Principles of Software Construction:
Objects, Design, and Concurrency

Part 2: Designing (Sub)systems

Introduction to concurrency and GUIs

Michael Hilton **Bogdan Vasilescu**

School of Computer Science
institute for SOFTWARE RESEARCH

Administrivia

- Homework 4b due Thursday, March 7th
  - Homework 4a feedback coming soon
- Reading due Tuesday: UML and Patterns Chapters 26.1 and 26.4
  - Adapter pattern
  - Factory pattern
- Still need Midterm 1?

Intro to Java

Git, CI

UML

Static Analysis

Performance

GUIs

GUIs

More Git

Design

Part 1: Design at a Class Level	Part 2: Designing (Sub)systems	Part 3: Designing Concurrent Systems
Design for Change: Information Hiding, Contracts, Unit Testing, Design Patterns	Understanding the Problem	Concurrency Primitives, Synchronization
Design for Reuse: Inheritance, Delegation, Immutability, LSP, Design Patterns	Responsibility Assignment, Design Patterns, GUI vs Core, Design Case Studies	Designing Abstractions for Concurrency
	Testing Subsystems	
	Design for Reuse at Scale: Frameworks and APIs	

Key concepts from Thursday

Key concepts from Thursday

- Revise, revise, revise: Refactoring and anti-patterns
- Test driven development

Key concepts from last recitation

- Discovering design patterns
- Observer design pattern

Observer pattern (a.k.a. publish/subscribe)

- Problem: Must notify other objects (observers) without becoming dependent on the objects receiving the notification
- Solution: Define a small interface to define how observers receive a notification, and only depend on the interface
- Consequences:
  - Loose coupling between observers and the source of the notifications
  - Notifications can cause a cascade effect

See edu.cmu.cs.cs214.rec06.alarmclock.AlarmListener…

Today

- Observer pattern
- Introduction to concurrency
- Introduction to GUIs

MULTITHREADED PROGRAMMING BASICS

What is a thread?

- Short for *thread of execution*
- Multiple threads can run in the same program concurrently
- Threads share the same address space
  - Changes made by one thread may be read by others
- Multithreaded programming
  - Also known as shared-memory multiprocessing

Threads vs. processes

- Threads are lightweight; processes heavyweight
- Threads share address space; processes have their own
- Threads require synchronization; processes don't
  - Threads hold locks while mutating objects
- It's unsafe to kill threads; safe to kill processes

Reasons to use threads

- Performance needed for blocking activities
- Performance on multi-core processors
- Natural concurrency in the real-world
- Existing multi-threaded, managed run-time environments
  - In Java threads are a fact of life
    - Example: garbage collector runs in its own thread

A simple threads example

```
public interface Runnable {  // java.lang.Runnable
    public void run();
}

public static void main(String[] args) {
    int n = Integer.parseInt(args[0]);  // Number of threads;

    Runnable greeter = new Runnable() {
        public void run() {
            System.out.println("Hi mom!");
        }
    };
    for (int i = 0; i < n; i++) {
        new Thread(greeter).start();
    }
}
```

A simple threads example

```
public interface Runnable {  // java.lang.Runnable
    public void run();
}

public static void main(String[] args) {
    int n = Integer.parseInt(args[0]);  // Number of threads;

    Runnable greeter = () -> System.out.println("Hi mom!");
    for (int i = 0; i < n; i++) {
        new Thread(greeter).start();
    }
}
```

A simple threads example

```
public interface Runnable {  // java.lang.Runnable
    public void run();
}

public static void main(String[] args) {
    int n = Integer.parseInt(args[0]);  // Number of threads;

    for (int i = 0; i < n; i++) {
        new Thread(() -> System.out.println("Hi mom!")).start();
    }
}
```

Aside: Anonymous inner class scope in Java

```
public interface Runnable {  // java.lang.Runnable
    public void run();
}

public static void main(String[] args) {
    int n = Integer.parseInt(args[0]);  // Number of threads;

    for (int i = 0; i < n; i++) {
        new Thread(() -> System.out.println("T" + i)).start();
    }
}
```

won't compile
because `i` mutates

Aside: Anonymous inner class scope in Java

```
public interface Runnable {  // java.lang.Runnable
    public void run();
}

public static void main(String[] args) {
    int n = Integer.parseInt(args[0]);  // Number of threads;

    for (int i = 0; i < n; i++) {
        int j = i;  // j unchanging within each loop
        new Thread(() -> System.out.println("T" + j)).start();
    }
}
```

j is *effectively final*

Threads for performance

- Generating cryptarithms from a 344-word corpus
  - Test all consecutive 3-word sequences: A + B = C   (342 possibilities)

Number of threads	Seconds to run
1	22.0
2	13.5
3	11.7
4	10.8

Shared mutable state requires synchronization

- If not properly synchronized, all bets are off!
- Three basic choices:
  1. **Don't mutate**: share only immutable state
  2. **Don't share**: isolate mutable state in individual threads
  3. If you must share mutable state: **synchronize properly**

The challenge of synchronization

- Not enough synchronization: *safety failure*
  - Incorrect computation
    - Changes aren't guaranteed to propagate thread to thread
    - Program can observe inconsistencies
    - Critical invariants can be corrupted
- Too much synchronization: *liveness failure*
  - No computation at all
    - Deadlock or other liveness failure

Today

- Observer pattern
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EVENT-BASED PROGRAMMING

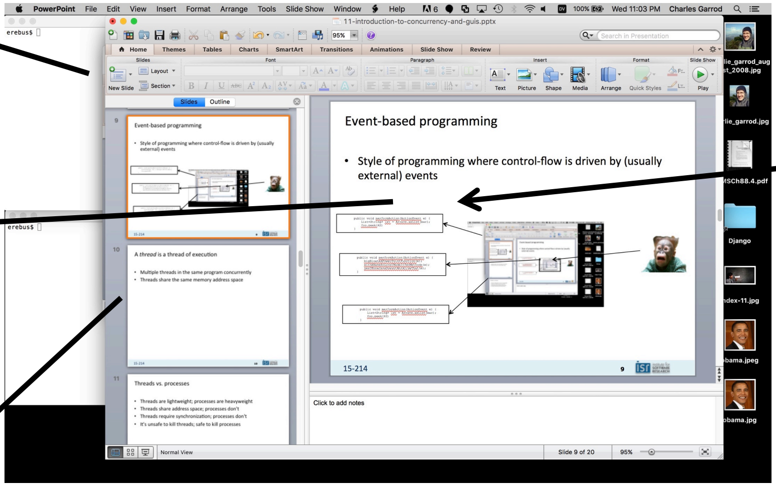
Event-based programming

- 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

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

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

Blocking interaction with command-line interfaces

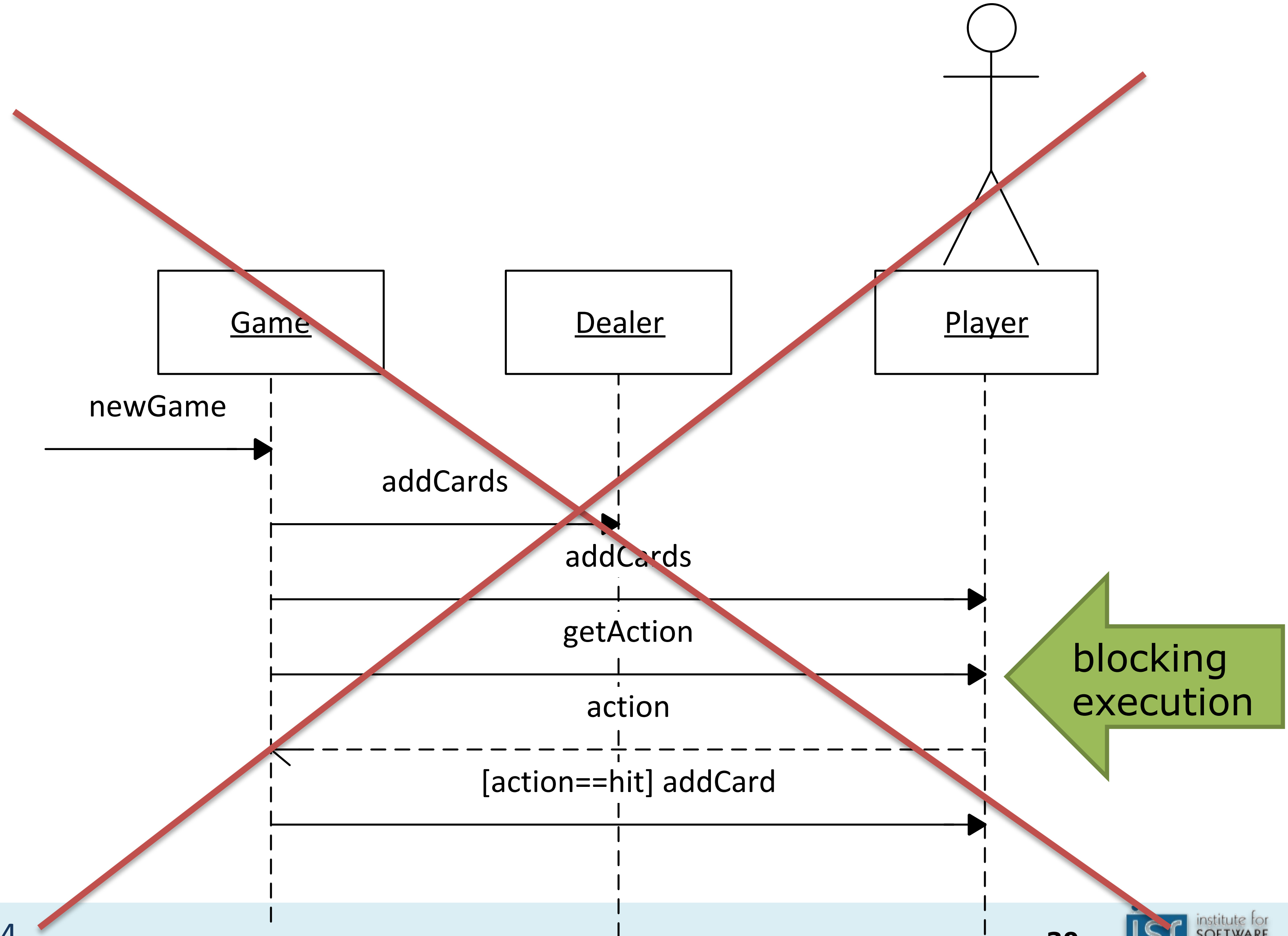
Terminal

File Edit View Search Terminal Help

```
scripts/kconfig/conf arch/x86/Kconfig
*
* Linux Kernel Configuration
*
*
* General setup
*
Prompt for development and/or incomplete code/drivers (EXPERIMENTAL) [Y/n/?]
Local version - append to kernel release (LOCALVERSION) []
Automatically append version information to the version string (LOCALVERSION_AUT
O) [N/y/?] y
Kernel compression mode
> 1. Gzip (KERNEL_GZIP)
  2. Bzip2 (KERNEL_BZIP2)
  3. LZMA (KERNEL_LZMA)
  4. LZO (KERNEL_LZO)
choice[1-4?]: 3
Support for paging of ano
System V IPC (SYSVIPC) [Y
POSIX Message Queues (POS
BSD Process Accounting (B
Export task/process stati
] y
  Enable per-task delay a
```

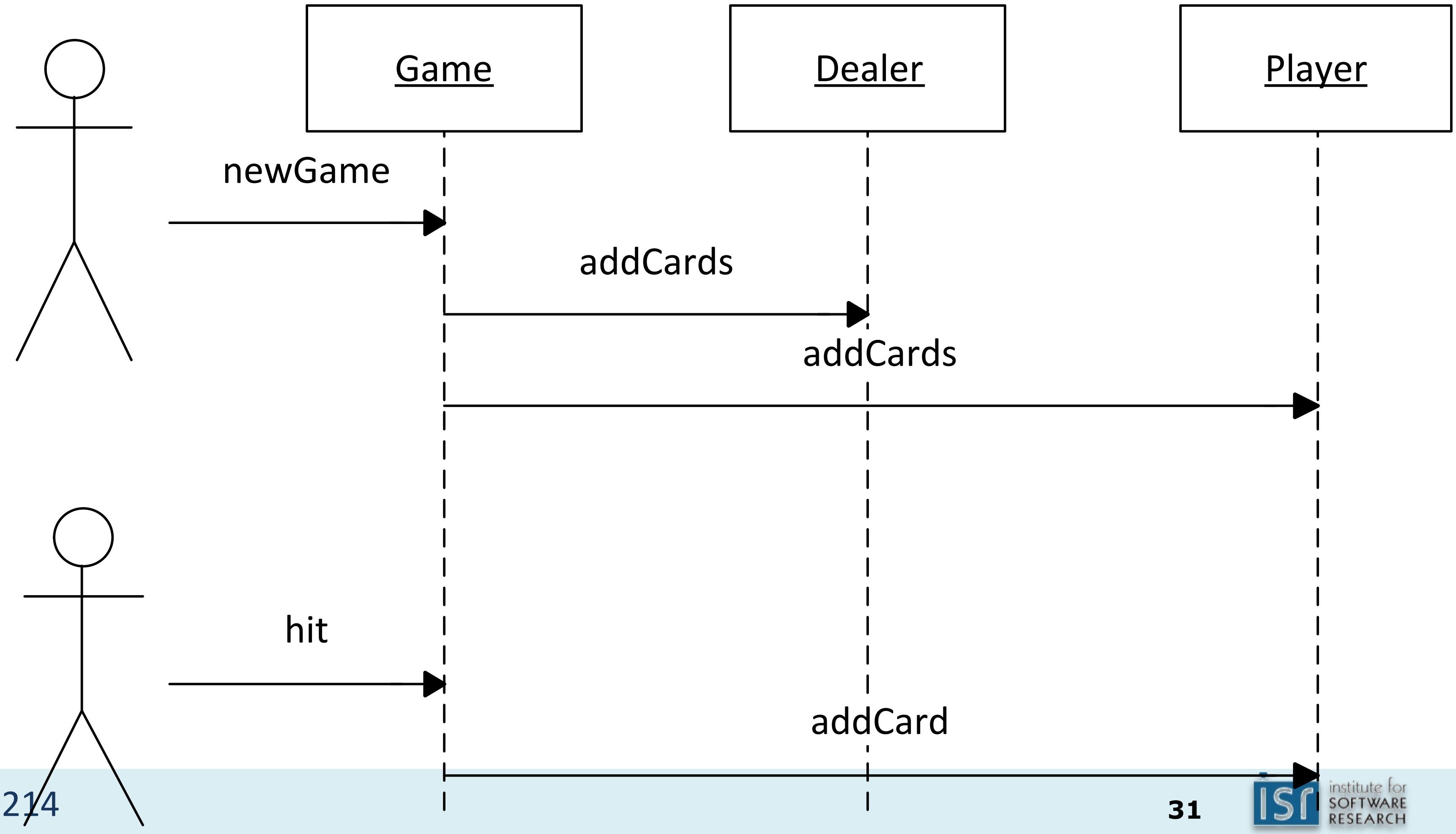
```java
Scanner input = new Scanner(System.in);
while (questions.hasNext()) {
      Question q = question.next();
      System.out.println(q.toString());
      String answer = input.nextLine();
      q.respond(answer);
}
```

Blocking interactions with users



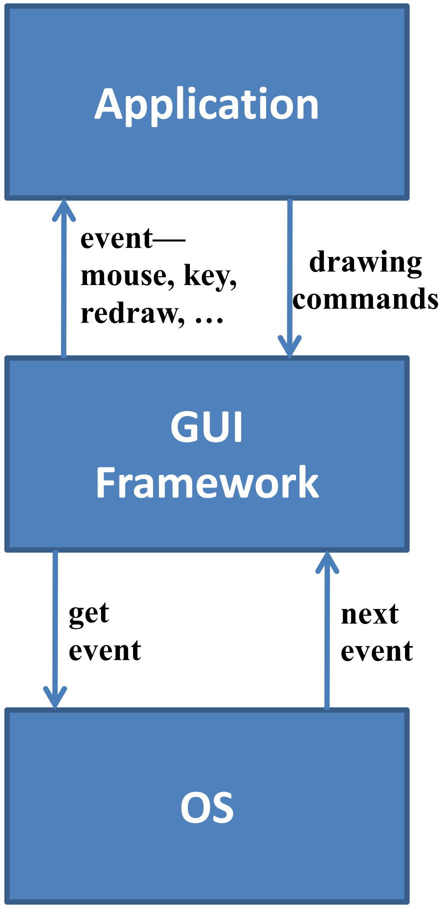
Interactions with users through events

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



An event-based GUI with a GUI framework

- Setup phase
  - Describe how the GUI window should look
  - Register observers to handle events
- Execution
  - Framework gets events from OS, processes events
    - Your code is mostly just event handlers



See edu.cmu.cs.cs214.rec06.alarmclock.AlarmWindow…

GUI PROGRAMMING

GUI frameworks in Java

- AWT – obsolete except as a part of Swing
- Swing – the most widely used, by far
- SWT – Little used outside of Eclipse
- JavaFX – Billed as a replacement for Swing
  - Released 2008 – has yet to gain traction
- A bunch of modern (web & mobile) frameworks
  - e.g., Android

GUI programming is inherently multi-threaded

- *Event-driven programming*
- Swing *Event dispatch thread* (EDT) handles all GUI events
  - Mouse events, keyboard events, timer events, etc.
- Program registers observers ("listeners")
- No other time-consuming activity allowed on the EDT
  - Violating this rule can cause liveness failures

Ensuring all GUI activity is on the EDT

- Violating this rule can cause safety failures
  - Never make a Swing call from any other thread
    - "Swing calls" include Swing constructors
- If not on EDT, make Swing calls with `invokeLater()`

Aside: `invokeLater`

```
public void actionPerformed(ActionEvent e)
{
  new Thread(new Runnable()
  {
    final String text = readHugeFile();
    SwingUtilities.invokeLater(new Runnable()
    {
      public void run()
      {
        textArea.setText(text);
      }
    });
  }).start();
}
```

https://alvinalexander.com/java/java-swingutilities-invoke-later-example-edt

Ensuring all GUI activity is on the EDT

- Violating this rule can cause safety failures
  - Never make a Swing call from any other thread
    - "Swing calls" include Swing constructors

- If not on EDT, make Swing calls with `invokeLater()`

- The code that initialises our GUI must also take place in an `invokeLater()`

```
public static void main(String[] args) {
    SwingUtilities.invokeLater(() -> new Test().setVisible(true));
}
```

Callbacks execute on the EDT

- You are a guest on the Event Dispatch Thread!
  - Don't abuse the privilege
- If you have more than a few ms of work to do, do it *off* the EDT
  - `javax.swing.SwingWorker` designed for this purpose

- Typical scenario:
  - long running task in a background thread
  - provide updates to the UI either when done, **or while processing**.

SwingWorker sample usage

```
final JLabel label;
class MeaningOfLifeFinder extends SwingWorker<String, Object> {
    @Override
    public String doInBackground() {
        return findTheMeaningOfLife();
    }

    @Override
    protected void done() {
        try {
            label.setText(get());
        } catch (Exception ignore) {
        }
    }
}

(new MeaningOfLifeFinder()).execute();
```

https://docs.oracle.com/javase/7/docs/api/javax/swing/SwingWorker.html

Components of a Swing application

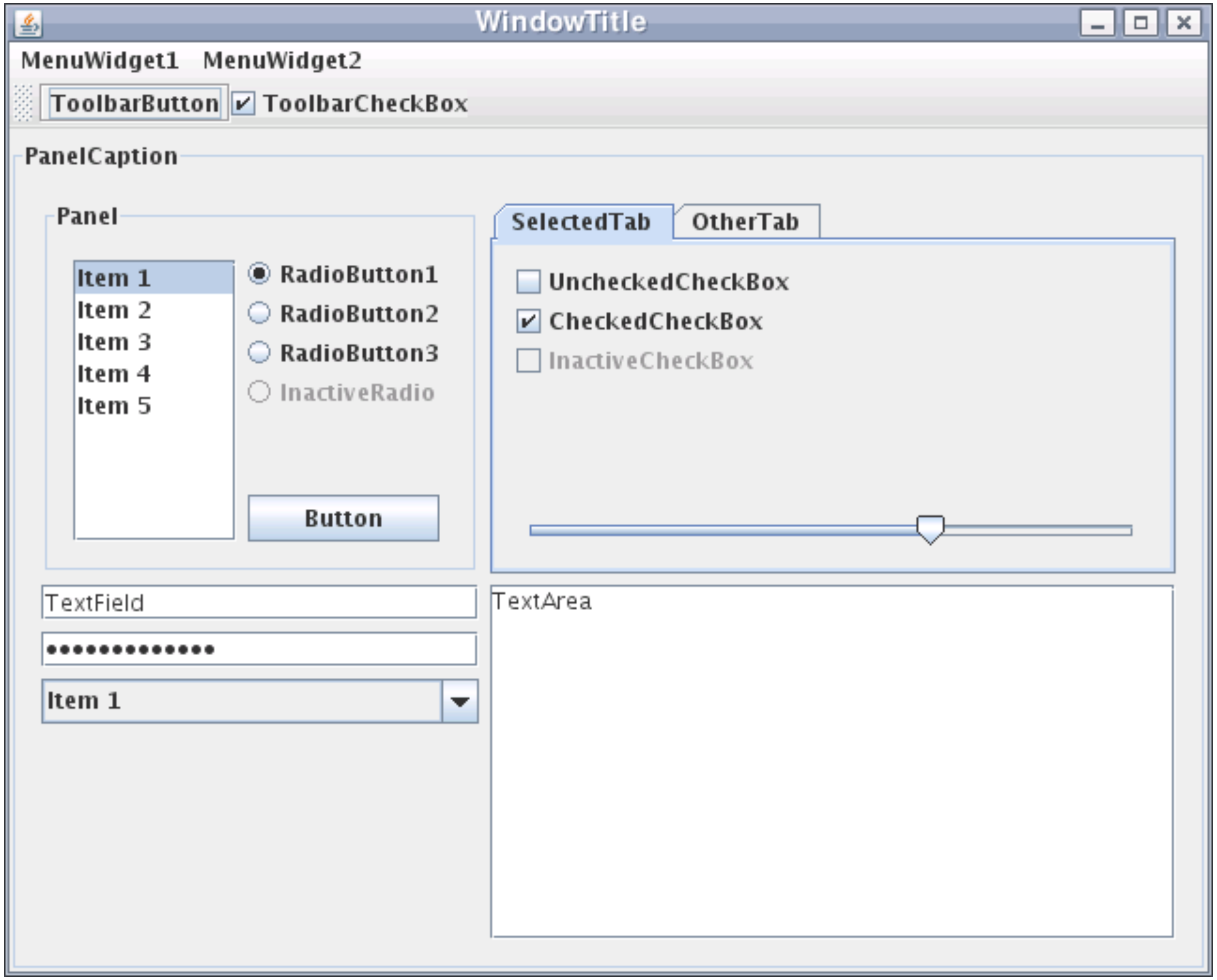
JFrame

JPanel

JButton

JTextField

…



Swing has many *widgets*

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

- `JFrame` is the Swing Window
- `JPanel` (a.k.a. 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…

E.g., 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);
```

panel to hold the button

register callback function

callback function implements ActionListener interface

E.g., creating a button

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

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

JButton button = new JButton(“Click me”);
button.addActionListener( (e) -> {
             System.out.println(“Button clicked");
});
panel.add(button);

window.setVisible(true);
```

panel to hold the button

register callback function

callback function implements ActionListener interface

The `javax.swing.ActionListener`

- Listeners are objects with callback functions
  - 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;
	…
}
```

Button 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`
- …

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

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

Summary: Swing constraints

- Time-consuming tasks should not be run on the *Event Dispatch Thread*. Otherwise the application becomes unresponsive.
- Swing components should be accessed on the *Event Dispatch Thread* only.

- Helpers: `invokeLater, SwingWorker`

For help writing Swing code

- Sun wrote a good tutorial
  - http://docs.oracle.com/javase/tutorial/uiswing/
- The many components shown with examples
  - http://docs.oracle.com/javase/tutorial/uiswing/components/componentlist.html
- Listeners supported by each component
  - http://docs.oracle.com/javase/tutorial/uiswing/events/eventsandcomponents.html

Summary

- Use the observer pattern to decouple two-way dependencies
- Multi-threaded programming is genuinely hard
  - Neither under- nor over-synchronize
  - Immutable types are your friend
- GUI programming is inherently multi-threaded
  - Swing calls must be made on the event dispatch thread
  - No other significant work should be done on the EDT