

Java 8 Concurrency Tutorial: Threads and Executors

April 07, 2015

Welcome to the first part of my Java 8 Concurrency tutorial. This guide teaches you **concurrent programming** in Java 8 with easily understood code examples. It's the first part out of a series of tutorials covering the Java Concurrency API. In the next 15 min you learn how to execute code in parallel via threads, tasks and executor services.

- Part 1: Threads and Executors
- Part 2: Synchronization and Locks
- Part 3: Atomic Variables and ConcurrentMap

The **Concurrency API** was first introduced with the release of Java 5 and then progressively enhanced with every new Java release. The majority of concepts shown in this article also work in older versions of Java. However my code samples focus on Java 8 and make heavy use of lambda expressions and other new features. If you're not yet familiar with lambdas I recommend reading my [Java 8 Tutorial](#) first.

Threads and Runnables

All modern operating systems support concurrency both via **processes** and **threads**. Processes are instances of programs which typically run independent to each other, e.g. if you start a java program the operating system spawns a new process which runs in parallel to other programs. Inside those processes we can utilize threads to execute code concurrently, so we can make the most out of the available cores of the CPU.

Java supports **Threads** since JDK 1.0. Before starting a new thread you have to specify the code to be executed by this thread, often called the *task*. This is done by implementing `Runnable` - a functional interface defining a single void no-args method `run()` as demonstrated in the following example:

```
Runnable task = () -> {
    String threadName = Thread.currentThread().getName();
    System.out.println("Hello " + threadName);
};

task.run();

Thread thread = new Thread(task);
thread.start();

System.out.println("Done!");
```

Since `Runnable` is a functional interface we can utilize Java 8 lambda expressions to print the current threads name to the console. First we execute the runnable directly on the main thread before starting a new thread.

The result on the console might look like this:

```
Hello main
Hello Thread-0
Done!
```

Or that:

```
Hello main
Done!
Hello Thread-0
```

Due to concurrent execution we cannot predict if the runnable will be invoked before or after printing 'done'. The order is non-deterministic, thus making concurrent programming a complex task in larger applications.

Threads can be put to sleep for a certain duration. This is quite handy to simulate long running tasks in the subsequent code samples of this article:

```
Runnable runnable = () -> {
    try {
        String name = Thread.currentThread().getName();
        System.out.println("Foo " + name);
        TimeUnit.SECONDS.sleep(1);
        System.out.println("Bar " + name);
    }
    catch (InterruptedException e) {
        e.printStackTrace();
    }
};
```

```
Thread thread = new Thread(runnable);  
thread.start();
```

When you run the above code you'll notice the one second delay between the first and the second print statement. `TimeUnit` is a useful enum for working with units of time. Alternatively you can achieve the same by calling `Thread.sleep(1000)`.

Working with the `Thread` class can be very tedious and error-prone. Due to that reason the **Concurrency API** has been introduced back in 2004 with the release of Java 5. The API is located in package `java.util.concurrent` and contains many useful classes for handling concurrent programming. Since that time the Concurrency API has been enhanced with every new Java release and even Java 8 provides new classes and methods for dealing with concurrency.

Now let's take a deeper look at one of the most important parts of the Concurrency API - the executor services.

Executors

The Concurrency API introduces the concept of an `ExecutorService` as a higher level replacement for working with threads directly. Executors are capable of running asynchronous tasks and typically manage a pool of threads, so we don't have to create new threads manually. All threads of the internal pool will be reused under the hood for reventant tasks, so we can run as many concurrent tasks as we want throughout the life-cycle of our application with a single executor service.

This is how the first thread-example looks like using executors:

```
ExecutorService executor = Executors.newSingleThreadExecutor();  
executor.submit(() -> {  
    String threadName = Thread.currentThread().getName();  
    System.out.println("Hello " + threadName);  
});  
  
// => Hello pool-1-thread-1
```

The class `Executors` provides convenient factory methods for creating different kinds of executor services. In this sample we use an executor with a thread pool of size one.

The result looks similar to the above sample but when running the code you'll notice an important difference: the java process never stops! Executors have to be stopped explicitly - otherwise they

keep listening for new tasks.

An `ExecutorService` provides two methods for that purpose: `shutdown()` waits for currently running tasks to finish while `shutdownNow()` interrupts all running tasks and shut the executor down immediately.

This is the preferred way how I typically shutdown executors:

```
try {
    System.out.println("attempt to shutdown executor");
    executor.shutdown();
    executor.awaitTermination(5, TimeUnit.SECONDS);
}
catch (InterruptedException e) {
    System.err.println("tasks interrupted");
}
finally {
    if (!executor.isTerminated()) {
        System.err.println("cancel non-finished tasks");
    }
    executor.shutdownNow();
    System.out.println("shutdown finished");
}
```

The executor shuts down softly by waiting a certain amount of time for termination of currently running tasks. After a maximum of five seconds the executor finally shuts down by interrupting all running tasks.

Callables and Futures

In addition to `Runnable` executors support another kind of task named `Callable`. Callables are functional interfaces just like runnables but instead of being `void` they return a value.

This lambda expression defines a callable returning an integer after sleeping for one second:

```
Callable<Integer> task = () -> {
    try {
        TimeUnit.SECONDS.sleep(1);
        return 123;
    }
    catch (InterruptedException e) {
        throw new IllegalStateException("task interrupted", e);
    }
};
```

Callables can be submitted to executor services just like runnables. But what about the callables result? Since `submit()` doesn't wait until the task completes, the executor service cannot return the result of the callable directly. Instead the executor returns a special result of type `Future` which can be used to retrieve the actual result at a later point in time.

```
ExecutorService executor = Executors.newFixedThreadPool(1);
Future<Integer> future = executor.submit(task);

System.out.println("future done? " + future.isDone());

Integer result = future.get();

System.out.println("future done? " + future.isDone());
System.out.print("result: " + result);
```

After submitting the callable to the executor we first check if the future has already been finished execution via `isDone()`. I'm pretty sure this isn't the case since the above callable sleeps for one second before returning the integer.

Calling the method `get()` blocks the current thread and waits until the callable completes before returning the actual result `123`. Now the future is finally done and we see the following result on the console:

```
future done? false
future done? true
result: 123
```

Futures are tightly coupled to the underlying executor service. Keep in mind that every non-terminated future will throw exceptions if you shutdown the executor:

```
executor.shutdownNow();
future.get();
```

You might have noticed that the creation of the executor slightly differs from the previous example. We use `newFixedThreadPool(1)` to create an executor service backed by a thread-pool of size one. This is equivalent to `newSingleThreadExecutor()` but we could later increase the pool size by simply passing a value larger than one.

Timeouts

Any call to `future.get()` will block and wait until the underlying callable has been terminated. In the worst case a callable runs forever - thus making your application unresponsive. You can

simply counteract those scenarios by passing a timeout:

```
ExecutorService executor = Executors.newFixedThreadPool(1);

Future<Integer> future = executor.submit(() -> {
    try {
        TimeUnit.SECONDS.sleep(2);
        return 123;
    }
    catch (InterruptedException e) {
        throw new IllegalStateException("task interrupted", e);
    }
});

future.get(1, TimeUnit.SECONDS);
```

Executing the above code results in a `TimeoutException`:

```
Exception in thread "main" java.util.concurrent.TimeoutException
    at java.util.concurrent.FutureTask.get(FutureTask.java:205)
```

You might already have guessed why this exception is thrown: We specified a maximum wait time of one second but the callable actually needs two seconds before returning the result.

InvokeAll

Executors support batch submitting of multiple callables at once via `invokeAll()`. This method accepts a collection of callables and returns a list of futures.

```
ExecutorService executor = Executors.newWorkStealingPool();

List<Callable<String>> callables = Arrays.asList(
    () -> "task1",
    () -> "task2",
    () -> "task3");

executor.invokeAll(callables)
    .stream()
    .map(future -> {
        try {
            return future.get();
        }
        catch (Exception e) {
            throw new IllegalStateException(e);
        }
    })
    .forEach(System.out::println);
```

In this example we utilize Java 8 functional streams in order to process all futures returned by the invocation of `invokeAll()`. We first map each future to its return value and then print each value to the console. If you're not yet familiar with streams read my [Java 8 Stream Tutorial](#).

InvokeAny

Another way of batch-submitting callables is the method `invokeAny()` which works slightly different to `invokeAll()`. Instead of returning future objects this method blocks until the first callable terminates and returns the result of that callable.

In order to test this behavior we use this helper method to simulate callables with different durations. The method returns a callable that sleeps for a certain amount of time until returning the given result:

```
Callable<String> callable(String result, long sleepSeconds) {  
    return () -> {  
        TimeUnit.SECONDS.sleep(sleepSeconds);  
        return result;  
    };  
}
```

We use this method to create a bunch of callables with different durations from one to three seconds. Submitting those callables to an executor via `invokeAny()` returns the string result of the fastest callable - in that case task2:

```
ExecutorService executor = Executors.newWorkStealingPool();  
  
List<Callable<String>> callables = Arrays.asList(  
    callable("task1", 2),  
    callable("task2", 1),  
    callable("task3", 3));  
  
String result = executor.invokeAny(callables);  
System.out.println(result);  
  
// => task2
```

The above example uses yet another type of executor created via `newWorkStealingPool()`. This factory method is part of Java 8 and returns an executor of type `ForkJoinPool` which works slightly different than normal executors. Instead of using a fixed size thread-pool `ForkJoinPools` are created for a given parallelism size which per default is the number of available cores of the hosts CPU.

ForkJoinPools exist since Java 7 and will be covered in detail in a later tutorial of this series. Let's finish this tutorial by taking a deeper look at scheduled executors.

Scheduled Executors

We've already learned how to submit and run tasks once on an executor. In order to periodically run common tasks multiple times, we can utilize scheduled thread pools.

A `ScheduledExecutorService` is capable of scheduling tasks to run either periodically or once after a certain amount of time has elapsed.

This code sample schedules a task to run after an initial delay of three seconds has passed:

```
ScheduledExecutorService executor = Executors.newScheduledThreadPool(1);

Runnable task = () -> System.out.println("Scheduling: " + System.nanoTime());
ScheduledFuture<?> future = executor.schedule(task, 3, TimeUnit.SECONDS);

TimeUnit.MILLISECONDS.sleep(1337);

long remainingDelay = future.getDelay(TimeUnit.MILLISECONDS);
System.out.printf("Remaining Delay: %sms", remainingDelay);
```

Scheduling a task produces a specialized future of type `ScheduledFuture` which - in addition to `Future` - provides the method `getDelay()` to retrieve the remaining delay. After this delay has elapsed the task will be executed concurrently.

In order to schedule tasks to be executed periodically, executors provide the two methods `scheduleAtFixedRate()` and `scheduleWithFixedDelay()`. The first method is capable of executing tasks with a fixed time rate, e.g. once every second as demonstrated in this example:

```
ScheduledExecutorService executor = Executors.newScheduledThreadPool(1);

Runnable task = () -> System.out.println("Scheduling: " + System.nanoTime());

int initialDelay = 0;
int period = 1;
executor.scheduleAtFixedRate(task, initialDelay, period, TimeUnit.SECONDS);
```

Additionally this method accepts an initial delay which describes the leading wait time before the task will be executed for the first time.

Please keep in mind that `scheduleAtFixedRate()` doesn't take into account the actual duration of the task. So if you specify a period of one second but the task needs 2 seconds to be

executed then the thread pool will working to capacity very soon.

In that case you should consider using `scheduleWithFixedDelay()` instead. This method works just like the counterpart described above. The difference is that the wait time period applies between the end of a task and the start of the next task. For example:

```
ScheduledExecutorService executor = Executors.newScheduledThreadPool(1);

Runnable task = () -> {
    try {
        TimeUnit.SECONDS.sleep(2);
        System.out.println("Scheduling: " + System.nanoTime());
    }
    catch (InterruptedException e) {
        System.err.println("task interrupted");
    }
};

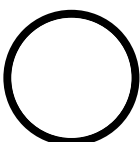
executor.scheduleWithFixedDelay(task, 0, 1, TimeUnit.SECONDS);
```

This example schedules a task with a fixed delay of one second between the end of an execution and the start of the next execution. The initial delay is zero and the tasks duration is two seconds. So we end up with an execution interval of 0s, 3s, 6s, 9s and so on. As you can see `scheduleWithFixedDelay()` is handy if you cannot predict the duration of the scheduled tasks.

This was the first part out of a series of concurrency tutorials. I recommend practicing the shown code samples by your own. You find all code samples from this article on [GitHub](#), so feel free to fork the repo and [give me star](#).

I hope you've enjoyed this article. If you have any further questions send me your feedback in the comments below or via [Twitter](#).

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Don Vaillancourt • 4 months ago

Very good and concise article.

3 ^ | v • Reply • Share >



ftudone • 2 years ago

I suggest having a look Quasar and the Parallel Universe stack as well:
<http://www.paraleluniverse.co...>

Quasar adds lightweight threads ("fibers") to the JVM and "strands", an abstraction unifying regular threads and fibers so that they can coexist and cooperate flawlessly, as well as Java concurrent utils working on any type of strands.

With fibers you can get the same performance of async frameworks without giving up the thread abstraction and imperative control flow constructs (sequence, cycles etc.). In addition Quasar offers fiber-enabled Erlang-style actors, Go-like channels and data-flow programming as well as bindings for popular web technologies (as part of the Comsat project).

Currently It has binding for Java, Clojure (which I highly recommend evaluating in addition to Scala) and soon Kotlin <http://kotlinlang.org> (which I highly recommend too).

2 ^ | v • Reply • Share >



Chetan • a year ago

This is really great description, Thanks for sharing.

Can we have create a thread with return value and also as daemon (as it does not block the main thread execution)? Can someone please provide me example?

1 ^ | v • Reply • Share >



James Patrick Michael Corrao • a month ago

Thanks for the article! Been playing with the Thread/Runnable method and using synchronized and/or static variables. Thanks for this easy to understand and easy-to-start intro to Executor's! Looking forward to digging into the next parts.

^ | v • Reply • Share >



Moshior Rahman • a month ago

one important characteristics i observed, When we did call `executor.invokeAll()` with the argument `List<Callable<String>>` which was retrieved by calling the callable method for each element of list and which had 2 parameter one is the result and another is time -- then then executor behaved such a way that it made sure that most amount of time is taken to complete the task then returned the result together. Can you explain a bit more about this regard.

^ | v • Reply • Share >



Anthony L. Burns • 2 months ago

great stuff - typo - I recommend practicing the shown code samples by your own. should be - I recommend practicing the shown code samples on your own.

^ | v • Reply • Share >



chloe • 2 months ago

Correct me if I am wrong, Runnable doesn't throw `InterruptedException`. so there is a unnecessary catch in the Runnable part which is misleading.

^ | v • Reply • Share >



nikli • 4 months ago

`InvokeAny` code part couldn't compile.

^ | v • Reply • Share >



ChangHyun Lee • 4 months ago

Thank you!

^ | v • Reply • Share >



deano7000 • 6 months ago

Simple, direct, concise. One of the best articles I've read on the topic.

^ | v • Reply • Share >



gp_jack • 6 months ago

Thanks for this. Very helpful explanation.

^ | v • Reply • Share >



Steve Schmidt • 6 months ago

It's a good tutorial, but it would have been nice if you had listed the imports that are needed to make it work. I had to keep Googling to find out what imports were needed every time I turned around.

^ | v • Reply • Share ›



দয়াল বাব্বা • 7 months ago

Probably one of the best articles on JDK8 threads and concurrency. Simple example, precise explanation ... not too verbose, not too short. Great work!

Well done mate !

^ | v • Reply • Share ›



natalija • 9 months ago

This is a great article and blog. Thank you for sharing!

^ | v • Reply • Share ›



FJK • 9 months ago

Hi, I'm using the Java class Future and the Method get to stop a computation after a certain time. However, I recognized that if I use hibernation of the system (for some reason, e. low energy, ...), the computation breaks when the system is up again. The reason is the the time limit is exceeded. Hence, I'd like to ask whether there is any possibility to use user time instead of real time?

^ | v • Reply • Share ›



Nikhil Khatwani • a year ago

Regarding shutdown executors code snippet, shutdownNow call inside finally block should come inside if check of executor.isTerminated(). Refer NetworkService Example <https://docs.oracle.com/javase...>

^ | v • Reply • Share ›



Edward Beckett • a year ago

Very nice article. Thanks for the contrib.

^ | v • Reply • Share ›



gargantua • a year ago

Hadn't doing concurrency for a while and was searching for Java 8 new feature about that. Your post is the perfect answer for this : simple example and explanation,

Thanks for your work :)

(bookmarked)

^ | v • Reply • Share ›



Sandeep • a year ago

i am using java 7,while executing a sql query its taking nearly 15 min .So,how can i resolve this issue please help me .

^ | v • Reply • Share ›



Degill • 2 years ago

"shutdownNow() interrupts all running tasks and shut the executor down immediately"

This actually only interrupts the thread by calling its interrupt() method (AFAIK) which does not

necessarily aborts execution of the thread. The code run by the Thread has to check for `Thread.currentThread().isInterrupted()` to check if it should abort execution. If it ignores it then the Thread will go on even though `shutdownNow` has been called.

Correct me if Im wrong :)

^ | v • Reply • Share ›



Oleg Abrazhaev • 2 years ago

Anyone have a link for same topic but for Java 7 ?

^ | v • Reply • Share ›



张坤 • 2 years ago

Hi,Benjamin.I translate this article into chinese,please see <http://ifeve.com/java8-concurr...>

^ | v • Reply • Share ›

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1 comment • 2 years ago•



Bharat — thanks, but very vague. Would be better if you had some result eg

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Kenn Sano — Thanx Saisurya,Solarized Dark is nice and Im using it now - only I changed the bgcolor to black.

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Michal Brzezinski — Great post, you really explain things in easy to understand way!

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Señor Barsum — Thanks! Very interesting

