Java Concurrency Framework

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Executive Summary

- This is a beginners introduction to the java concurrency framework
- Some familiarity with concurrent programs is assumed
  - However the presentation does go through a quick background on concurrency
  - So readers unfamiliar with concurrent programming should still get something out of this
- The structure of the presentation is as follows
  - A brief history into concurrent programming is provided
  - Issues in concurrent programming are explored
  - The framework structure with all its major components are covered in some detail
  - Examples are provided for each major section to reinforce some of the major ideas

Concurrency in Java - Overview

- Java like most other languages supports concurrency through thread
  - The JVM creates the Initial thread, which begins execution from main
  - The main method can then spawn additional threads

Thread Basics

- All modern OS support the idea of processes – independently running programs that are isolated from each other
- Thread can be thought of as light weight processes
  - Like processes they have independent program counters, call stacks etc
  - Unlike Processes they share main memory, file pointers and other process state
  - This means thread are easier for the OS to maintain and switch between
  - This also means we need to synchronize threads for access to shared resources

Threads Continued…

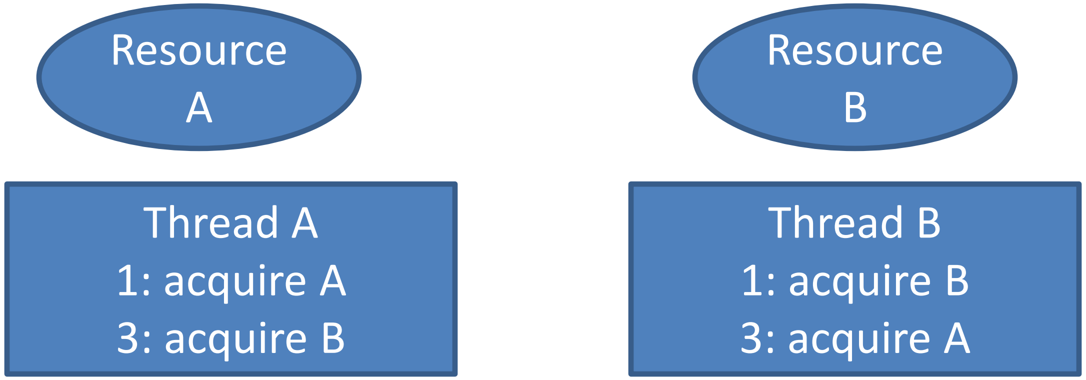
- So why use threads ?
  - Multi CPU systems: Most modern systems host multiple CPU’s, by splitting execution between them we can greatly speed up execution
  - Handling Asynchronous Events: Servers handle multiple clients. Processing each client is best done through a separate thread, because the Server blocks until a new message is received
  - UI or event driven Processing: event handlers that respond to user input are best handled through separate threads, this makes code easier to write and understand

Synchronization Primitives in Java

- How does the java language handle synchronization
  - Concurrent execution is supported through the *Thread* class.
  - Access to shared resources is controlled through
    - Synchronized objects
    - Synchronized methods
  - Locking and Unlocking shared resources is handled automatically
  - However only one (duh.) thread can hold a shared object at one time
  - A thread that cannot acquire a lock will block.

Writing Concurrent Programs

- But its not so easy..
  - Writing non trivial concurrent programs is not so straight – forward, here are a few of the issues you could run into
    - Deadlock: Two or more threads waiting for each other to release a resource



Concurrency issues continued..

- Race Conditions: Non deterministic output, that depends on the order of thread execution

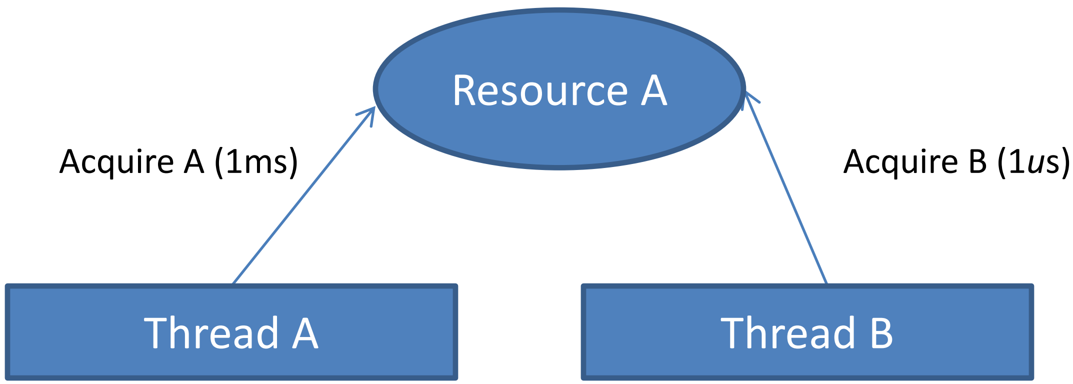
Thread A
While(true)
Print 1

Thread B
While(true)
Print 2

- Output:
  - 11111111… or
  - 12121212… or etc

Concurrency issues continued..

- Starvation: A slow thread being starved of a resource by a fast thread



- This brings us to thread safe classes
  - A class that guarantees the internal state of the class as well as returned values from methods are correct while invoked concurrently from multiple thread

Where does this leave us?

- This shows us writing concurrent programs is hard and prone to bugs
- The synchronization primitives java provides are of too low a granularity and do not scale with program complexity
- It would be nice if we could abstract some of this complexity away
- Further many of the problems encountered writing parallel programs are common across a wide area
- We really should not have to reinvent the wheel each time we want to write a concurrent program
- This is where the Java Concurrency Framework comes in..

Framework Overview

- The Concurrency utilities includes the following:

1. **Task Scheduling Framework**: The Executor is a framework for handling the invocation, scheduling and execution of tasks
2. **Concurrent Collection**: Concurrent implementations of commonly used classes like map, list and queue (no more reinventing the wheel ☺).
3. **Atomic Variables**: classes for atomic manipulation of single variables, provides higher performance than simply using synchronization primitives
4. **Locks**: High performance implementation of locks with the same semantics as the *synchronized* keyword, with additional functionality like timeouts.
5. **Timers**: Provides access to a nanosecond timer for making fine grained timing measurements, useful for methods that accept timeouts.

Advantages of using the framework

- **Reusability and effort reduction**: Many commonly used concurrent classes already implemented
- **Superior performance**: Inbuilt implementation highly optimized and peer reviewed by experts
- **Higher reliability, less bugs**: Working from already developed building blocks lead to more reliable programs
- **Improved maintainability and scalability:** Reusable components leads to programs that are easier to maintain and scale much better
- **Increased productivity:** Developers no longer have to reinvent the wheel each time, programs easier to debug, more likely to understand standard library implementations

The Executor Framework

- The Executor framework provides a mechanism for invoking, scheduling, and executing tasks according to a set of policies
- Also provides an implementation of thread pools through the *ThreadPoolExecutor* class
- This provides a way to decouple task submission from task execution policy
- Makes it easy to change task execution policy
- Supports several different execution policies by default, and developers can create Executors supporting arbitrary execution policies

Interlude: Thread pools

- Consider writing a web server that handles an arbitrary number of clients
- One way of implementing this is to spawn a new thread for each client that makes a request
- However under high load this could crash the server, due to the large amount of resources used to create and maintain the threads
- Worse we are creating far more threads than can be handled by the server, probably most threads will sit around waiting for CPU time.

Thread pools continued…

- A smarter way to handle this is to use the idea of a thread pool
- We create a fixed number of threads called a thread pool
- We use a queue data structure into which tasks are submitted
- Each free thread picks a task of the queue and processes it
- If all threads are busy, tasks wait in queue for threads to free up
- This way we never overload the server, and get the most efficient implementation

Executor Framework Continued…

- The Executor interface is fairly simple
  - it describes an object, which executes *Runnables*

```
Public interface Executor {
    void  execute(Runnable task )
}
```

  - A class that wishes to use the Executor framework, must implement the Executor interface and provide an implementation for execute

```
Class ImpExecutor implements Executor {
    void  execute(Runnable t ) {
      new Thread(t).start    //This executor creates a new thread for each task submitted
    }
}
```

Executor Framework Continued…

- The Executor framework comes with several implementations of Executor that implement different execution policies
  - execution policy determines when a task will run, it priority and other associated parameters

1. ***Executor.newCachedThreadPool***: Creates a thread pool of unlimited size, but if threads get freed up, they are reused
2. ***Executor.newFixedThreadPool***: Create a thread pool of fixed size, if pool is exhausted, tasks must wait till a thread becomes free
3. ***Executor.newSingleThreadExecutor***: Creates only a single thread, tasks are executed sequentially form the queue

- **class WebServer {**
- Executor execs **=**
- Executors**.newFixedThreadPool(7);**
- **public static void main(String[] args) {**
- ServerSocket soc **= new ServerSocket(80);**
- **while (true) {**
- **Socket conn = soc.accept();**
- Runnable r **= new Runnable() {**
- **public void run() {**
- handleRequest**(conn);**
- **}**
- **};**
- pool**.execute(r);**
- **}**
- **}**
- **}**

Example code modified from the book “java concurrency in practice”

Code Walkthrough

- That was a quick example of how to use the executor framework and thread pools
- We have used an inbuilt executor “Fixed ThreadPool” to create a pool of 7 threads
- We create a runnable to handle new connections
- We then hand the runnalble to the executor for execution
- Thus task execution is decoupled from task submission

Concurrent Collections

- The Concurrency framework provides implementation of several commonly used collections classes optimized for concurrent operations
  1. **public interface Queue<E>extends Collection<E>**: A collection class that hold elements prior to processing, generally orders element in a FIFO manner (however can also be LIFO etc). Supports the following functionality
     - Offer method inserts an element if possible else return false
     - remove() and poll() return and remove the head of the queue
     - element() and peek() return but do not remove the head of the queue

Concurrent Collections Continued..

1. The **BlockingQueueInterface** extends this interface
   - Supports all queue functionality, and additionally waits for a queue to become non-empty before retrieving an element and waits for space to become available when storing an element
   - Intended primarily for use as a producer-consumer queues
   - BlockingQueue implementations are thread safe, with all queue operations achieved atomically
   - Some bulk collection operations are not atomic, but will fail if other threads interfere before the operation is completed

Concurrent Collections Continued..

1. **public interface ConcurrentMap<K,V> extends Map<K,V>**: an extension to the Map interface that provides support for concurrency
   - Supports concurrent putIfAbsent, remove and replace methods
   - putIfAbsent(key, value): If the specifed key is not associated with a value associate it with a value. Performed atomically
   - remove(key, value): Removes entry for a key if associated with value. Performed atomically
   - remove(key, oldvalue, newvalue): Replaces entry for a key if associated with oldvalue with newvalue. Performed atomically

```
public class consumerthread implements Runnable{
	private static int capacity ;
	private BlockingQueue<Integer> intqueue;

	public consumerthread(BlockingQueue<Integer> queue, int cap)
	{
		capacity = cap;
		this.intqueue = queue;
	}

	public void run()
	{
		int num;
		for(int i = 0; i<capacity; i++)
		{
			try {
				num = intqueue.take();
				if(num == -1)
					break;
				System.out.println("The Square of " + num  + " is " + 
num*num);
			} catch (InterruptedException e) {
				e.printStackTrace();
			}
		}
	}

}
```

```java
public class producerthread implements Runnable  {
        private static int capacity ;
        private BlockingQueue<Integer> intqueue;

        public producerthread(BlockingQueue<Integer> queue, int cap)
        {
                capacity = cap;
                this.intqueue = queue;
        }

        public void run()
        {
                for(int i = 0; i<capacity-1; i++)
                {
                        try {
                                intqueue.put(i);
                        } catch (InterruptedException e) {
                                e.printStackTrace();
                        }
                }
                try {
                        intqueue.put(-1);
                } catch (InterruptedException e) {
                        e.printStackTrace();
                }
        }

}
```

```java
public class test {

        public static void main(String [] args)
        {
                BlockingQueue<Integer> queue = new ArrayBlockingQueue<Integer>(100);
                consumerthread consumer = new consumerthread(queue, 100);
                producerthread producer = new producerthread(queue, 100);
                new Thread(consumer).start();
                new Thread(producer).start();
        }

}
```

Code Walkthrough

- That was an example of using blocking queues to implement producer consumer relationships
- The producer class fills in a queue of integers
- The consumer class pulls integers of this queue and finds the square
- If the queue is empty a take() blocks, if full a put() blocks
- We could extend this to use a thread pool for the producers

Synchronizer Classes

- Includes a set of classes that aid synchronization between threads
- Includes semaphores, mutexes, barriers, latches and exchangers

Semaphores

- Implements a counting semaphore (Djikstra Counting Semaphore)
  - you can think of a counting semaphore as holding a certain number of permits
  - If the permits are all used up, succeeding threads must wait for one to become available.
  - The same thread can hold multiple permits
  - Useful for imposing a resource limit
  - A thread invokes the acquire() method to obtain a permit, acquire() blocks if no permits available
  - A thread invokes release() to release a permit back to the pool

Synchronizer Classes Continued…

Mutexes

- Special case of the semaphore
- Stands for mutual exclusion semaphore
- A Semaphore with a single permit
- Used to gain exclusive access to a resource
- Similar to a lock with one key difference: can be released by a thread other then the one holding the mutex

Synchronizer Classes Continued…

Barriers (Cyclic Barrier)

- A synchronization aid that allows a set of threads to all reach a common point before proceeding
- Useful in programs that involve a fixed number of threads that must wait for each other at some point
- Called cyclic because barrier can be reused
- A thread signals it has reached the barrier by calling CyclicBarrier.await()
- The threads blocks until all other threads have reached the barrier (which signal this the same way)
- Can specify a timeout at which time the thread will stop blocking

Synchronizer Classes Continued…

Latches (CountDown Latches)

- Similar to a Cyclic Barrier, used to synchronize a set of threads that have a task divided amongst themselves
- The CountDownLatch is intialized with a given count
- On reaching the synchronization point a thread can invoke the countdown() method which decrements the internal count
- Threads that call the await() method will block until the count has reached zero
- At this point all waiting threads are released
- Calling await() after count has reached zero, has no effect (the thread will continue executing)
- Threads that call countdown() are not required to call await() (and can proceed executing)
- This is useful when the main thread has split execution between a number of worker threads
- The worker threads call countdown() on completing their task, the main thread blocks on await() until count has reached zero

Synchronizer Classes Continued…

Exchangers

- A synchronization point at which two threads can exchange objects
- Can be thought of as a CyclicBarrier with a count of two plus allowing an exchange of state at the barrier
- On calling the exchange() method the thread provides some object as input
- The exhange() methods returns the object entered as input by the second thread to the calling thread
- Useful for example in the case where one thread is filling a buffer (filler thread) and the other emptying (emptying thread)
- On calling exchange() the filler thread is passed an empty buffer
- The emptying thread obtain the newly full buffer from the filler thread

```
class cyclicbarriertest {
void compute(Task t, int num)
	{
		final CyclicBarrier barrier = new CyclicBarrier(num, //two inputs,num_threads
		new Runnable() {				//runnable tasks
for (int i = 0; i < nThreads; ++i)   //split computation betweeen threads
	{
		final int id = i;
		Runnable worker = new Runnable() {      // new worker
		final Segment segment = t.createSegment(id);
		public void run() {
		try {
		segment.update();
		barrier.await();
}
catch(Exception e) { return; }
}
};
new Thread(worker).start();
}
}
```

- **Example code modified from the book "java concurrency in practice"**

Code Walkthrough

- Example program that shows the usage of cyclic barriers
- Our function takes as input as task t and number of threads num
- It creates a cyclic barrier that takes two inputs num, and task
- Task execution is split among a group of worker threads
- Each worker computes a portion of the problem and waits to see if all other threads have finished (using a cyclic barrier to synchronize)

Atomic Variables

- A set of classes that provide lock free thread safe programming on single variables
- Provides for atomic conditional updating of single variables
  - Boolean comapreAndSet(expected, update): atomically set value of variable to update value provided It holds expected value
  - WeakCompareAnd Set is more efficient but any invocation of this method may fail, with the guarantee that repeated invocations will eventually succeed
  - Also provides methods for getting and unconditionally setting values
- Instance of classes AtomicInteger, AtomicBoolean, AtomicLong, AtomicRefrence provide access and update to single variables of that type

Locks

- A generalization of built-in locking behavior, but with several different types of locks with superior functionality
- Reentrant lock: This has the same overall semantics as the “synchronized” keyword, with the exception that locks must be explicitly obtained and released
  - Provides better throughput than synchronized when multiple threads are vying for the same lock
- ReadWrite lock: A pair of locks, one for reading and one for writing. The read lock can be simultaneously held by multiple threads. The write lock is exclusive
- AbstractQueuedSynchronizer: provides a framework for implementing locks and related synchronizers

- Lock syntax

- lock.**lock();**
- **try {**
- // operations protected by lock
- **}**
- **catch(Exception ex) {**
- **}**
- **finally {**
- lock.**unlock();**
- **}**

Summary

- So What did we cover
  - Thread basics
  - Java language support for concurrency
  - Examples of why concurrency is hard
  - Overview of the Java Concurrency framework
  - A look at the principle classes in the framework and the functionality offered
  - A few examples covering some of the major concepts
- For a more in depth look at the Concurrency Framework have a look at the excellent “Java Concurrency in Practice” book by Brian Goetz et al.