Using Java 8 Lambdas And Stampedlock To Manage Thread Safety

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What is StampedLock?

- **Java 8 synchronizer**
- **Allows optimistic reads**
  - **ReentrantReadWriteLock only has pessimistic reads**
- **Not reentrant**
  - **This is *not* a feature**
- **Use to enforce invariants across multiple fields**
  - **For simple classes, synchronized/volatile is easier and faster**

Pessimistic Exclusive Lock (write)

```
public class StampedLock {
  long writeLock() // never returns 0, might block

  // returns new write stamp if successful; otherwise 0
  long tryConvertToWriteLock(long stamp)

  void unlockWrite(long stamp) // needs write stamp


// and a bunch of other methods left out for brevity
```

Pessimistic Non-Exclusive Lock (read)

```
public class StampedLock { // continued ...
  long readLock() // never returns 0, might block

  // returns new read stamp if successful; otherwise 0
  long tryConvertToReadLock(long stamp)

  void unlockRead(long stamp) // needs read stamp

  void unlock(long stamp) // unlocks read or write
```

Optimistic Non-Exclusive Read (No Lock)

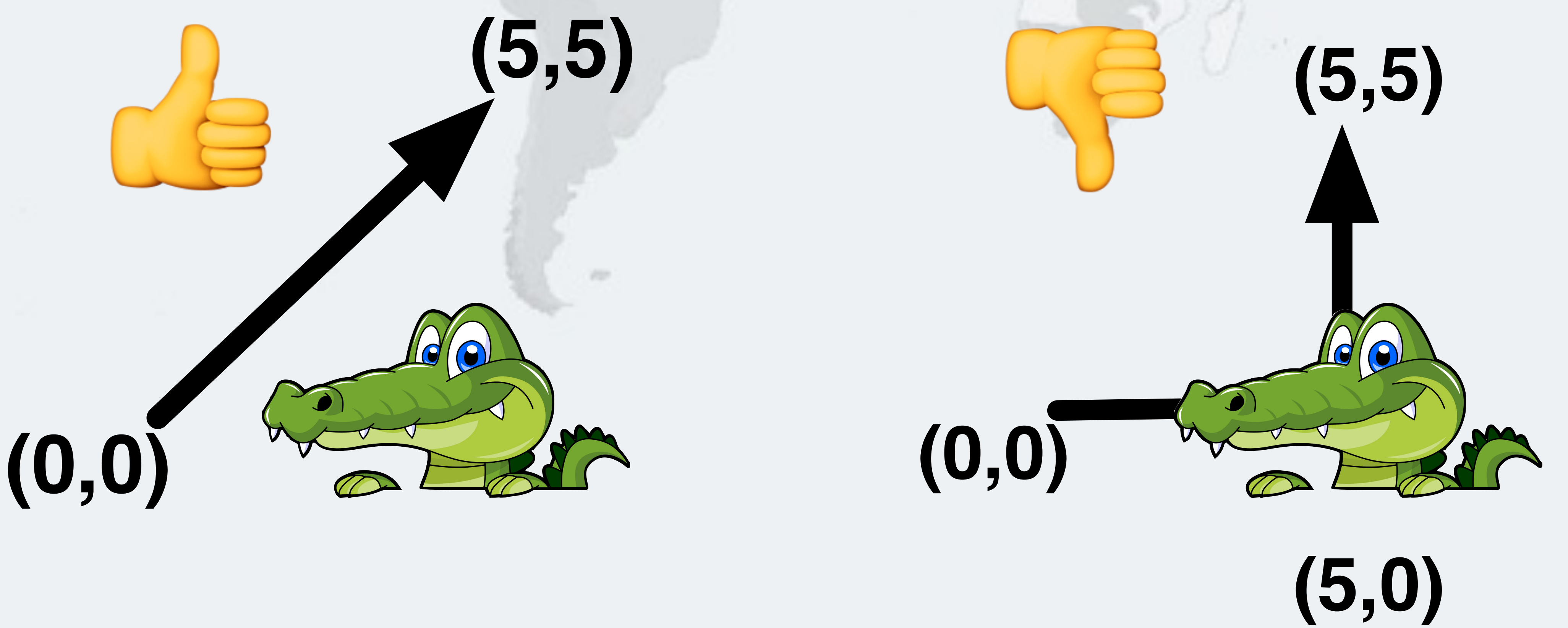
```
public class StampedLock { // continued ...
  // could return 0 if a write stamp has been issued
  long tryOptimisticRead()

  // return true if stamp was non-zero and no write
  // lock has been requested by another thread since
  // the call to tryOptimisticRead()
  boolean validate(long stamp)
```

Sifis the Crocodile (RIP)

Introducing the Position Class

- **When moving from (0,0) to (5,5), we want to go in a diagonal line**
  - **We don't want to ever see our position at (0,5) or (5,0)**



Moving Our Position

- **Similar to ReentrantLock code**

```
public class Position {
  private double x, y;
  private final StampedLock sl = new StampedLock();

  // method is modifying x and y, needs exclusive lock
  public void move(double deltaX, double deltaY) {
    long stamp = sl.writeLock();
    try {
      x += deltaX;
      y += deltaY;
    } finally {
      sl.unlockWrite(stamp);
    }
  }
```

Using AtomicReference

- **do-while until we finally manage to move**

```
public class PositionAtomicNonBlocking {
  private final AtomicReference<double[]> xy =
      new AtomicReference<>(new double[2]);

  public void move(double deltaX, double deltaY) {
   double[] current, next = new double[2];
    do {
      current = xy.get();
      next[0] = current[0] + deltaX;
      next[1] = current[1] + deltaY;
    } while(!xy.compareAndSet(current, next));
  }
```

CompareAndSwap with sun.misc.Unsafe

- **First we find the memory location offset of the field "xy"**

```
public class PositionUnsafeNonBlocking {
  private final static Unsafe UNSAFE =
      Unsafe.getUnsafe();
  private static final long XY_OFFSET;
  static {
    try {
      XY_OFFSET = UNSAFE.objectFieldOffset(
          PositionUnsafeNonBlocking.class.
            getDeclaredField("xy"));
    } catch (NoSuchFieldException e) {
      throw new ExceptionInInitializerError(e);
    }
  }
  private volatile double[] xy = new double[2];
```

CompareAndSwap with sun.misc.Unsafe

- **Our move() method is similar to AtomicReference**

```
public void move(double deltaX, double deltaY) {
  double[] current, next = new double[2];
  do {
    current = xy;
    next[0] = current[0] + deltaX;
    next[1] = current[1] + deltaY;
  } while (!UNSAFE.compareAndSwapObject(
      this, XY_OFFSET, current, next));
}
```

Single Writer with sun.misc.Unsafe

- **If we can *guarantee* that only *one thread* will ever write**

```
public void move(double deltaX, double deltaY) {
  double[] newXY = xy.clone();
  newXY[0] += deltaX;
  newXY[1] += deltaY;
  UNSAFE.putOrderedObject(this, XY_OFFSET, newXY);
}
```

- **Similar code for AtomicReference**

```
public void move(double deltaX, double deltaY) {
  double[] newXY = xy.get().clone();
  newXY[0] += deltaX;
  newXY[1] += deltaY;
  xy.lazySet(newXY);
}
```

So When To Use Unsafe?

- **Simple answer: never**
- **Reputation of "running close to bare metal"**
  - **But just like "Quick Sort", it can be slower than alternatives**
- **AtomicFieldUpdaters have increased in performance**
  - **http://shipilev.net/blog/2015/faster-atomic-fu/**
- **Next: VarHandles in Java 9**

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VarHandles Instead of Unsafe/AtomicReference

- **VarHandles remove biggest temptation to use Unsafe**
  - Java 9: https://bugs.openjdk.java.net/browse/JDK-8080588
- **Seems to be as fast, or faster, than Unsafe**
- **Additional cool features, such as:**
  - getVolatile() / setVolatile()
  - getAcquire() / setRelease()
  - getOpaque() / setOpaque()
  - compareAndSet(), returning boolean
  - compareAndExchangeVolatile(), more like a proper CAS
  - fullFence(), acquireFence(), releaseFence(), loadLoadFence(), storeStoreFence()

VarHandles Instead of Unsafe/AtomicReference

- **First step is to set up the VarHandle**

```
public class PositionVarHandlesNonBlocking {
  private static final VarHandle XY_HANDLE;

  static {
    try {
      XY_HANDLE = MethodHandles.lookup().findVarHandle(
        PositionVarHandlesNonBlocking.class,
        "xy", double[].class);
    } catch (ReflectiveOperationException e) {
      throw new Error(e);
    }
  }
```

Note: Exact API might still change

CompareAndSet with VarHandle

- **Our move() method almost identical to "Unsafe" version**

```
public void move(double deltaX, double deltaY) {
  double[] current, next = new double[2];
  do {
    current = xy;
    next[0] = current[0] + deltaX;
    next[1] = current[1] + deltaY;
  } while (!XY_HANDLE.compareAndSet(this, current, next));
}
```

compareAndExchangeVolatile() with VarHandle

- **Instead of having to read the volatile field, get it from CAS**

```
public void move(double deltaX, double deltaY) {
  double[] current, swapResult = xy, next = new double[2];
  do {
    current = swapResult;
    next[0] = current[0] + deltaX;
    next[1] = current[1] + deltaY;
  }
  while ((swapResult =
    (double[]) XY_HANDLE.compareAndExchangeVolatile(
      this, current, next)) != current);
}
```

Back to StampedLock: Optimistic Read

- **Avoids pessimistic read locking**
- **Better throughput than ReadWriteLock**

Code Idiom for Optimistic Read

```
public double optimisticRead() {
  long stamp = sl.tryOptimisticRead();
  double currentState1 = state1,
         currentState2 = state2, ... etc.;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentState1 = state1;
      currentState2 = state2, ... etc.;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return calculateSomething(currentState1, currentState2);
}
```

Code Idiom for Optimistic Read

```
public double optimisticRead() {
  long stamp = sl.tryOptimisticRead();
  double currentState1 = state1,
         currentState2 = state2, ... etc.;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentState1 = state1;
      currentState2 = state2, ... etc.;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return calculateSomething(currentState1, currentState2);
}
```

We get a stamp to use for the optimistic read

Code Idiom for Optimistic Read

```
public double optimisticRead() {
  long stamp = sl.tryOptimisticRead();
  double currentState1 = state1,
         currentState2 = state2, ... etc.;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentState1 = state1;
      currentState2 = state2, ... etc.;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return calculateSomething(currentState1, currentState2);
}
```

We read field values into local fields

Code Idiom for Optimistic Read

```
public double optimisticRead() {
  long stamp = sl.tryOptimisticRead();
  double currentState1 = state1,
         currentState2 = state2, ... etc.;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentState1 = state1;
      currentState2 = state2, ... etc.;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return calculateSomething(currentState1, currentState2);
}
```

Next we validate that no write locks have been issued in the meanwhile

Code Idiom for Optimistic Read

```
public double optimisticRead() {
  long stamp = sl.tryOptimisticRead();
  double currentState1 = state1,
         currentState2 = state2, ... etc.;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentState1 = state1;
      currentState2 = state2, ... etc.;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return calculateSomething(currentState
}
```

If they have, then we don't know if our state is clean

Thus we acquire a pessimistic read lock and read the state into local fields

Code Idiom for Optimistic Read

```
public double optimisticRead() {
  long stamp = sl.tryOptimisticRead();
  double currentState1 = state1,
         currentState2 = state2, ... etc.;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentState1 = state1;
      currentState2 = state2, ... etc.;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return calculateSomething(currentState1, currentState2);
}
```

Optimistic Read in our Position class

```
public double distanceFromOrigin() {
  long stamp = sl.tryOptimisticRead();
  double currentX = x, currentY = y;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentX = x;
      currentY = y;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return Math.hypot(currentX, currentY);
}
```

The shorter the code path from tryOptimisticRead() to validate(), the better the chances of success

Distance Calculation with AtomicReference

- **Extremely easy and very fast**

```
public double distanceFromOrigin() {
  double[] current = xy.get();
  return Math.hypot(current[0], current[1]);
}
```

Distance Calculation with Unsafe/VarHandle

- **Even easier**

```
public double distanceFromOrigin() {
  double[] current = xy;
  return Math.hypot(current[0], current[1]);
}
```

Conditional Change Idiom with StampedLock

```
public boolean moveIfAt(double oldX, double oldY,
                        double newX, double newY) {
  long stamp = sl.readLock();
  try {
    while (x == oldX && y == oldY) {
      long writeStamp = sl.tryConvertToWriteLock(stamp);
      if (writeStamp != 0L) {
        stamp = writeStamp;
        x = newX; y = newY;
        return true;
      } else {
        sl.unlockRead(stamp);
        stamp = sl.writeLock();
      }
    }
    return false;
  } finally { sl.unlock(stamp); }
}
```

Unlike ReentrantReadWriteLock, this will not deadlock

Previous Idiom is Only of Academic Interest

- **This is easier to understand, and faster!**

```
public boolean moveIfAt(double oldX, double oldY,
                        double newX, double newY) {
  long stamp = sl.writeLock();
  try {
    if (x == oldX && y == oldY) {
        x = newX;
        y = newY;
        return true;
    }
  } finally {
    sl.unlock(stamp);
  }
  return false;
}
```

Conditional Move with VarHandle

- **Multi-threaded is *much* faster than StampedLock version**

```
public void moveIfAt(double oldX, double oldY,
                     double newX, double newY) {
  double[] current = xy;
  if (current[0] == oldX && current[1] == oldY) {
    double[] next = {newX, newY};
    do {
     if (XY_HANDLE.compareAndSet(this, current, next))
        return;
      current = xy;
    } while (current[0] == oldX && current[1] == oldY);
  }
}
```

But is it correct? Good question! Difficult to test.

StampedLock Idioms are Difficult to Master

- **Instead, we can define static helper methods**
  - **Gang-of-Four Facade Pattern**
- **Lambdas make helper methods pluggable**

Moving with StampedLockIdioms

- **The old move() method**

```
public void move(double deltaX, double deltaY) {
  long stamp = sl.writeLock();
  try {
    x += deltaX;
    y += deltaY;
  } finally {
    sl.unlockWrite(stamp);
  }
}
```

- **Now looks like this**

```
public void move(double deltaX, double deltaY) {
  StampedLockIdioms.writeLock(sl, () -> {
    x += deltaX;
    y += deltaY;
  });
}
```

Our StampedLockIdioms

- **We simply call writeJob.run() inside the locked section**

```
public class StampedLockIdioms {
  public static void writeLock(StampedLock sl,
                               Runnable writeJob) {
    long stamp = sl.writeLock();
    try {
      writeJob.run();
    } finally {
      sl.unlockWrite(stamp);
    }
  }
  // ...
```

- **Checked exceptions would be an issue though**

Optimistic Read using StampedLockIdioms

- **Our old distanceFromOrigin**

```
public double distanceFromOrigin() {
  long stamp = sl.tryOptimisticRead();
  double currentX = x, currentY = y;
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      currentX = x;
      currentY = y;
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return Math.hypot(currentX, currentY);
}
```

Optimistic Read using StampedLockIdioms

- **Becomes this new mechanism**

```
public double distanceFromOrigin() {
  double[] current = new double[2];
  return StampedLockIdioms.optimisticRead(sl,
      () -> {
        current[0] = x;
        current[1] = y;
      },
      () -> Math.hypot(current[0], current[1]));
}
```

Our StampedLockIdioms.optimisticRead() Method

- **The reading.run() call would probably be inlined**

```
public static <T> T optimisticRead(
        StampedLock sl,
        Runnable reading,
        Supplier<T> computation) {
  long stamp = sl.tryOptimisticRead();
  reading.run();
  if (!sl.validate(stamp)) {
    stamp = sl.readLock();
    try {
      reading.run();
    } finally {
      sl.unlockRead(stamp);
    }
  }
  return computation.get();
}
```

Conditional Change using StampedLockIdioms

- **Our old moveIfAt()**

```
public boolean moveIfAt(double oldX, double oldY,
                        double newX, double newY) {
  long stamp = sl.readLock();
  try {
    while (x == oldX && y == oldY) {
      long writeStamp = sl.tryConvertToWriteLock(stamp);
      if (writeStamp != 0L) {
        stamp = writeStamp;
        x = newX; y = newY;
        return true;
      } else {
        sl.unlockRead(stamp);
        stamp = sl.writeLock();
      }
    }
    return false;
  } finally { sl.unlock(stamp); }
}
```

Optimistic Read using StampedLockIdioms

- **Becomes this new mechanism**

```
public boolean moveIfAt(double oldX, double oldY,
                        double newX, double newY) {
  return StampedLockIdioms.conditionalWrite(
      sl,
      () -> x == oldX && y == oldY,
      () -> {
        x = newX;
        y = newY;
      }
  );
```

Our StampedLockIdioms.conditionalWrite()

```
public static boolean conditionalWrite(
    StampedLock sl, BooleanSupplier condition,
    Runnable action) {
  long stamp = sl.readLock();
  try {
    while (condition.getAsBoolean()) {
      long writeStamp = sl.tryConvertToWriteLock(stamp);
      if (writeStamp != 0L) {
        action.run();
        stamp = writeStamp;
        return true;
      } else {
        sl.unlockRead(stamp);
        stamp = sl.writeLock();
      }
    }
    return false;
  } finally { sl.unlock(stamp); }
}
```

Using AtomicReference with Lambdas

- The old move() method

```
public void move(double deltaX, double deltaY) {
  double[] current, next = new double[2];
  do {
    current = xy.get();
    next[0] = current[0] + deltaX;
    next[1] = current[1] + deltaY;
  } while (!xy.compareAndSet(current, next));
}
```

- Now looks like this

```
public void move(double deltaX, double deltaY) {
  xy.accumulateAndGet(new double[2], (current, next) ->  {
    next[0] = current[0] + deltaX;
    next[1] = current[1] + deltaY;
    return next;
  });
}
```

Conclusion

- **Java 8 Lambdas help to correctly use concurrency idioms**
  - **Example in JDK is AtomicReference.accumulateAndGet()**
  - **Might increase object creation rate**
    - **Although escape analysis might minimize this**
- **Performance of new Java 9 VarHandles as good as Unsafe**
  - **Very few use cases for Unsafe going forward**
  - **Looking forward to seeing the JDK concurrency classes rewritten**
    - **ConcurrentLinkedQueue, ConcurrentHashMap, Random, CopyOnWriteArrayList, ForkJoinPool, etc.**
    - **Basically any class that does any concurrency …**

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