Concurrency in Java

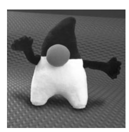
Prof. Stephen A. Edwards

The Java Language

- Developed by James Gosling et al. at Sun Microsystems in the early 1990s
- Originally called "Oak," first intended application was as an OS for TV set top boxes
- Main goals were portability and safety
- Originally for embedded consumer software

The Java Language

- Set-top boxes: nobody cared
- Next big application: "applets"
  - Little programs dynamically added to web browsers
- Enormous Sun marketing blitz
- Partial failure:
  - Incompatible Java implementations
  - Few users had enough bandwidth
  - Fantastically slow Java interpreters
- Javascript has largely taken over this role
  - High-level scripting language
  - Has nothing to do with the Java language



The Java Language

- Where does Java succeed?
- Corporate programming
  - E.g., dynamic web page generation from large corporate databases in banks
  - Environment demands simpler language
    - Unskilled programmers, unreleased software
  - Speed, Space not critical
    - Tends to be run on very large servers
  - Main objective is reduced development time

The Java Language

- Where does Java succeed?
- Education
  - Well-designed general-purpose programming language
  - Spares programmer from many common pitfalls
    - Uninitialized pointers
    - Memory management
  - Widely known and used, not just a teaching language
- Embedded Systems?
  - Jury is still out

Overview of Java

- Derived from C++, but incompatible
- Didn't want to call it "C += 2"?
- No "loose" functions: everything part of a class
- Better package support (no preprocessor)
- Safer object references instead of pointers
- Large, powerful class library
- Automatic garbage collection
  - Programmer spared from memory management

Concurrency in Java

- **Language supports threads**
- **Multiple contexts/program counters running within the same memory space**
- **All objects can be shared among threads**
- **Fundamentally nondeterministic**
- **Language provide some facilities to help avoid it**

Thread Basics

- **How to create a thread:**

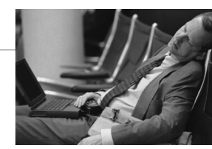
```
class MyThread extends Thread {
  public void run() { /* thread body */ }
}

MyThread mt = new MyThread;    // Create thread
mt.start();          // Starts thread running at run()
                     // Returns immediately
```


Thread Basics

- **A thread is a separate program counter**
  … and stack, local variables, etc.
- **Not an object or a collection of things**
- **Classes, objects, methods, etc. do not belong to a thread**
- **Any method may be executed by one or more threads, even simultaneously**

The Sleep Method



```
public void run() {
  for(;;) {
    try {
      sleep(1000); // Pause for 1 second
    } catch (InterruptedException e) {
       return;        // caused by thread.interrupt()
    }
    System.out.println("Tick");
  }
}
```


The Sleep Method

Does this print Tick once a second? No.

sleep() delay a lower bound

Rest of loop takes indeterminate amount of time

```
public void run() {
  for(;;) {
    try {
      sleep(1000);
    } catch (InterruptedException e) {
       return;
    }
    System.out.println("Tick");
  }
}
```

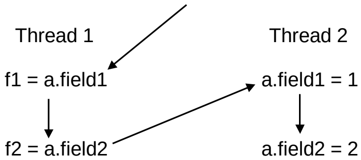

Races

- **In a concurrent world, always assume someone else is accessing your objects**
- **Other threads are your adversary**
- **Consider what can happen when simultaneously reading and writing:**

Thread 1	Thread 2
f1 = a.field1	a.field1 = 1
f2 = a.field2	a.field2 = 2

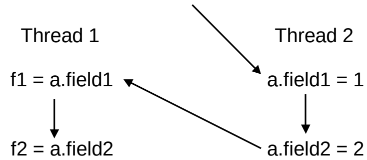
Races

- **Thread 1 goes first**
- **Thread 1 reads original values**



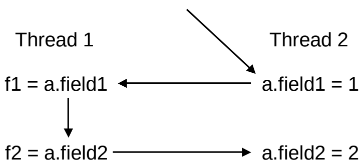
Races

- **Thread 2 goes first**
- **Thread 1 reads new values**



Races

- **Interleaved execution**
- **Thread 1 sees one new value, one old value**



Non-atomic Operations

- **32-bit reads and writes are guaranteed atomic**
- **64-bit operations may not be**

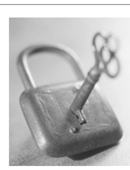
- **Therefore,**

int i; double d;

Thread 1	**Thread 2**	
i = 10;	**i = 20;**	**i will contain 10 or 20**
d = 10.0;	**d = 20.0;**	**i might contain garbage**

Per-Object Locks

- **Each Java object has a lock that may be owned by at least one thread**
- **A thread waits if it attempts to obtain an already-obtained lock**
- **The lock is a counter: one thread may lock an object more than once**



The Synchronized Statement

- **A synchronized statement gets an object's lock before running its body**

```
Counter mycount = new Counter;
synchronized(mycount) {
  mycount.count();
}
```

"get the lock for mycount before calling count()"

- **Releases the lock when the body terminates**
- **Choice of object to lock is by convention**

Synchronized Methods

```
class AtomicCounter {
  private int _count;

  public synchronized void count() {
    _count++;
  }
}
```

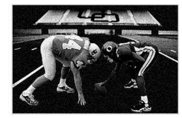
"get the lock for the AtomicCounter object before running this method"

This implementation guarantees at most one thread can increment the counter at any time

Deadlock

```
synchronized(Foo) {
  synchronized(Bar) {
    /* Deadlocked */
  }
}
```

```
synchronized(Bar) {
  synchronized(Foo) {
    /* Deadlocked */
  }
}
```



- **Rule: always acquire locks in the same order**

Priorities

- **Each thread has a priority from 1 to 10 (5 typical)**
- **Scheduler's job is to keep highest-priority threads running**
- **thread.setPriority(5)**

What the Language Spec. Says

- **From *The Java Language Specification***

> **Every thread has a *priorit*y. When there is competition for processing resources, threads with higher priority are generally executed in preference to threads with lower priority. Such preference is not, however, a guarantee that the highest priority thread will always be running, and thread priorities cannot be used to reliably implement mutual exclusion.**

- **Vague enough for you?**

Multiple threads at same priority?

- **Language gives implementer freedom**
- **Calling yield() suspends current thread to allow other at same priority to run … maybe**
- **Solaris implementation runs threads until they stop themselves (wait(), yield(), etc.)**
- **Windows implementation timeslices**

Starvation

- **Not a fair scheduler**
- **Higher-priority threads can consume all resources, prevent lower-priority threads from running**
- **This is called starvation**
- **Timing dependent: function of program, hardware, and Java implementation**

Waiting for a Condition

- Say you want a thread to wait for a condition before proceeding
- An infinite loop may deadlock the system

```
while (!condition) {}
```

- Yielding avoids deadlock, but is very inefficient

```
while (!condition) yield();
```

Java's Solution: wait() and notify()

- wait() like yield(), but requires other thread to reawaken it

```
while (!condition) wait();
```

- Thread that might affect this condition calls() notify to resume the thread
- Programmer responsible for ensuring each wait() has a matching notify()

wait() and notify()

- Each object has a set of threads that are waiting for its lock (its wait set)

```
synchronized (obj) {    // Acquire lock on obj
  obj.wait();           // suspend
                        // add thread to obj's wait set
                        // relinquish locks on obj
In other thread:
obj.notify();           // enable some waiting thread
```


wait() and notify()

1. Thread 1 acquires lock on object
2. Thread 1 calls wait() on object
3. Thread 1 releases lock on object, adds itself to object's wait set
4. Thread 2 calls notify() on object (must own lock)
5. Thread 1 is reawakened: it was in object's wait set
6. Thread 1 reacquires lock on object
7. Thread 1 continues from the wait()

wait() and notify()

- Confusing enough?
- notify() nodeterministically chooses one thread to reawaken (may be many waiting on same object)
  - What happens when there's more than one?
- notifyAll() enables all waiting threads
  - Much safer?

Building a Blocking Buffer

```
class OnePlace {
  El value;

  public synchronized void write(El e) { … }
  public synchronized El read() { … }
}
```

- Idea: One thread at a time can write to or read from the buffer
- Thread will block on read if no data is available
- Thread will block on write if data has not been read

Building a Blocking Buffer

```
synchronized void write(El e) throws InterruptedException
{
  while (value != null) wait();       // Block while full
  value = e;
  notifyAll();                        // Awaken any waiting read
}

public synchronized El read() throws InterruptedException
{
  while (value == null) wait();       // Block while empty
  El e = value; value = null;
  notifyAll();                        // Awaken any waiting write
  return e;
}
```


Thread States