Final Exam

CMSC 433
Programming Language Technologies and Paradigms
Fall 2002

December 21, 2002

Guidelines

The exam time is from **10:30 am to 12:30 pm**, totalling 2 hours.

This exam has 11 pages; count them to make sure have all of them (the last page is blank). Put your name and class account number on each page before starting the exam. Write your answers directly on the exam sheets, using the back of the page as necessary. If you finish early, you may bring your exam to the front, but please be as quiet as possible.

If you have a question, raise your hand and I will come to you. However, to minimize interruptions, you may only do this once for the entire exam. Therefore, wait until you are sure you don't have any more questions before raising your hand. Errors on the exam will be posted on the board as they are discovered. If you feel an exam question assumes something that is not written, write it down on your exam sheet. Barring some unforeseen error on the exam, however, you shouldn't need to do this at all, so be careful when making assumptions.

Good luck, and have a great break!

Question	Points	Score
1	20	
2	15	
3	15	
4	15	
5	20	
6	15	
Total	100	

1. (Short Answer, 20 points)

   (a) (5 points) Describe the difference between *white box* and *black box* testing, for a given class. Which one is JUnit more suited for, and why?

   Answer:

   A black-box test tests a class's functionality by using its external interface, while a white box test examines a particular class's implementation by looking at its internal structure, including instance variables, control-flow, etc. JUnit is better suited for black box tests because it can only interact with a class via its public interface.

   (b) (5 points) Describe as concisely as possible how a program consisting of two threads can be in a state of deadlock. In what way can you guarantee that for any multithreaded program that uses locks it will never be deadlocked?

   Answer:

   The first thread is trying to acquire a lock held by the second thread, while the second thread is trying to acquire a lock held by the first thread. You can prevent deadlock outright by never allowing a thread to hold more than one lock at a time.

   (c) (4 points) Explain why `wait` should nearly always be called from within a loop. What undesirable situation can arise when this is not the case?

   Answer:

   Just because a thread blocked on `wait` wakes up does not imply that the condition it was waiting on has become true. This is because other threads might have run since the thread woke up and altered the condition, or because the condition was never true and the thread woke up due to a timeout or was interrupted.

   (d) (6 points) Name two features that Java RMI provides automatically when dealing with Remote objects. More to the point, what functionality did you have to implement yourself in project 1 for RemoteLogClient and RemoteLogServer that you did not have to implement when writing your RMIRemoteLogClient and RMIRemoteLogServer?

   Answer:

   RMI provides generates stubs and skeletons to perform (1) communication between a local proxy methods and those of a remote object, and (2) marshalling and unmarshalling of arguments to these methods. In project 1, communication was performed manually via Socket (i.e. TCP) connections, along with a dispatching loop at the server side, and marshalling and unmarshalled occurred via user-defined protocol. Project 5 voided the need for these features, since RMI provides them automatically.

2. (Short Answer, 15 points)

(a) (4 points) Name two ways that JVM can acquire a stub to a Remote object using Java RMI. As a hint (for one of these two), think about how the RMIRemoteLogClient acquired a stub to a Remote LocalLog living on the RMIRemoteLogServer.

Answer:

This question was a bit ambiguous; there were two sets of possible answers:

- *If you read this to mean how do you acquire stub* objects*, the answer was: use the registry via* `Naming.lookup()` *and related methods, and receive objects returned from methods executed on a remote site.*
- *If you read this to mean how do you acquire stub* code*, the asnwer was: acquire it from the owning JVM's codebase, and get it from the local classpath.*

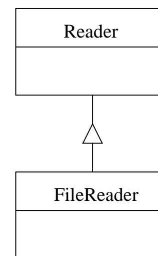
You were not allowed to mix and match answers.

(b) (3 points) What is the effect of the Java `volatile` qualifier?

Answer:

It ensures that updates to variables having this keyword are made available to all threads, even if synchronization is not being used.

(c) (3 points) What is the relationship between the classes `Reader` and `FileReader` that is shown in the following class interaction diagram?



Answer:

`FileReader` *is a subclass of* `Reader`*.*

(d) (5 points) One of the principles of design patterns is to *encapsulate what varies.* That is, when looking at the functional and/or structural decomposition of a system, often certain parts are essentially fixed while other parts vary. Pick a design pattern and explain how it implements this principle, perhaps using a small example.

Answer:

There are many possible answers. For example, the strategy pattern encapsulates an algorithm; the abstract factory pattern encapsulates the means for creating related objects; the proxy pattern encapsulates ways of modifying access the underlying object, etc.

A number of people said Decorator because the underlying classes it wraps can vary while it stays fixed. This is backwards: a Decorator wraps a fixed underlying object type *(e.g. Reader), but can be implemented to have many behaviors (e.g. adding Line Numbers, adding Buffering, etc.).*

3. (Concurrency Patterns, 15 points) A simple implementation of a *copy-on-write set* is given below.

```
public class CopyOnWriteSet {
    private Object[] array_;
    public CopyOnWriteSet() { array_ = new Object[0]; }

    // look through the array for the given object
    public synchronized boolean member(Object o) {
        for (int i = 0; i<array_.length; i++) {
            if (array_[i] == o || (o != null && o.equals(array_[i])))
                return true;
        }
        return false;
    }

    // make a copy of the array, add the object, and update
    //   the array reference to point to the new array
    public synchronized void add(Object o) {
        int len = array_.length;
        Object[] newArray = new Object[len+1];
        System.arraycopy(array_, 0, newArray, 0, len);
        newArray[len] = o;
        array_ = newArray;
    }
}
```

This implementation uses a *conservative update* for the `add` method; that is, it holds a lock while performing the entire `add` operation. Change this implementation to perform `add` as an *optimistic update* instead, using two additional methods `array()` and `commit()`. A partial implementation is given on the next page with space for you to insert your code; some additional background information is below.

Addtional background information (i.e. hints!):

A *copy-on-write* set is one in which a write to the set results in its contents being copied first. This allows existing threads that are in the process of using the set, e.g., iterating over it, to continue to do so safely.

Because we assume for copy-on-write sets that `add` calls are rare and membership tests are frequent, we can use *optimistic* updates to increase program availability. As explained in class, an optimistic update works by (1) grabbing the existing state, (2) operating on that state in some way, and (3) committing the end result; the lock must only be held for the first and third operations, increasing availability. The commit operation ensures that no other thread has performed a commit since the current thread acquired the state. If this turns out to be the case, then the current thread must reacquire the state, redo its change, and try to commit again. This ensures that no changes are lost. The drawback of this approach is that work could be wasted if threads constantly must redo their changes due to failed commits.

```
public class CopyOnWriteSet {
    // array_, CopyOnWriteSet() and member(Object o) same as above

    private synchronized Object[] array() { return array_; }
    private synchronized boolean commit(Object[] oldArray,
                                        Object[] newArray) {
        boolean success = (oldArray == array_);
        if (success) array_ = newArray;
        return success;
    }

    public void add(Object o) { // WRITE CODE BELOW









    }
}
```

Answer:

The code for the `add` *method is as follows:*

```
while (!Thread.interrupted()) {
  Object[] oldArray = array();
  int len = oldArray.length;
  Object[] newArray = new Object[len+1];
  System.arraycopy(oldArray, 0, newArray, 0, len);
  newArray[len] = o;
  if (commit(oldArray, newArray)) break;
  Thread.yield();
}
```

Note that you could also just use an infinite loop rather than checking the interrupted status; including this gets you bonus points!

4. (Concurrency, 15 points) The code snippets below *may* allow for race conditions or deadlock. If so, describe the problem in general, and then describe an execution trace that illustrates the problem. In the first two cases, assume that multiple threads may be manipulating the object at once. In the third case, assume that `startComputations` is called with $n \geq 1$.

   (a) (5 points)

```
// a user can post a message that are later retrieved
1:  public class MessageBoard {
2:    String msg = null;
3:
4:    void post(String aMsg) {
5:      synchronized (this) {
6:        while (msg != null) wait();
7:      }
8:      synchronized (this) {
9:        msg = aMsg; notifyAll();
10:     }
11:   }
12:
13:   String retrieve() {
14:     synchronized (this) {
15:       while (msg == null) wait();
16:     }
17:     synchronized (this) {
18:       String aMsg = msg; msg = null;
19:       notifyAll(); return aMsg;
20:     }
21:   }
22: }
```

Answer:

Multiple threads can execute in the latter half of post() or retrieve(), since there is no synchronization around the while loop and *the latter half. For example, given two retriever threads, the first (call it* t1*) can check if messages are present, find some, and so exit the while loop, and then be context-switched before entering the next synchronized block. The second thread* t2 *can then do exactly the same thing but proceed through the synchronized blocks, retrieving* `msg` *and nulling it out. When thread* t1 *is rescheduled, it will then retrieve* `msg`*, but this is now null.*

(b) (5 points)

```
1:  public class MyInteger {
2:    private int i;
3:
4:    public MyInteger(int i) { this.i = i; }
5:
6:    public MyInteger add(MyInteger x) {
7:      return new MyInteger(x.i + this.i);
8:    }
9:  }
```

Answer:

There are no synchronization problems in this class, because it is immutable. *Once it is created, its instance variable* `i` *is never modified, and so can never be subject to a race condition.*

(c) (5 points)

```
// assume doComputation manipulates its object without
//   synchronization
1:  public class CompThread extends Thread {
2:    private Object o;
3:    public CompThread(Object toComputeWith) { o = toComputeWith; }
4:
5:    public void run() {
6:      synchronized (this) {
7:        doComputation(o);
8:      }
9:    }
10:
11:   public static void startComputations(int n, Object toComputeWith) {
12:     for (int j = 0; j<n; j++) {
13:       new CompThread(toComputeWith).start();
14:     }
15:   }
16: }
```

Answer:

There is the possibility of a race condition on `o` *because each thread will acquire its own lock (this), rather than acquiring a single shared lock.*

5. (Design Patterns, 20 points) A *thread-safe* class is one in which objects of that class will work properly when handled by multiple threads. This typically means that all accesses to the object must be synchronized. However, as we saw in Dr. Pugh's Java One slides, making a class synchronized by default can impose a significant performance penalty when the class doesn't actually need the synchronization, i.e. it's used in a single-threaded program.

   Write a *proxy* for objects conforming to the MyMap interface (shown below) called SynchronizedMyMap that adds synchronization to an unsynchronized MyMap object (a similar function is performed by the Collections.synchronizedMap() method). Make sure that the proxy will work even if multiple SynchronizedMyMap objects are created that wrap the same underlying MyMap object.

```
public interface MyMap {
  public void put(Object key, Object value);
  public Object get(Object key);
  public Object remove(Object key);
  public int size();
}
```

Answer:

```
public class SynchronizedMyMap implements MyMap {
  private MyMap map_;

  public SynchronizedMyMap(MyMap map) {
    map_ = map;
  }

  public void put(Object key, Object value) {
    synchronized(map_) { map_.put(key,value); }
  }

  public Object get(Object key) {
    synchronized(map_) { return map_.get(key); }
  }

  public Object remove(Object key) {
    synchronized(map_) { return map_.remove(key); }
  }

  public int size() {
    synchronized(map_) { return map_.size(); }
  }
}
```

Notice that synchronization takes place on the `map_` object rather than the SynchronizedMyMap object (as would be the case if we used synchronized methods); this ensures that if multiple SynchronizedMyMap objects wrap the same Map object, accesses to that Map object will still be properly synchronized.

6. (Design Patterns, 15 points) It is sometimes useful when reading in a text file to prepend each line of the file with the current line number. We could do this using inheritance by overriding the `read` method of some implementation of the abstract class `Reader` (shown below) to output the line number when a newline is seen in the original text. This idea is shown in the code on the next page by extending the `FileReader` class (whose signature is shown below).

   The disadvantage of using inheritance in this way is that it will only apply to a particular subclass, in this case `FileReader`. Here we would have to write a separate subclass of `BufferedReader` to implement line prepending, rather than reuse the code that subclassed the `FileReader` class.

   To fix this problem, we can use the *Decorator* pattern. A decorator *wraps*, via composition, a related class's methods to perform additional functionality, similar to a proxy. This way, you need to write the decorator only once, and it will work for *all* classes that it can wrap.

   Change the code on the next page to be a decorator instead, implementing line number prepending by decorating instances of the `Reader` class. Most of the code on the following page will not change. You can mark up the code provided there, and write in additional methods yourself, as necessary. Your answer must be precise enough that someone could code up the entire correct answer based on what you say.

```
public abstract class Reader {
  public abstract void close() throws IOException;
  public abstract int read() throws IOException;
}

public class FileReader extends Reader {
  public FileReader(String filename) throws FileNotFoundException;
  public void close() throws IOException;
  public int read() throws IOException;
}
```

```
1:  public class FileLineReader extends FileReader {
2:      private int n = 1;                 // current line number in file
3:      private String number = "1:\t";   // line number to print out
4:      private int numberIdx = 0;         // current index in number variable
5:
6:      public FileLineReader(String filename) throws FileNotFoundException {
7:          super(filename);
8:      }
9:
10:     public int read() throws IOException {
11:         // if we are outputting the line number, continue doing so
12:         if (numberIdx >= 0) {
13:             char c = number.charAt(numberIdx);
14:             if (numberIdx + 1 == number.length()) {
15:                 n++;
16:                 number = null;
17:                 numberIdx = -1;
18:             }
19:             else numberIdx++;
20:             return (int)c;
21:         }
22:         // read the next character
23:         int c = super.read();
24:
25:         // check for an end-of-line;
26:         // if found, start outputting the line number
27:         if (c == '\n') {
28:             number = (new Integer(n).toString()) + ":\t";
29:             numberIdx = 0;
30:         }
31:         return c;
32:     }
33: }
```

Answer:

Answer is on subsequent page. The parts that have changed from the other class are shown in boxes.

This page intentionally left blank.

Answer:

```
public class LineReaderDecorator extends Reader {
    private int n = 1;
    private String number = "1:\t";
    private int numberIdx = 0;
    private Reader r;

    public LineReaderDecorator(Reader reader) {
        r = reader;
    }

    public void close() throws IOException { r.close(); }

    public int read() throws IOException {
        // if we are outputting the line number, continue doing so
        if (numberIdx >= 0) {
            char c = number.charAt(numberIdx);
            if (numberIdx + 1 == number.length()) {
                n++;
                number = null;
                numberIdx = -1;
            }
            else numberIdx++;
            return (int)c;
        }
        // read the next character
        int c = r.read();

        // check for an end-of-line;
        // if found, start outputting the line number
        if (c == '\n') {
            number = (new Integer(n).toString()) + ":\t";
            numberIdx = 0;
        }
        return c;
    }
}
```