Lecture 8
Java SE – Advanced Multithreading
Agenda for Lecture 8 – JSE Multithreading

1. Advanced Java Multithreading
2. Java 8 Multi-Threading with Lambda
3. Exchange Ideas
Advanced Multi-Threading

java.util.concurrent - Executor & ExecutorService, Callable, Future
1. Summary of Multi-threading in C vs. Java

Multi-threading vs. Multi-process “quite good/imperfect” analogies & terms:

USE MULTI-THREADING for
- PARALLELISM (e.g. adding 2 matrixes in parallel) and/or;
- CONCURENCY (e.g. handling GUI on one thread & business processing on other thread / even on mono-processor PC, handling multiple HTTP requests from the network / cooperation on the same data structure between at least 2 threads – producer and consumer)

Mutexes are used to prevent data inconsistencies due to race conditions. A race condition often occurs when two or more threads need to perform operations on the same memory area, but the results of computations depends on the order in which these operations are performed.

Mutexes are used for serializing shared resources. Anytime a global resource is accessed by more than one thread the resource should have a Mutex associated with it.

One can apply a mutex to protect a segment of memory ("critical region") from other threads.

Mutexes can be applied only to threads in a single process and do not work between processes as do semaphores in Linux IPC.

In Java Mutex is quite ↔ synchronized (also please see java.util.concurrent.*)
Advantages of Multithreading:

- Reactive systems – constantly monitoring
- More responsive to user input – GUI application can interrupt a time-consuming task
- Server can handle multiple clients simultaneously
- Can take advantage of parallel processing

When Multithreading?:

Concurrency (incl. Cooperation)
and/or Parallelism
The join() Method

You can use the join() method to force one thread to wait for another thread to finish.

```java
public void run() { //print100 - method
    Thread thread4printA = new Thread(
        new PrintChar('A', 40));
    thread4printA.start();
    try {
        for (int i = 1; i <= lastNum; i++) {
            System.out.print(" "+i);
            if (i == 50) thread4printA.join();
        }
    }
    catch (InterruptedException ex) {
    }
}
```

The numbers after 50 are printed after thread printA is finished.
1. Threads Concurrency – Synchronization

Java Multi-threading
Cooperation – The \textit{join()} method

```java
class SampleThread extends Thread {
    private String message;
    private double result;

    public SampleThread(String m) {this.message = m; this.result = 0.0;}
    public void run() {
        this.result = this.doAlgorithm();
    }
    private double doAlgorithm() {
        double val = 0;
        val++; // but could be 200 lines of code running for 10 sec
        try {
            this.sleep(3000);
        } catch(InterruptedException ie) { ie.printStackTrace(); }
        return val;
    }
    public double getSolution() {return this.result;}
}

public class ProgMainJoin {
    public static void main(String[] args) {
        SampleThread t = new SampleThread("T1");
        t.start();
        try {
            t.join(); // if this is comment, then the solution is NOT consistent
            System.out.println("Result = " + t.getSolution());
        } catch(InterruptedException ie) { ie.printStackTrace(); }
    }
}
```
1. Threads States - Recapitulation

- New thread
  - Call start
  - Runnable thread
    - Thread completes
    - Dead thread
    - Blocked thread
      - Call sleep
      - Call wait
      - Blocking I/O request
      - Sleep time ends
      - Call notify or notify all
      - I/O complete
A thread can be in one of five states: New, Ready, Running, Blocked, or Finished.
isAlive()
• method used to find out the state of a thread.
• returns true: thread is in the Ready, Blocked, or Running state
• returns false: thread is new and has not started or if it is finished.

interrupt()
If a thread is currently in the Ready or Running state, its interrupted flag is set; if a thread is currently blocked, it is awakened and enters the Ready state, and an `java.io.InterruptedIOException` is thrown.

The `isInterrupted()` method tests whether the thread is interrupted.
1. Threads Methods

The deprecated `stop()`, `suspend()`, and `resume()` Methods

NOTE: The `Thread` class also contains the `stop()`, `suspend()`, and `resume()` methods. As of Java 2, these methods are *deprecated* (or *outdated*) because they are known to be inherently unsafe. You should assign `null` to a `Thread` variable to indicate that it is stopped rather than use the `stop()` method.
Thread Priority

- Each thread is assigned a default priority of `Thread.NORM_PRIORITY` (constant of 5). You can reset the priority using `setPriority(int priority)`.

- Some constants for priorities include `Thread.MIN_PRIORITY` `Thread.MAX_PRIORITY` `Thread.NORM_PRIORITY`

- By default, a thread has the priority level of the thread that created it.

- An operating system’s thread scheduler determines which thread runs next.
- Most operating systems use *timeslicing* for threads of equal priority.
- **Preemptive scheduling:** when a thread of higher priority enters the running state, it preempts the current thread.
- **Starvation:** Higher-priority threads can postpone (possible forever) the execution of lower-priority threads.
1. Threads Concurrency – Synchronization

Java Multithreading Cooperation - Thread Priority

```java
class SampleThread extends Thread {
    String message;
    public SampleThread(String m) {this.message = m;}
    public void run() {
        for (int i = 0; i < 100; i++) {
            System.out.println(this.message);
            this.yield();
        }
    }
}

public class ProgMainPriority {
    public static void main(String[] args) {
        SampleThread f1 = new SampleThread("f1");
        SampleThread f2 = new SampleThread("f2");

        Thread current = Thread.currentThread();
        f1.setPriority(current.getPriority() - 1);
        f2.setPriority(current.getPriority() + 3);
        f1.start();
        f2.start();
    }
}
```
1. Threads Concurrency & Parallelism

Thread Pool

- Starting a new thread for each task could limit throughput and cause poor performance.
- A thread pool is ideal to manage the number of tasks executing concurrently.

**Executor** interface for executing Runnable objects in a thread pool

**ExecutorService** is a sub-interface of **Executor**.

```
<interface>
java.util.concurrent.ExecutorService
+shutdown(): void
+shutdownNow(): List<Runnable>
+isShutdown(): boolean
+isTerminated(): boolean
</interface>
```

```
<interface>
java.util.concurrent.Executor
+execute(Runnable object): void
</interface>
```

Executes the runnable task.

Shuts down the executor, but allows the tasks in the executor to complete. Once shutdown, it cannot accept new tasks.

Shuts down the executor immediately even though there are unfinished threads in the pool. Returns a list of unfinished tasks.

Returns true if the executor has been shutdown.

Returns true if all tasks in the pool are terminated.
Thread Pool

To create an Executor object, use the static methods in the Executors class.
1. Threads Concurrency & Parallelism
1. Threads Concurrency & Parallelism

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**Thread Pool**

```java
class ThreadPoolExecutorDemo {
    public static void main(String[] args) {
        // Create a fixed thread pool with maximum three threads
        ExecutorService executor = Executors.newFixedThreadPool(3);

        // Submit runnable tasks to the executor
        executor.execute(new PrintChar('a', 100));
        executor.execute(new PrintChar('b', 100));
        executor.execute(new PrintNum(100));

        // Shut down the executor
        executor.shutdown();

        // Optional if main methods needs the results
        executor.awaitTermination();
        System.out.println("\nMain Thread Ends");
    }
}
```

---

```
import java.util.concurrent.*;

class PrintChar implements Runnable {
    private char character;
    private int noOfTimes;

    PrintChar(char ch, int n) {
        character = ch;
        noOfTimes = n;
    }

    public void run() {
        for(int i=0; i<noOfTimes; i++)
            System.out.print(character + " ");
    }
}

class PrintNum implements Runnable {
    private int num;

    PrintNum(int num) {
        this.num = num;
    }

    public void run() {
        for(int i = 0; i < num; i++)
            System.out.print(i + " ");
    }
}
```
1. Threads Concurrency & Parallelism
public class MyRunnable implements Runnable
{
    private final long countUntil;

    MyRunnable(long countUntil) {
        this.countUntil = countUntil;
    }

    @Override
    public void run() {
        long sum = 0;
        for (long i = 1; i < countUntil; i++) {
            sum += i;
        }
        System.out.println(sum);
    }
}
import java.util.ArrayList;
import java.util.List;
public class ProgMain {
    public static void main(String[] args) {
        // We will store the threads so that we can check if they are done
        List<Thread> threads = new ArrayList<Thread>();
        for (int i = 0; i < 500; i++) {
            Runnable task = new MyRunnable(1000000L + i);
            Thread worker = new Thread(task);
            worker.setName(String.valueOf(i));
            // Start the thread, never call method run() direct
            worker.start();
            threads.add(worker);
        }
        int running = 0;
        do {
            running = 0;
            for (Thread thread : threads) {
                if (thread.isAlive()) {
                    running++;  
                }
            }
            System.out.println("We have "+ running + " running threads.");
        } while (running > 0);
    }  //end main
} //end class
import java.util.concurrent.ExecutorService;
import java.util.concurrent.Executors;

public class Main {
    private static final int NTHREDS = 10;

    public static void main(String[] args) {
        ExecutorService executor = Executors.newFixedThreadPool(NTHREDS);
        for (int i = 0; i < 500; i++) {
            Runnable worker = new MyRunnable(1000000L + i);
            executor.execute(worker);
        }
        // This will make the executor accept no new threads
        // and finish all existing threads in the queue
        executor.shutdown();
        // Wait until all threads are finish
        executor.awaitTermination();
        System.out.println("Finished all threads");
    }
}
1. Threads Concurrency & Parallelism

“Classic” Thread Pool, Executor Framework, Callable & Future

```java
//package de.vogella.concurrency.callables;

import java.util.concurrent.Callable;

public class MyCallable implements Callable<Long> {

    @Override
    public Long call() throws Exception {
        long sum = 0;
        for (long i = 0; i <= 100; i++) {
            sum += i;
        }
        return sum;
    }
}
```

http://www.vogella.com/tutorials/JavaConcurrency/article.html
import java.util.*;
import java.util.concurrent.*;
public class CallableFutures {
    private static final int NTHREDS = 10;
    public static void main(String[] args) {
        ExecutorService executor = Executors.newFixedThreadPool(NTHREDS);
        List<Future<Long>> list = new ArrayList<Future<Long>>();
        for (int i = 0; i < 20000; i++) {
            Callable<Long> worker = new MyCallable();
            Future<Long> submit = executor.submit(worker);
            list.add(submit);
        }
        long sum = 0;
        // now retrieve the result - System.out.println(list.size());
        for (Future<Long> future : list) {
            try {
                sum += future.get();
            } catch (InterruptedException e) {
                e.printStackTrace();
            } catch (ExecutionException e) {
                e.printStackTrace();
            }
        }
        System.out.println(sum); executor.shutdown();
    }
}
1. Threads Concurrency – Synchronization

Analogy with multi-threading synch is the synch in distributed systems

Horizontal lines are the time axis and the points are the potential hours when an event may occur.

In the use-case a), the person with 2 bank accounts in the subsidiary A and B has in total, 200 $, at 3.00 pm => 100$ in subsidiary A nothing in subsidiary B. The total amount in the both subsidiaries A and B is 200 $. There are 2 assumptions:
1. Both servers clocks of the subsidiary A and subsidiary B are perfectly synchronized.
2. All the transactions between the both subsidiaries are all done fully before or after 3.00 pm.

In the use-case b), the servers’ clocks are in sync, but a 100$ transfer transaction from the subsidiary A to B starts at 2.59 pm and it stops at 3.01. If the total will be calculated at 3.00 pm, then the overall amount is 0 $.

In the use-case c), the person will have the double amount of money (200 $), at 3.00 pm, because the servers clock are not synchronized.
A shared resource may be corrupted if it is accessed simultaneously by multiple threads.

Example: two unsynchronized threads accessing the same bank account may cause conflict.

```
Step | balance | thread[i]                                                     | thread[j]                                                     |
-----|---------|---------------------------------------------------------------|---------------------------------------------------------------|
1    | 0       | newBalance = bank.getBalance() + 1;                          | newBalance = bank.getBalance() + 1;                          |
2    | 0       |                                                              | newBalance = bank.getBalance() + 1;                          |
3    | 1       | bank.setBalance(newBalance);                                  | bank.setBalance(newBalance);                                  |
4    | 1       |                                                              |                                                              |
```
Example: Showing Resource Conflict – AccountWithoutSync.java

- Objective: Write a program that demonstrates the problem of resource conflict. Suppose that you create and launch one hundred threads, each of which adds a penny to an account. Assume that the account is initially empty.
Race Condition

What, then, caused the error in the example? Here is a possible scenario:

<table>
<thead>
<tr>
<th>Step</th>
<th>balance</th>
<th>Task 1</th>
<th>Task 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>newBalance = balance + 1;</td>
<td>newBalance = balance + 1;</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>balance = newBalance;</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td>balance = newBalance;</td>
</tr>
</tbody>
</table>

• Effect: Task 1 did nothing (in Step 4 Task 2 overrides the result)
• Problem: Task 1 and Task 2 are accessing a common resource in a way that causes conflict.
• Known as a *race condition* in multithreaded programs.
• A *thread-safe* class does not cause a race condition in the presence of multiple threads.
• The Account class is not thread-safe.
• Problem: race conditions
• Solution: give exclusive access to one thread at a time to code that manipulates a shared object.
• Synchronization keeps other threads waiting until the object is available.
• The synchronized keyword synchronizes the method so that only one thread can access the method at a time.
• The critical region in the AccountWithoutSynch.java is the entire deposit method.
• One way to correct the problem in source code: make Account thread-safe by adding the synchronized keyword in deposit:

```java
public synchronized void deposit(double amount)
```
Synchronizing Instance Methods and Static Methods

- A synchronized method acquires a lock before it executes.
- Instance method: the lock is on the object for which it was invoked.
- Static method: the lock is on the class.
- If one thread invokes a synchronized instance method (respectively, static method) on an object, the lock of that object (respectively, class) is acquired, then the method is executed, and finally the lock is released.
- Another thread invoking the same method of that object (respectively, class) is blocked until the lock is released.
Synchronizing Instance Methods and Static Methods

With the deposit method synchronized, the preceding scenario cannot happen. If Task 2 starts to enter the method, and Task 1 is already in the method, Task 2 is blocked until Task 1 finishes the method.

```
1. Threads Concurrency – Synchronization

Synchronizing Instance Methods and Static Methods

With the deposit method synchronized, the preceding scenario cannot happen. If Task 2 starts to enter the method, and Task 1 is already in the method, Task 2 is blocked until Task 1 finishes the method.

Task 1

Acquire a lock on the object account

<table>
<thead>
<tr>
<th>Execute the deposit method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release the lock</td>
</tr>
</tbody>
</table>

Task 2

Wait to acquire the lock

<table>
<thead>
<tr>
<th>Acquire a lock on the object account</th>
</tr>
</thead>
<tbody>
<tr>
<td>Execute the deposit method</td>
</tr>
<tr>
<td>Release the lock</td>
</tr>
</tbody>
</table>
```
Synchronizing Statements

• Invoking a synchronized instance method of an object acquires a lock on the object.

• Invoking a synchronized static method of a class acquires a lock on the class.

• A synchronized block can be used to acquire a lock on any object, not just this object, when executing a block of code.

```java
synchronized (expr) {
    statements;
}
```

• expr must evaluate to an object reference.

• If the object is already locked by another thread, the thread is blocked until the lock is released.

• When a lock is obtained on the object, the statements in the synchronized block are executed, and then the lock is released.
Synchronizing Statements vs. Methods

Any synchronized instance method can be converted into a synchronized statement. Suppose that the following is a synchronized instance method:

```java
public synchronized void xMethod() {
    // method body
}
```

This method is equivalent to

```java
public void xMethod() {
    synchronized (this) {
        // method body
    }
}
```
1. Multi-threading in Java

Java Multi-threading Synchronization for Concurrent (Producer-Consumer) Programming

**Critical region** = is a section of the byte-code/executable machine code, which is impacting in a concurrent manner the same area of memory, from a multi-threading environment. The role of the synchronization in this case is to ensure the exclusive access to the common memory Resource.

The methods `wait()`, `notify()`, `notifyAll()` (e.g. in the producer-consumer sample) are inherited from the java.lang.Object class, NOT from Thread class. The `wait()` method can be called only from a synchronized method. Sometimes the boolean condition for waiting a thread may be associated with a if/while statement plus a flag showing if the should still wait or not the boolean condition (e.g. in the producer-consumer sample):

**Produce:**
```java
while (Condition) {
    wait();
}
availableFlag = true;
notifyAll();
```

**Consume:**
```java
while (!Condition) {
    wait();
}
availableFlab = false;
notifyAll();
```
1. Multi-threading in Java

Java Multi-threading Synchronization for Concurrent (Producer-Consumer) Programming
1. Multi-threading in Java

Java Multi-threading Cooperation

The method `yield()` allows the JVM and OS to commute the control from the current thread to another thread. In the samples, in the lecture, are samples for showing the `setPriority()/getPriority()`, `join()`, `join(...)`, `isAlive()` and `interrupt()` methods.

For the common resource that is in the memory, a race condition may appear in the concurrency created into an multi-threading environment and it is recommended to use `volatile` keyword for that object/variable from the memory, in order to instruct the JVM to write immediately in the memory, instead keeping into the register for the optimization.

Java MUTEX ⇔ synchronized * is recommended to use it only at method level if the method is NOT into a class which implements Runnable or extends Thread.

What is the difference between the semaphore and mutex in JVM? What is the difference between semaphore and mutex in the POSIX Threads within Linux OS?

What objects/instances are thread-safe within JVM? – immutable, singleton, POJO?
• A synchronized instance method implicitly acquires a lock on the instance before it executes the method.
• You can use locks explicitly to obtain more control for coordinating threads.
• A lock is an instance of the Lock interface, which declares the methods for acquiring and releasing locks.
• newCondition() method creates Condition objects, which can be used for thread communication.

<table>
<thead>
<tr>
<th>«interface»</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.util.concurrent.locks.Lock</td>
</tr>
<tr>
<td>+lock(): void</td>
</tr>
<tr>
<td>+unlock(): void</td>
</tr>
<tr>
<td>+newCondition(): Condition</td>
</tr>
</tbody>
</table>

Acquires the lock.
Releases the lock.
Returns a new Condition instance that is bound to this Lock instance.

<table>
<thead>
<tr>
<th>java.util.concurrent.locks.ReentrantLock</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ReentrantLock()</td>
</tr>
<tr>
<td>+ReentrantLock(fair: boolean)</td>
</tr>
</tbody>
</table>

Same as ReentrantLock(false).
Creates a lock with the given fairness policy. When the fairness is true, the longest-waiting thread will get the lock. Otherwise, there is no particular access order.
• **ReentrantLock**: concrete implementation of `Lock` for creating mutually exclusive locks.

• Create a lock with the specified fairness policy.

• True fairness policies guarantee the longest-wait thread to obtain the lock first.

• False fairness policies grant a lock to a waiting thread without any access order.

• Programs using fair locks accessed by many threads may have poor overall performance than those using the default setting, but have smaller variances in times to obtain locks and guarantee lack of starvation.
Example: Using Locks

This example revises AccountWithoutSync.java in AccountWithoutSyncUsingLock.java to synchronize the account modification using explicit locks.
Cooperation Among Threads

• Conditions can be used for communication among threads.
• A thread can specify what to do under a certain condition.
• `newCondition()` method of `Lock` object.

• Condition methods:
  • `await()` current thread waits until the condition is signaled
  • `signal()` wakes up a waiting thread
  • `signalAll()` wakes all waiting threads

### interface java.util.concurrent.Condition

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>+await(): void</code></td>
<td>Causes the current thread to wait until the condition is signaled.</td>
</tr>
<tr>
<td><code>+signal(): void</code></td>
<td>Wakes up one waiting thread.</td>
</tr>
<tr>
<td><code>+signalAll(): Condition</code></td>
<td>Wakes up all waiting threads.</td>
</tr>
</tbody>
</table>
Cooperation Among Threads

• Lock with a condition to synchronize operations: newDeposit
• If the balance is less than the amount to be withdrawn, the withdraw task will wait for the newDeposit condition.
• When the deposit task adds money to the account, the task signals the waiting withdraw task to try again.

• Interaction between the two tasks:

```
Withdraw Task
lock.lock();
while (balance < withdrawAmount)
  newDeposit.await();
balance -= withdrawAmount
lock.unlock();

Deposit Task
lock.lock();
balance += depositAmount
newDeposit.signalAll();
lock.unlock();
```

Liang, Introduction to Java Programming, Seventh Edition, (c)2009 Pearson Education, Inc. All rights reserved. 0136012671
Example: Thread Cooperation

Write a program that demonstrates thread cooperation (ThreadCooperation.java). Suppose that you create and launch two threads, one deposits to an account, and the other withdraws from the same account. The second thread has to wait if the amount to be withdrawn is more than the current balance in the account. Whenever new fund is deposited to the account, the first thread notifies the second thread to resume. If the amount is still not enough for a withdrawal, the second thread has to continue to wait for more fund in the account. Assume the initial balance is 0 and the amount to deposit and to withdraw is randomly generated.
Java’s Built-in Monitors

• Locks and conditions are new starting with Java 5.
• Prior to Java 5, thread communications were programmed using object’s built-in monitors.

• Locks and conditions are more powerful and flexible than the built-in monitor.
• A monitor is an object with mutual exclusion and synchronization capabilities.

• Only one thread can execute a method at a time in the monitor.
• A thread enters the monitor by acquiring a lock (synchronized keyword on method / block) on the monitor and exits by releasing the lock.
• A thread can wait in a monitor if the condition is not right for it to continue executing in the monitor.

• Any object can be a monitor. An object becomes a monitor once a thread locks it.
wait(), notify(), and notifyAll()

Use the `wait()`, `notify()`, and `notifyAll()` methods to facilitate communication among threads.

The `wait()`, `notify()`, and `notifyAll()` methods must be called in a synchronized method or a synchronized block on the calling object of these methods. Otherwise, an `IllegalMonitorStateException` would occur.

The `wait()` method lets the thread wait until some condition occurs. When it occurs, you can use the `notify()` or `notifyAll()` methods to notify the waiting threads to resume normal execution. The `notifyAll()` method wakes up all waiting threads, while `notify()` picks up only one thread from a waiting queue.
The `wait()`, `notify()`, and `notifyAll()` methods must be called in a synchronized method or a synchronized block on the receiving object of these methods. Otherwise, an `IllegalMonitorStateException` will occur.

When `wait()` is invoked, it pauses the thread and simultaneously releases the lock on the object. When the thread is restarted after being notified, the lock is automatically reacquired.

The `wait()`, `notify()`, and `notifyAll()` methods on an object are analogous to the `await()`, `signal()`, and `signalAll()` methods on a condition.
1. Threads Cooperation – Consumer / Producer

Case Study: Producer/Consumer

Consider the classic Consumer/Producer example. Suppose you use a buffer to store integers. The buffer size is limited. The buffer provides the method `write(int)` to add an int value to the buffer and the method `read()` to read and delete an int value from the buffer. To synchronize the operations, use a lock with two conditions: `notEmpty` (i.e., buffer is not empty) and `notFull` (i.e., buffer is not full). When a task adds an int to the buffer, if the buffer is full, the task will wait for the `notFull` condition. When a task deletes an int from the buffer, if the buffer is empty, the task will wait for the `notEmpty` condition. The interaction between the two tasks is shown:

![Diagram of producer and consumer tasks]

```
while (count == CAPACITY)
    notFull.await();

Add an int to the buffer

notEmpty.signal();
```

```
while (count == 0)
    notEmpty.await();

Delete an int to the buffer

notFull.signal();
```
Case Study: Producer/Consumer

ConsumerProducer.java presents the complete program. The program contains the Buffer class (lines 43-89) and two tasks for repeatedly producing and consuming numbers to and from the buffer (lines 15-41). The write(int) method (line 58) adds an integer to the buffer. The read() method (line 75) deletes and returns an integer from the buffer.

For simplicity, the buffer is implemented using a linked list (lines 48-49). Two conditions notEmpty and notFull on the lock are created in lines 55-56. The conditions are bound to a lock. A lock must be acquired before a condition can be applied. If you use the wait() and notify() methods to rewrite this example, you have to designate two objects as monitors.
Semaphores

Semaphores can be used to restrict the number of threads that access a shared resource. Before accessing the resource, a thread must acquire a permit from the semaphore. After finishing with the resource, the thread must return the permit back to the semaphore, as shown:

```java
A thread accessing a shared resource

Acquire a permit from a semaphore. Wait if the permit is not available.

Access the resource

Release the permit to the semaphore
```

```java
A thread accessing a shared resource

semaphore.acquire();

Access the resource

semaphore.release();
```
Creating Semaphores

To create a semaphore, you have to specify the number of permits with an optional fairness policy (see the figure). A task acquires a permit by invoking the semaphore’s acquire() method and releases the permit by invoking the semaphore’s release() method. Once a permit is acquired, the total number of available permits in a semaphore is reduced by 1. Once a permit is released, the total number of available permits in a semaphore is increased by 1.

<table>
<thead>
<tr>
<th>java.util.concurrent.Semaphore</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Semaphore(numberOfPermits: int)</td>
</tr>
<tr>
<td>+Semaphore(numberOfPermits: int, fair: boolean)</td>
</tr>
<tr>
<td>+acquire(): void</td>
</tr>
<tr>
<td>+release(): void</td>
</tr>
</tbody>
</table>

Creates a semaphore with the specified number of permits. The fairness policy is false.

Creates a semaphore with the specified number of permits and the fairness policy.

Acquires a permit from this semaphore. If no permit is available, the thread is blocked until one is available.

Releases a permit back to the semaphore.
Deadlock

• Sometimes two or more threads need to acquire the locks on several shared objects.
• This could cause *deadlock*, in which each thread has the lock on one of the objects and is waiting for the lock on the other object.
• In the figure below, the two threads wait for each other to release the in order to get a lock, and neither can continue to run.

```
1. Threads Concurrency on Shared Resource

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```

```
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1. Threads Concurrency on Shared Resource

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```

```
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Preventing Deadlock

• Deadlock can be easily avoided by resource ordering.
• With this technique, assign an order on all the objects whose locks must be acquired and ensure that the locks are acquired in that order.
• How does this prevent deadlock in the previous example?
Synchronized Collections

• The classes in the Java Collections Framework are not thread-safe.
• Their contents may be corrupted if they are accessed and updated concurrently by multiple threads.
• You can protect the data in a collection by locking the collection or using synchronized collections.

The Collections class provides six static methods for creating synchronization wrappers.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>synchronizedCollection(c: Collection): Collection</td>
<td>Returns a synchronized collection.</td>
</tr>
<tr>
<td>synchronizedList(list: List): List</td>
<td>Returns a synchronized list from the specified list.</td>
</tr>
<tr>
<td>synchronizedMap(m: Map): Map</td>
<td>Returns a synchronized map from the specified map.</td>
</tr>
<tr>
<td>synchronizedSet(s: Set): Set</td>
<td>Returns a synchronized set from the specified set.</td>
</tr>
<tr>
<td>synchronizedSortedMap(s: SortedMap): SortedMap</td>
<td>Returns a synchronized sorted map from the specified</td>
</tr>
<tr>
<td></td>
<td>sorted map.</td>
</tr>
<tr>
<td>synchronizedSortedSet(s: SortedSet): SortedSet</td>
<td>Returns a synchronized sorted set.</td>
</tr>
</tbody>
</table>
Vector, Stack, and Hashtable

Invoking `synchronizedCollection(Collection c)` returns a new `Collection` object, in which all the methods that access and update the original `collection c` are synchronized. These methods are implemented using the `synchronized` keyword. For example, the `add` method is implemented like this:

```java
public boolean add(E o) {
    synchronized (this) { return c.add(o); }
}
```

The synchronized collections can be safely accessed and modified by multiple threads concurrently.

The methods in `java.util.Vector`, `java.util.Stack`, and `Hashtable` are already synchronized. These are old classes introduced in JDK 1.0. In JDK 1.5, you should use `java.util.ArrayList` to replace `Vector`, `java.util.LinkedList` to replace `Stack`, and `java.util.Map` to replace `Hashtable`. If synchronization is needed, use a synchronization wrapper.
Fail-Fast

The synchronization wrapper classes are thread-safe, but the iterator is *fail-fast*. This means that if you are using an iterator to traverse a collection while the underlying collection is being modified by another thread, then the iterator will immediately fail by throwing `java.util.ConcurrentModificationException`, which is a subclass of `RuntimeException`. To avoid this error, you need to create a synchronized collection object and acquire a lock on the object when traversing it. For example, suppose you want to traverse a set, you have to write the code like this:

```java
Set hashSet = Collections.synchronizedSet(new HashSet());
synchronized (hashSet) { // Must synchronize it
    Iterator iterator = hashSet.iterator();
    while (iterator.hasNext()) {
        System.out.println(iterator.next());
    }
}
```

Failure to do so may result in nondeterministic behavior, such as `ConcurrentModificationException`. 
GUI event handling and painting code executes in a single thread, called the *event dispatcher thread*. This ensures that each event handler finishes executing before the next one executes and the painting isn’t interrupted by events.
In certain situations, you need to run the code in the event dispatcher thread to avoid possible deadlock. You can use the static methods, `invokeLater` and `invokeAndWait`, in the `javax.swing.SwingUtilities` class to run the code in the event dispatcher thread. You must put this code in the `run` method of a `Runnable` object and specify the `Runnable` object as the argument to `invokeLater` and `invokeAndWait`. The `invokeLater` method returns immediately, without waiting for the event dispatcher thread to execute the code. The `invokeAndWait` method is just like `invokeLater`, except that `invokeAndWait` doesn't return until the event-dispatching thread has executed the specified code.
Launch Application from Main Method

So far, you have launched your GUI application from the main method by creating a frame and making it visible. This works fine for most applications. In certain situations, however, it could cause problems. To avoid possible thread deadlock, you should launch GUI creation from the event dispatcher thread as follows:

```java
public static void main(String[] args) {
    SwingUtilities.invokeLater(new Runnable() {
        public void run() {
            // Place the code for creating a frame and setting it properties
        }
    });
}
```
Fact: **Multi-threading vs. Multi-process**

In few **samples** it is easy to understand:
- Necessity: Parallelism vs. Concurrency
- Multi-Process vs. Multi-Threading
- Atomic operations (counter++)
- Multi-threading model mapping
Java 8 Multi-Threading Lambda and Functional Interface in HPC Use Cases | Same concepts from the previous sections are translated into Lambda expressions for the multi-threading

Java 8 Lambda Multi-Threading Intro
The **Concurrency API** was first introduced with the release of Java 5 and then progressively enhanced with every new Java release.

**This section is dedicating for Multi-threading Programming using Java 8 Lambda Expressions and Runnable Functional Interface.**

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 and/or parallel (e.g. Java Fork-Join mechanism), 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:

```java
Runnable taskJava7 = new Runnable () {
    @Override
    public void run() {
        String threadName = Thread.currentThread().getName();
        System.out.println("Hello " + threadName);
    }
};
taskJava7.run();

Thread threadJ7 = new Thread(taskJava7);
threadJ7.start();

Runnable taskJava8 = () -> {
    String threadName = Thread.currentThread().getName();
    System.out.println("Hello " + threadName);
};
taskJava8.run();

Thread threadJ8 = new Thread(taskJava8);
threadJ8.start();
```
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.

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 revanent tasks, so we can run as many concurrent tasks as we want throughout the life-cycle of our application with a single executor service.

```
ExecutorService executor = Executors.newSingleThreadExecutor();
executor.submit(() -> {
    String threadName = Thread.currentThread().getName();
    System.out.println("Hello " + threadName);
}); // => Hello pool-1-thread-1
```
2. Java 8 – Lambda Threads & Executors - Executors

The result looks similar to the first Runnable lambda 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. Typically shutdown executors statements:

```java
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.

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In addition to Runnable executors support another kind of task named Callable. Callables are functional interfaces just like Runnable, but instead of being void, they return a value. This lambda expression defines a callable returning an integer after sleeping for one second:

```java
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.

```java
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(). 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.
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:

```java
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 - see Lambda and Java 8 Processing Streams

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

```java
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.
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:

```java
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:

```java
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.

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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:

```java
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: %s ms", 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.
### 2. Java 8 – Lambda Threads & Executors – Future-Callable

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:

```java
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:

```java
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.
2. Java 8 – Lambda Thread: Synchronization & Locks

When writing multi-threaded code you have to pay particular attention when accessing shared mutable variables concurrently from multiple threads. Let's just say we want to increment an integer which is accessible simultaneously from multiple threads.

We define a field count with a method increment() to increase count by one:

```java
int count = 0;
void increment() {
    count = count + 1;
}
```

When calling this method concurrently from multiple threads we're in serious trouble:

```java
ExecutorService executor = Executors.newFixedThreadPool(2);
IntStream.range(0, 10000).forEach(i -> executor.submit(this::increment));
// stop(executor); // procedure of shutting-down the executor-service
System.out.println(count); // 9965
```

Instead of seeing a constant result count of 10000 the actual result varies with every execution of the above code. The reason is that we share a mutable variable upon different threads without synchronizing the access to this variable which results in a race condition.
Java supports thread-synchronization since the early days via the `synchronized` keyword. We can utilize synchronized to fix the above race conditions when incrementing the count:

```java
synchronized void incrementSync() { count = count + 1; }
```

When using `incrementSync()` concurrently we get the desired result count of 10000. No race conditions occur any longer and the result is stable with every execution of the code:

```java
ExecutorService executor = Executors.newFixedThreadPool(2);
IntStream.range(0, 10000).forEach(i -> executor.submit(this::incrementSync));
// stop(executor); // procedure of shutting-down the executor-service
System.out.println(count); // 10000
```

Internally Java uses a so called `monitor` also known as `monitor lock or intrinsic lock` in order to manage synchronization. This monitor is bound to an object, e.g. when using synchronized methods each method share the same monitor of the corresponding object.

All implicit monitors implement the `reentrant` characteristics. Reentrant means that locks are bound to the current thread. A thread can safely acquire the same lock multiple times without running into deadlocks (e.g. a synchronized method calls another synchronized method on the same object).
2. Java 8 – Lambda Thread: Synchronization & Locks

Locks
Instead of using implicit locking via the synchronized keyword the Concurrency API supports various explicit locks specified by the Lock interface. Locks support various methods for finer grained lock control thus are more expressive than implicit monitors. Multiple lock implementations are available in the standard JDK which will be demonstrated in the following sections.

ReentrantLock
The class ReentrantLock is a mutual exclusion lock with the same basic behavior as the implicit monitors accessed via the synchronized keyword but with extended capabilities. As the name suggests this lock implements reentrant characteristics just as implicit monitors. Let's see how the above sample looks like using ReentrantLock:

```java
ReentrantLock myLock = new ReentrantLock();
int count = 0;
void increment() {
    myLock.lock();
    try { count++; }
    finally { myLock.unlock(); }
}
```

A lock is acquired via lock() and released via unlock(). It's important to wrap your code into a try/finally block to ensure unlocking in case of exceptions. This method is thread-safe just like the synchronized counterpart. If another thread has already acquired the lock subsequent calls to lock() pause the current thread until the lock has been unlocked. Only one thread can hold the lock at any given time.
Locks support various methods for fine grained control as seen in the next sample:

```java
ExecutorService executor = Executors.newFixedThreadPool(2);
ReentrantLock myLock = new ReentrantLock();
executor.submit(() -> {
    myLock.lock();
    try {
        sleep(2);
    } finally {
        myLock.unlock();
    }
});
executor.submit(() -> { System.out.println("Locked: " + myLock.isLocked());
System.out.println("Held by me: " + myLock.isHeldByCurrentThread());
boolean locked = myLock.tryLock();
System.out.println("Lock acquired: " + locked); });
//stop(executor);
```

While the first task holds the lock for one second the second task obtains different information about the current state of the lock:

- Locked: true
- Held by me: false
- Lock acquired: false

The method tryLock() as an alternative to lock() tries to acquire the lock without pausing the current thread. The boolean result must be used to check if the lock has actually been acquired before accessing any shared mutable variables.
2. Java 8 – Lambda Thread: Synchronization & Locks

ReadOnlyLock
The interface ReadOnlyLock specifies another type of lock maintaining a pair of locks for read and write access. The idea behind read-write locks is that it's usually safe to read mutable variables concurrently as long as nobody is writing to this variable. So the read-lock can be held simultaneously by multiple threads as long as no threads hold the write-lock. This can improve performance and throughput in case that reads are more frequent than writes.

```java
ExecutorService executor = Executors.newFixedThreadPool(2);
Map<String, String> map = new HashMap<>();
ReadWriteLock lock = new ReentrantReadWriteLock();
executor.submit(() -> {
    lock.writeLock().lock();
    try {
        sleep(1); map.put("foo", "bar");
    } finally {
        lock.writeLock().unlock();
    }
});
```

The above example first acquires a write-lock in order to put a new value to the map after sleeping for one second. Before this task has finished two other tasks are being submitted trying to read the entry from the map and sleep for one second:

```java
Runnable readTask = () -> {
    lock.readLock().lock();
    try {
        System.out.println(map.get("foo")); sleep(1);
    } finally {
        lock.readLock().unlock();
    }
};
executor.submit(readTask); executor.submit(readTask); // do NOT forget to stop(executor);
```

When you execute this code sample you'll notice that both read tasks have to wait the whole second until the write task has finished. After the write lock has been released both read tasks are executed in parallel and print the result simultaneously to the console. They don't have to wait for each other to finish because read-locks can safely be acquired concurrently as long as no write-lock is held by another thread.

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2. Java 8 – Lambda Thread: Synchronization & Locks

StampedLock

Java 8 ships with a new kind of lock called StampedLock which also support read and write locks just like in the example above. In contrast to ReadWriteLock the locking methods of a StampedLock return a stamp represented by a long value. You can use these stamps to either release a lock or to check if the lock is still valid. Additionally stamped locks support another lock mode called optimistic locking.

Let's rewrite the last example code to use StampedLock instead of ReadWriteLock:

```java
ExecutorService executor = Executors.newFixedThreadPool(2);
Map<String, String> map = new HashMap<>();
StampedLock myLock = new StampedLock();
ext.executor.submit(() -> {
    long stamp = myLock.writeLock();
    try { sleep(1); map.put("foo", "bar"); } finally { myLock.unlockWrite(stamp); }
});
Runnable readTask = () -> {
    long stamp = myLock.readLock();
    try { System.out.println(map.get("foo")); sleep(1); } finally { myLock.unlockRead(stamp); }
}
executor.submit(readTask); executor.submit(readTask);
//stop(executor);
```

Obtaining a read or write lock via readLock() or writeLock() returns a stamp which is later used for unlocking within the finally block. Keep in mind that stamped locks don't implement reentrant characteristics. Each call to lock returns a new stamp and blocks if no lock is available even if the same thread already holds a lock. So you have to pay particular attention not to run into deadlocks.

Just like in the previous ReadWriteLock example both read tasks have to wait until the write lock has been released. Then both read tasks print to the console simultaneously because multiple reads doesn't block each other as long as no write-lock is held.
What is mutex and semaphore in Java? What is the main difference?

“Semaphore can be counted, while mutex can only count to 1.
Suppose you have a thread running which accepts client connections. This thread can handle 10 clients simultaneously. Then each new client sets the semaphore until it reaches 10. When the Semaphore has 10 flags, then your thread won't accept new connections. Mutex are usually used for guarding stuff. Suppose your 10 clients can access multiple parts of the system. Then you can protect a part of the system with a mutex so when 1 client is connected to that sub-system, no one else should have access. You can use a Semaphore for this purpose too.”

“This is not quite true. The same thread can enter the same mutex more than once, so a count needs to be maintained to ensure entries `& exits are balanced`.”

Unfortunately everyone has missed the most important difference between the semaphore and the mutex; the concept of "ownership".

Semaphores have no notion of ownership, this means that any thread can release a semaphore (this can lead to many problems in itself but can help with "death detection"). Whereas a mutex does have the concept of ownership (i.e. you can only release a mutex you have acquired). Ownership is incredibly important for safe programming of concurrent systems. I would always recommend using mutex in preference to a semaphore (but there are performance implications).

Mutexes also may support priority inheritance (which can help with the priority inversion problem) and recursion (eliminating one type of deadlock). It should also be pointed out that there are "binary" semaphores and "counting/general" semaphores. Java's semaphore is a counting semaphore and thus allows it to be initialized with a value greater than one (whereas, as pointed out, a mutex can only a conceptual count of one). The usefulness of this has been pointed out in other posts. So to summarize, unless you have multiple resources to manage, I would always recommend the mutex over the semaphore.
2. Java 8 – Lambda Thread: Mutex vs. Semaphores

Java multi threads example to show you how to use Semaphore and Mutex to limit the number of threads to access resources.

1. **Semaphores** – Restrict the number of threads that can access a resource. Example, limit max 10 connections to access a file simultaneously.

2. **Mutex** – Only one thread to access a resource at once. Example, when a client is accessing a file, no one else should have access the same file at the same time.

In addition to locks the Concurrency API also supports counting semaphores. Whereas locks usually grant exclusive access to variables or resources, a semaphore is capable of maintaining whole sets of permits. This is useful in different scenarios where you have to limit the amount concurrent access to certain parts of your application.

Here's an example how to limit access to a long running task simulated by sleep(5):

```java
ExecutorService executor = Executors.newFixedThreadPool(10);
Semaphore semaphore = new Semaphore(5);
Runnable longRunningTask = () -> {
    boolean permit = false;
    try {
        permit = semaphore.tryAcquire(1, TimeUnit.SECONDS);
        if (permit) { System.out.println("Semaphore acquired"); sleep(5); }
        else { System.out.println("Could not acquire semaphore"); }
    } catch (InterruptedException e) {
        throw new IllegalStateException(e);
    } finally { if (permit) { semaphore.release(); } }
}
IntStream.range(0, 10).forEach( i ->executor.submit(longRunningTask));
//stop(executor);
```

The executor can potentially run 10 tasks concurrently but we use a semaphore of size 5, thus limiting concurrent access to 5. It's important to use a try/finally block to properly release the semaphore even in case of exceptions.
Executing the previous code results in the following output:
Semaphore acquired
Semaphore acquired
Semaphore acquired
Semaphore acquired
Semaphore acquired
Could not acquire semaphore
Could not acquire semaphore
Could not acquire semaphore
Could not acquire semaphore
Could not acquire semaphore

The semaphores permits access to the actual long running operation simulated by sleep(5) up to a maximum of 5. Every subsequent call to tryAcquire() elapses the maximum wait timeout of one second, resulting in the appropriate console output that no semaphore could be acquired.
The package `java.concurrent.atomic` contains many useful classes to perform atomic operations. An operation is atomic when you can safely perform the operation in parallel on multiple threads without using the `synchronized` keyword or locks as shown in the previous sections. Internally, the atomic classes make heavy use of `compare-and-swap` (CAS), an atomic instruction directly supported by most modern CPUs. Those instructions usually are much faster than synchronizing via locks. So my advice is to prefer atomic classes over locks in case you just have to change a single mutable variable concurrently. Now let's pick one of the atomic classes for a few examples: `AtomicInteger`

```java
AtomicInteger atomicInt = new AtomicInteger(0);
ExecutorService executor = Executors.newFixedThreadPool(2);
IntStream.range(0, 1000).forEach(i -> executor.submit(atomicInt::incrementAndGet));
```

By using `AtomicInteger` as a replacement for `Integer` we're able to increment the number concurrently in a thread-safe manor without synchronizing the access to the variable. The method `incrementAndGet()` is an atomic operation so we can safely call this method from multiple threads.
AtomicInteger supports various kinds of atomic operations. The method `updateAndGet()` accepts a lambda expression in order to perform arbitrary arithmetic operations upon the integer:

```java
AtomicInteger atomicInt = new AtomicInteger(0);
ExecutorService executor = Executors.newFixedThreadPool(2);
IntStream.range(0, 1000).forEach(i -> {
    Runnable task = () -> atomicInt.updateAndGet(n -> n + 2);
    executor.submit(task);
});
System.out.println(atomicInt.get()); // => 2000
```

The method `accumulateAndGet()` accepts another kind of lambda expression of type `IntBinaryOperator`.

Other useful atomic classes are: `AtomicBoolean`, `AtomicLong` and `AtomicReference`. 
LongAdder

The class LongAdder as an alternative to AtomicLong can be used to consecutively add values to a number.

```java
ExecutorService executor = Executors.newFixedThreadPool(2);
LongerAdder adder = new LongerAdder();
IntStream.range(0, 1000).forEach(i -> executor.submit(adder::increment));
// stop(executor);
System.out.println(adder.sumThenReset()); // => 1000
```

LongAdder provides methods `add()` and `increment()` just like the atomic number classes and is also thread-safe. But instead of summing up a single result this class maintains a set of variables internally to reduce contention over threads. The actual result can be retrieved by calling `sum()` or `sumThenReset()`.

This class is usually preferable over atomic numbers when updates from multiple threads are more common than reads. This is often the case when capturing statistical data, e.g. you want to count the number of requests served on a web server. *The drawback of LongAdder is higher memory consumption because a set of variables is held in-memory.* For other details, please see LongAccumulator as well.
ConcurrentMap

The interface ConcurrentMap extends the map interface and defines one of the most useful concurrent collection types. Java 8 introduces functional programming by adding new methods to this interface.

In the next code snippets we use the following sample map to demonstrates those new methods:

```java
ConcurrentMap<String, String> map = new ConcurrentHashMap<>();
map.put("foo", "bar");
map.put("han", "solo");
map.put("r2", "d2");
map.put("c3", "p0");
```

The method `forEach()` accepts a lambda expression of type `BiConsumer` with both the key and value of the map passed as parameters. It can be used as a replacement to `for-each` loops to iterate over the entries of the concurrent map. The iteration is performed sequentially on the current thread.

```java
map.forEach((key, value) -> System.out.printf("%s = %s\n", key, value));
```
The method `putIfAbsent()` puts a new value into the map only if no value exists for the given key. At least for the `ConcurrentHashMap` implementation of this method is thread-safe just like `put()` so you don't have to synchronize when accessing the map concurrently from different threads:

```java
String value = map.putIfAbsent("c3", "p1");
System.out.println(value); // p0
```

The method `getOrDefault()` returns the value for the given key. In case no entry exists for this key the passed default value is returned:

```java
String value = map.getOrDefault("hi", "there");
System.out.println(value); // there
```

The method `replaceAll()` accepts a lambda expression of type `BiFunction`. `BiFunctions` take two parameters and return a single value. In this case the function is called with the key and the value of each map entry and returns a new value to be assigned for the current key:

```java
map.replaceAll((key, value) -> "r2".equals(key) ? "d3" : value);
System.out.println(map.get("r2")); // d3
```
Instead of replacing all values of the map `compute()` let's us transform a single entry. The method accepts both the key to be computed and a bi-function to specify the transformation of the value.

```java
map.compute("foo", (key, value) -> value + value);
System.out.println(map.get("foo")); // barbar
```

In addition to `compute()` two variants exist: `computeIfAbsent()` and `computeIfPresent()`. The functional parameters of these methods only get called if the key is absent or present respectively.

Finally, the method `merge()` can be utilized to unify a new value with an existing value in the map. Merge accepts a key, the new value to be merged into the existing entry and a bi-function to specify the merging behavior of both values:

```java
map.merge("foo", "boo", (oldVal, newVal) -> newVal + " was " + oldVal);
System.out.println(map.get("foo")); // boo was foo
```
ConcurrentHashMap

All those methods above are part of the ConcurrentHashMap interface, thereby available to all implementations of that interface.

In addition the most important implementation ConcurrentHashMap has been further enhanced with a couple of new methods to perform parallel operations upon the map. Just like parallel streams those methods use a special ForkJoinPool available via ForkJoinPool.commonPool() in Java 8. This pool uses a preset parallelism which depends on the number of available cores. Four CPU cores are available on my machine which results in a parallelism of three:

```
System.out.println(ForkJoinPool.getCommonPoolParallelism()); // 3
```

This value can be decreased or increased by setting the following JVM parameter:

```
-Djava.util.concurrent.ForkJoinPool.common.parallelism=5
```
We use the same example map for demonstrating purposes but this time we work upon the concrete implementation ConcurrentHashMap instead of the interface ConcurrentMap, so we can access all public methods from this class:

```java
ConcurrentMap<String, String> map = new ConcurrentHashMap<>();
map.put("foo", "bar");
map.put("han", "solo");
map.put("r2", "d2");
map.put("c3", "p0");
```

Java 8 introduces three kinds of parallel operations: `forEach`, `search` and `reduce`. Each of those operations are available in four forms accepting functions with keys, values, entries and key-value pair arguments.

All of those methods use a common first argument called `parallelismThreshold`. This threshold indicates the minimum collection size when the operation should be executed in parallel. E.g. if you pass a threshold of 500 and the actual size of the map is 499 the operation will be performed sequentially on a single thread. In the next examples we use a threshold of one to always force parallel execution for demonstrating purposes.
2. Java 8 – Lambda Thread: Atomic Variables & ConcurrentMap

**ForEach**

The method `forEach()` is capable of iterating over the key-value pairs of the map in parallel. The lambda expression of type `BiConsumer` is called with the key and value of the current iteration step. In order to visualize parallel execution we print the current threads name to the console. Keep in mind that in my case the underlying `ForkJoinPool` uses up to a maximum of 3 threads.

```java
map.forEach((key, value) ->
    System.out.printf("key: %s; value: %s; thread: %s\n", key, value, Thread.currentThread().getName()));

// key: r2; value: d2; thread: main
// key: foo; value: bar; thread: ForkJoinPool.commonPool-worker-1
// key: han; value: solo; thread: ForkJoinPool.commonPool-worker-2
// key: c3; value: p0; thread: main
```

Copyright: http://winterbe.com/posts/2015/05/22/java8-concurrency-tutorial-atomic-concurrent-map-examples/
Search

The method `search()` accepts a `BiFunction` returning a non-null search result for the current key-value pair or null if the current iteration doesn't match the desired search criteria. As soon as a non-null result is returned further processing is suppressed. Keep in mind that `ConcurrentHashMap` is unordered. The search function should not depend on the actual processing order of the map. If multiple entries of the map match the given search function the result may be non-deterministic.

```java
String result = map.search(1, (key, value) -> {
    System.out.println(Thread.currentThread().getName());
    if ("foo".equals(key)) { return value; } return null; });
System.out.println("Result: "+ result);
```

Here's another example searching solely on the values of the map:

```java
String result = map.searchValues(1, value -> {
    System.out.println(Thread.currentThread().getName());
    if (value.length() > 3) { return value; } return null; });
System.out.println("Result: "+ result);
```

Reduce

The method `reduce()` already known from Java 8 Streams accepts two lambda expressions of type `BiFunction`. The first function transforms each key-value pair into a single value of any type. The second function combines all those transformed values into a single result, ignoring any possible null values.

```java
String result = map.reduce(1, (key, value) -> {
    System.out.println("Transform: " + Thread.currentThread().getName());
    return key + "=" + value;
},
(s1, s2) -> {
    System.out.println("Reduce: " + Thread.currentThread().getName());
    return s1 + ", " + s2;
});
```

```java
System.out.println("Result: " + result);
```

// Transform: main
// Reduce: ForkJoinPool.commonPool-worker-3
// Transform: main
// Reduce: main
// Reduce: main
// Result: r2=d2, c3=p0, han=solo, foo=bar

https://github.com/winterbe/java8-tutorial
Section Conclusions

Java 8 Lambda Expressions for the Multi-Threading programming:

- Concurrency API / Threads and Executors
- Future-Callable
- Concurrency API / Fork-Join mechanisms
- Synchronization and Locks/Mutex
- Mutex vs. Semaphores
- Atomic Variables
- ConcurrentHashMap and Thread-safe data-structures (Java Collection Framework)
Share knowledge, Empowering Minds

Communicate & Exchange Ideas
Questions & Answers!

But wait...

There’s More!
Flynn Taxonomy
Parallel vs. Distributed Systems

Parallel vs. Distributed Computing / Algorithms

http://en.wikipedia.org/wiki/Distributed_computing
http://en.wikipedia.org/wiki/Flynn's_taxonomy
Parallel Computing Hint – OpenMP / OpenCL

https://computing.llnl.gov/tutorials/parallel_comp/
Thanks!