CMSC 433 Fall 2014
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(Some slides due to Rance Cleaveland)

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Lecture 6
Synchronization and Visibility

Covers JCIP Chap 2.2, 3.1

Atomicity

- Atomic operations are uninterruptible
  - They have either not started, or have finished: there is no "middle"
  - Procedural abstraction: permits method calls to be viewed as atomic, even though they consist of multiple operations
  - Concurrency can break procedural abstraction!
- Thread-safety: use of locking or other mechanisms to give illusion of atomicity to method calls *vis à vis* a class specification

Atomicity in Java

- What is guaranteed to be atomic in Java?
  - Reads, writes of non-64-bit primitive types (ints, chars, floats, etc.)
  - Reads, writes of references (32-bit and 64-bit)
- Guarantee: if you read a non-64-bit primitive-typed variable, you will see a value that some thread actually wrote to it
  - This guarantee is sometimes called *out-of-thin-air safety*

64-bit Reads, Writes

- Not guaranteed to be atomic!
  - E.g. `double x = 1.0;`
    - x is a 64-bit variable
    - Java spec says a JVM can implement this as two 32-bit writes
    - If a thread reads this variable during a write operation to it, it can get 32 “stale” bits and 32 “fresh” bits (a value that no thread ever wrote)!
  - Other data type like this: `long`
- To safely reads or write these variables we need to use synchronization

`Atomic*` classes

- `AtomicInteger`
- `AtomicBoolean`
- `AtomicLong`
- `AtomicReference<V>`
- …

- Operations `get()` and `set()`, and more
  – More later

Synchronization and Visibility

- Two aspects to an operation
  - Atomicity: does it have a "middle" that other threads can see?
  - Visibility: when is its effect perceived by other threads?
- Visibility is tricky

What Can Following Code Do?

(adapted from textbook, Listing 3.1)

```
public class NoVisibilityAlt {
  private static boolean ready;
  private static int number;

  private static class ReaderThread
    extends Thread {
    public void run () {
      while (!ready)
        Thread.yield ();
      System.out.println (number);
    }
  }
  public static void main(…) {
    new ReaderThread ().start ();
    number = 42;
    ready = true;
  }
}
```

- Most of the time it prints 42
- It could print 0
- It could even never terminate!
- Why?
  - Assignments to number, ready are atomic
  - However, visibility is not guaranteed
    - Java language specification lets compilers reorder statements, use caches, etc.
    - So while `number = 42` is atomic, the operation's effect may not be visible until after thread executes `println`!
    - In this case, previous stale value of number is what thread sees

Reordering in Java

- Java permits effects of statements to be *reordered*
  - `number = 42` could update thread-local cache
  - `ready = true` could update main memory
  - Other thread might only see main memory and not cache
- Reorderings often driven by memory hardware / firmware
  - Sequential behavior is preserved
  - Behavior of multi-threaded applications is problematic

Dealing with Visibility: `volatile`

- Previous example highlights visibility anomalies in Java
  - Java language spec allows (unrelated) operations to be reordered, so long as sequential consistency is preserved

    e.g.

    ```
    new ReaderThread ().start ();
    ready = true;
    number = 42;
    ```

    Assignments to number, ready can be reordered because they are unrelated
  - This can wreak havoc with threaded applications
- Some visibility problems can be fixed by declaring variables to be volatile
  - Declaring variables volatile indicates they are shared, and operations should not be reordered
  - E.g.

    ```
    private static volatile boolean ready;
    private static volatile int number;
    ```
  - Ensures that assignment to number occurs before ready is made true, and that there is no delay in thread seeing truth of ready
- Volatility does not make non-reads/writes atomic, however! It just affects visibility of atomic operations

Visibility and Locking (1/3)

- Locking also fixes visibility problems!
- Consider following fragment from synchronized BoundedCounter class:

```
public synchronized int current () {
     return value;
}
…
public synchronized void inc () {
     if (!isMaxed()) ++value;
}
```

- Further suppose a class implementing threads that increment a counter:

```
public class BoundedCounterIncThread implements Runnable {
  private BoundedCounter counter;
  BoundedCounterIncThread (BoundedCounter c){ this.counter = c; }
  public void run () { counter.inc(); }
}
```

Visibility and Locking (2/3)

- What is output of following?

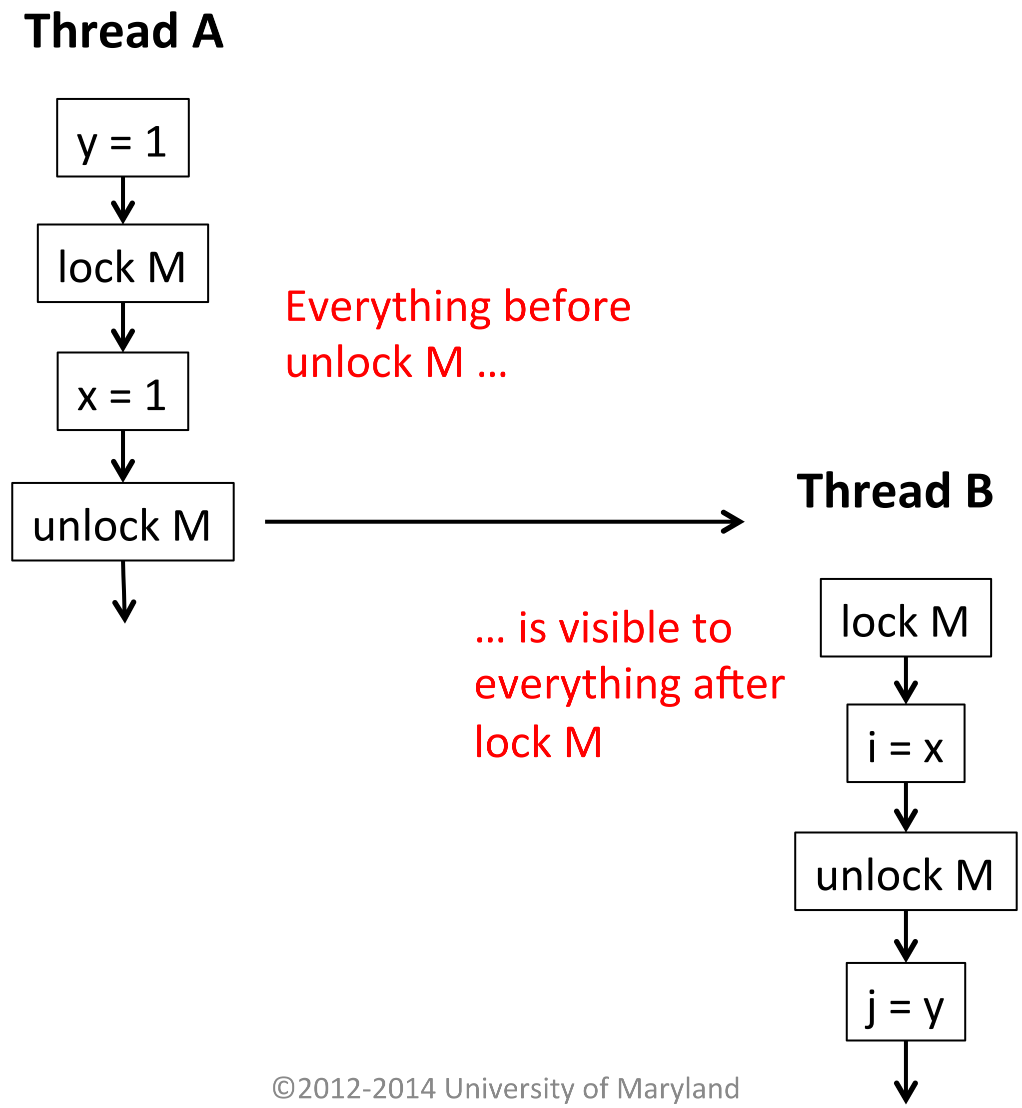
```
public static void main(String[] args) throws
InterruptedException {
  BoundedCounter c = new BoundedCounter (2);
  Thread t1 = new Thread (new BoundedCounterIncThread (c));
  Thread t2 = new Thread (new BoundedCounterIncThread (c));
  t1.start();
  t2.start();
  t1.join();
  t2.join();
  System.out.println (c.current());
}
```

Visibility and Locking (3/3)

- Answer: 2
- Why?

  The results of the inc operations performed by one thread are visible to the other
- A general principle of Java
  - When a lock is released, operations guarded by the lock become visible to operations following the reacquisition of the **same lock**
  - In the previous example, the intrinsic lock of the **BoundedCounter** object **c** plays this role!

Locking and Visibility (from textbook)



Another way to view volatile

This

- volatile int x;
  - x = …; // write
  - … = … x …; // read

is equivalent to this

- SyncInt x = new SyncInt ();
  - x.set(…); // write
  - … = … x.get() …; // read

```
public class SyncInt {
  private int value; // guarded by this

  public synchronized int get() { return value; }
  public synchronized void set(int x) { value = x; }
}
```

Visibility in Detail

- The Java Memory Model (part of the Java Language Specification) defines precisely how visibility works
  - JCIP Chapter 16; more detail next time
- Key notions
  - Event sequences
  - “happens-before”
- Intuitively: if an event happens before another, the effect of the first event is visible to the second