COMP 103 : Test 2

WITH SOLUTIONS

November 1, 2023

9:30 AM - 11:30 AM

Test Instructions

- **Time Limit:** 120 Minutes
- Write your **Full Name** and **Student ID** at the top of the **first page** of the test paper. For all subsequent pages, include your **Student ID** at the top.
- Attempt **all questions** in the test paper.
- The test will be marked out of **120 marks**.
- Answer in the appropriate boxes if possible. If you write your answer elsewhere, make it clear where your answer can be found.
- There are spare pages for your working and your answers in this test, but you may ask for additional paper if you need it.
- If you encounter a question that appears unclear, feel free to request **clarification** from the invigilator.
- A brief Java Documentation and a summary of collections are made available with the test.
- You can assume that all libraries required for programs are imported and are available for you to use.

Question	Max. mark	Earned mark
1. Properties of Collections	20	
2. Using Collections	22	
3. Cost of Algorithms	20	
4. General Trees	30	
5. Traversing Graphs	12	
6. Binary Search	8	
7. Heaps	8	
TOTAL	120	

Examiners use only

Question 1. Properties of Collections [20 marks]

For questions **1.a., 1.b, 1.c, 1.d.** and **1.e.**, circle the right answer(s) from the list.

1.a. [4 marks]

Which implementation of the 'Set' interface in Java's collections framework maintains elements in a sorted order?

1. ArrayList 2. LinkedHashSet 3. HashSet 4. TreeSet

```
// Answer: 1. TreeSet
```

1.b. [4 marks]

Which data structure in Java's collections framework provides fast random access to elements but may be less efficient for insertions and removals in the middle?

1. HashSet 2. PriorityQueue 3. TreeMap 4. ArrayList

```
// Answer: 4. ArrayList
```

1.c. [4 marks]

When implementing the `equals()` method for a class, which of the following statements is true regarding the `compareTo()` method if we want *to maintain consistency*, assuming the class has both methods implemented?

1. The `compareTo()` method should return -1 for any two objects that are considered equal by `equals()`.
2. The `compareTo()` method should return 0 for any two objects that are considered equal by `equals()`.
3. The `compareTo()` method should return 1 for any two objects that are considered equal by `equals()`.
4. None of the above is necessary.

```
// Answer: 2.
```

1.d. [4 marks]

Consider the following lines of Java code. Which of these examples demonstrates the practice of 'programming to interface'? Select the line(s) that represent(s) the 'programming to interface' concept.

1. `ArrayList<String> list = new ArrayList<>();`
2. `Map<String, Integer> map = new HashMap<>();`
3. `Set<Double> set = new HashSet<>();`
4. `LinkedList<Character> linkedList = new LinkedList<>();`

```
//Answer: Lines 2. and 3.
```

1.e. [4 marks]

Which one of the following data structures in Java's Collection Framework cannot have a `null` element?

```
  1. ArrayList         2. HashSet         3. TreeSet         4. LinkedList

// Answer: 3. TreeSet
```

Question 2. Using Collections [22 marks]

Given `WordData` class as bellow,

```
public class WordData {
    public String word; // a word encountered in the text
    public int count;   // frequency count
    WordData(String w) {
        word = w;
        count = 1; // Count is set to be 1 when a a WordData onject is created
    }
}
```

complete the following class called `WordFrequencyAnalyser`. The goal of this program is to count the frequency of words encountered in a text and save them along with their corresponding `WordData` objects in an appropriate data structure in *ascending* alphabetical order and ignoring the case of letters. You'll need to complete the following tasks:

2.a. [3 marks]

Declare and initialise a `TreeMap` to store the words and their corresponding `WordData` objects.

```
public class WordFrequencyAnalyser {
    // Answer to 2.a.=============

    private Map<String, WordData> words = new TreeMap<>();
```

2.b. [8 marks]

Implement the `processWord` method to process a word and update the `WordData` objects in your data structure. If the word is encountered for the first time, create a new `WordData` object. If it has been encountered before, update the count. Ignore the case of the letters: e.g., `Book` and `book` are considered the same.

```
public void processWord(String word) {
        //Answer to 2.b.==================
        if (word != null) { // [1 mark for nullity check]
            word = word.toLowerCase(); // Normalize word to lowercase
                                       // [1 mark for checking case correctly]
```

```
            if (words.containsKey(word)) {//[3 marks for incrementing count]
                // Word already exists, update count
                WordData existingWordData = words.get(word);
                existingWordData.count++;
            } else {
                // Word is encountered for the first time [3 marks]
                WordData newWordData = new WordData(word);
                words.put(word, newWordData);
            }
        }
}
```

2.c. [6 marks]

Implement the `getFrequencySorted` method to return a `List` of `WordData` objects from `words` that is sorted by word frequency in *descending order*. Use a lambda expression for sorting

```
public List<WordData> getFrequencySorted() {

        // Answer:======================
        List<WordData> wordList = new ArrayList<>(words.values());//[2 marks]
        wordList.sort((a, b) -> b.count - a.count); // [3 marks]
        // OR: Collections.sort( wordList, (a,b) -> b.count - a.count );
        return wordList; //[1 mark]


    }
```

2.d. [5 marks]

Implement the `print()` method to 1. Using the map, print all the words along with their frequencies where the words are sorted *alphabetically*, and then 2. Using the list, print all the words along with their frequencies where the words are sorted by *frequency*. Make use of `getFrequencySorted` method.

```
    public void print() {
        // Answer:==============================
        // Output data from the map (sorted by word) [2 marks]
        for (WordData data : words.values()) {
            UI.println(data.word + " (" + data.count + ")");
        }
```

```
        // Output data from the list (sorted by frequency) [3 marks]
        List<WordData> wordList = getFrequencySorted();
        UI.println("\nList of words sorted by frequency of occurrence:\n");
        for (WordData data : wordList) {
            UI.println(data.word + " (" + data.count + ")");
        }
    } // End of print() method
} // End of WordFrequencyAnalyser class
```

Question 3. Cost of Algorithms [20 marks]

3.a. [5 marks]

Consider the Big-O (worst-case) costs of the fragment of code below, where `mylist` is an `ArrayList<String>`, of size n.

```
List<String> words = new ArrayList<String>();//cost = O(1), times=1
for (int i = 0; i < mylist.size(); i++) {
    for (int j = 0; j < mylist.size(); j++) {
        if (mylist.get(i).charAt(0) == mylist.get(j).charAt(0)) {
                                          //cost = O( 1 ), times=n^2
            words.add(mylist.get(i));     //cost = O( 1 ), times=n^2
        }
    }
}
                                            // Total Cost=O(n^2)
```

3.b. [5 marks]

Consider the Big-O (worst-case) costs of the fragment of code below, where `mylist` is an `ArrayList<Integer>`, of size n.

```
Set<Integer> numbers = new TreeSet<Integer>();//cost = O(1), times=1
for (int i = 0; i < mylist.size(); i+=3) {
    if (mylist.get(i) % 2 == 0) {            // cost = O(1), times=n/3
        numbers.add(mylist.get(i));      // cost = O(Log n), times=n/3
    }
}
                                             // Total Cost=O(n Log n)
```

3.c. [5 marks]

A clinic uses a HashMap to store its patients, where the Patient ID is the key, and the patient's medical history is the value. If it takes 80 nanoseconds to retrieve a patient's medical history when the clinic has 10,000 patients, how long would you expect it to take when the clinic has 100,000 patients? Explain your reasoning.

```
ANSWER: It would still take approximately 80 nanoseconds to retrieve a patient's medical
↪  history. HashMaps, when utilized effectively and avoiding hash collisions, provide
↪  constant-time performance, O(1), for retrieval operations regardless of their size.
```

3.d. [5 marks]

A hospital uses a *sorted* `ArrayList` to maintain its list of appointments in chronological (i.e., sorted by appointment time) order. When the hospital has 1,000 appointments scheduled, it takes 5 milliseconds to insert a new appointment into the correct position in the list. If the hospital had 10,000 scheduled appointments, how long would you expect it to take to insert a new appointment in the correct position? Explain your reasoning.

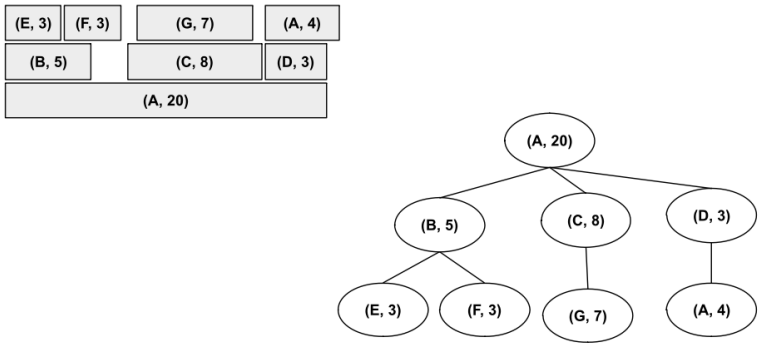
```
ANSWER: 50 milliseconds. Inserting an element into a sorted ArrayList takes O(n) time. If
 ↪ inserting into a list of 1,000 appointments takes 5 milliseconds, then for a list ten
 ↪ times bigger (10,000 appointments), it would take approximately 10 times longer, or 50
 ↪ milliseconds, to insert a new appointment. This is because the operation involves
 ↪ searching for the correct position, which is O(log n) with binary search, and then
 ↪ inserting, which is O(n) due to potential shifting of elements. These costs add, so the
 ↪ dominant factor here is the O(n) insertion.
```

Question 4. General Trees [30 marks]

In this question we use general trees to implement a simple Box Stacking game. Each box has a width, and contains a letter ("A", "B",...). The program represents each box as a Box object, which stores data about its width, the letter, and a list of any other boxes that are stacked directly on top. The Box class has the following methods:

```
Box class:
public String getLetter (); // get the letter of the box
public double getWidth();  // get the width of the box
public List<Box> getTopBoxes(); // get the list of the boxes
                                // directly on top of the selected box
public String toString (); // return a String with format "(letter, width)"
```

The following figure shows an example of a set of stacked boxes (left-hand side) and its representation as a general tree (right-hand side). (A, 20) represents a box with letter `A` and width 20. If `getTopBoxes()` is called on (A,20) it will return a list consisting of (B,5), (C,8) and (D,3). And, if it is called on (B,5) it will return a list consisting of (E,3) and (F,3).



4.a. [10 marks]

Complete `printBoxes()` method which is given the root node, and prints out all the boxes in the tree, using indentation to show the structure. For example, the tree on the previous page should be printed as:

```
(A, 20)
    (B, 5)
        (E, 3)
        (F, 3)
    (C, 8)
        (G, 7)
    (D, 3)
        (A, 4)
```

```
    public void printBoxes(Box root){
    // Answer:=================
        printBoxes(root , "");
    }

    public void printBoxes(Box root, String indent){
        UI.println(indent + root.toString());
        for (Box child : root.getTopBoxes())
            printBoxes(child , indent+" ");
    }
```

4.b. [10 marks]

Complete the following `numOccurrences()` method which is given the root node and a letter. The method should return the number of boxes containing the given letter (in lowercase or uppercase).

For example, calling `numOccurrences(root, "A")` returns 2.

```
    public int numOccurrences(Box root, String letter ){

        // Answer: ====================
         int count = 0;
        if (root.getLetter().equalsIgnoreCase(letter))
            count = 1;
        for(Box box: root.getTopBoxes()){
            count += numOccurrences(box, letter);
        }
        return count;
    }

//
```

4.c. [10 marks]

In the game, a box is unstable if the total width of boxes directly on top is greater than its own width. Complete the following `findUnstableBoxes()` method which is given the root node, and returns a list of unstable boxes.

For example, calling `findUnstableBoxes(root)` returns a list containing two boxes (B, 5) and (D, 3).

```
public List <Box> findUnstableBoxes(Box root){

// Answer:================
    List<Box> ans = new ArrayList<Box>();
    findUnstableNodes(root, ans);
    return ans;
}

public void findUnstableBoxes(Box root, List<Box> ans){
    double width = root.getWidth();

    //sum all the widths
    double topWidth = 0;
    for(Box box: root.getTopBoxes()){
        topWidth += box.getWidth();
    }
    if(width<topWidth)
        ans.add(root);

    for(Box box: root.getTopBoxes()){
        findUnstableBoxes(box, ans);
    }
}
```

Question 5. Traversing Graphs [12 marks]

You are writing a travel app that helps customers to navigate in a train network containing multiple train stations. You can use a graph to represent the train network where each node represents a train station. Two stations are considered 'neighbours' if they are connected directly in the graph (without any other station/nodes in between). The Station class has the following methods:

```
Station class :
public String getName(); // get the name of the Station
public Set<Station> getNeighbours(); // get the set of neighbouring stations
```

5.a. [6 marks]

Complete the following `isConnected()` method which returns `true` if two Stations are connected, directly or indirectly, in the network and returns `false` otherwise.

```
    public boolean isConnected(Station s1, Station s2){

        // Answer:======================
        return isConnected(s1, s2, new HashSet<Station>());
    }

    public boolean isConnected(Station s1, Station s2) {
        // Create a set to keep track of visited stations during DFS
        Set<Station> visited = new HashSet<>();

        // Start DFS from s1 to see if it can reach s2
        return dfs(s1, s2, visited);
    }

    private boolean dfs(Station current, Station target, Set<Station> visited) {
        // If we have reached the target station, they are connected
        if (current == target) {
            return true;
        }

        // Mark the current station as visited
        visited.add(current);

        // Iterate through neighbors of the current station
        for (Station neighbor : current.getNeighbors()) {
            // If the neighbor has not been visited, recursively check if it can reach the
            ↪  target
```

```
            if (!visited.contains(neighbor) && dfs(neighbor, target, visited)) {
                return true;
            }
        }

        // If no path is found after exploring neighbors, return false
        return false;
    }
```

5.b. [6 marks]

Complete the following `withinDistance()` method, which should return a set of train stations reachable from the starting station (`start`) while considering a maximum number (`maxDist`) of intermediate stations that can be traversed.

```
    public Set<Station> withinDistance(Station start, int maxDist) {

    // Answer:====================
        return withinDistance(start, maxDist, 0, new HashSet<Station>());
    }

    public Set<Station> withinDistance(Station start,
                                       int maxDist,
                                       int currentDist,
                                       Set<Station> within) {
        if (currentDist <= maxDist) {
            within.add(start);
        }
        if (currentDist > maxDist) {
            return within;
        }

        for (Station stn : start.getNeighbours()) {
            withinDistance(stn, maxDist, currentDist + 1, within);
        }
        return within;
    }
```

Question 6. Binary Search [8 marks]

6.a. [4 marks]

A music store has a collection of albums sorted by release date. If the store has 1,024 albums and uses binary search to find an album, what is the maximum number of comparisons the store would need to make?

```
ANSWER: 10 (i.e. log2 of 1,024)
```

6.b. [4 marks]

Consider the sequence [10, 20, 30, 40, 50, 60, 70, 80, 90]. If you're searching for the number 35 using binary search, how many comparisons will you need before determining that 35 is not in the list?

```
ANSWER: 3 comparisons (First 50, then 30, then 40)
```

Question 7. Heaps [8 marks]

Background: In this course, we have studied the "heap": a complete binary tree, implemented using an array, that maintains the heap property. For a max heap, every parent node has a value greater than or equal to any of its children.

Suppose you have a max heap that was created as follows:

```
   private List<Integer> heap = new ArrayList<>();
```

And which has since then been populated with several integer values.

Below is a method that inserts a value into the Max Heap. It uses a helper method `pushUp(index)` which ensures the heap property is maintained after the insertion. Complete the `pushUp(index)` method.

```
public void insert(int value) {
    heap.add(value); // add to the end of the heap
    pushUp(heap.size() - 1); // start pushing up from the last position (where the new
    ↪ value was added)
}
```

```
private void pushUp(int index) {
    //Answer
    if(index == 0) return; // root of the heap, nothing to push up

    int parentIndex = (index - 1) / 2;

    if(heap.get(parentIndex) < heap.get(index)) {
        // swap parent with current value
        int temp = heap.get(parentIndex);
        heap.set(parentIndex, heap.get(index));
        heap.set(index, temp);

        pushUp(parentIndex);
    }
}
```