Some JMM Issues for Programmers

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Based in part on slides from talks at JavaOne 2000

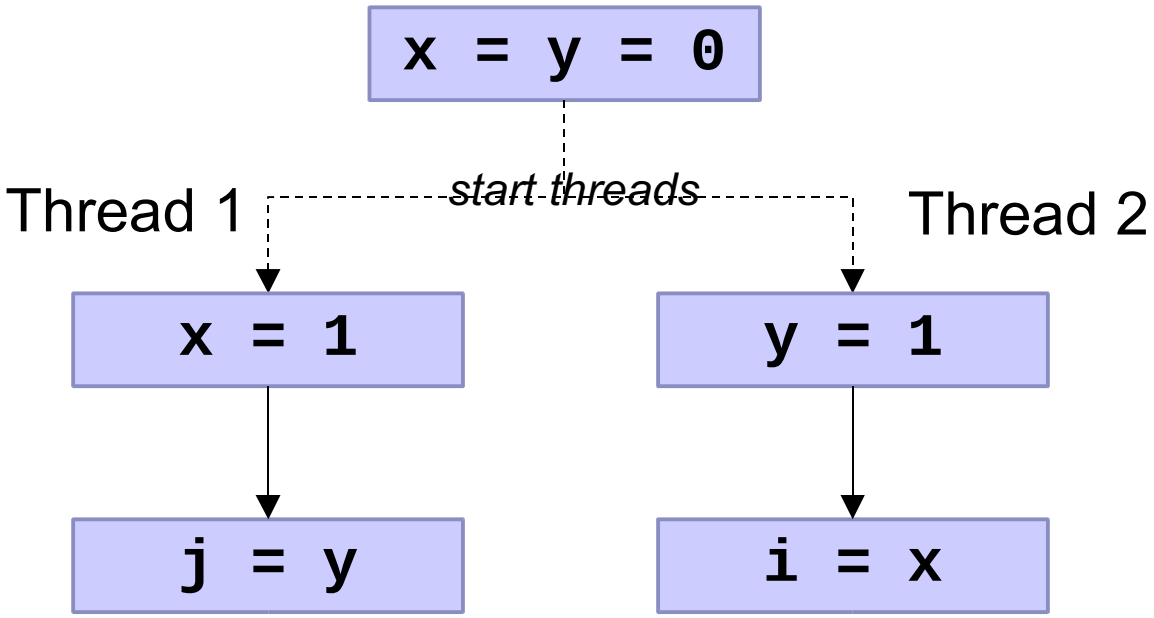
Outline

- Programmer view of memory model
  - **`synchronized`**, **`volatile`**, **`final`**
- Some issues and examples
  - When and why to synchronize
  - Initialization
  - Documentation

Three Aspects of Synchronization

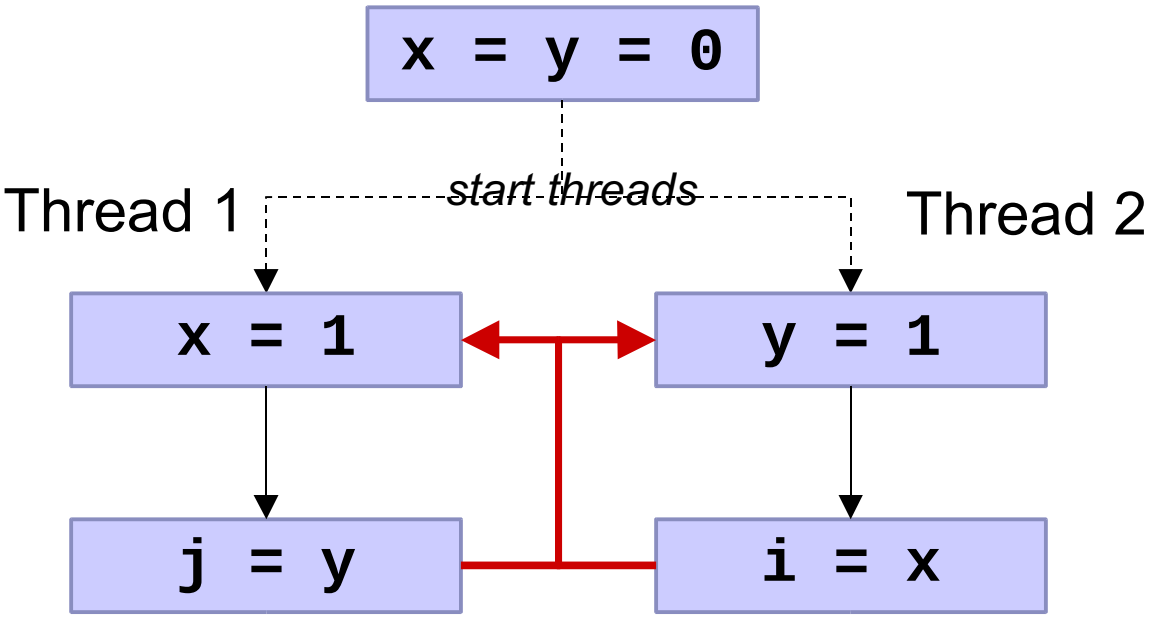
- Atomicity
  - Locking to obtain mutual exclusion
  - Atomic read/write granularity
- Visibility
  - Ensuring that changes to object fields made in one thread are seen in other threads
- Ordering
  - Ensuring that you aren't surprised by the order in which statements are executed

Quiz Time



an thi re ult in i = 0 and j = 0?

Answer: Yes!



How an i = 0 and j = 0?

How Can This Happen?

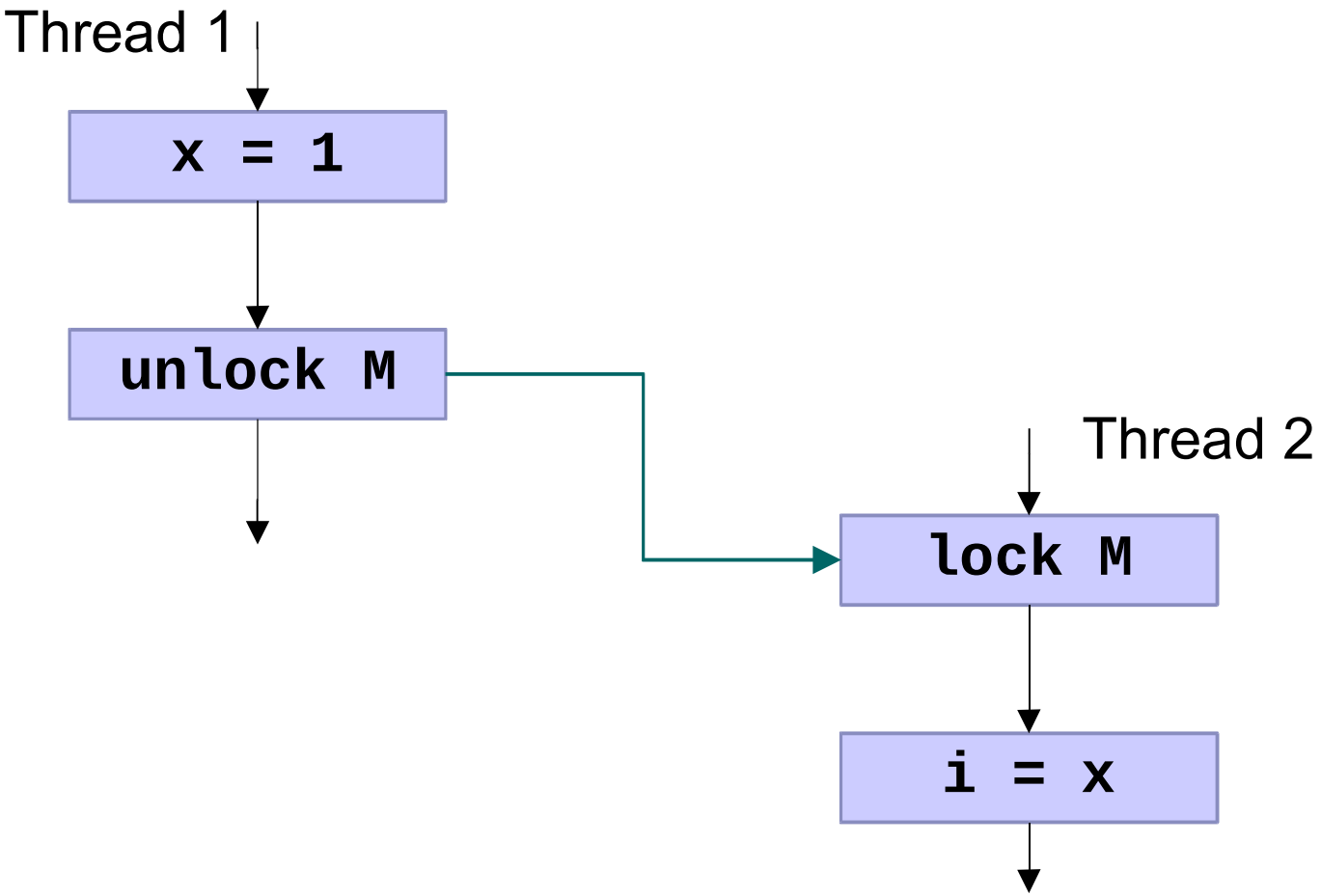
- Compiler can reorder statements
  - Or keep values in registers
- Processor can reorder them
- On multiprocessor, values held in caches without synchronizing global memory

- Must use synchronization to enforce visibility and ordering
  - As well as mutual exclusion

Programmer view of Synchronization

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

When Are Actions Visible to Other Threads?



Volatile Fields

- Volatile reads/writes go directly to memory
  - Sequentially consistent with respect to each other and to monitor enter/exit.
  - Can’t be cached in registers or local memory
  - In quiz example, if x and y are volatile, it is im−possible to see i = 0 and j = 0
- Reads and writes of volatile longs and dou−bles are atomic
- But many JVMs don’t comply

Using Volatile

```
class Animator implements Runnable {
   volatile boolean stop = false;
   public void stop() { stop = true; }
   public void run() {
     while (!stop)
       oneStep();
   }
   void oneStep() { /*...*/ }
}
```

- **`stop`** must be declared volatile
  - Otherwise, compiler could keep in register

Limitations of Volatile

```
class Future { // DO NOT USE!
  private volatile boolean ready = false;
  private Object data = null;
  public Object get() {
    if (!ready) return null;
    return data;
  }
  // only one thread ever calls put
  public void put(Object o) {
    data = o;
    ready = true;
  }
}
```

- Reading volatile does not "guard" read of non-volatile

Final Fields

- JLS ch17 does not even mention final fields
  - In part because it predated "blank finals"
  - So, currently, **`final`** has no memory semantics
- Any plausible JMM should guarantee that:

  A final field initialized in constructor is always read as having its final value

  (... unless programmers do something stupid.)
  - CPJ2e says this is true now!
  - Details are intrinsically messy since there is no syntax to say an array element is final
    - Impacts java.lang.String

JMM impact on programmers

- Programs with a lot of synchronization run slowly
  - Even if they do not generate threads
- Sophisticated programmers who try to mini−mize synchronization often get it wrong
  - Some clever idioms are not guaranteed to work
  - A clear JMM is needed to guide use
- Unsophisticated programmers often produce unsafe code that "works"
  - Even "works" on Sparc and Intel MPs, but isn’t correct according to any plausible JMM

Essential synchronization is rarely a bottleneck

- Synch only in places where threads interact
  - Needs careful thought, good documentation
  - But can be more error−prone than blanket synchronization
    - Races harder to debug than liveness failures
    - Longer development time
- Synchronizing thread local objects is useless
  - But in practice accounts for majority of synchronizations

Library classes

- Library code cannot know whether it is used by multiple threads.
  - Usually synchronized even when multithreaded use extremely rare
    - java.io Streams, Vector, StringBuffer, ...
- The most frequent cause of useless synch
  - In places where not required in current context, but is required in other contexts.
  - Optimization algorithms to detect and eliminate such locks are still not practical.

Writing safe reusable code

How to efficiently synch code when you don't know usage contexts

- Provide only large units of granularity?
  - Can enable more efficient internals
  - Can lead to ugly, awkward interfaces
- Impose usage restrictions?
  - Examples: Swing, EJB
  - Compliance generally uncheckable
- Supply safe versions layered over unsafe?
  - Example: java.util synchronizedCollection
  - But best MT code is not always synchronized version of best single−threaded code

Lock granularity example

Create new value and add to Hashtable only if key absent

- Naïve unsynched user code is unsafe:

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

- Synching user method causes useless synch
- Directly support?

```
Object putIfAbsent(Object k, Callback c)
```

Field Access Methods

- Sometimes, synchronizing access methods is obviously the right thing to do:

  `account.getTotalBalance()`

  - Consequent fine−granularity locking is desirable

- In other cases it is a useless bottleneck
  - And doesn't preserve intended invariants:

  `x = point.getX(); y = point.getY();`

- Often, the best decision is just to omit access methods
  - **`queue`** doesn't need **`getSize()`**

Unsynchronized Accessors

(or equivalently, public raw field access)

- Sometimes stale values OK
  - or avoidable by using volatile fields

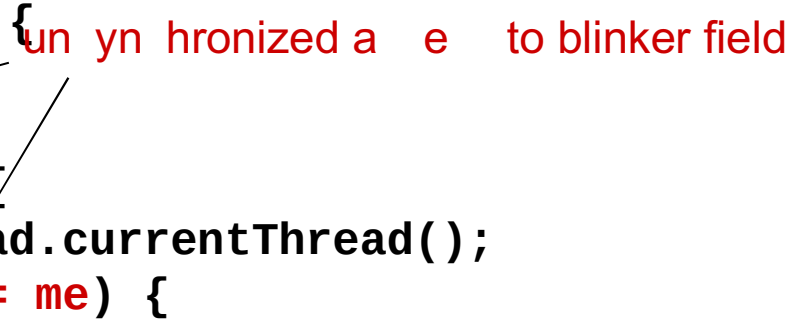
```
thermometer.getTemperature()
```

- Almost always dangerous for references
  - Read of ref doesn't guarantee read of field
  - Doesn't help to synchronize only setX

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

Color getColor() { return color; }
```

Example: demo code

```
Thread blinker = null;
public void start() {
  blinker = new Thread(this);
  blinker.start();
}

public void stop() {
  blinker = null;}

public void run() {
  Thread me = Thread.currentThread();
  while (blinker == me) {
    try {Thread.sleep(delay);}
    catch (InterruptedException e) {
      return;
    }
    repaint();
  }
}
```



Initialization

- Rules for finals cover only one case of (conceptually) "write once" fields.
- Most other cases require synch:
  - When no−arg constructors are mandated
  - When deserializing
  - Build−then−release patterns

```
synchronized Bean makeBean() {
  Bean b = new MyBean();
  b.setAttributeA("finalValue");
  return b;
}
```

  - Lazy initialization

Lazy Initialization

Basic version:

```
class Service {
  Parser parser = null;
  public synchronized void command(){
    if (parser == null)
      parser = new Parser(...);
    doCommand(parser.parse(...));
   }
  // ...
}
```

Initialization checks

```
class ServiceV2 {
  Parser parser = null;
  synchronized Parser getParser() {
    Parser p = parser;
    return (p != null) ? p :
      (parser = new Parser());
  }
  public void command(...) {
    doCommand(getParser().parse(...));
  }
}
```

Isolating checks reduces lock durations, usually improving MT performance

Single−Check

```
class ServiceV3 { // DO NOT USE
   Parser parser = null;
   Parser getParser() { // no synch
     Parser p = parser;
     return (p != null) ? p :
       (parser = new Parser());
   }
}
```

- Possible to see p as non−null, but not see p's fields initialized when p is then used
- Possible to create more than one Parser

Double−Check

```
class ServiceV4 { // DO NOT USE
   Parser parser = null;
   Parser getParser() {
     if (parser == null)
       synchronized(this) {
         if (parser == null)
           parser = new Parser();
       }
     return parser;
   }
}
```

- Still possible to see parser as non−null, but not see parser's fields initialized

Static Singletons

```
class ServiceV5 {
   static class ServiceParser {
     static Parser it = new Parser();
   }
   Parser getParser() {
     return ServiceParser.it;
   }
 }
```

- Embed parser object in own class
  - Only useful for statics
- First use of a class forces class initialization
  - Later uses guaranteed to see class initialization
  - No explicit check needed

Isolation in Swing

- AWT thread owns all Swing components
  - No other thread may access them
- Eliminates need for locking
  - Still need care during initialization
- Can be fragile
  - Every programmer must obey rules
- But rules are usually easy to follow
  - Most Swing components accessed in handlers triggered within AWT thread

Accessing Isolated Objects

- Need safe inter−thread communication
- Swing uses runnable Event objects
  - Created by user thread
  - Serviced by AWT thread

```
SwingUtilities.
   invokeLater(new Runnable(){
     public void run() {
       statusMessage.setText("Running");
     }});
```

Some "Expert" issues

- Explicit memory barriers
  - For example: Only sometimes would you like a read of a certain reference to force fresh reads of referenced object fields
- CompareAndSwap (CAS)
  - Or transactional memory, etc
  - Most optimistic algorithms are not directly implementable otherwise.

Compliance

- It would be useful to check whether something claiming to be "thread safe" actually is.
- Safety means "bad things never happen"
  - Can only blindly check for a few bad things
    - Mainly surrounding data races
    - Even these are merely *almost* always bad
  - Others rely on programmer assertions and documentation
    - Leads to several hard problems...

Relative safety

- Writing code that is safe only within intended usage contexts is not a sin.
  - But not documenting these intentions is.
  - Documentation of such classes is hard work.
- ***Unsafe*** usually boils down to:

  A method or class imposes extra contextual side conditions that must hold for its intended post−conditions, effects, or invariants to hold.
  - Even unsafe Java code preserves minimal safety properties: no wild pointers, etc
- Potential non−liveness defined similarly, but phrased in terms of progress guarantees

Sample policy constraints

- Ownership
  - Method m is only called from Thread t.
  - Object x is only accessed by Thread t.
  - Object x is only accessed by Object y.
- Dynamic Exclusion
  - Either Object x is only accessed by one thread, or current thread holds an exclusion lock cover−ing x for duration of method m.
- Ordering
  - Method m2 is called only after method m1
  - Lock L2 is held only if lock L1 is held
- Blocking
  - Callback method m does not wait()

Specifying safety properties

- Need ways to explicitly state constraints, pre−conditions, etc
  - Many fall under a few common categories
  - A useful subset can be expressed via **`assert`**
- Potentially amenable to tool−based compli−ance checking
  - But requires a more formal approach than most programmers are willing to undertake
  - But concurrent components often have compli−cated specifications

Documenting constraints

- Failure−based approach:
  - List specific race hazards, etc and their conse−quences
    - List common errors that lead to them
  - Not always possible due to polymorphism
- Constructive approach:
  - Explain in documentation exactly how to meet constraints in common usage contexts.
  - But not as helpful when people encounter un−common contexts.

Conclusions

- A memory model can:
  - Clarify which low−synch idioms are effective
  - Enable more optimization
  - Make it easier to find mistakes
  - Enable better automated safety checks