# Principles of Software Construction: Objects, Design, and Concurrency

## Introduction to concurrency and GUIs

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# Administrivia

- Reading due Tuesday: UML and Patterns 26.1 and 26.4
- Homework 4a due tonight
  - Homework 4a feedback coming next week
- Homework 4b due Thursday, March 25th
  - An aside: testing

# Key concepts from Tuesday

- Internal representations matter
- Good code is clean and concise
- Good coding habits matter

# Key concepts from yesterday's 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

- The observer pattern
- Introduction to concurrency
- Introduction to GUIs

# A *thread* is a thread of execution

- Multiple threads in the same program concurrently
- Threads share the same memory 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 are heavyweight
- Threads share address space; processes don't
- Threads require synchronization; processes don't
- 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

# 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*

# Example: generating cryptarithms

```
static List<String> cryptarithms(String[] words, int start, int end) {
    List<String> result = new ArrayList<>();
    String[] tokens = new String[] {"", "+", "", "=", ""};
    // Check if each adjacent triple in words is a "good" cryptarithm
    for (int i = start; i < end - 2; i++) {
        tokens[0] = words[i];
        tokens[2] = words[i + 1];
        tokens[4] = words[i + 2];
        try {
            Cryptarithm c = new Cryptarithm(tokens);
            if (c.solve().size() == 1)
                result.add(c.toString()); // We found a "good" one
        } catch (IllegalArgumentException e) {
            // too many letters in cryptarithm; ignore
        }
    }
    return result;
}
```

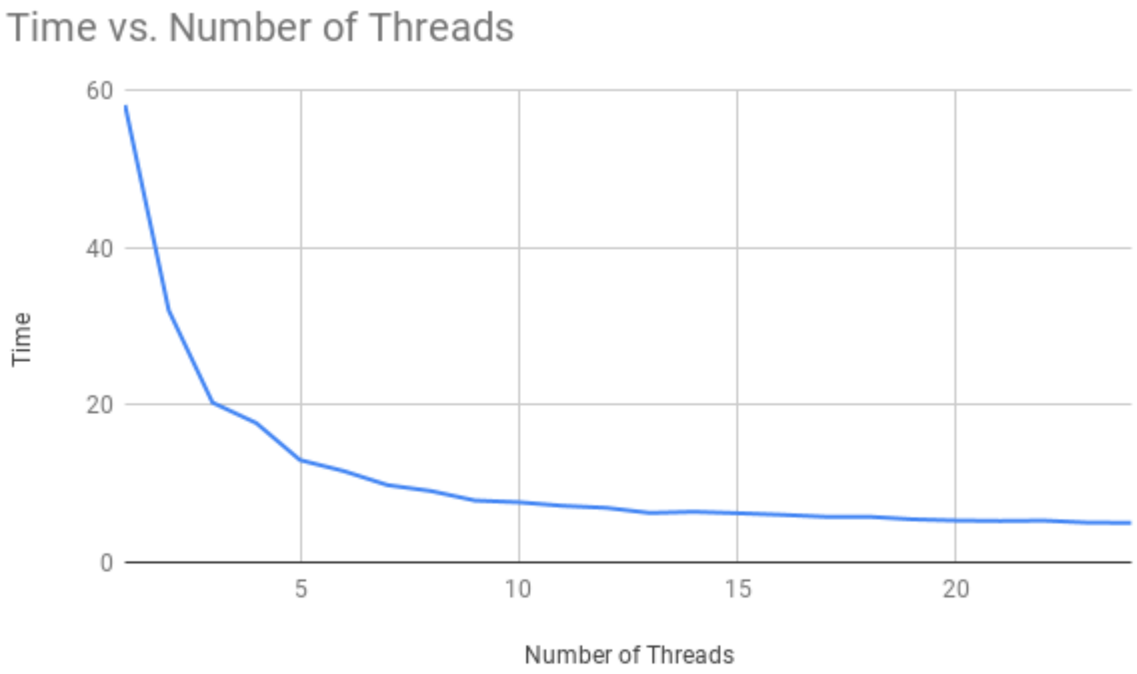
# Single-threaded driver

```
public static void main(String[] words) {
    Instant start = Instant.now();
    List<String> cryptarithms = cryptarithms(words, 0, words.length);
    Instant end = Instant.now();

    Duration time = Duration.between(start, end);
    System.out.printf("Time: %d ms%n", time.toMillis());
    System.out.println(cryptarithms);
}
```

# Multithreaded driver

```
public static void main(String[] args) throws InterruptedException {
    int n = Integer.parseInt(args[0]);  // Number of threads
    Instant startTime = Instant.now();
    String[] words = Arrays.copyOfRange(args, 1, args.length);
    int wordsPerThread = words.length / n;
    Thread[] threads = new Thread[n];
    Object[] results = new Object[n];
    for (int i = 0; i < n; i++) {  // Create the threads
        int start = i == 0 ? 0 : i * wordsPerThread - 2;
        int end = i == n-1 ? words.length : (i + 1) * wordsPerThread;
        int j = i; // Only constants can be captured by lambdas
        threads[i] = new Thread(() -> {
            results[j] = cryptarithms(words, start, end);
        });
    }
    for (Thread t : threads) t.start();
    for (Thread t : threads) t.join();
    Instant endTime = Instant.now();

    Duration time = Duration.between(startTime, endTime);
    System.out.printf("Time: %d ms%n", time.toMillis());
}
```

# Cryptarithm generation performance



Generating cryptarithms from *The Cat in the Hat* (1635 words)

- Test all consecutive 3-word sequences (1633 possibilities)
- 12 cores, 24 hyperthreads
- 1 thread: 58.1s, 24 threads 5.02s (11.6x faster)

# **Shared mutable state** requires synchronization

- 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
- Too much synchronization:  *liveness failure*
  - Possibly: No computation at all

# Synchronization in the cryptarithm example

- How did we avoid sync in multithreaded cryptarithm generator?
- *Embarrassingly parallelizable computation*
- Each thread is entirely independent of the others
  - They solve different cryptarithms…
  - And write results to different array elements
- No shared mutable state to speak of
  - Main thread implicitly synchronizes with workers using `join`

# Today

- The observer pattern
- Introduction to concurrency
- Introduction to GUIs

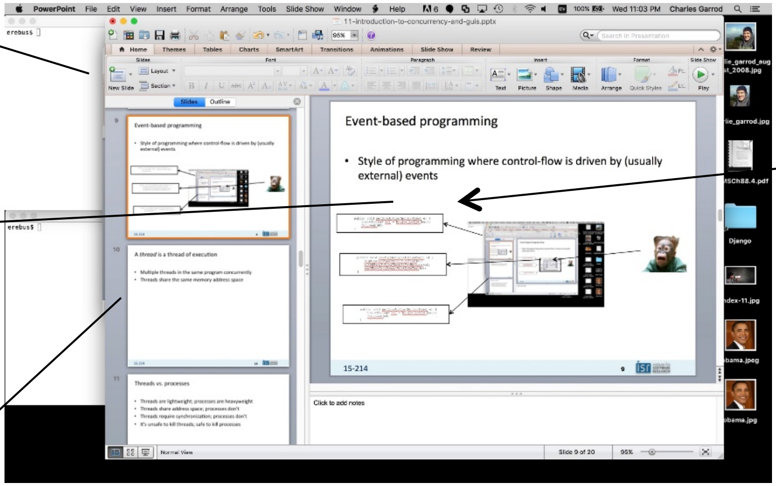
# Event-based programming

- 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)
}
```



Event-based programming

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15-214

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Threads vs. processes

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- Threads require synchronization; processes don't
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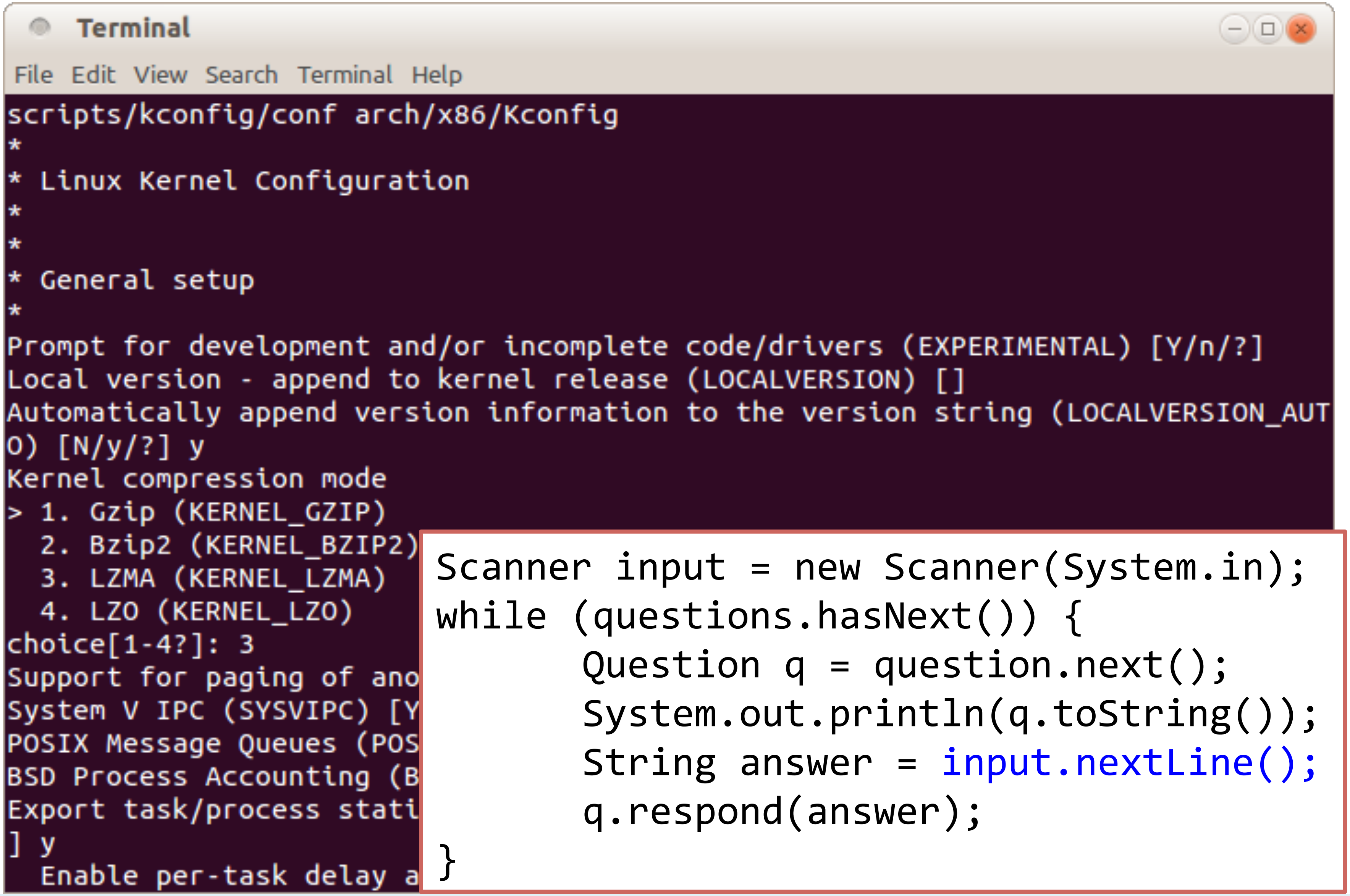
Click to add notes

# 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, …

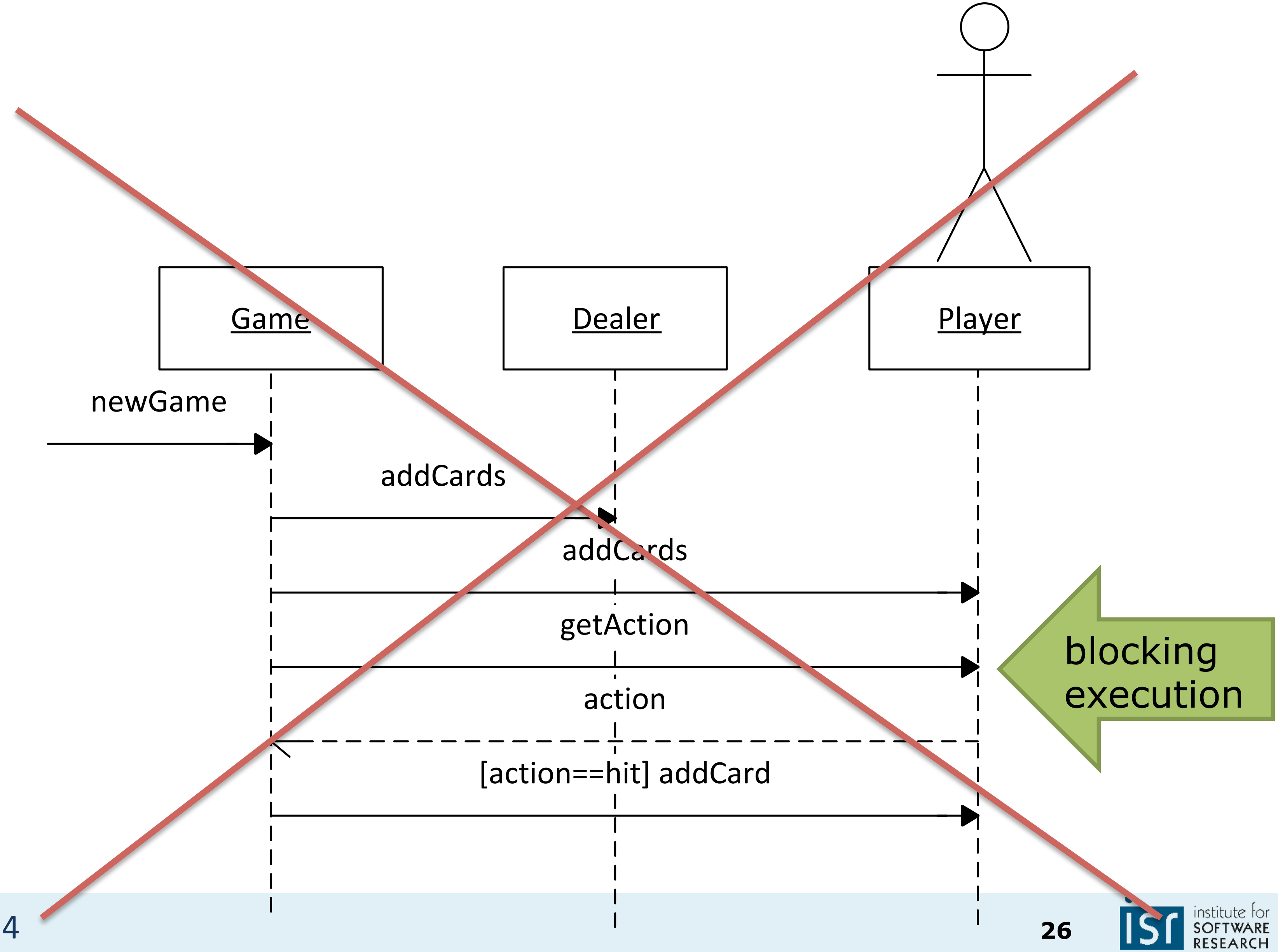
# Blocking interaction with command-line interfaces



```
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
```

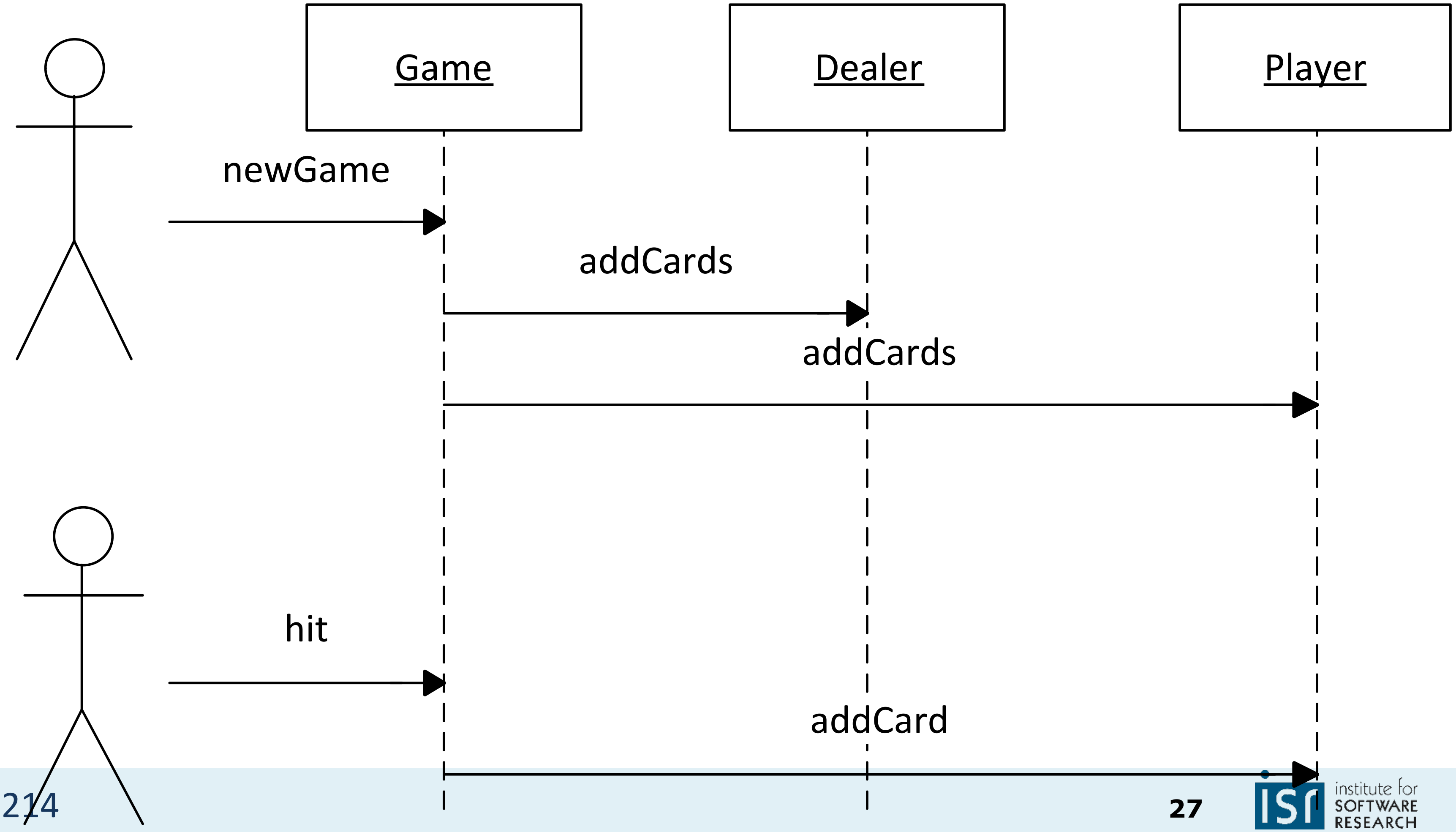
```
Scanner input = new Scanner(System.in);
while (questions.hasNext()) {
      Question q = question.next();
      System.out.println(q.toString());
      String answer = input.nextLine();
      q.respond(answer);
}
```

# Blocking interactions with users



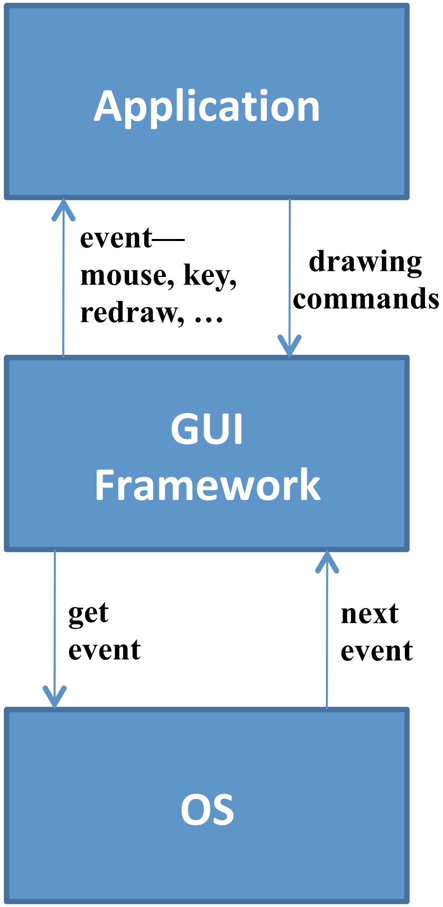
# Interactions with users through events

- 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 frameworks in Java

- AWT – obsolete except as a part of Swing
- Swing – widely used
- SWT – Little used outside of Eclipse
- JavaFX – Billed as a replacement for Swing
  - Released 2008 – never gained traction
- A bunch of modern (web & mobile) frameworks
  - e.g., Android

# GUI programming is inherently multi-threaded

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

# Ensuring all GUI activity is on the EDT

- Never make a Swing call from any other thread
  - "Swing calls" include Swing constructors
- If not on EDT, make Swing calls with `invokeLater`:

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

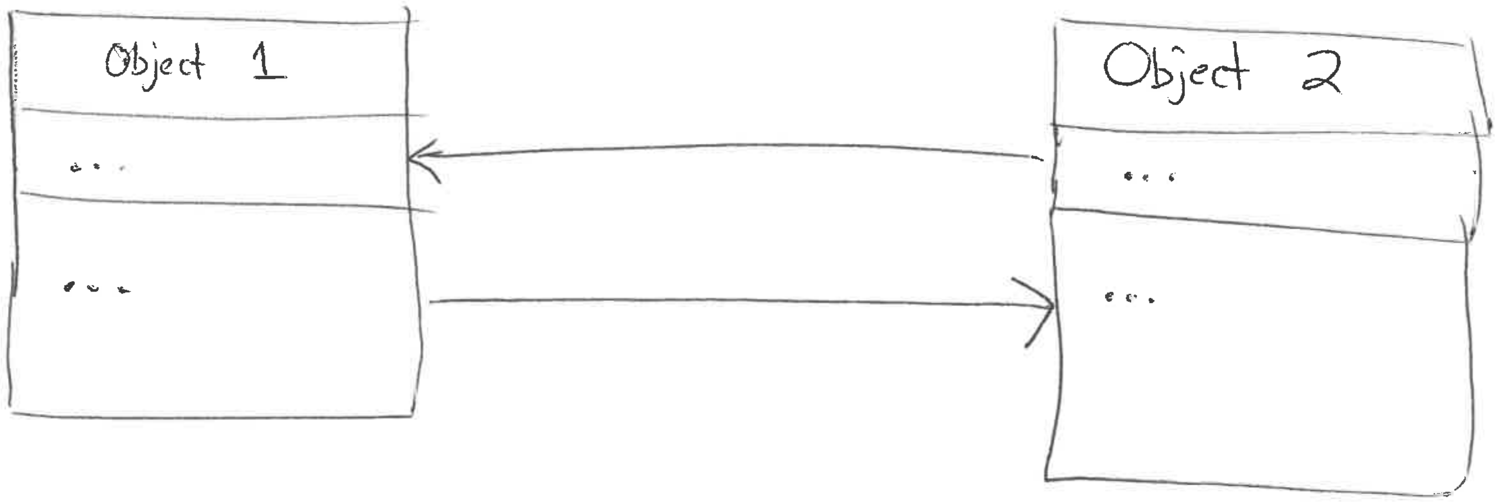
# Callbacks execute on the EDT

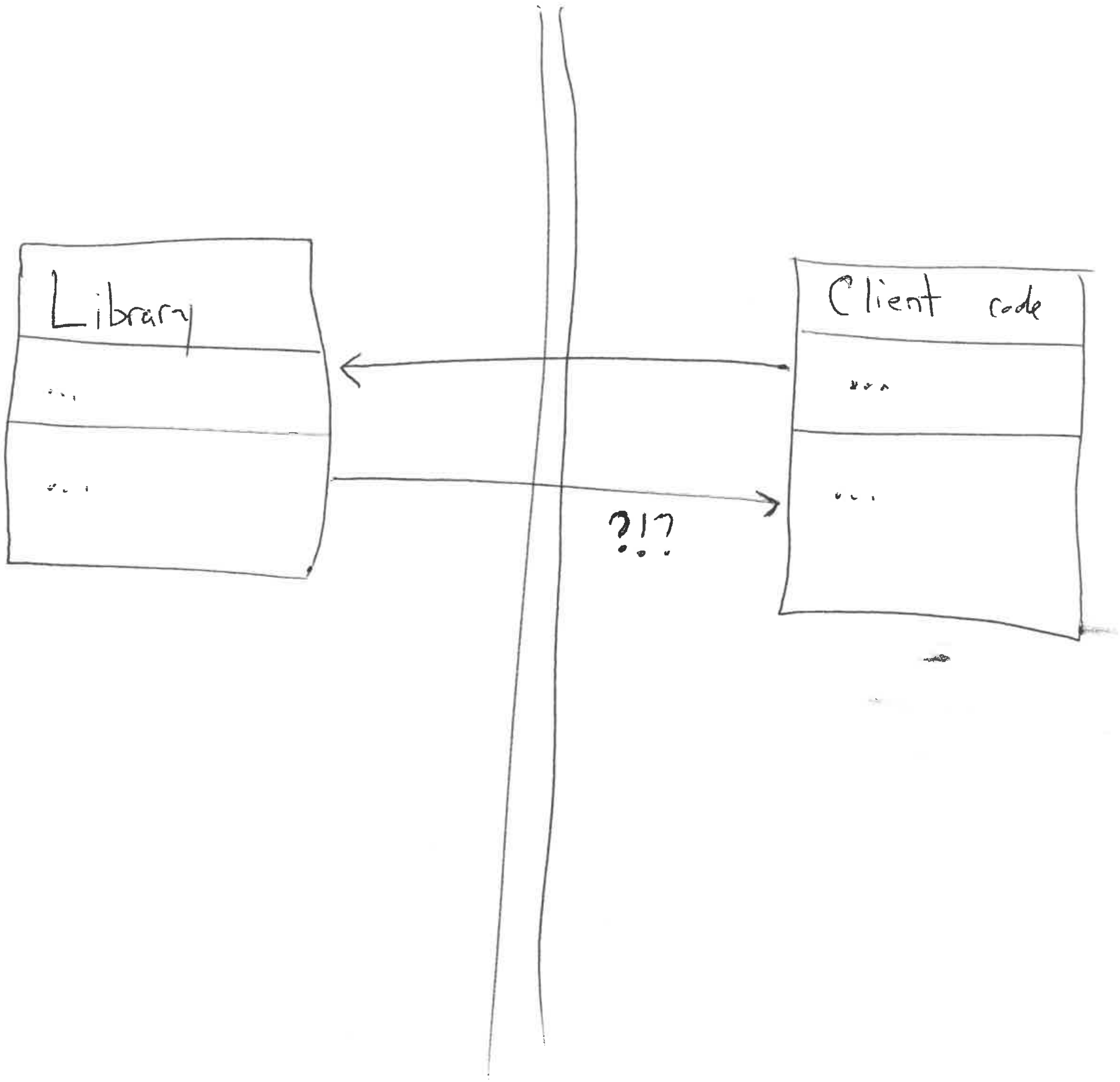
- You are a guest on the Event Dispatch Thread!
  - Don't abuse the privilege
- If > a few ms of work to do, do it *off* the EDT
  - `javax.swing.SwingWorker` designed for this purpose

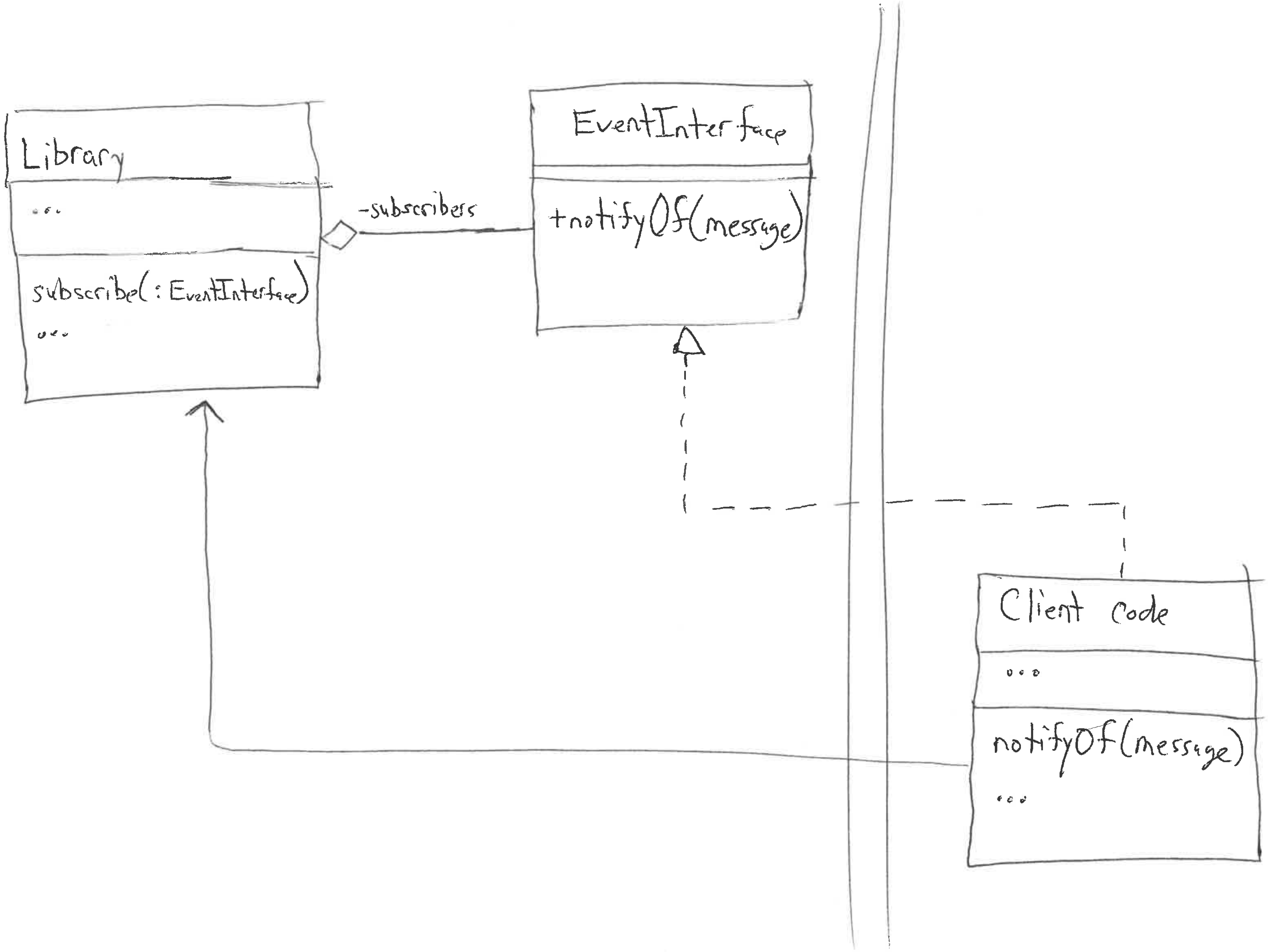
# Summary

- Use the observer pattern to decouple two-way dependences
- 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

# Paper slides from lecture are scanned below..


Object 1
...
...
Object 2
...
...


Library
...
...
Client code
...
...
?!?


Library
...
subscribe( : EventInterface)
...
-subscribers
EventInterface
+notifyOf(message)
Client code
...
notifyOf(message)
...