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Introduction to Thread Pools in Java

Last modified: August 27, 2017

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1. Introduction

This article is a look at thread pools in Java – starting with the different implementations in the standard Java library and then looking at Google's Guava library.

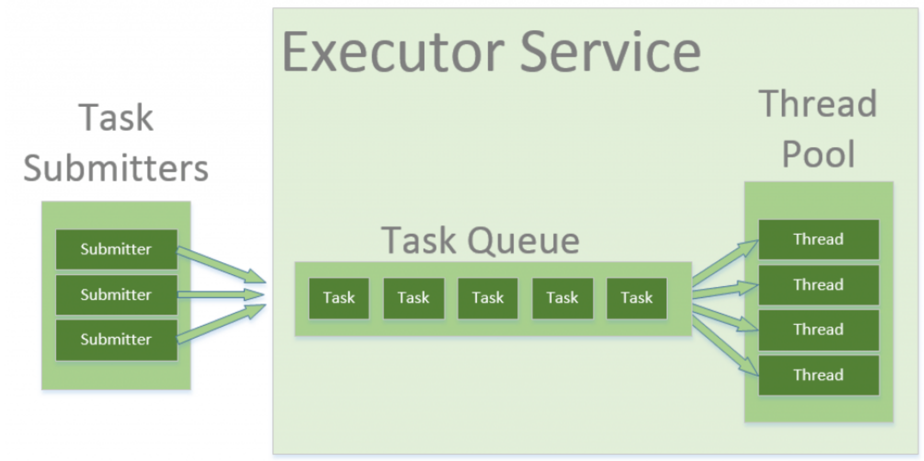
2. The Thread Pool

In Java, threads are mapped to system-level threads which are operating system's resources. If you create threads uncontrollably, you may run out of these resources quickly.

The context switching between threads is done by the operating system as well – in order to emulate parallelism. A simplistic view is that – the more threads you spawn, the less time each thread spends doing actual work.

The Thread Pool pattern helps to save resources in a multithreaded application, and also to contain the parallelism in certain predefined limits.

When you use a thread pool, you **write your concurrent code in the form of parallel tasks and submit them for execution to an instance of a thread pool**. This instance controls several re-used threads for executing these tasks.



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The pattern allows you to **control the number of threads the application is creating**, their lifecycle, as well as to schedule tasks' execution and keep incoming tasks in a queue.

3. Thread Pools in Java

3.1. *Executors*, *Executor* and *ExecutorService*

The *Executors* helper class contains several methods for creation of pre-configured thread pool instances for you. Those classes are a good place to start with – use it if you don't need to apply any custom fine-tuning.

The *Executor* and *ExecutorService* interfaces are used to work with different thread pool implementations in Java. Usually, you should **keep your code decoupled from the actual implementation of the thread pool** and use these interfaces throughout your application.

The *Executor* interface has a single *execute* method to submit *Runnable* instances for execution.

Here's a quick example of how you can use the *Executors* API to acquire an *Executor* instance backed by a single thread pool and an unbounded queue for executing tasks sequentially. Here, we execute a single task that simply prints "*Hello World*" on the screen. The task is submitted as a lambda (a Java 8 feature) which is inferred to be *Runnable*.

```java
Executor executor = Executors.newSingleThreadExecutor();
executor.execute(() -> System.out.println("Hello World"));
```

The *ExecutorService* interface contains a large number of methods for **controlling the progress of the tasks and managing the termination of the service**. Using this interface, you can submit the tasks for execution and also control their execution using the returned *Future* instance.

In the following example, we create an *ExecutorService*, submit a task and then use the returned *Future*'s *get* method to wait until the submitted task is finished and the value is returned:

```java
ExecutorService executorService = Executors.newFixedThreadPool(10);
Future<String> future = executorService.submit(() -> "Hello World");
// some operations
String result = future.get();
```

Of course, in a real-life scenario you usually don't want to call *future.get()* right away, but defer calling it until you actually need the value of the computation.

The *submit* method is overloaded to take either *Runnable* or *Callable* both of which are functional interfaces and can be passed as lambdas (starting with Java 8).

Runnable's single method does not throw an exception and does not return value. *Callable* interface may be more convenient, as it allows to throw an exception and return a value.

Finally – to let the compiler infer the *Callable* type, simply return a value from the lambda.

For more examples on using the *ExecutorService* interface and futures, have a look at "A Guide to the Java ExecutorService (/java-executor-service-tutorial)".

3.2. *ThreadPoolExecutor*

The *ThreadPoolExecutor* is an extensible thread pool implementation with lots of parameters and hooks for fine-tuning.

The main configuration parameters that we'll discuss here are: ***corePoolSize***, ***maximumPoolSize***, and ***keepAliveTime***.

The pool consists of a fixed number of core threads that are kept inside all the time, and some excessive threads that may be spawned and then terminated when they are not needed anymore. The *corePoolSize* parameter is the amount of core threads which will be instantiated and kept in the pool. If all core threads are busy and more tasks are submitted, then the pool is allowed to grow up to a *maximumPoolSize*.

The *keepAliveTime* parameter is the interval of time for which the excessive threads (i.e. threads that are instantiated in excess of the *corePoolSize*) are allowed to exist in the idle state.

These parameters cover a wide range of use cases, but **the most typical configurations are predefined in the *Executors* static methods**.

For example, *newFixedThreadPool* method creates a *ThreadPoolExecutor* with equal *corePoolSize* and *maximumPoolSize* parameter values and a zero *keepAliveTime.* This means that the number of threads in this thread pool is always the same:

```
ThreadPoolExecutor executor =
  (ThreadPoolExecutor) Executors.newFixedThreadPool(2);
executor.submit(() -> {
    Thread.sleep(1000);
    return null;
});
executor.submit(() -> {
    Thread.sleep(1000);
    return null;
});
executor.submit(() -> {
    Thread.sleep(1000);
    return null;
});

assertEquals(2, executor.getPoolSize());
assertEquals(1, executor.getQueue().size());
```

In the example above we instantiate a *ThreadPoolExecutor* with a fixed thread count of 2. This means that if the amount of simultaneously running tasks is less or equal to two at all times, then they get executed right away. Otherwise **some of these tasks may be put into a queue to wait for their turn**.

We created three *Callable* tasks that imitate heavy work by sleeping for 1000 milliseconds. The first two tasks will be executed at once, and the third one will have to wait in the queue. We can verify it by calling the *getPoolSize()* and *getQueue().size()* methods immediately after submitting the tasks.

Another pre-configured *ThreadPoolExecutor* can be created with the *Executors.newCachedThreadPool()* method. This method does not receive a number of threads at all. The *corePoolSize* is actually set to 0, and the *maximumPoolSize* is set to *Integer.MAX_VALUE* for this instance. The *keepAliveTime* is 60 seconds for this one.

These parameter values mean that **the cached thread pool may grow without bounds to accommodate any amount of submitted tasks**. But when the threads are not needed anymore, they will be disposed of after 60 seconds of inactivity. A typical use case is when you have a lot of short-living tasks in your application.

```
ThreadPoolExecutor executor = 
  (ThreadPoolExecutor) Executors.newCachedThreadPool();
executor.submit(() -> {
    Thread.sleep(1000);
    return null;
});
executor.submit(() -> {
    Thread.sleep(1000);
    return null;
});
executor.submit(() -> {
    Thread.sleep(1000);
    return null;
});

assertEquals(3, executor.getPoolSize());
assertEquals(0, executor.getQueue().size());
```

The queue size in the example above will always be zero because internally a *SynchronousQueue* instance is used. In a *SynchronousQueue*, pairs of *insert* and *remove* operations always occur simultaneously, so the queue never actually contains anything.

The *Executors.newSingleThreadExecutor()* API creates another typical form of *ThreadPoolExecutor* containing a single thread. **The single thread executor is ideal for creating an event loop.** The *corePoolSize* and *maximumPoolSize* parameters are equal to 1, and the *keepAliveTime* is zero.

Tasks in the above example will be executed sequentially, so the flag value will be 2 after task's completion:

```
AtomicInteger counter = new AtomicInteger();

ExecutorService executor = Executors.newSingleThreadExecutor();
executor.submit(() -> {
    counter.set(1);
});
executor.submit(() -> {
    counter.compareAndSet(1, 2);
});
```

Additionally, this *ThreadPoolExecutor* is decorated with an immutable wrapper, so it cannot be reconfigured after creation. Note that also this is the reason we cannot cast it to a *ThreadPoolExecutor*.

3.3. *ScheduledThreadPoolExecutor*

The *ScheduledThreadPoolExecutor* extends the *ThreadPoolExecutor* class and also implements the *ScheduledExecutorService* interface with several additional methods:

- *schedule* method allows to execute a task once after a specified delay;
- *scheduleAtFixedRate* method allows to execute a task after a specified initial delay and then execute it repeatedly with a certain period; the *period* argument is the time **measured between the starting times of the tasks**, so the execution rate is fixed;
- *scheduleWithFixedDelay* method is similar to *scheduleAtFixedRate* in that it repeatedly executes the given task, but the specified delay is **measured between the end of the previous task and the start of the next**; the execution rate may vary depending on the time it takes to execute any given task.

The *Executors.newScheduledThreadPool()* method is typically used to create a *ScheduledThreadPoolExecutor* with a given *corePoolSize*, unbounded *maximumPoolSize* and zero *keepAliveTime*. Here's how to schedule a task for execution in 500 milliseconds:

```
ScheduledExecutorService executor = Executors.newScheduledThreadPool(5);
executor.schedule(() -> {
    System.out.println("Hello World");
}, 500, TimeUnit.MILLISECONDS);
```

The following code shows how to execute a task after 500 milliseconds delay and then repeat it every 100 milliseconds. After scheduling the task, we wait until it fires three times using the *CountDownLatch* lock*,* then cancel it using the *Future.cancel()* method.

```
CountDownLatch lock = new CountDownLatch(3);

ScheduledExecutorService executor = Executors.newScheduledThreadPool(5);
ScheduledFuture<?> future = executor.scheduleAtFixedRate(() -> {
    System.out.println("Hello World");
    lock.countDown();
}, 500, 100, TimeUnit.MILLISECONDS);

lock.await(1000, TimeUnit.MILLISECONDS);
future.cancel(true);
```

3.4. *ForkJoinPool*

ForkJoinPool is the central part of the *fork/join* framework introduced in Java 7. It solves a common problem of **spawning multiple tasks in recursive algorithms**. Using a simple *ThreadPoolExecutor*, you will run out of threads quickly, as every task or subtask requires its own thread to run.

In a *fork/join* framework, any task can spawn (*fork*) a number of subtasks and wait for their completion using the *join* method. The benefit of the *fork/join* framework is that it **does not create a new thread for each task or subtask**, implementing the Work Stealing algorithm instead. This framework is thoroughly described in the article "Guide to the Fork/Join Framework in Java (/java-fork-join)"

Let's look at a simple example of using *ForkJoinPool* to traverse a tree of nodes and calculate the sum of all leaf values. Here's a simple implementation of a tree consisting of a node, an *int* value and a set of child nodes:

```
static class TreeNode {

    int value;

    Set<TreeNode> children;

    TreeNode(int value, TreeNode... children) {
        this.value = value;
        this.children = Sets.newHashSet(children);
    }
}
```

Now if we want to sum all values in a tree in parallel, we need to implement a *RecursiveTask<Integer>* interface. Each task receives its own node and adds its value to the sum of values of its *children*. To calculate the sum of *children* values, the task implementation does the following:

- streams the *children* set,
- maps over this stream, creating a new *CountingTask* for each element,
- executes each subtask by forking it,
- collects the results by calling the *join* method on each forked task,
- sums the results using the *Collectors.summingInt* collector.

```
public static class CountingTask extends RecursiveTask<Integer> {

    private final TreeNode node;

    public CountingTask(TreeNode node) {
        this.node = node;
    }

    @Override
    protected Integer compute() {
        return node.value + node.children.stream()
          .map(childNode -> new CountingTask(childNode).fork())
          .collect(Collectors.summingInt(ForkJoinTask::join));
    }
}
```

The code to run the calculation on an actual tree is very simple:

```
TreeNode tree = new TreeNode(5,
  new TreeNode(3), new TreeNode(2,
    new TreeNode(2), new TreeNode(8)));

ForkJoinPool forkJoinPool = ForkJoinPool.commonPool();
int sum = forkJoinPool.invoke(new CountingTask(tree));
```

4. Thread Pool's Implementation in Guava

Guava (https://github.com/google/guava) is a popular Google library of utilities. It has many useful concurrency classes, including several handy implementations of *ExecutorService*. The implementing classes are not accessible for direct instantiation or subclassing, so the only entry point for creating their instances is the *MoreExecutors* helper class.

4.1. Adding Guava as a Maven Dependency

Add the following dependency to your Maven pom file to include the Guava library to your project. You can find the latest version of Guava library in the Maven Central (http://search.maven.org/#search%7Cgav%7C1%7Cg%3A%22com.google.guava%22%20AND%20a%3A%22guava%22) repository:

```
<dependency>
    <groupId>com.google.guava</groupId>
    <artifactId>guava</artifactId>
    <version>19.0</version>
</dependency>
```

4.2. Direct Executor and Direct Executor Service

Sometimes you want to execute the task either in the current thread, or in a thread pool, depending on some conditions. You would prefer to use a single *Executor* interface and just switch the implementation. Although it is not so hard to come up with an implementation of *Executor* or *ExecutorService* that executes the tasks in the current thread, it still requires writing some boilerplate code.

Gladly, Guava provides predefined instances for us.

Here's an example that demonstrates execution of a task in the same thread. Although the provided task sleeps for 500 milliseconds, it **blocks the current thread**, and the result is available immediately after the *execute* call is finished:

```
Executor executor = MoreExecutors.directExecutor();

AtomicBoolean executed = new AtomicBoolean();

executor.execute(() -> {
    try {
        Thread.sleep(500);
    } catch (InterruptedException e) {
        e.printStackTrace();
    }
    executed.set(true);
});

assertTrue(executed.get());
```

The instance returned by the *directExecutor()* method is actually a static singleton, so using this method does not provide any overhead on object creation at all.

You should prefer this method to the *MoreExecutors.newDirectExecutorService()*, because that API creates a full-fledged executor service implementation on every call.

4.3. Exiting Executor Services

Another common problem is **shutting down the virtual machine** while a thread pool is still running its tasks. Even with a cancellation mechanism in place, there is no guarantee that the tasks will behave nicely and stop their work when the executor service shuts down. This may cause JVM to hang indefinitely while the tasks keep doing their work.

To solve this problem, Guava introduces a family of exiting executor services. They are based on **daemon threads which terminate together with the JVM**.

These services also add a shutdown hook with the *Runtime.getRuntime().addShutdownHook()* method and prevent the VM from terminating for a configured amount of time before giving up on hung tasks.

In the following example we're submitting the task that contains an infinite loop, but we use an exiting executor service with a configured time of 100 milliseconds to wait for the tasks upon VM termination. Without the *exitingExecutorService* in place, this task would cause the VM to hang indefinitely:

```
ThreadPoolExecutor executor =
  (ThreadPoolExecutor) Executors.newFixedThreadPool(5);
ExecutorService executorService =
  MoreExecutors.getExitingExecutorService(executor,
    100, TimeUnit.MILLISECONDS);

executorService.submit(() -> {
    while (true) {
    }
});
```

4.4. Listening Decorators

Listening decorators allow you to wrap the *ExecutorService* and receive *ListenableFuture* instances upon task submission instead of simple *Future* instances. The *ListenableFuture* interface extends *Future* and has a single additional method *addListener*. This method allows adding a listener that is called upon future completion.

You'll rarely want to use *ListenableFuture.addListener()* method directly, but it is **essential to most of the helper methods in the *Futures* utility class**. For instance, with the *Futures.allAsList()* method you can combine several *ListenableFuture* instances in a single *ListenableFuture* that completes upon the successful completion of all the futures combined:

```
ExecutorService executorService = Executors.newCachedThreadPool();
ListeningExecutorService listeningExecutorService =
  MoreExecutors.listeningDecorator(executorService);

ListenableFuture<String> future1 =
  listeningExecutorService.submit(() -> "Hello");
ListenableFuture<String> future2 =
  listeningExecutorService.submit(() -> "World");

String greeting = Futures.allAsList(future1, future2).get()
  .stream()
  .collect(Collectors.joining(" "));
                                          g);
```

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