# Parallel Computing

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# Shared memory: Java threads

# Introduction

- Java provides built-in multithreading
  - Low level primitives:
    - Class Thread / Interface Runnable
  - High level framework:
    - Java Concurrency Utilities

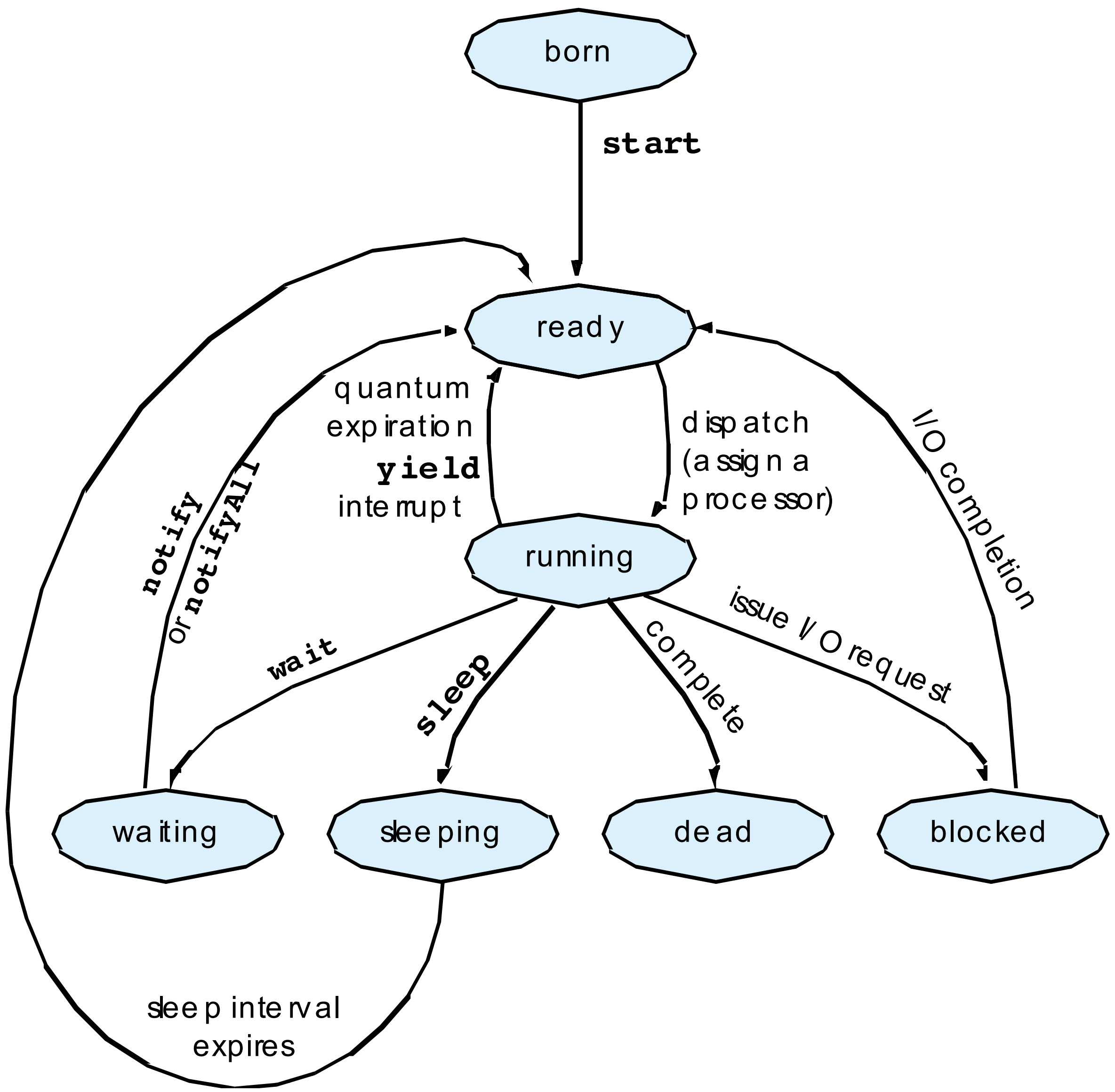
# Low level primitives

# Class Thread

- Class Thread constructors
  `public Thread( String threadName )`
  `public Thread()`
- Code for thread in thread's `run` method
- Method `sleep` makes thread inactive
- Method `yield` hints the scheduler that the thread is willing to yield its current use of processor
- Method `interrupt` interrupts a running thread
- Method `isAlive` checks status of a thread
- Method `setName` sets a thread's name
- Method `join` waits for thread to finish and continues from current thread

# Thread states

- Born state
  - Thread was just created
- Ready state
  - Thread's start method invoked
  - Thread can now execute
- Running state
  - Thread is assigned a processor and running
- Dead state
  - Thread has completed or exited
  - Eventually disposed of by system



# Hello world

```
public class ThreadHelloWorld {

    public static void main(String[] args) throws
                                            InterruptedException {
        Thread myThread = new Thread() {
            public void run() {
                System.out.println("Hello from new thread");
            }
        };

        myThread.start();
        Thread.yield(); // gives the thread a chance to run first
        System.out.println("Hello from main thread");
        myThread.join();
    }
}
```

The order of the output will change…
Remind: make no assumptions regarding execution order

# Thread synchronization

- Java uses monitors for thread synchronization
- The `synchronized` keyword uses the lock that is built into every Java `Object`
  - Every synchronized method of an object has a monitor
    - we can synchronize any statement acquiring the lock on an object
  - One thread inside a synchronized method at a time
  - All other threads block until method finishes
  - Next highest priority thread runs when method finishes

# Thread synchronization

```
public synchronized void method() {
   // statements
}
```

- is syntactic sugar for

```
public void method() {
   synchronized(this) {
      // statements
   }
}
```

synchronizing statements allows a finer granularity in parallelism

# Sync example

```
public class RaceCondition {
  public static void main(String[] args)
throws InterruptedException {
     class Counter {
        private int count = 0;

        public void increment() {
                ++count;
        }

        public int getCount() {
                return count;
        }
     }
     final Counter counter = new Counter();

     class CountingThread extends Thread {
        public void run() {
          for (int x = 0; x < 10000; ++x)
              counter.increment();
          }
     }
```

```
class ReadingThread extends Thread {
    public void run() {

System.out.println(counter.getCount());
    }
}

  CountingThread t1 = new CountingThread();
  CountingThread t2 = new CountingThread();
  ReadingThread t3 = new ReadingThread();
  t1.start();
  t2.start();
  t3.start();
  t1.join();
  t2.join();
  t3.join();

System.out.println(counter.getCount());
  }
}
```

# Sync example

```
public class RaceCondition {
  public static void main(String[] args)
throws InterruptedException {
     class Counter {
        private int count = 0;

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

        public synchronized int getCount() {
                return count;
        }
     }
     final Counter counter = new Counter();

     class CountingThread extends Thread {
        public void run() {
          for (int x = 0; x < 10000; ++x)
              counter.increment();
          }
     }
```

```
class ReadingThread extends Thread {
    public void run() {

System.out.println(counter.getCount());
    }
}

  CountingThread t1 = new CountingThread();
  CountingThread t2 = new CountingThread();
  ReadingThread t3 = new ReadingThread();
  t1.start();
  t2.start();
  t3.start();
  t1.join();
  t2.join();
  t3.join();

System.out.println(counter.getCount());
  }
}
```

# Sync using objects

```
class Chopstick {
     private int id;
     public Chopstick(int id) { this.id =
id; }
  public int getId() { return id; }
}
```

```
import java.util.Random;
class Philosopher extends Thread {
  private Chopstick first, second;
  private Random random;
  private int thinkCount;

  public Philosopher(Chopstick left, Chopstick right) {
    if(left.getId() < right.getId()) {
      first = left; second = right;
    } else {
      first = right; second = left;
    }
    random = new Random();
  }
 public void run() {
    try {
      while(true) {
        ++thinkCount;
        if (thinkCount % 10 == 0)
          System.out.println("Philosopher " + this + " has thought " + thinkCount + " times");
        Thread.sleep(random.nextInt(1000));     // Think for a while
        synchronized(first) {                   // Grab first chopstick
          synchronized(second) {                // Grab second chopstick
            Thread.sleep(random.nextInt(1000)); // Eat for a while
          }
        }
      }
    } catch(InterruptedException e) {}
  }
}
```

The objects act as mutexes

# Sync using objects

```
class Chopstick {
     private int id;
     public Chopstick(int id) { this.id =
id; }
  public int getId() { return id; }
}
```

```
import java.util.Random;
class Philosopher extends Thread {
  private Chopstick first, second;
  private Random random;
  private int thinkCount;

  public Philosopher(Chopstick left, Chopstick right) {
    if(left.getId() < right.getId()) {
```

```
public static void main(String[] args) throws InterruptedException {
    Philosopher[] philosophers = new Philosopher[5];
    Chopstick[] chopsticks = new Chopstick[5];

    for (int i = 0; i < 5; ++i)
      chopsticks[i] = new Chopstick(i);
    for (int i = 0; i < 5; ++i) {
      philosophers[i] = new Philosopher(chopsticks[i], chopsticks[(i + 1) % 5]);
      philosophers[i].start();
    }
    for (int i = 0; i < 5; ++i)
      philosophers[i].join();
  }
```

```
thinkCount + " times");
          synchronized(first) {                    // Grab first chopstick
            synchronized(second) {                 // Grab second chopstick
              Thread.sleep(random.nextInt(1000)); // Eat for a while
            }
          }
        }
      } catch(InterruptedException e) {}
    }
  }
```

The objects act as mutexes

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# Sync using objects

```
class Chopstick {
     private int id;
     public Chopstick(int id) { this.id = 
id; }
  public int getId() { return id; }
}
```

```
import java.util.Random;
class Philosopher extends Thread {
  private Chopstick first, second;
  private Random random;
  private int thinkCount;

  public Philosopher(Chopstick left, Chopstick right) {
    if(left.getId() < right.getId()) {
```

```
public static void main(String[] args) throws InterruptedException {
    Philosopher[] philosophers = new Philosopher[5];
    Chopstick[] chopsticks = new Chopstick[5];

    for (int i = 0; i < 5; ++i)
      chopsticks[i] = new Chopstick(i);
    for (int i = 0; i < 5; ++i) {
      philosophers[i] = new Philosopher(chopsticks[i], chopsticks[(i + 1) % 5]);
      philosophers[i].start();
    }
    for (int i = 0; i < 5; ++i)
      philosophers[i].join();
  }
```

```
thinkCount + " times");
        synchronized(first) {              // Grab first chopstick
          synchronized(second) {           // Grab second chopstick
```

The objects act as mutexes

This is the solution provided by Dijkstra: relative ordering of resources and ordered acquisition

```
          }
        }
      } catch(InterruptedException e) {}
    }
  }
```

# Alien methods

- A synchronized method should not call a method it knows nothing about - an **alien method** - since it may acquire a second lock without respecting the correct order, thus risking deadlock.
- Solution: reduce synchronization to statements and do not call the alien method in that synchronized section.

# Alien method example

```
class Downloader extends Thread {

  private InputStream in;
  private OutputStream out;
  private ArrayList<ProgressListener>
listeners;

  public Downloader(URL url, String
outputFilename) throws IOException {
    in =
url.openConnection().getInputStream();
    out = new
FileOutputStream(outputFilename);
    listeners = new
ArrayList<ProgressListener>();

  }

  public synchronized void
addListener(ProgressListener listener) {
   listeners.add(listener);
 }

  public synchronized void
removeListener(ProgressListener listener)
{
   listeners.remove(listener);
 }

  private synchronized void
updateProgress(int n) {
   for (ProgressListener listener:
listeners)
     listener.onProgress(n);
 }

  public void run() {
   int n = 0, total = 0;
   byte[] buffer = new byte[1024];
   try {
     while((n = in.read(buffer)) != -1) {
       out.write(buffer, 0, n);
       total += n;
       updateProgress(total);
     }
     out.flush();
   } catch (IOException e) { }
 }
}
```

# Alien method example

```
class Downloader extends Thread {

  private InputStream in;
  private OutputStream out;
  private ArrayList<ProgressListener>
listeners;

  public Downloader(URL url, String
outputFilename) throws IOException {
    in =
url.openConnection().getInputStream();
    out = new
FileOutputStream(outp
    listeners = new
ArrayList<ProgressListener>();

  }

  public synchronized void
addListener(ProgressListener listener) {
   listeners.add(listener);
 }
```

```
  public synchronized void
removeListener(ProgressListener listener)
{
   listeners.remove(listener);
 }

  private synchronized void
updateProgress(int n) {
   for (ProgressListener listener:
listeners)
     listener.onProgress(n);
 }
```

The methods of the Subject are synchronized but the notification method class an alien method in the observer

```
   try {
     while((n = in.read(buffer)) != -1) {
       out.write(buffer, 0, n);
       total += n;
       updateProgress(total);
     }
     out.flush();
   } catch (IOException e) { }
 }
}
```

# Alien method example

```
class Downloader extends Thread {

  private InputStream in;
  private OutputStream out;
  private ArrayList<ProgressListener>
```

```
  }
```

```
  public synchronized void
removeListener(ProgressListener listener)
{
    listeners.remove(listener);
 }

  private synchronized void
```

```
   } catch (IOException e) { }
 }
}
```

**Solution**

```
private void updateProgress(int n) {
    ArrayList<ProgressListener> listenersCopy;
    synchronized(this) {
      listenersCopy = (ArrayList<ProgressListener>)listeners.clone();
    }
    for (ProgressListener listener: listenersCopy)
      listener.onProgress(n);
  }
```

# wait/notify

- The Object class provides other means to synchronize threads, acting as monitors of a queue whose access is controlled by wait/notify methods:
- `public final void wait() throws InterruptedException`
- `public final void wait(long timeout, int nanos) throws InterruptedException`
  - Causes the current thread to wait until another thread invokes the `notify()` method or the `notifyAll()`
  - The current thread must own this object's monitor. The thread releases ownership of this monitor
- `public final void notify()`
- `public final void notifyAll()`
  - Wakes up a single thread that is waiting on this object's monitor / wake up all threads waiting.
  - The awakened thread will not be able to proceed until the current thread relinquishes the lock on this object.

# wait/notify

- A thread can call wait() on an object that has locked:
  - the lock is released
  - the thread goes into waiting state
- Other threads may obtain that released lock, then they perform the required operations and call:
  - notify() to awaken a waiting thread
  - notifyAll() to awaken all the threads waiting the object
  - The awakened threads have to acquire the lock
  - notifications are not cumulated

# wait/notify

- A thread can call wait() on an object that has locked:

**Producer**

```
synchronized void put() {
   while buffer=full
      wait()
   Put in buffer
   notify()
}
```

**Consumer**

```
synchronized void get() {
   while buffer=empty
      wait()
   Get from buffer
   notify()
}
```

- The awakened threads have to acquire the lock
- notifications are not cumulated

# wait/notify example

```
public class Monitor {
    private boolean full = false;
    private boolean stop = false;
    private String buffer;

    synchronized void send(String msg) {
        if (full) {
            try {
                wait(); // if full wait until
                        // it becomes empty
            } catch (InterruptedException e) {
                e.printStackTrace();
            }
        }
        // if empty becomes full
        // and receive the msg
        full = true;
        notify();
        buffer = msg;
    }

    synchronized void endMessages() {
        stop = true; // no more messages
                     // from the producer
    }

    synchronized String receive() {
        if (!full) {
            try {
                wait();
            } catch (InterruptedException e) {
                e.printStackTrace();
            }
        }
        full = false;
        notify();
        return buffer;
    }

    synchronized boolean isEndCommunications()
{
        return stop & !full; // true if there
     // are no more messages to consume and
     // the producer said it was going to stop
    }
}
```

Use this monitor to communicate between threads

# High level framework

# Beyond intrinsic locks

- Locking on an object with synchronized, as with low level APIs has some limitations:
  - lock acquisition and release are only in the same method or start/end of statements
  - a thread may have to wait a long time before acquiring it
  - no timeout while waiting for the lock

# `java.util.concurrent.locks.ReentrantLock`

- It is a more powerful alternative to intrinsic lock:
  - can be created with a fairness parameter to give precedence to threads that have been waiting a long time
    - lower throughput but less variances in time to obtain locks
  - can be acquired and released in different methods
  - interruptible lock waits that support time-out
  - immediate acquisition of lock, independently of how many other threads were waiting for it

# java.util.concurrent.locks.ReentrantLock

- It is a more powerful alternative to intrinsic lock:

```
Lock lock = new ReentrantLock();
lock.lock();
try {
  // use shared resources
} finally {
  lock.unlock();
}
```

Use the finally to be sure to release the lock!

parameter to give
e been waiting a long

riances in time to obtain

n different methods

  - interruptible lock waits that support time-out
  - immediate acquisition of lock, independently of how many other threads were waiting for it

# java.util.concurrent.locks.ReentrantLock

- It is a more powerful alternative to i

```
private ReentrantLock lock;

public void foo() {
  ...
  lock.lock();
  ...
}

public void bar() {
  ...
  lock.unlock();
  ...
}
```

```
Lock lock = new ReentrantLock();
lock.lock();
try {
  // use shared resources
} finally {
  lock.unlock();
}
```

Use the finally to be sure to release the lock!

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  - interruptible lock waits that support time-out
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```
Lock lock = new ReentrantLock();
lock.lock();
try {
  // use shared resources
} finally {
  lock.unlock();
}
```

Use the finally to be sure to release the lock!

```
private ReentrantLock lock;

public void foo() {
  ...
  lock.lock();
  ...
}

public void bar() {
  ...
  lock.unlock();
  ...
}
```

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  - interruptible lock waits that support time-out

```
public boolean tryLock(long timeout, TimeUnit unit)
```

  - immediate acquisition of lock, independently of how many other threads were waiting for it

# java.util.concurrent.locks.ReentrantLock

- It is a more powerful alternative to i

```java
Lock lock = new ReentrantLock();
lock.lock();
try {
  // use shared resources
} finally {
  lock.unlock();
}
```

Use the finally to be sure to release the lock!

```java
private ReentrantLock lock;

public void foo() {
  ...
  lock.lock();
  ...
}

public void bar() {
  ...
  lock.unlock();
  ...
}
```

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  - interruptible lock waits that support time-out

```java
public boolean tryLock(long timeout, TimeUnit unit)
```

  - immediate acquisition of lock, independently of how many other threads were waiting for it

```java
public boolean tryLock()
```

# Interruptible locking

- A lock due to intrinsic locking is not interruptible (i.e. Thread interrupt method does not stop it)
  - therefore a deadlock can be stopped only by killing the JVM !
- ReentrantLock is interruptible

# Interruptible locking

```
final Object lock1 = new Object();
final Object lock2 = new Object();

Thread t1 = new Thread() { public void run() {
  try {
    synchronized(lock1) {
      Thread.sleep(1000);
        synchronized(lock2) {}
    }
  } catch (InterruptedException e) {
    System.out.println("t1 interrupted");
  }
}
```

If another thread acquires o1 and o2 in the opposite order we have a deadlock!

# Interruptible locking

```
final ReentrantLock lock1 = new ReentrantLock();
final ReentrantLock lock2 = new ReentrantLock();

Thread t1 = new Thread() {
  public void run() {
    try {
      lock1.lockInterruptibly();
      Thread.sleep(1000);
      lock2.lockInterruptibly();
    } catch (InterruptedException e {
      System.out.println("t1 interrupted");
    }
  }
};
```

a `t1.interrupt()` now stops the deadlock (if another thread acquires the two locks with a different order…)

# Interruptible locking

```
final ReentrantLock lock1 = new ReentrantLock();
final ReentrantLock lock2 = new ReentrantLock();

Thread t1 = new Thread() {
  public void run() {
    try {
      lock1.lockInterruptibly();
      Thread.sleep(1000);
      lock2.lockInterruptibly();
    } catch (InterruptedException e {
      System.out.println("t1 interrupted");
    }
  }
};
```

Note: **reentrant** is a term that indicates a block of code that can be entered by another actor before an earlier invocation has finished, without affecting the path that the first actor would have taken through the code. That is, it is possible to *re-enter* the code while it's already running and still produce correct results. E.g. some code that can be interrupted in the middle of its execution and then safely called again.

# `tryLock` and livelocks

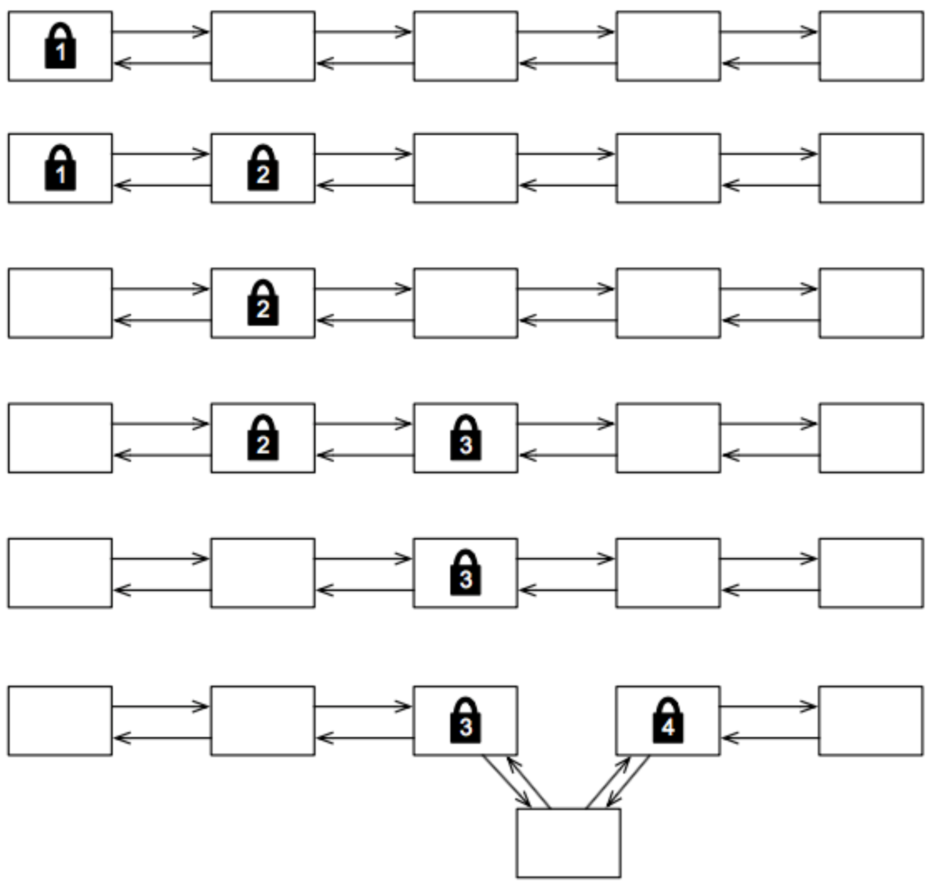
- It may be temping to use a tryLock with timeout to solve a deadlock, since there's no need to acquire resources in the required order but…
  - … we are not avoiding deadlock, just recovering from them
  - … we are risking a livelock: if multiple threads timeout at the same time they may have immediately another deadlock.
    Threads are not really progressing, unless we randomize the timeout.

# Hand-over-hand locking

- It’s a fine-grained locking, where multiple locks are used to lock the smallest possible part of a data structure that the current thread needs to operate on.
  - As we acquire new locks we unlock the older ones.
  - Can be implemented with ReentrantLock, that allows to lock/unlock whenever we need.

# Concurrent Linked List

- Locking the whole method that inserts/searches an element does not scale: access becomes too much sequential… we need fine grained lock.
- Solution: lock only the position we are examining for the insertion: hand-over-hand lock.
  - Each node needs a ReentrantLock




To insert a node, we need to lock the two nodes on either side of the point we're going to insert. We start by locking the first two nodes of the list. If this isn't the right place to insert the new node, we unlock the first node and lock the third… This continues until we find the appropriate place, insert the new node, and finally unlock the nodes on either side.

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
               return;
            }
          } finally {
        current.lock.unlock();
          }

          current = next;
          next = current.next;
        }
      } finally {
        next.lock.unlock();
      }
    }
```

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
```

Lock head of list

```
               return;
            }
         } finally {
       current.lock.unlock();
           }

           current = next;
           next = current.next;
         }
       } finally {
          next.lock.unlock();
       }
     }
```

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
                 return;
              }
            } finally {
          current.lock.unlock();
            }

            current = next;
            next = current.next;
          }
        } finally {
         next.lock.unlock();
        }
      }
```

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
```

```
             return;
          }
        } finally {
      current.lock.unlock();
        }

        current = next;
        t = current.next;
      }
    } finally {
       next.lock.unlock();
    }
  }
```

Lock next node

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
               return;
            }
          } finally {
        current.lock.unlock();
          }

          current = next;
          next = current.next;
        }
      } finally {
         next.lock.unlock();
      }
    }
```

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   cu
   N
    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
             Node node = new
Node(value, current, next);
             next.prev = node;
             current.next = node;
                 return;
              }
           } finally {
current.lock.unlock();
           }

           current = next;
           next = current.next;
         }
       } finally {
         next.lock.unlock();
       }
     }
```

If this is not the right position unlock current node and loop

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# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
                  return;
               }
             } finally {
           current.lock.unlock();
             }

             current = next;
             next = current.next;
           }
         } finally {
            next.lock.unlock();
         }
       }
```

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
```

If it is the right position the new node is added and locks are unlocked in the two finally statements

```
       try {
          if (next == tail ||
next.value < value) {
              Node node = new
Node(value, current, next);
              next.prev = node;
              current.next = node;
                 return;
              }
            } finally {
           current.lock.unlock();
            }
          }
        } finally {
           next.lock.unlock();
        }
    }
```

# Concurrent Sorted List: example

```
public void insert(int value) {
   Node current = head;
   current.lock.lock();
   Node next = current.next;

    try {
     while (true) {
       next.lock.lock();
       try {
         if (next == tail ||
next.value < value) {
           Node node = new
Node(value, current, next);
           next.prev = node;
           current.next = node;
              return;
           }
         } finally {
       current.lock.unlock();
         }

         current = next;
         next = current.next;
       }
     } finally {
       next.lock.unlock();
     }
   }
```

# Concurrent Sorted List: example

```
public int size() {
   Node current = tail;
   int count = 0;

    while (current.prev != head) {
     ReentrantLock lock = current.lock;
     lock.lock();
     try {
       ++count;
       current = current.prev;
     } finally { lock.unlock(); }
   }

    return count;
}
```

We can use this method concurrently with insertion, if working on different areas of the list.
There is no risk of deadlock: this method acquires **only 1** lock: there's no need to follow the rule that says to acquire locks in a fixed global order (i.e. Dijkstra)

# Semaphore

- java.util.concurrent.Semaphore provides counting semaphores. The number of threads that can get a permit to access a critical section is decided in the initialization.
  - initializing to one creates a binary semaphore

```
static int counter = 0;
static Semaphore semaphore = new Semaphore(1);

public static void incrementCounter() {
  try {
     semaphore.acquire();
     counter++;
     semaphore.release();
  } catch (InterruptedException ex) {
  }
}
```

# Condition variables

- To use a condition variable effectively, we need to follow a very specific pattern:

```
ReentrantLock lock = new ReentrantLock();
Condition condition = lock.newCondition();

lock.lock();
try {
    while (! condition_is_true)
        condition.await();
    // use shared resources
} finally {
    lock.unlock();
}
```

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}
```

- A condition variable is associated with a lock, and a thread must hold that lock before being able to wait on the condition.
- Once it holds the lock, it checks to see if the condition that it's interested in is already true.
- If it is, then it continues with whatever it wants to do and unlocks the lock.

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```

- If, however, the condition is not true, it calls await(), which atomically unlocks the lock and blocks on the condition variable.
- When another thread calls signal() or signalAll() to indicate that the condition might now be true, await() unblocks and automatically reacquires the lock. When await() returns, it only indicates that the condition might be true. This is why await() is called within a loop—we need to go back, recheck whether the condition is true, and potentially block on await() again if necessary.

# Atomic variables

- java.util.concurrent.atomic provides a set of types that can be accessed and modified atomically, without need of synchronization or locks.
  - we can not miss locks
  - we can not have a deadlock, since there are no locks
  - we can implement non-blocking, lock-free algorithms
  - Example:
    ```
    final AtomicInteger counter = new AtomicInteger();
    ```
    is a good substitute for the counter class that required synchronized methods

# Atomic variables

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  - Example:
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final AtomicInteger counter = new
AtomicInteger();
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    is a good substitute for the counter class that required synchronized methods

Atomic types provide methods such as set/get, compareAndSet, getAndSet

# Executors and Thread pools

- In small applications is OK to manually create and start threads, but in more complex cases it is better to encapsulate the creation in an Executor:
    - it separates thread management and creation from the rest of the application.
- Threads are created from pools of threads, avoiding the creation of an excessive number of threads, thus keeping low the overhead

# Executors

- An executor will take a runnable object and execute it:
- `e.execute(r);`
- versus
- `(new Thread(r)).start();`
- an importante difference is that the executor will likely take an already existing thread to assign the runnable object to it.
- The pool of thread may have a fixed or a dynamic size

# Executors: example

```
public class EchoServer {

  public static void main(String[] args) throws
IOException {

    class ConnectionHandler implements Runnable
{
     InputStream in; OutputStream out;
     ConnectionHandler(Socket socket) throws
IOException {
       in = socket.getInputStream();
       out = socket.getOutputStream();
     }

      public void run() {
       try {
         int n;
         byte[] buffer = new byte[1024];
         while((n = in.read(buffer)) != -1) {
           out.write(buffer, 0, n);
           out.flush();
         }
       } catch (IOException e) {}
     }
   }
```

```
    ServerSocket server = new
ServerSocket(4567);
   int threadPoolSize =
Runtime.getRuntime().availableProcessors() * 2;
   ExecutorService executor =
Executors.newFixedThreadPool(threadPoolSize);
   while (true) {
     Socket socket = server.accept();
     executor.execute(new
ConnectionHandler(socket));
   }
 }
}
```

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      Socket socket = server.accept();
      executor.execute(new
ConnectionHandler(socket));
    }
  }
```

```
    }
  }
```

The old approach would have been:

```
while (true) {
    Socket socket = server.accept();
    Thread handler = new Thread(new ConnectionHandler(socket));
    handler.start();
}
```

# Executors: example

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                  {
                  ket = server.accept();
                  xecute(new
                  er(socket));
```

**How many threads ?**

A good rule of thumb is that for computation-intensive tasks, you probably want to have approximately the same number of threads as available cores.
Larger numbers are appropriate for I/O-intensive tasks.

```
        }
      } catch (IOException e) {}
    }
}
```

# Synchronized Collections

- It is possible to transform a thread-unsafe collection (e.g. ArrayList) into a thread-safe version using wrappers like:
```
public
static <T> Collection<T> synchronizedCollection
(Collection<T> c)
```

- If all access is performed using the returned collection, then serial access through synchronized code is guaranteed.
E.g.:
```
List list =
Collections.synchronizedList(new ArrayList());
```

# Concurrent Collections

- The java.util.concurrent package includes several data structures design for concurrent access:
  - BlockingQueue defines a FIFO structure that blocks or times out when you attempt to add to a full queue, or retrieve from an empty queue.
  - ConcurrentMap is a Map with atomic operations. The standard implementation is ConcurrentHashMap, which is a concurrent analog of HashMap.
  - ConcurrentNavigableMap is a sort of ConcurrentMap that supports approximate matches. The standard implementation is ConcurrentSkipListMap, which is a concurrent analog of TreeMap.

# Copy-on-write Collections

- Copy-on-write is a strategy to manage local identical copies of some information that occasionally is modified by some task.
  Each task receives a pointer to the data and a local copy is created only when new data is written.
  Other tasks do not see the modified data.

- CopyOnWriteArrayList<E> is a thread-safe variant of ArrayList in which all mutative operations (add, set, and so on) are implemented by making a fresh copy of the underlying array.

  - There is also CopyOnWriteArraySet<E>

# Copy-on-write Collections

Reconsider the alien method example using a copy-on-write data structure:

```
private CopyOnWriteArrayList<ProgressListener> listeners;

public void addListener(ProgressListener listener) {
    listeners.add(listener);
}

public void removeListener(ProgressListener listener) {
    listeners.remove(listener);
}

private void updateProgress(int n) {
    for (ProgressListener listener: listeners)
        listener.onProgress(n);
}
```

# Producer/Consumer: example

```
class FrameExtractor implements Runnable {
  private BlockingQueue<FFMpegFrame> queue;
  private FFMpegVideo video;

  public FrameExtractor(String videoName,
                        BlockingQueue<FFMpegFrame> queue) {
    video.open(videoName);
    this.queue = queue;
  }

  public void run() {
    try {
      FFMpegFrame frame = video.getNextFrame();
      queue.put(frame);
    } catch (Exception e) {
      e.printStackTrace();
    }
  }
}
```

# Producer/Consumer: example

```
class FrameProcessor implements Runnable {
  private BlockingQueue<FFMpegFrame> queue;
  private ConcurrentMap<Integer, VisualFeature> results;
  private VisualFeatureProcessor processor = new CNNProcessor();

  public FrameProcessor(BlockingQueue<FFMpegFrame> queue, ConcurrentMap<Integer,
VisualFeatures> results) {
    this.queue = queue;
    this.results = results;
  }

  public void run() {
    try {
      while(true) {
        FFMpegFrame frame = queue.take();
        if (frame.isNull())
          break;

        VisualFeature features = processor.process(frame);
        results.put(frame.getFrameNumber(), features);
      }
    } catch (Exception e) {
        e.printStackTrace();
    }
  }
}
```

# Producer/Consumer: example

```
ArrayBlockingQueue<FFMpegFrame> queue = new
    ArrayBlockingQueue<FFMpegFrame>(100);
ConcurrentHashMap<Integer, VisualFeature> results = new
    ConcurrentHashMap<Integer, VisualFeature>();

Thread consumer = new Thread(new FrameProcessor(queue,
results));
Thread producer = new Thread(new FrameExtractor(queue));

consumer.start();
producer.start();
producer.join();
queue.put(new VideoFrame(Null)); // signal end
                                 // of processing
consumer.join();
```

1 producer and 1 consumer

# Producer/Consumer: example

```
ArrayBlockingQueue<FFMpegFrame> queue = new
    ArrayBlockingQueue<FFMpegFrame>(100);
ConcurrentHashMap<Integer, VisualFeature> results = new
    ConcurrentHashMap<Integer, VisualFeature>();

ExecutorService executor = Executors.newCachedThreadPool();
for (int i = 0; i < NUM_CONSUMERS; ++i)
  executor.execute(new FrameProcessor(queue, results));
Thread producer = new Thread(new FrameExtractor(queue));

producer.start();
producer.join();
for (int i = 0; i < NUM_CONSUMERS; ++i)
  queue.put(new VideoFrame(Null));
executor.shutdown();
executor.awaitTermination(10L, TimeUnit.MINUTES);
```

# Producer/Consumer: example

- Further speedup can be reached by changing the consumers:
  - instead of updating a shared concurrent hash map they can update a local hash map then merge the results to the global map at the end of the while(true) loop.
  - reducing access to shared variables increases parallelism…

# Books

- Parallel Programming for Multicore and Cluster Systems, Thomas Dauber and Gudula Rünger, Springer - Chapt. 6

- Principles of Parallel Programming, Calvin Lyn and Lawrence Snyder, Pearson - Chapt. 6