The Secrets of Concurrency

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The Secrets of Concurrency

- **In this talk you will learn the most important secrets to writing multi-threaded Java code…**

Background

- **Heinz Kabutz**
  - **German-Dutch South African married to a English-Greek South African, living in Greece with 3 kids**
  - **The Java Specialists' Newsletter**
    - **30 000 readers in 115 countries**
    - **Hand in business card to get free subscription**
  - **Java Champion**
  - **Actively code Java**
  - **Teach Java to companies:**
    - **Java Foundations Course**
    - ***Java Specialist Master Course***
    - **Java Design Patterns Course**
    - **http://www.javaspecialists.eu/courses**

Structure of Talk

- The Laws of Concurrency
  - Law 1: The Law of the Sabotaged Doorbell
  - Law 2: The Law of the Distracted Spearfisherman
  - Law 3: The Law of the Overstocked Haberdashery
  - Law 4: The Law of South African Crime
  - Law 5: The Law of the Leaked Memo
  - Law 6: The Law of the Corrupt Politician
  - Law 7: The Law of the Micromanager
  - Law 8: The Law of Greek Driving
  - Law 9: The Law of Sudden Riches
  - Law 10: The Law of the Uneaten Spinach

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The Law of the Sabotaged Doorbell

Instead of arbitrarily suppressing interruptions, manage them better.

*** Removing the batteries from your doorbell to avoid hawkers also shuts out people that you want to have as visitors**

Law 1: The Law of the Sabotaged Doorbell

- **Have you ever seen code like this?**

```
try {
  Thread.sleep(1000);
} catch(InterruptedException ex) {
  // this won't happen here
}
```

- **We will answer the following questions:**
  - **What does InterruptedException mean?**
  - **How should we handle it?**

Shutting Down Threads

- **Shutdown threads when they are inactive**
  - **In WAITING or TIMED_WAITING states:**
    - `Thread.sleep()`
    - `BlockingQueue.get()`
    - `Semaphore.acquire()`
    - `wait()`
    - `join()`
- **e.g. Retrenchments**
  - **Get rid of dead wood first!**

Law 1: The Law of the Sabotaged Doorbell

Thread "interrupted" Status

- **You can interrupt a thread with:**
  - `someThread.interrupt();`
  - **Sets the "interrupted" status to `true`**
  - **What else?**
    - **If thread is in state WAITING or TIMED_WAITING, the thread immediately returns by throwing InterruptedException and sets "interrupted" status back to `false`**
    - **Else, the thread does nothing else. In this case, `someThread.isInterrupted()` will return `true`**
- **Beware of `Thread.interrupted()` side effect**

Law 1: The Law of the Sabotaged Doorbell

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How to Handle InterruptedException?

- **Option 1: Simply re-throw InterruptedException**
  - **Approach used by java.util.concurrency**
  - **Not always possible if we are overriding a method**
- **Option 2: Catch it and return**
  - **Our current "interrupted" state should be set to true**

```
while (!Thread.currentThread().isInterrupted()) {
  // do something
  try {
    TimeUnit.SECONDS.sleep(1000);
  } catch (InterruptedException e) {
    Thread.currentThread().interrupt();
    break;
  }
}
```

Law 1: The Law of the Sabotaged Doorbell

The Law of Distracted Spearfisherman

Focus on one thread at a time. The *school of threads* will blind you.

*** The best defence for a fish is to swim next to a bigger, better fish.**

Law 2: The Law of the Distracted Spearfisherman

- **You must understand what every thread is doing in your system**
  - **Good reason to have fewer threads!**
- **Don't jump from thread to thread, hoping to find problems**

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Causing Thread Dumps

- The jstack tool dumps threads of process
  - Similar to CTRL+Break (Windows) or CTRL+\ (Unix)
- For thread dump JSP page
  - http://javaspecialists.eu/archive/Issue132.html
  - Sorted threads allow you to diff between calls

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The Law of the Overstocked Haberdashery

Having too many threads is bad for your application. Performance will degrade and debugging will become difficult.

*** Haberdashery: A shop selling sewing wares, e.g. threads and needles.**

Law 3: The Law of the Overstocked Haberdashery

- **Story: Client-side library running on server**
- **We will answer the following questions:**
  - **How many threads can you create?**
  - **What is the limiting factor?**
  - **How can we create more threads?**

Quick Demo

How many *inactive* threads can we create, before running out of memory?

JRE Dies with Internal Error

```
Exception in thread "main" java.lang.OutOfMemoryError:
   unable to create new native thread
    at java.lang.Thread.start0(Native Method)
    at java.lang.Thread.start(Thread.java:597)
    at ThreadCreationTest$1.<init>(ThreadCreationTest.java:
   8)
    at ThreadCreationTest.main(ThreadCreationTest.java:7)
#
# An unexpected error has been detected by Java Runtime
   Environment:
#
#  Internal Error (455843455054494F4E530E4350500134) #
# Java VM: Java HotSpot(TM) Client VM (1.6.0_01-b06 mixed
   mode, sharing)
# An error report file with more information is saved as
   hs_err_pid22142.log
#
Aborted (core dumped)
```

How to Create More Threads?

- We created about 9000 threads
- Reduce stack size
  - java –Xss48k ThreadCreationTest
    - 32284 threads
    - Had to kill with -9
  - My first computer had 48k total memory
    - Imagine 32000 ZX Spectrums connected as one computer!
  - Can cause other problems
    - See The Law of the Distracted Spearfisherman

Law 3: The Law of the Overstocked Haberdashery

How Many Threads is Healthy?

- **Additional threads should improve performance**
- **Not too many active threads**
  - **± 4 active per core**
- **Inactive threads**
  - **Number is architecture specific**
  - **But 9000 per core is way too much**
    - **Consume memory**
    - **Can cause sudden death of the JVM**
    - **What if a few hundred threads become active suddenly?**

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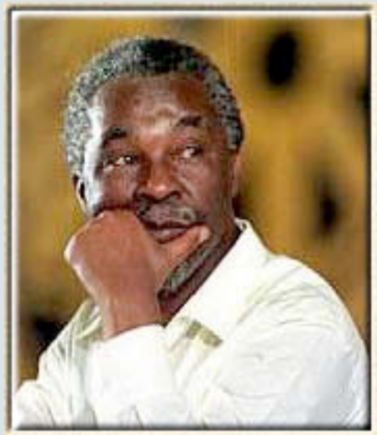
Traffic Calming

- Thread pooling good way to control number
- Use new ExecutorService
  - Fixed Thread Pool
- For small tasks, thread pools can be faster
  - Not main consideration
- See http://www.javaspecialists.eu/archive/Issue149.html

The Law of South African Crime

You might miss important information if you try to be too clever.



*** “Crime is a perception”**

Law 4: The Law of South African Crime

- **Java Memory Model allows thread to keep local copy of fields**
- **Your thread might not see another thread's changes**
- **Usually happens when you try to avoid synchronization**

Calling shutdown() might have no effect

```
public class Runner {
  private boolean running = true;
  public void doJob() {
    while(running) {
      // do something
    }
  }
  public void shutdown() {
    running = false;
  }
}
```

Law 4: The Law of South African Crime

Why?

- **Thread1 calls** `doJob()` **and makes a local copy of** `running`
- **Thread2 calls** `shutdown()` **and modifies the value of field** `running`
- **Thread1 does not see the changed value of** `running` **and continues reading the local stale value**

Making Field Changes Visible

- **Three ways of preventing this**
  - **Make field volatile**
  - **Make field final puts a "freeze" on value**
  - **Make read and writes to field synchronized**
    - **Also includes new locks**

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Better MyThread

```
public class Runner {
  private volatile boolean running = true;
  public void doJob() {
    while(running) {
      // do something
    }
  }
  public void shutdown() {
    running = false;
  }
}
```

The Law of the Leaked Memo

The JVM is allowed to reorder your statements resulting in seemingly impossible states (seen from the outside)

*** Memo about hostile takeover bid left lying in photocopy machine**

Law 5: The Law of the Leaked Memo

- **If two threads call f() and g(), what are the possible values of a and b ?**

```
public class EarlyWrites {
  private int x;
  private int y;
  public void f() {
    int a = x;
    y = 3;
  }
  public void g() {
    int b = y;
    x = 4;
  }
}
```

Early writes can result in: a=4, b=3

The order of Things

- **Java Memory Model allows reordering of statements**
- **Includes writing of fields**
- **To the writing thread, statements appear in order**

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How to Prevent This?

- **JVM is not allowed to move writes out of synchronized block**
  - **Allowed to move statements into a synchronized block**
- **Keyword** volatile **prevents early writes**
  - **From the Java Memory Model:**
    - **There is a happens-before edge from a write to a volatile variable v to all subsequent reads of v by any thread (where subsequent is defined according to the synchronization order)**

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The Law of the Corrupt Politician

In the absence of proper controls, corruption is unavoidable.

* **Lord Acton:** ***Power tends to corrupt. Absolute power corrupts absolutely.***

Law 6: The Law of the Corrupt Politician

- **Without controls, the best code can go bad**

```
public class BankAccount {
  private int balance;
  public BankAccount(int balance) {
    this.balance = balance;
  }
  public void deposit(int amount) {
    balance += amount;
  }
  public void withdraw(int amount) {
    deposit(-amount);
  }
  public int getBalance() { return balance; }
}
```

What happens?

- The += operation is not atomic
- Thread 1
  - Reads balance = 1000
  - Locally adds 100 = 1100
  - Before the balance written, Thread 1 is swapped out
- Thread 2
  - Reads balance=1000
  - Locally subtracts 100 = 900
  - Writes 900 to the balance field
- Thread 1
  - Writes 1100 to the balance field

Solutions

- Pre Java 5
  - synchronized
    - But avoid using “this” as a monitor
    - Rather use a private final object field as a lock
- Java 5 and 6
  - Lock, ReadWriteLock
  - AtomicInteger – dealt with in The Law of the Micromanager

Pre-Java 5

```
public class BankAccount {
  private int balance;
  private final Object lock = new Object();
  public BankAccount(int balance) {
    this.balance = balance;
  }
  public void deposit(int amount) {
    synchronized(lock) { balance += amount; }
  }
  public void withdraw(int amount) {
    deposit(-amount);
  }
  public int getBalance() {
    synchronized(lock) { return balance; }
  }
}
```

Law 6: The Law of the Corrupt Politician

ReentrantLocks

- Basic monitors cannot be interrupted and will never give up trying to get locked
  - The Law of the Uneaten Spinach
- Java 5 Locks can be interrupted or time out after some time
- Remember to unlock in a finally block

```
private final Lock lock = new ReentrantLock();

public void deposit(int amount) {
  lock.lock();
  try {
    balance += amount;
  } finally {
    lock.unlock();
  }
}

public int getBalance() {
  lock.lock();
  try {
    return balance;
  } finally {
    lock.unlock();
  }
}
```

Law 6: The Law of the Corrupt Politician

ReadWriteLocks

- Can distinguish read and write locks
- Use ReentrantReadWriteLock
- Then lock either the write or the read action
  - lock.writeLock().lock();
  - lock.writeLock().unlock();

Law 6: The Law of the Corrupt Politician

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```
private final ReadWriteLock lock =
    new ReentrantReadWriteLock();

public void deposit(int amount) {
  lock.writeLock().lock();
  try {
    balance += amount;
  } finally {
    lock.writeLock().unlock();
  }
}

public int getBalance() {
  lock.readLock().lock();
  try {
    return balance;
  } finally {
    lock.readLock().unlock();
  }
}
```

Law 6: The Law of the Corrupt Politician

The Law of the Micromanager

Even in life, it wastes effort and frustrates the other *threads*.

* *mi·cro·man·age*: **to manage or control with excessive attention to minor details.**

Law 7: The Law of the Micromanager

- **Thread contention is difficult to spot**
- **Performance does not scale**
- **None of the usual suspects**
  - CPU
  - Disk
  - Network
  - Garbage collection
- **Points to thread contention**

Real Example – *Don't Do This!*

- **"How to add contention 101"**
  - `String WRITE_LOCK_OBJECT = "WRITE_LOCK_OBJECT";`
- **Later on in the class**
  - `synchronized(WRITE_LOCK_OBJECT) { ... }`
- **Constant Strings are flyweights!**
  - **Multiple parts of code locking on one object**
  - **Can also cause deadlocks and livelocks**

AtomicInteger

- Thread safe without explicit locking
- Tries to update the value repeatedly until success
  - AtomicInteger.equals() is not overridden

```
public final int addAndGet(int delta) {
  for (;;) {
    int current = get();
    int next = current + delta;
    if (compareAndSet(current, next))
      return next;
  }
}
```

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```
import java.util.concurrent.atomic.AtomicInteger;

public class BankAccount {
  private final AtomicInteger balance =
    new AtomicInteger();

  public BankAccount(int balance) {
    this.balance.set(balance);
  }
  public void deposit(int amount) {
    balance.addAndGet(amount);
  }
  public void withdraw(int amount) {
    deposit(-amount);
  }
  public int getBalance() {
    return balance.intValue();
  }
}
```

Law 7: The Law of the Micromanager

The Law of Greek Driving

The JVM does not enforce all the rules.
Your code is probably wrong, even if it works.

*** Don't *stop* at a stop sign if you treasure your car!**

Law 8: The Law of Greek Driving

- **Learn the JVM Rules !**
- **Example from JSR 133 – Java Memory Model**
  - **VM implementers are encouraged to avoid splitting their 64-bit values where possible. Programmers are encouraged to declare shared 64-bit values as volatile or synchronize their programs correctly to avoid this.**

JSR 133 allows this – NOT a Bug

- **Method set() called by two threads with**
  - **0x12345678ABCD0000L**
  - **0x1111111111111111L**

```
public class LongFields {
  private long value;
  public void set(long v) { value = v; }
  public long get()       { return value; }
}
```

- **Besides obvious answers, "value" could now also be**
  - **0x11111111ABCD0000L or 0x1234567811111111L**

Law 8: The Law of Greek Driving

Java Virtual Machine Specification

- **Gives great freedom to JVM writers**
- **Makes it difficult to write 100% correct Java**
  - **It might work on all JVMs to date, but that does not mean it is correct!**
- **Theory vs Practice clash**

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Synchronize at the Right Places

- **Too much synchronization causes contention**
  - **As you increase CPUs, performance does not improve**
  - **The Law of the Micromanager**
- **Lack of synchronization leads to corrupt data**
  - **The Law of the Corrupt Politician**
- **Fields might be written early**
  - **The Law of the Leaked Memo**
- **Changes to shared fields might not be visible**
  - **The Law of South African Crime**

Law 8: The Law of Greek Driving

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The Law of Sudden Riches

Additional resources (faster CPU, disk or network, more memory) for seemingly stable system can make it unstable.

*** Sudden inheritance or lottery win …**

Law 9: The Law of Sudden Riches

- **Better hardware can break system**
  - **Old system: Dual processor**
  - **New system: Dual core, dual processor**

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Faster Hardware

- **Latent defects show up more quickly**
  - **Instead of once a year, now once a week**
- **Faster hardware often coincides with higher utilization by customers**
  - **More contention**
- **E.g. DOM tree becomes corrupted**
  - **Detected problem by synchronizing all subsystem access**
  - **Fixed by copying the nodes whenever they were read**

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The Law of the Uneaten Spinach

A deadlock in Java can only be resolved by restarting the Java Virtual Machine.

* Imagine a stubborn father insisting that his stubborn daughter eat her spinach before going to bed

Law 10: The Law of the Uneaten Spinach

- **Part of program stops responding**
- **GUI does not repaint**
  - **Under Swing**
- **Users cannot log in anymore**
  - **Could also be The Law of the Corrupt Politician**
- **Two threads want what the other has**
  - **And are not willing to part with what they already have**

Using Multiple Locks

```
public class ProblemChild {
  private final Object lock = new Object();
  public synchronized void f() {
    synchronized(lock) {
      // do something ...
    }
  }
  public void g() {
    synchronized(lock) {
      f();
    }
  }
}
```

Law 10: The Law of the Uneaten Spinach

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Finding the Deadlock

- **Pressing CTRL+Break or CTRL+\ or use jstack**

```
Full thread dump:
Found one Java-level deadlock:
=============================
"g()":
  waiting to lock monitor 0x0023e274 (object
   0x22ac5808, a com.maxoft.ProblemChild),
  which is held by "f()"
"f()":
  waiting to lock monitor 0x0023e294 (object
   0x22ac5818, a java.lang.Object),
  which is held by "g()"
```

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Deadlock Means You Are Dead ! ! !

- Deadlock can be found with jconsole
- However, there is no way to resolve it
- Better to automatically raise critical error
  - Newsletter 130 – Deadlock Detection with new Lock
    - http://www.javaspecialists.eu/archive/Issue130.html

Conclusion

- **Threading is a lot easier when you know the rules**
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