VICTORIA
UNIVERSITY OF WELLINGTON

EXAMINATIONS – 2012
MID-YEAR

SWEN221
Software Development

Time Allowed: 2 Hours

Instructions: There are 120 possible marks on the exam.
Answer all questions in the boxes provided.
Every box requires an answer.
If additional space is required you may use a separate answer booklet.
Non-electronic Foreign language dictionaries are allowed.
Calculators ARE NOT ALLOWED.
No reference material is allowed.

Question	Topic	Marks
1.	Debugging and Exceptions	20
2.	Encapsulation and Object Contracts	20
3.	Testing	20
4.	Inheritance and Polymorphism	20
5.	Java Generics	20
6.	Threading	20
	Total	120

Question 1. Debugging and Exceptions [20 marks]

Consider the following implementation of a Character Buffer, which compiles without error:

```
1  public class CharBuffer {
2   private char[] buffer;
3   private int length = 0;
4
5   public CharBuffer(int max) { buffer = new char[max]; }
6
7   public CharBuffer(char[] buffer) {
8    this.buffer = buffer;
9    this.length = buffer.length;
10  }
11
12  public void append(char c) {
13   if(length == buffer.length) {
14    // not enough space in buffer!
15    char[] nbuffer = new char[buffer.length * 2];
16    // copy elements from old buffer to new buffer
17    System.arraycopy(buffer,0,nbuffer,0,buffer.length);
18    // activate new buffer
19    buffer = nbuffer;
20   }
21   buffer[length] = c;
22   length = length + 1;
23  }
24
25  public char charAt(int index) {
26   if(index < 0 || index >= length) {
27    throw new IndexOutOfBoundsException();
28   }
29   return buffer[index];
30  }
31
32  // set the character at a given index
33  public void set(int index, char c) {
34    buffer[index] = c;
35  }
36
37  // Return size of buffer's active portion
38  public int length() { return length; }
39
40  // Construct string from active portion of buffer.
41  public String toString() {
42   return new String(buffer,0,length);
43  }
44 }
```

(a) The `charAt(int)` method returns the character at a given index in a `CharBuffer`.

(i) [2 marks] Under what circumstance is it impossible to call `charAt(int)` on a `CharBuffer` without raising an exception?

When the `CharBuffer` is empty

(ii) [2 marks] The `charAt(int)` method throws an exception when an error occurs. Rewrite this method to use an `assert` statement instead.

```
public char charAt(int index) {
assert index >= 0 && index < length;
return buffer[index];
}
```

(b) Another important method in `CharBuffer` is `append(char)`.

(i) [4 marks] In your own words, describe what `append(char)` does.

This method appends a character onto the end of the `CharBuffer`. When the internal `buffer` array is full, the method automatically resizes it to make space for the new character by creating a new array which is twice the size of the old and copying its contents over.

(ii) [2 marks] Under what circumstances does `append(char)` fail to work correctly?

When the `CharBuffer` is initialised with a `max` size of 0, since $2 * 0 = 0$.

(iii) [2 marks] Rewrite `CharBuffer(int)` to ensure `append(char)` will always work correctly.

```
public CharBuffer(int max) {
assert max > 0;
...
}
```

(c) Jim wrote the following code:

```
1  public static void main(String[] args){
2    char[] array = {'H','e','l','l','o'};
3    CharBuffer left = new CharBuffer(array);
4    CharBuffer right = new CharBuffer(array);
5    right.set(0,'h');
6    System.out.println(left.toString() + "␣=>␣" + right.toString());
7  }
```

Jim expected his code to print `"Hello␣=>␣hello"` when executed. However, he was surprised because it did not.

(i) [2 marks] What output was printed when Jim ran his code?

`"hello␣=>␣hello"`

(ii) [4 marks] In your own words, describe what happened. You may use diagrams to support your explanation.

The `CharBuffer(int[])` constructor simply assigns the reference parameter `buffer` into the field `this.buffer` — it does not create a copy of that array. Therefore, both the `left` and `right` objects above *refer to the same array* and, when Jim updated the `right` array, this also updated the `left` array since they are the same.

(iii) [2 marks] Suggest how `CharBuffer` could be improved to protect against this unexpected behaviour.

The `CharBuffer(int[])` should *defensively copy* the array parameter by creating an `int[]` of the same size and then copying the contents over using e.g. `System.arraycopy()`.

Cross out rough working that you do not want marked.
Specify the question number for work that you do want marked.

Question 2. Encapsulation and Object Contracts [20 marks]

Consider the following implementation for *arithmetic expressions*, which compiles without error:

```
1  public abstract class Expression implements Cloneable {
2    public abstract int evaluate(Map<String,Integer> env);
3    public abstract Expression clone();
4  }
5
6  public final class Constant extends Expression {
7    private final int constant;
8
9    public Constant(int constant) { this.constant = constant; }
10   public int evaluate(Map<String,Integer> env) { return constant; }
11   public Constant clone() { return this; }
12 }
13
14 public final class Variable extends Expression {
15   private final String name;
16
17   public Variable(String name) { this.name = name; }
18
19   public int evaluate(Map<String,Integer> env) {
20     return env.get(name);
21   }
22
23   public Variable clone() { return this; }
24 }
25
26 public final class Sum extends Expression {
27   public final Expression[] operands;
28
29   public Sum(Expression[] ops) {
30     this.operands = new Expression[ops.length];
31     int i = 0 ;
32     for(Expression e : ops) { this.operands[i++] = e; }
33   }
34
35   public int evaluate(Map<String,Integer> env) {
36     int r = 0;
37     for(Expression e : operands) { r = r + e.evaluate(env); }
38     return r;
39   }
40
41   public Sum clone() { return new Sum(operands); }
42 }
```

(a) [2 marks] The code above represents arithmetic expressions. Illustrate how to create an instance of `Expression` corresponding to `2+x`.

```
Expression two = new Constant(2);
Expression x = new Variable("x");
Expression sum = new Sum(new Expression[]{two,x});
```

(b) [4 marks] The `evaluate(Map<String,Integer> env)` method is required for all instances of `Expression`. Briefly, discuss the different implementations of this method.

- The `evaluate(Map<String,Integer> env)` is an abstract method defined in `Expression`, which must be implemented by its subclasses.
- The `Constant` class simply returns the integer constant it represents.
- The `Variable` class looks up the integer value which its `name` is assigned to in the `env` map.
- The `Sum` variable recursively calls `evaluate()` on all of its operands, and sums the returned values.

(c) The `Expression` class provides a `clone()` method.

(i) [2 marks] There are two standard ways of implementing a clone method. Which kind of clone is implemented by the subclasses of `Expression` given on page 6?

Shallow Clone

(ii) [4 marks] Briefly, discuss how you would modify the subclasses of `Expression` given on page 6 to implement the other type of clone.

- We could modify line 10 to `return new Constant(constant);`.
- We could modify line 23 to `return new Variable(name);`.
- We could modify line 41 to loop through each of the operands and clone them, whilst assigning each of the cloned objects into a new array which is then passed into `Sum(Expression[])`.

(iii) [4 marks] The `Constant` and `Variable` classes provide `clone()` methods that return **`this`**. Briefly, discuss if and why this is a sensible approach in these cases.

The fields in these two classes are declared final, meaning they cannot be modified after construction. Therefore, it's impossible to modify the object returned by their `clone()` methods and, hence, to observe a difference between the original and cloned objects.

(d) [4 marks] The `operands` field of `Sum` is public. Using this as an example, discuss why public fields are considered bad practice.

Public fields are considered bad practice for two reasons:

- They can be modified by methods external to their class and, hence, we cannot ensure that values assigned to them are sensible (i.e. that their class invariants are maintained).
- Any changes to the implementation of such fields (e.g. converting **`int`**`[]` to `ArrayList<Integer>`) may break external code which uses the fields directly.

For this reason, it is preferred that fields are marked **`private`** with appropriate getters and setters provided. This makes code less *brittle* and more *maintainable*.

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Cross out rough working that you do not want marked.
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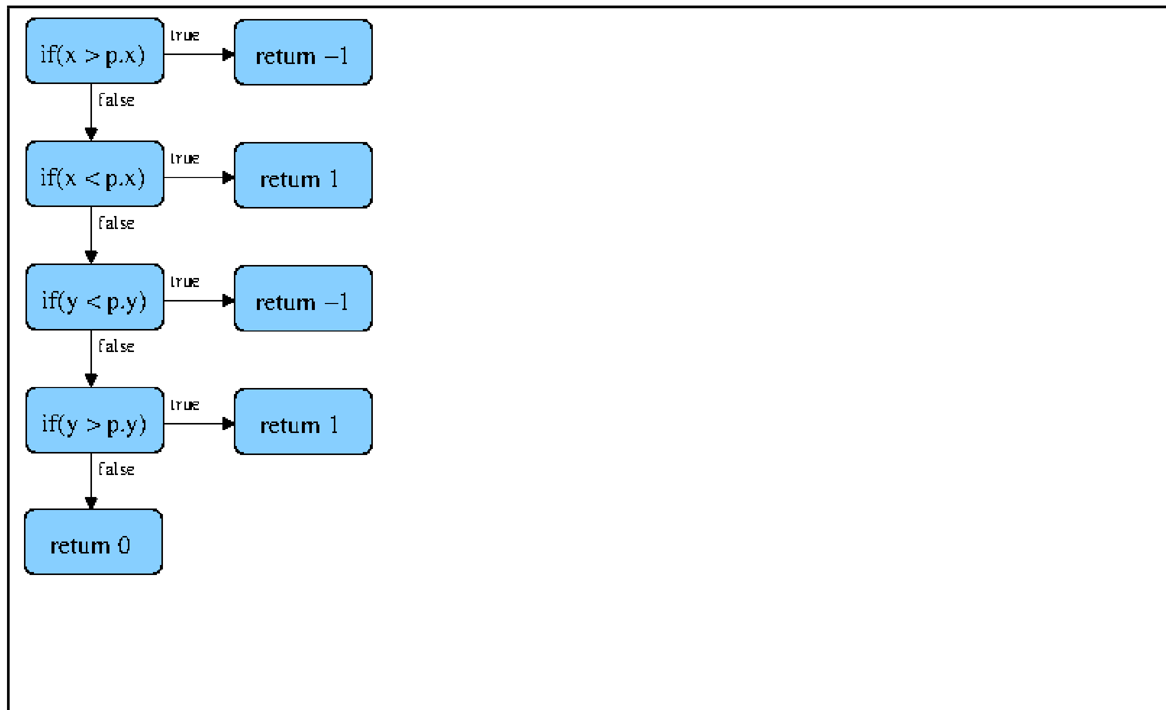
Question 3. Testing [20 marks]

Consider the following code representing a 2-dimensional point:

```
1  public class Point {
2    private int x, y;
3    public Point(int x, int y) { this.x = x; this.y = y; }
4
5    public boolean equals(Object o) {
6      if(o instanceof Point) {
7        Point c = (Point) o;
8          if(c.x != x) { return false; }
9          if(c.y != y) { return false; }
10         return true;
11     }
12     return false;
13   }
14
15   public int compareTo(Point p) {
16     if(x > p.x) { return -1; }
17     if(x < p.x) { return 1; }
18     if(y < p.y) { return -1; }
19     if(y > p.y) { return 1; }
20     return 0;
21   }
22 }
23
24 public class PointTests {
25   @Test void testEquals() {
26     assertTrue(new Point(1,2).equals(new Point(1,2)));
27   }
28
29   @Test void testEquals() {
30     assertFalse(new Point(1,2).equals(new Point(2,2)));
31   }
32
33   @Test void testCompare() {
34     assertTrue(new Point(2,3).compareTo(new Point(2,1)) > 0);
35   }
36
37   @Test void testCompare() {
38     assertTrue(new Point(2,1).compareTo(new Point(2,3)) < 0);
39   }
40 }
```

(a) [4 marks] Draw the *control-flow graph* for the `Point.compareTo(Point)` method:



(b) A common way to measure the effectiveness of a test suite is to calculate *coverage*.

(i) [2 marks] State the *statement coverage* criterion.

The proportion of statements covered by the tests

(ii) [2 marks] Give the total *statement coverage* of `Point` obtained with `PointTests`.

There were 14 statements covered out of 19 statements in total. Hence, statement coverage is $14/19 = 74\%$

(iii) [2 marks] State the *branch coverage* criterion.

The proportion of branching statements where both sides of the branch are tested

(iv) [2 marks] Give the total *branch coverage* of `Point` obtained with `PointTests`.

There are 7 branching statements in total, of which only 2 had both possibilities covered. Hence, branch coverage is $2/7 = 29\%$.

(v) [4 marks] Briefly, discuss why *branch coverage* is superior to *statement coverage*.

Branch coverage is generally considered superior to statement coverage because it reports a better estimate of the number of execution paths that were tested. In many cases, as in this example, statement coverage can be high whilst branch coverage is not. Consider the function:

```
int f(int x,int y) {
if(x > y) { x = y;}
return x;
}
```

In this case, if execution goes into the true branch then statement coverage will report 100% for this function *even though the case where* $x <= y$ *has never been tested.*

(c) The *path coverage* criterion counts the proportion of all possible execution paths which are tested.

(i) [2 marks] Why is path coverage impossible to measure in general?

Because, in the presence of loops and polymorphism, there are potentially an infinite number of possible execution paths.

(ii) [2 marks] State what the *simple path coverage* criterion is.

That each loop body is executed zero times, and at least once.

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Cross out rough working that you do not want marked.
Specify the question number for work that you do want marked.

Question 4. Inheritance and Polymorphism [20 marks]

Consider the following Java classes.

```
1  public class A{
2    public static int x=1;
3    public int m(A a, B b) {
4      return a.m(b,b)+x;
5    }
6  }
7
8  public class B extends A {
9    public int m(A a1, B a2){
10     if(a1==a2)return x;
11     return super.m(a1,a2);
12   }
13 }
```

(a) Given the above declarations, state whether the following classes compile without error. For any which do not compile, briefly describe the problem.

(i) [2 marks]

```
1  public class C extends B {
2    public float m(A a1, B a2){
3      return 1.2f;
4    }
5  }
```

Invalid overriding, the return type is incompatible with B.m(A, B)

(ii) [2 marks]

```
1  public class D extends B {
2    public D(int f){
3      super();
4      x=3;
5    }
6  }
```

correct

(b) Given classes A and B on page 14, state the output from the following code snippets.

(i) [2 marks]

```
1 public class Main {
2   public static void main(String[] args) {
3     B b1=new B();
4     A a1=b1;
5     A a2=b1;
6     System.out.println(a1.m(a2,b1));
7 } }
```

Prints: 1

(ii) [2 marks]

```
1 public class Main {
2   public static void main(String[] args) {
3     A a1=new A();
4     A a2=new A();
5     B b1=new B();
6     System.out.println(a1.m(a2,b1));
7 } }
```

Prints: 3

(iii) [3 marks]

```
1 public class Main {
2   public static void main(String[] args) {
3     A.x=2;
4     A a1=new A();
5     B b1=new B();
6     System.out.println(b1.m(a1,b1));
7 } }
```

Prints: 6

(iv) [3 marks]

```
1 public class Main{
2   public static void main(String[] args){
3     A a1=new A();
4     A a2=new A(){ int m(A a,B b){return 10;}};
5     B b1=new B();
6     System.out.println(a1.m(a2,b1));
7   }
8 }
```

Prints: 11

(v) [3 marks]

```
1 public class Main{
2   public static void main(String[] args){
3     A a1=new A();
4     A a2=new A();
5     B b1=(B)a1;
6     System.out.println(a1.m(a2,b1));
7   }
8 }
```

Termination by ClassCastException

(vi) [3 marks]

```
1 public class Main{
2   public static void main(String[] args){
3     B b1=new B(){int m(A a,A b){return 10;}};
4     System.out.println(b1.m(b1,b1));
5   }
6 }
```

Prints: 1

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Cross out rough working that you do not want marked.
Specify the question number for work that you do want marked.

Question 5. Java Generics [20 marks]

(a) The `Box` class, shown below, implements a generic container for `Items`. The only thing relevant for a general item is the value.

(i) [10 marks] By writing neatly on the box below turn `Box` into a generic version, `Box<T extends Item>`, where `T` specifies the type of item held in the box.

```
1  public abstract class Item { abstract int value(); }
2
3  public class Box {
4
5    private Item item;
6
7    public Box(Item item) { this.item=item; }
8
9    public Item getItem() { return this.item; }
10
11   public void setItem(Item item) { this.item=item; }
12
13   public static void swap(Box b1, Box b2) {
14
15     Item aux=b1.item;
16     b1.item=b2.item;
17     b2.item=aux;
18   }
19
20   public static List boxAll(List items) {
21
22     List result=new ArrayList();
23
24     for(Object i : items) { result.add(new Box((Item)i)); }
25     return result;
26   }
27
28   public static void sort(List boxes) {
29
30     Collections.sort(boxes,new Comparator() {
31
32       public int compare(Object b1, Object b2) {
33
34         return ((Box)b1).item.value()-((Box)b2).item.value();
35       }
36     });
37   }
38 }
```

(see page 19 for answer)

(ii) [3 marks] In the box below, provide code which define a minimal concrete `Toy` class and create an instance of a generic `Box` which holds `Toy`s.

```
class Toy extends Item{
  int value() { return 1; }
  }
...
Box<Toy> bp=new Box<Toy>(new Toy());
```

(iii) [2 marks] Briefly, discuss why the generic `Box<T>` is preferable to the non-generic version.

In the non-generic version of `Box`, one could not be sure exactly what items were stored in the box. Thus, one would need to cast items as they came out of the box, leading to potential `ClassCastException`s at runtime. With the generic version, one knows that every item in an instance of `Box<T>` is at least an instance of `T` — no casting is required.

(b) [5 marks] In Java, `Box<Toy>` is **not** a supertype of `Box<Item>`. Discuss why this is not permitted, using example code to illustrate.

The reason for this is that, otherwise, one could break the invariants maintained by the generic type. The following illustrates:

```
Toy m(){
  Item i=new Item(){int value(){return 100;}};
  Box<Item> k=new Box<Item>(i);
  Box<Toy> a=k; // ok if Box<Item> <:  Box<Toy>
  return a.item; // ClassCastException here
}
```

If `Box<Toy>` were a supertype of `Box<Item>`, this code would compile — but, there would be a serious problem. This is because the code would allows any item to be returned as a Toy.

(answer to Question 5a)

```
1  abstract class Item{abstract int value();}
2
3  class Box<T extends Item>{
4
5    private T item;
6
7    public Box(T item){this.item=item;}
8
9    public T getItem(){return this.item;}
10
11   public void setItem(T item){this.item=item;}
12
13   public static <T0 extends Item>void swap(Box<T0> b1,Box<T0> b2){
14
15     T0 aux=b1.item;
16     b1.item=b2.item;
17     b2.item=aux;
18   }
19
20   public static <T0 extends Item>List<Box<T0>> boxAll(List<T0> items){
21
22     List<Box<T0>> result=new ArrayList<Box<T0>>();
23
24     for(T0 i:items) result.add(new Box<T0>(i));
25     return result;
26   }
27
28 public static <T0 extends Item>void sort(List<Box<T0>> boxes){
29
30     Collections.sort(boxes,new Comparator<Box<T0>>(){
31
32         public int compare(Box<T0> b1, Box<T0> b2) {
33             return b1.item.value()-b2.item.value();
34         }});
35   }
36 }
```

Question 6. Threading [20 marks]

Consider the following implementation of a *parallel sum*, which compiles without error:

```
1  public class ParSum {
2    private int sum;
3    private int[] data;
4
5    public ParSum(int[] data) {
6      this.data = data;
7    }
8
9    public long go(int numProcessors) {
10     // determine job size based on number of available processors
11     int jobSize = data.length / numProcessors;
12
13     // create and start each job
14     int index = 0;
15     SumJob[] jobs = new SumJob[numProcessors];
16     for (int i = 0; i != numProcessors; ++i) {
17       jobs[i] = new SumJob(index, index + jobSize);
18       jobs[i].start();
19       index = index + jobSize;
20     }
21
22     // return the result
23     return sum;
24   }
25
26   // SumJob is a non-static inner class
27   private class SumJob extends Thread {
28     private int start;
29     private int end;
30
31     public SumJob(int start, int end) {
32       this.start = start;
33       this.end = end;
34     }
35
36     public void run() {
37       for(int i=start;i!=end;++i) {
38         sum = sum + data[i];
39       }
40     }
41   }
42 }
```

(a) The code shown on page 21 contains several problems. For each problem identified below, briefly discuss what the issue is and how the code can be modified to fix the problem.

(i) [5 marks] *Reads and writes to the field `sum` are not synchronised.*

The field sum is read and written on line 38 by each `SumJob` that is created. Unfortunately, there is no synchronisation while accessing that field and, hence, the order in which reads and writes occur is not guaranteed. We can fix the problem by making a **`synchronized`** method in the parent class which adds a given data item to `sum`, and changing line 38 to use this instead of accessing `sum` directly.

(ii) [5 marks] *The result from `go()` is returned before jobs finish.*

The method `go(int)` does not wait for the `SumJob` threads it created to finished before returning the result. Therefore, the result may not include the sum of all elements in `data` array. We can fix this problem by adding a second **`for`** loop to that method which calls `join()` on each `SumJob`, thereby ensuring that each has finished before the method returns.

(iii) [5 marks] *Elements of `data` are sometimes ignored completely.*

When the length of the `data` array is not evenly divisible by the number of processors, elements at the end of the array will be ignored. This happens because the job size calculation (i.e. `jobSize = data.length / numProcessors`) assumes every job must process the same number of elements. To fix this issue, we simply make sure that the last `SumJob` created includes all of the elements from `index` upto `data.length`. This way, any extra elements at the end of the array will be included.

(b) [5 marks] In multi-threaded code, synchronisation should be *minimised* to increase performance. Outline how you could redesign `ParSum` to improve performance.

The current design of `ParSum` assumes that there is a single `sum` field into which all `SumJob`s will accumulate the answer. This is an inherently *bad design* because it requires that all `SumJob`s must perform synchronization (as discussed in **a(i)**) to access this field. In fact, we can redesign `ParSum` to eliminate this synchronisation completely. This is done by putting the `sum` field into the `SumJob` class. Thus, each `SumJob` will have its own local sum for those array elements it is operating on. Once all the `SumJob`s have finished, we then loop over each one and accumulate its `sum` field into the result.

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