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

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!**

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;
  }
}
```

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**

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

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?

```
import java.util.concurrent.atomic.AtomicInteger;
public class ThreadCreationTest {
  public static void main(String[ ] args) {
    final AtomicInteger threads_created =
      new AtomicInteger(0);
    while (true) {
      new Thread() { { start(); }
        public void run() {
          System.out.println("threads created: " +
            threads_created.incrementAndGet());
          synchronized (this) {
            try { wait(); }
            catch (InterruptedException e) {
              Thread.currentThread().interrupt();
            }
          }
        }
      };
    }
  }
}
```

Law 3: The Law of the Overstocked Haberdashery

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?

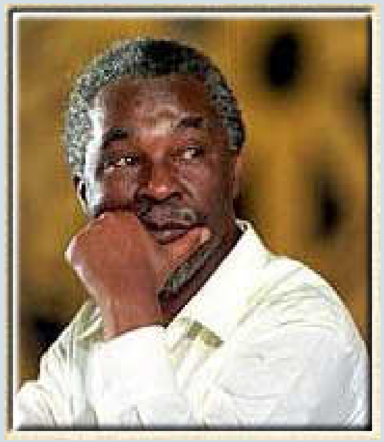
- Additional threads should improve performance
- Not too many active threads
  - ± 4 active per core
- Inactive threads
  - Number is architecture specific
  - But 9000 per core is way too much
    - Consume memory
    - Can cause sudden death of the JVM
    - What if a few hundred threads become active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

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;
  }
}
```

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;
  }
}
```

Law 4: The Law of South African Crime

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

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)**

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; }
  }
}
```

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**

Law 6: The Law of the Corrupt Politician

```
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();**

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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**

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

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**

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**

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();
    }
  }
}
```

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
- Tons of free articles on JavaSpecialists.EU
  - http://www.javaspecialists.eu
- Hand in your business card to get subscribed

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I would love to hear from you!

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