java.util.concurrent

CSCI 5828: Foundations of Software Engineering
Lecture 25 — 11/15/2016
Goals

• Explore the services of java.util.concurrent
  • ExecutorService
  • Callable/Future
  • ForkJoinPool and ForkJoinTask

• The examples in this lecture come from the excellent book: Programming Concurrency on the JVM from Pragmatic Programmers

• Source Code for these examples is available here:
  • https://pragprog.com/book/vspcon/programming-concurrency-on-the-jvm#links

• I’m not allowed to distribute it myself
ExecutorService (I)

• ExecutorService is a Java interface that defines a common set of services for an abstract *thread pool*;
  • this interface has a variety of concrete implementations that provide a range of concurrent behavior to developers

• What’s a thread pool? *(A review)*
  • Thread creation is a slow process
  • Thread pools create a bunch of threads all at once (typically at launch)
  • When a new thread is needed, one is taken from the pool and it starts executing immediately
    • very helpful in situations where, e.g., a server is responding to incoming network requests
ExecutorService (II)

• Static factory methods on the Executors class are used to create instances of the ExecutorService; for instance

  • **CachedThreadPool**: creates threads as needed but will reuse previous ones if they are available

  • **FixedThreadPool**: creates a fixed set of threads

  • **ScheduledThreadPool**: creates a thread pool that can execute tasks after a delay or periodically

  • **SingleThreadExecutor**: creates a thread pool with only a single thread

• You write code that only depends on the *interface* ExecutorService and then be free to select the actual threading behavior you get *at run-time* based on external factors

  • you can even *switch* threading behaviors *on the fly*
ExecutorService (III)

• The API of the ExecutorService allows you to
  • submit a single task for execution
  • submit a collection of tasks for execution
    • where you want all of the tasks results (invokeAll)
    • or where you want just one of the results (invokeAny)
  • shutdown the thread pool when you are done with it
Callable/Future: Making this all work

• In order to give tasks to the thread pool and receive results back, you make use of two additional interfaces
  
  • Callable<T> and Future<T>

• Both make use of Java generics to give flexibility in the return types of the computation

• For instance, I can promise that my task returns a string

```java
Callable<String> callMe = new Callable<String>() {
    public String call() throws Exception {
        ...; return result;
    }
}
```

• callMe is now a Task that I can hand to an ExecutorService
Callable/Future (II)

• When I give `callMe` to an `ExecutorService`, it is going to hand the task to a thread and ask the thread to execute it
  • At the time, we have no idea how long it will take for the task to complete
    • Thus, the `ExecutorService` gives me an instance of `Future<String>` so I can get the value once the task is complete
      • `Future<String> myString = service.submit(callMe);`
  • This call does **NOT** block, I get a reference to `myString` almost immediately
  • I can then decide to retrieve the string whenever I need it by calling `get()`
    • `String result = myString.get();`
  • This call **MAY** block, if the task is still being executed; otherwise, I get the result right away. I can also call a version of `get()` that accepts a timeout.
Portfolio Calculator (I)

- A simple program to retrieve stock quotes from Yahoo
  - Designed as one abstract superclass `AbstractNAV` (Net Asset Value)
    - methods for
      - reading in stock symbols and number of shares
      - timing how long it takes to calculate the portfolio
  - Two subclasses
    - one sequential => loops over list of symbols and calls Yahoo to get current price
    - one concurrent => creates futures for each stock to retrieve prices; hands them all over to an executor service to execute in parallel
Portfolio Calculator (II)

• Since these tasks are IO bound, the program needs to decide how many threads it will need

  • Each task is going to be blocked for most of its life and then it will do a single calculation: numberOfShares * retrievedPrice

  • We estimate that waiting for Yahoo to give us the current price is going to take about 90% of the task’s life cycle

• So to estimate the number of threads, we use the following formula

  • Number of Threads = Number of Cores / (1 - Blocking Coefficient)

• My machine has 8 cores, so

  • \( \frac{8}{1-0.9} = \frac{8}{0.1} = 80 \) threads
Portfolio Calculator (III)

• It then creates an array to store all of our Callable objects
  
  • final List<Callable<Double>> partitions = new ArrayList<Callable<Double>>();

• It populates that List by creating one Callable<Double> for each stock symbol
  
  • It then hands the list over to the executor service which hands back a list of Future<Double> objects
    
    • final List<Future<Double>> valueOfStocks = executorPool.invokeAll(partitions, 10000, TimeUnit.SECONDS);

• Finally, it loops over each Future object and totals up the final value
  
  • for (final Future<Double> valueOfAStock : valueOfStocks) {
    • netAssetValue += valueOfAStock.get();
  • }

• It is this call to get() that can finally block, waiting for the task to complete
Portfolio Calculator (IV)

• Let’s see this in action
  
  • As you will see, the concurrent version of the program is significantly faster
    
    • Why? => Latency!

  • Each request to Yahoo takes a certain amount of time to create the connection, wait for Yahoo to retrieve the data, and stream the result back

• With the sequential version of the program, we take that latency and add it for each stock request; say the latency was 2 seconds
  
  • For 80 stocks, we would expect to wait 160 seconds for the whole sequential program to complete

  • In the concurrent program, all tasks contact Yahoo at the same time, the 2 second latency for each task overlaps. As a result, the program takes ~2-3 seconds
Finding Primes

- The reason we saw such an amazing speed-up with the previous program was due to the fact that its tasks were IO-bound.

  - With compute-bound tasks, we have to limit the number of threads to the number of cores

  - Let’s just look at the code to see how it creates a bunch of Callable<Integer> tasks that count primes for a given partition

    - The executor service then gives us back a list of Future<Integer> and we call those to total up the number of primes in a given range
Coordinating Threads (I)

• A key challenge in the design of concurrent systems is the coordination of threads

• We may want to

  • start them

  • wait for them to finish

  • assign tasks to them

  • retrieve results from them

  • allow threads to exchange data

  • etc.
Coordinating Threads (II)

• With the ExecutorService, the most typical case now involves
  • submitting a task to a thread pool of type Callable
  • receiving a Future in response
  • when ready, calling get() on the Future to retrieve the result

• Let’s see this in action with an example called File Size Calculator
  • First, let’s take a look at the sequential version of this program

• Design is straightforward; recursive function that returns either the size for a
  single file or, for directories, the combined size of all of its children
Disk Cache

• With programs that target the disk, performance will vary
  • The first time through a particular section of the disk, the time will be slower than subsequent runs on the same section of the disk

• The reason for this is the disk cache
  • The operating system will
    • take the most recently read sections of disk
    • and cache them in memory
    • under the assumption that they will be read again fairly soon

• The difference may not be major but it will be there
  • First run sequential on /usr: 36.02 seconds; Second run: 27.3 seconds
First Stab at Concurrency

• Creates a thread pool of 100 threads

• Makes use of recursive function to calculate size of files and directories
  
  • If its handed a file, return the file size
  
  • If its handed a directory
    
    • loop through children
      
      • submit() a task to the thread pool to calculate the size of the child
        
        • Each task is a Callable<Long>
          
          • Thread pool returns a Future<Long> that gets added to an array
            
            • loop through array calling get() on each Future to add up subtotals
              
              • return the result
Result? DEADLOCK!

• This approach to the program has a flaw that appears on “deep directories”
  • Each task adds new tasks to the thread pool and then waits for those tasks to return
  • That means that the calling task is STILL ON THE POOL
    • blocked waiting for its subtasks to complete
  • If your directory has lots of subdirectories (more than 100 in this case)
    • You can get into the situation where each of the 100 threads in the thread pool are blocked waiting for subdirectory calculations to complete
      • when this happens, the program deadlocks
        • or thanks to the timeout that we set, eventually the timeout fires and the program terminates
Discussion

• This problem is unfortunate because
  • the approach is straightforward and understandable
    • you’d likely come up with it on a first pass design
  • But, a machine’s resources are finite
    • you might be able to make this code work on more directories by upping the number of threads
    • but that approach is not generic
      • eventually you’ll run into the limit concerning the number of threads the operating system will allow a single process to create
    • and you’ll be stuck
New Approach: Find Directories, Total Later

- To make progress, we need an approach that
  - submits tasks for sub-directories
    - but doesn’t require the submitting task to hang around for the results

- New Approach
  - Create a data structure that holds the total size of a directory’s files and a list of all of that directory’s sub-directories
  - Tasks now calculate the size of files in their assigned directory and create a list of all subdirectories; allowing them to complete and not stick around
  - The main thread takes care of submitting new tasks and totaling results
    - 6 seconds vs. 36 seconds!
Terrific Results But...

• increased complexity!
  
  • We got great results but the approach we used is not intuitive
    
    • Creating a class to store partial (immutable) results
    
    • Creating the function executed by tasks such that it completes quickly
    
    • Adopting a while loop strategy in main to iterate while there were directories to process
      
      • and then ensuring that the while loop would not terminate until all directories had been processed
    
  
  • Let’s look at features that java.util.concurrent has that might reduce the complexity of the code
CountDownLatch (I)

• The next approach examines the use of a CountDownLatch
  • plus it relaxes our constraint to avoid shared mutability
• but it achieves the same results with simpler code
  • Simplicity is not to be discounted
    • it has significant impacts on the ability to maintain software systems
CountDownLatch (II)

- What’s a CountDownLatch?
  - It is a synchronization aid to help coordinate threads
  - It maintains a count and has three primary methods
    - `CountDownLatch(n)` - creates the latch with a specific count
    - `await()` - block the calling thread until the latch’s `count == 0`
    - `countDown()` -- decrement the count of the latch
- Typical scenario:
  - create a bunch of threads and `start()` them
  - but don’t let them `run()` until some point in the future
    - i.e. have their first line in `run()` call `await()`
New Approach

• Instead of returning subdirectories, we let each task update two shared variables
  • each an instance of AtomicLong (like AtomicInteger but stores long value)
  • One AtomicLong stores the total file size
  • The second AtomicLong stores the number of “pending file visits”
    • This value gets incremented each time we find a subdirectory to visit
    • It gets decremented each time we are done processing a subdirectory
    • When this value equals zero, we call countDown() on the latch
• The main thread initializes the latch to a value of 1, starts the directory search, and calls await()
Performance

• Comparable performance to previous approach (4.6 seconds vs 6.1 seconds)
  • but with simpler code!
Third Approach: Queue (I)

• We have seen two approaches for exchanging data between threads
  • Callable/Future and Atomic<Type>
  • both techniques ensured that we could pass information between threads

• A third approach is to use a data structure such as a queue to pass information between threads
  • as long as there is space in the queue, producers will not block
  • as long as there are items on the queue, consumers will not block
  • contention will occur only when the queue is full (producers) or when it is empty (consumers)
Third Approach: Queue (II)

• This version of the program creates a blocking queue with 500 slots

• An atomic long is used to keep track of pending file visits

• Tasks traverse the directories as normal, adding file sizes to the queue and updating the atomic long as they submit more tasks to the thread pool

• The main program kicks off the traversal and then sits in a loop

  • it reads items off the queue until there are no more file visits pending and the queue is empty

• Performance:

  • First Run: 4.96 seconds

  • Essentially same performance, just slightly different abstractions, perhaps simpler

    • not by much
Java 7: Fork-Join API

• Java 7 introduced a new type of thread pool and task
  • ForkJoinPool and ForkJoinTask

• The key benefit of this new thread pool is that threads can steal tasks generated by other active tasks
  • This solves the problem we encountered with the first approach to the concurrent file size calculator

  • When a task generates a bunch of other tasks and blocks, its thread can let it go and work on the other tasks

• With this approach, we get a program very similar to our “naive” approach
  • without the danger for deadlock like we saw before => 5.5 seconds
Summary

• We learned the ins and outs of using the ExecutorService in various ways
  • Saw how Callable and Future work to allow us to pass information between threads
  • Explored various problems that can still occur when using ExecutorService
  • Saw a number of different ways to design the same program
    • Performance was usually the same
      • What was different was the complexity of each design
        • Certain designs provided more simplicity than others
        • If two designs perform the same, prefer the one that is less complex to make it easier to maintain that solution
Coming Up Next

• Lecture 25: Refactoring a poorly designed concurrent program written in Java