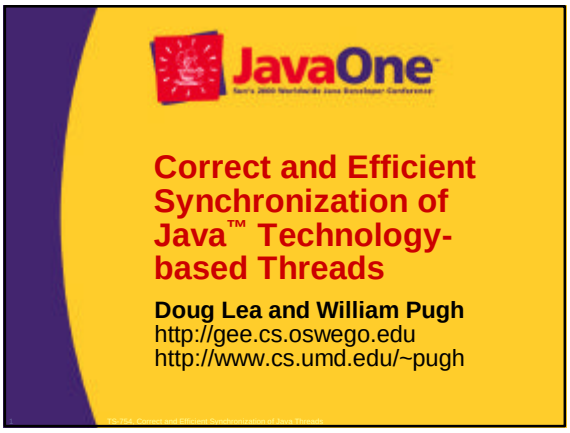


Audience

- Assume you are familiar with basics of Java™ technology-based threads ("Java threads")
  - Creating, starting and joining threads
  - Synchronization
  - `wait` and `notifyAll`
- Will talk about things that surprised a lot of experts
  - Including us, James Gosling, Guy Steele, …

  (others discovered many of these)

Java Thread Specification

- Chapter 17 of the Java Language Spec
  - Chapter 8 of the Virtual Machine Spec
- Very, very hard to understand
  - Not even the authors understood it
  - Has subtle implications
    - That forbid standard compiler optimizations
  - All existing JVMs violate the specification
    - Some parts should be violated

Safety Issues in Multithreaded Systems

- Many intuitive assumptions do not hold
- Some widely used idioms are not safe
  - Double-check idiom
  - Checking non-volatile flag for thread termination
- Can't use testing to check for errors
  - Some anomalies will occur only on some platforms
    - e.g., multiprocessors

Revising the Thread Spec

- Work is underway to consider revising the Java Thread Spec
  - http://www.cs.umd.edu/~pugh/java/memoryModel
- Goals
  - Clear and easy to understand
  - Foster reliable multithreaded code
  - Allow for high performance JVMs
- Will affect JVMs
  - And badly written existing code
    - Including parts of Sun's JDK

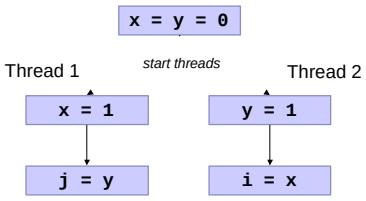
Three Aspects of Synchronization

- Atomicity
  - Locking to obtain mutual exclusion
- Visibility
  - Ensuring that changes to object fields made in one thread are seen in other threads
- Ordering
  - Ensuring that you aren't surprised by the order in which statements are executed

Don't Be Too Clever

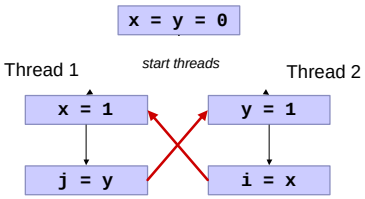
- People worry about the cost of synchronization
  - They try to devise schemes to communicate between threads
    - Without using synchronization
- Very difficult to do correctly
  - Inter-thread communication without synchronization is not intuitive

Quiz Time



Can this result in i = 0 and j = 0?

Answer: Yes!



How can i = 0 and j = 0?

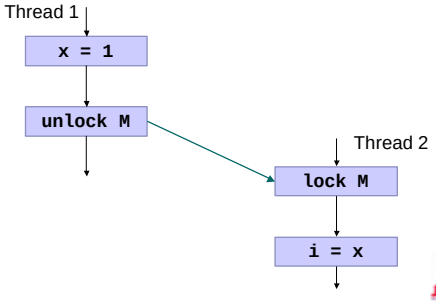
How Can This Happen?

- Compiler can reorder statements
  - Or keep values in registers
- Processor can reorder them
- On multi-processor, values not synchronized in global memory
- Must use synchronization to enforce visibility and ordering
  - As well as mutual exclusion

Synchronization Actions (approximately)

```
// block until obtain lock
synchronized(anObject) {
  // get main memory value of field1
  and field2
  int x = anObject.field1;
  int y = anotherObject.field2;
  anotherObject.field3 = x+y;
  // commit value of field3 to main
  memory
}
// release lock
moreCode();
```

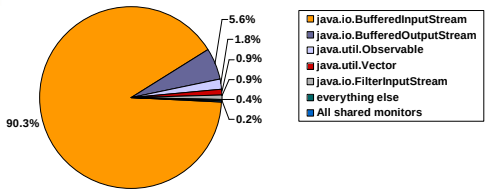
When Are Actions Visible to Other Threads?



Cost of Synchronization

- Few good public multithreaded benchmarks
  - See us if you want to help
- Volano Benchmark
  - Most widely used server benchmark
  - Multithreaded chat room server
  - Client performs 4.8M synchronizations
    - 8K useful (0.2%)
  - Server 43M synchronizations
    - 1.7M useful (4%)

Synchronization in VolanoMark Client



7,684 synchronizations on shared monitors
4,828,130 thread local synchronizations

Cost of Synchronization in VolanoMark

- Removed synchronization of
  - java.io.BufferedInputStream
  - java.io.BufferedOutputStream
- Performance (2 processor Ultra 60)
  - Larger is better
  - HotSpot (1.3 beta)
    - Original: 4788
    - Altered: 4923 (+3%)
  - Exact VM (1.2.2)
    - Original: 6649
    - Altered: 6874 (+3%)

Most Synchronization is on Thread Local Objects

- Synchronization on thread local object
  - Is useless
  - Current spec says it isn't quite a no-op
    - But very hard to use usefully
  - Revised spec will likely make it a no-op
- Largely arises from using synchronized classes
  - In places where not required

Synchronize when Needed

- Places where threads interact
  - Need synchronization
  - Need careful thought
  - Need documentation
  - Cost of required synchronization not significant
    - For most applications
    - No need to get tricky
- Elsewhere, using a synchronized class can be expensive

Synchronized Classes

- Some library classes are synchronized
  - Vector, Hashtable, Stack
  - Most Input/Output Streams
- Contrast with 1.2 Collection classes
  - By default, not synchronized
  - Can request synchronized version
- Using synchronized classes
  - Often doesn't suffice for concurrent interaction

Synchronized Collections Aren't Always Enough

- Transactions (THIS DOESN'T WORK)

```
ID getID(String name) {
       ID x = (ID) h.get(name);
       if (x == null) {
           x = new ID();
           h.put(name, x);}
       return x; }
```

- Iterators
  - Can't modify collection while another thread is iterating through it

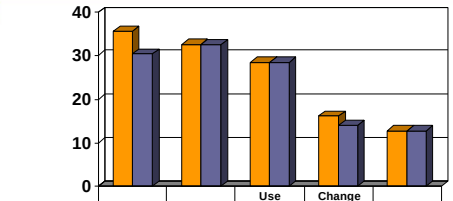
Concurrent Interactions

- Often need entire transactions to be atomic
  - Reading and updating a Map
  - Writing a record to an OutputStream
- OutputStreams are synchronized
  - Can have multiple threads trying to write to the same OutputStream
  - Output from each thread is non-deterministically interleaved
  - Essentially useless

Cost of Synchronization in SpecJVM DB Benchmark

- Program in the SpecJVM benchmark
- Does lots of synchronization
  - > 53,000,000 syncs
    - 99.9% comes from use of Vector
  - Benchmark is single threaded, all of it is useless
- Tried
  - Remove synchronizations
  - Switching to ArrayList
  - Improving the algorithm

Execution Time of SpecJVM _209_db, Hotspot Server



	Original	Use ArrayList	Use ArrayList and other minor	Change Shell Sort to Merge Sort	All
Original	35.5	32.6	28.5	16.2	12.8
Without Syncs	30.3	32.5	28.5	14.0	12.8

Lessons

- Synchronization cost can be substantial
  - 10-20% for DB benchmark
  - Consider replacing all uses of Vector, Hashtable and Stack
- Use profiling
- Use better algorithms!
  - Cost of stupidity higher than cost of synchronization
  - Used built-in merge sort rather than hand-coded shell sort

Designing Fast Code

- Make it right before you make it fast
- Avoid synchronization
  - Avoid sharing across threads
  - Don't lock already-protected objects
  - Use immutable fields and objects
  - Use volatile (carefully)
- Avoid contention
  - Reduce lock scopes
  - Reduce lock durations

Unsynchronized Reads/Writes of References

- Beware of unsynchronized getX/setX methods that return a reference
  - Same problems as double check
  - Doesn't help to synchronize only setX

```
private Color color;
void setColor(int rgb) {
     color = new Color(rgb);
     }
Color getColor() {
     return color;
     }
```

Problems

- Don't assume another thread will see your writes
  - Just because you did them
- Calling sleep doesn't guarantee you see changes made while you slept
  - Nothing to force thread that called stop to push change out of registers/cache

Wrap-up

- Cost of synchronization operations can be significant
  - But cost of *needed* synchronization rarely is
- Thread interaction needs careful thought
  - But not too clever
- Need for synchronization...

Wrapup - Synchronization

- Communication between threads
  - Requires both threads to synchronize
    - Or communication through volatile fields
- Synchronizing everything
  - Is rarely necessary
  - Can be expensive (3%-20% overhead)
  - May lead to deadlock
  - May not provide enough synchronization
    - e.g., transactions