TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Student ID: .....

EXAMINATIONS — 2010

END YEAR

COMP103
Introduction to
Data Structures and Algorithms

Time Allowed: 3 Hours

Instructions:

1. Attempt **all** of the questions.
2. *Read each question carefully before attempting it.* (Suggestion: You do not have to answer the questions in the order shown. Do the questions you find easiest first.)
3. This examination will be marked out of **180** marks, so allocate approximately one minute per mark.
4. Write your answers in the boxes in this test paper and hand in all sheets.
5. Non-electronic translation dictionaries are permitted.
6. Calculators are allowed.
7. Documentation on some relevant Java classes and interfaces can be found at the end of the paper.

Questions	**Marks**
1. Basic Questions	[26]
2. Using Collections	[25]
3. Implementing Collections	[23]
4. Recursion, and Sorting	[20]
5. Linked Lists, and Trees	[28]
6. Binary Search Trees	[17]
7. Partially Ordered Trees and Heaps	[22]
8. Various Topics	[19]

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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.

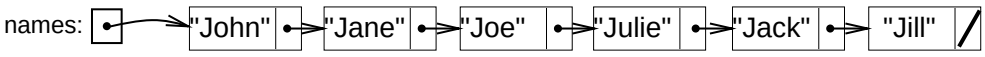
Question 1. Basic questions [26 marks]

(a) [2 marks] State one difference between an Array and an ArrayList.

(b) [2 marks] What is the average case Big-O cost of searching for an item in a Set of n items implemented using an unsorted array?

(c) [2 marks] Name a sorting algorithm with an average case Big-O cost of $O(n^2)$.

Consider the diagram below of a variable containing a linked list. Assume that each node of the list has the fields item and next.



(d) [2 marks] What is the value of names.next.item?

(e) [2 marks] What is the value of names.next.next.next.item?

(Question 1 continued on next page)

(Question 1 continued)

(f) [10 marks] Draw lines between the physical things on the left and the collections on the right indicating the best choice of collection for that physical thing. Note: it may or may not be a 1:1 mapping.

Clothes in a load of washing.	QUEUE
Layers in sedimentary rock.	SET
Music notes in a tune.	STACK
Cars in a drive-through.	MAP
Museums and their phone numbers.	LIST

(g) [2 marks] What is the maximum number of <u>leaves</u> in a binary tree of depth 3 (four levels of nodes)?

(h) [2 marks] If a Bag is implemented using an array of values, would the *addElement* method be faster if the values were sorted or un-sorted?

(i) [2 marks] What is the name of a good algorithm for finding an item in a sorted array of items.

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Cross out rough working that you do not want marked.
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Question 2. Using Collections [25 marks]

This question requires you to complete three methods for a program for processing enrolment data for a university. The program reads a couple of files, and then prints out a list of schools for each student, and a list of students for each school.

(a) [6 marks] The first method reads the `courses-schools.txt` file that lists all the courses in the university and the schools that teach them, and constructs a Map for looking up the school that teaches a given course. The file has one line for each course, containing the course code and the abbreviation of the school. For example:

```
COMP102    ECS
COMP103    ECS
MATH114    SMSOR
PHYS105    SCPS
TECH102    SCPS
BIOL123    SBS
...
```

Complete the readCourses() method below that will initialise and fill the courseToSchool field. Documentation for Set, Map, List, etc. is given in an appendix at the end of this exam.

```
import java. util .*;
public class Enrolment{

    private Map<String, String> courseToSchool; // map from course name to school name

    /* Reads a file of school − course pairs into a map indexed by course */
    public void readCourses(){









        try {
            Scanner sc = new Scanner (new File ("courses-schools.txt"));
            while ( sc.hasNext() ){









            }
            sc.close ();
        }
        catch(Exception e){System.out.println("readCourses failed");}
    }
```

(Question 2 continued on next page)

(Question 2 continued)

Another file (`enrolments.txt`) contains the list of courses that each student has enroled for. Each line of this file starts with a student ID followed by the course codes. An example file might be:

```
4000675123  COMP102 COMP103 MATH114 TECH102 BIOL103
4001725125  BIOL101 BIOL102 BIOL103
4001997126  COMP102 BIOL101 COMP103 BIOL103
...
```

(b) [9 marks] The second method should print out the schools that each student needs approval from. *It should not list a school more than once per row*, even if the student is taking several courses from the school. For example, given the three students above, it should print out this:

```
4000675123:  ECS SMSOR SCPS BIO
4001725125:  SBS
4001997126:  ECS SBS
```

Complete the listsOfSchools() method below. For each student, the method will need to read each course and look up the school in the courseToSchool map. It will need a collection to keep track of the schools for the current student. *Nb:* remember that all three methods are in the same class.

```
public void listsOfSchools(){
    try {
        Scanner sc = new Scanner(new File("enrolments.txt"));
        while ( sc.hasNext() ){
            int ID = sc.nextInt();          // read student ID
                                            // read courses
            while ( sc.hasNext() && !sc.hasNextInt() ){
                String course = sc.next();
                                            // print out ID and list of schools
        }
        sc.close();
    }catch(Exception e){System.out.println("listsOfSchools failed");}
}
```

(Question 2 continued on next page)

(Question 2 continued)

(c) [10 marks] The third method should print out a list for each school containing all the students taking courses in the school. *Nb:* remember that all three methods are in the same class.

Complete the listsOfStudents() method below. The method will need to read the whole of the enrolments.txt file, building a data structure that keeps track of all the students taking courses in each school. It will then print out the list of students for each school.

```
public void listsOfStudents(){
    try {
        // Map with key being a school
        Map<String, Set<Integer>> schoolToIDs = new HashMap<String, Set<Integer>>();
        Scanner sc = new Scanner (new File ("enrolments.txt"));
        while ( sc.hasNext() ){
            int ID = sc.nextInt ();
            while ( sc.hasNext() && !sc.hasNextInt() ){
                String course = sc.next ();









        }
        sc.close ();
        // Print out lists










    }catch(Exception e){System.out.println("listsOfStudents failed");}
}
```

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Question 3. Implementing Collections [23 marks]

A Set is a type of collection that has no structure, but it is not allowed to contain duplicates. Part of the code for the ArraySet class is shown below.

```
import java.util.*;

public class ArraySet<E> extends AbstractCollection<E> {
    private static int INITIALCAPACITY = 10;
    private int count = 0;
    private E[] data;

    public ArraySet() {
        data = (E[]) new Object[INITIALCAPACITY];
    }

    public boolean add(E item) {
        ...
    }

    public boolean contains(Object item) {
        ...
    }

    public boolean remove(Object item) {
        if (item == null) return false;
        for(int i = 0; i < count; i++) {
            if (data[i].equals(item)) {
                count--;
                data[i] = data[count];
                return true;
            }
        }
        return false;
    }

    private void ensureCapacity () {
        if (count < data.length) return;
        E[] newArray = (E[])(new Object[data.length*2]);
        for (int i = 0; i < count; i++) newArray[i] = data[i];
        data = newArray;
    }

    public Iterator <E> iterator() {
        return new ArraySetIterator <E> (this);
    }
}
```

(Question 3 continued on next page)

(Question 3 continued)

You are to complete two methods of the ArraySet class below. Before doing so, note that:

- ArraySet does not need to keep items in order.
- this implementation of ArraySet does not use a separate "findIndex" method.

(a) [5 marks] Complete the contains(Object item) method, that will return true if the ArraySet contains an value equal to item and will otherwise return false.

```
public boolean contains(Object item) {




}
```

(b) [6 marks] Complete the add method which will insert an item into the set, unless the item is already present. add will return true if and only if it modifies the set. Before adding an item, add should call the ensureCapacity method to make sure there is sufficient room in the data array.

```
    public boolean add(E item){









    }
```

(Question 3 continued on next page)

(Question 3 continued)

(c) [8 marks] Complete the following ArraySetIterator class that defines an iterator for an ArraySet. Note that ArraySetIterator is a private inner class of ArraySet.

The constructor, and remove, have been done for you.

```
private class ArraySetIterator <E> implements Iterator <E> {
    private ArraySet<E> set;




    private ArraySetIterator(ArraySet<E> s) {
        set = s;
    }

    public boolean hasNext() {




    }

    public E next() {









    }

    public void remove() {
        throw new UnsupportedOperationException();
    }
}
```

(Question 3 continued on next page)

(Question 3 continued)

(d) [4 marks] Write a ReverseRobotComparator that compares two Robots (i.e. 2 items of type Robot) in reverse (decreasing) order according to their battery life. Assume that the class Robot has a method getBatts(), which returns the battery life of a Robot as an integer.

```
private static class ReverseRobotComparator implements ...









}
```

Question 4. Recursion and Sorting [20 marks]

Consider the following code:

```
public int recursiveFunc(int n) {
    if (n==0)
        return(1);
    else
        return( recursiveFunc(n−1) + 1 );
}
```

(a) [3 marks] What value is returned by recursiveFunc(150)?

(b) [2 marks] What is the time complexity ("big-$\mathcal{O}$" cost) of the method recursiveFunc, expressed in terms of the parameter n?

Consider another recursive method:

```
public int recursiveFunc2(int n) {
    if (n == 0)
        return(0);
    else
        return( recursiveFunc2(n/2)+1 );
}
```

(c) [3 marks] What value will be returned by calling recursiveFunc2(17) ?

(d) [2 marks] What is the time complexity ("big-$\mathcal{O}$" cost) of the method recursiveFunc2, expressed in terms of the parameter n?

(Question 4 continued on next page)

(Question 4 continued)

(e) [2 marks] List one advantage and one disadvantage, of Merge Sort over Quick Sort.

Advantage:

Disadvantage:

Consider the following code:

```
public int split ( int low, int high) {
    if (low+1 >= high) return 1;
    int mid = (low+high)/2;
    int lowResult = split (low,mid);
    int highResult = split (mid,high);
    return(lowResult+highResult+1);
}

public int mergeVal(String s) {
    return split (0,s.length ());
}
```

(f) [4 marks] What value would be printed to the screen if `mergeVal` is called in the following code? (*Hint: consider drawing the binary tree of recursive calls*)

```
System.out.println(mergeVal("abcdefgh"));
```

(g) [4 marks] If the length of the parameter string, `s`, is n, what is the big-$\mathcal{O}$ cost of `mergeVal`?

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Question 5. Linked Lists and Trees [28 marks]

(a) [4 marks] Write an iterative or recursive method, lastActionHero, that returns the last value (of type ActionHero) from a list of ActionHeros implemented as a list of LinkedNodes.

```
/**Returns the value in the last node of a list starting at a node */
public ActionHero lastActionHero (LinkedNode<ActionHero> list){




}
```

(b) [4 marks] In a "ternary" tree, each node has up to 3 children. If a ternary tree is complete, and contains 40 nodes, what is its height?

(c) [10 marks] Consider the following TreeNode class:

```
public class TreeNode {
    private String word;
    private Set<TreeNode> children = new HashSet<TreeNode>();
      :
      :
}
```

In the box below, complete the find method in a TreeNode class. This should use recursion to search the tree below node for a node having a field word matching the argument text.

```
private TreeNode find(TreeNode node, String text) {




}
```

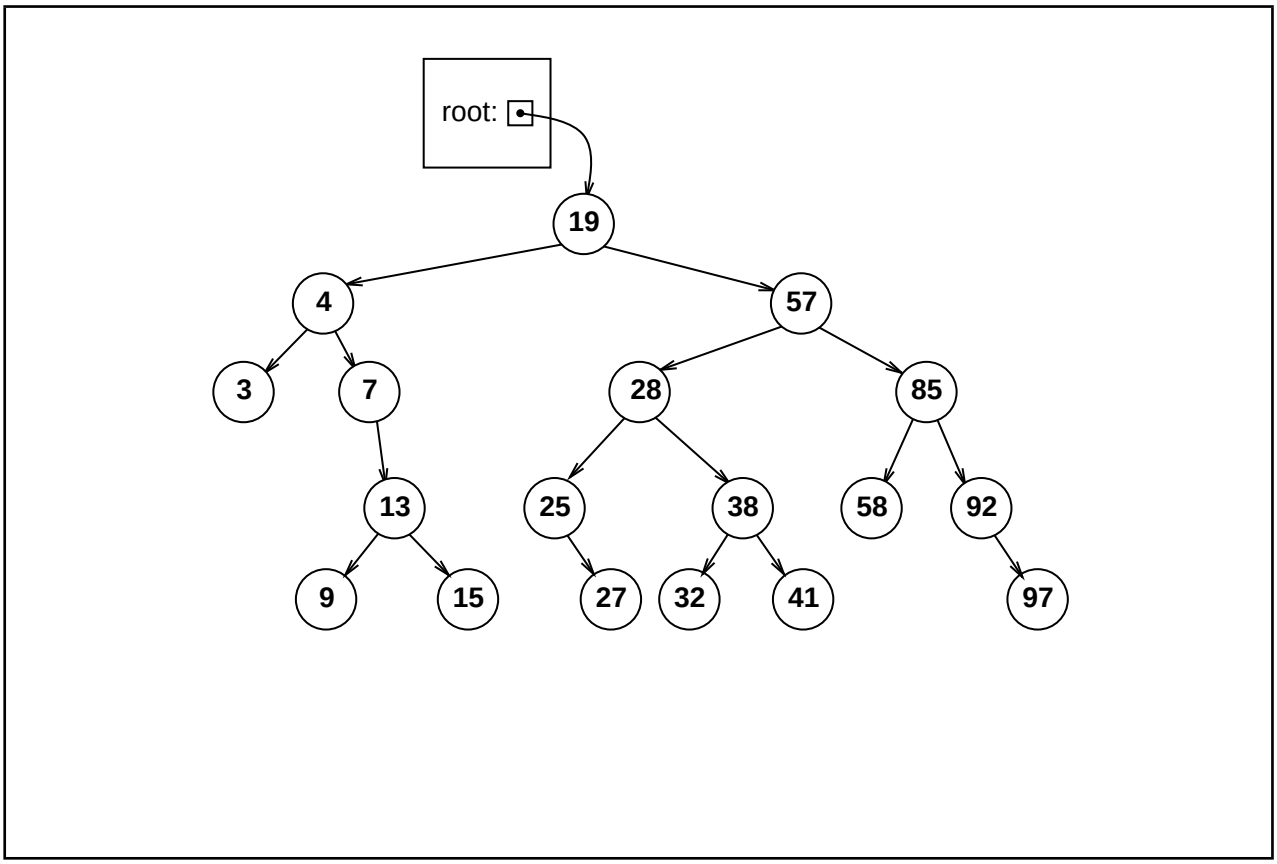
(d) [6 marks] In lectures, we discussed the use of a Queue for carrying out a breadth-first traversal of a general tree. In the box below, give *pseudocode* for this iterative algorithm.

.

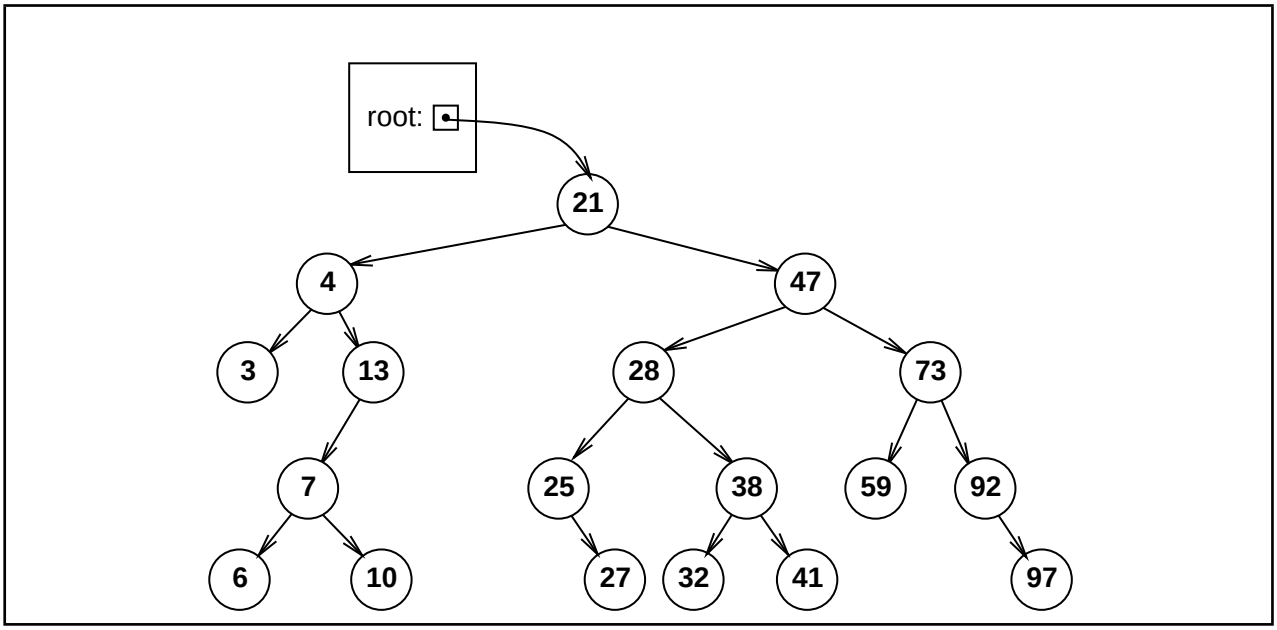
(e) [4 marks] A simple change to the algorithm in (d) would result in a different kind of traversal of the same tree. What is the change, and what kind of traversal does it result in?

Question 6. Binary Search Trees [17 marks]

(a) [4 marks] Consider the following diagram of a Set of numbers implemented as a Binary Search Tree. On the diagram, show what the tree would look like if the values 2, 5, 20, and 56 were added to the set.



(b) [6 marks] On the diagram, show what the tree below would look like if the values 32, 7, and 47 were removed from the Set.



(Question 6 continued on next page)

(Question 6 continued)

(c) [3 marks] Suppose a binary search tree was constructed by inserting elements in a strictly *decreasing* order (*ie.* with the largest elements coming first). Describe the structure of the tree.

(d) [4 marks] Suppose the items `Z`, `J`, `K`, `L`, `A`, `B`, `Y`, and `D` are added, in that order, to a Binary Search Tree that starts off empty. Draw the resulting tree.

Question 7. Partially Ordered Trees and Heaps [22 marks]

(a) [4 marks] Suppose the items `Z`, `J`, `K`, `L`, `A`, `B`, `Y`, and `D` are added, in that order, to a heap that starts off empty. Assuming that letters towards the beginning of the alphabet have higher priority, draw the resulting heap **as a tree**.

(b) [2 marks] State the property a binary tree must satisfy in order to be a partially ordered tree.

(c) [2 marks] Because heaps are complete binary trees, it is possible to store a heap efficiently in an array data structure, with the root stored at index 0. Suppose a node in a heap has a parent node (i.e. it is not the root node). If this node is at position i in the array which stores the heap, what is the position of its parent node?

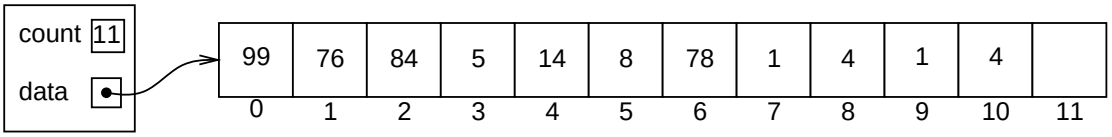
(d) [2 marks] what are the indices of the children (if they exist)?

(e) [2 marks] What is the big-O cost of heapify?

(Question 7 continued on next page)

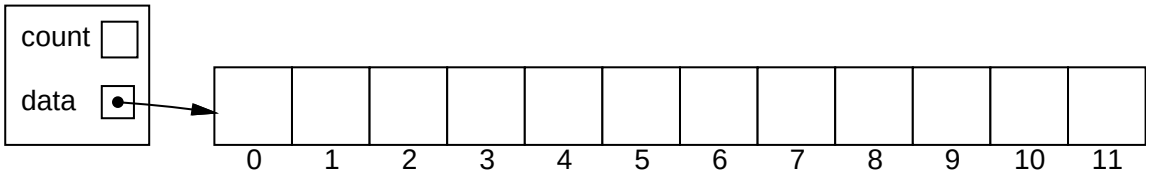
(Question 7 continued)

Consider the following HeapQueue, where the integer represents the priority of each element in the array (larger numbers are higher priority). The number under each box is just its index in the array.



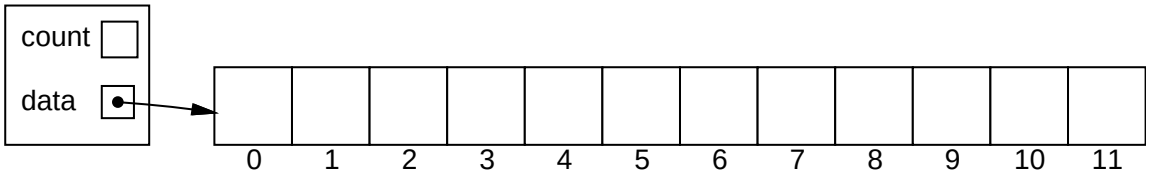
(f) [5 marks] Show the state of the HeapQueue after poll() has been called on it once.
Hint: it might help to first draw the heap as a tree.

After poll:



(g) [5 marks] Re-starting from the HeapQueue shown *at the top of the page*, show its state if a new element with priority 21 is offered to the queue.

After offer:



Question 8. Various Topics [19 marks]

(a) [11 marks] Complete the table below, which gives the asymptotic ("big O") average costs of operations under 3 different implementations of the Bag interface. The first one is done for you.

Data Structure	*Adding*	*Finding*	*Removing*
Unsorted Array	$\mathcal{O}(1)$		
Sorted Array			
Linked List (unsorted)			
Binary Search Tree (assuming it is balanced)			

Suppose a hash function for string values returns an integer between 0 and 2^{32}, and a hash table is of size 37.

(b) [2 marks] How could the hash function value be restricted to index the hash table?

(c) [2 marks] Why is the value 37 better for the size of the hash table, than 39?

(d) [4 marks] Give two other attributes the hash function should possess to make it a good hash function.

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Appendix (may be removed)

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();

public class LinkedNode<E>
  public E get();
  public void set(E item);
  public LinkedNode<E> next();
  public void setNext(LinkedNode<E> nextNode);
```