Principles of Software Construction: Objects, Design, and Concurrency

Part 42: Concurrency

Introduction to concurrency

Josh Bloch **Charlie Garrod** Darya Melicher

Carnegie Mellon University
School of Computer Science

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Administrivia

- Homework 5 team sign-up deadline tonight
  - Team sizes, presentation slots, …
- Midterm exam in class Thursday (November 1st)
  - Review session today 7-9 p.m. Porter Hall 100
- Next required reading due Tuesday
  - Java Concurrency in Practice, Sections 11.3 and 11.4
- Homework 5 frameworks discussion

Today

- Some puzzlers
- API design conclusions
- Introduction to concurrency

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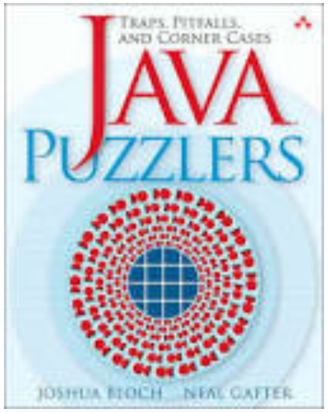
1. "Time for a Change" (2002)

If you pay $2.00 for a gasket that costs $1.10, how much change do you get?

```
public class Change {
    public static void main(String args[]) {
        System.out.println(2.00 - 1.10);
    }
}
```



What does it print?

(a) `0.9`
(b) `0.90`
(c) It varies
(d) None of the above

```
public class Change {
    public static void main(String args[]) {
        System.out.println(2.00 - 1.10);
    }
}
```

What does it print?

(a) `0.9`

(b) `0.90`

(c) It varies

(d) None of the above: `0.8999999999999999`

Decimal values can't be represented exactly by `float` or `double`

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Another look

```
public class Change {
    public static void main(String args[]) {
        System.out.println(2.00 - 1.10);
    }
}
```

How do you fix it?

```
// You could fix it this way...
import java.math.BigDecimal;
public class Change {
    public static void main(String args[]) {
        System.out.println(
            new BigDecimal("2.00").subtract(
                new BigDecimal("1.10")));
    }
}
```

Prints 0.90

```
// ...or you could fix it this way
public class Change {
    public static void main(String args[]) {
        System.out.println(200 - 110);
    }
}
```

Prints 90

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The moral

- Avoid `float` and `double` where exact answers are required
  - For example, when dealing with money
- Use `BigDecimal`, `int`, or `long` instead

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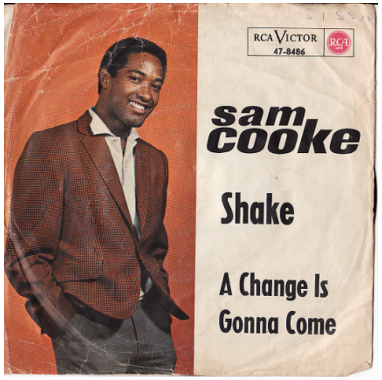
2. "A Change is Gonna Come"



If you pay $2.00 for a gasket that costs $1.10, how much change do you get?

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal(2.00);
        BigDecimal cost = new BigDecimal(1.10);
        System.out.println(payment.subtract(cost));
    }
}
```

What does it print?

(a) `0.9`
(b) `0.90`
(c) `0.8999999999999999`
(d) None of the above

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal(2.00);
        BigDecimal cost = new BigDecimal(1.10);
        System.out.println(payment.subtract(cost));
    }
}
```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What does it print?

(a) `0.9`

(b) `0.90`

(c) `0.8999999999999999`

(d) None of the above:

`0.899999999999999911182158029987476766109466552734375`

We used the wrong `BigDecimal` constructor

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Another look

The spec says:

```
public BigDecimal(double val)
```

Translates a double into a BigDecimal which is the exact decimal representation of the double's binary floating-point value.

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal(2.00);
        BigDecimal cost = new BigDecimal(1.10);
        System.out.println(payment.subtract(cost));
    }
}
```

How do you fix it?

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal("2.00");
        BigDecimal cost = new BigDecimal("1.10");
        System.out.println(payment.subtract(cost));
    }
}
```

Prints `0.90`

The moral

- Use `new BigDecimal(String)`,
  not `new BigDecimal(double)`
- `BigDecimal.valueOf(double)` is better, but not perfect
  - Use it for non-constant values.
- For API designers
  - Make it easy to do the commonly correct thing
  - Make it hard to misuse
  - Make it possible to do exotic things

Key concepts from last Thursday

Key design principle: Information hiding

- "When in doubt, leave it out."

Minimize mutability

- Classes should be immutable unless there's a good reason to do otherwise
  - Advantages: simple, thread-safe, reusable
    - See java.lang.String
  - Disadvantage: separate object for each value
- Mutable objects require careful management of visibility and side effects
  - e.g. `Component.getSize()` returns a mutable `Dimension`
- Document mutability
  - Carefully describe state space

Fail fast

- Report errors as soon as they are detectable
  - Check preconditions at the beginning of each method
  - Avoid dynamic type casts, run-time type-checking

```
// A Properties instance maps Strings to Strings
public class Properties extends HashTable {
  public Object put(Object key, Object value);

  // Throws ClassCastException if this instance
  // contains any keys or values that are not Strings
  public void save(OutputStream out, String comments);
}
```

Subtleties of information hiding

- Prevent subtle leaks of implementation details
  - Documentation
  - Lack of documentation
  - Implementation-specific return types
  - Implementation-specific exceptions
  - Output formats
  - `implements Serializable`

Avoid behavior that demands special processing

- Do not return `null` to indicate an empty value
  - e.g., Use an empty `Collection` or array instead
- Do not return `null` to indicate an error
  - Use an exception instead

Throw exceptions only for exceptional behavior

- Do not force client to use exceptions for control flow:

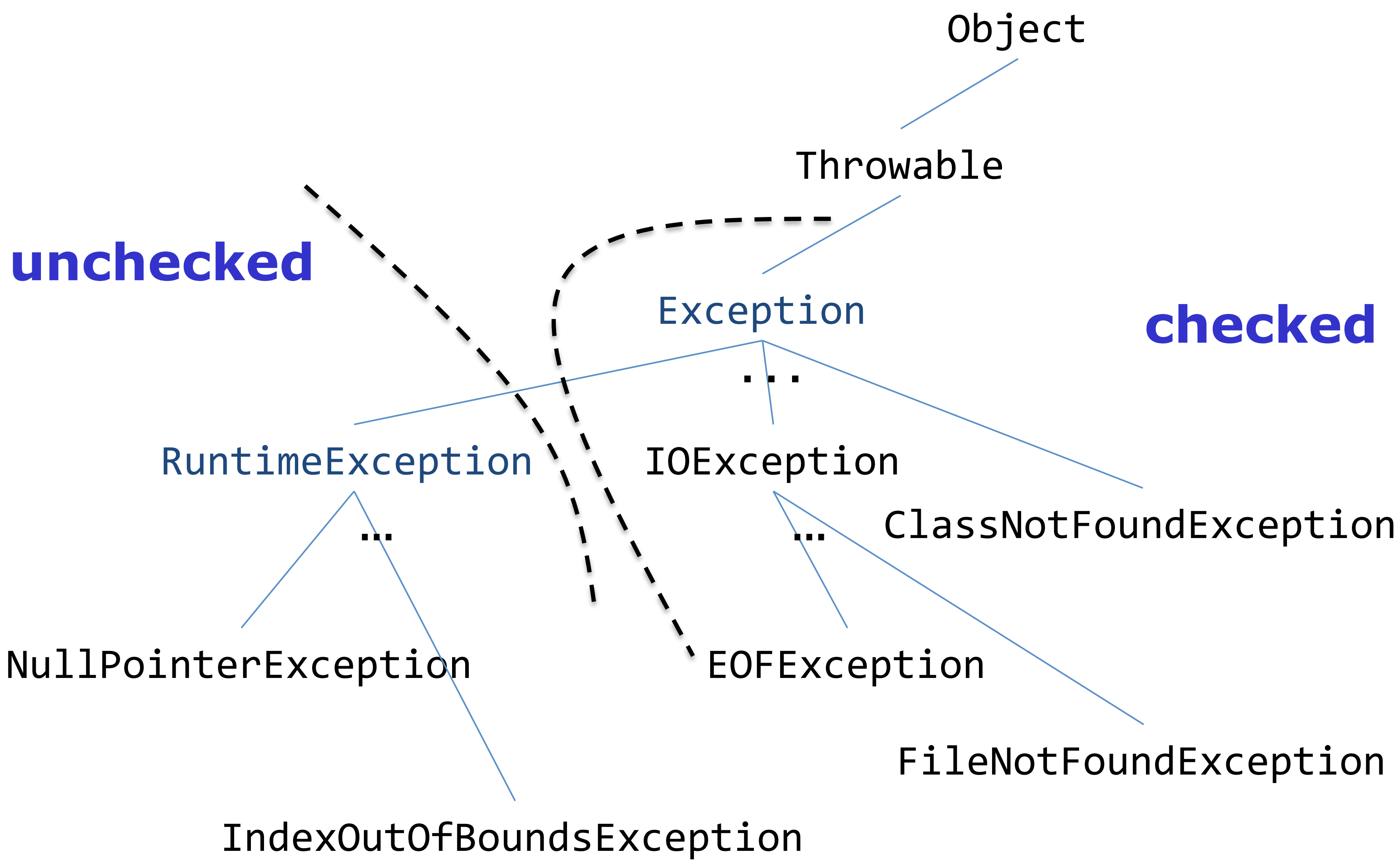
```
private byte[] a = new byte[CHUNK_SIZE];

void processBuffer (ByteBuffer buffer) {
  try {
    while (true) {
      buffer.get(a);
      …
    }
  } catch (BufferUnderflowException e) {
    int remaining = buffer.remaining();
    buffer.get(a, 0, remaining);
    …
  }
}
```

- Conversely, don't fail silently:

```
ThreadGroup.enumerate(Thread[] list)
```

Context: The exception hierarchy in Java



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Avoid checked exceptions, if possible

- Overuse of checked exceptions causes boilerplate code:

```
try {
    Foo f = (Foo) g.clone();
} catch (CloneNotSupportedException e) {
    // This exception can't happen if Foo is Cloneable
    throw new AssertionError(e);
}
```

Don't let your output become your de facto API

- Document the fact that output formats may evolve in the future
- Provide programmatic access to all data available in string form

```
org.omg.CORBA.MARSHAL: com.ibm.ws.pmi.server.DataDescriptor; IllegalAccessException  minor code: 4942F23E  comp
        at com.ibm.rmi.io.ValueHandlerImpl.readValue(ValueHandlerImpl.java:199)
        at com.ibm.rmi.iiop.CDRInputStream.read_value(CDRInputStream.java:1429)
        at com.ibm.rmi.io.ValueHandlerImpl.read_Array(ValueHandlerImpl.java:625)
        at com.ibm.rmi.io.ValueHandlerImpl.readValueInternal(ValueHandlerImpl.java:273)
        at com.ibm.rmi.io.ValueHandlerImpl.readValue(ValueHandlerImpl.java:189)
        at com.ibm.rmi.iiop.CDRInputStream.read_value(CDRInputStream.java:1429)
        at com.ibm.ejs.sm.beans._EJSRemoteStatelessPmiService_Tie._invoke(_EJSRemoteStatelessPmiService_Tie.ja
        at com.ibm.CORBA.iiop.ExtendedServerDelegate.dispatch(ExtendedServerDelegate.java:515)
        at com.ibm.CORBA.iiop.ORB.process(ORB.java:2377)
        at com.ibm.CORBA.iiop.OrbWorker.run(OrbWorker.java:186)
        at com.ibm.ejs.oa.pool.ThreadPool$PooledWorker.run(ThreadPool.java:104)
        at com.ibm.ws.util.CachedThread.run(ThreadPool.java:137)
```

Don't let your output become your de facto API

- Document the fact that output formats may evolve in the future
- Provide programmatic access to all data available in string form

```
public class Throwable {
  public void printStackTrace(PrintStream s);
  public StackTraceElement[] getStackTrace(); // since 1.4
}

public final class StackTraceElement {
  public String  getFileName();
  public int     getLineNumber();
  public String  getClassName();
  public String  getMethodName();
  public boolean isNativeMethod();
}
```

API design summary

- Accept the fact that you, and others, will make mistakes
  - Use your API as you design it
  - Get feedback from others
  - Hide information to give yourself maximum flexibility later
  - Design for inattentive, hurried users
  - Document religiously
- It takes a lot of work to make something that appears obvious

Semester overview

- Introduction to Java and O-O
- Introduction to **design**
  - **Design** goals, principles, patterns
- **Design**ing classes
  - **Design** for change
  - **Design** for reuse
- **Design**ing (sub)systems
  - **Design** for robustness
  - **Design** for change (cont.)
- **Design** case studies
- **Design** for large-scale reuse
- Explicit concurrency

- Crosscutting topics:
  - Modern development tools: IDEs, version control, build automation, continuous integration, static analysis
  - Modeling and specification, formal and informal
  - Functional correctness: Testing, static analysis, verification

Concurrency, motivation and primitives

- The backstory
  - Motivation, goals, problems, …
- Concurrency primitives in Java
- Coming soon (not today):
  - Higher-level abstractions for concurrency
  - Program structure for concurrency
  - Frameworks for concurrent computation

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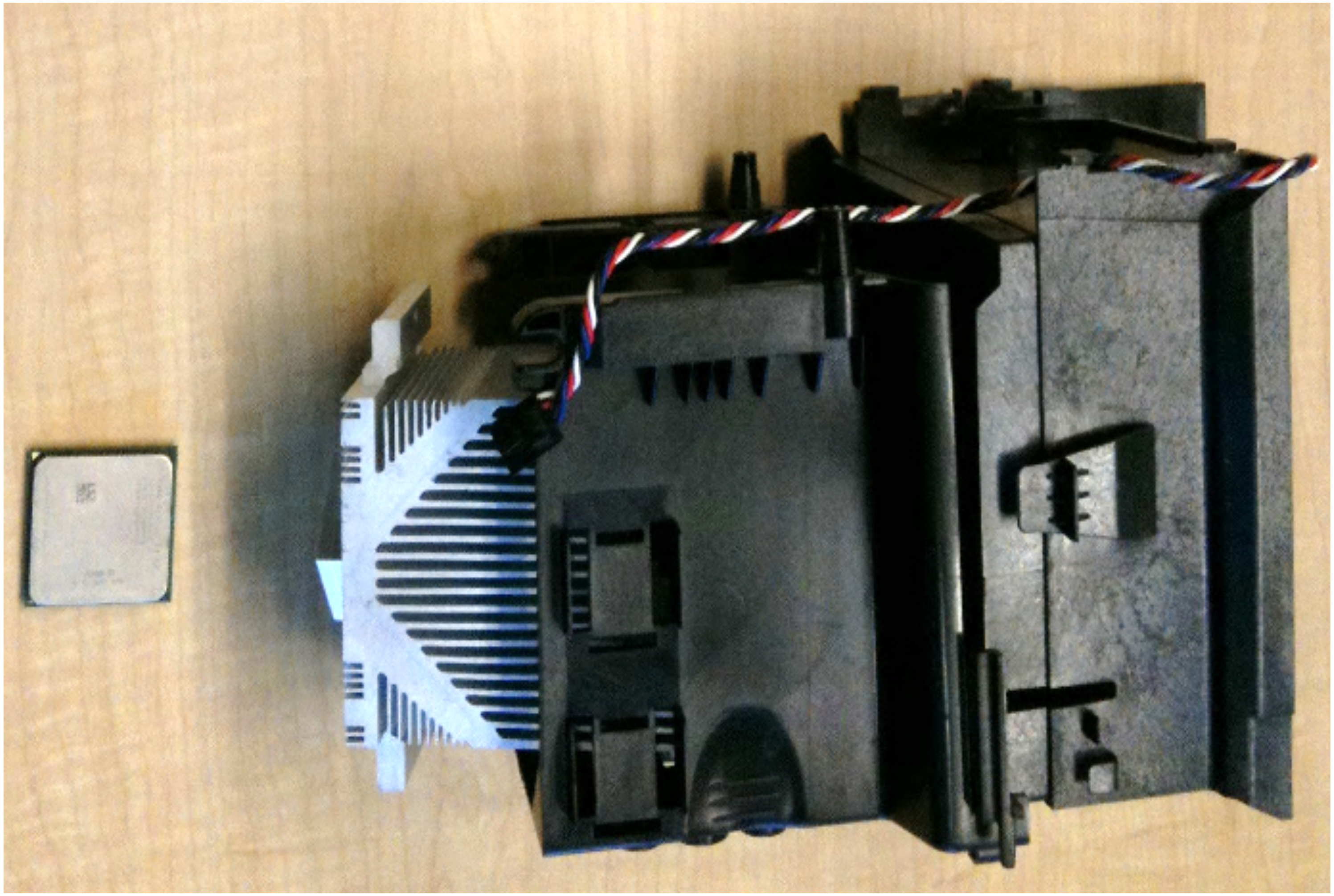
Power requirements of a CPU

- Approx.: **C**apacitance * **V**oltage^2 * **F**requency
- To increase performance:
  - More transistors, thinner wires
    - More power leakage: increase **V**
  - Increase clock frequency **F**
    - Change electrical state faster: increase **V**
- *Dennard scaling*: As transistors get smaller, power density is approximately constant…
  - …until early 2000s
- Heat output is proportional to power input

One option: fix the symptom

- Dissipate the heat



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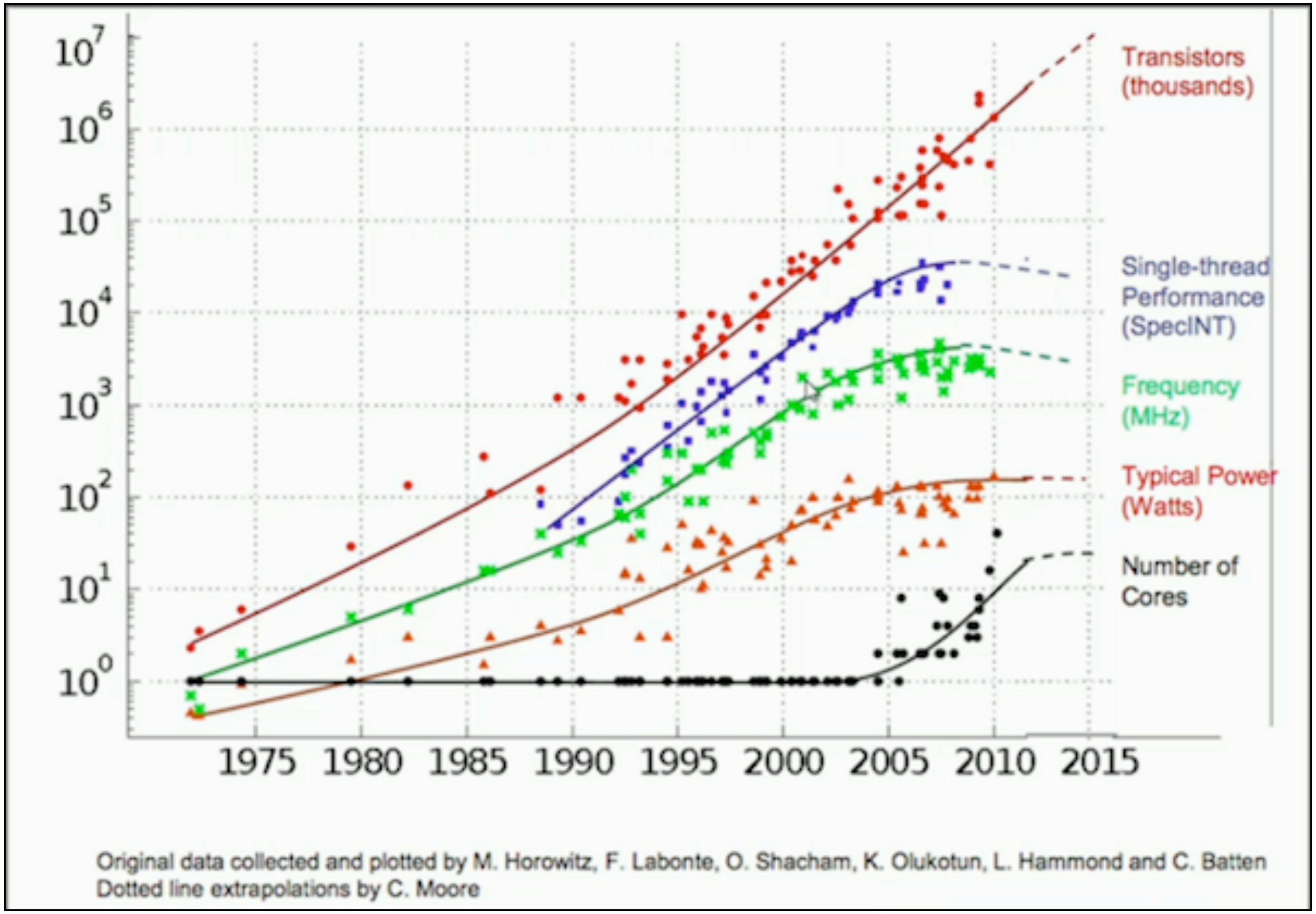
One option: fix the symptom

- Better: Dissipate the heat with liquid nitrogen
  - Overclocking by Tom's Hardware's 5 GHz project

http://www.tomshardware.com/reviews/5-ghz-project,731-8.html

Processor characteristics over time



Concurrency then and now

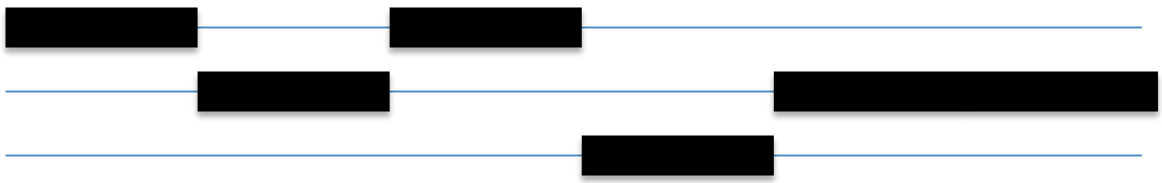
- In the past, multi-threading just a convenient abstraction
  - GUI design: event dispatch thread
  - Server design: isolate each client's work
  - Workflow design: isolate producers and consumers
- Now: required for scalability and performance

We are all concurrent programmers

- Java is inherently multithreaded
- To utilize modern processors, we must write multithreaded code
- Good news: a lot of it is written for you
  - Excellent libraries exist (`java.util.concurrent`)
- Bad news: you still must understand fundamentals
  - …to use libraries effectively
  - …to debug programs that make use of them

Aside: Concurrency vs. parallelism, visualized

- Concurrency without parallelism:



- Concurrency with parallelism:

Basic concurrency in Java

- An interface representing a task

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

- A class to execute a task in a thread

```
public class Thread {
    public Thread(Runnable task);
    public void start();
    public void join();
    …
}
```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Example: Money-grab (1)

```
public class BankAccount {
    private long balance;

    public BankAccount(long balance) {
        this.balance = balance;
    }
    static void transferFrom(BankAccount source,
                             BankAccount dest, long amount) {
        source.balance -= amount;
        dest.balance   += amount;
    }
    public long balance() {
        return balance;
    }
}
```

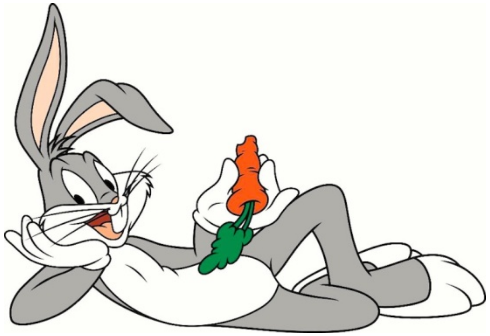
Example: Money-grab (2)

```
public static void main(String[] args) throws InterruptedException
   {
    BankAccount bugs = new BankAccount(100);
    BankAccount daffy = new BankAccount(100);

    Thread bugsThread = new Thread(()-> {
        for (int i = 0; i < 1_000_000; i++)
            transferFrom(daffy, bugs, 100);
    });

    Thread daffyThread = new Thread(()-> {
        for (int i = 0; i < 1_000_000; i++)
            transferFrom(bugs, daffy, 100);
    });

    bugsThread.start(); daffyThread.start();
    bugsThread.join(); daffyThread.join();
    System.out.println(bugs.balance() + daffy.balance());
}
```



What went wrong?

- Daffy & Bugs threads had a *race condition* for shared data
  - Transfers did not happen in sequence
- Reads and writes interleaved randomly
  - Random results ensued

The challenge of concurrency control

- Not enough concurrency control: *safety failure*
  - Incorrect computation
- Too much concurrency control: *liveness failure*
  - Possibly no computation at all (*deadlock* or *livelock*)

Shared mutable state requires concurrency control

- 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: *limit concurrency to achieve safety*

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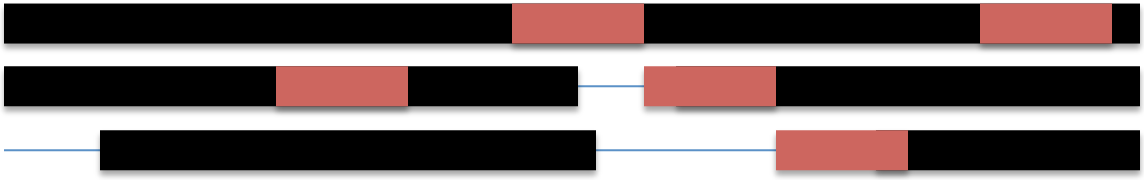
An easy fix:

```
public class BankAccount {
    private long balance;

    public BankAccount(long balance) {
        this.balance = balance;
    }
    static synchronized void transferFrom(BankAccount source,
                                 BankAccount dest, long amount) {
        source.balance -= amount;
        dest.balance   += amount;
    }
    public synchronized long balance() {
        return balance;
    }
}
```

Concurrency control with Java's *intrinsic* locks

- `synchronized (foo) { … }`
  - Synchronizes entire block on object `foo`; cannot forget to unlock
  - Intrinsic locks are *exclusive*: One thread at a time holds the lock
  - Intrinsic locks are *reentrant*: A thread can repeatedly get same lock



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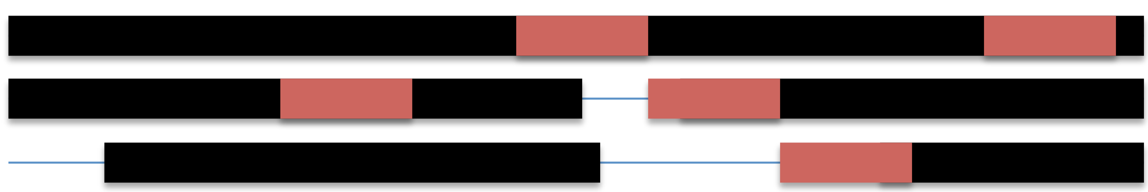
Concurrency control with Java's *intrinsic* locks

- `synchronized (foo)` { … }
  - Synchronizes entire block on object `foo`; cannot forget to unlock
  - Intrinsic locks are *exclusive*: One thread at a time holds the lock
  - Intrinsic locks are *reentrant*: A thread can repeatedly get same lock
- `synchronized` on an instance method
  - Equivalent to `synchronized (this)` { … } for entire method
- `synchronized` on a static method in class Foo
  - Equivalent to `synchronized (Foo.class)` { … } for entire method



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Summary

- Like it or not, you're a concurrent programmer
- Ideally, avoid shared mutable state
  - If you can't avoid it, synchronize properly

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