# 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

Dr Heinz Kabutz

- German-Dutch South African married to an English-Greek South African, living in Greece with 3 beautiful kids
- The Java Specialists' Newsletter
  - 50 000 readers in 115 countries
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- Java Champion
- Actively code Java
- Teach Java to companies:
  - 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 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 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

# 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(1);
  } catch (InterruptedException e) {
    Thread.currentThread().interrupt();
    break;
  }
}
```

# Backup boolean Field

Sometimes, older code does not handle InterruptedException correctly

- We should typically also have a backup boolean variable if we want to shut down threads

```
private volatile boolean running = true;
public void shutdown() {
  running = false;
  Thread.currentThread().interrupt();
}
// ...
while (running && !Thread.currentThread().isInterrupted()) {
  // do something
}
```

# 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?

```
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();
            }
          }
        }
      };
    }
  }
}
```

# 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 Env:
#
#  Internal Error (455843455054494F4E530E4350500134) #
# Java VM: Java HotSpot(TM) Client VM (1.6.0_01 mixed mode)
# 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

# 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

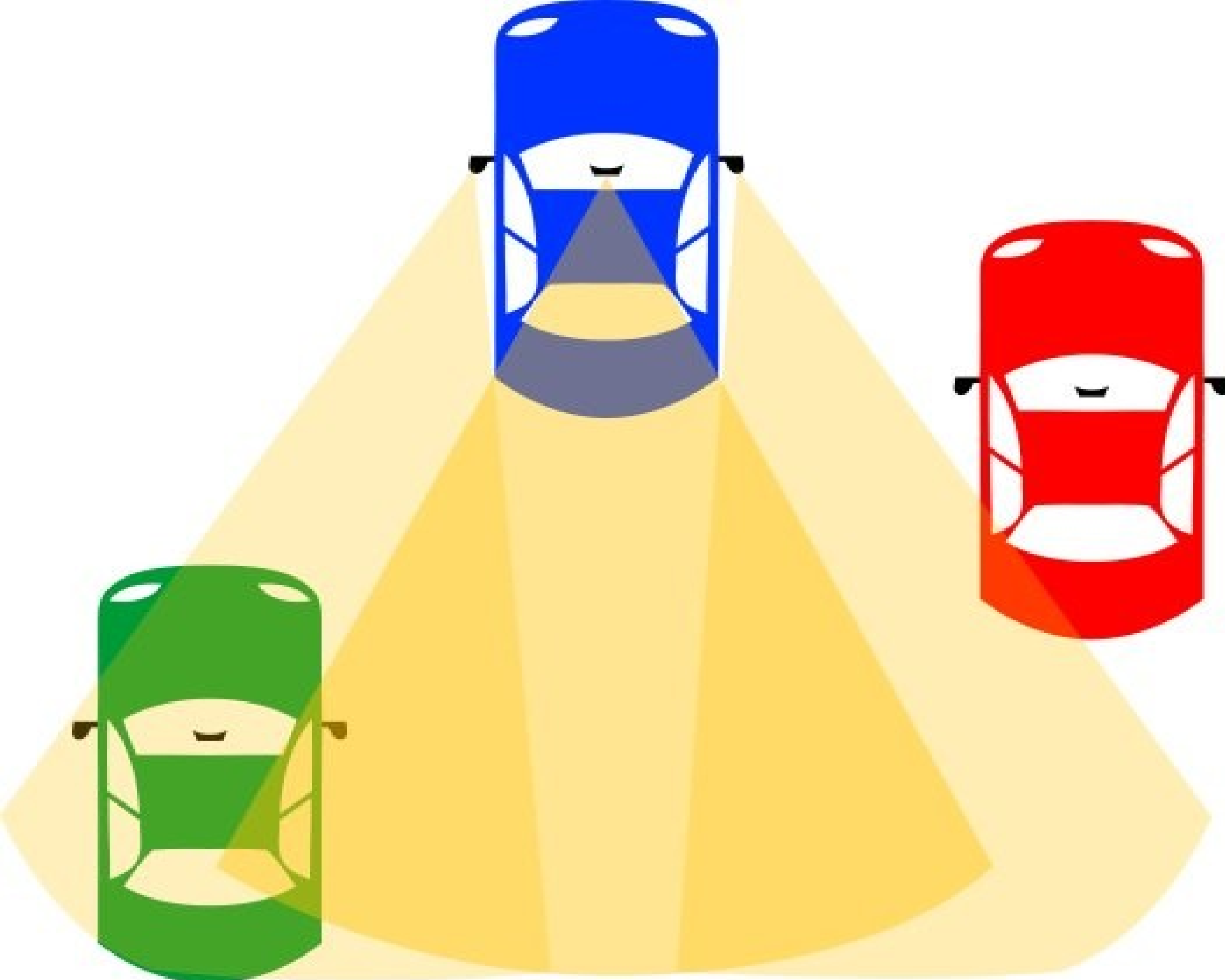
Thread pooling good way to control number

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 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;
  }
}
```

# 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

# 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

# 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

```
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 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;
    }
  }
}
```

```
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 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 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

# 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 dad insisting that his stubborn son eat his 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 HappyLockers {
  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 easy way to resolve it

Better to automatically raise critical error

- Newsletter 130 – Deadlock Detection with new Lock
  - http://www.javaspecialists.eu/archive/Issue130.html
- Newsletter 160 – Stopping deadlocked threads
  - http://www.javaspecialists.eu/archive/Issue161.html

# Conclusion

Threading is a lot easier when you know the rules

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