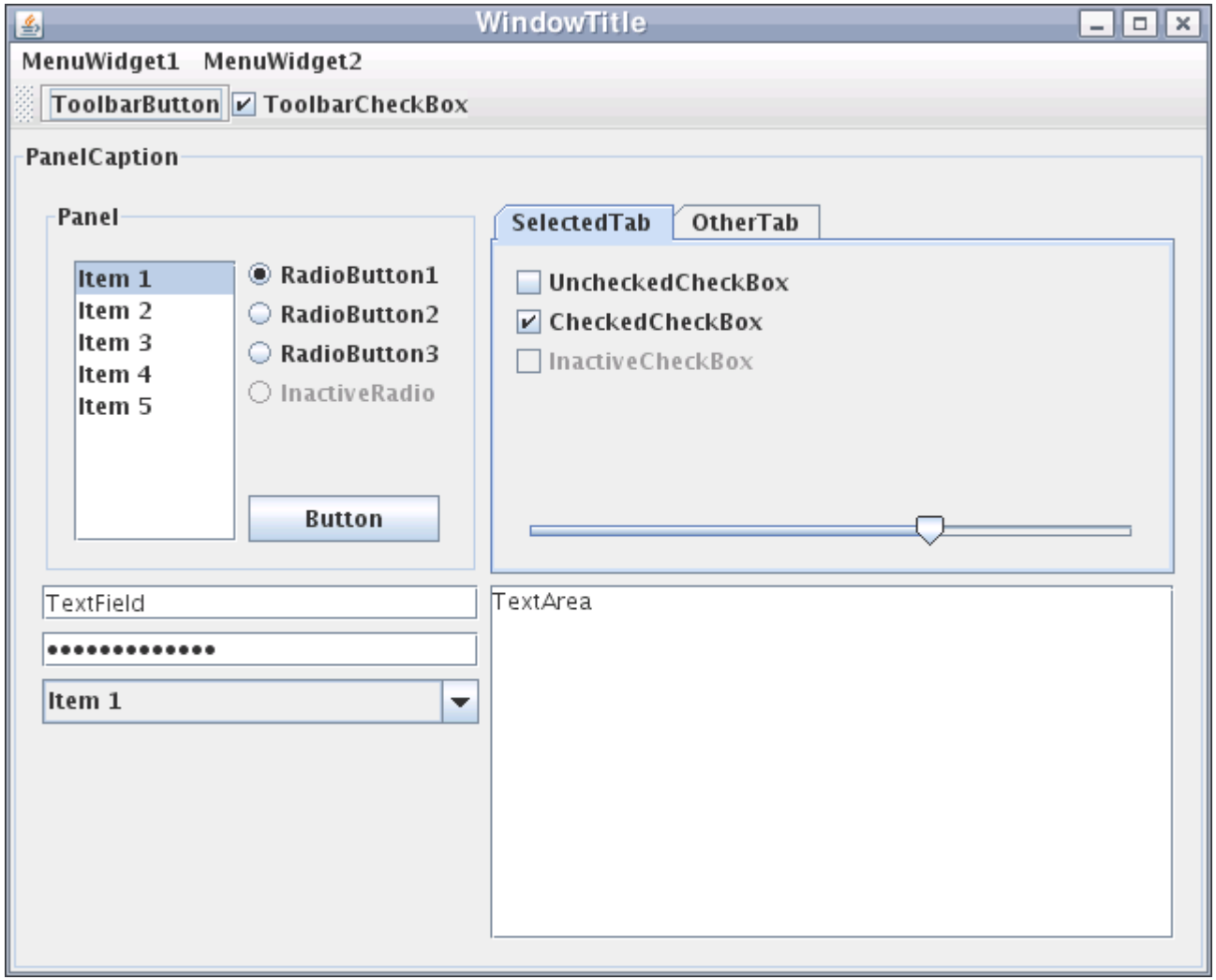
JFrame

JPanel

JButton

JTextField

...



Swing has many *widgets*

- JLabel
- JButton
- JCheckBox
- JChoice
- JRadioButton
- JTextField
- JTextArea
- JList
- JScrollBar
- … and more

- JFrame is the Swing Window
- JPanel (aka a pane) is the container to which you add your components (or other containers)

To create a simple Swing application

- Make a Window (a JFrame)
- Make a container (a JPanel)
  - Put it in the window
- Add components (Buttons, Boxes, etc.) to the container
  - Use layouts to control positioning
  - Set up observers (a.k.a. listeners) to respond to events
  - Optionally, write custom widgets with application-specific display logic
- Set up the window to display the container

- Then wait for events to arrive…

Reacting to events

Creating a button

```
//static public void main…
JFrame window = …

JPanel panel = new JPanel();
window.setContentPane(panel);

JButton button = new JButton(“Click me”);
button.addActionListener(new ActionListener() {
       public void actionPerformed(ActionEvent e) {
              System.out.println(“Button clicked”);
       }
});
panel.add(button);

window.setVisible(true);
```

Creating a button

```
//static public void main…
JFrame window = …

JPanel panel = new JPanel();
window.setContentPane(panel);

JButton button = new JButton("Click me");
button.addActionListener(new ActionListener() {
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panel.add(button);

window.setVisible(true);
```
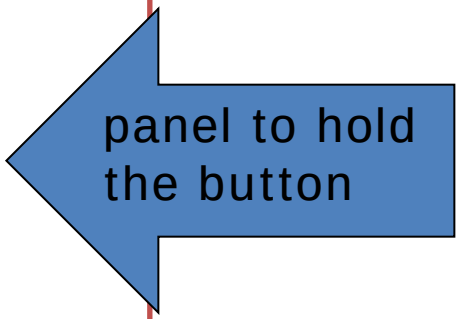
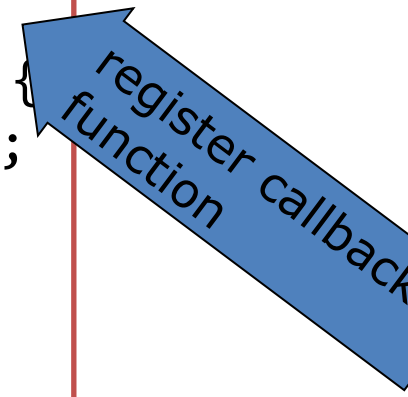
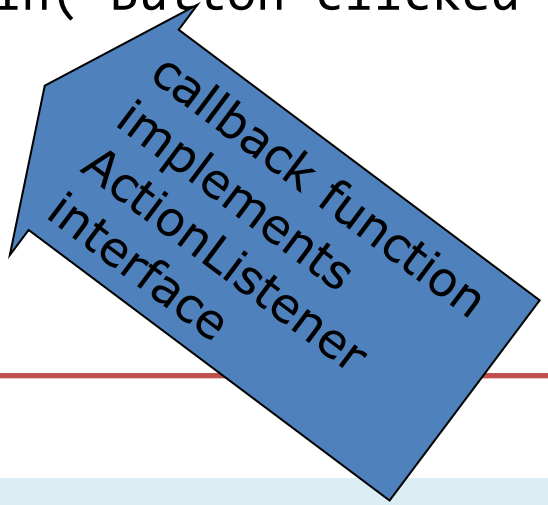







ActionListeners

- Listeners are objects with callback functions
- Listeners can be registered to handle events on widgets
- All registered widgets are called if event occurs

```
interface ActionListener {
        void actionPerformed(ActionEvent e);
}
```

```
class ActionEvent {
        int when;
        String actionCommand;
        int modifiers;
        Object source();
        int id;
        …
}
```

ActionListeners

- Listeners are objects with callback functions
- Listeners can be registered to handle events on widgets
- All registered widgets are called if event occurs

```
interface ActionListener {
	void actionPerformed(ActionEvent e);
}
```

```
class ActionEvent {
```

```
class AbstractButton extends JComponent {
	private List<ActionListener> listeners;
	public void addActionListener(ActionListener l) {
		listeners.add(l);
	}
	protected void fireActionPerformed(ActionEvent e) {
		for (ActionListener l: listeners)
			l.actionPerformed(e);
	}
}
```

ActionListeners

What design pattern is this?

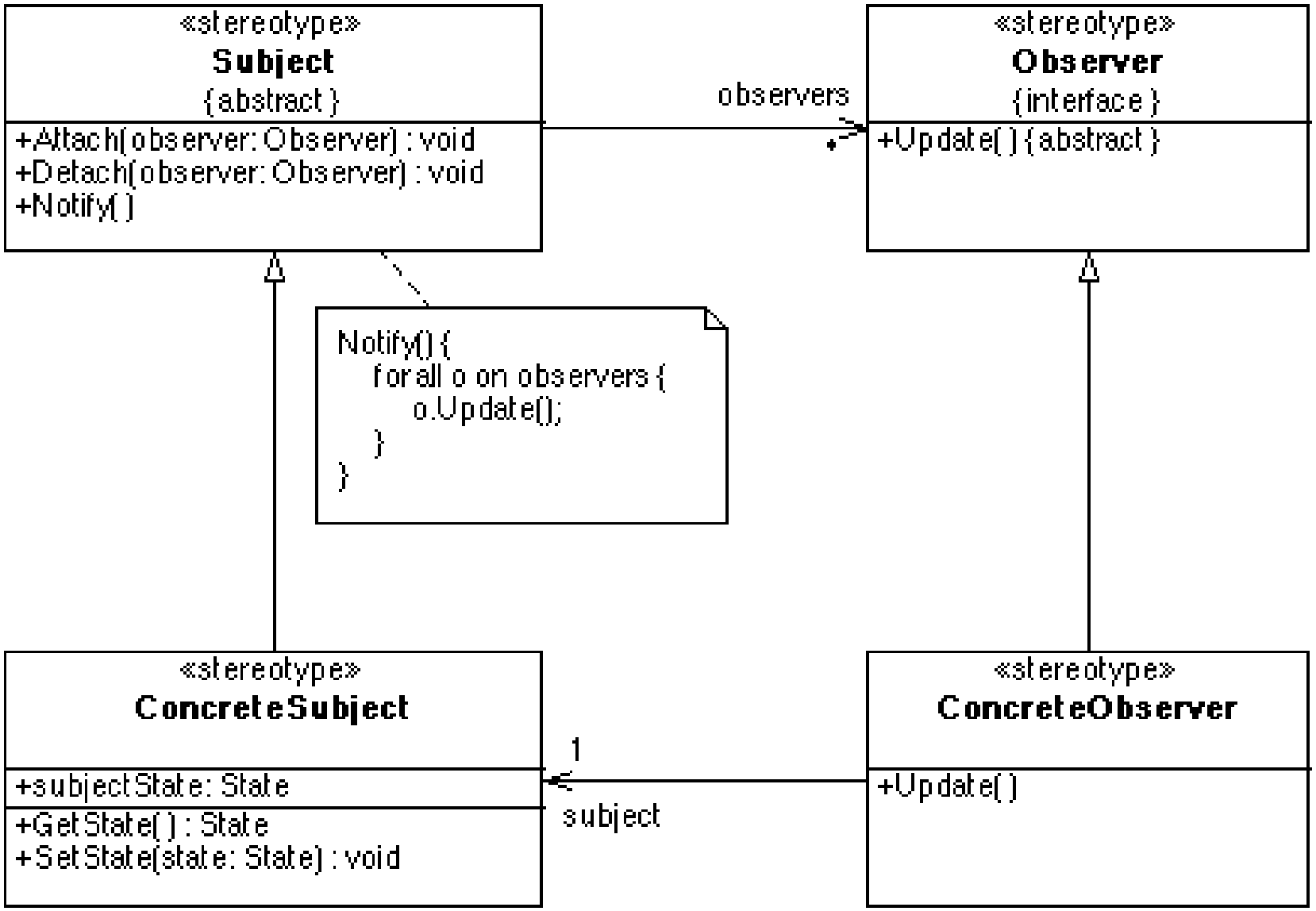
- Listeners are objects with callback functions
- Listeners can be registered to handle events on widgets
- All registered widgets are called if event occurs

```
interface ActionListener {
	void actionPerformed(ActionEvent e);
}
```

```
class ActionEvent {
```

```
class AbstractButton extends JComponent {
	private List<ActionListener> listeners;
	public void addActionListener(ActionListener l) {
		listeners.add(l);
	}
	protected void fireActionPerformed(ActionEvent e) {
		for (ActionListener l: listeners)
			l.actionPerformed(e);
	}
}
```

Recall the observer design pattern



Design discussion

- Button implementation should be reusable but customizable
  - Different button label, different event-handling
- Must decouple button's action from the button itself
- Listeners are separate independent objects
  - A single button can have multiple listeners
  - Multiple buttons can share the same listener

Swing has many event listener interfaces:

- ActionListener
- AdjustmentListener
- FocusListener
- ItemListener
- KeyListener
- MouseListener
- TreeExpansionListener
- TextListener
- WindowListener
- …and on and on…

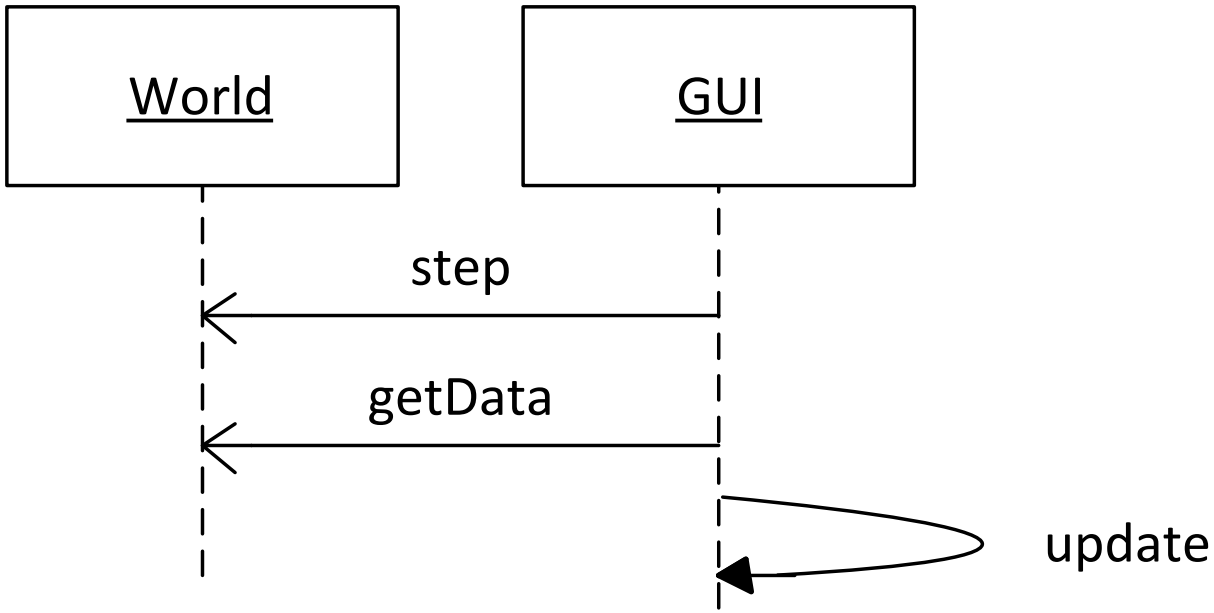
```
interface ActionListener {
        void actionPerformed(ActionEvent e);
}
```

```
class ActionEvent {
        int when;
        String actionCommand;
        int modifiers;
        Object source();
```

Decoupling from a GUI

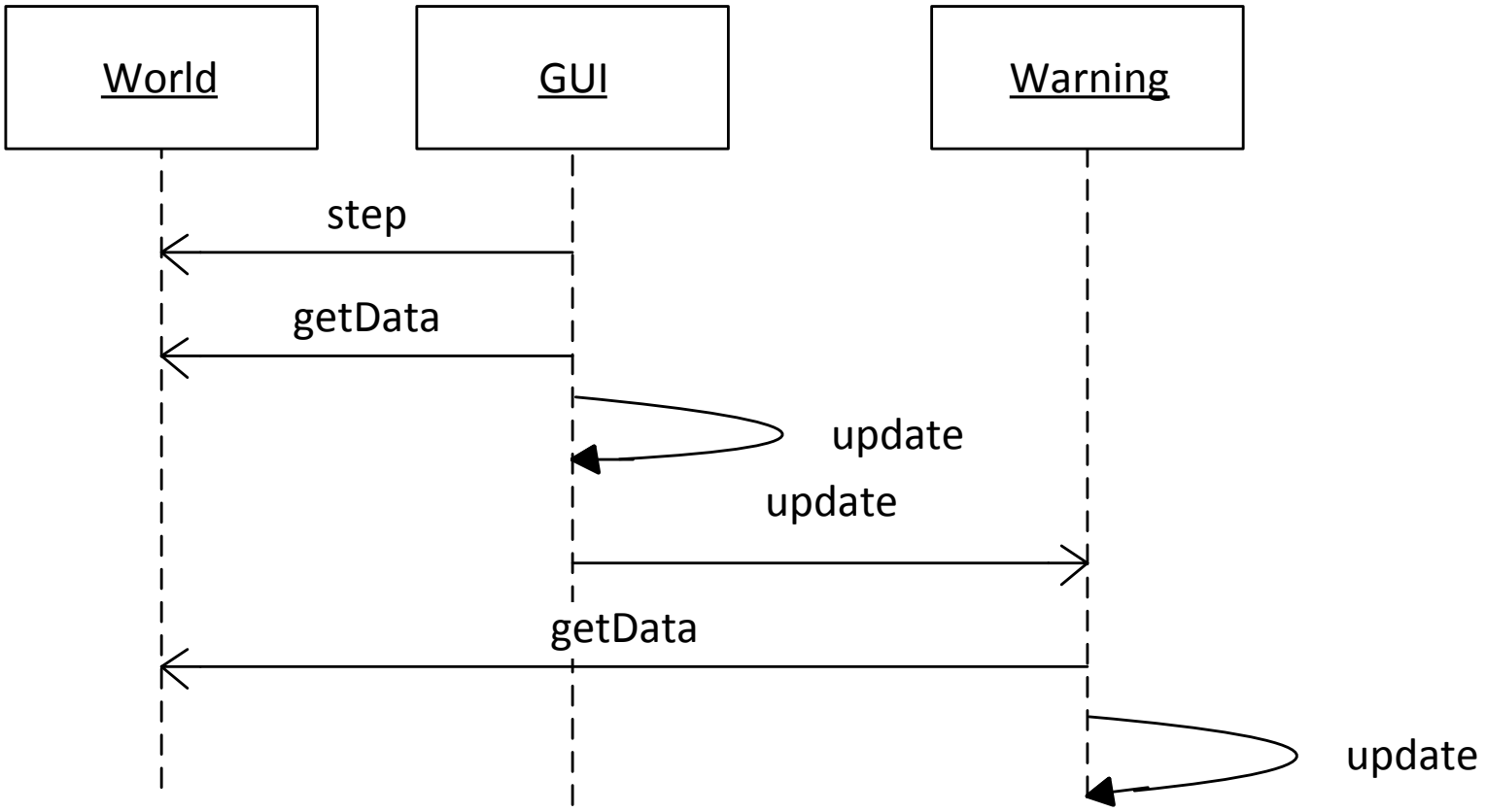
A GUI design challenge

- Consider the transit simulator, implemented by a `World` class:
  - Simulator `World` stores all entities
  - GUI shows entities, triggers new events in simulator
  - When should the GUI update the screen?



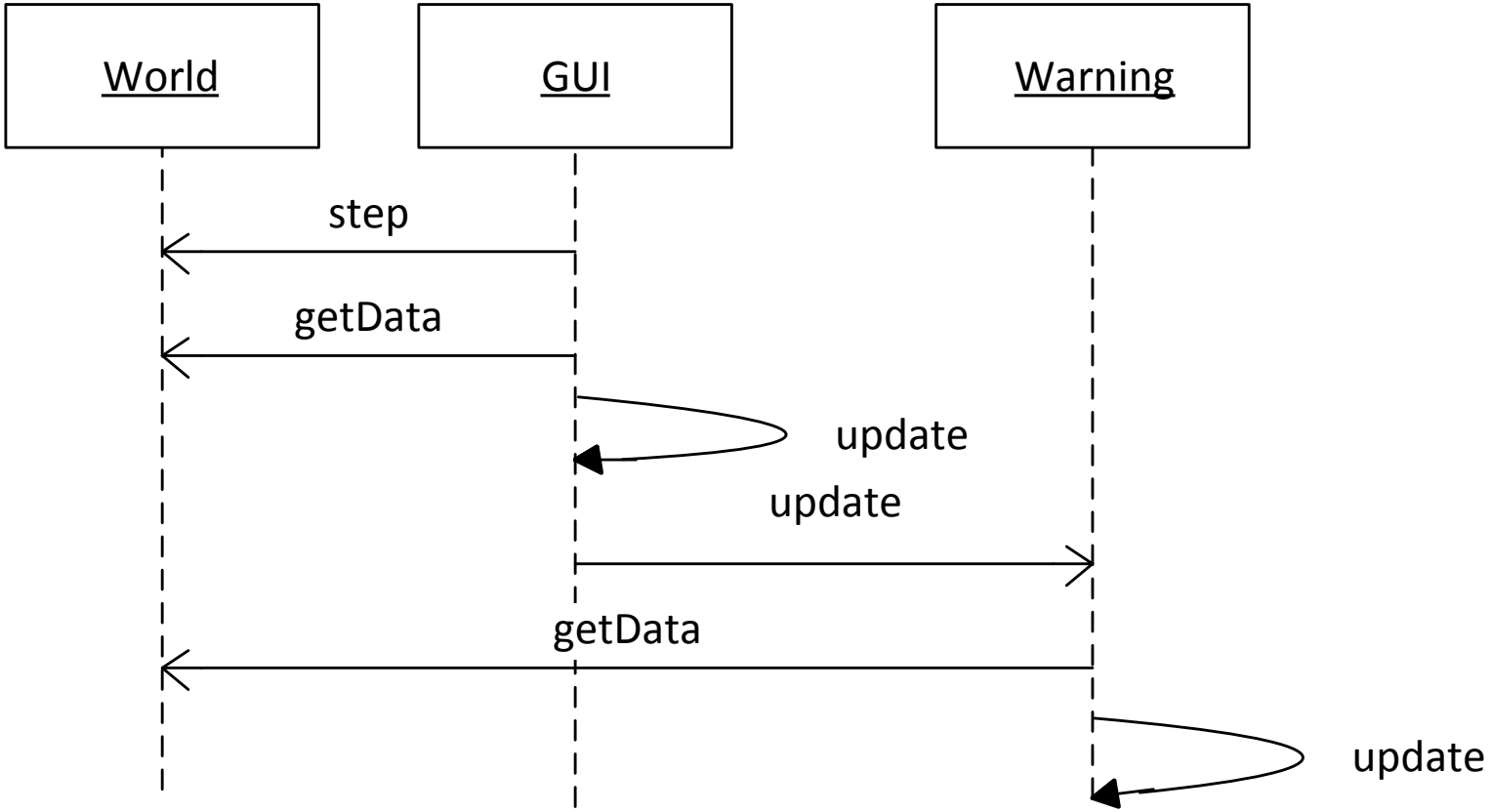
A GUI design challenge, part 2

- What if we add a warning to alert if a bus has moved?



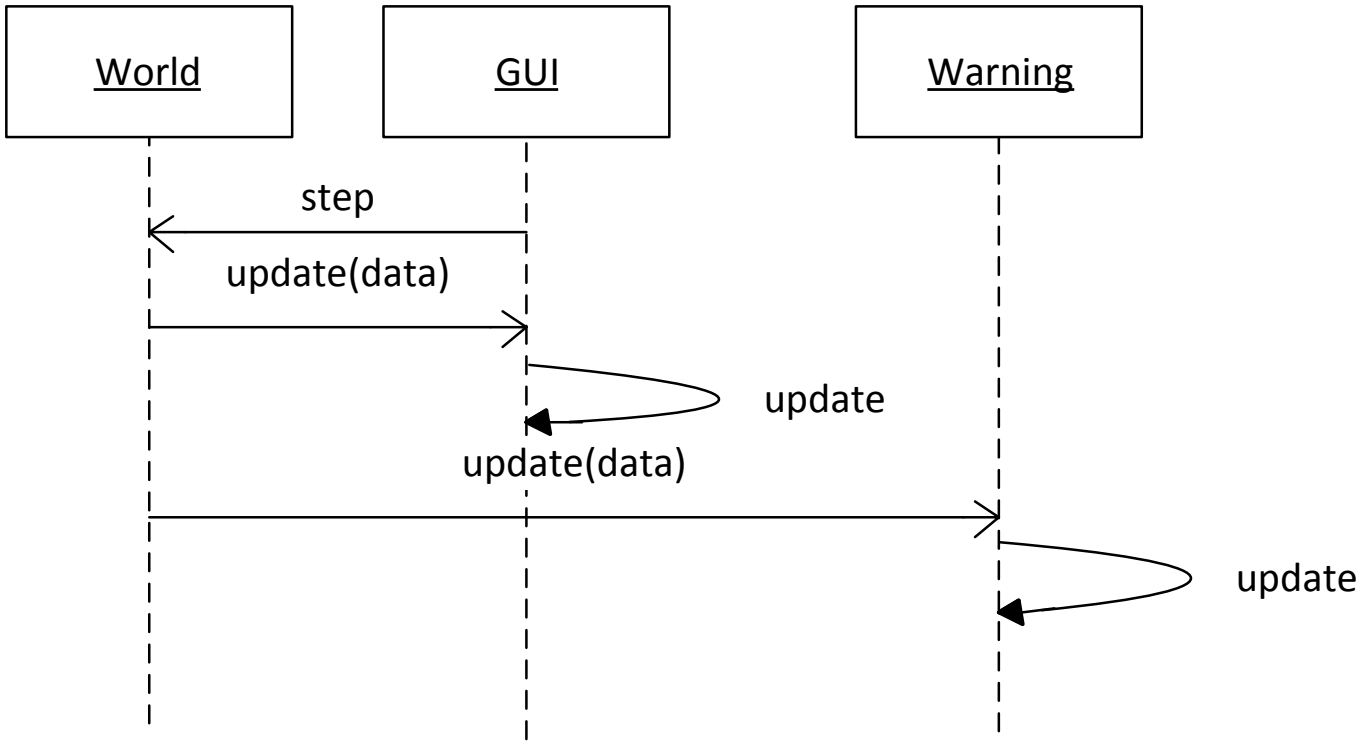
A GUI design challenge, part 3

- What if the simulator world changes for reasons not caused by the GUI?



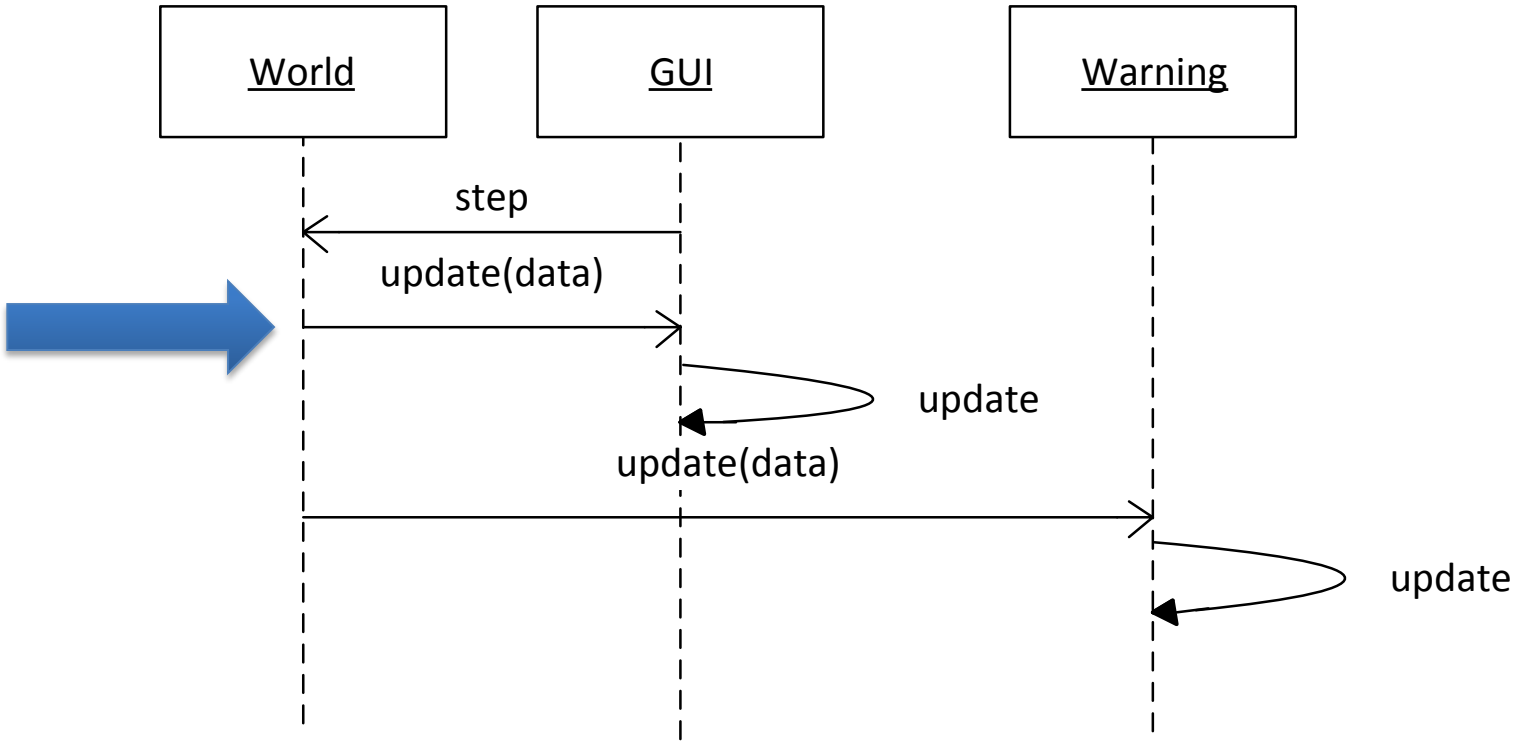
A GUI design challenge, part 3: one possible design

- Let the `World` tell the GUI that something happened



A GUI design challenge, part 3: one possible design

- Let the `World` tell the GUI that something happened



Problem: This couples the `World` to the GUI implementation.

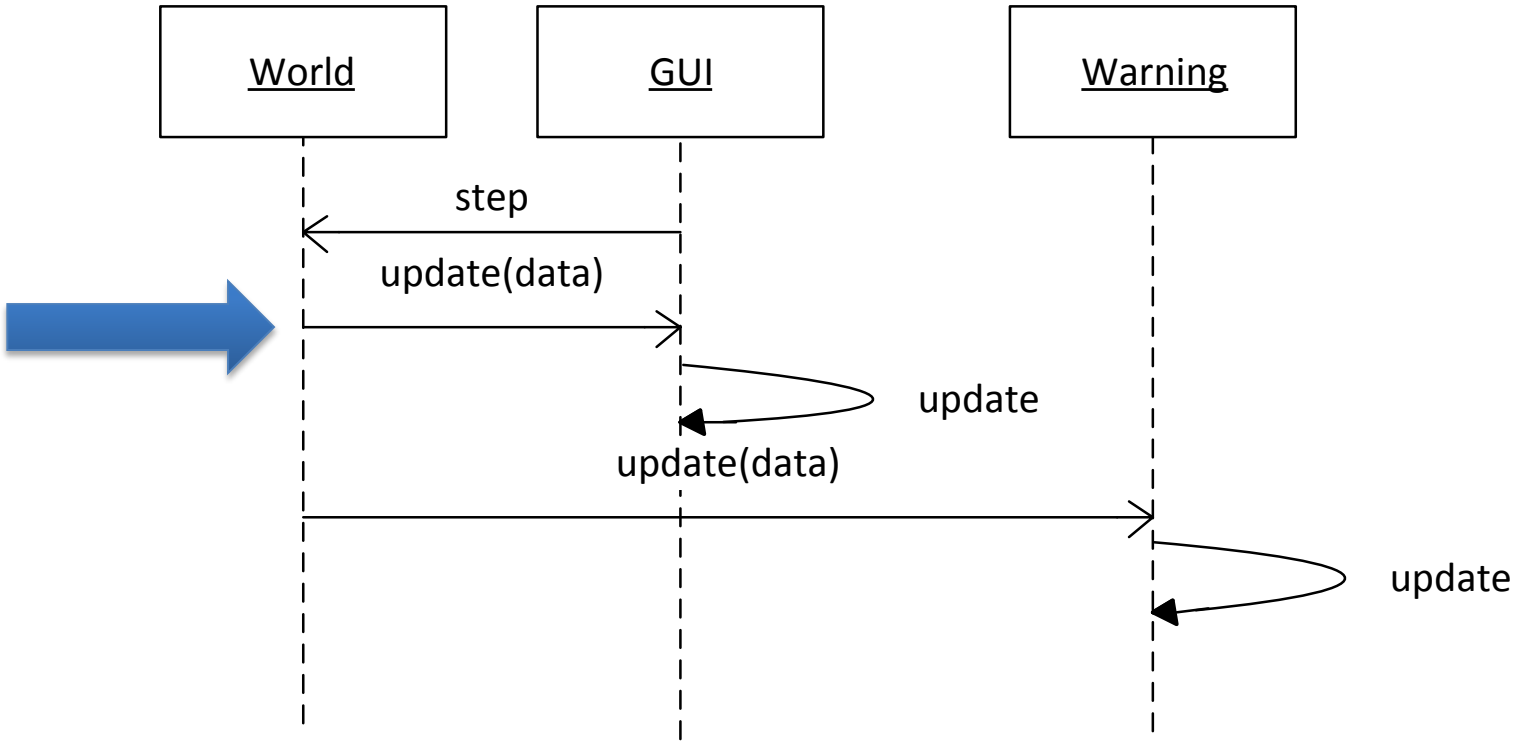
Core implementation vs. GUI

- Core implementation: Application logic
  - Computing some result, updating data
- GUI
  - Graphical representation of data
  - Source of user interactions

- Design guideline: *Avoid coupling the GUI with core application*
  - Multiple UIs with single core implementation
  - Test core without UI
  - *Design for change, design for reuse, design for division of labor; low coupling, high cohesion*

A GUI design challenge, part 3: one possible design

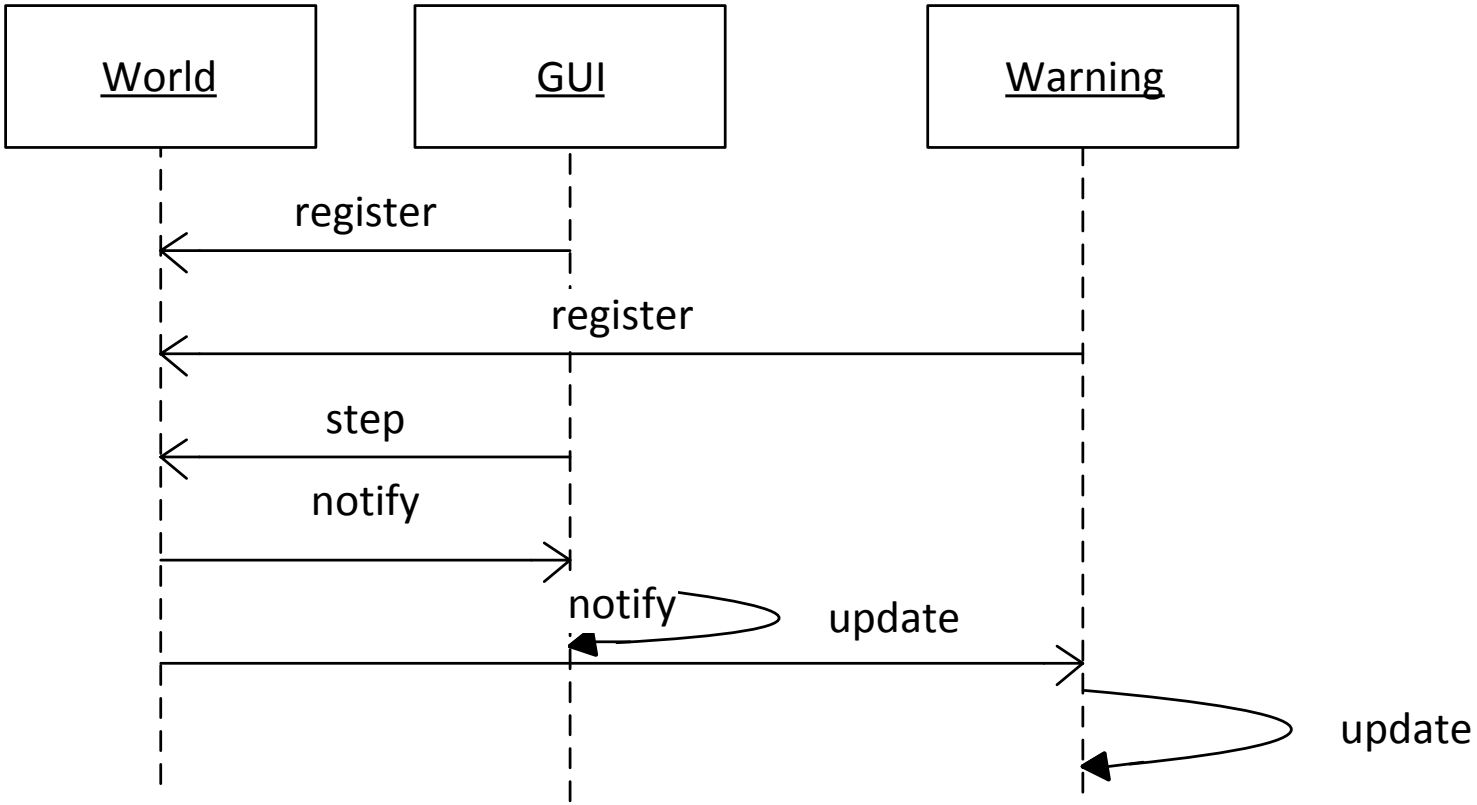
- Let the `World` tell the GUI that something happened



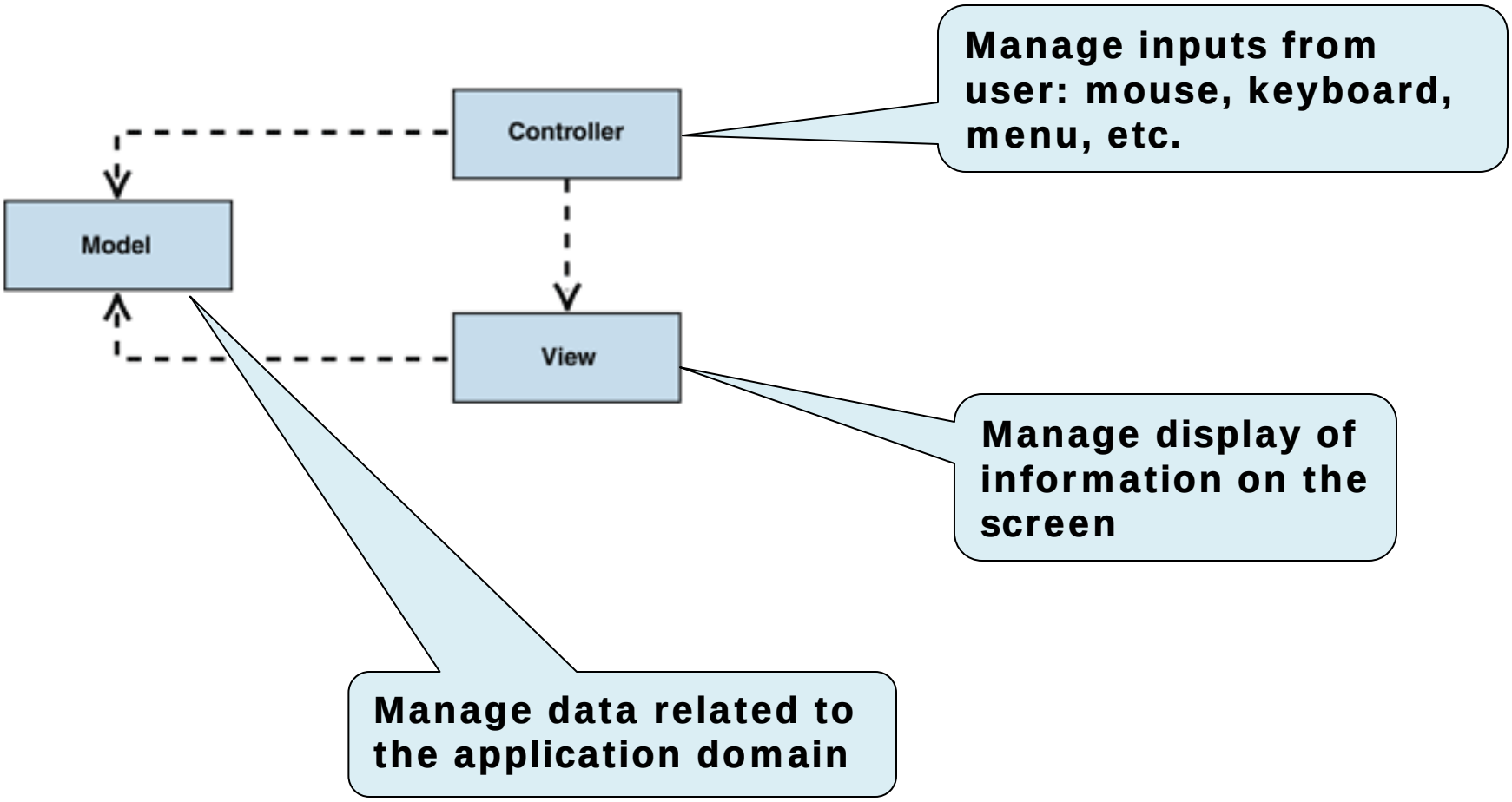
Problem: This couples the `World` to the GUI implementation.

Decoupling with the Observer pattern

- Let the world tell *all* interested components about updates

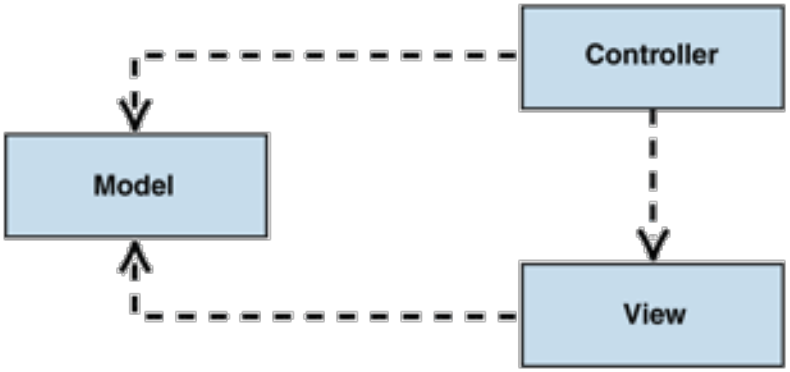


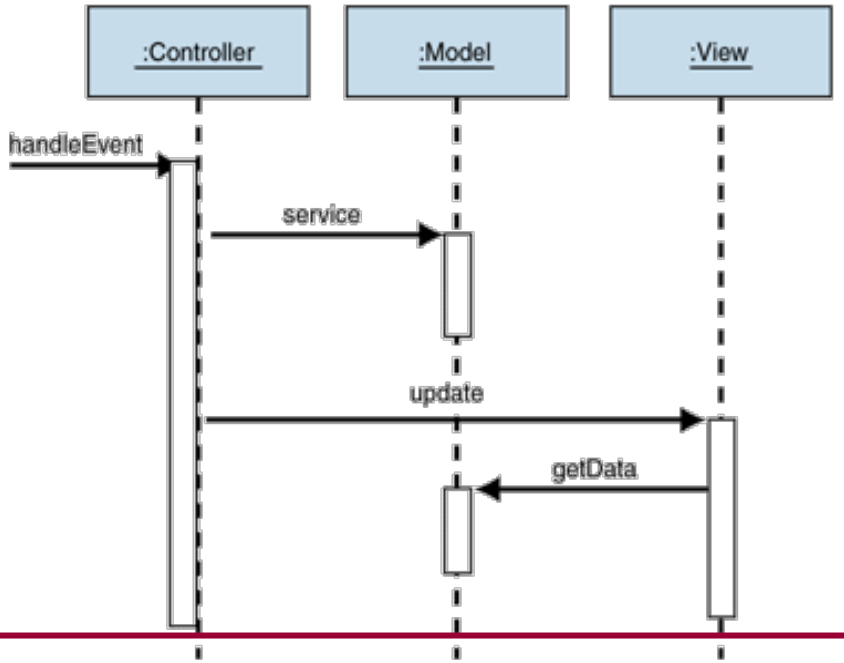
An architectural pattern: Model-View-Controller (MVC)



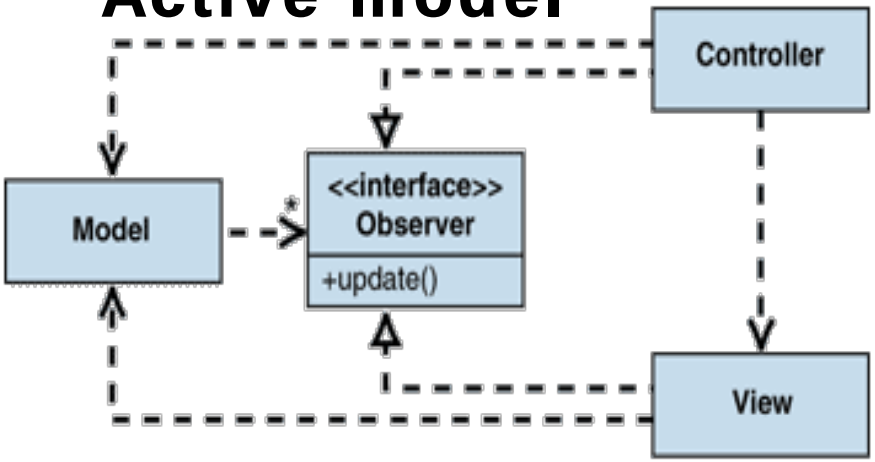
Model-View-Controller (MVC)

Passive model

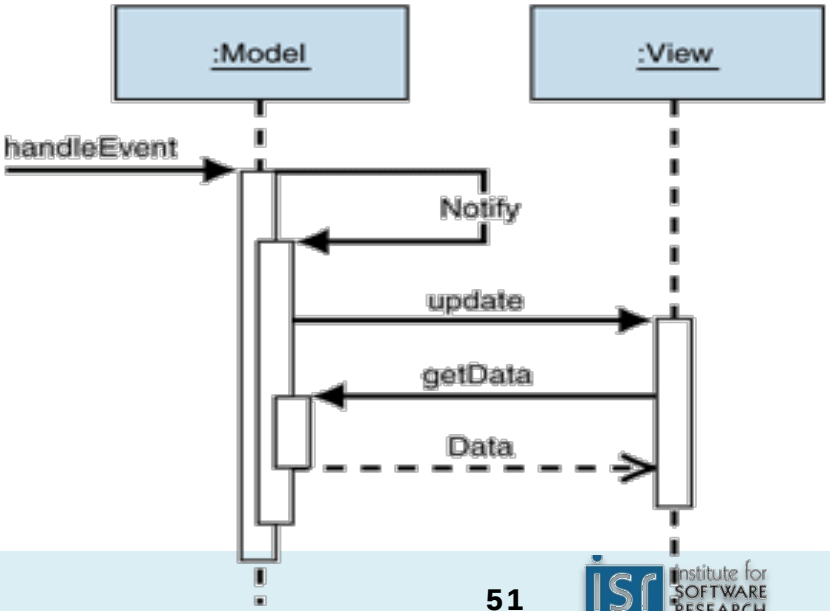




Active model

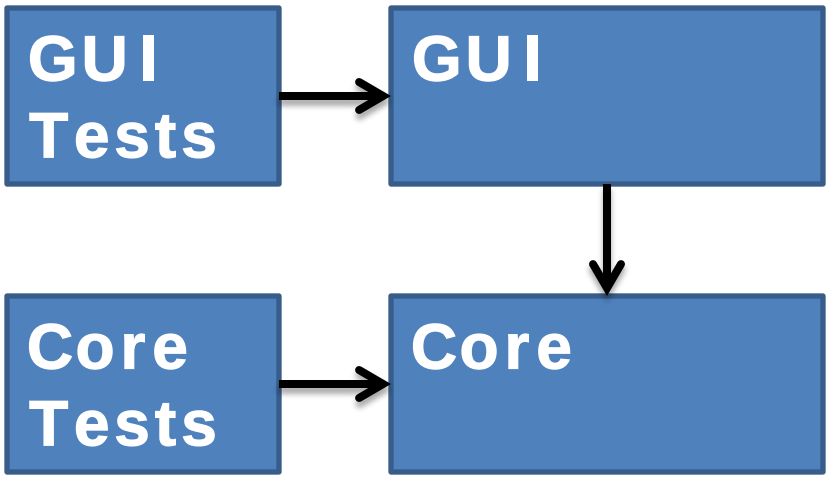


http://msdn.microsoft.com/en-us/library/ff649643.aspx



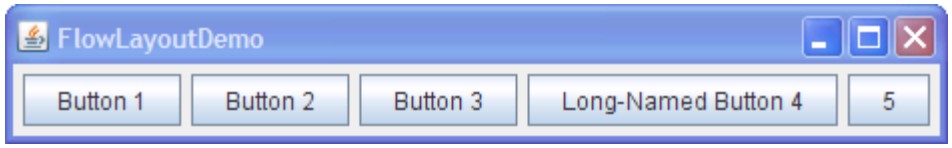
Separating application core and GUI, a summary

- Reduce coupling: do not allow core to depend on UI
- Create and test the core without a GUI
  - Use the Observer pattern to communicate information from the core (Model) to the GUI (View)

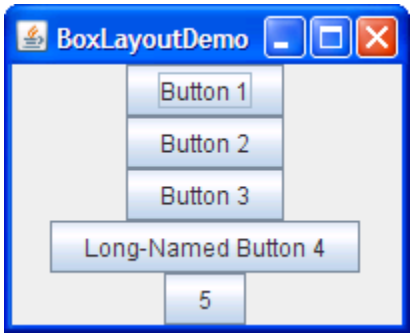


More GUI design challenges

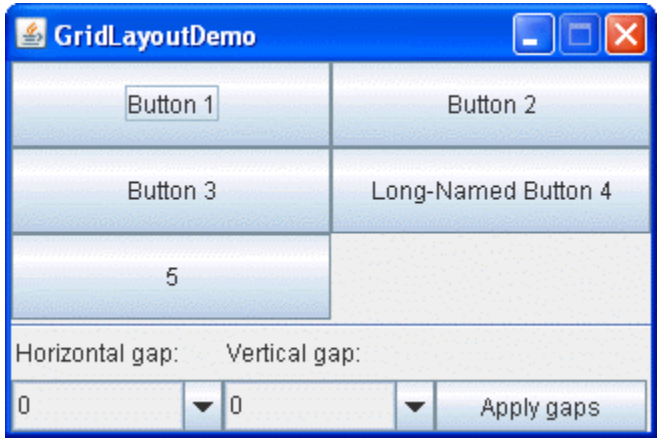
Swing layouts

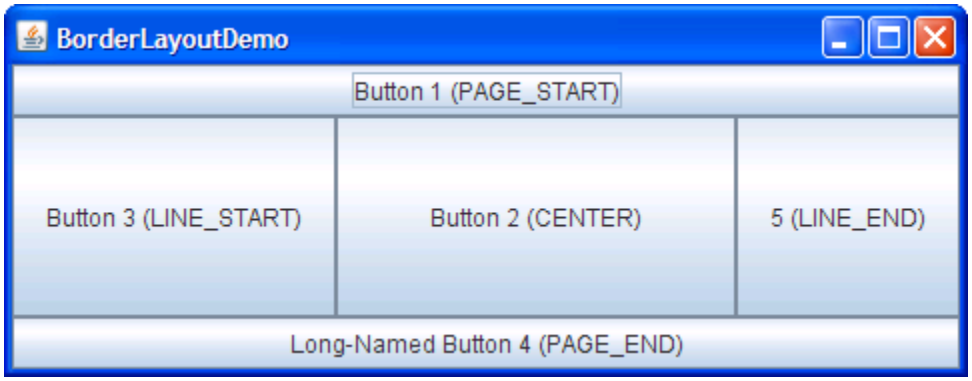


The simplest, and default, layout.
Wraps around when out of space.



Like FlowLayout, but no wrappin





More sophisticated layout managers

see http://docs.oracle.com/javase/tutorial/uiswing/layout/visual.html

A naïve hard-coded implementation

```
class JPanel {
     protected void doLayout() {
       switch(getLayoutType()) {
              case BOX_LAYOUT: adjustSizeBox(); break;
              case BORDER_LAYOUT: adjustSizeBorder(); break;
              ...
       }
     }
     private adjustSizeBox() { … }
}
```

- A new layout would require changing or overriding JPanel

A better solution: delegate the layout responsibilities

- Layout classes, e.g.:

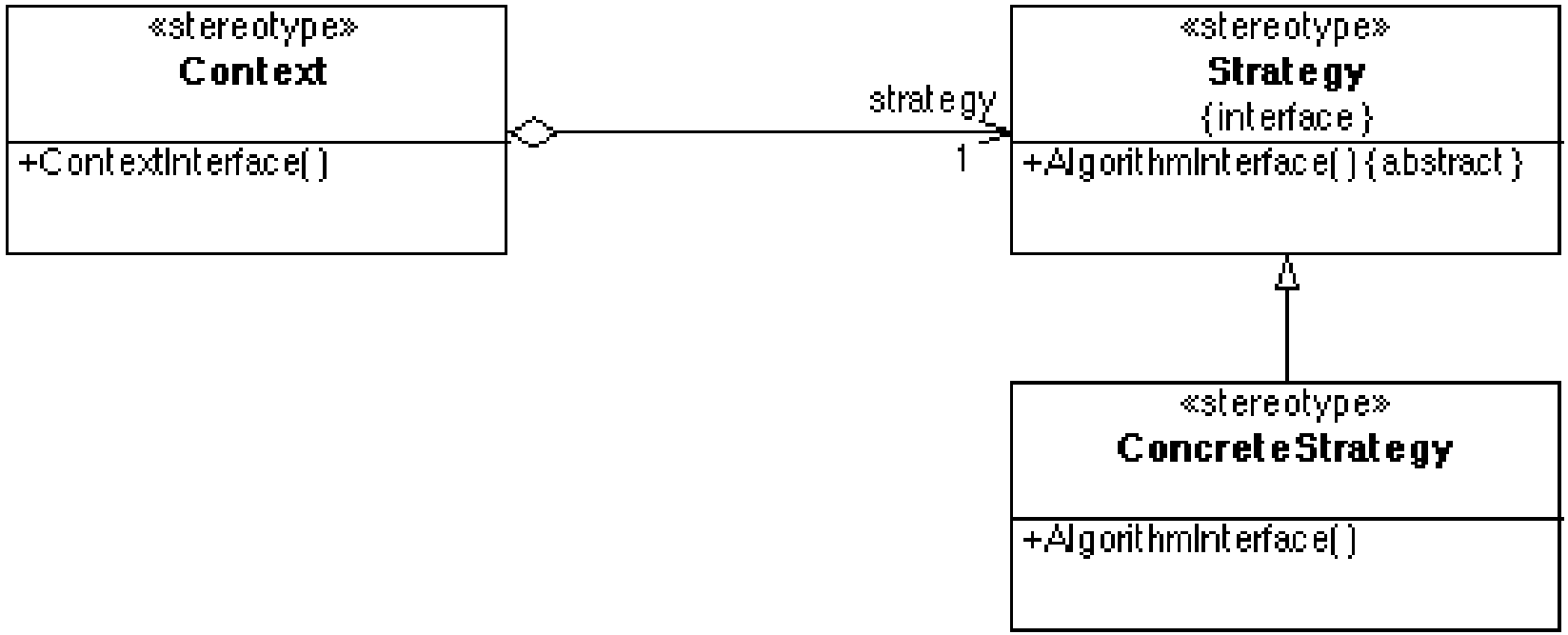
```
contentPane.setLayout(new FlowLayout());
contentPane.setLayout(new GridLayout(4,2));
```

- Similarly, there are border classes to draw the borders, e.g.:

```
contentPane.setBorder(new EmptyBorder(5, 5, 5, 5));
```

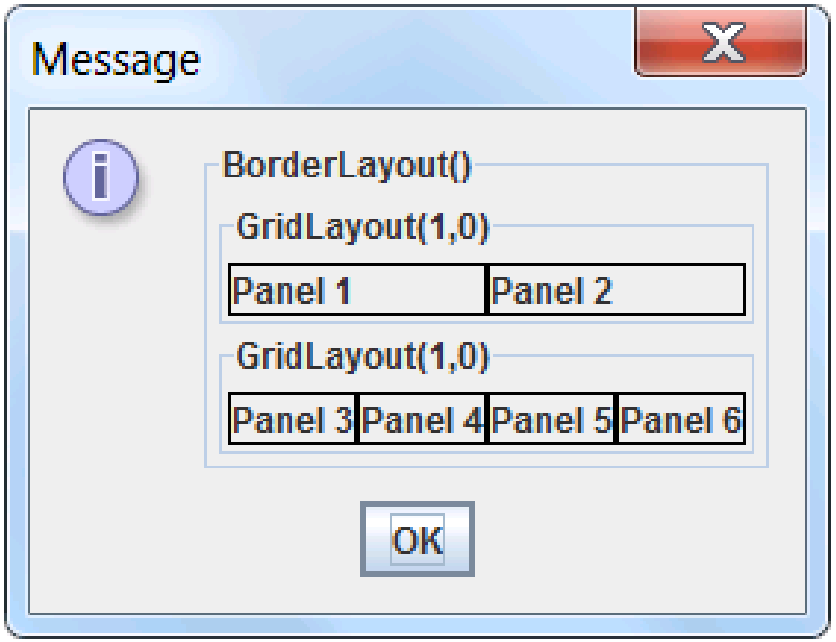
What design pattern is this?

Recall the strategy pattern



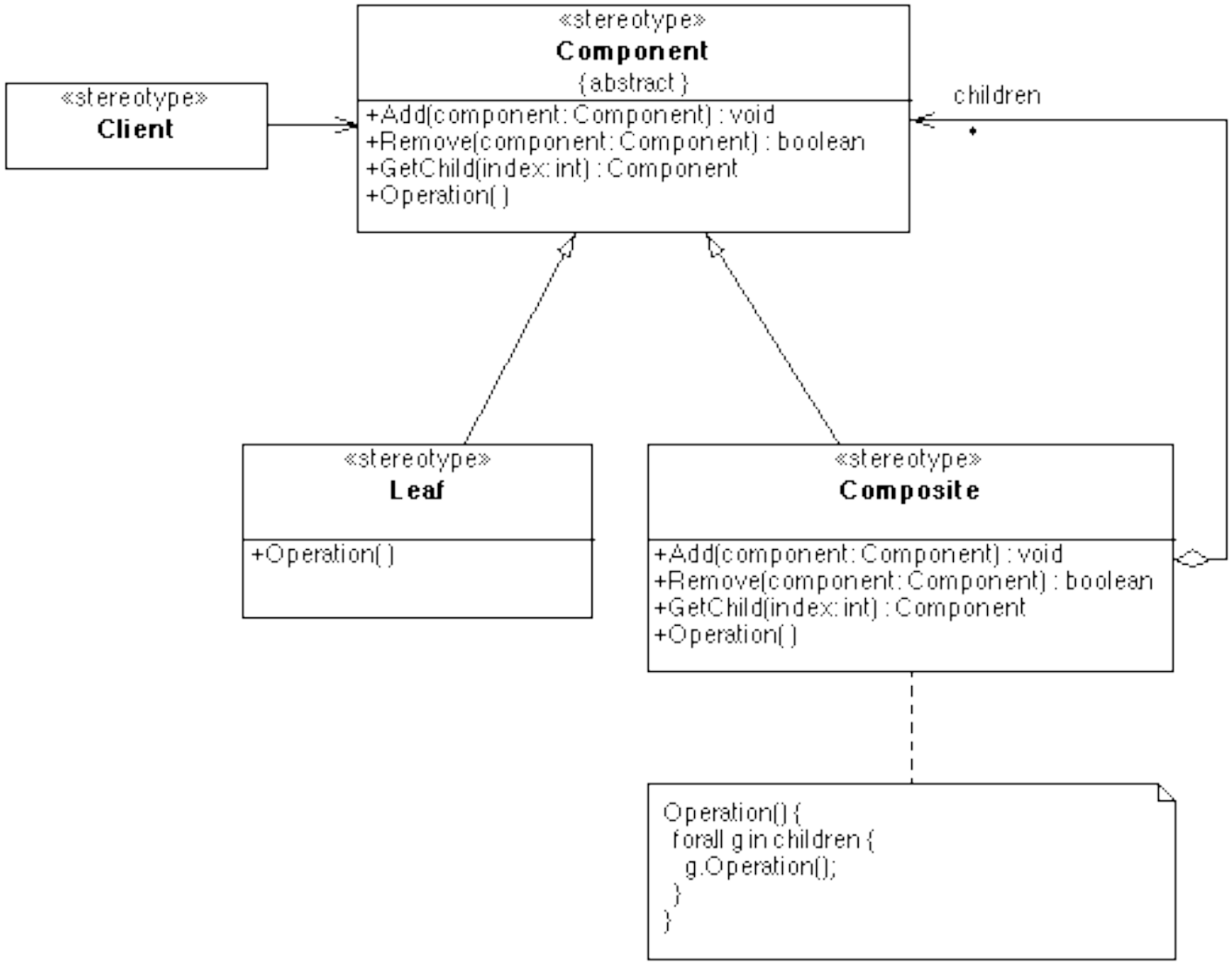
Another GUI design challenge: nesting containers

- A `JFrame` contains a `JPanel`, which contains a `JPanel` (and/or other widgets), which contains a `JPanel` (and/or other widgets), which contains…



What design pattern best models this?

Recall the composite design pattern



Yet another GUI design challenge: partial customization

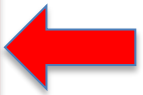
`JComponent`.

paint

`public void` **`paint`**`(Graphics g)`

Invoked by Swing to draw components. Applications should not invoke `paint` directly, but should instead use the `repaint` method to schedule the component for redrawing.

This method actually delegates the work of painting to three protected methods: `paintComponent`, `paintBorder`, and `paintChildren`. They're called in the order listed to ensure that children appear on top of component itself. Generally speaking, the component and its children should not paint in the insets area allocated to the border. Subclasses can just override this method, as always. A subclass that just wants to specialize the UI (look and feel) delegate's `paint` method should just override `paintComponent`.



Overrides:

`paint` in class `Container`

Parameters:

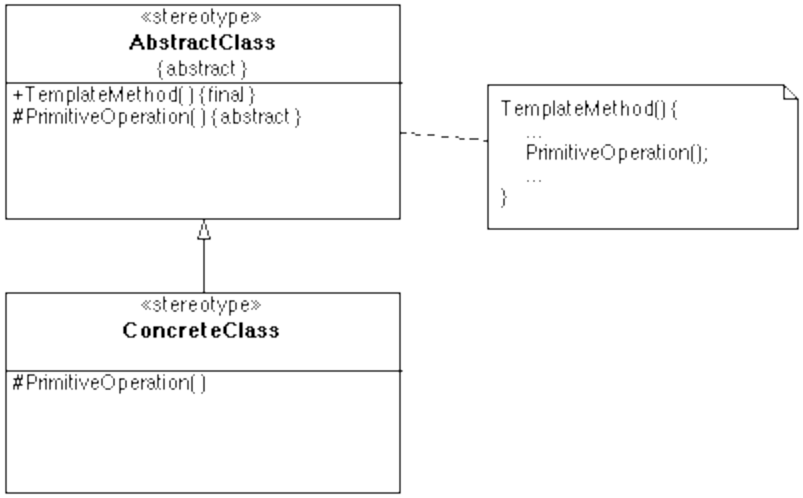
`g` - the `Graphics` context in which to paint

See Also:

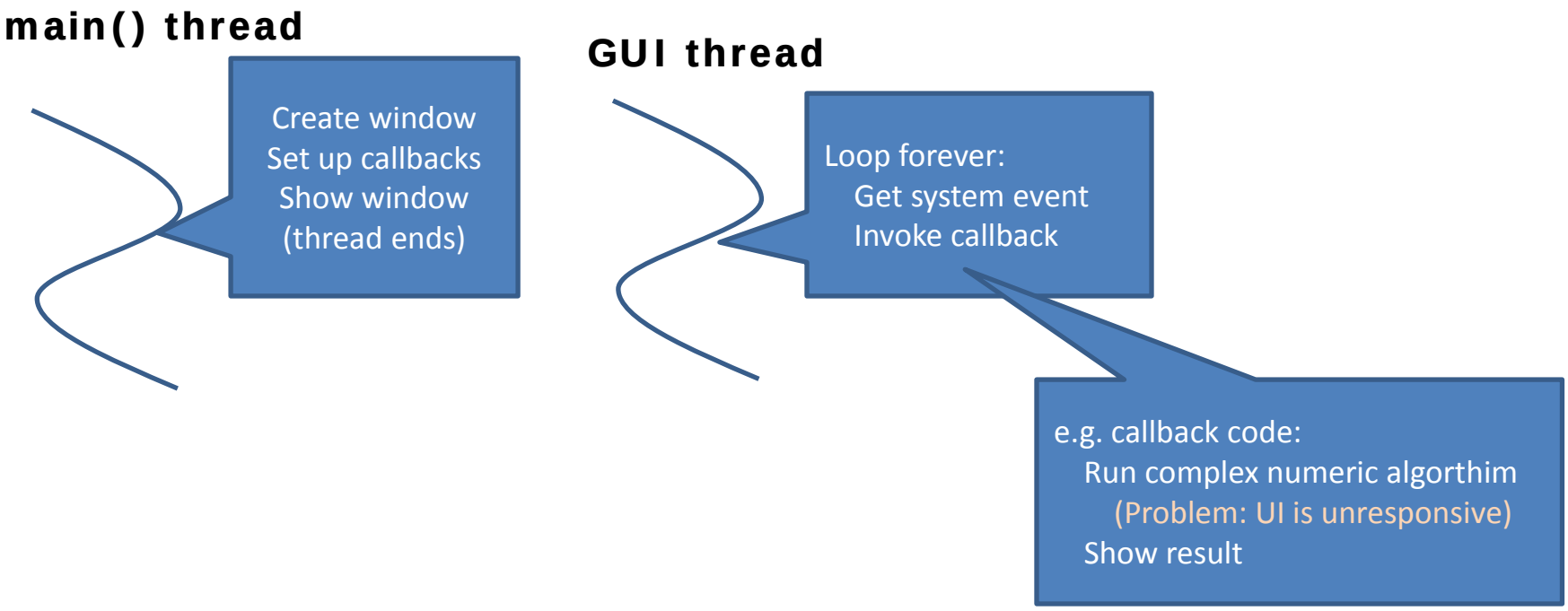
`paintComponent(java.awt.Graphics)`, `paintBorder(java.awt.Graphics)`, `paintChildren(java.awt.Graphics)`, `getComponentGraphics(java.awt.Graphics)`, `repaint(long, int, int, ...`

Recall the template method pattern

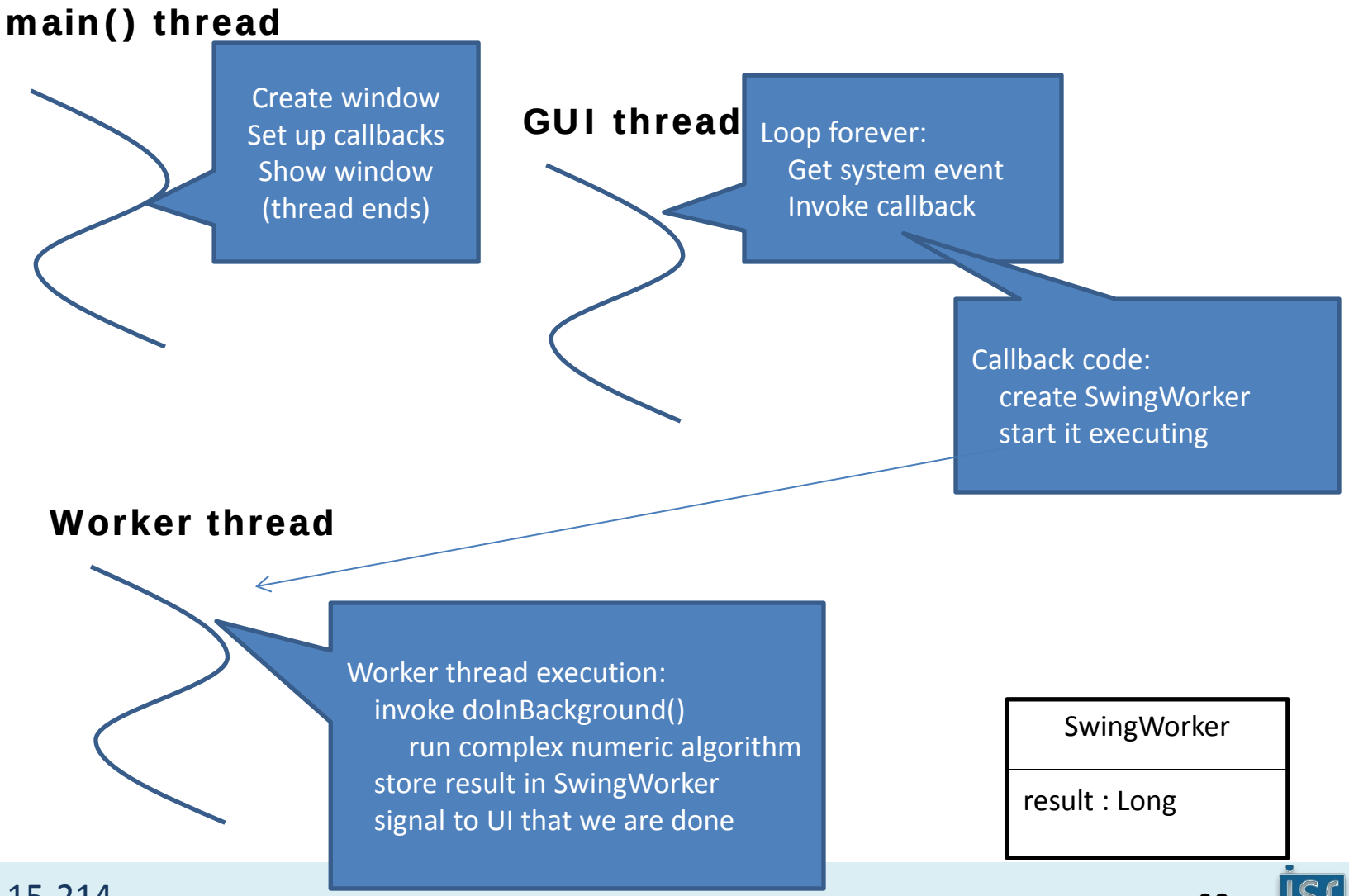
- Applicability
  - When an algorithm consists of varying and invariant parts that must be customized
  - When common behavior in subclasses should be factored and localized to avoid code duplication
  - To control subclass extensions to specific operations
- Consequences
  - Code reuse
  - Inverted “Hollywood” control: don’t call us, we’ll call you
  - Ensures the invariant parts of the algorithm are not changed by subclasses



The Swing threading architecture



The Swing threading architecture: worker threads



Summary

- GUIs are full of design patterns
  - Strategy pattern
  - Template Method pattern
  - Composite pattern
  - Observer pattern
  - Decorator pattern
  - Façade pattern
  - Adapter pattern
  - Command pattern
  - Model-View-Controller
- Swing for Java GUIs
- Separation of GUI and Core