Concurrent Programming

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While we will focus on basics of the Linux threading API.

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Processes are running binaries and threads are the smallest unit of execution schedulable by an operating system's process scheduler.

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If a process contains more than one thread, then there is more than one thing going on at once. We call such processes multithreaded.

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}
```

The run method is executed in thread.

A task can be executed:

- in a specifically created thread;
- via an executor.

Executor service scheduler…

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A ThreadFactory can be passed to control the creation of new threads.

Example

```java
Runnable hellos = () -> {
  for( int i=0 ; i<1000 ; i++ ) {
    System.out.println("Hello "+i);
  }
};
Runnable goodbyes = () -> {
  for( int i=0 ; i<1000 ; i++ ) {
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};
ExecutorService executor = Executors.newCachedThreadPool();
executor.execute(hellos);
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The call method can throw arbitrary exceptions which can be relayed to the code that obtains the result.

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```
V get() throws Interrupted Exception, ExecutionException

V get(long timeout, TimeUnit unit)
  throws Interrupted Exception, ExecutionException,
  TimeoutException

boolean cancel(boolean mayInterruptIfRunning)
boolean isCancelled()
boolean isDone()
```

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The execution of current thread is blocked until all the tasks have terminated (either successfully or unsuccessfully).

Another option we can use when we have to work on multiple tasks is `invokeAny`. In this case the result of the first (successfully) terminating task is returned. Other tasks are cancelled.

A lot of work is done by the `ExecutorService` that is responsible for execution and coordination of tasks!

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CompletableFuture<V> f = ...;
f.thenAccept( (V v) -> process results );
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CompletableFuture<V> f = ...;
f.thenAccept( (V v) -> process results );
```

In this way the result is processed, without blocking, as soon as it is available!

Asynchronous computations

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To run a task asynchronously, (static) method supplyAsync can be used:

```
static <U> CompletableFuture<U> supplyAsync(
    Supplier<U> supplier , Executor executor )

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- a result is computed;
- an exception is thrown.

To handle termination, method whenComplete can be used:

```
public CompletableFuture<T> whenComplete(
  BiConsumer<? super T,? super Throwable> action
)
```

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boolean complete(T value)
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Method `complete` and `completeExceptionally` can be used to complete a future:

```
boolean complete(T value)

boolean completeExceptionally(Throwable ex)
```

A future can be completed by multiple threads (only the first one is stored).

Composing futures...

Class CompletableFuture<T> provides a set of methods that can be used to process values in a chain:

```
<U> CompletableFuture<U> thenApply(
      Function<? super T,? extends U> fn)

CompletableFuture<Void> thenAccept(Consumer<? super T> fn)

<U> CompletableFuture<U> thenCompose(
    Function<? super T,? extends CompletionStage<U>> fn)

<U> CompletableFuture<U> handle(
    BiFunction<? super T,Throwable,? extends U> fn)

CompletableFuture<Void> thenRun(Runnable action)
```

Another example. . .

```
private static boolean done = false;

public static void main(String[] argv) {
  Runnable hellos = () -> {
    for( int i=0 ; i<1000 ; i++ ) {
      System.out.println("Hello "+i);
    }
    done = true;
  };
  Runnable goodbyes = () -> {
    int i=0;
    while (!done) { i++; }
    System.out.println("Goodbye "+i);
  };
  ExecutorService executor = Executors.newCachedThreadPool();
  executor.execute(hellos);
  executor.execute(goodbyes);
}
```

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There are ways to ensure that an update to a variable is visible:

- The value of a final value is visible after initialisation;
- The initial value of a static variable is visible after static initialisation;
- Changes to volatile variables are visible;
- Changes happening before realising a lock are visible to anyone acquiring the lock.

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There are ways to ensure that an update to a variable is visible:

- The value of a `final` value is visible after initialisation;
- The initial value of a `static` variable is visible after static initialisation;
- Changes to `volatile` variables are visible;
- Changes happening before realising a lock are visible to anyone acquiring the lock.

To solve the problem in previous example, we have to declare `done` `volatile` .

Race condition. . .

```
private static volatile int count = 0;

public static void main(String[] argv) {
  ExecutorService executor = Executors.newCachedThreadPool();
  for( int i=0 ; i<100 ; i++ ) {
    int taskId = i;
    Runnable task =  () -> {
      for(int k=0 ; k<1000; k++) {
        count++;
      }
      System.out.println(taskId+": "+count);
    };
    executor.execute(task);
  }
}
```

Race condition

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Immutability: share immutable objects.

Critical Section/Locking: granting exclusive access to shared resource.

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It is guaranteed that at most one thread is executing a synchronized block labelled with a given object o.

Synchronized blocks. . .

In a synchronized block, value `o` acts as a lock:

- lock is acquired when a thread enters in the block;
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Example:

```
Runnable task =  () -> {
  for(int k=0 ; k<1000; k++) {
    synchronized (executor) {
      count++;
    }
  }
  System.out.println(taskId+": "+count);
};
```

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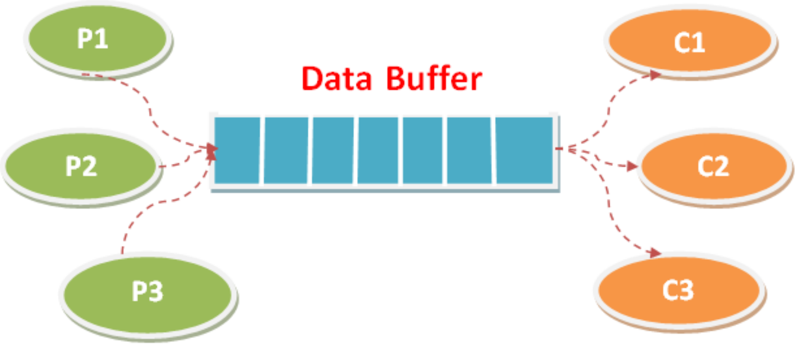
This code is equivalent to:

```
public void increment() {
  synchronized (this) {
    count++;
  }
}
```

Example: Producer/Consumer



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What happen it the buffer is full? Action add is blocking!

What happen when a new item is inserted? Threads waiting for a new item are notified!

What happen when a new item is removed? Threads waiting for adding an item are notified!

Monitors

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A condition variable is basically a container of threads that are waiting for a certain condition (thread's computation is suspended until the condition is satisfied).

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Any object in Java can play the role of a monitor.

To guarantee atomic executions of methods (that are the monitor's actions), these are declared `synchronize`.

Each Java object provides methods that allow a thread to suspend its execution and then waiting for a notification!

These methods are:

- `void wait() throws InterruptedException`
- `void wait(long) throws InterruptedException`
- `notify ()`
- `notifyAll ()`

Producer/Consumer in Java

```
public class ProducerConsumer<T> {

  private final LinkedList<T> buffer;
  private final int size;

  public ProducerConsumer( int size ) {
    this.buffer = new LinkedList<>();
    this.size = size;
  }

  public synchronized boolean isEmpty() {
    return buffer.size()==0;
  }

  public synchronized boolean isFull() {
    return buffer.size()==size;
  }
```

Producer/Consumer in Java

```
  public synchronized void add(T item) throws
   InterruptedException {
    while (!this.isFull()) {
      wait();
    }
    this.notifyAll();
    buffer.add(item);
  }

  public T get() throws InterruptedException {
    while (!this.isEmpty()) {
      wait();
    }
    this.notifyAll();
    return buffer.poll();
  }
}
```

High Level Concurrency Objects

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Concurrent collections make it easier to manage large collections of data, and can greatly reduce the need for synchronization.

Atomic variables have features that minimize synchronization and help avoid memory consistency errors.

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- support a wait/notify mechanism, through their associated `Condition` objects.

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- only one thread can own a `Lock` object at a time;
- support a wait/notify mechanism, through their associated `Condition` objects.

The biggest advantage of `Lock` objects over implicit locks is their ability to back out of an attempt to acquire a lock:

- `tryLock` method backs out if the lock is not available immediately or before a timeout expires (if specified);
- `lockInterruptibly` method backs out if another thread sends an interrupt before the lock is acquired.

Lock Objects

`void lock()`, Acquires the lock.

`void lockInterruptibly ()`, Acquires the lock unless the current thread is interrupted.

`Condition newCondition()`, Returns a new Condition instance that is bound to this Lock instance.

`boolean tryLock()`, Acquires the lock only if it is free at the time of invocation.

`boolean tryLock(long time, TimeUnit unit)`, Acquires the lock if it is free within the given waiting time and the current thread has not been interrupted.

`void unlock()`, Releases the lock.

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The key property that waiting for a condition provides is that it atomically releases the associated lock and suspends the current thread, just like `Object.wait`.

A Condition instance is intrinsically bound to a lock. To obtain a Condition instance for a particular Lock instance use its newCondition() method.

Producer/Consumer in Java

Lock based implementation

```
public class ProducerConsumerLock<T> {
  private final Lock lock = new ReentrantLock();
  private final Condition notFull = lock.newCondition();
  private final Condition notEmpty = lock.newCondition();
  private final LinkedList<T> buffer;
  private final int size;

  public ProducerConsumerLock( int size ) {
    this.buffer = new LinkedList<>();
    this.size = size;
  }

  public boolean isEmpty() {
    return buffer.size()==0;
  }

  public boolean isFull() {
    return buffer.size()==size;
  }
```

Condition

`void await()`, Causes the current thread to wait until it is signalled or interrupted.

`boolean await(long time, TimeUnit unit)`, Causes the current thread to wait until it is signalled or interrupted, or the specified waiting time elapses.

`long awaitNanos(long nanosTimeout)`, Causes the current thread to wait until it is signalled or interrupted, or the specified waiting time elapses.

`void awaitUninterruptibly ()`, Causes the current thread to wait until it is signalled.

`boolean awaitUntil (Date deadline)`, Causes the current thread to wait until it is signalled or interrupted, or the specified deadline elapses.

`void signal ()`, Wakes up one waiting thread.

`void signalAll ()`, Wakes up all waiting threads.

Producer/Consumer in Java

Lock based implementation

```
public void add(T item) throws InterruptedException {
  lock.lock();
  try {
    while (this.isFull()) {
      System.out.println("Buffer is full! Waiting for space
  ...");
      notFull.await();;
    }
    notEmpty.signal();
    buffer.add(item);
    System.out.println("Item added (size="+buffer.size()+")
 ");
  } finally {
    lock.unlock();
  }
}
```

Producer/Consumer in Java

Lock based implementation

```
public T get() throws InterruptedException {
  lock.lock();
  try {
    while (this.isEmpty()) {
      System.out.println("Buffer is empty! Waiting for an
 item...");
      notEmpty.await();;
    }
    notFull.signal();
    System.out.println("Item removed (size="+(buffer.size()
 -1)+")");
    return buffer.poll();
  } finally {
    lock.unlock();
  }
}
```

Atomic Variables

The `java.util.concurrent.atomic` package defines classes that support atomic operations on single variables.

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The atomic compareAndSet method also has these memory consistency features, as do the simple atomic arithmetic methods that apply to integer atomic variables.

To be continued. . .