Family Name: . . . . **Other Names:** . . . .

ID Number: . . . .

COMP103 Test

1st Sept, 2008

| ************ WITH SOLUTIONS ************

Instructions

- Time: **90 minutes**.
- Answer **all** the questions.
- There are 90 marks in total.
- Write your answers in the boxes in this test paper and hand in all sheets.
- Every box with a heavy outline requires an answer.
- If you do not understand a question, ask for clarification.
- There are useful formulas and documentation at the end of the exam paper.

		Marks		
1.	Collection Types	[17]	1	
2.	Using Collections	[20]	2	
3.	Implementing a Collection	[10]	3	
4.	Sorting Algorithms	[19]	4	
5.	Cost of Algorithms	[16]	5	
6.	Linked Lists	[8]	6	
			Total:	

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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 1. Collection Types [17 marks]

(a) [12 marks]

Complete the following table of properties of the standard collection abstract data types.

Collection type	Ordered?	Duplicates?	Restricted access? (describe)
Bag	no	yes	no restrictions
Set	no	no	no restriction
Queue	yes	yes	poll only front, offer only to back. FIFO)
Stack	yes	yes	FILO: only peep/pop/push at the top
List	yes	yes	no restriction

(b) [2 marks] Maps are more complex than just collections of items, in that they have both keys and values. Are duplicate keys, or duplicate values, allowed in a map?

Duplicate keys allowed? No

Duplicate values allowed? Yes Values can only be accessed via their keys. So duplicate keys are not possible (they form a set), but duplicate values are.

(c) [3 marks] In Java, collections can only contain Objects. How does Java allow for collections whose elements are primitive types (int for example)?

Wrapper classes such as Integer, for example. An int is wrapped up as an object of type Integer, and unwrapped again when it is used. This is mostly done automatically.

Question 2. Using Collections [20 marks]

Consider the following line of code that declares and initializes a variable containing a set of queues of shapes.

```
Set <Queue<Shape>> allShapes = new HashSet <Queue<Shape>> ();
```

(a) [2 marks] On the right hand side, why is HashSet used, rather than just Set?

| Set is merely an interface: to actually make one requires an implementation, such as HashSet.

(b) [2 marks] On the left hand side, why is Set used, rather than HashSet?

| This is describes the collection type, which is supposed to be independent of its implementation. In principle the implementation could differ between instances, or be changed. This shouldn't affect the correctness of the code (only its performance).

(Question 2 continued on next page)

(Question 2 continued)

(c) [16 marks]

People learning a new language need to practice their comprehension, for example by reading a simple paragraph of text. It might be useful to have a list of the vocabulary used in the paragraph, grouped by word length.

Complete the following method that takes an argument paragraph that is a List of the words as they occur in the text. The method returns a List of Sets of words: the first item consists of the set of all words of length 1 in the paragraph, the second item is the set of all words of length 2, and so on. Assume that the longest word is at most 15 characters long.

```
public List<Set<String>> produceVocabSets (List<String> paragraph) {

    List<Set<String>> ans = new ArrayList<Set<String>> ();
    for ( int i=0; i<15; i++) {
        ans.add(new HashSet<String> ());
    }

    for (String word : paragraph) {
        // find out the length
        int L = word.length();
        ans.get(L−1).add(word);
    }

    return ans;

}
```

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Question 3. Implementing a Collection [10 marks]

(a) [5 marks] The ArraySet class defines a Set collection that stores the items in an array. The header and fields of the class are given below:

```
public class ArraySet <E> extends AbstractSet <E> {
  private static int INITIALCAPACITY = 10;
  private int count = 0;
  private E [] data = (E[])( new Object[INITIALCAPACITY]);
```

The class uses a method to copy the items to a new larger data array if the current array is full. The best way to implement this method is to "double and copy". A not so good way is to make a new array that is a fixed amount larger than the current one.
Complete the code for ensureCapacityBad, which uses this not-so-good way.

```
private void ensureCapacityBad () {
    if (count < data.length) return;
    E [] newArray = (E[])(new Object[data.length + INITIALCAPACITY]);
    for ( int i = 0; i < count; i++)
        newArray[i] = data[i ];
    data = newArray;
}
```

(b) [5 marks] (*Hard*) By calculating the amortised (average) "big-O" cost of incrementally building up an array of size n using the above method, show that ensureCapacityBad is much less efficient than the "double and copy" version.

Look at the calculation done in lectures, where we track the item number, the cost per item, and the cumulative cost. This gives a pattern from which we can infer the big-O cost of building the whole set. Then divide this by n to get the big-O cost per item. This is O(1) for double-and-copy, but O(n) for the fixed increase version ("ensureCapacityBad").

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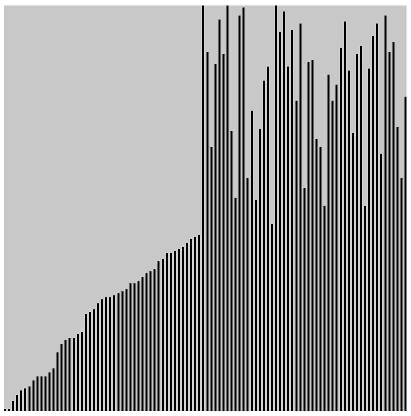
Question 4. Sorting Algorithms [19 marks]

The lectures gave code for five common sorting algorithms:

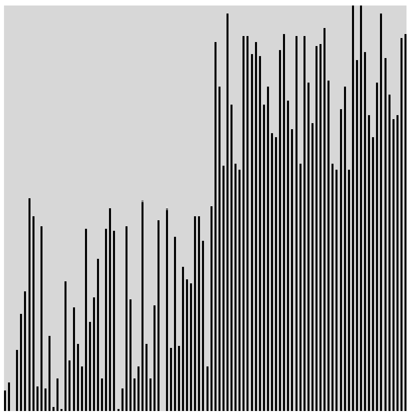
- BubbleSort
- MergeSort
- InsertionSort
- QuickSort
- SelectionSort

(a) [15 marks] Each of the examples below shows a different sorting algorithm caught part of the way through its operations on an array. Use your knowledge of the algorithms to decide which is being used in each case. Each algorithm appears once only. Write your answer below each picture.



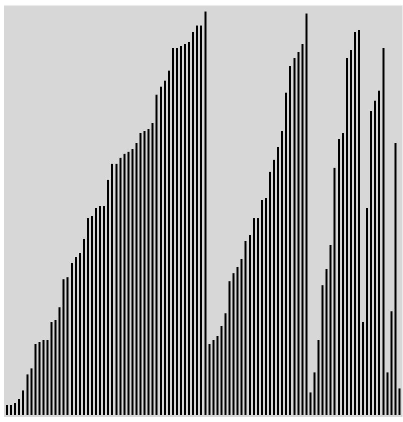
Algorithm: Selection

Justification: build-up on l.h.s.



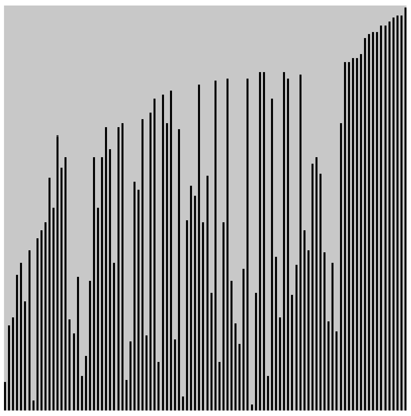
Algorithm: QuickSort

Justification: partitioning, pivot



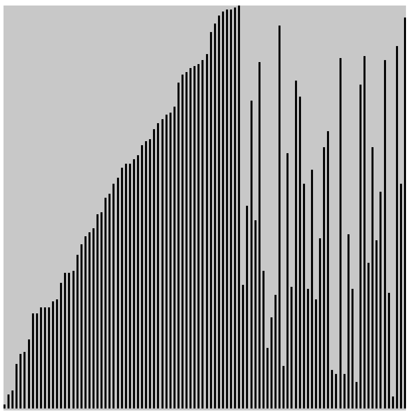
Algorithm: MergeSort

Justification: recursion



Algorithm: BubbleSort

Justification: sorted top, partial elsewhere



Algorithm: Insertion

Justification: from below, full vertical range.

(b) [2 marks] One algorithm performs much better when most of the items are already in order. Which one?

| Insertion.

(c) [2 marks] Name ONE of the algorithms that is *stable* (*i.e.*, keeps equal items in their original order).

| One from Insertion, Bubble, MergeSort.

Question 5. Cost of Algorithms [16 marks]

(a) [2 marks] ArraySet uses an array to implement a collection that is not allowed to contain any duplicate items. We often need to check that a given item is not already in the collection, using the contains method. The average amount of time taken to do this check can be reduced if the items are stored in the array *in order*. What is the cost ("big-O" complexity) of checking contains on a set of n items, for the unsorted and sorted cases? (Note: ignore the cost of the sorting itself).

Complexity if unsorted: $O(\; n \;)$

Complexity if sorted: $O(\; \log(n) \;)$

(b) [2 marks] Explain how the sorted case can be done more efficiently.

Ordered array means we can use binary search, which is efficient

The following printInts method prints out integers. When called with printInts(8) it produces the output shown on the right.

```
public void printInts (int n){
    int k=0;
    for (int i=1; i<=n; i=i+1) {
        for (int j=0; j<i; j++) {
            k++;
            System.out.printf("%3d ",k);
        }
        for (int j=i; j<n; j++)
            System.out.printf(" * ");
        System.out.printf("\n");
    }
}
```

```
  1   *   *   *   *   *   *   *
  2   3   *   *   *   *   *   *
  4   5   6   *   *   *   *   *
  7   8   9  10   *   *   *   *
 11  12  13  14  15   *   *   *
 16  17  18  19  20  21   *   *
 22  23  24  25  26  27  28   *
 29  30  31  32  33  34  35  36
```

(c) [4 marks] What is the asymptotic ("Big-O") complexity of printInts, as a function of n, and why?

Complexity: $O(\; n^2 \;)$

Justification: Outside loop is done n times. The two inside loops will do a total of n steps (the first loop does i steps, the second does $n - i$ steps). So the total is $n \times n$.

(Question 5 continued on next page)

(Question 5 continued)

Now consider the modified version of printInts(8) below. The only change is to the first for loop:

```
public void printInts (int n){
    int k=0;
    for (int i=1; i<=n; i=i*2) { // CHANGED
        for (int j=0; j<i; j++) {
            k++;
            System.out.printf("%3d ",k);
        }
        for (int j=i; j<n; j++)
            System.out.printf(" * ");
        System.out.printf("\n");
    }
}
```

```
1   *   *   *   *   *   *   *
2   3   *   *   *   *   *   *
4   5   6   7   *   *   *   *
8   9  10  11  12  13  14  15
```

(d) [4 marks] What is the "Big-O" complexity of this printInts, and why?

Complexity: This one is $O($ $n\log(n)$ $)$

Justification: The outside loop is done $log(n)$ times, since i doubles every time. The two inside loops will do a total of n steps (the first loop does i steps, the second does $n - i$ steps). So the total is $\log(n) \times n$.

The following version of printInts is the same, except that it doesn't print out any stars ("*").

```
public void printInts (int n){
    int k=0;
    for (int i=1; i<=n; i=i*2) {
        for (int j=0; j<i; j++) {
            k++;
            System.out.printf("%3d ",k);
        }
        System.out.printf("\n");
    }
}
```

```
1
2   3
4   5   6   7
8   9  10  11  12  13  14  15
```

(e) [4 marks] What is the "Big-O" complexity of this printInts, and why?

Complexity: $O($ n $)$

Justification: As before, the outside loop is done $log(n)$ times, but each one does a different amount of work so it's not just $log(n)$ times something... But look at k: it is incremented inside the inner loop so the number of times it is printed is a good measure of the cost. It will print $2n$ times, so the complexity is $O(n)$.

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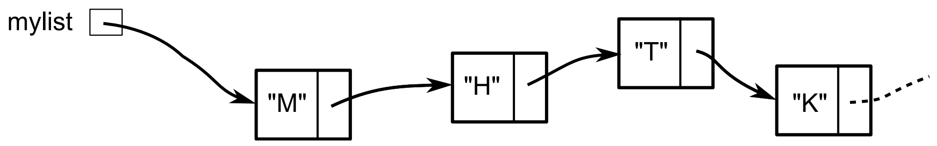
Question 6. Programming with LinkedNodes [8 marks]

This question uses a LinkedNode class, like the one in lectures, which defines LinkedNode objects that contain a value and a reference to another LinkedNode. The class is given on the facing page.

In your answers below, you should use the getValue(), getNext(), and setNext() methods, rather than the value and next fields.

Suppose myList is a variable of type LinkedNode<string>, which contains a linked list of LinkedNodes. For example, it might contain:



(a) [3 marks] Write a statement that will insert the string "A" at the second position of the list in myList. For the example above, mylist should insert "A" between "M" and "H".

```
mylist.setNext(new LinkedNode<String>("A", mylist.getNext()));
```

(b) [5 marks] Complete the following lastValue method that is passed a linked list whose values are string objects. It should return the value of the last item in the list. You may write a recursive or iterative version. The LinkedNode class is given on the next page.

```
public String lastValue(LinkedNode<String> list){
    if ( list == null) throw new RuntimeException("list is empty");
   // recursive version
   if ( list .getNext()==null) return list .getValue();
   return lastValue( list .getNext());
\\OR
   // iterative version
   for(LinkedNode<String> rest=list; rest.getNext()!=null; rest=rest.getNext()){}
     if (rest.getValue().equals(item)) return true;
   return rest.getValue();





}
```

The LinkedNode class:

```
public class LinkedNode <E>{
  private E value;
  private LinkedNode<E> next;

  public LinkedNode(E item, LinkedNode<E> nextNode){
    value = item;
    next = nextNode;
  }
  public E getValue(){
    return value;
  }
  public LinkedNode<E> getNext(){
    return next;
  }
  public void setNext(LinkedNode<E> n){
    next = n;
  }
}
```

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Cross out rough working that you do not want marked.
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Appendices (may be removed)

Possibly useful formulas:

- $1 + 2 + 3 + 4 + \cdots + k \; = \; \frac{k(k+1)}{2}$
- $1 + 2 + 4 + 8 + \cdots + 2^k \; = \; 2^{k+1} - 1$

Table of base 2 logarithms:

n	1	2	4	8	16	32	64	128	256	512	1024	1,048,576
$\log(n)$	0	1	2	3	4	5	6	7	8	9	10	20

Brief (and simplified) specifications of some relevant interfaces and classes.

```
public interface Iterator <E>
   public boolean hasNext();
   public E next();
   public void remove();

public interface Iterable <E>                  // Can use in the "for each" loop
   public Iterator <E> iterator();

public interface Comparable<E>                 // Can compare this to another E
   public int compareTo(E o);

public interface Comparator<E>                 // Can use this to compare two E's
   public int compare(E o1, E o2);
public interface Collection<E>
   public boolean isEmpty();
   public int  size ();
   public boolean add();
   public  Iterator <E> iterator();

public interface List<E> extends Collection<E>
   // Implementations: ArrayList
   public E get( int  index);
   public void set( int  index,  E element);
   public void add(E element);
   public void add(int index,  E element);
   public void remove(int index);
   public void remove(Object element);

public interface Set extends Collection<E>
   // Implementations: ArraySet, SortedArraySet, HashSet
   public boolean contains(Object element);
   public boolean add(E element);
   public boolean remove(Object element);

public interface Queue<E> extends Collection<E>
   // Implementations: ArrayQueue, LinkedList
   public E peek ();                          // returns null if queue is empty
   public E poll  ();                         // returns null if queue is empty
   public boolean offer  (E element);

public class Stack<E> implements Collection<E>
   public E peek ();                          // returns null if stack is empty
   public E pop ();                           // returns null if stack is empty
   public E push (E element);

public interface Map<K, V>
   // Implementations: HashMap, TreeMap, ArrayMap
   public V get(K key);                       // returns null if no such key
   public void put(K key,  V value);
   public void remove(K key);
   public Set<Map.Entry<K, V>> entrySet();
```