LECTURE 4: ADVANCED CONCURRENCY IN THE JAVA LANGUAGE

Lecture Contents

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SECTION 4.1: MONITORS IN JAVA

Monitors in Java

- Java implements a slimmed down version of monitors.
- Java's monitor supports two kinds of thread synchronization: *mutual exclusion* and *cooperation*:
  - *Mutual exclusion*:
    - Supported in JVM via object locks (aka 'mutex'),
    - Enables multiple threads to independently work on shared data without interfering with each other.
  - *Cooperation*:
    - Supported in JVM via the `wait()`, `notify()` methods of class `Object`,
    - Enables threads to work together towards a common goal.

Monitors in Java: Recap on Threads (/2)

- Java thread is a lightweight process with own stack & execution context, access to all variables in its scope.
- Can be programmed by extending `Thread` class or implementing `runnable` interface.
- Both of these are part of standard `java.lang` package.
- `Thread` instance is created by:

```
Thread myProcess = new Thread ( );
```

- New thread started by executing:

```
MyProcess.start ( );
```

  `start` method invokes a `run` method in the thread.
- As `run` method is undefined as yet, code above does nothing.

Monitors in Java: Recap on Threads (/3)

- We can define the `run` method by extending the `Thread` class:

```
class  myProcess extends Thread ( );
{
       public void run ( )
       {
       System.out.println ("Hello from the thread");
       }
}
myProcess p = new myProcess ( );
p.start ( );
```

- Best to terminate threads by letting `run` method to terminate.
- If don't need a ref to new thread omit `p` and simply write:

```
new myProcess ( ).start( );
```

Monitors in Java: Recap on Threads (/4)

- As well as extending `Thread` class, can create lightweight processes by implementing `Runnable`.
- Advantage is can make your own class, or a system-defined one, into a process.
- Not possible with threads as Java only allows for one class at a time to be extended.
- Using the `Runnable` interface, previous example becomes:

```
class  myProcess implements Runnable ( );
{
        public void run ( )         {
        System.out.println ("Hello from the thread");
        }
}
Runnable p = new myProcess ( );
New Thread(p).start ( );
```


Monitors in Java: Recap on Threads (/5)

- If it has nothing immediate to do (eg it updates screen regularly) should suspend thread by putting it to sleep.
- 2 flavours of `sleep( )` method (specifying different times)
- `join( )` awaits specified thread finishing, giving basic synchronisation with other threads.
  - i.e. "join" start of a thread's execution to end of another thread's execution
  - thus thread will not start until other thread is done.
- If `join()` is called on a Thread instance, the currently running thread will block until the Thread instance has finished executing:

```
        try
{
        otherThread.join (1000); // wait for 1 sec
}
catch (InterruptedException e ) {}
```

Monitors in Java: Synchronization

- Conceptually threads in Java execute concurrently, so could simultaneously access shared variables (aka *A Race Condition*)
- To prevent when updating a shared variable, Java provides synchronisation via a slimmed-down monitor.
- Java's keyword `synchronized` provides mutual exclusion and can be used with a group of statements or with an entire method.
- The following class will potentially have problems if its update method is executed by several threads concurrently:

```
class  Problematic
{
        private int data = 0;
        public void update ( )      {
                data++;
        }
}
```


Monitors in Java: Synchronization (/2)

- Conceptually threads in Java execute concurrently and therefore could simultaneously access shared variables.

```
class ExclusionByMethod {
        private int data = 0;
        public synchronized void update ( ){
                data++;
        }
}
```

- This is a simple monitor where the monitor's permanent variables are private variables in the class;
- Monitor procedures are implemented as `synchronized` methods.
- Only 1 lock per object in Java thus if a `synchronized` method is invoked the following occurs:
  - it waits to obtain the lock,
  - executes the method, and then
  - releases the lock.
- This is known as *intrinsic locking*.

Monitors in Java: Synchronization (/3)

- Can also have Mutual exclusion with **synchronized** statement in method's body:

```
class ExclusionByGroup {
        private int data = 0;
        public void update ( ){
                synchronized (this) {  // lock this object for
                        data++;        // the following group of
                }                      // statements
        }
}
```

- The keyword **this** refers to object invoking the update method.
- The lock is obtained on the invoking object.
- A **synchronized** statement specifies that the following group of statements is executed as an atomic, non interruptible, action.
- A **synchronized** method is equivalent to a monitor procedure.

Monitors in Java: Condition Variables

- While Java does not explicitly support condition variables, there is one *implicitly* declared for each synchronised object.
- Java's `wait()` & `notify()` resemble can only be executed in `synchronized` code parts (when object is locked):
  - `wait()` releases object lock, suspending the executing thread in a FIFO delay queue (one per object).
  - thus gets it to yield the monitor & sleep until some thread enters monitor & calls **`notify()`**
  - so `notify()` wakes thread at the front of object's delay queue.
  - `notify()` has signal-and-continue semantics, so thread calling `notify()` still holds the object lock.
- Awakened thread goes later when it reacquires the object lock
- Java has `notifyAll()`, waking all threads blocked on same object.

Monitors in Java: Example 1: **Queue** Class

- `wait()` & `notify()` in Java are used in `Queue` implementation:

```
/**
* One thread calls push() to put an object on the queue. Another calls pop() to
* get an object off the queue. If there is none, pop() waits until there is
* using wait()/notify(). wait() and notify() must be used within a synchronized
* method or block.
*/
import java.util.*;

public class Queue {
        LinkedList q = new LinkedList();  // Where objects are stored
        public synchronized void push(Object o) {
                q.add(o);           // Append the object at end of the list
                this.notify();      // Tell waiting threads data is ready
        }
        public synchronized Object pop() {
                while(q.size() == 0) {
                        try { this.wait(); }
                catch (InterruptedException e) { /* Ignore this exception */ }
                }
                return q.remove(0);
        }
}
```


Monitors in Java: Example 2: **Readers/Writers** Class

```
class ReadersWriters
{
   private int data = 0;  // our database
   private int nr = 0;

   private synchronized void startRead(){
       nr++;
   }

   private synchronized void endRead(){
       nr--;
       if (nr == 0) notify();  // wake a
   }                           //waiting writer

   public void read ( )   {
       startRead ( );
       System.out.println("read"+data);
       endRead ( );
   }

   public synchronized void write ( ) {
       while (nr > 0)
         try {
            wait ( ); //wait if any
                      //active readers
         }
         catch (InterruptedException ex){
            return;
         }
       data++;
       System.out.println("write"+data);
       notify (); // wake a waiting writer
   }
}
```

Example 2: Readers/Writers Class (/2)

```
class Reader extends Thread {
   int rounds;
   ReadersWriters RW;

   Reader(int rounds, ReadersWriters RW) {
        this.rounds = rounds;
        this.RW = RW;
   }

   public void run ( ){
        for (int i = 0; i < rounds; i++)
          RW.read ( );
   }
}
```

```
class Writer extends Thread {
   int rounds;
   ReadersWriters RW;

   Writer(int rounds, ReadersWriters RW) {
        this.rounds = rounds;
        this.RW = RW;
   }

   public void run ( ){
        for (int i = 0; i < rounds; i++)
          RW.write ( );
   }
}

class RWProblem {
   static ReadersWriters RW = new
        ReadersWriters ( );

   public static void main(String[] args){
        int rounds = Integer.parseInt
                (args[0], 10);
        new Reader(rounds, RW).start ( );
        new Writer(rounds, RW).start ( );
   }
}
```

- This is the *Reader Preference* Solution. How to make this fair?

SECTION 4.2: DEVELOPMENTS IN `JAVA.UTIL.CONCURRENT`

Developments in `java.util.concurrent`

- Thus far, have focused on low-level APIs that were part of Java from the onset.
- These are ok for basic tasks, but need higher-level constructs for more advanced tasks
  - esp for many-thread parallel apps exploiting multi-core systems.
- In this lecture we focus on some high-level concurrency features of more recent Java releases.
- Most of these are implemented in `java.util.concurrent`
- Also have concurrent data structures in the Java `Collections` Framework.

Features in Brief

- `Semaphore` objects resemble those seen already; except `acquire()` & `release()` instead of `P`, `V` (resp)
- `Lock` objects support locking idioms that simplify many concurrent applications (don't mix up with *implicit* locks!)
- `Executors` give high-level API for launching, managing threads.
- `Executor` implementations provide thread pool management suitable for large-scale applications.
- Concurrent `Collections` support concurrent management of large data collections in Hash Tables, different kinds of Queues etc.
- `Future` objects are enhanced to have their status queried and return values when used in connection with asynchronous threads.
- Atomic variables (eg `AtomicInteger`) support atomic operations on single variables
  - features that minimize synchronization & help avoid memory consistency errors
  - i.e. useful in applications that call for atomically incremented counters

`Semaphore` Objects

- *Constructors for semaphore*

1. `Semaphore` object maintains a set of permits:

   `Semaphore(int permits);`

   – Each `acquire` blocks til `permit` is available; Each `release` adds a `permit`

   – No `permit` objects *per se* – just keeps a count of available `permits`

2. `Semaphore` constructor also accepts a fairness parameter:

   `Semaphore(int permits, boolean fair);`

   `permits`: initial value

   `fair`:

   – if true semaphore uses FIFO to manage blocked threads

   – if set false, class doesn't guarantee order threads acquire permits.

   – In particular, lets barging (ie, thread doing `acquire()` can get a permit ahead of one waiting longer)

Example 3: `Semaphore` Example

```
//SemApp: code to demonstrate throttling with semaphore class © Ted Neward
import java.util.*;import java.util.concurrent.*;

public class SemApp          {
    public static void main( String[] args ) {
          Runnable limitedcall = new Runnable           {
              final Random rand = new Random();
              final Semaphore available = new Semaphore(3); //semaphore obj with 3 permits
              int count = 0;
              public void run()        {
                    int time = rand.nextInt(15);
                    int num = count++;
                    try {
                              available.acquire();
                              System.out.println("Executing " + "long-
          run action for " + time + " secs.. #" + num);
                              Thread.sleep(time * 1000);
                              System.out.println("Done with # " + num);
                              available.release();
                              }
                    catch (InterruptedException intEx)            {
                              intEx.printStackTrace();
                    }
              }
         };
         for (int i=0; i<10; i++)
          new Thread(limitedCall).start(); // kick off worker threads
      } // end main
} // end SemApp
```

Example 3: **`Semaphore`** Example (/2)

- *Throttling* with Semaphore class

Often must throttle number of open requests for a resource.

- Can improve throughput of a system
  - Does this by reducing contention for that particular resource.
- Alternatively it might be a question of starvation prevention.
- This was shown in the room case of Dining Philosophers (above)
  - Only want to let 4 philosophers in the room at any one time
- Can write the throttling code by hand, but it's often easier to use `semaphore` class - does it for you.

Example 3: **`Semaphore`** Class (/2)

- Even though the 10 threads in this code are running, only three are active.
- You can verify by executing `jstack` against the Java process running `SemApp`),
- The other seven are held at bay pending release of one of the semaphore counts.
- Actually, the `Semaphore` class supports acquiring and releasing more than one *permit* at a time,
- That wouldn't make sense in this scenario, however.

Interface `Lock`

- `Lock` implementations operate like the implicit locks used by `synchronized` code (only 1 thread can own a `Lock` object at a time[1].)
- Unlike intrinsic locking all `lock` and `unlock` operations are explicit and have bound to them explicit `Condition` objects.
- Biggest advantage over implicit locks is can back out of an attempt to acquire a `Lock`:
  - i.e. livelock, starvation & deadlock are not a problem
- `Lock` methods:
  - `tryLock()` returns if lock is not available immediately or before a timeout (optional parameter) expires.
  - `lockInterruptibly()` returns if another thread sends an interrupt before the lock is acquired.

[1] *A thread can't get a lock owned by another thread, but it can get a lock that it already owns. Letting a thread acquire the same lock more than once enables Reentrant Synchronization (i.e. tread with the lock on a synchronized code snippet can invoke another bit of synchronized code e.g. in a monitor.)*

Interface `Lock`

- `Lock` interface also supports a `wait/notify` mechanism, through the associated `Condition` objects

- Thus do away with basic monitor methods (`wait()`, `notify()` & `notifyAll()`) with specific objects:
  - `Lock` in place of `synchronized` methods and statements.
  - An associated `Condition` in place of Object's monitor methods.
  - A `Condition` instance is intrinsically bound to a `Lock`.

- To obtain a `Condition` instance for a particular `Lock` instance use its `newCondition()` method.

Reentrantlocks & synchronized Methods

- Reentrantlock implements lock interface with the same mutual exclusion guarantees as synchronized.
- Acquiring/releasing a Reentrantlock has the same memory semantics as entering/exiting a synchronized block.
- So why use a Reentrantlock in the first place?
  - Using synchronized gives access to the implicit lock an object has, but forces all lock acquisition/release to occur in a block-structured way:

    if multiple locks are acquired they must be released in the opposite order.
  - Reentrantlock allows a more flexible locking/releasing mechanism.
  - Reentrantlock supports scalability and is nice where there is high contention among threads.
- So why not get rid of synchronized?
  - Firstly, a lot of legacy Java code uses it
  - Secondly, there are performance implications to using Reentrantlock

Example 4: Bounded Buffer Using Lock & Condition Objects

```
class BoundedBuffer {
    final Lock lock = new ReentrantLock();
    final Condition notFull = lock.newCondition();
    final Condition notEmpty= lock.newCondition();
    final Object[] items = new Object[100];
    int putptr, takeptr, count;

    public void put(Object x) throws
                    InterruptedException {
        lock.lock(); // Acquire lock on object
        try {
          while (count == items.length)
                    notFull.await();
          items[putptr] = x;
          if (++putptr == items.length)
                    putptr = 0;
          ++count;
          notEmpty.signal();
          }
          finally {
          lock.unlock(); // release the lock
          }
     }

    public Object take() throws
                    InterruptedException {
        lock.lock();// Acquire lock on object
        try {
          while (count == 0)
            notEmpty.await();
          Object x = items[takeptr];
          if (++takeptr == items.length)
                    takeptr = 0;
          --count;
          notFull.signal();
          return x;
         }
         finally {
         lock.unlock(); // release the lock
        }
    }
}
```

Example 5: Bank Account Example using **Lock** & **Condition** Objects

```java
package net.jcip.examples;
import java.util.*;
import java.util.concurrent.*;
import java.util.concurrent.locks.*;
import static java.util.concurrent.TimeUnit.NANOSECONDS;
/**
 * DeadlockAvoidance: * Avoiding lock-ordering deadlock using tryLock *
 * @author Brian Goetz and Tim Peierls
 */
public class DeadlockAvoidance {
    private static Random rnd = new Random();
    public boolean transferMoney(Account fromAcct,
                                 Account toAcct,
                                 DollarAmount amount,
                                 long timeout,
                                 TimeUnit unit)
            throws InsufficientFundsException, InterruptedException {
        long fixedDelay = getFixedDelayComponentNanos(timeout, unit);
        long randMod = getRandomDelayModulusNanos(timeout, unit);
        long stopTime = System.nanoTime() + unit.toNanos(timeout);
        while (true) {
            if (fromAcct.lock.tryLock()) {
                try {
                    if (toAcct.lock.tryLock()) {
                        try {
                            if (fromAcct.getBalance().compareTo(amount) < 0)
                                throw new InsufficientFundsException();
                            else {
                                fromAcct.debit(amount);
                                toAcct.credit(amount);
                                return true;
                            }
                        } finally {
                            toAcct.lock.unlock();
                        }
                    }
```


Example 5: Bank Account Example using **Lock** & **Condition** Objects (/2)

```java
                } finally {
                    fromAcct.lock.unlock();
                }
            }
            if (System.nanoTime() < stopTime)
                return false;
            NANOSECONDS.sleep(fixedDelay + rnd.nextLong() % randMod);
        }
    }

    private static final int DELAY_FIXED = 1;
    private static final int DELAY_RANDOM = 2;

    static long getFixedDelayComponentNanos(long timeout, TimeUnit unit
        return DELAY_FIXED;
    }

    static long getRandomDelayModulusNanos(long timeout, TimeUnit unit)
        return DELAY_RANDOM;
    }

    static class DollarAmount implements Comparable<DollarAmount> {
        public int compareTo(DollarAmount other) {
            return 0;
        }

        DollarAmount(int dollars) {
        }
    }
```

```java
    class Account {
        public Lock lock;

        void debit(DollarAmount d) {
        }

        void credit(DollarAmount d) {
        }

        DollarAmount getBalance() {
            return null;
        }
    }

    class InsufficientFundsException extends
    }
}
```

Example 5: Bank Account Example using **Lock** & **Condition** Objects (/3)

- With intrinsic locks deadlock can be serious, so `tryLock()` is used to allow control to be regained if all the locks cannot be acquired.
- `tryLock()` returns if lock is unavailable immediately or before a timeout expires (parameters specified).
- At `fromAcct.lock.tryLock` thread tries to get `lock` on `fromAcct`:
  - If successful, tries and acquire the lock on `toAcct`.
  - If former is successful but the latter is unsuccessful, can back off, release the one acquired and retry at a later time.
  - On acquiring both & with enough US$ in the `fromAcct`, call `debit()` on this object for the sum amount & `credit()` on `toAcct` is called for the same amount & boolean `TransferMoney()` comes back as true
  - If there are insufficient funds, an exception to that effect is returned.

Example 6: Dining Philosophers Using **Lock** Objects

```
public class Fork {
  private final int id;
  public Fork(int id) {
    this.id = id;  }
// equals, hashcode, and toString() omitted
}
public interface ForkOrder {
  Fork[] getOrder(Fork left, Fork right);
} // We will need to establish an order of pickup

// Vanilla option w. set pickup order implemented
class Philo implements Runnable {
  public final int id;
  private final Fork[] Forks;
  protected final ForkOrder order;

  public Philo(int id, Fork[] Forks, ForkOrder
order) {
    this.id = id;
    this.Forks = Forks;
    this.order = order;
  }
```

```
  public void run() {
    while(true) { eat();
    }
  }

  protected void eat() {
// Left and then Right Forks picked up
    Fork[] ForkOrder = order.getOrder(getLeft(),
getRight());
    synchronized(ForkOrder[0]) {
      synchronized(ForkOrder[1]) {
        Util.sleep(1000);
      }
    }
  }

  Fork getLeft() {  return Forks[id]; }
  Fork getRight() { return Forks[(id+1) %
Forks.length]; }
  }
}
```

- This can, in principle, be run & philosophers just eat forever: choosing which fork to pick first; picking it up; then picking the other one up then eating etc.
- If you look at the code above in the eat() method, 'grab the fork' by synchronizing on it, locking the fork's monitor.

Example 6: Dining Philosophers Using `Lock` Objects (/2)

☺ Same as Before ☺

```
class Philo implements Runnable {
  public final int id;
  private final Fork[] Forks;
  protected final ForkOrder order;

  public Philo(int id, Fork[] Forks, ForkOrder
order) {
    this.id = id;
    this.Forks = Forks;
    this.order = order;
  }

public class GraciousPhilo extends Philo {
  private static Map ForkLocks = new
ConcurrentHashMap();

  public GraciousPhilo(int id, Fork[] Forks,
ForkOrder order) {
    super(id, Forks, order);
// Every Philo creates a lock for their left Fork
    ForkLocks.put(getLeft(), new ReentrantLock());
  }
```

```
  protected void eat() {
    Fork[] ForkOrder = order.getOrder(getLeft(),
getRight());
    Lock firstLock = ForkLocks.get(ForkOrder[0]);
    Lock secondLock = ForkLocks.get(ForkOrder[1]);
    firstLock.lock();

    try {
        secondLock.lock();

        try {
          Util.sleep(1000);
        } finally {
          secondLock.unlock();
                    }
    } finally {
        firstLock.unlock();
          }
  }
}
```

- Just replace `synchronized` with `lock()` & end of `synchronized` block with a `try { } finally { unlock() }.`
- This allows for timed wait (until finally successful) or
- `lockInterruptibly()` - block if lock already held, wait until lock is acquired; if another thread interrupts waiting thread `lockInterruptibly()` - will throw `InterruptedException`

Dining Philosophers Using `ReentrantLocks` (/3)

- Can leverage additional power of `ReentrantLock` to do some niceties:
  - First, don't have to block forever on the `lock` call.
  - Instead we can do a timed wait using `tryLock()`.
  - One form of this method returns immediately if the lock is already held
  - Other can wait for some time for the lock to become available before giving up.
  - In both, could effectively loop and retry the `tryLock()` until it succeeds.

- Another nice option is to `lockInterruptibly()`
  - Calling this allows for waiting indefinitely but reply to thread being interrupted.
  - Possible to write an external monitor that either watches for deadlock or allows a user to forcibly interrupt one of the working threads.
  - Could be provided via JMX to allow a user to recover from a deadlock.

Pre-History of Executors

- As seen above, one method of creating a multithreaded application is to implement `Runnable`.
- In `J2SE 5.0`, this became the *preferred* means (using package `java.lang`)
- Built-in methods and classes are used to create Threads that execute the `Runnable`s.
- As also seen, the `Runnable` interface declares a single method named `run`.
- `Runnable`s are executed by an object of a class that implements the `Executor` interface.
- This can be found in package `java.util.concurrent`.

Executors (new)

- Seen how to create multiple threads and coordinate them via synchronized methods and blocks, as well as via `Lock` objects.
- But how do we execute the threads to different cores on a multicore machine?
- There are 2 mechanisms in Java
  - `Executor` Interface and Thread Pools
  - Fork/Join Framework

Executors: **`Executor`** Interface & Thread Pools

- `java.util.concurrent` package provides 3 executor interfaces:
  - `Executor`: Simple interface that launches new tasks.
  - `ExecutorService`: Subinterface of `Executor` that adds features that help manage tasks' lifecycle.
  - `ScheduledExecutorService`: Subinterface of `ExecutorService` supporting future and/or periodic execution of tasks.
- The `Executor` interface provides a single method, `execute`.
- For runnable object `r`, Executor object `e` then

```
e.execute (r) ;
```

may simply execute a thread,

or it may use an existing worker thread to run **`r`**,

or, with thread pools, queue **`r`** to wait for available worker thread.

Executors: **`Executor`** Interface & Thread Pools (/2)

- Thread pool threads execute `Runnable` objects passed to `execute()`
- The `Executor` assigns each `Runnable` to an available thread in the thread pool.
- If none available, it creates one or waits for one to become available & assigns that thread the `Runnable` passed to method `execute`.
- Depending on the `Executor` type, there may be a limit to the number of threads that can be created.
- A subinterface of Executor (Interface `ExecutorService`) declares other methods to manage both `Executor` and task/ thread life cycle
- An object implementing the `ExecutorService` sub-interface can be created using static methods declared in class `Executors`.

Example 7: Executors

```
//From Deitel & Deitel PrintTask class sleeps a random time 0 - 5 seconds
import java.util.Random;

class PrintTask implements Runnable {
        private int sleepTime; // random sleep time for thread
        private String threadName; // name of thread
        private static Random generator = new Random();
        // assign name to thread
        public PrintTask(String name)
             threadName = name; // set name of thread
             sleepTime = generator.nextInt(5000); // random sleep 0-5 secs
        } // end PrintTask constructor

        // method run is the code to be executed by new thread
        public void run()
             try // put thread to sleep for sleepTime {
                 System.out.printf("%s sleeps for %d ms.\n",threadName,sleepTime );
                 Thread.sleep( sleepTime ); // put thread to sleep
             } // end try
                 // if thread interrupted while sleeping, print stack trace
             catch ( InterruptedException exception )        {
                 exception.printStackTrace();
             } // end catch
                 // print thread name
             System.out.printf( "%s done sleeping\n", threadName );
        } // end method run
} // end class PrintTask
```


Example 7: Executors (/2)

- When a **PrintTask** is assigned to a processor for the first time, its **run** method begins execution.
- Static method **sleep** of class **Thread** is called to place the thread into the timed waiting state.
- At this point, thread loses the processor & system lets another execute.
- When the thread awakens, it re-enters the runnable state.
- When the **PrintTask** is assigned to a processor again, thread’s name is output saying thread is done sleeping; **run** terminates.

Example 7: Executors Main Code

```
//RunnableTester: Multiple threads printing at different intervals
import java.util.concurrent.Executors;
import java.util.concurrent.ExecutorService;

public class RunnableTester       {
        public static void main( String[] args )    {
        // create and name each runnable
                PrintTask task1 = new PrintTask( "thread1" );
                PrintTask task2 = new PrintTask( "thread2" );
                PrintTask task3 = new PrintTask( "thread3" );

                System.out.println( "Starting threads" );

                // create ExecutorService to manage threads
                ExecutorService threadExecutor
                        = Executors.newFixedThreadPool( 3 );
                // start threads and place in runnable state
                threadExecutor.execute( task1 ); // start task1
                threadExecutor.execute( task2 ); // start task2
                threadExecutor.execute( task3 ); // start task3

                threadExecutor.shutdown(); // shutdown worker threads

                System.out.println( "Threads started, main ends\n" );
    } // end main
} // end RunnableTester
```


Example 7: Executors Main Code (/2)

- The code above creates three threads of execution using the `PrintTask` class.
- `main`
  - creates & names three `PrintTask` objects.
  - creates a new `ExecutorService` using method `newFixedThreadPool()` of class `Executors`, which creates a pool consisting of a fixed number (3) of threads.
  - These threads are used by `threadExecutor` to run the execute method of the `Runnables`.
  - If `execute()` is called and all threads in `ExecutorService` are in use, the `Runnable` will be placed in a queue
  - It is then assigned to the first thread completing its previous task.

Example 7: Executors Main Sample Output

```
Starting threads
Threads started, main ends

thread1 sleeps for 1217 ms.
thread2 sleeps for 3989 ms.
thread3 sleeps for 662 ms.
thread3 done sleeping
thread1 done sleeping
thread2 done sleeping
```


Executors: Futures/Callables

- Pre-Java 8 version of `Futures` was quite weak, only supporting waiting for `Future` to complete.
- Also `executor` framework uses `Runnable`s & `Runnable` can't return a result.
- A `Callable` object allows return values after completion.
- `Callable` uses generics to define type of object returned.
- If you submit a `Callable` object to an `Executor`, framework returns `java.util.concurrent.Future` object.
- This `Future` object can be used to check the status of a `Callable` and to retrieve the result from the `Callable`.

Executors: Futures/Callables (/2)

- So writing asynchronous concurrent programs that return results using executor framework requires:
  - Define class/task implementing either `Runnable` or `Callable` interface
  - Configure & implement `ExecutorService`
  - (This because need `ExecutorService` to run the `Callable` object.)
  - The service accepts `Callable`s to run using `submit()` method
  - Submit task using `Future` class to retrieve result if task is `Callable`
- Difference between a `Runnable` and `Callable`:
  - `Runnable` interfaces do not return a result V `Callable` permits returning values after completion.
  - When a `Callable` is submitted to the executor framework, it returns an object of type `java.util.concurrent.Future`.
  - The `Future` can be used to retrieve results

Executors: Futures/Callables (/3) Example 8[1]

```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;
  }
}
```

[1] This code and associated piece on the next page were written and are Copyright © Lars Vogel. Source Code can be found at *de.vogella.concurrency.callables*.

Executors: Futures/Callables (/4) Example 8[1]

```java
package de.vogella.concurrency.callables;
import java.util.ArrayList;
import java.util.List;import java.util.concurrent.Callable;
import java.util.concurrent.ExecutionException;
import java.util.concurrent.ExecutorService;
import java.util.concurrent.Executors;import java.util.concurrent.Future;
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;
    System.out.println(list.size());
    // now retrieve the result
    for (Future<Long> future : list) {
      try {
        sum += future.get(); //get() method of Future will block until task is completed
      } catch (InterruptedException e) {
        e.printStackTrace();
      } catch (ExecutionException e) {
        e.printStackTrace();
      }
    }
    System.out.println(sum);executor.shutdown();
  }
}
```

[1] Copyright © Lars Vogel, 2013

ForkJoin Framework

- Since Java 7, the Fork/Join framework can be used to distribute threads among multiple cores.
- It's an implementation of `ExecutorService` interface designed for work that can be broken into smaller pieces recursively.
- Goal: use all available processors to enhance application performance
- This framework thus adopts a divide-and-conquer approach:

```
If task can be easily solved
        -> current thread returns its result.
Otherwise ->
     thread divides the task into simpler tasks and
     forks a thread for each sub-task.
When all sub-tasks are done, the current thread returns its
result obtained from combining the results of its sub-tasks.
```

- Key difference between `Fork/Join` framework and `Executor` Interface is the former implements a *work stealing* algorithm.
  - This allows idle threads to steal work from busy threads (i.e. pre-empting).

`ForkJoin` Framework (/2)

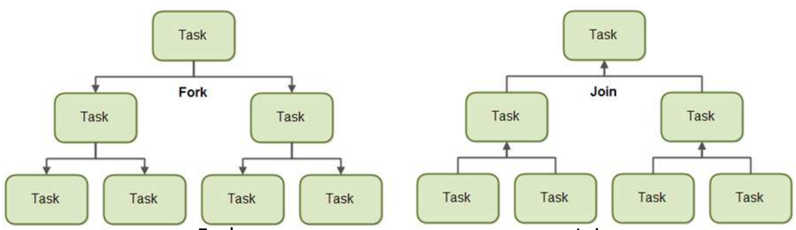
- A key class is the `ForkJoinPool` (an implementation of `ExecutorService` implementing work-stealing.)
- A `ForkJoinPool` is instantiated thus:

```
numberOfCores = Runtime.getRunTime( ).availableProcessors( );
ForkJoinPool pool = new ForkJoinPool( numberOfCores );
```

- Pool size is changed automatically at any time giving enough active threads.
- Unlike `ExecutorService`, `ForkJoinPool` needn't be explicitly shutdown.
- There are 3 ways to submit tasks to a `ForkJoinPool`
  - `execute()` : asynchronous execution
  - `invoke()` : synchronous execution - wait for the result
  - `invoke()` : asynchronous execution - returns a Future object that can be used to check the status of the execution and obtain the results.

`ForkJoin` Framework (/3)

- Thus, `ForkJoinPool` facilitates tasks to split work up into smaller tasks
- These smaller tasks are then submitted to the `ForkJoinPool` too.
- This aspect differentiates `ForkJoinPool` from `ExecutorService`
- Task only splits itself up into subtasks if work it was given is large enough for this to make sense.
- Reason for this is the overhead to splitting up a task into subtasks.
- So for small tasks this may be greater than speedup from executing subtasks concurrently.



Fork Join

ForkJoin Framework (/4)

- Submitting tasks to a `ForkJoinPool` is like submitting tasks to an `ExecutorService`.
- Can submit two types of tasks.
  - A task that does not return any result (aka an "action"), and
  - One which does return a result (a "task").
- These two types of tasks are represented by `RecursiveAction` and `RecursiveTask` classes, respectively.
- To use a `ForkJoinPool` to return a result:
  1. first create a subclass of `RecursiveTask<V>` for some type `V`
  2. In the subclass, override the `compute()` method.
  3. Then you call the `invoke()` method on the `ForkJoinPool` passing an object of type `RecursiveTask<V>`
- The use of tasks and how to submit them is summarised in the following example.

Example 9: Returning a Result from a ForkJoinPool

```
import java.util.concurrent.ForkJoinPool;
import java.util.concurrent.RecursiveTask;

class Globals {
    static ForkJoinPool fjPool = new
ForkJoinPool();
}

//This is how you return a result from fjpool
class Sum extends RecursiveTask<Long> {
static final int SEQ_LIMIT = 5000;

    int low;
    int high;
    int[] array;

    Sum(int[] arr, int lo, int hi) {
        array = arr;
        low   = lo;
        high  = hi;
    }
```

```
      protected Long compute() {
    // override the compute() method
        if(high - low <= SEQ_LIMIT) {
            long sum = 0;
            for(int i=low; i < high; ++i)
                sum += array[i];
            return sum;
        } else {
            int mid = low + (high - low) / 2;
            Sum left  = new Sum(array, low, mid);
            Sum right = new Sum(array,mid, high);
            left.fork();
            long rightAns = right.compute();
            long leftAns  = left.join();
            return leftAns + rightAns;
        }
     }

     static long sumArray(int[] array) {
         return Globals.fjPool.invoke(new
                     Sum(array,0,array.length));
     }
}
```

- This example sums all the elements of an array, using parallelism to potentially process different 5000-element segments in parallel.

Example 9: Returning a Result from a `ForkJoinPool` (/2)

- `Sum` object gets an array & its range; `compute` sums elements in range.
  - If range has < `SEQ_LIMIT` elements, use a simple for-loop
  - Else, create two `Sum` objects for problems of half the size.
- Uses `fork` to compute left half in parallel to computing the right half, which this object does itself by calling `right.compute()`.
- To get the answer for the left, it calls `left.join()`.
- Create more `Sum` objects than available processors as it's framework's job to do a number of parallel tasks efficiently
- But also to schedule them well - having lots of fairly small parallel tasks can do a better job.
- Especially true if number of processors available varies during execution (e.g., due to OS is also running other programs)
- Or maybe, despite load balancing, tasks end up taking different time.

Concurrent Annotations

- Annotations were added as part of Java 5.
- Java comes with some predefined annotations (e.g. `@override`), but custom annotations are also possible (e.g. `@GuardedBy`).
- Many frameworks and libraries make good use of custom annotations. JAX-RS, for instance, uses them to turn POJOs into WS resources.
- Annotations are processed at compile time or at runtime (or both).
- Good programming practice to use annotations to document code
- Here is an Example:

```
public class BankAccount {
  private Object credential = new Object();
  @GuardedBy("credential") // amount guarded by credential because
  private int amount; // access only if synch lock on credential held
}
```

- Will revisit annotations again later with Web Services.

Lecture Summary

- Concurrency support in Java has developed greatly since early versions:
  - Native `semaphore` class
  - Extra functionality in explicit `Lock/Condition` objects
- Perhaps in terms of large-scale thread have there been greatest strides since the `runnable` interface
- `Interface Executor` provides many different support mechanisms for threads:
  - For allocation of threads to different cores on a multicore machine
  - For returning future results from an asynchronous task
  - For pre-empting/work-stealing using `ForkJoin`
  - Annotations have many applications. E.g., JAX-WS uses annoted POJOs for generating WS resources