COMP 322: Fundamentals of Parallel Programming

Lecture 30: Java's synchronized statement (contd), Advanced locking in Java

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- ECE 3005 course slides from Georgia Tech
  - http://users.ece.gatech.edu/~copeland/jac/3055-05/ppt/ch07-sync-b.ppt
- A Sophomoric Introduction to Shared-Memory Parallelism and Concurrency, Lecture 6, Dan Grossman, U. Washington
  - http://www.cs.washington.edu/homes/djg/teachingMaterials/grossmanSPAC_lec6.pptx

Topics for today

- <u>Java's synchronized statement</u>

- Advanced locking in Java

Complete Bounded Buffer using Java Synchronization (Recap)

```
public class BoundedBuffer implements Buffer
{
   private static final int BUFFER SIZE = 5;
   private int count, in, out;
   private Object[] buffer;
   public BoundedBuffer() { // buffer is initially empty
               count = 0;
               in = 0;
               out = 0;
               buffer = new Object[BUFFER SIZE];
   }
   public synchronized void insert(Object item) { // See previous slides
   }
   public synchronized Object remove() { // See previous slides
   }
}
```

insert() with wait/notify Methods

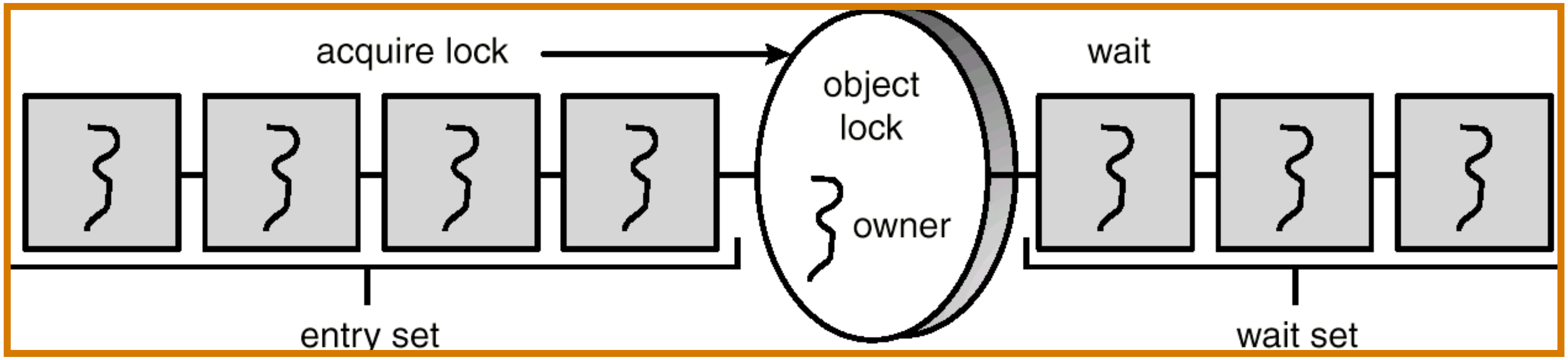
```
public synchronized void insert(Object item) {
 while (count == BUFFER SIZE) {
           try {
                 wait();
           }
           catch (InterruptedException e) { }
 }
 ++count;
 buffer[in] = item;
     in = (in + 1) % BUFFER SIZE;
     notify(); // Should we use notifyall() instead?
 }
```

remove() with wait/notify Methods

```
public synchronized Object remove() {
 Object item;
 while (count == 0) {
           try {
                 wait();
           }
           catch (InterruptedException e) { }
 }
 --count;
     item = buffer[out];
     out = (out + 1) % BUFFER SIZE;
     notify(); // Should we use notifyall() instead?
     return item;
}
```

Entry and Wait Sets

Scenario in which multiple producers and consumers can be in wait set for BUFFER_SIZE = 1



Time-step	Entry set	Buffer state	Wait set
t	P0	EMPTY	C0, C1
t+1	C0, P1	FULL	C1
t+2	C0	FULL	P1, C1

Problem: notify() may select the “wrong” thread each time, leading to livelock. Use notifyAll() instead.

Two Tips for working with Java Threads

- Any variable from an outer scope that is accessed in an anonymous inner class (e.g., in the run() method) must be declared final.

```
final int len = X.length;
Runnable r = new Runnable() {
  public void run() {
    for(int i=0 ; i < len/2 ; i++) sum1 += X[i];
  }
};
```

- Remember to call the start() method on any thread that you create. Otherwise, the thread's computation does not get executed.

```
Thread t = new Thread(r); t.start();
```

Cancelling Threads: Interruption

- Problem: how do we shut down a thread like a web server?
- Need to communicate that shutdown has been requested
  - Could set a flag that is polled in the main loop

    But main loop could be blocked in `accept()`
- Interruption provides a means of signalling a request to another thread
- Each `Thread` has an "interrupted status" which is
  - Set when `interrupt()` method is invoked on it
  - Queried by `isInterrupted()` method
- Many blocking methods respect interruption requests and return early by throwing checked `InterruptedException`
  - `Object.wait()`
  - Throwing IE usually clears interrupted status

Calling methods that may throw InterruptedException

- Many methods in Java thread libraries may throw an InterruptedException e.g., <thread>.join(), <object>.wait(),
- When calling any such method, you will either need to include each call to join() in a try-catch block, or add a "throws InterruptedException" clause to the definition of the method that includes the call to join()
- Try-catch example

```
public class Foo implements Runnable {

    public void run() {
        try {
            t1.join();
        }
        catch (InterruptedException e) {
            Thread.currentThread().interrupt();
        } } }
```

TrafficSignal example (throws clause)

- The `wait` methods will
  - Atomically release the lock and block the current thread
  - Reacquire lock before returning
- `notify()` means wake up one waiting thread
- `notifyAll()` means wake up all waiting threads

```
public class TrafficSignal {
    public enum Color { GREEN, YELLOW, RED };
    private Color color;
    public synchronized void setColor(Color color) {
        this.color = color;
        notifyAll();
    }
    public synchronized void awaitGreen() throws InterruptedException
{
      while (color != Color.GREEN) wait(); // waits on “this” object
    }
}
```

Responses to Interruption

- Re-throw IE
  - So caller can handle interruption request
- Cancel and return early
  - Clean up and exit without signalling an error
  - May require rollback or recovery
- Ignore interruption
  - When it is too dangerous to stop
  - Should re-assert interrupted status before returning
- Postpone interruption
  - Remember that interrupt occurred
  - Finish what you are doing and then throw IE
- Throw a general failure exception
  - When interruption is one of many reasons method can fail

Example: Shutting Down the Web Server

```
public class WebServerWithShutdown {
   private final ServerSocket server;
   private Thread serverThread;
   public WebServerWithShutdown(int port) throws IOException {
      server = new ServerSocket(port);
      server.setSoTimeout(5000);  // so we can check for interruption
   }
   public synchronized void shutdownServer() throws IE..,IOException {
      if (serverThread == null) throw new IllegalStateException();
      serverThread.interrupt();
      serverThread.join(5000);  // wait 5s before closing socket
      server.close();           // to give thread a chance to cleanup
  }
  public synchronized void startServer() {
     if (serverThread == null) {
        (serverThread = new Thread() {
           public void run() {
              while (!Thread.interrupted()) {
                 try { processRequest(server.accept()); }
                 catch (SocketTimeoutException e) { continue; }
                 catch (IOException ex) { /* log it */ }
              }
           }
        }).start();
     }
  }
}
```

Note: shutdownServer can be harmlessly called more than once

Use of class objects in synchronized statements/methods

- A class object exists for every class
- static synchronized methods lock the class object
- class object can be locked explicitly:
  - synchronized(Foo.class) { /* ... */ }
- No connection between locking the Class object and locking an instance of the class
  - Locking the Class object does not lock any instance
  - Instance methods that use static variables must synchronize access to them explicitly by locking the Class object

Always use the class literal to get reference to Class object—not this.getClass() as you may access a subclass object

Topics for today

- **Java's synchronized statement**

- **Advanced locking in Java**

java.util.concurrent

- General purpose toolkit for developing concurrent applications
  - import java.util.concurrent.*

- Goals: "Something for Everyone!"
  - Make some problems trivial to solve by everyone
    - Develop thread-safe classes, such as servlets, built on concurrent building blocks like `ConcurrentHashMap`
  - Make some problems easier to solve by concurrent programmers
    - Develop concurrent applications using thread pools, barriers, latches, and blocking queues
  - Make some problems possible to solve by concurrency experts
    - Develop custom locking classes, lock-free algorithms

- HJ approach
  - Build HJ runtime on top of java.util.concurrent library

Key Functional Groups in j.u.c.

- Atomic variables
  - The key to writing lock-free algorithms
- Concurrent Collections:
  - Queues, blocking queues, concurrent hash map, …
  - Data structures designed for concurrent environments
- Locks and Conditions
  - More flexible synchronization control
  - Read/write locks
- Executors, Thread pools and Futures
  - Execution frameworks for asynchronous tasking
- Synchronizers: Semaphore, Latch, Barrier, Exchanger
  - Ready made tools for thread coordination

Locks

- Use of monitor synchronization is just fine for most applications, but it has some shortcomings
  - Single wait-set per lock
  - No way to interrupt or time-out when waiting for a lock
  - Locking must be block-structured
    - Inconvenient to acquire a variable number of locks at once
    - Advanced techniques, such as hand-over-hand locking, are not possible
- Lock objects address these limitations
  - But harder to use: Need **`finally`** block to ensure release
  - So if you don’t need them, stick with **`synchronized`**

Example of hand-over-hand locking:

- **L1.lock() … L2.lock() … L1.unlock() … L3.lock() … L2.unlock() ….**

java.util.concurrent.locks.Lock interface

```
interface Lock {
  void lock();
  void lockInterruptibly() throws InterruptedException;
  boolean tryLock();
  boolean tryLock(long timeout, TimeUnit unit)
                                   throws InterruptedException;
  void unlock();
  Condition newCondition();
   // can associate multiple condition vars with lock
}
```

- java.util.concurrent.locks.Lock interface is implemented by java.util.concurrent.locks.ReentrantLock class

Simple ReentrantLock() example

- Used extensively within **`java.util.concurrent`**

```
final Lock lock = new ReentrantLock();
 ...
 lock.lock();
 try {
   // perform operations protected by lock
 }
 catch(Exception ex) {
   // restore invariants & rethrow
 }
 finally {
   lock.unlock();
 }
```

- **Must manually ensure lock is released**

java.util.concurrent.locks.condition interface

- Can be allocated by calling ReentrantLock.newCondition()
- Supports multiple condition variables per lock
- Methods supported by an instance of condition
  - void await()   // NOTE: not wait
    - Causes current thread to wait until it is signaled or interrupted
    - Variants available with support for interruption and timeout
  - void signal() // NOTE: not notify
    - Wakes up one thread waiting on this condition
  - void signalAll() // NOTE: not notifyAll()
    - Wakes up all threads waiting on this condition
- For additional details see
  - http://download.oracle.com/javase/1.5.0/docs/api/java/util/concurrent/locks/Condition.html

BoundedBuffer implementation using two conditions, notFull and notEmpty

```
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;

   . . .
```

BoundedBuffer implementation using two conditions, notFull and notEmpty (contd)

```
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();
  }
}
```

BoundedBuffer implementation using two conditions, notFull and notEmpty (contd)

```
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();
  }
}
```

Reading vs. writing

- Recall that the use of synchronization is to protect interfering accesses
  — Multiple concurrent reads of same memory: Not a problem
  — Multiple concurrent writes of same memory: Problem
  — Multiple concurrent read & write of same memory: Problem

So far:

— If concurrent write/write or read/write might occur, use synchronization to ensure one-thread-at-a-time

But:

— This is unnecessarily conservative: we could still allow multiple simultaneous readers

Consider a hashtable with one coarse-grained lock

— So only one thread can perform operations at a time

But suppose:

— There are many simultaneous `lookup` operations

— `insert` operations are very rare

java.util.concurrent.locks.ReadWriteLock interface

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

- Even though the interface appears to just define a pair of locks, the semantics of the pair of locks is coupled as follows
  - Case 1: a thread has successfully acquired writeLock().lock()
    - No other thread can acquire readLock() or writeLock()
  - Case 2: no thread has acquired writeLock().lock()
    - Multiple threads can acquire readLock()
    - No other thread can acquire writeLock()
- java.util.concurrent.locks.ReadWriteLock interface is implemented by java.util.concurrent.locks.ReadWriteReentrantLock class

Example code

```
class Hashtable<K,V> {
  …
  // coarse-grained, one lock for table
  ReadWriteLock lk = new ReentrantReadWriteLock();
  V lookup(K key) {
    int bucket = hasher(key);
    lk.readLock().lock(); // only blocks writers
    … read array[bucket] …
    lk.readLock().unlock();
  }
  void insert(K key, V val) {
    int bucket = hasher(key);
    lk.writeLock().lock(); // blocks readers and writers
    … write array[bucket] …
    lk.writeLock().unlock();
  }
}
```

Announcements

- Homework 5 (written assignment) due on Friday, April 6th
- Graded midterms are now available.
- Graded HW3 will be returned next week