MET CS 622: Concurrency

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Outline

- Thread Concepts
- Locks
  - Structured Lock
  - Unstructured Locks

Outline

- **Thread Concepts**
- Locks
  - Structured Lock
  - Unstructured Locks

Problem with Disk Operation

- Performing an operation inside memory is very fast.
- In contrast, accessing disk and performing I/O is slow process.
- If a process need something from disk, usually it should wait until that particular information gets available and then uses it.
- Considering slow disk access the performance of computers could be very poor.
- Computers are multi-task and should run several things in parallel. Operating systems resolve this challenge by introducing a **multi-thread feature**, which is called **concurrency**.

Thread


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Definitions

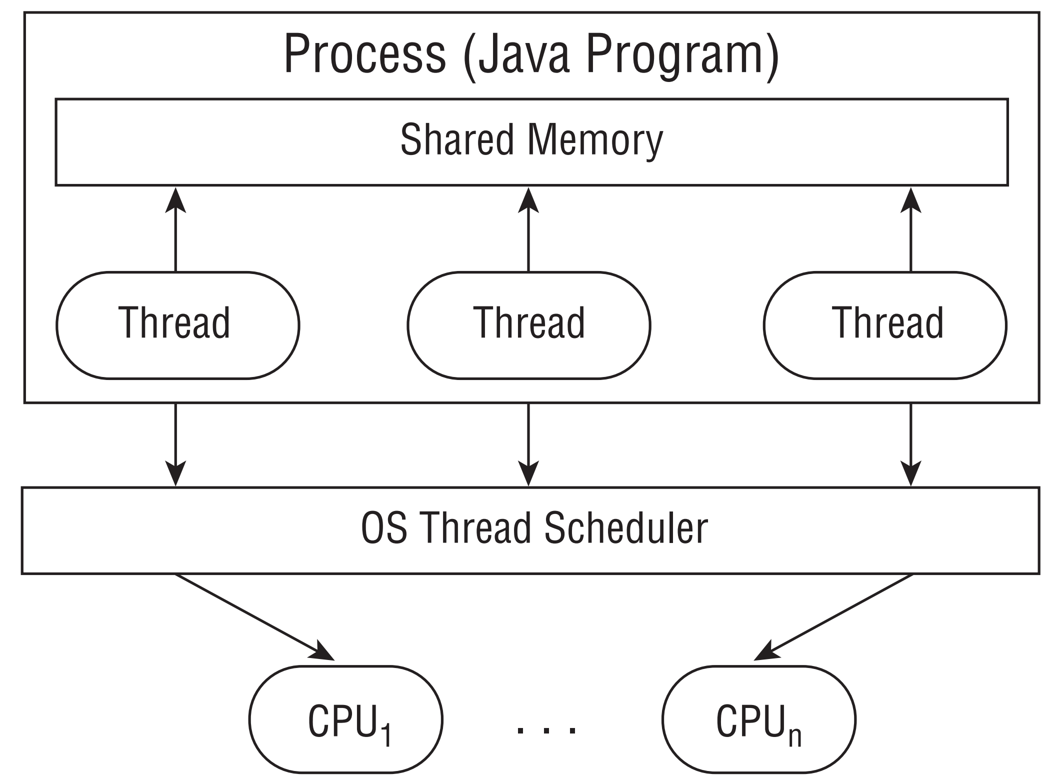
- **Thread** is the smallest unit of execution that can be scheduled by the operating system.
- A **process** is a set of threads that execute in the same shared environment (shared memory space).
- A **task** is a unit of a work that is performed by a thread.
- Executing multiple threads or processes at a time is called **concurrency**.
- Most of Java applications are multi-thread.

CPU and Thread

- A single core CPU can execute only one thread.
- A multi core CPU can execute more than one thread, but the number of threads could be larger than the number of CPU cores.
- Operating systems use something called **thread scheduler**, which decide what should be executed.

Thread Scheduler

- Operating system use thread scheduler to determine which thread should be running on a CPU core.
- Thread schedulers can use a **round-robin algorithm** to determine resource to thread assignment.
- The round-robin algorithm focus on *equal resource assignment* to each thread, in a circular fashion.
- To be honest, thread scheduling algorithms are far more complex than round-robin, but we need to be familiar with the concept of round-robin algorithm.



Source: OCP_ Oracle Certified Professional Java SE 8 Programmer II Study Guide_ Exam 1Z0-809-Sybex

Thread Priority

- Java enables us to assign a priority to a thread.
- It supports three thread priorities:
  - `Thread.MIN_PRIORITY`
  - `Thread.NORM_PRIORITY`
  - `Thread.MAX_PRIORITY`

Runnable

- `java.lang.Runnable` is a **functional java interface** that is used to define the work that a thread should execute.

- A functional interface is an interface that contains only **one abstract method**, but it can have any number of non-abstract methods.

- Until now, we use main as an application execution entry point. However, for thread execution we need to call the `run()` method inside the `java.lang.Runnable` interface.

```
@FunctionalInterface
public interface Runnable {
    void run();
}
```

Lambda Expression

- We can also use lambda expression that implicitly implements the Runnable interface.

```
() -> System.out.println("Hello World")

() -> {int i=10; i++;}

() -> {return;}

() -> {}
```

An example class that runs something inside a thread

```
public class ThreadExample implements Runnable {
   public void run(){
     // what is running inside the thread goes here
   }
}
```

Creating a Thread

There are two steps required to create a thread.

1. Defining the thread within the tasks it should perform.

2. Starting the thread.

There is no guarantee about the order of threads to be executed in Java.

Helloworld Thread

```
package edu.bu.met622.threadtest;

public class SuperSimplePrint implements Runnable{

  @Override
  public void run() {
    for (int i=0; i<10; i++) {
      System.out.println("i is:"+i);
    }
  }
  public static void main(String[] args) {
    Thread t = new Thread(new SuperSimplePrint());
    t.start();
  }

}
```

Summary of Concurrency in Java

- Thread is a **class**
- Runnable is an **interface**
- The **Thread class implements Runnable**
- The argument passed to the thread constructor must be a Runnable.
- The threads spawned by a process run asynchronously

Now we make two threads and each one is printing a number (their task).

```java
package edu.bu.met622.threadtest;

public class FirstThread implements Runnable{

    @Override
    public void run() {
        for (int i =0; i<100 ; i++) {
            System.out.println("-from FirstThread: i:"+i);
        }
    }
}
```

```java
package edu.bu.met622.threadtest;

public class SecondThread implements Runnable{

    @Override
    public void run() {
        for (int j =0; j<100 ; j++) {
            System.out.println("-from SecondThread: j:"+j);
        }
    }

}
```

```java
package edu.bu.met622.threadtest;

import edu.bu.met622.threadtest.FirstThread;
import edu.bu.met622.threadtest.SecondThread;

public class TesttwoThread {
  public static void main(String[] args) {
    FirstThread firstT = new FirstThread() ;
    Thread a = new Thread(firstT);

    SecondThread secondT = new SecondThread();
    Thread b = new Thread(secondT);

    a.start();
    b.start();
  }
}
```

Difference between `run()` and `start()`

- The method `start()`, will starts a new thread and the JVM assigns it to a CPU core.

- The `run()`, will execute the content of a thread.

Some Common Job Interview Questions about Threads

- Explain the difference between extending the Thread class and implementing Runnable.

  A. If we need to define our own thread rules, upon which multiple tasks will rely, e.g. a **priority thread**, extending thread may be preferable.

  B. Java doesn't support multiple inheritance, and thus **extending Thread** does not allow us to extend any other class, whereas implementing Runnable lets you extend another class.

  C. **Implementing Runnable** is often a better object-oriented design practice, because **it separates the task being performed from the Thread object that are performing it**.

  D. Implementing Runnable allows the class to be used by numerous Concurrency API classes.

Some Common Job Interview Questions about Threads

- Explain the difference between <u>extending the Thread class</u> and <u>implementing Runnable</u>.

  A. If we need to define our own thread rules, upon which multiple tasks will rely, e.g. a **priority thread**, extending thread may be preferable.

  B. Java does [illegible] **tending Thread** does not a[illegible] mplementing Runnable [illegible]

  C. **Implementing Runnable** is often a better object-oriented design practice, because **it separates the task being performed from the Thread object that are performing it**.

  D. Implementing Runnable allows the class to be used by numerous Concurrency API classes.

Many books recommend avoid extending Thread class, unless you must doing it.

Thread Join

experiment this code with/without join

The join method allows one thread to wait until another thread gets accepted.

```java
package edu.bu.met622.threadtest;

public class TestThreadJoin {
    public static void main(String[] args) throws InterruptedException {
        Thread t1 = new Thread() {
            public void run() {
                for (int j=0 ; j<20; j++) {
                    System.out.println("t1");
                }
            }
        };
        Thread t2 = new Thread() {
            public void run() {
                for (int j=0 ; j<20; j++) {
                    System.out.println("t2");
                }

            }
        };
        t1.start();
//      Lets comment and uncomment t2.join and see the differences.
        t2.join();
        t2.start();
        System.out.println("End");
    }
}
```

Thread Sleep

- As it has been explained a threads is running out of our control after it has been started.
- Some times it is useful if we can pause thread execution temporary.
- `Thread.sleep(xxx)`, causes a thread to pauses its execution for `xxx` milliseconds.
- `sleep()` is a **static** method in Thread.
- The `sleep()` method throws a checked exception, namely `InterruptedException.`

More example

```
public class TestThreadJoin {
    public static void main(String[] args) throws InterruptedException {
        Thread t1 = new Thread() {
            public void run() {
                for (int j=0 ; j<100; j++) {
                    System.out.println("taaaaaa1");
                }
            }
        };
        Thread t2 = new Thread() {
            public void run() {
                for (int j=0 ; j<100; j++) {
                    System.out.println("t222222");
                }
            }
        };
        Thread t3 = new Thread() {
            public void run() {
                for (int k=0 ; k<100; k++) {
                    System.out.println("t333333");
                }
            }
        };
        t1.start();
        t1.sleep(1000);
        t2.start();
        t3.start();
//      Lets comment and uncomment t2.join and see the differences.
//      t2.join();
        System.out.println("End");
    }
}
```

Thread Sleep

experiment with/without sleep

```
package edu.bu.met622.threadtest;

public class SleepTest1 {
   public static void main(String args[]) throws InterruptedException {
      String importantInfo[] = { “msg 1", "msg 2", "msg 3”, "msg 4” };

      for (int i = 0; i < importantInfo.length; i++) {
         // Pause for 1 seconds
         Thread.sleep(2000);
         // Print a message
         System.out.println(importantInfo[i]);
      }
   }
}
```

Outline

- Thread Concepts
- **Locks**
  - Structured Lock
  - Unstructured Locks

Race Condition Problem

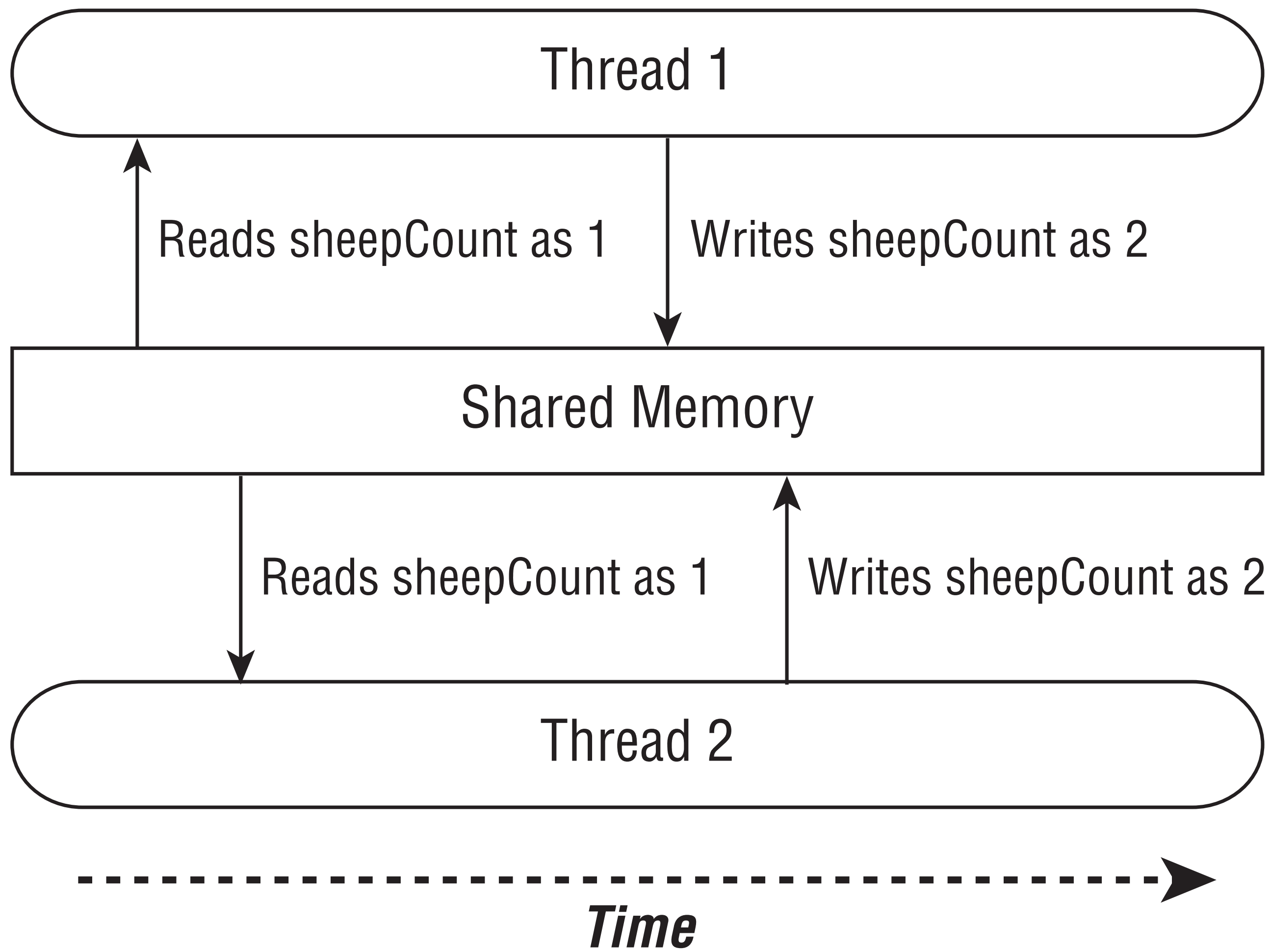
- Suppose we have a method that count an object inside our limited memory, e.g. `increment(val)` as follows:

```
void increment(val){
   val = val+1
   }
```

- Now imagine we have two threads, `T1` and `T2`, and both are calling `increment(val)`

- They are not aware about each other, but they do the same thing. When `T1` calls `increment(val)`and increases `val` from zero to one, then `T2` calls val to increments it to 1, but mistakingly it will increased to 2, because `T1` did increase to 1.

Another Example
Sheep Counting



Source: *OCP: Oracle Certified Professional Java SE 8 Programmer II Study Guide: Exam 1Z0-809*. John Wiley & Sons.

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Structured Lock

- To avoid such a confusion we can use the `synchronize` keyword, which imposes a **lock** on the `increment` while a thread is working with it. Or we can use atomic classes, which will be described later.

```
synchronized void increment(val){
   val = val+1
}
```

- A content of the synchronized method is called **mutually exclusive**, because one thread at a time can work with it. As soon as the thread is starting to work with this method, there will be **lock** on this method and no other method can use it. When a thread is done, the lock will be released and other threads can use it.

Locking an Object with synchronized

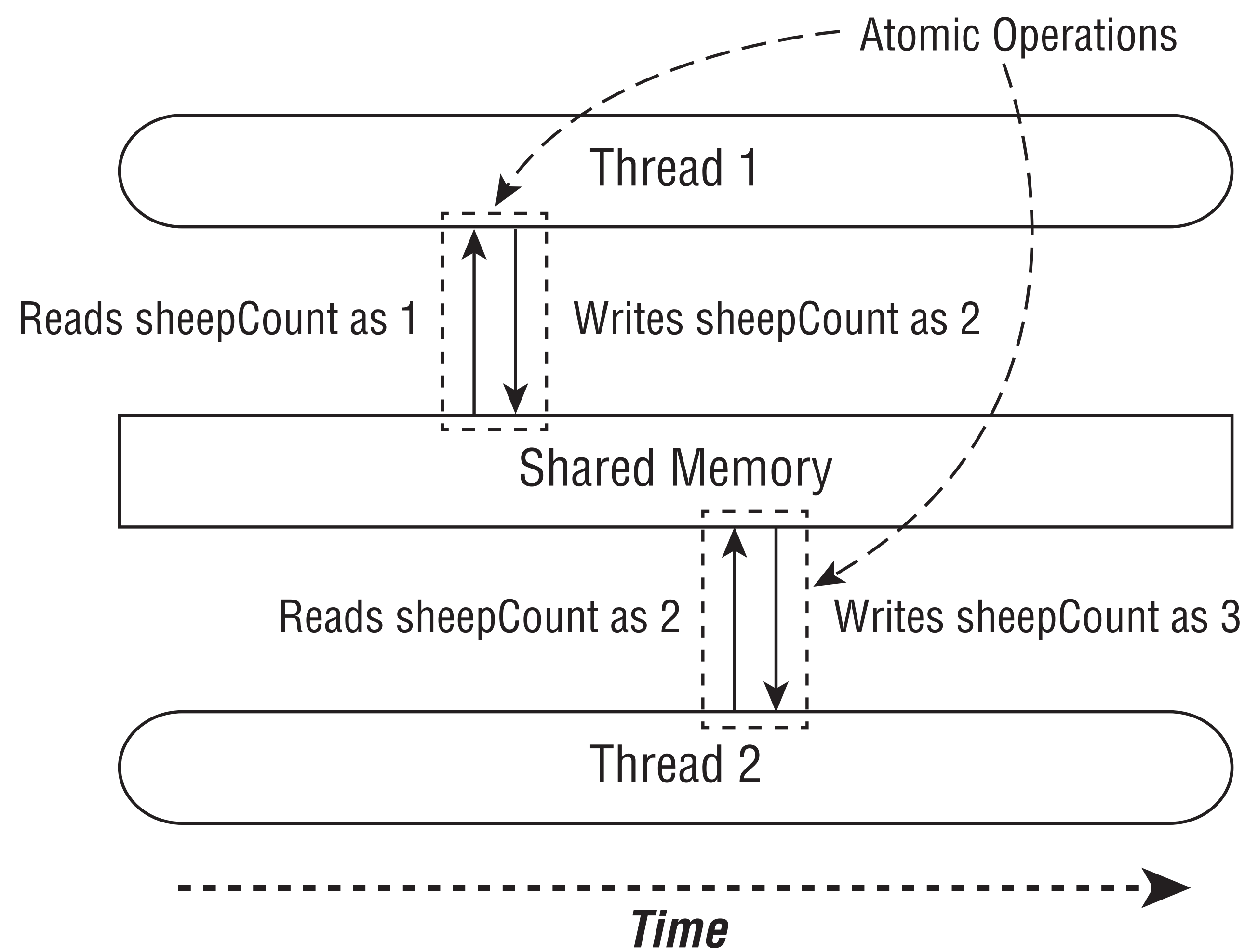
- Some time locking the entire method might negatively impact the other tasks of the method. We can also lock a an object in a block of code.

```
BufferVal buf = new BufferVal{
   …
   synchronized(buf){
     val = val+1;
     …
    }
   …
   }
```

Atomic

- Atomic is a property of operation, which **disables any other thread interference** on that operation.

It is more restricted than Synchronized lock. There are limited number of Atomic classes and Methods and we need to keep them in mind.



Atomic classes and Methods

- Atomic Classes: `AtomicBoolean`, `AtomicInteger`, `AtomicIntegerArray`, `AtomicLong`, `AtomicLongArray`, `AtomicReference`, `AtomicReferenceArray`
- Atomic Methods: `get()`, `set()`, `getAndSet()`, `incrementAndGet()`, `getAndIncrement()`, `decrementAndGet()`, `getAndDecrement()`

`AtomicInteger` Example

```
private AtomicInteger sheepCount = new AtomicInteger(0);

private void incrementAndReport() {
    System.out.print(sheepCount.incrementAndGet()+" ");
}
```

What are the disadvantage of using Synchronized for thread?

Synchronization Disadvantage

- The objective of multi-threat programming is doing task multiple tasks in parallel. By enforcing a lock we disable the multi tasking features, which might increase response time.
- Synchronization protects data integrity, but its costs will be on response time.
- Being able to identify the **performance bottleneck of a system**, especially in multithread environment is very valuable capability.

Outline

- Thread Concepts
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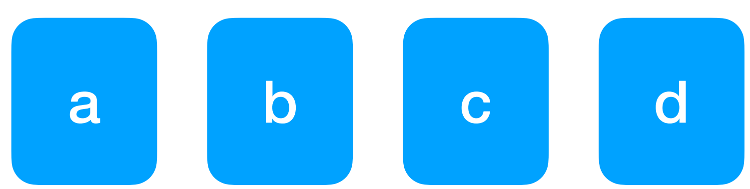
  - Structured Lock
  - **Unstructured Locks**

Unstructured Lock

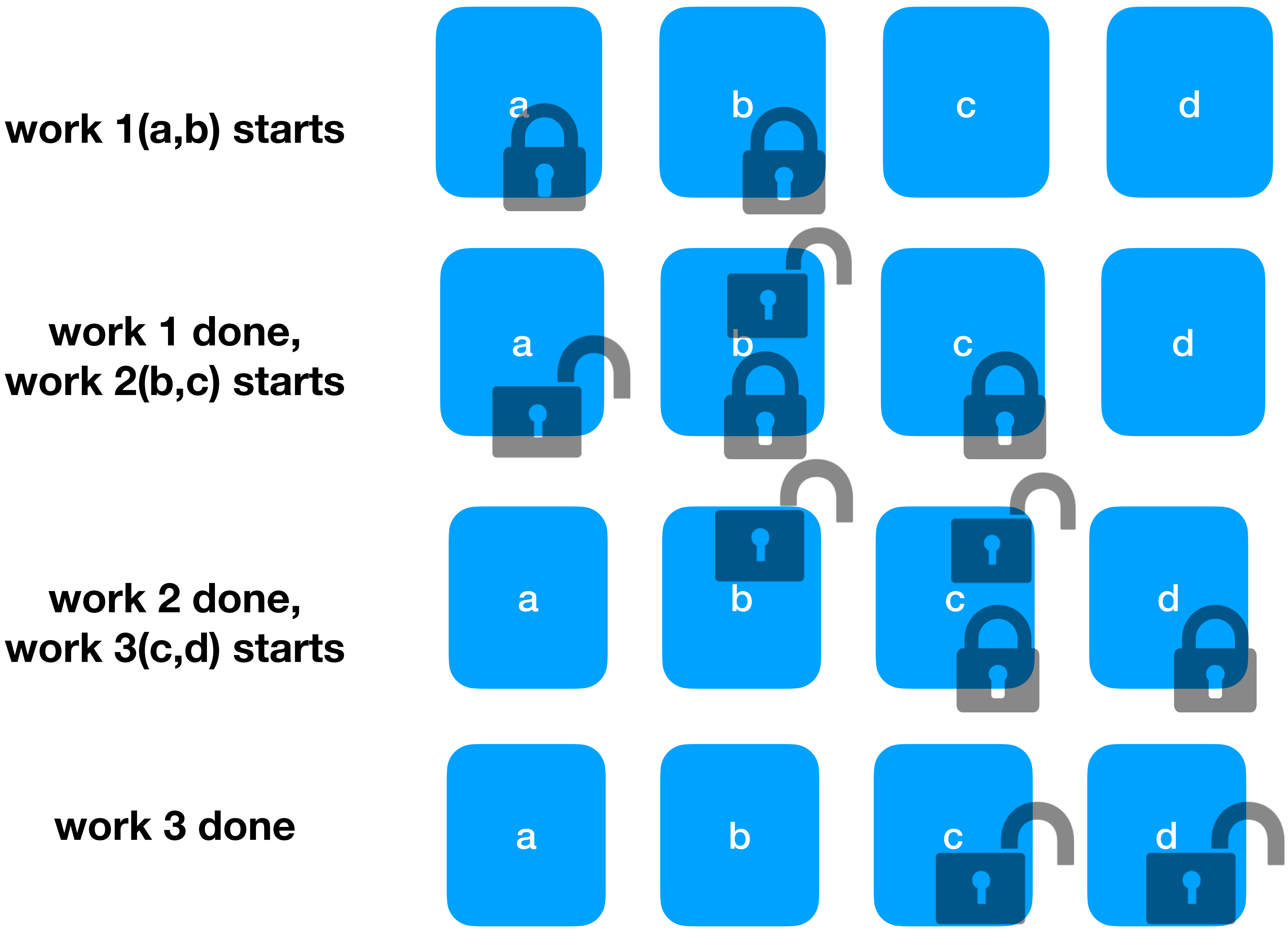
Assume we have a four objects (a,b,c,d) and we have three works that should to be executed in a sequence, we need to do with these objects (w1, w2, w3).

Each of these works require two objects: w1(a,b), w2(b,c) , w3(c,d)

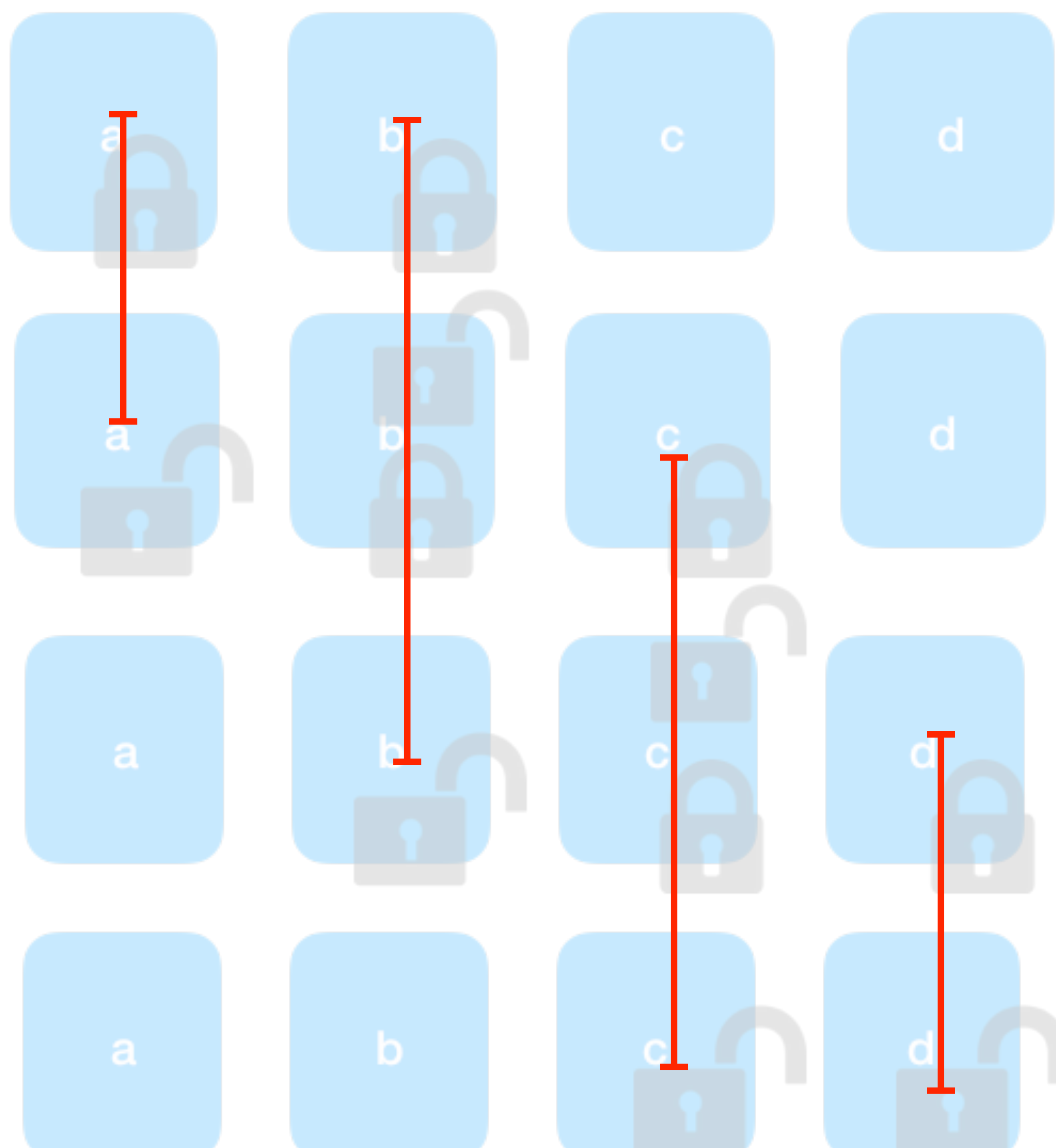


work 1(a,b)
work 2(b,c)
work 3(c,d)

Unstructured Lock



Locks are nested inside each other



work 1(a,b) starts

work 1 done,
work 2(b,c) starts

work 2 done,
work 3(c,d) starts

work 3 done

How to Resolve Nested Locks

- There are two solutions designed to handle nested locks, using a **ReentrantLock** (**Interface Lock** or **Try Lock**) and using **Read/Write** Lock.

- ReentrantLock will hold the lock until the thread is done.

- Read/Write Lock <u>separates read and write operation</u> and implement different locks for them

ReentrantLock

- **`Lock`** implementations provide more extensive locking operations than can be obtained using **`synchronized`** methods and statements. They allow more flexible structuring.

```
Lock lock = new ...;
    lock.lock();
    try{
          // use the resource protected by this lock
    }
    finally {
      lock.unlock();
    }
```

Try Lock Example (1/3)

```
package edu.bu.met622.threadtest.trylock;

public class MyThread extends Thread{

    PrintThread printT;
    MyThread(String name, PrintThread pt){
        super(name);
        this.printT = pt;

    }
    @Override
    public void run() {
        System.out.printf(
            "%s starts printing a document\n”,
Thread.currentThread().getName());
        printT.print();
    }

}
```

Try Lock Example (2/3)

```
package edu.bu.met622.threadtest.trylock;

import java.util.concurrent.locks.Lock;
import java.util.concurrent.locks.ReentrantLock;

public class PrintThread {
      private final Lock queueLock = new ReentrantLock();

      public void print() {
         queueLock.lock();

         try {
            Long duration = (long) (Math.random() * 1000);
             // Play with this duration to show lock changes
            System.out.println(Thread.currentThread().getName() +
                                    " Time Taken " + (duration / 1000) + " secs.");
            Thread.sleep(duration);
         } catch (InterruptedException e) {
            e.printStackTrace();
         } finally {
            System.out.printf(
               "%s printed the document successfully.\n",
Thread.currentThread().getName());
            queueLock.unlock();
         }
      }
}
```

Try Lock Example (3/3)

```java
package edu.bu.met622.threadtest.trylock;

public class TestThread {
     public static void main(String args[]) {
         PrintThread PD = new PrintThread();

         MyThread t1 = new MyThread("Thread - 1 ", PD);
         MyThread t2 = new MyThread("Thread - 2 ", PD);
         MyThread t3 = new MyThread("Thread - 3 ", PD);
         MyThread t4 = new MyThread("Thread - 4 ", PD);

         t1.start();
         t2.start();
         t3.start();
         t4.start();
      }
}
```

Source: https://www.tutorialspoint.com/java_concurrency/concurrency_lock.htm

Read/Write Lock

- It is a solution to mitigate nested locks.
- For example, assume we have an application that both read and write a set of objects. The read threads occurs more often than write, but some writes threads are also there.
- We can define two locks:
    - **Read Lock:** It will be unlocked if no thread is reading or writing.
    - **Write Lock:** It will be unlocked if no thread is writing and no thread has requested write access.
- ***More than one thread can hold a Read Lock, but only one thread can holds the Write Lock***

```java
public class ReadWriteLock{

  private int readers       = 0;
  private int writers       = 0;
  private int writeRequests = 0;

  public synchronized void lockRead() throws InterruptedException{
    while(writers > 0 || writeRequests > 0){
      wait();
    }
    readers++;
  }

  public synchronized void unlockRead(){
    readers--;
    notifyAll();
  }

  public synchronized void lockWrite() throws InterruptedException{
    writeRequests++;

    while(readers > 0 || writers > 0){
      wait();
    }
    writeRequests--;
    writers++;
  }

  public synchronized void unlockWrite() throws InterruptedException{
    writers--;
    notifyAll();
  }
}
```

source: http://tutorials.jenkov.com/java-concurrency/read-write-locks.html

Semantic Errors in Concurrency (Liveness problems)

- DeadLock
- LiveLock
- Starvation

DeadLock

DeadLock

Thread 1:

```
synch(A) {
    synch(B) {
    }
}
```

Thread 2:

```
synch(B) {
    synch(A) {
    }
}
```

Thread 1 starts and acquires a lock on A, then Thread 2 starts and acquires a lock on B. Now thread 1 is willing to acquire the lock on B, but thread 2 is holding it. Also thread B is waiting for thread A to release the lock, but A is waiting for B.

LiveLock

Threads are not blocked, but they are in a mode, which do not make any progress toward finishing their task.

Thread 1:

```
do {
    synch(x) {
       x=x+1
     }
  } while (x<2)
```

Thread 2:

```
do {
    synch(x) {
       x=x-1
     }
  } while (x>-2)
```

LiveLock

Thread 1:

```
do {
      synch(x) {
         x=x+1
       }
   } while (x<3)
```

Thread 2:

```
do {
      synch(x) {
         x=x-1
       }
   } while (x>-3)
```

x=0
T1: x=1
T2: x=0
T1: x=1
T1: x=2
T2: x=1
T2: x=0
T2: x=-1
T1: x=0
...

Starvation

- Assume we have many threads, e.g. 500 threads (T1, … T500) and each are designed to do a small task, which might be similar or dissimilar tasks.
- We start all of them together, and they continuously get called and execute their tasks.
- Since we have too many threads, some threads might never get called, e.g. T1,….T498, called but the last two ones never get called, T499 and T500.
- Then we can say T499 and T500 are starved.

Starvation

- Assume we have many threads, e.g. 500 threads (T1, … T500) and each are designed to do a small task, which might be similar or dissimilar tasks.

- We s … sly get calle…

This usually happen in read/write locks. We do lots of read threads and write threads are getting starved.

- Since we have too many threads, some threads might never get called, e.g. T1,….T498, called but the last two ones never get called, T499 and T500.

- Then we can say T400 and T500 are starved.

ExecutorService & Thread Pools

- Previous Java thread classes are complex to make them scalable. Because thread creation and management will be handled inside other codes.

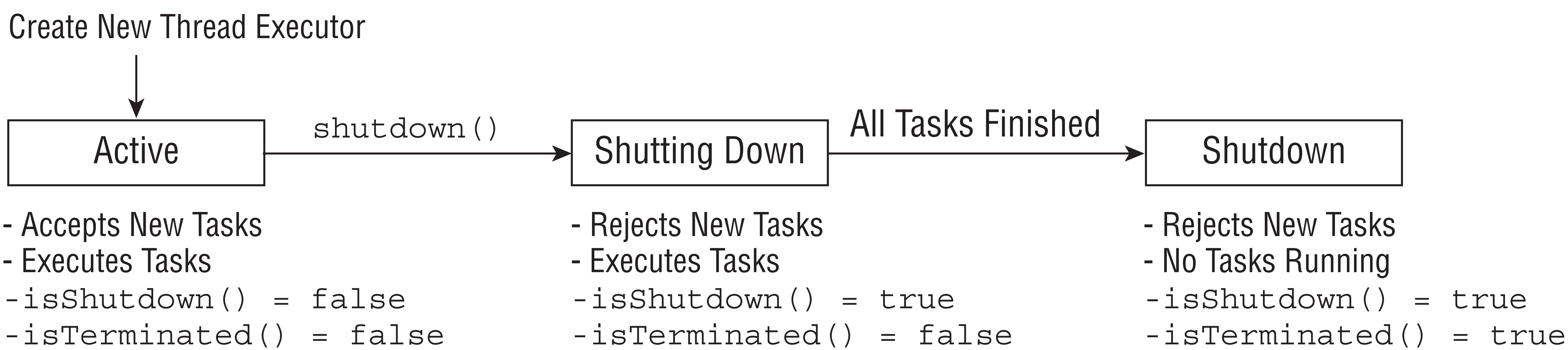
- Java tries to mitigate this challenge by introducing the **Executor Framework**. It helps us in thread creation, management and task assignment to the thread pool:

1. **`Executor`:** It is an interface, with an **`execute()`** method to launch a task specified by a **`Runnable`** object.

2. **`ExecutorService`:** It implements the **`Executor`** interface and adds functionality to manage life cycle of the **task**.
   It also includes **`submit()`** method which is a newer version of **`execute()`**. It returns **`Callable`** object. Callable objects are similar to Runnable but they have output as well.

3. **`ScheduledExecutorService`:** A sub-interface of `ExecutorService`, but it has the functionality to the execution of tasks as well.

Executor LifeCycle



Callable vs Submit

- The `execute()` takes a Runnable object and completes the task. It **doesn’t return anything about the success or failure of task completion** (fire-and-forget).

- The `submit()` is a newer method which **returns the future object, which is the result of thread execution**. This object can assist us identifying the result of thread execution.

`void execute(Runnable command):` Executes a Runnable task at some point in the future.

`<T> Future<T> submit(Callable<T> task):` Executes a Callable task at some point in the future and returns a Future object which is representing the pending results of the task.

Future Object

The Future class includes methods that are useful in determining the state of a task.

`boolean isDone():` Returns true if the task was compiled.

`boolean isCancelled():`

`boolean cancel():` Attempt to cancel the execution of a task.

`V get():` Retrieves the result of task.

`V get(long timeout, TimeUnit unit):` Retrieves the result of a task, waiting the specified amount of time. If the result is not ready by the time the timeout is reached, a checked TimeoutException will be thrown.

Executor Example (1)

```java
package edu.bu.met622.threadtest.executor2eg;

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

public class ExecutorExample {
      public static void main(String[] args) {
            System.out.println("Inside : " + Thread.currentThread().getName());

            // Callable (returns future object)
//            System.out.println("Creating a Runnable...");
            Runnable runnable = () -> {
//                System.out.println("Inside : " + Thread.currentThread().getName());
            };

            Callable callable = Executors.callable(runnable);
            System.out.print("---Callable output:"+ callable.getClass().getSimpleName());
            System.out.print("---Callable output2:"+ callable.getClass().getTypeName());

            // Executor (does not return future object)
//          System.out.println("Creating Executor Service...");
            ExecutorService executorService = Executors.newSingleThreadExecutor();

//          System.out.println("Submit the task specified by the runnable to the executor service.");
            executorService.submit(runnable);
            executorService.shutdown();
        }
}
```

Executor Example (2-1)

```java
package edu.bu.met622.threadtest.executoreg;

class Counter {
   private int c = 0;
   public void increment() {
      System.out.println("Thread Id: " +
                              Thread.currentThread().getId());
      c = c + 1;
   }
   public int getvalue() {return c;}
}
```

Executor Example (2-2)

```
package edu.bu.met622.threadtest.executoreg;

class First implements Runnable {
     private int i;
     private Counter ctr;
     public First(int i, Counter c) {
      this.i = i;
         this.ctr = c;
     }
     public void changeCounter(Counter cntr) {
      if (i > 0) {
            synchronized(cntr) {cntr.increment();}
      }
     }
     public void run() {
        changeCounter(ctr);
     }
}
```

Executor Example (2-3)

```
package edu.bu.met622.threadtest.executoreg;

import java.util.concurrent.*;
public class ThreadPoolExecuteService
{
      public static void main(String[] args) throws InterruptedException
      {
       Counter sharedcounter = new Counter();
       ExecutorService ex = Executors.newCachedThreadPool();
       ex.execute(new First(1, sharedcounter));
       ex.execute(new First(2, sharedcounter));
       ex.execute(new First(3, sharedcounter));

       ex.shutdown();

//       ex.awaitTermination(50, TimeUnit.MILLISECONDS);
       if (ex.isTerminated()) System.out.println("Final count = " +
sharedcounter.getvalue());

      }
}
```

References

https://www.coursera.org/instructor/vivek-sarkar

https://www.callicoder.com/java-executor-service-and-thread-pool-tutorial/