

The Secrets of Concurrency

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Heinz Kabutz

● Brief Biography

- **German-Dutch-South-African-Greek from Cape Town, now lives in Chania on Island of Crete**
 - **Dozens of Bulgarian friends**
- **The Java Specialists' Newsletter - javaspecialists.eu**
 - **134 countries**
- **Java Champion since 2005**
- **JavaOne Rock Star 2012**

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The Secrets of Concurrency

- **Writing correct concurrent code can be a real challenge; only *perfect* is good enough**
- **You need to synchronize in the precisely correct places**
 - Too much synchronization and you risk deadlock and contention
 - Too little synchronization and you risk seeing early writes, corrupt data, race conditions and stale local copies of fields
- **In this section, we will look at ten laws that will make it easier for you to write correct thread-safe**

The Secrets of Concurrency

- **Ten laws that will help you write thread-safe code**
 - **Law 1: The Law of the Sabotaged Doorbell**
 - **Law 2: The Law of the Xerox Copier**
 - **Law 3: The Law of the Overstocked Haberdashery**
 - **Law 4: The Law of the Blind Spot**
 - **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 Cretan Driving**
 - **Law 9: The Law of Sudden Riches**
 - **Law 10: The Law of the Uneaten Lutefisk**

1. 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?

Law 1: The Law of the Sabotaged Doorbell

Shutting Down Threads

- **Shutdown threads when they are inactive**
 - In **WAITING** or **TIMED_WAITING** states:
 - **Thread.sleep()**
 - **BlockingQueue.get()**
 - **Semaphore.acquire()**
 - **wait()**
 - **join()**

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`**

Law 1: The Law of the Sabotaged Doorbell

How to Handle InterruptedException?

- **Option 1: Simply re-throw InterruptedException**

- Approach used by `java.util.concurrent`
- Not always possible if we are overriding a method

- **Option 2: Catch it and return**

- Our current “interrupted” state should be set to true
- Add a boolean volatile “running” field as backup mechanism

```
while (running) {  
    // do something  
    try {  
        TimeUnit.SECONDS.sleep(1);  
    } catch (InterruptedException e) {  
        Thread.currentThread().interrupt();  
        break;  
    }  
}
```

Law 1: The Law of the Sabotaged Doorbell

JCache is Here - Jaromir Hamala

```
17
18 private void doComplicatedBusinessLogic() {
19     try {
20         Thread.sleep(3000);
21     } catch (InterruptedException e) {
22         Thread.currentThread().interrupt();
23     }
24 }
25 }
26
```

2. The Law of the Xerox Copier

Protect yourself by making copies of objects

*** Never give your originals to anyone, even a bank!**

"Safe as a Bank"

- Our home loan application was on the desk the day this bank was trashed by rioters
- *Fortunately, we had only given them copies of our important documents!*



© Greg Manset

Law 2: The Law of the Xerox Copier

Law 2: The Law of the Xerox Copier

- **Immutable objects are always thread safe**
 - No stale values, race conditions or early writes
- **For concurrency, *immutable* means [Goetz'06]**
 - State cannot be modified after construction
 - All the fields are final
 - 'this' reference does not escape during construction

How do we use an Immutable Object?

- **Whenever we want to change it, make a copy**
 - e.g. String '+' operator produces a new String
- **Additional GC expense, but concurrency is easier**

Basic Thread-Safe ArrayList

```
public class ImmutableArrayList<E> implements Iterable<E> {
    private final Object[] elements;

    public ImmutableArrayList() {
        this.elements = new Object[0];
    }

    private ImmutableArrayList(Object[] elements) {
        this.elements = elements;
    }

    public int size() { return elements.length; }

    public ImmutableArrayList<E> add(E o) {
        Object[] new_elements = new Object[elements.length + 1];
        System.arraycopy(elements, 0,
            new_elements, 0, elements.length);
        new_elements[new_elements.length - 1] = o;
        return new ImmutableArrayList<E>(new_elements);
    }
}
```


Thread-Safe Iterator

```
public Iterator<E> iterator() {
    return new Iterator<E>() {
        int pos = 0;

        public boolean hasNext() {
            return pos < elements.length;
        }

        public E next() {
            return (E) elements[pos++];
        }

        public void remove() {
            throw new UnsupportedOperationException();
        }
    };
}
```

Using ImmutableList

- We use this in a more functional approach:

```
ImmutableArrayList<String> ial = new ImmutableList<>();  
ial = ial.add("Heinz").add("Max").add("Kabutz");  
for (Object o : ial) {  
    System.out.println("o = " + o);  
}
```

3. 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 the JVM crashes?



Some JVMs Core Dump

```
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: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)
# 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 2000 threads on Mac OS X**
 - Had to kill with -9
- **Stack size can cause `OutOfMemoryError` if too large**

Law 3: The Law of the Overstocked Haberdashery

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

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
 - Consume memory
 - Can cause sudden death of the JVM
 - What if a few thousand threads suddenly become active?

Law 3: The Law of the Overstocked Haberdashery

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 www.javaspecialists.eu/archive/Issue149.html**

4. The Law of the Blind Spot

It is not always possible to see what other threads (cars) are doing with shared data (road)

Law 4: The Law of the Blind Spot

- **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 the Blind Spot

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**

Law 4: The Law of the Blind Spot

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


5. 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;
    }
}
```

Law 5: The Law of the Leaked Memo

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`

Law 5: The Law of the Leaked Memo

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)

How to Cause This Error (Victor Grazi)

- **Actually this is easy to produce. Here are the steps:**
 - Write some production code that depends on correct ordering
 - Test it thoroughly
 - (Don't worry all tests will pass)
 - Release to production
 - Wait for the next corporate change freeze
 - Check your inbox - you will have 500 emails from irate users who were bitten by the bug

6. 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; }  
}
```

Law 6: The Law of the Corrupt Politician

What happens?

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

Law 6: The Law of the Corrupt Politician

Solutions

● Pre Java 5

- synchronized
 - But avoid using “this” as a monitor
 - Rather use a private final object field as a lock

● Java 5,6,7

- Lock, ReadWriteLock
- AtomicInteger – dealt with in The Law of the Micromanager

● Java 8

- StampedLock

Law 6: The Law of the Corrupt Politician

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 Lutefisk
- **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();`
- **Careful: Starvation can happen!**

Law 6: The Law of the Corrupt Politician

```
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

7. 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**

Law 7: The Law of the Micromanager

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;
    }
}
```

Law 7: The Law of the Micromanager

```
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

8. The Law of Cretan 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 Cretan 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 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 the Blind Spot

Law 8: The Law of Cretan Driving

9. 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

10. The Law of the Uneaten Lutfisk

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

* Imagine a Viking father insisting that his stubborn child eat its

Delicioussssssss!!!



Law 10: The Law of the Uneaten Lutefisk

- **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

Law 10: The Law of the Uneaten Lutefisk

Using Multiple Locks

```
public class HappyLocker {
    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 Lutefisk

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
HappyLocker),
which is held by "f()"

"f()":

waiting to lock monitor 0x0023e294 (object 0x22ac5818, a
java.lang.Object),
which is held by "g()"

Law 10: The Law of the Uneaten Lutefisk

Deadlock Means You Are Dead !!!

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

Conclusion

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