Introduction to Concurrency

4010-441
Principles of Concurrent System Design
Logistics (On myCourses)

Texts

- *Java Concurrency in Practice*, Brian Goetz, et. al.
- *Programming Concurrency on the JVM*, Venkat Subramaniam.

Rough Calendar

- 4 weeks on controlling shared, mutable state + 1 exam + project
- 2 weeks on actors + 1 exam + project
- 1.5 weeks on (software) transactional memory
- 1.5 weeks on classic concurrency problems
- 1 week on other approaches to concurrency
Grading

• (5%) Preparation & Presentation
• (15%) Activities (2-3 persons for a week or less)
• (30%) Two projects (15% lowest each)
• (30%) Two in-class exams (15% each)
• (20%) Final exam in finals week
Projects

• 4-5 persons for 2+ weeks
• I'll pick the teams
• You'll have an opportunity to assess the contributions of your teammates via Peer2Peer.
• Individual grade is team grade, adjusted as appropriate based on peer evaluations.

Activities

• 2-3 persons for <= 1 week
• I'll pick the teams - sub-teams of projects where feasible
• Always traded on a 10 point basis
Preparation & Participation

• Do the readings before the specified due date
• I'll consider participation in answering questions and engaging in discussions.
• In participating in discussions, I will *never* penalize you for a “wrong” answer (unless you're flippant).
• Woody Allen: 80% of success is showing up.
Now on to the good stuff!
What Is "Concurrency?"
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What Is a Process?
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What Is a Thread?
What Is “Concurrency?”

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A process has a self-contained execution environment. A process generally has a complete, private set of basic run-time resources; in particular, each process has its own memory space.

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What Is a Thread?

Threads exist within a process — every process has at least one. Threads share the process's resources, including memory and open files. This makes for efficient, but potentially problematic, communication.
The Promises of Concurrency

• Original (OS centric processes)
  – Better resource utilization.
  – Fairness among multiple users with multiple computations.
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• Current (process centric threads)
  – Exploiting multiple processors
  – Modeling: Divide & conquer on loosely related tasks.
  – Simplify handling asynchronicity (e.g., mouse events)
  – Throughput (even on single CPU systems)
  – Responsiveness
The Perils of Concurrency

- Safety: Nothing bad happens
  - Incorrect behavior in context of concurrency
  - Race conditions
  - Memory barrier (caching)
  - Overly optimistic compiler optimizations
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  – One or more threads cannot make progress
  – Deadlock
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• Fairness: Let's share, boys and girls
  – Starvation
  – Livelock
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• Performance
  – TANSTAAFL (There Ain’t No Such Thing As A Free Lunch)
  – Context switching overhead
  – Disabled compiler optimizations
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- **Testing, hair-pulling, and Heisenbugs**
The Perils of Concurrency

• 1985-1987 -- **Therac-25 medical accelerator.** A radiation therapy device malfunctions and delivers lethal radiation doses at several medical facilities. Based upon a previous design, the Therac-25 was an "improved" therapy system that could deliver two different kinds of radiation: either a low-power electron beam (beta particles) or X-rays. The Therac-25's X-rays were generated by smashing high-power electrons into a metal target positioned between the electron gun and the patient. A second "improvement" was the replacement of the older Therac-20's electromechanical safety interlocks with software control, a decision made because software was perceived to be more reliable.

• What engineers didn't know was that both the 20 and the 25 were built upon an operating system that had been kludged together by a programmer with no formal training. Because of a subtle bug called a "race condition," a quick-fingered typist could accidentally configure the Therac-25 so the electron beam would fire in high-power mode but with the metal X-ray target out of position. At least five patients die; others are seriously injured.

(Source: “History's Worst Software Bugs”, Wired)
The Ultimate Culprit - Shared, Mutable State

• Most of your development has been in imperative languages.
• The fundamental operation is assignment to change state.
  – Assignable variables are mutable.
  – May be exposed as public (bad karma).
  – May be exposed via interface methods (medium warm karma).
  – Things get tricky very fast when > 1 thread can invoke a mutating function.
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```java
public class Counter {
    private int count = 0;

    public void increment() {
        count = count + 1;
    }

    public int getCount() {
        return count;
    }
}
```

If we call `increment()` 10,000 times and then call `getCount()`, what value is returned?
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• Three basic approaches:
  – Make things immutable.
  – Hide shared state behind sequential access.
  – Provide mechanisms to support controlled access to shared, mutable state.
Other Issues

• Thread management
  – How many threads at one time?
  – Allocation of tasks to threads.
  – Thread scheduling.

• Higher level constructs
  – Fork / join
  – Callables & Futures

• Distributed state management
  – State consistency
  – Decision consensus