Lecture 27: Concurrency in Java

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Synchronized blocks

- Control access w/ synchronized blocks:
  - `synchronized(someObj){...}`
  - Must hold lock to access. Release when exit.
- Synchronized methods:
  - Implicitly use “this” as lock on method body

Shared Variables

- Variables read/written by more than one process are vulnerable to race conditions.
  - Even ++n is vulnerable, as not atomic
  - But there are “atomic” types like AtomicInteger
- If multiple threads access the same mutable state variable you have two options:
  - Make the state variable immutable
  - Use synchronization whenever accessing the state variable

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Shared Variables

- Visibility of changes:
  - If one thread executes synchronized block, and then another thread enters a block with same lock, then current values of variables accessible by first are visible to second when acquires lock
  - Without synchronization, no guarantees!
    - May reorder, may be in cache or register or …
- If synchronization not necessary, then label vble as volatile to force changes to be visible

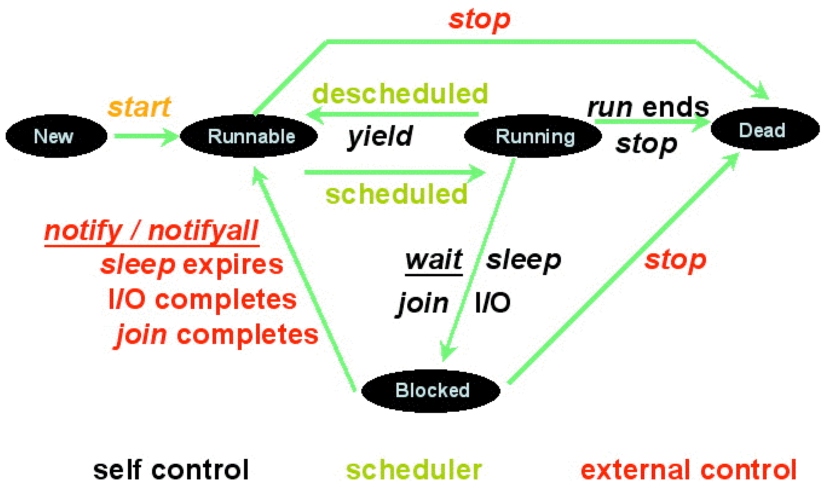
Conditional Waiting

- Every object has a wait set
- `wait()`: release lock & pause until another thread calls notify or notifyAll.
- `notify(), notifyAll()`: wake up waiting threads, which try to grab lock
  - *Can only be used in synchronized code*
  - *Notify wakes up single thread -- arbitrary choice*
  - *NotifyAll wakes up all waiting threads*
  - *Much better than busy-waiting (spin-locks)*

Thread States in Java

- New -- declared, but not yet started
- Runnable -- ready to run
- Running -- currently running
- Blocked -- on I/O, wait on monitor, sleep, join
- Dead -- run has ended

Concurrency in Java



stop

start

descheduled

run ends

New

Runnable

yield

Running

stop

Dead

scheduled

notify / notifyall

sleep expires

I/O completes

join completes

wait

sleep

join

I/O

stop

Blocked

self control **scheduler** **external control**

Monitor in Java

```
public class BoundedBuffer {
   protected int numSlots;
   private int[] buffer;
   private int takeOut = 0, putIn = 0;
   private int count=0;

   public BoundedBuffer(int numSlots) {
      if(numSlots < 0) {
         throw new IllegalArgumentException(
                                    "numSlots <= 0");
      }
      this.numSlots = numSlots;
      buffer = new int[numSlots];
   }
```

From Mitchell, hmwk 14.7

```
    public synchronized void put(int value)
                          throws InterruptedException {
       while (count == numSlots) wait();
       buffer[putIn] = value;
       putIn = (putIn + 1) % numSlots;
       count++;
       notifyAll();
    }

    public synchronized int get()
                          throws InterruptedException {
       while (count == 0) wait();
       int value = buffer[takeOut];
       takeOut = (takeOut + 1) % numSlots;
       count--;
       notifyAll();
       return value;
    }
 }
```

Java Critique

- Brinch Hansen - designer w/Hoare of Monitors hates Java concurrency!
  - Doesn't require programmer to have all methods synchronized,
  - can leave instance variables accessible w/out going through synchronized methods, it is easy to mess up access w/concurrent programs.
  - Felt that should have had a monitor class that would only allow synchronized methods.

Java Threads

- Portable since part of language
  - Easier to use than C system calls
  - Garbage collector runs in separate thread
- Difficult to combine sequential/concurrent code
  - Using sequential code in concurrent -- may not work
  - Java collection classes have synchronized wrappers!
  - Using concurrent in sequential programs bad!
    - Useless synchronization
    - 10-20% useless overhead

Rough Spots

- Fairness not guaranteed
  - Choose arbitrarily among equal priority threads
- Wait set is not FIFO queue
  - notifyAll notifies all waiting threads, not necessarily highest priority, longest-waiting, etc.
- Nested monitor problem can cause deadlock.

Nested Monitor Lockout Problem

```
class Stack {
   LinkedListlist = new LinkedList();
   public synchronized void push(Object x) {
      synchronized(list) {
         list.addLast( x ); notify();
       } }
   public synchronized Object pop() {
      synchronized(list) {
         if( list.size() <= 0 ) wait();
         return list.removeLast();
      } }
}
```

Releases lock on Stack object but not lock on list; a push from another thread will deadlock

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Java 5: util.concurrent

- Doug Lea utility classes
  - A few general purpose interfaces
  - Implementations tested over several years
- Principal interfaces & implementations
  - Sync -- protocols to acquire and release locks,
    - e.g. Semaphore w/ acquire, release methods
  - BlockingQueue -- classes to insert and delete objects
    - support put, take that block (like bounded buffer)
  - Executor -- executes Runnable tasks
    - You provide control of threads

Java 5 Concurrency Features

```
class BoundedBuffer {   <- array based queue
   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();
     try {
       while (count == items.length)
         notFull.await();
       items[putptr] = x;
       if (++putptr == items.length) putptr = 0;
       ++count;
       notEmpty.signal();
     } finally {
       lock.unlock();
     }
   }
```

Java 5 Concurrency cont.

```
public Object take() throws InterruptedException {
     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();
     }
   }
 }
```

- Advantage: Separate queues for nonEmpty and nonFull conditions on same lock.

Message Passing: Ada

Ada Tasks

- Synchronous message passing
- Tasks have some features of monitors
  - But they are active (have own thread)
- Exports entry names (w/ parameters)
- Entry names have FIFO queues

Accepting an entry

```
select
   [when <cond> =>] <select alternative>
   {or [when <cond> =>] <select alternative>}
   [else <statements>]
end select
```

```
task body Buffer is
    MaxBufferSize: constant INTEGER := 50;
    Store: array(1..MaxBufferSize) of CHARACTER;
    BufferStart: INTEGER := 1;
    BufferEnd: INTEGER := 0;
    BufferSize: INTEGER := 0;
begin
    loop
        select
            when BufferSize < MaxBufferSize =>
                accept insert(ch: in CHARACTER) do
                    Store(BufferEnd) := ch;
                end insert;
                BufferSize := BufferSize + 1;
                BufferEnd := BufferEnd mod MaxBufferSize + 1;
            or when BufferSize > 0 =>
                accept delete(ch: out CHARACTER) do
                    ch := Store(BufferStart);
                end delete;
                BufferSize := BufferSize -1;
                BufferStart := BufferStart mod MaxBufferSize + 1;
            or
                accept more (notEmpty: out BOOLEAN) do
                    notEmpty := BufferSize > 0;
                end more;
            or
                terminate;
        end select;
    end loop
end Buffer;
```

Caller only blocked in accept
but only one entry can be executed at a time

Concurrent ML

Parallellism in Functional Langs

- Extremely natural.
  - When evaluating f(exp1,exp2,exp3), why not evaluate all in parallel?
  - Experts suggest using immutable data for parallelism to avoid race conditions
  - If no side effects then order of evaluation not relevant. No race conditions!!!
- What could go wrong?