Principles of Software Construction: Objects, Design, and Concurrency

Concurrency: Safety & Immutability

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Today

- A bit more on GUIs
  - Why HTML?
  - Event Handling
- Concurrency Patterns
  - Immutability
  - Safety, liveness
  - Designing for Concurrency

Mini-Quiz

https://rb.gy/heh2ks

HTML: how did we get here?

- Up till Spring, this course leaned on Java Swing
  - Obviously not compatible with JS
  - But also, fading in support

Swing

Anyone know of an app using a Swing UI?

Components of a Swing application

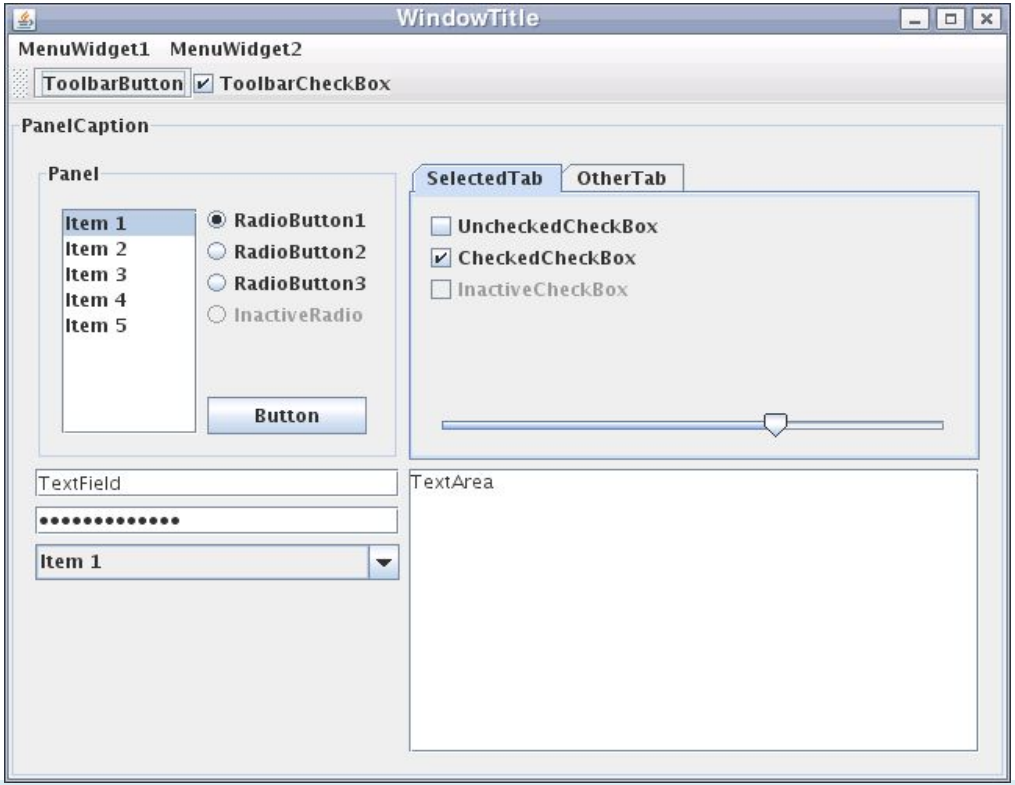
JFrame

JPanel

JButton

JTextField

...

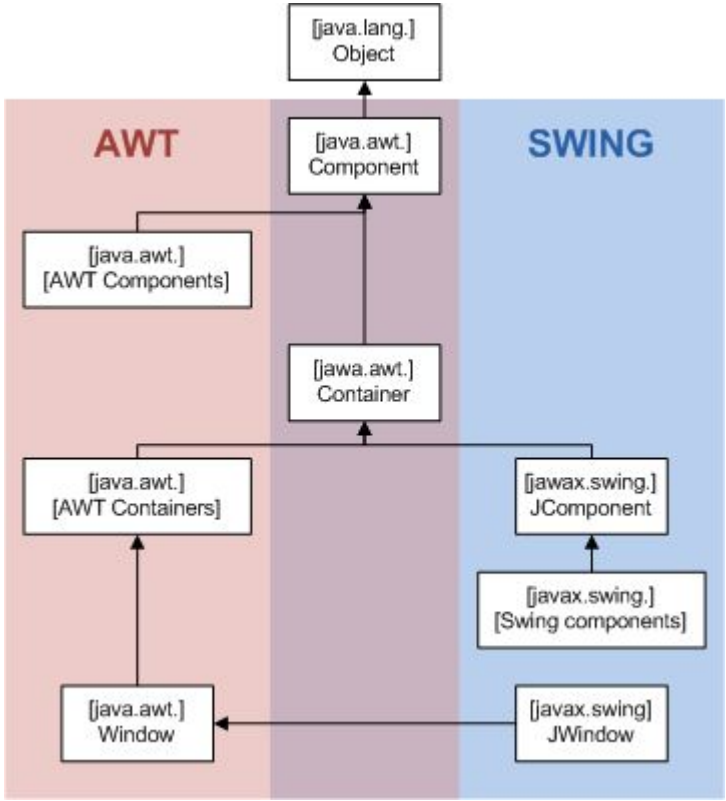


Quick Swing Demo

```java
import javax.swing.*;

public class SwingDemo extends JFrame {
    private final JButton b = new JButton();

    public SwingDemo() {
        super();
        this.setTitle("Swing Demo");
        this.setBounds( x: 100,  y: 100,  width: 180,  height: 140);
        this.add(makeButton());
        this.setVisible(true);
        this.setDefaultCloseOperation(EXIT_ON_CLOSE);
    }

    private JButton makeButton() {
        b.setText("Click me!");
        b.setBounds( x: 40,  y: 40,  width: 100,  height: 30);
        b.addActionListener(e -> JOptionPane.showMessageDialog(b,  message: "Hello World!"));
        return b;
    }

    public static void main(String[] args) throws InterruptedException, InvocationTargetException {
        // Swing calls must be run by the event dispatching thread.
        SwingUtilities.invokeAndWait(() -> new SwingDemo());
    }
}
```

So what is AWT doing here?

- Abstract Window Toolkit
  - The original Java UI
  - Wraps native code, so heavily platform-dependent



https://en.wikipedia.org/wiki/File:AWTSwingClassHierarchy.png

AWT

Why be platform-dependent?

Look and Feel

Eternal dilemma

- Platform-specific:
  - Better integration in terms of speed, appearance, features
- Platform-agnostic:
  - Broader deployment, more uniform experience
    - E.g., tablet, phone, computer, tv

Look and Feel

Eternal dilemma

- Platform-specific:
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- Platform-agnostic:
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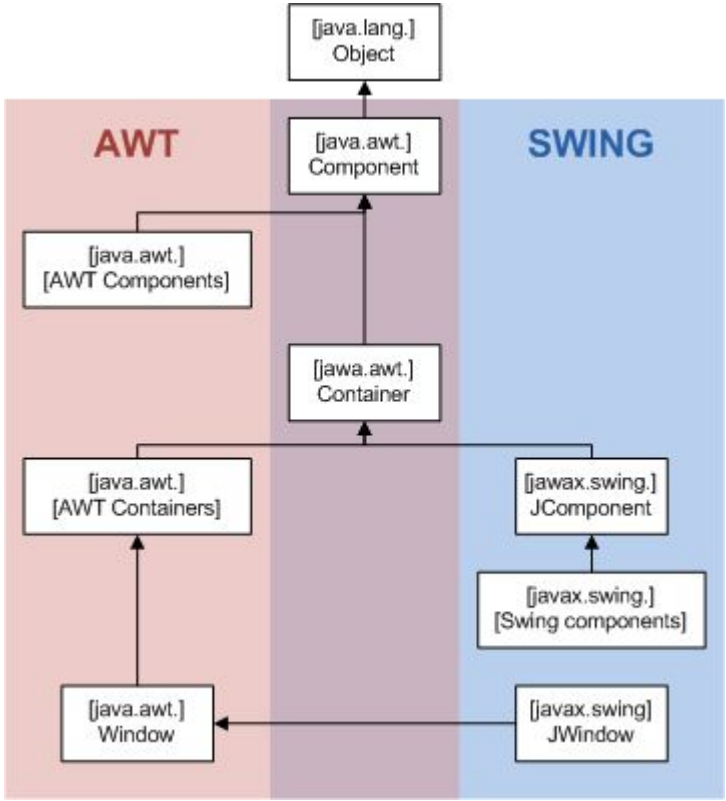
Which one is HTML+CSS?

So what is AWT doing here?

- To compare with Swing
  - Swing draws its own widgets
    - Using Java2D
  - Requires no native resources
- Swing still leans on AWT
  - So not quite “lightweight”



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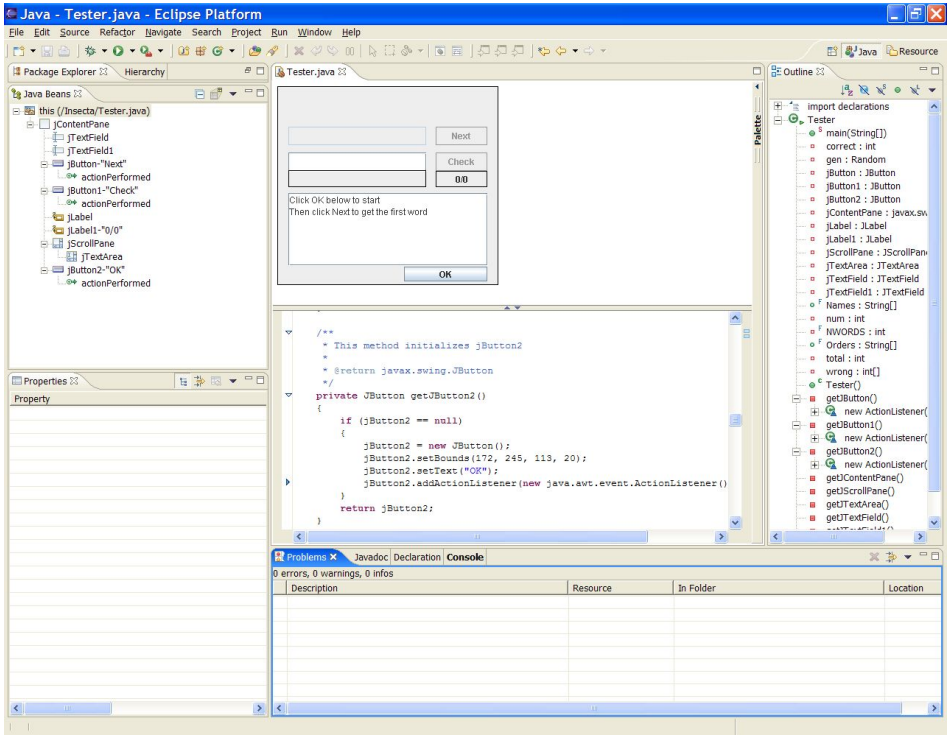
What about SWT?

- Powers Eclipse IDE
  - Developed by IBM
- Uses native code
  - Like AWT
  - But also provides own GUI code, when absent



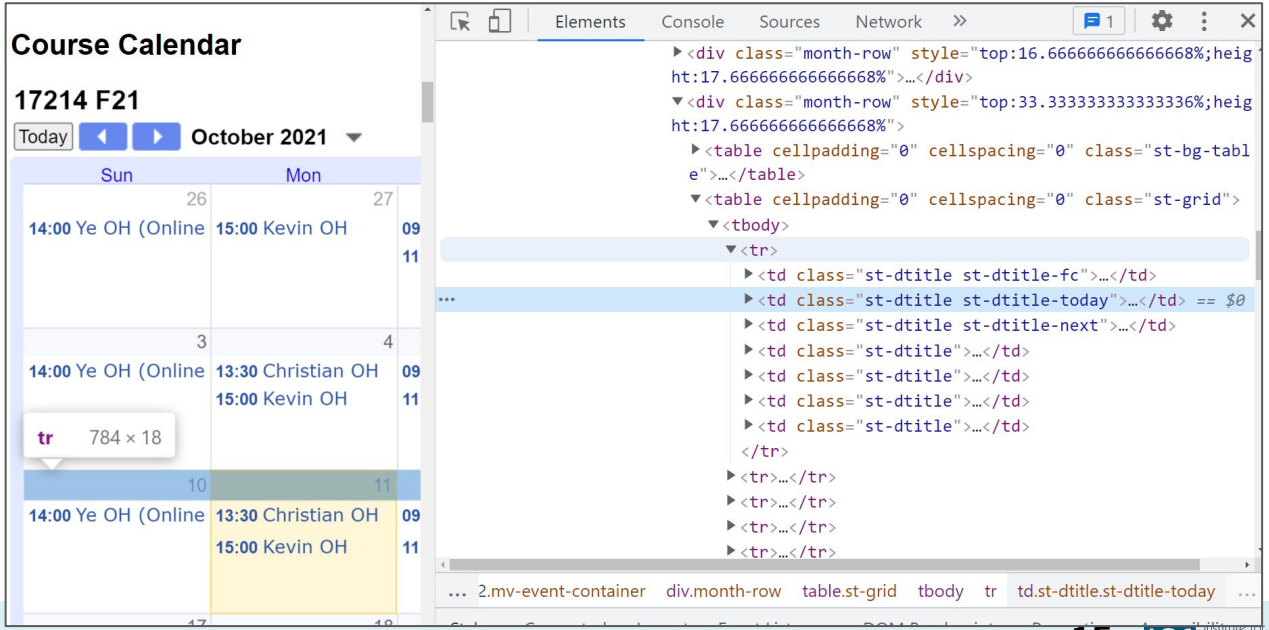
https://en.wikipedia.org/wiki/Standard_Widget_Toolkit#/media/File:EclipseScreenshot.png

Which One is Better?

- Perhaps a matter of preference
  - Benchmarks show no real performance diff. between Swing & SWT
- Then there's Android, iOS, various wrappers (e.g., One UI)
- Why does this matter?

HTML + CSS

- Once upon a time, a web-page specific language



HTML + CSS

- Grown into a general UI language
  - Involved some consolidation as recently as 2019
- Specifically, we are on HTML5
  - A “living standard”
  - Rich multimedia support, incl. SVG, video, audio, “canvas”

HTML + CSS

- Broadly adopted for GUI design
  - Including new settings, such as app development
    - E.g., with Cordova
  - Easy use with template engines
    - Like Handlebars

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Looping back to Event Loops

- Where are we “listening”?

```
private JButton makeButton() {
    b.setText("Click me!");
    b.setBounds( x: 40,  y: 40,  width: 100,  height: 30);
    b.addActionListener(e -> JOptionPane.showMessageDialog(b,  message: "Hello World!"));
    return b;
}
```

There’s a thread for that

- The **E**vent **D**ispatch **T**hread (EDT)
  - Job: wait and dispatch
  - For JS, which is single-threaded, involve an **Event Loop** (later)

There’s a thread for that

- The **E**vent **D**ispatch **T**hread (EDT)
  - Job: wait and dispatch
  - For JS, which is single-threaded, involve an **Event Loop** (later)
- This thread is pretty busy
  - Move your mouse, hit keys? It’s listening
  - For instance, Swing’s EDT calls `actionPerformed` to notify subscribers
  - It needs to handle things quickly or the UI blocks
    - So don’t waste its time!

There’s a thread for that

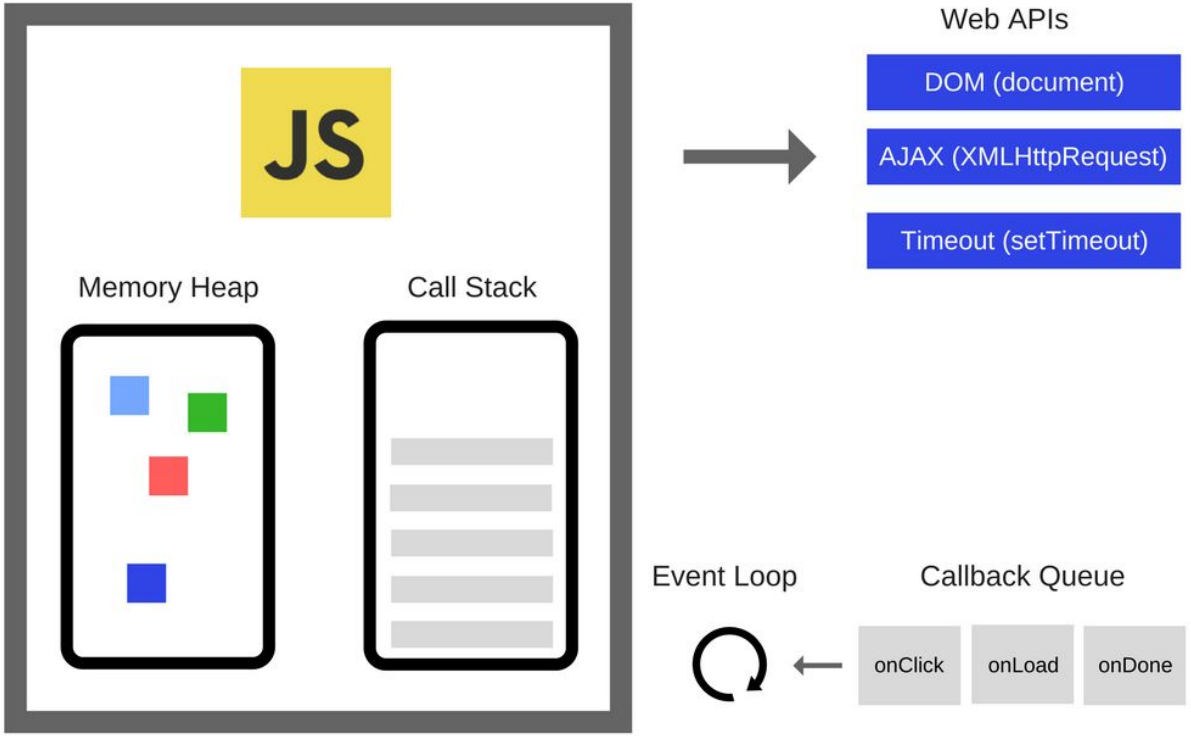
- This is why we `invokeAndWait`
  - Hand control of the task to Swing

```
    public static void main(String[] args) throws InterruptedException, InvocationTargetException {
        // Swing calls must be run by the event dispatching thread.
        SwingUtilities.invokeAndWait(() -> new SwingDemo());
    }
}
```

Event Loop

- At the heart, operates with a **queue**
  - Messages get added to the end
  - Oldest message are processed first
- In JS:
  - Waits *synchronously*
  - Executes each task *completely* without task-switching

Event Loop in JS



https://blog.sessionstack.com/how-javascript-works-event-loop-and-the-rise-of-async-programming-5-ways-to-better-coding-with-2f077c4438b5

Event Loop in JS

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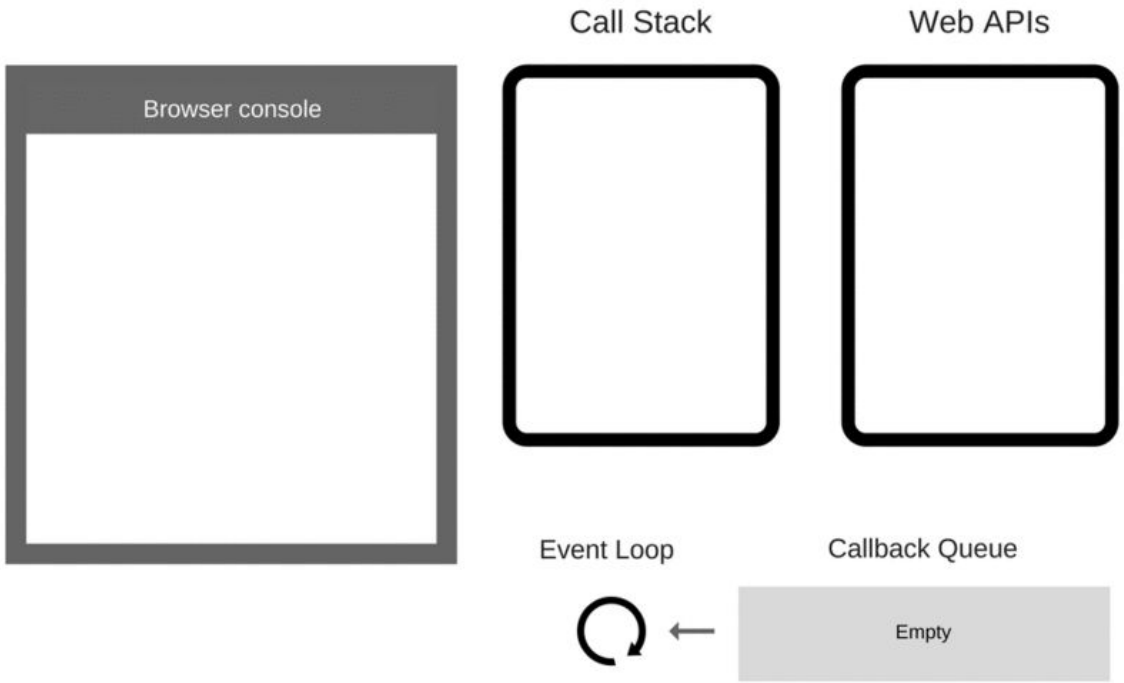

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Event Loops

- So JS **never blocks**
  - Meaning, the thread is never waiting to be granted power
    - (modulo rare exceptions)
  - Does that mean it is always responsive?

Event Loops

- So where do we do “heavy” work?

Event Loops

- So where do we do “heavy” work?
  - Chunk up slightly larger jobs
    - Allows other events to be handled in between
  - If we really need parallelism: WebWorkers
    - E.g., for rendering complex/large scenes
  - Ideally, move heavy work to the backend
    - A GUI shouldn’t be doing much work anyways

Event Loops

More on jobs and promises on Thursday

Forming Design Patterns

- We’ve seen:
  - Function-based dispatch (callbacks)
  - Using queues to manage asynchronous events
- Some of the building blocks of concurrent, distributed systems

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What if my Thread isn't Alone?

- Recall, in JS event loops:
  - Waiting is synchronous
  - Each message is processed fully without interruption
- What if we wanted multiple threads?
  - For parallelism
  - Multiple users on a website

What will Happen:

```
public class Synchronization {
    static long balance1 = 100;
    static long balance2 = 100;

    public static void main(String[] args) throws InterruptedException {
        Thread thread1 = new Thread(Synchronization::from1To2);
        Thread thread2 = new Thread(Synchronization::from2To1);

        thread1.start(); thread2.start();
        thread1.join(); thread2.join();
        System.out.println(balance1 + ", " + balance2);
    }

    private static void from1To2() {
        for (int i = 0; i < 10000; i++) {
            balance1 -= 100;
            balance2 += 100;
        }
    }

    private static void from2To1() {
        for (int i = 0; i < 10000; i++) {
            balance2 -= 100;
            balance1 += 100;
        }
    }
}
```

What will Happen:

Where does this fail?

What if single threaded?

Could we make it work with 2 threads?

```
public class Synchronization {
    static long balance1 = 100;
    static long balance2 = 100;

    public static void main(String[] args) throws InterruptedException {
        Thread thread1 = new Thread(Synchronization::from1To2);
        Thread thread2 = new Thread(Synchronization::from2To1);

        thread1.start(); thread2.start();
        thread1.join(); thread2.join();
        System.out.println(balance1 + ", " + balance2);
    }

    private static void from1To2() {
        for (int i = 0; i < 10000; i++) {
            balance1 -= 100;
            balance2 += 100;
        }
    }

    private static void from2To1() {
        for (int i = 0; i < 10000; i++) {
            balance2 -= 100;
            balance1 += 100;
        }
    }
}
```

Atomicity

Competing access needs to be managed.

```
public class Synchronization {
    static AtomicInteger balance1 = new AtomicInteger( initialValue: 100);
    static AtomicInteger balance2 = new AtomicInteger( initialValue: 100);

    public static void main(String[] args) throws InterruptedException {
        Thread thread1 = new Thread(Synchronization::from1To2);
        Thread thread2 = new Thread(Synchronization::from2To1);

        thread1.start(); thread2.start();
        thread1.join(); thread2.join();
        System.out.println(balance1 + ", " + balance2);
    }

    private static void from1To2() {
        for (int i = 0; i < 10000; i++) {
            balance1.getAndAdd( delta: -100);
            balance2.getAndAdd( delta: 100);
        }
    }

    private static void from2To1() {
        for (int i = 0; i < 10000; i++) {
            balance1.getAndAdd( delta: 100);
            balance2.getAndAdd( delta: -100);
        }
    }
}
```

Atomicity

Competing access needs to be managed.

- Atomic operations take place as a single unit
  - `getAndAdd` == read and write -- nobody else gets to touch it.
  - Is `balance++` atomic?
  - How about `pauseThread = true`

How to Prevent Competing Access?

- Any other ideas?

How to Prevent Competing Access?

- Any other ideas?
  - Don’t have state!
  - Don’t have shared state!
  - Don’t have shared mutable state!

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  - **Immutability**
  - Safety, liveness
  - Designing for Concurrency

Immutability

- A key principle in design, not just for concurrency
  - Inherently Thread-safe
  - No risks in sharing
  - Can make things very simple

Ensuring Immutability

- Don’t provide any mutators
- Ensure that no methods may be overridden
- Make all fields final
- Make all fields private
- Ensure security of any mutable components

Immutability

What if you need to make a change?

Immutability

What if you need to make a change?

```
function newGame(board: Board, nextPlayer: Player, history: Game[]): Game {
    return {
        board: board,
        play: function (x: number, y: number): Game {
            if (board.getCell(x,y)!==null) return this
            if (this.getWinner()!==null) return this
            const newHistory = history.slice()
            newHistory.push(this)
            return newGame(
                board.updateCell(x, y, nextPlayer),
                1 - nextPlayer,
                newHistory)
        },
```

https://github.com/CMU-17-214/rec07-gui/blob/7e9f9202f22d3e015a1f7dd422794834f3386d4d/ts-express/src/game.ts

Immutability

What functionality was made really easy by this design?

```
function newGame(board: Board, nextPlayer: Player, history: Game[]): Game {
    return {
        board: board,
        play: function (x: number, y: number): Game {
            if (board.getCell(x,y)!==null) return this
            if (this.getWinner()!==null) return this
            const newHistory = history.slice()
            newHistory.push(this)
            return newGame(
                board.updateCell(x, y, nextPlayer),
                1 - nextPlayer,
                newHistory)
        },
```

Making a Class Immutable

```
public final class Complex {
    private final double re, im;

    public Complex(double re, double im) {
        this.re = re;
        this.im = im;
    }

    // Getters without corresponding setters
    public double getRealPart()      { return re; }
    public double getImaginaryPart() { return im; }

    // subtract, multiply, divide similar to add
    public Complex add(Complex c) {
        return new Complex(re + c.re, im + c.im);
    }
```

Immutability

Any disadvantages?

Immutability

Any disadvantages?

```
String x = "It was the best of times, ..."; // An entire book.

x += "The end.";
```

Immutability

Any disadvantages?

```
String x = "It was the best of times, ..."; // An entire book.
x += "The end.";
```

- Provide mutable helpers (e.g. StringBuilder).
- Bundle common actions

Designing for Immutability

In short: make things immutable unless you really can’t

- Especially, smaller data-classes
- Not realistic for classes whose state naturally changes
  - BankAccount: return a new account for each transaction?
  - In that case, minimize mutable part

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  - **Safety, liveness**
  - Designing for Concurrency

Thread Safety

- Let’s define what we want:
  - **Thread safe** means no assumptions required to operate correctly with multiple threads.
  - Why was the earlier example not thread-safe?

Thread Safety

- Let's define what we want:
  - **Thread safe** means no assumptions required to operate correctly with multiple threads.
  - Why was the earlier example not thread-safe?
- If a program is not thread-safe, it can:
  - Corrupt program state (as before)
  - Fail to properly share state (cause liveness failure)
  - Get stuck in infinite mutual waiting loop (deadlock)

Back to: Atomicity

- Recall: atomic operations take place as a single unit
  - Read and write -- nobody else gets to touch it.
- Is atomicity sufficient for thread-safety?

Liveness Failure

```
public class LivenessFailure {

    private static boolean stopRequested;

    public static void main(String[] args) throws InterruptedException {
        Thread backgroundThread = new Thread(new Runnable() {
            public void run() {
                int i = 0;
                while (!stopRequested) {
                    i++;
                }
            }
        });
        backgroundThread.start();
        TimeUnit.SECONDS.sleep( timeout: 1);
        stopRequested = true;
    }
}
```

Back to: Atomicity

- Recall: atomic operations take place as a single unit
  - Read and write -- nobody else gets to touch it.
- Is atomicity sufficient for thread-safety?
  - No. Shared memory is complicated

Shared State

- *Volatile* fields always return the most recently written value
  - Does not guarantee atomicity
  - Useful if only one thread writes

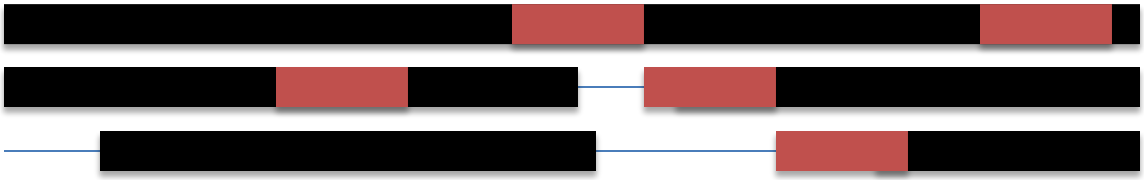
```
public class VolatileExample {
    private static volatile long nextSerialNumber = 0;

    public static long generateSerialNumber() {
        return nextSerialNumber++;
    }

    public static void main(String[] args) throws InterruptedException {
        Thread threads[] = new Thread[5];
        for (int i = 0; i < threads.length; i++) {
            threads[i] = new Thread(() -> {
                for (int j = 0; j < 1_000_000; j++)
                    generateSerialNumber();
            });
            threads[i].start();
        }
        for(Thread thread : threads)
            thread.join();
        System.out.println(generateSerialNumber());
    }
}
```

Shared State

- *Volatile* fields always return the most recently written value
  - Does not guarantee atomicity
  - Useful if only one thread writes
- Are atomicity + coordinated communication sufficient for thread safety?

Synchronization

- Safe Communication + Exclusion
  - Requires a lock. In Java, tied to an object instance.
  - Complete ownership of resource, no caching risks.
  - Can make parallelism quite slow!



Back to “Blocking”

- Why does JS not have these issues?
  - Atomicity? Shared Reality? Safety?

Back to “Blocking”

- Why does JS not have these issues?
  - Atomicity: no thread can interrupt an action
    - The event loop completely finishes each task
  - Shared reality: no concurrent reads possible
    - Single-threaded by design
  - Safety: obvious.
- But, more burden on developers!

Is Threading all Bad?

- Not at all!
  - Obviously useful for parallelism and asynchronous I/O
  - But also, we can have **good design**.
- Threads map to tasks
  - Commonly assign one thread per task
  - Convenient abstract for handling large workloads
- Help manage complex event loops
  - Message passed from one handle to another in single-threaded envs.
    - See ‘promises’ on Thursday

Synchronization

There is a lot more to discuss

- How to synchronize, avoid deadlocks
- Active vs. passive waiting

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  - **Designing for Concurrency**

Forming Design Patterns

- We've seen:

  Concurrency strategies:

  - Function-based dispatch (callbacks)
  - Using queues to manage asynchronous events

  Thread-safety strategies:

  - Immutability where possible
  - Synchronization on mutable state

Forming Design Patterns

- We've not yet talked about:
  - Handling complex/multiple callbacks
    - Promises, Async/await
  - Guarding entire objects
    - Concurrency Encapsulation
  - Managing consumers & producers
    - Coupling, performance

Designing with Concurrency in Mind

- More on Thursday

Summary

- Event Loops require a different attitude
  - Avoid heavy lifting; think about blocking
  - More on Thursday
- Concurrency comes with some head-aches
  - Shared state is very complicated. Avoid it entirely!
  - Or synchronize well -- steep learning curve.
- Thursday:
  - “Callback hell” and why we need promises
  - Bits on React

HW4 Effort

https://rb.gy/qyjpof