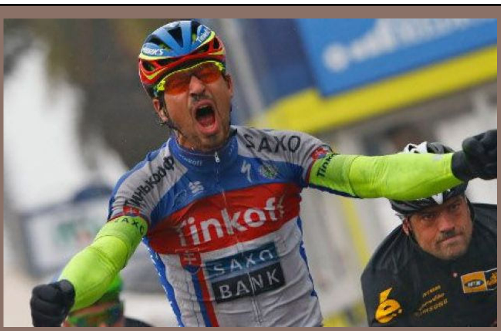

RACE CONDITIONS & SYNCHRONIZATION

Lecture 23 – CS2110 – Spring 2016

Announcements

- Recitation this week: Help on A8. Bring laptop (if you want). Ask questions. Get individual help. Ask for an explanation of some aspect for whole class.

Recap

- A "race condition" arises if two threads try to read and write the same data
- Might see the data in the middle of an update in a inconsistent stare"
  - A "race condition": correctness depends on the update racing to completion without the reader managing to glimpse the in-progress update
  - Synchronization (also known as mutual exclusion) solves this

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Java Synchronization (Locking)

```
private Stack<String> stack= new Stack<String>();

public void doSomething() {
  synchronized (stack) {
    if (stack.isEmpty()) return;
    String s= stack.pop();
  }
  //do something with s...
}
```

`synchronized` block

- Put critical operations in a `synchronized` block
- The `stack` object acts as a lock
- Only one thread can own the lock at a time

Java Synchronization (Locking)

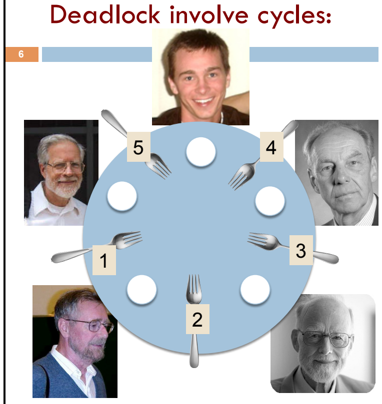
- You can lock on any object, including `this`

```
public synchronized void doSomething() {
    ...
}
```

Above is syntactic sugar for the stuff below. They mean the same thing

```
public void doSomething() {
  synchronized (this) {
    ...
  }
}
```

Deadlock involve cycles:



Simple solution to deadlock:

Acquire resources in a certain order:

Pick up smaller fork first
1. think
2. eat (2 forks)

eat is then:
- pick up smaller fork
- pick up bigger fork
- pick up food, shovel it
- put down bigger fork
- put down smallerfork

notify(), notifyAll(), wait(), wait(n)

There are times when a method in a synchronized block has to relinquish the lock and acquire it later.

Example: It needs to get an element from a set and the set is empty.

Example: It needs to add something to a set that can't hold any more; must wait until something is deleted from the set.

For these reasons, these methods are in class Object:

notify(), notifyAll(), wait(), wait(n)

About wait(), wait(n), notify(), notifyAll()

A thread that holds a lock on object OB and is executing in its synchronized code can make (at least) these calls.

1. wait(); It is put into set 2. Another thread from set 1 gets the lock.
2. wait(n); It is put into set 2 and stays there for at least n millisecs. Another thread from set 1 gets the lock.
3. notify(); Move one "possible" thread from set 2 to set 1.
4. notifyAll(); Move all "threads" from set 2 to set 1.

Two sets:

1. Runnable threads: Threads waiting to get the OB lock.

2. Waiting threads: Threads that called wait and are waiting to be notified

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Important example: bounded buffer

We illustrate these methods using an important example, which you should study and understand. **Bounded Buffer**

Example: A baker produces breads and puts them on the shelf, like a queue. Customers take them off the shelf.

- Threads A: produce loaves of bread and put them in the queue
- Threads B: consume loaves by taking them off the queue
- This is the produce/consumer model, using a bounded buffer, the shelf (which can contain at most 20 (say) loaves of bread).

producer

shelves

consumer

Array implementation of a queue of max size 6

Array b[0..5]

	0	1	2	3	4	5	b.length
b	5	3	6	2	4		

push values 5 3 6 2 4

For later purposes, we show how to implement a bounded queue —one with some maximum size— in an array.

A neat little implementation! We give you code for it on course website.

Array implementation of a queue of max size 6

Array b[0..5]   n = 6

	0	1	2	3	4	5	b.length
b	5	3	6	2	4		

push values 5 3 6 2 4

pop, pop, pop

Array implementation of a queue of max size 6

Array b[0..5]

	0	1	2	3	4	5	b.length
b	3	5		2	4	1	

Values wrap around!!

push values 5 3 6 2 4

pop, pop, pop

push value 1 3 5

Bounded buffer

```
/** Implement a bounded-size queue in an array */
public class ArrayQueue<E> {
   int[] b; // The n elements of the queue are in
   int n;   //  b[h], b[(h+1) % b.length, ... b[(h+n-1) % b.length]
   int h;   //  0 <= h < b.length

   public ArrayQueue(int n) {b= new int[n];}

   public void put(E e) { //Add e to the queue (error if full)
      b[(h+n) % b.length]= e;  n= n+1;
   }

   public int get() {  // remove head of queue and return it
      int e= b[h];       // (error if empty)
      h= (h+1) % b.length;  n= n-1;
      return e;
   }}
```

Also other methods, like isEmpty(), isFull()

Bounded Buffer

```
/** An instance maintains a bounded buffer of limited size */
class BoundedBuffer {
     ArrayQueue aq;  // bounded buffer is implemented in aq

    /**  Constructor: empty bounded buffer of max size n*/
    public BoundedBuffer(int n) {
         aq= new ArrayQueue(n);
    }
}
```

Separation of concerns:

1. How do you implement a queue in an array?
2. How do you implement a bounded buffer, which allows producers to add to it and consumers to take things from it, all in parallel?

Bounded Buffer

```
/** An instance maintains a bounded buffer of limited size */
class BoundedBuffer {
     ArrayQueue aq;  // bounded buffer is implemented in aq

    /** Put v into the bounded buffer. */
    public synchronized void produce(int v) {
      while (aq.isFull()) {this.wait()};  // Wait until not full
      aq.put(v);
      this.notifyAll();                        // Signal: not empty.
    }
}
```

Problem with the above. The wait may throw an InterruptedException. The thread was interrupted. Need a throws clause OR … (next slide)

Bounded Buffer

```
/** An instance maintains a bounded buffer of limited size */
class BoundedBuffer {
     ArrayQueue aq;  // bounded buffer is implemented in aq

    /** Put v into the bounded buffer. */
    public synchronized void produce(int v) {
      while (aq.isFull()) {
         try { wait(); }                 // wait until not full
         catch (InterruptedException e) {}
      }
      aq.put(v);
      this.notifyAll();                  // Signal: not empty
    }
}
```

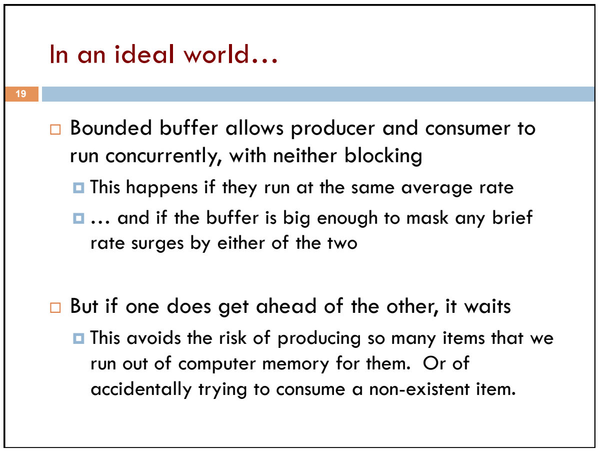
Not good solution. Good solution beyond 2110 scope. See http://www.ibm.com/developerworks/library/j-jtp05236/

Bounded Buffer

```
class BoundedBuffer {
    ArrayQueue aq;
    …

    /** Remove first element from bounded buffer and return it. */
    public synchronized int consume() {
       while (aq.isEmpty()) {
          try {wait();}                     // Wait until not empty
          catch (InterruptedException e) {}
       }
       int item= aq.get();
       this.notifyAll();                    // Signal: not full
       return item;
    }
}
```

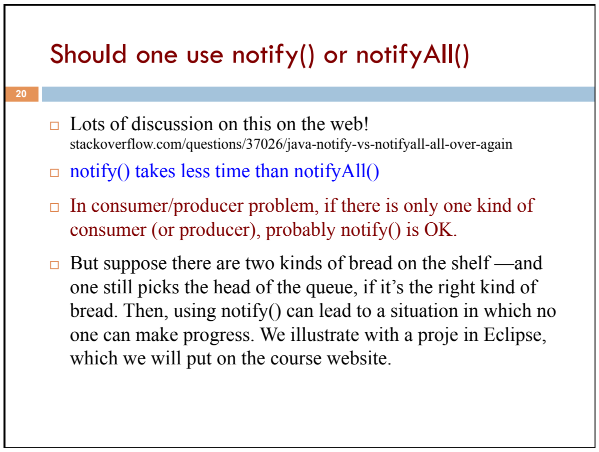
Things to notice

- Use a `while` loop because we can't predict exactly which thread will wake up "next"
- wait() waits on the same object that is used for synchronizing (in our example, **`this`**, which is this instance of the bounded buffer)
- Method `notify()` wakes up one waiting thread, `notifyAll()` wakes all of them up



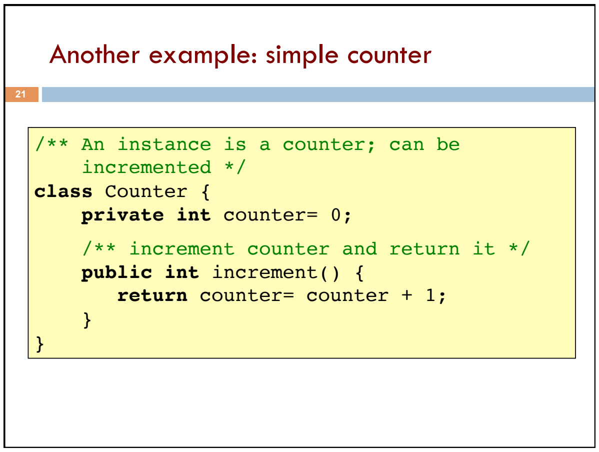
In an ideal world…

- Bounded buffer allows producer and consumer to run concurrently, with neither blocking
  - This happens if they run at the same average rate
  - … and if the buffer is big enough to mask any brief rate surges by either of the two
- But if one does get ahead of the other, it waits
  - This avoids the risk of producing so many items that we run out of computer memory for them. Or of accidentally trying to consume a non-existent item.



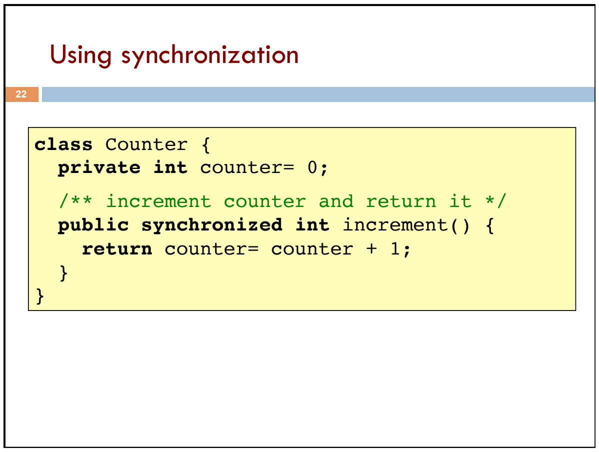
Should one use notify() or notifyAll()

- Lots of discussion on this on the web! stackoverflow.com/questions/37026/java-notify-vs-notifyall-all-over-again
- notify() takes less time than notifyAll()
- In consumer/producer problem, if there is only one kind of consumer (or producer), probably notify() is OK.
- But suppose there are two kinds of bread on the shelf —and one still picks the head of the queue, if it's the right kind of bread. Then, using notify() can lead to a situation in which no one can make progress. We illustrate with a proje in Eclipse, which we will put on the course website.



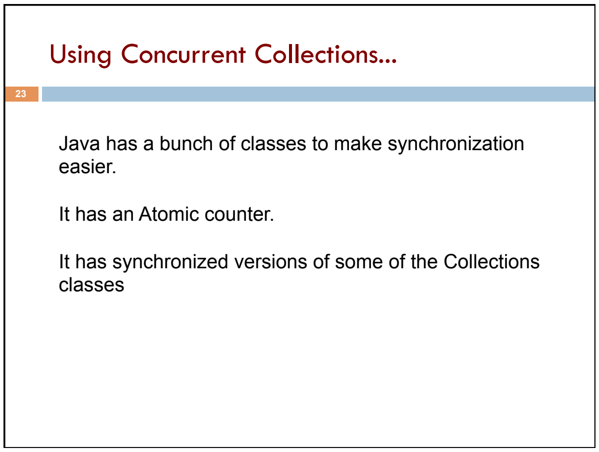
Another example: simple counter

```
/** An instance is a counter; can be
    incremented */
class Counter {
    private int counter= 0;

    /** increment counter and return it */
    public int increment() {
       return counter= counter + 1;
    }
}
```



Using synchronization

```
class Counter {
  private int counter= 0;

  /** increment counter and return it */
  public synchronized int increment() {
    return counter= counter + 1;
  }
}
```

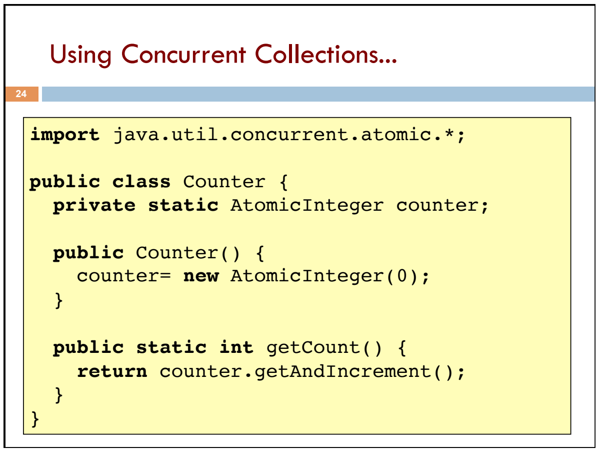


Using Concurrent Collections...

Java has a bunch of classes to make synchronization easier.

It has an Atomic counter.

It has synchronized versions of some of the Collections classes



Using Concurrent Collections...

```
import java.util.concurrent.atomic.*;

public class Counter {
  private static AtomicInteger counter;

  public Counter() {
    counter= new AtomicInteger(0);
  }

  public static int getCount() {
    return counter.getAndIncrement();
  }
}
```

Summary

Use of multiple processes and multiple threads within each process can exploit concurrency

- may be real (multicore) or virtual (an illusion)

Be careful when using threads:

- synchronize shared memory to avoid race conditions
- avoid deadlock

Even with proper locking concurrent programs can have other problems such as "livelock"

Serious treatment of concurrency is a complex topic (covered in more detail in cs3410 and cs4410)

Nice tutorial at
http://docs.oracle.com/javase/tutorial/essential/concurrency/index.html

Conference on Jay Misra's retirement

Gries was at a conference in Austin, Texas, in honor of the retirement of Jay Misra, a professor there.

Two days of 15-minute talks by well-known computer scientists (including Tony Hoare), dealing mainly with Jay's main interests:

- Concurrency
- Correctness proofs
- Programming methodology

Both theory and practice

Major in CS and you will hear more about the problems in these area. Do you PhD, and you may work in these areas and help solve the problems.