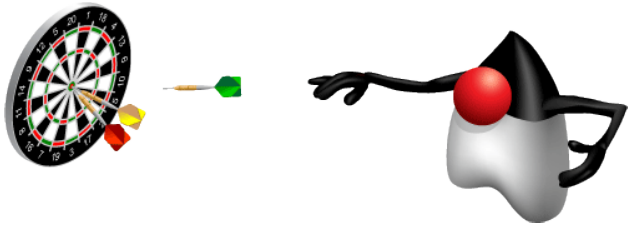
15

Concurrency

Objectives

After completing this lesson, you should be able to:

- Describe operating system task scheduling
- Create worker threads using `Runnable` and `Callable`
- Use an `ExecutorService` to concurrently execute tasks
- Identify potential threading problems
- Use `synchronized` and concurrent atomic to manage atomicity
- Use monitor locks to control the order of thread execution
- Use the `java.util.concurrent` collections



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Task Scheduling

Modern operating systems use preemptive multitasking to allocate CPU time to applications. There are two types of tasks that can be scheduled for execution:

- **Processes:** A process is an area of memory that contains both code and data. A process has a thread of execution that is scheduled to receive CPU time slices.
- **Thread:** A thread is a scheduled execution of a process. Concurrent threads are possible. All threads for a process share the same data memory but may be following different paths through a code section.

Legacy `Thread` and `Runnable`

Prior to Java 5, the `Thread` class was used to create and start threads. Code to be executed by a thread is placed in a class, which does either of the following:

- Extends the `Thread` class
  - Simpler code
- Implements the `Runnable` interface
  - More flexible
  - `extends` is still free.

Extending Thread

Extend `java.lang.Thread` and override the `run` method:

```
public class ExampleThread extends Thread {
    @Override
    public void run() {
        for(int i = 0; i < 10; i++) {
            System.out.println("i:" + i);
        }
    }
}
```

Implementing Runnable

Implement java.lang.Runnable and implement the run method:

```
public class ExampleRunnable implements Runnable {
    private final String name;

    public ExampleRunnable(String name) {
        this.name = name;
    }

    @Override
    public void run() {
        for (int i = 0; i < 10; i++) {
            System.out.println(name + ":" + i);
        }
    }
}
```

The `java.util.concurrent` Package

Java 5 introduced the `java.util.concurrent` package, which contains classes that are useful in concurrent programming. Features include:

- Concurrent collections
- Synchronization and locking alternatives
- Thread pools
  - Fixed and dynamic thread count pools available
  - Parallel divide and conquer (Fork-Join) new in Java 7

Recommended Threading Classes

Traditional `Thread` related APIs are difficult to code properly. Recommended concurrency classes include:

- `java.util.concurrent.ExecutorService`, a higher level mechanism used to execute tasks
  - It may create and reuse `Thread` objects for you.
  - It allows you to submit work and check on the results in the future.
- The Fork-Join framework, a specialized work-stealing `ExecutorService` new in Java 7

java.util.concurrent.ExecutorService

An `ExecutorService` is used to execute tasks.

- It eliminates the need to manually create and manage threads.
- Tasks **might** be executed in parallel depending on the `ExecutorService` implementation.
- Tasks can be:
  - `java.lang.Runnable`
  - `java.util.concurrent.Callable`
- Implementing instances can be obtained with `Executors`.

```
ExecutorService es = Executors.newCachedThreadPool();
```

Example `ExecutorService`

This example illustrates using an `ExecutorService` to execute `Runnable` tasks:

```
package com.example;

import java.util.concurrent.ExecutorService;
import java.util.concurrent.Executors;

public class ExecutorExample {
    public static void main(String[] args) {
        ExecutorService es = Executors.newCachedThreadPool();
        es.execute(new ExampleRunnable("one"));
        es.execute(new ExampleRunnable("two"));
        es.shutdown();
    }
}
```

Execute this Runnable task sometime in the future

Shut down the executor

Shutting Down an `ExecutorService`

Shutting down an `ExecutorService` is important because its threads are nondaemon threads and will keep your JVM from shutting down.

Stop accepting new `Callables`.

If you want to wait for the `Callables` to finish

```
es.shutdown();

try {
    es.awaitTermination(5, TimeUnit.SECONDS);
} catch (InterruptedException ex) {
    System.out.println("Stopped waiting early");
}
```

java.util.concurrent.Callable

The `Callable` interface:

- Defines a task submitted to an `ExecutorService`
- Is similar in nature to `Runnable`, but can:
  - Return a result using generics
  - Throw a checked exception

```
package java.util.concurrent;
public interface Callable<V> {
    V call() throws Exception;
}
```

Example `Callable` Task

```
public class ExampleCallable implements Callable {

  private final String name;
  private final int len;
  private int sum = 0;

  public ExampleCallable(String name, int len) {
    this.name = name;
    this.len = len;
  }

  @Override
  public String call() throws Exception {
    for (int i = 0; i < len; i++) {
      System.out.println(name + ":" + i);
      sum += i;
    }
    return "sum: " + sum;
  }
}
```

Return a String from this task: the sum of the series

java.util.concurrent.Future

The `Future` interface is used to obtain the results from a `Callable`'s `V call()` method.

```
Future<V> future = es.submit(callable);
//submit many callables
try {
    V result = future.get();
} catch (ExecutionException|InterruptedException ex) {

}
```

`ExecutorService` controls when the work is done.

Gets the result of the `Callable`'s `call` method (blocks if needed).

If the `Callable` threw an `Exception`

Example

```
public static void main(String[] args) {

  ExecutorService es = Executors.newFixedThreadPool(4);
  Future<String> f1 = es.submit(new ExampleCallable("one",10));
  Future<String> f2 = es.submit(new ExampleCallable("two",20));

  try {
    es.shutdown();
    es.awaitTermination(5, TimeUnit.SECONDS);
    String result1 = f1.get();
    System.out.println("Result of one: " + result1);
    String result2 = f2.get();
    System.out.println("Result of two: " + result2);
  } catch (ExecutionException | InterruptedException ex) {
    System.out.println("Exception: " + ex);
  }

}
```

Wait 5 seconds for the tasks to complete

Get the results of tasks f1 and f2

Threading Concerns

- Thread Safety
  - Classes should continue to behave correctly when accessed from multiple threads.
- Performance: Deadlock and livelock
  - Threads typically interact with other threads. As more threads are introduced into an application, the possibility exists that threads will reach a point where they cannot continue.

Shared Data

Static and instance fields are potentially shared by threads.

```
public class SharedValue {
    private int i;

    // Return a unique value
    public int getNext() {
        return i++;
    }
}
```

Potentially shared variable

Problems with Shared Data

Shared data must be accessed cautiously. Instance and static fields:

- Are created in an area of memory known as heap space
- Can potentially be shared by any thread
- Might be changed concurrently by multiple threads
  - There are no compiler or IDE warnings.
  - “Safely” accessing shared fields is your responsibility.

Two threads accessing an instance of the `SharedValue` class might produce the following:

```
i:0,i:0,i:1,i:2,i:3,i:4,i:5,i:6,i:7,i:8,i:9,i:10,i:12,i:11 ...
```

Zero produced twice

Out of sequence

Nonshared Data

Some variable types are never shared. The following types are always thread-safe:

- Local variables
- Method parameters
- Exception handler parameters
- Immutable data

Atomic Operations

Atomic operations function as a single operation. A single statement in the Java language is not always atomic.

- `i++;`
  - Creates a temporary copy of the value in `i`
  - Increments the temporary copy
  - Writes the new value back to `i`
- `l = 0xffff_ffff_ffff_ffff;`
  - 64-bit variables might be accessed using two separate 32-bit operations.

What inconsistencies might two threads incrementing the same field encounter?

What if that field is long?

Out-of-Order Execution

- Operations performed in one thread may not appear to execute in order if you observe the results from another thread.
  - Code optimization may result in out-of-order operation.
  - Threads operate on cached copies of shared variables.
- To ensure consistent behavior in your threads, you must synchronize their actions.
  - You need a way to state that an action happens before another.
  - You need a way to flush changes to shared variables back to main memory.

The `synchronized` Keyword

The `synchronized` keyword is used to create thread-safe code blocks. A `synchronized` code block:

- Causes a thread to write all of its changes to main memory when the end of the block is reached
- Is used to group blocks of code for exclusive execution
  - Threads block until they can get exclusive access
  - Solves the atomic problem

synchronized Methods

```java
public class SynchronizedCounter {
  private static int i = 0;

  public synchronized void increment(){
    i++;
  }

  public synchronized void decrement(){
    i--;
  }

  public synchronized int getValue(){
    return i;
  }
}
```

`synchronized` Blocks

```
public void run(){
  for (int i = 0; i < countSize; i++){
    synchronized(this){
      count.increment();
      System.out.println(threadName
           + " Current Count: " + count.getValue());
    }
  }
}
```

Object Monitor Locking

Each object in Java is associated with a monitor, which a thread can lock or unlock.

- `synchronized` methods use the monitor for the `this` object.
- `static synchronized` methods use the classes' monitor.
- `synchronized` blocks must specify which object's monitor to lock or unlock.

```
synchronized ( this ) { }
```

- `synchronized` blocks can be nested.

Threading Performance

To execute a program as quickly as possible, you must avoid performance bottlenecks. Some of these bottlenecks are:

- Resource Contention: Two or more tasks waiting for exclusive use of a resource
- Blocking I/O operations: Doing nothing while waiting for disk or network data transfers
- Underutilization of CPUs: A single-threaded application uses only a single CPU

Performance Issue: Examples

- **Deadlock** results when two or more threads are blocked forever, waiting for each other.

```
synchronized(obj1) {
  synchronized(obj2) {
  }
}
```

Thread 1 pauses after locking obj1's monitor.

```
synchronized(obj2) {
  synchronized(obj1) {
  }
}
```

Thread 2 pauses after locking obj2's monitor.

- **Starvation** and **Livelock**

`java.util.concurrent` Classes and Packages

The `java.util.concurrent` package contains a number of classes that help with your concurrent applications. Here are just a few examples.

- `java.util.concurrent.atomic` package
  - Lock free thread-safe variables
- `CyclicBarrier`
  - A class that blocks until a specified number of threads are waiting for the thread to complete.
- Concurrency collections

The `java.util.concurrent.atomic` Package

The `java.util.concurrent.atomic` package contains classes that support lock-free thread-safe programming on single variables.

```
    public static void main(String[] args) {
        AtomicInteger ai = new AtomicInteger(5);
        System.out.println("New value: "
          + ai.incrementAndGet());
        System.out.println("New value: "
          + ai.getAndIncrement());
        System.out.println("New value: "
          + ai.getAndIncrement());

    }
```

An atomic operation increments value to 6 and returns the value.

java.util.concurrent.CyclicBarrier

The `CyclicBarrier` is an example of the synchronizer category of classes provided by `java.util.concurrent`.

```
final CyclicBarrier barrier = new CyclicBarrier(2);
// lines omitted
    public void run() {
      try {
        System.out.println("before await - "
          + threadCount.incrementAndGet());
        barrier.await();
        System.out.println("after await - "
          + threadCount.get());
      } catch (BrokenBarrierException|InterruptedException
ex) {

      }
```

Two threads must await before they can unblock.

May not be reached

java.util.concurrent.CyclicBarrier

- If line 18 is uncommented, the program will exit

```
 9 public class CyclicBarrierExample implements Runnable{
10     final CyclicBarrier barrier = new CyclicBarrier(2);
11     AtomicInteger threadCount = new AtomicInteger(0);
12
13
14     public static void main(String[] args) {
15       ExecutorService es = Executors.newFixedThreadPool(4);
16
17       CyclicBarrierExample ex = new CyclicBarrierExample();
18       es.submit(ex);
19       //es.submit(ex);
20
21       es.shutdown();
22     }
```

Thread-Safe Collections

The `java.util` collections are not thread-safe. To use collections in a thread-safe fashion:

- Use synchronized code blocks for all access to a collection if writes are performed
- Create a synchronized wrapper using library methods, such as `java.util.Collections.synchronizedList(List<T>)`
- Use the `java.util.concurrent` collections

Note: Just because a `Collection` is made thread-safe, this does not make its elements thread-safe.

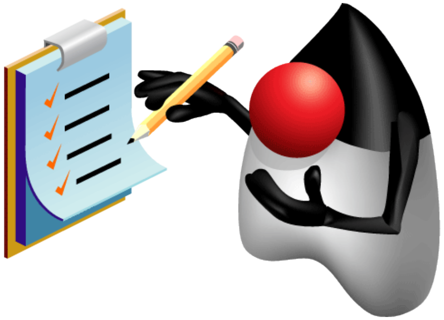
`CopyOnWriteArrayList`: Example

```
public class ArrayListTest implements Runnable{
  private CopyOnWriteArrayList<String> wordList =
    new CopyOnWriteArrayList<>();

  public static void main(String[] args) {
    ExecutorService es = Executors.newCachedThreadPool();
    ArrayListTest test = new ArrayListTest();

    es.submit(test); es.submit(test);  es.shutdown();

  // Print code here
  public void run(){
    wordList.add("A");
    wordList.add("B");
    wordList.add("C");
  }
```

Summary

In this lesson, you should have learned how to:

- Describe operating system task scheduling
- Use an `ExecutorService` to concurrently execute tasks
- Identify potential threading problems
- Use `synchronized` and concurrent atomic to manage atomicity
- Use monitor locks to control the order of thread execution
- Use the `java.util.concurrent` collections



Practice 15-1 Overview: Using the `java.util.concurrent` Package

This practice covers the following topics:

- Using a cached thread pool (`ExecutorService`)
- Implementing `Callable`
- Receiving `Callable` results with a `Future`

Quiz

An `ExecutorService` will always attempt to use all of the available CPUs in a system.

a. True

b. False

Quiz

Variables are thread-safe if they are:

a. `local`

b. `static`

c. `final`

d. `private`