JavaSpecialists.EU

The Secrets of Concurrency

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The Java Specialists' Newsletter

http://www.javaspecialists.eu

The Secrets of Concurrency

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

Background

- Dr Heinz M. Kabutz
  - German-Dutch South African married to an English-Greek South African, living in Chania with 3 kids
  - The Java Specialists' Newsletter
    - 30 000 readers in 114 countries
  - 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

JAVA™ CHAMPIONS

Conference Fatigue

- Time for confession
  - I struggle to concentrate listening to presentations
  - Usually too difficult for me to understand
  - Transition from basic to advanced happens too quickly
- Lots of APIs, XML, Java demos that no one can read
  - <demo usefulness="0">Hey, let's use a font size of 10! Don't you love this demo? I know you cannot read this, but showing off all this XML makes me feel so so clever <smiley /></demo>

Structure of Talk

- The Laws of Concurrency
  - Law 1: The Law of the Ritalin Child
  - 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 Ritalin Child

Instead of suppressing interruptions, deal with the cause.

* Ritalin: A drug commonly prescribed to deal with naughty children.

Law 1: The Law of the Ritalin Child

- 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

- Retrenchments
  - Get rid of dead wood first!
- Shutdown threads when they are inactive
  - Thread.sleep()
  - BlockingQueue.get()
  - Semaphore.acquire()
  - wait()
  - join()

Thread “interrupted” Status

- Thread “interrupted” == true
  - At next blocking code, InterruptedException is thrown
  - isInterrupted() returns true
- You can set “interrupted” status to true
- someThread.interrupt();
- “interrupted” is set to false when
  - InterruptedException is thrown
  - Thread.interrupted() is called
    - Beware of side effect!

Law 1: The Law of the Ritalin Child

How to Handle InterruptedExcepti

- 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 the Distracted Spearfisherman

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

* The best defense 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.

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

Law 3: The Law of the Overstocke 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?

```
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 (45584345054494F4E530E4350500134) #
# 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)
```

Law 3: The Law of the Overstocked Haberdashery

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
- Azul Systems (http://www.azulsystems.com)
  - Build systems with 768 cores and 768GB memory
  - Can have thousands of active threads

Traffic Calming

- Thread pooling good way to control number
- Use new ExecutorService
  - Fixed Thread Pool
- For lots of small tasks, thread pools can be faster
  - Not main consideration

```
import java.util.concurrent.*;

public class ThreadConstructTest {
  private static final int NUMBER_OF_THREADS = 100 * 1000;

  private Semaphore semaphore = new Semaphore(10);
  private final Runnable job = new Runnable() {
    public void run() {
      semaphore.release();
    }
  };

  public void noThreadPool() throws InterruptedException {
    for (int i = 0; i < NUMBER_OF_THREADS; i++) {
      semaphore.acquire();
      new Thread(job).start();
    }
    // wait for all jobs to finish
    semaphore.acquire(10);
    semaphore.release(10);
  }
```

Law 3: The Law of the Overstocked Haberdashery

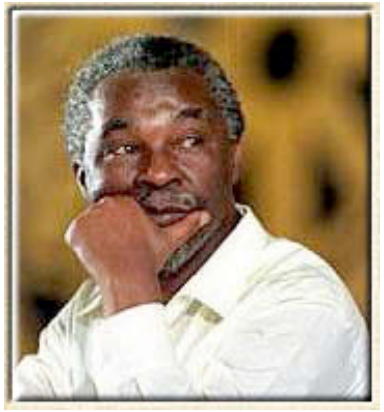
```
public void fixedThreadPool() throws InterruptedException{
  ExecutorService pool = Executors.newFixedThreadPool(12);
  for (int i = 0; i < NUMBER_OF_THREADS; i++) {
    semaphore.acquire();
    pool.submit(job);
  }
  semaphore.acquire(10); semaphore.release(10);
  pool.shutdown();
}

public static void main(String[] args) throws Exception {
  ThreadConstructTest test = new ThreadConstructTest();

  long time = System.currentTimeMillis();
  test.noThreadPool();
  System.out.println(System.currentTimeMillis() - time);

  time = System.currentTimeMillis();
  test.fixedThreadPool();
  System.out.println(System.currentTimeMillis() - time);
 }
}
```

```
16004
842
```

Law 3: The Law of the Overstocked Haberdashery

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

MyThread Might Never End!

```
public class MyThread extends Thread {
  private boolean running = true;
  public void run() {
    while(running) {
      // do something
    }
  }
  public void shutdown() {
    running = false;
  }
}
```

Law 4: The Law of South African Crime

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

Better MyThread

```
public class MyThread extends Thread {
  private volatile boolean running = true;
  public void run() {
    while(running) {
      // do something
    }
  }
  public void shutdown() {
    running = false;
  }
}
```

The Law of the Leaked Memo

This may never happen, but when it does, check your synchronization

* Memo about hostile takeover bid left lying in photocopy machine

Law 5: The Law of the Leaked Mer

- If two threads call f() and g(), what are 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.

* Power corrupts. 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();
  }
}
```

ReadWriteLocks

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

```
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();
  }
}
```

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
  - String WRITE_LOCK_OBJECT = "WRITE_LOCK_OBJECT";
- Later on in the class
  - **synchronized**(WRITE_LOCK_OBJECT) { ... }
- Constant Strings are flyweights!
  - Multiple parts of the code locking on one object
  - Can also cause deadlocks and livelocks
- Thanks to Java Specialists' Newsletter subscriber David Hallett for sharing this with me

AtomicInteger

- Thread safe without explicit locking
- Tries to update the value repeatedly until success

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

```
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();
  }
}
```

The Law of Greek Driving

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

* Don’t ever *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

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

Does This Code Work?

```
public class CASCounter implements Counter {
  private long count = 0;
  private Thread owner;
  public long getCount() { return count; }
  public void increment() {
    do {
      while (this.owner != null);    // wait
      this.owner = Thread.currentThread();
      for (int i = 0; i < 6; i++);   // delay
    } while (this.owner != Thread.currentThread());
    this.count++;
    this.owner = null;
  }
```

Law 8: The Law of Greek Driving

Answer: It did …

- At least, on the architectures we tried ...
- What could go wrong?
  - Variable owner might not get updated in your thread
    - Visibility problem
      - The Law of South African Crime
    - Can cause an infinite loop
  - Other race conditions exist as well

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()"

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 easy, when you know the rules
- Tons of resources on JavaSpecialists.EU
  - http://www.javaspecialists.eu

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I would love to hear from you!