JSR-166: Concurrency Utilities

- The java.util.concurrent package aims to do for concurrency what java.util.Collections did for data structures. It makes
  - Some problems go away
  - Some problems trivial to solve by everyone
  - Some problems easier to solve by concurrent programmers
  - Some problems possible to solve by experts

Whenever you are about to use...

```
Object.wait, notify, notifyAll,
synchronized,
new Thread();
```

Check first if there is a class that ...

- automates what you are trying to do, or
- would be a simpler starting point for your own solution

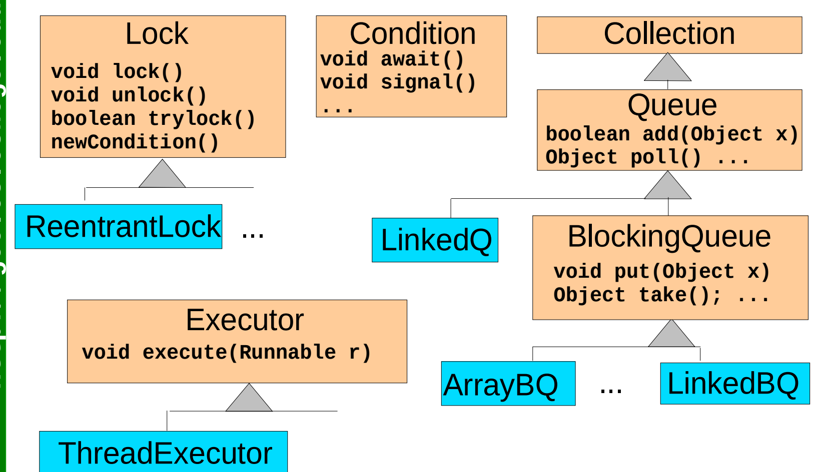
Present and Future

- JSR-166 is based on over 3 years experience with `EDU.oswego.cs.dl.util.concurrent`
- Many refactorings and functionality improvements
- Additional native/JVM support
  - Timing, atomics, built-in monitor extensions
- A preliminary release of JSR-166 APIs, implementations, and JVM enhancements will be available soon

JSR-166 Components

- Executors, Thread pools, and Futures
- Queues and blocking queues
- Timing
- Locks and Conditions
- Synchronizers: Semaphores, Barriers, etc
- Atomic variables
- Miscellany

Main Interfaces



Executors

- Standardize asynchronous invocation
  - use `anExecutor.execute(aRunnable)`
  - not `new Thread(aRunnable).start()`
- Two styles supported:
  - Actions: `Runnables`
  - Functions (indirectly): `Callables`
  - Also cancellation and shutdown support
- Most access via `Executors` utility class
  - Configures very flexible `ThreadExecutor`
  - Also `ScheduledExecutor` for time-delayed tasks

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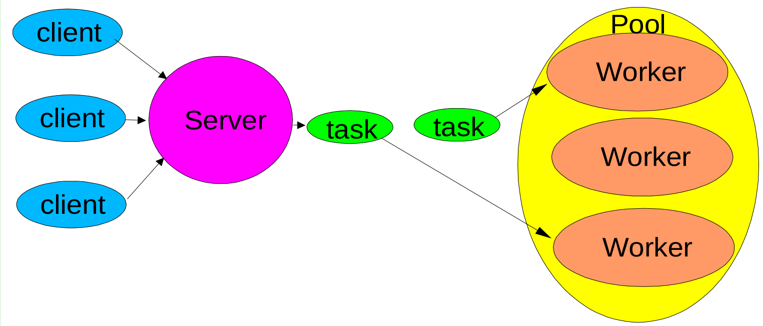
Thread Pools in Service Designs



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Thread Pool Example

```
class WebService {
  public static void main(String[] args) {
    Executor pool =
      Executors.newFixedThreadPool(7);
    ServerSocket socket = new ServerSocket(999);

    for (;;) {
      final Socket connection = socket.accept();
      pool.execute(new Runnable() {
        public void run() {
          new Handler().process(connection);
      }});
    }
  }
}

class Handler { void process(Socket s); }
```

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Thread Pools

- `ThreadExecutors` can vary in:
  - The kind of task queue
  - Maximum and minimum number of threads
  - Shutdown policy
    - Immediate, wait for current tasks
  - Keep-alive interval until idle threads die
    - To be later replaced by new ones if necessary
  - Before/after methods around tasks
- Factory methods package some common settings
  - `newSingleThreadExecutor()`
  - `newFixedThreadPool(int nthreads)`
  - `newCachedThreadPool()`
    - Reuses threads when available, else constructs

Futures and Callables

- `Callable` is functional analog of `Runnable`

```
interface Callable<V> {
  V call() throws Exception;
}
```

  – Normally implement with an inner class that supplies arguments to the function
- `Future` holds result of asynchronous call, normally to a `Callable`

```
interface Future<V> {
  V get() throws InterruptedException,
                 ExecutionException;
  // plus timeout versions and misc
}
```


Futures Example

```
class ImageRenderer { Image render(byte[] raw); }
class App { // ...
  Executor executor = ...;        // any executor
  ImageRenderer renderer = new ImageRenderer();

  public void display(final byte[] rawimage) {
    try {
      Future<Image> image = Executors.invoke(executor,
        new Callable<Image>(){
          public Image call() {
            return renderer.render(rawImage);
      }});
      drawBorders(); // do other things ...
      drawCaption(); // ... while executing

      drawImage(image.get()); // use future
    }
    catch (Exception ex) {
      cleanup();
      return;
    }
} }
```


Queues

- `Queue` interface added to `java.util`

```
interface Queue<E> extends Collection<E>{
  boolean add(E x);
  E poll();
  E remove() throws NoSuchElem...;
  E peek();
  E element() throws NoSuchEle..;
}
```

  – Retrofit (non-thread-safe) `java.util.LinkedList` to implement
  – Add (non-thread-safe) `java.util.PriorityQueue`
  – Fast thread-safe non-blocking `java.util.concurrent.LinkedQueue`

Blocking Queues

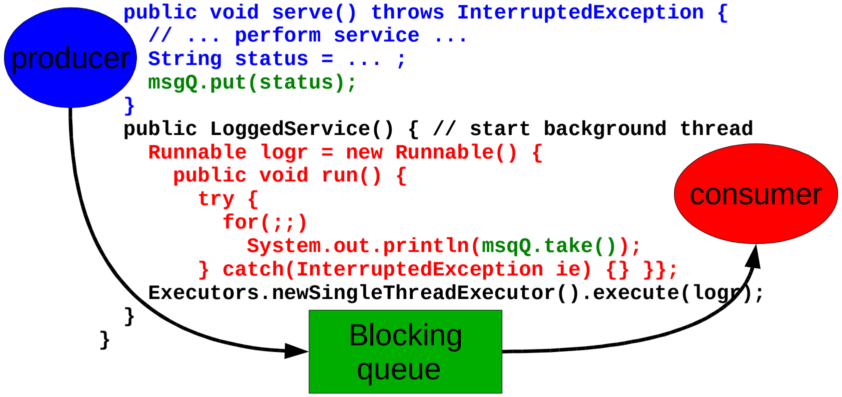
```
interface BlockingQueue<E> extends Queue<E> {
  void put(E x) throws IE;
  boolean offer(E x, long time,TimeUnit unit)
                throws InterruptedException;

  E take() throws InterruptedException;
  E poll(long timeout, TimeUnit unit)
                throwsInterruptedException;
}
```

  – Common in producer-consumer designs
- Some first-rate implementations
  - `LinkedBlockingQueue`, `PriorityBlockingQueue`, `ArrayBlockingQueue`, and `SynchronousQueue`

Blocking Queue Example

```
class LoggedService { // ...
  final BlockingQueue<String> msgQ =
    new LinkedBlockingQueue<String>();
  public void serve() throws InterruptedException {
    // ... perform service ...
    String status = ... ;
    msgQ.put(status);
  }
  public LoggedService() { // start background thread
    Runnable logr = new Runnable() {
      public void run() {
        try {
          for(;;)
            System.out.println(msgQ.take());
        } catch(InterruptedException ie) {} }};
    Executors.newSingleThreadExecutor().execute(logr);
  }
}
```



TimeUnits

- Standardize time usage across APIs, without forcing use of inappropriate units
  - SECONDS, MILLISECONDS, MICROSECONDS, NANOSECONDS

    `x = queue.poll(3, TimeUnit.SECONDS)`
  - TimeUnit class also supplies conversions and other time-based utilities
- Provides high resolution timing support
  - `static long nanoTime()`
  - Value is *unrelated* to `java.util.Date`, `System.currentTimeMillis` etc

Locks

- Flexibility at expense of verbosity

```
lock.lock();
try {
  action();
}
finally {
  lock.unlock();
}
```

- Overcomes limitations of `synchronized`
  - Doesn't force block structured locking/unlocking
  - Allow interruptible lock acquisition and "try lock"
  - Can define customized implementations

Lock API

```
interface Lock {
  void lock();
  void lockInterruptibly() throws IE;
  boolean trylock();
  boolean trylock(long timeout,
                  TimeUnit unit)throws IE;
  void unlock();
  Condition newCondition();
}
```

- Concrete `ReentrantLock` implementation
  - Fast, scalable with synchronized block semantics, and additional query methods
  - Also `FairReentrantLock` subclass with slower but more predictable first-in-first-out arbitration

Lock Example

```
class ParticleUsingLock {
  private int x, y;
  private final Random rng = new Random();
  private final Lock lock = new ReentrantLock();

  public void move() throws InterruptedException {
    lock.lockInterruptibly(); // allow cancellation
    try {
      x += rng.nextInt(3) - 1;
      y += rng.nextInt(3) – 1;
    }
    finally { lock.unlock(); }
  }
  public void draw(Graphics g) {
    int lx, ly;
    lock.lock(); // no interrupts – AWT Event Thread
    try {
      lx = x; ly = y;
    }
    finally { lock.unlock(); }
    g.drawRect(lx, ly, 10, 10);
  }  } }
```

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Read-Write Locks

```
interface ReadWriteLock {
  Lock readLock();
  Lock writeLock();
}
```

- A pair of locks for enforcing multiple-reader, single-writer access
  - Each used in the same way as ordinary locks
- Concrete `ReentrantReadWriteLock`
  - Almost always the best choice for apps
  - Each lock acts like a reentrant lock
  - Write lock can "downgrade" to read lock (not vice-versa)

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Conditions

```
interface Condition {
  void await() throws IE;
  void awaitUninterruptibly();
  long awaitNanos(long nanos) throws IE;
  boolean awaitUntil(Date deadline) throws IE;
  void signal();
  void signalAll();
}
```

- Allows more than one wait condition per object
  - Even for built-in locks, via `Locks` utility class
- Allows much simpler implementation of some classic concurrent designs

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Bounded Buffers using Conditions

```
class BoundedBuffer {
  Lock lock = new ReentrantLock();
  Condition notFull  = lock.newCondition();
  Condition notEmpty = lock.newCondition();
  Object[] items = new Object[100];
  int putptr, takeptr, count;
  public void put(Object x)throws IE {
    lock.lock(); try {
      while (count == items.length)notFull.await();
      items[putptr] = x;
      if (++putptr == items.length) putptr = 0;
      ++count;
      notEmpty.signal();
    } finally { lock.unlock(); }
  }
  public Object take() throws IE {
    lock.lock(); try {
      while (count == 0) notEmpty.await();
      Object x = items[takeptr];
      if (++takeptr == items.length) takeptr = 0;
      --count;
      notFull.signal();
      return x;
    } finally { lock.unlock(); }
} }
```

Synchronizers

- A small collection of small classes that:
  - Provide good solutions to common special-purpose synchronization problems
  - Provide better ways of thinking about designs
    - But worse ways when they don't naturally apply!
  - Can be tricky or tedious to write yourself
- `Semaphore`, `FairSemaphore`
- `CountDownLatch`
- `CyclicBarrier`
- `Exchanger`

Semaphores

- Semaphores can be seen as permit holders
  - Create with initial number of permits
  - `acquire` takes a permit, waiting if necessary
  - `release` adds a permit
  - But no actual permits change hands.
    - Semaphore just maintains the current count.
- Can use for both "locking" and "synchronizing"
  - With initial permits=1, can serve as a lock
  - Useful in buffers, resource controllers
  - Use in designs prone to missed signals
    - Semaphores "remember" past signals

Semaphores in Resource Pools

```
class ResourcePool {
  FairSemaphore available =
    new FairSemaphore(N);
  Object[] items = ... ;

  public Object getItem() throws IE {
    available.acquire();
    return nextAvailable();
  }

  public void returnItem(Object x) {
    if (unmark(x))
      available.release();
  }
  synchronized Object nextAvailable();
  synchronized boolean unmark(Object x);
}
```


CountDownLatch Example

```
class Driver { // ...
  void main(int N) throws InterruptedException {
    final CountDownLatch startSignal = new CountDownLatch(1);
    final CountDownLatch doneSignal = new CountDownLatch(N);

    for (int i = 0; i < N; ++i) // Make threads
      new Thread() {
        public void run() {
          try {
            startSignal.wait();
            doWork();
            doneSignal.countDown();
          }
          catch(InterruptedException ie) {}
        }}.start();

    initialize();
    startSignal.countDown();  // Let all threads proceed
    doSomethingElse();
    doneSignal.await();       // Wait for all to complete
    cleanup();
  }
}
```

CyclicBarrier Example

```
class Solver { // Code sketch
  void solve(final Problem p, int nThreads) {

    final CyclicBarrier barrier = new CyclicBarrier(nThreads,
      new Runnable() {
        public void run() { p.checkConvergence(); }}
    );

    for (int i = 0; i < nThreads; ++i) {
      final int id = i;
      Runnable worker = new Runnable() {
        final Segment segment = p.createSegment(id);
        public void run() {
          try {
            while (!p.converged()) {
              segment.update();
              barrier.await();
            }
          }
          catch(Exception e) { return; }
        }
      };
      new Thread(worker).start();
   }
}
```


Exchanger Example

```
class FillAndEmpty {
  Exchanger ex = new Exchanger();
  Buffer initialEmptyBuffer = ... // a made-up type
  Buffer initialFullBuffer = ...;

  class FillingLoop implements Runnable {
    public void run() {
      Buffer b = initialEmptyBuffer;
      try {
        while (b != null) {
          addToBuffer(b);
          if (b.full()) b = (Buffer)(ex.exchange(b));
        } } catch(...) ... }
  }

  class EmptyingLoop implements Runnable {
    public void run() {
      Buffer b = initialFullBuffer;
      try {
        while (b != null) {
          takeFromBuffer(b);
          if (b.empty()) b = (Buffer)(ex.exchange(b));
        } } catch(...) ... }
    }
```


Atomics

- `j.u.c.atomic` contains classes representing scalars supporting "CAS"

  `boolean compareAndSet(expectedV, newV)`

  - Atomically set to `newV` if holding `expectedV`
  - Always used in a loop
- Essential for writing efficient code on MPs
  - Nonblocking data structures, optimistic algorithms, reducing overhead and contention when updates center on a single field
- JVMs use best construct available on platform
  - Compare-and-swap, Load-linked/Store-conditional, Locks
- j.u.c.a also supplies reflection-based classes that allow CAS on given volatile fields of other classes

Atomic Variable Example

```
class Random {       // snippets
  private AtomicLong seed;
  Random(long s) {
    seed = new AtomicLong(s); }
  long next(){
    for(;;) {
      long s = seed.get();
      long nexts = s * ... + ...;
      if (seed.compareAndSet(s,nexts))
        return s;
    }
  }
}
```

- Faster and less contention in programs with a single `Random` accessed by many threads

Optimistic Linked Lists

```
class OptimisticLinkedList {     // incomplete
  static class Node {
    volatile Object item;
    final AtomicReference<Node> next;
    Node(Object x, Node n) {
      item = x; next = new AtomicReference(n); }
  }
  final AtomicReference head = new AtomicReference(null);

  public void prepend(Object x) {
    if (x == null) throw new IllegalArgumentException();
    for(;;) {
       Node h = head.get();
       if (head.compareAndSet(h, new Node(x, h))) return;
    }
  }
  public boolean search(Object x) {
    Node p = head.get();
    while (p != null && x != null && !p.item.equals(x))
      p = p.next.get();
    return p != null && x != null;
  }
}                  // remove(x) is much harder!
```

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Other JSR-166 Features

- Customizable per-Thread `UncaughtExceptionHandlers`
- Concurrent Collection implementations
  - `ConcurrentHashMap`, `CopyOnWriteArrayList`
  - Improvements to existing thread-safe collections in part based on JSR-133 Memory Model rules
- `ThreadLocal.remove`
  - Helps avoid resource exhaustion

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JSR-133: Fixing the Memory Model

- A memory model specifies how threads and objects interact
  - Atomicity
    - Locking to obtain mutual exclusion for field updates
  - Visibility
    - Ensuring that changes made in one thread are seen in other threads
  - Ordering
    - Ensuring that you aren't surprised by the order in which statements are executed
- Original JLS spec was broken and impossible to understand
  - Included unwanted constraints on compilers and JVMs, omissions, inconsistencies
- JSR-133 still officially "in progress" but Sun JDKs conform to main rules as of 1.4.0
  - The basic rules are easy. The more formal spec is not.

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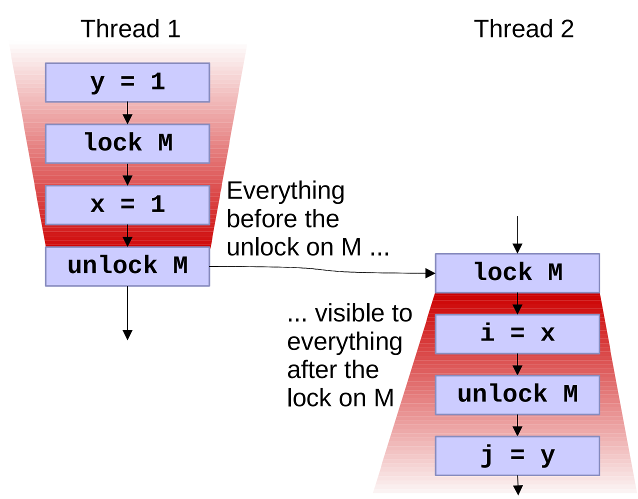
JSR-133 Main Rule



Additional JSR-133 Rules

- Variants of lock rule apply to volatile fields and thread control
  - Writing a volatile has same basic memory effects as unlock
  - Reading a volatile has same basic memory effects as lock
  - Similarly for thread start and termination
  - Details differ from locks in minor ways
- Final fields
  - All threads will read the final value so long as it is guaranteed to be assigned before the object could be made visible to other threads. So DON'T write:

```
class Stupid implements Runnable {
  final int id;
  Stupid(int i) { new Thread(this).start(); id = i; }
  public void run() { System.out.println(id); }
}
```

- Extremely weak rules for unsynchronized, non-volatile, non-final reads and writes
  - type-safe, not-out-of-thin-air, but can be reordered, invisible