Java 8 Concurrency Tutorial: Synchronization and Locks

April 30, 2015  
Welcome to the second part of my Java 8 Concurrency Tutorial out of a series of guides teaching multi-threaded programming in Java 8 with easily understood code examples. In the next 15 min you learn how to synchronize access to mutable shared variables via the synchronized keyword, locks and semaphores.

* Part 1: [Threads and Executors](https://winterbe.com/posts/2015/04/07/java8-concurrency-tutorial-thread-executor-examples/)
* Part 2: Synchronization and Locks
* Part 3: [Atomic Variables and ConcurrentMap](https://winterbe.com/posts/2015/05/22/java8-concurrency-tutorial-atomic-concurrent-map-examples/)

The majority of concepts shown in this article also work in older versions of Java. However the code samples focus on Java 8 and make heavy use of lambda expressions and new concurrency features. If you're not yet familiar with lambdas I recommend reading my [Java 8 Tutorial](https://winterbe.com/posts/2014/03/16/java-8-tutorial/) first.

For simplicity the code samples of this tutorial make use of the two helper methods sleep(seconds) and stop(executor) as defined [here](https://github.com/winterbe/java8-tutorial/blob/master/src/com/winterbe/java8/samples/concurrent/ConcurrentUtils.java).

Synchronized[**#**](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/#synchronized)

In the [previous tutorial](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/(/posts/2015/04/07/java8-concurrency-tutorial-thread-executor-examples/)) we've learned how to execute code in parallel via executor services. When writing such multi-threaded code you have to pay particular attention when accessing shared mutable variables concurrently from multiple threads. Let's just say we want to increment an integer which is accessible simultaneously from multiple threads.

We define a field count with a method increment() to increase count by one:

int count = 0;

void **increment**() {

    count = count + 1;

}

When calling this method concurrently from multiple threads we're in serious trouble:

ExecutorService executor = Executors.**newFixedThreadPool**(2);

IntStream.**range**(0, 10000)

    .**forEach**(i -> executor.**submit**(this::increment));

**stop**(executor);

System.out.**println**(count);  *// 9965*

Instead of seeing a constant result count of 10000 the actual result varies with every execution of the above code. The reason is that we share a mutable variable upon different threads without synchronizing the access to this variable which results in a [race condition](http://en.wikipedia.org/wiki/Race_condition).

Three steps have to be performed in order to increment the number: (i) read the current value, (ii) increase this value by one and (iii) write the new value to the variable. If two threads perform these steps in parallel it's possible that both threads perform step 1 simultaneously thus reading the same current value. This results in lost writes so the actual result is lower. In the above sample 35 increments got lost due to concurrent unsynchronized access to count but you may see different results when executing the code by yourself.

Luckily Java supports thread-synchronization since the early days via the synchronized keyword. We can utilize synchronized to fix the above race conditions when incrementing the count:

synchronized void **incrementSync**() {

    count = count + 1;

}

When using incrementSync() concurrently we get the desired result count of 10000. No race conditions occur any longer and the result is stable with every execution of the code:

ExecutorService executor = Executors.**newFixedThreadPool**(2);

IntStream.**range**(0, 10000)

    .**forEach**(i -> executor.**submit**(this::incrementSync));

**stop**(executor);

System.out.**println**(count);  *// 10000*

The synchronized keyword is also available as a block statement.

void **incrementSync**() {

    synchronized (this) {

        count = count + 1;

    }

}

Internally Java uses a so called *monitor* also known as [monitor lock or intrinsic lock](https://docs.oracle.com/javase/tutorial/essential/concurrency/locksync.html) in order to manage synchronization. This monitor is bound to an object, e.g. *when using synchronized methods each method share the same monitor of the corresponding object.*

All implicit monitors implement the *reentrant* characteristics. Reentrant means that locks are bound to the current thread. A thread can safely acquire the same lock multiple times without running into deadlocks (e.g. a synchronized method calls another synchronized method on the same object).

**import** java.util.concurrent.ExecutorService;  
**import** java.util.concurrent.Executors;  
**import** java.util.stream.IntStream;  
  
**public class** Synchronized1 {  
  
 **private static final int *NUM\_INCREMENTS*** = 10000;  
  
 **private static int** *count* = 0;  
  
 **public static void** main(String[] args) {  
 *testSyncIncrement*();  
 *testNonSyncIncrement*();

*//print out  
 // Sync: 10000  
 // NonSync: 9967*

}  
  
 **private static void** testSyncIncrement() {  
 *count* = 0;  
 ExecutorService executor = Executors.*newFixedThreadPool*(2);  
  
 IntStream.*range*(0, ***NUM\_INCREMENTS***)  
 .forEach(i -> executor.submit(Synchronized1::*incrementSync*));  
  
 ConcurrentUtils.*stop*(executor);  
 System.***out***.println(**" Sync: "** + *count*);  
 }  
  
 **private static void** testNonSyncIncrement() {  
 *count* = 0;  
 ExecutorService executor = Executors.*newFixedThreadPool*(2);  
  
 IntStream.*range*(0, ***NUM\_INCREMENTS***)  
 .forEach(i -> executor.submit(Synchronized1::*increment*));  
  
 ConcurrentUtils.*stop*(executor);  
 System.***out***.println(**"NonSync: "** + *count*);  
 }  
  
 **private static synchronized void** incrementSync() {  
 *count* = *count* + 1;  
 }

***private static void*** *incrementSync() {* ***synchronized*** *(Synchronized2.****class****) {  
 count = count + 1;  
 }  
 }*

**private static void** increment() {  
 *count* = *count* + 1;  
 }  
  
}

Locks[**#**](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/#locks)

Instead of using implicit locking via the synchronized keyword the Concurrency API supports various explicit locks specified by the Lock interface. Locks support various methods for finer grained lock control thus are more expressive than implicit monitors.

Multiple lock implementations are available in the standard JDK which will be demonstrated in the following sections.

ReentrantLock[**#**](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/#reentrantlock)

The class ReentrantLock is a mutual exclusion lock with the same basic behavior as the implicit monitors accessed via the synchronized keyword but with extended capabilities. As the name suggests this lock implements reentrant characteristics just as implicit monitors.

Let's see how the above sample looks like using ReentrantLock:

ReentrantLock lock = new **ReentrantLock**();

int count = 0;

void **increment**() {

    lock.**lock**();

    try {

        count++;

    } finally {

        lock.**unlock**();

    }

}

A lock is acquired via lock() and released via unlock(). It's important to wrap your code into a try/finally block to ensure unlocking in case of exceptions. This method is thread-safe just like the synchronized counterpart. If another thread has already acquired the lock subsequent calls to lock() pause the current thread until the lock has been unlocked. Only one thread can hold the lock at any given time.

Locks support various methods for fine grained control as seen in the next sample:

ExecutorService executor = Executors.**newFixedThreadPool**(2);

ReentrantLock lock = new **ReentrantLock**();

executor.**submit**(() -> {

    lock.**lock**();

    try {

**sleep**(1);

    } finally {

        lock.**unlock**();

    }

});

executor.**submit**(() -> {

    System.out.**println**("Locked: " + lock.**isLocked**());

    System.out.**println**("Held by me: " + lock.**isHeldByCurrentThread**());

    boolean locked = lock.**tryLock**();

    System.out.**println**("Lock acquired: " + locked);

});

**stop**(executor);

While the first task holds the lock for one second the second task obtains different information about the current state of the lock:

Locked: true

Held by me: false

Lock acquired: false

The method tryLock() as an alternative to lock() tries to acquire the lock without pausing the current thread. The boolean result must be used to check if the lock has actually been acquired before accessing any shared mutable variables.

**import** java.util.concurrent.ExecutorService;  
**import** java.util.concurrent.Executors;  
**import** java.util.concurrent.locks.ReentrantLock;  
**public class** Lock2 {  
  
 **public static void** main(String[] args) {  
 */\* print out:  
 First-Start pool-1-thread-****1****@1617070348419  
 Second-Start pool-1-thread-****2****@1617070348419  
 >> 2nd Locked: true  
 >> 2nd Held by me: false  
 >> 2nd Lock acquired: false  
 Second-End pool-1-thread-****2****@1617070348419  
 Third-Start pool-1-thread-****3****@1617070348419  
 First-End pool-1-thread-****1****@1617070349435  
 >> 3rd Locked: false  
 >> 3rd Held by me: false  
 >> 3rd Lock acquired: true  
 Third-End pool-1-thread-****3****@1617070350430  
 \*/* ExecutorService executor = Executors.*newFixedThreadPool*(3);  
  
 ReentrantLock lock = **new** ReentrantLock();  
  
 executor.submit(() -> {  
 System.***out***.println(**"First-Start "** + Thread.*currentThread*().getName() + **"@"** + System.*currentTimeMillis*());  
 lock.lock();  
 **try** {  
 ConcurrentUtils.*sleep*(1);  
 } **finally** {  
 lock.unlock();  
 }  
 System.***out***.println(**"First-End "** + Thread.*currentThread*().getName() + **"@"** + System.*currentTimeMillis*());  
 });  
  
 executor.submit(() -> {  
 System.***out***.println(**"Second-Start "** + Thread.*currentThread*().getName() + **"@"** + System.*currentTimeMillis*());  
 System.***out***.println(**">> 2nd Locked: "** + lock.isLocked());  
 System.***out***.println(**">> 2nd Held by me: "** + lock.isHeldByCurrentThread());  
 **boolean** locked = lock.tryLock();  
 System.***out***.println(**">> 2nd Lock acquired: "** + locked);  
 System.***out***.println(**"Second-End "** + Thread.*currentThread*().getName() + **"@"** + System.*currentTimeMillis*());  
 });  
  
 executor.submit(() -> {  
 System.***out***.println(**"Third-Start "** + Thread.*currentThread*().getName() + **"@"** + System.*currentTimeMillis*());  
 ConcurrentUtils.*sleep*(2);  
 System.***out***.println(**">> 3rd Locked: "** + lock.isLocked());  
 System.***out***.println(**">> 3rd Held by me: "** + lock.isHeldByCurrentThread());  
 **boolean** locked = lock.tryLock();  
 System.***out***.println(**">> 3rd Lock acquired: "** + locked);  
 System.***out***.println(**"Third-End "** + Thread.*currentThread*().getName() + **"@"** + System.*currentTimeMillis*());  
 });  
  
 ConcurrentUtils.*stop*(executor);  
 }  
  
}

ReadWriteLock[**#**](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/#readwritelock)

The interface ReadWriteLock specifies another type of lock maintaining a pair of locks for read and write access. The idea behind read-write locks is that it's usually safe to read mutable variables concurrently as long as nobody is writing to this variable. So the read-lock can be held simultaneously by multiple threads as long as no threads hold the write-lock. This can improve performance and throughput in case that reads are more frequent than writes.

ExecutorService executor = Executors.**newFixedThreadPool**(2);

Map<String, String> map = new HashMap<>();

ReadWriteLock lock = new **ReentrantReadWriteLock**();

executor.**submit**(() -> {

    lock.**writeLock**().**lock**();

    try {

**sleep**(1);

        map.**put**("foo", "bar");

    } finally {

        lock.**writeLock**().**unlock**();

    }

});

The above example first acquires a write-lock in order to put a new value to the map after sleeping for one second. Before this task has finished two other tasks are being submitted trying to read the entry from the map and sleep for one second:

Runnable readTask = () -> {

    lock.**readLock**().**lock**();

    try {

        System.out.**println**(map.**get**("foo"));

**sleep**(1);

    } finally {

        lock.**readLock**().**unlock**();

    }

};

executor.**submit**(readTask);

executor.**submit**(readTask);

**stop**(executor);

When you execute this code sample you'll notice that both read tasks have to wait the whole second until the write task has finished. After the write lock has been released both read tasks are executed in parallel and print the result simultaneously to the console. They don't have to wait for each other to finish because read-locks can safely be acquired concurrently as long as no write-lock is held by another thread.

StampedLock[**#**](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/#stampedlock)

Java 8 ships with a new kind of lock called StampedLock which also support read and write locks just like in the example above. In contrast to ReadWriteLock the locking methods of a StampedLock return a stamp represented by a long value. You can use these stamps to either release a lock or to check if the lock is still valid. Additionally stamped locks support another lock mode called *optimistic locking*.

Let's rewrite the last example code to use StampedLock instead of ReadWriteLock:

ExecutorService executor = Executors.**newFixedThreadPool**(2);

Map<String, String> map = new HashMap<>();

StampedLock lock = new **StampedLock**();

executor.**submit**(() -> {

    long stamp = lock.**writeLock**();

    try {

**sleep**(1);

        map.**put**("foo", "bar");

    } finally {

        lock.**unlockWrite**(stamp);

    }

});

Runnable readTask = () -> {

    long stamp = lock.**readLock**();

    try {

        System.out.**println**(map.**get**("foo"));

**sleep**(1);

    } finally {

        lock.**unlockRead**(stamp);

    }

};

executor.**submit**(readTask);

executor.**submit**(readTask);

**stop**(executor);

Obtaining a read or write lock via readLock() or writeLock() returns a stamp which is later used for unlocking within the finally block. Keep in mind that stamped locks don't implement reentrant characteristics. Each call to lock returns a new stamp and blocks if no lock is available even if the same thread already holds a lock. So you have to pay particular attention not to run into deadlocks.

Just like in the previous ReadWriteLock example both read tasks have to wait until the write lock has been released. Then both read tasks print to the console simultaneously because multiple reads doesn't block each other as long as no write-lock is held.

The next example demonstrates *optimistic locking*:

ExecutorService executor = Executors.**newFixedThreadPool**(2);

StampedLock lock = new **StampedLock**();

executor.**submit**(() -> {

    long stamp = lock.**tryOptimisticRead**();

    try {

        System.out.**println**("Optimistic Lock Valid: " + lock.**validate**(stamp));

**sleep**(1);

        System.out.**println**("Optimistic Lock Valid: " + lock.**validate**(stamp));

**sleep**(2);

        System.out.**println**("Optimistic Lock Valid: " + lock.**validate**(stamp));

    } finally {

        lock.**unlock**(stamp);

    }

});

executor.**submit**(() -> {

    long stamp = lock.**writeLock**();

    try {

        System.out.**println**("Write Lock acquired");

**sleep**(2);

    } finally {

        lock.**unlock**(stamp);

        System.out.**println**("Write done");

    }

});

**stop**(executor);

An optimistic read lock is acquired by calling tryOptimisticRead() which always returns a stamp without blocking the current thread, no matter if the lock is actually available. If there's already a write lock active the returned stamp equals zero. You can always check if a stamp is valid by calling lock.validate(stamp).

Executing the above code results in the following output:

Optimistic Lock Valid: true

Write Lock acquired

Optimistic Lock Valid: false

Write done

Optimistic Lock Valid: false

The optimistic lock is valid right after acquiring the lock. In contrast to normal read locks an optimistic lock doesn't prevent other threads to obtain a write lock instantaneously. After sending the first thread to sleep for one second the second thread obtains a write lock without waiting for the optimistic read lock to be released. From this point the optimistic read lock is no longer valid. Even when the write lock is released the optimistic read locks stays invalid.

So when working with optimistic locks you have to validate the lock every time *after* accessing any shared mutable variable to make sure the read was still valid.

Sometimes it's useful to convert a read lock into a write lock without unlocking and locking again. StampedLock provides the method tryConvertToWriteLock() for that purpose as seen in the next sample:

ExecutorService executor = Executors.**newFixedThreadPool**(2);

StampedLock lock = new **StampedLock**();

executor.**submit**(() -> {

    long stamp = lock.**readLock**();

    try {

        if (count == 0) {

            stamp = lock.**tryConvertToWriteLock**(stamp);

            if (stamp == 0L) {

                System.out.**println**("Could not convert to write lock");

                stamp = lock.**writeLock**();

            }

            count = 23;

        }

        System.out.**println**(count);

    } finally {

        lock.**unlock**(stamp);

    }

});

**stop**(executor);

The task first obtains a read lock and prints the current value of field count to the console. But if the current value is zero we want to assign a new value of 23. We first have to convert the read lock into a write lock to not break potential concurrent access by other threads. Calling tryConvertToWriteLock() doesn't block but may return a zero stamp indicating that no write lock is currently available. In that case we call writeLock() to block the current thread until a write lock is available.

Semaphores[**#**](https://winterbe.com/posts/2015/04/30/java8-concurrency-tutorial-synchronized-locks-examples/#semaphores)

In addition to locks the Concurrency API also supports counting semaphores. Whereas locks usually grant exclusive access to variables or resources, a semaphore is capable of maintaining whole sets of permits. This is useful in different scenarios where you have to limit the amount concurrent access to certain parts of your application.

Here's an example how to limit access to a long running task simulated by sleep(5):

ExecutorService executor = Executors.**newFixedThreadPool**(10);

Semaphore semaphore = new **Semaphore**(5);

Runnable longRunningTask = () -> {

    boolean permit = false;

    try {

        permit = semaphore.**tryAcquire**(1, TimeUnit.SECONDS);

        if (permit) {

            System.out.**println**("Semaphore acquired");

**sleep**(5);

        } else {

            System.out.**println**("Could not acquire semaphore");

        }

    } catch (InterruptedException e) {

        throw new **IllegalStateException**(e);

    } finally {

        if (permit) {

            semaphore.**release**();

        }

    }

}

IntStream.**range**(0, 10)

    .**forEach**(i -> executor.**submit**(longRunningTask));

**stop**(executor);

The executor can potentially run 10 tasks concurrently but we use a semaphore of size 5, thus limiting concurrent access to 5. It's important to use a try/finally block to properly release the semaphore even in case of exceptions.

Executing the above code results in the following output:

Semaphore acquired

Semaphore acquired

Semaphore acquired

Semaphore acquired

Semaphore acquired

Could not acquire semaphore

Could not acquire semaphore

Could not acquire semaphore

Could not acquire semaphore

Could not acquire semaphore

The semaphores permits access to the actual long running operation simulated by sleep(5) up to a maximum of 5. Every subsequent call to tryAcquire() elapses the maximum wait timeout of one second, resulting in the appropriate console output that no semaphore could be acquired.

This was the second part out of a series of concurrency tutorials. More parts will be released in the near future, so stay tuned. As usual you find all code samples from this article on [GitHub](https://github.com/winterbe/java8-tutorial), so feel free to fork the repo and try it by your own.

I hope you've enjoyed this article. If you have any further questions send me your feedback in the comments below. You should also [follow me on Twitter](https://twitter.com/winterbe_) for more dev-related stuff!

* Part 1: [Threads and Executors](https://winterbe.com/posts/2015/04/07/java8-concurrency-tutorial-thread-executor-examples/)
* Part 2: Synchronization and Locks
* Part 3: [Atomic Variables and ConcurrentMap](https://winterbe.com/posts/2015/05/22/java8-concurrency-tutorial-atomic-concurrent-map-examples/)