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

**EXAMINATIONS – 2018**

**TRIMESTER 2**

**COMP 103**
**INTRODUCTION TO DATA STRUCTURES AND ALGORITHMS**

**Time Allowed:** TWO HOURS

**CLOSED BOOK** ******** WITH SOLUTIONS **********

**Permitted materials:** Silent non-programmable calculators or silent programmable calculators with their memories cleared are permitted in this examination.

Printed foreign language–English dictionaries are permitted.

No other material is permitted.

**Instructions:** Attempt ALL Questions.
The examination will be marked out of 120 marks.
Brief Documentation is at the end of the examination script
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 examination, but you may ask for additional paper if you need it.

## Questions:



# Date of revision: November 22, 2018

**Question 1. Collection Types** **[16 marks]**

(a) **[4 marks]** What is the key property of the Java Set type that distinguishes it from the more general Collection type?

no duplicates are allowed

(b) **[4 marks]** Suppose you are writing a program to plan the procession of floats in the city's annual Christmas parade.

- What collection type would you use to record the floats and their order in the parade?
- Justify your choice.

List of floats, the list keeps the order, but lets you add and remove at any position.

(c) **[4 marks]** Suppose you are writing a program to manage email requests for an on-line help-desk.

- Why would it be a bad idea to store the requests in a Stack?
- What would be a better Collection type?

The oldest requests would be at the bottom and might never get processed. A queue would be better.
Alternatively: You might need to be able to access any of the emails, so a List would be better

(Question 1 continued on next page)

**(Question 1 continued)**

(d) **[4 marks]** A PriorityQueue has the same operations (offer, poll, and peek) as an ordinary Queue (eg ArrayDeque) but it behaves differently.

- How does PriorityQueue behave differently from ordinary Queues?
- Give an example of when a PriorityQueue would be a better choice than an ordinary queue.

Difference:

In ordinary queues, the item removed is always the oldest item that was added to the queue.
In a PriorityQueue the item removed is the highest priority item, regardless of when it was added.

Example:

In a simulation of a hospital, where patients are treated according to priority.
In a program to manage requests for repairs where the urgency of the repair is important.

**Question 2. Lists, Maps, and Sorting** **[28 marks]**

Suppose you are writing part of a program that processes orders from an online store.

The program has an allOrders field containing a List of Orders.

- Each Order has a list of items in the order;
- Each Item has a productID and a count of how many of the product are wanted.

The program also has an allProducts field that contains a Map containing information about each of the Products. The key of the allProducts map is the productID (a String). Each Product contains a productID, a price, and a set of products that complement the product.

```
private List<Order> allOrders;
private Map<String, Product> allProducts;
```

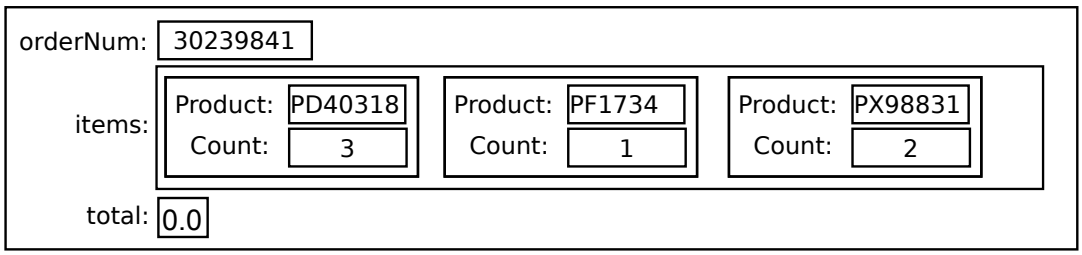
Here are descriptions of the methods of the Order, Item, and Product classes:

```
public class Order {
    public String getOrderNumber()        // returns the invoice number of the order
    public List<Item> getItems()          // returns the List of Items in the order
    public void setTotal(double amt)      // records the total price of an order
}
```

```
public class Item {
    public String getProductID()      // returns the productID being ordered
    public int getCount()             // returns how many of the product are being ordered
}
```

```
public class Product {
    public String getID()                  // returns the productID of the product
    public double getPrice()               // returns the price of the produce
    public Set<String> getComplements() // returns a set of productIDs of other products
                                           //     that complement this product
}
```

Here is a sketch of one possible Order in allOrders. The Order contains three Items: 3 of product PD40318, 1 of product PF1734, and 2 of product PX98831. The total of the Order has not yet been computed.




(Question 2 continued on next page)

**(Question 2 continued)**

(a) **[9 marks]** Complete the following computeAllTotals method. For each Order in the allOrders field, it should compute the total price of the order, based on the price of each product in the order and the count of that product and then store the total in the Order.

```
public void computeAllTotals(){
    for (Order order : allOrders){
        double total = 0;
        for (Item item : order.getItems()){
            Product product = allProducts.get(item.getProductID());
            total = total + item.getCount() * product.getPrice();
        }
        order.setTotal(total);
    }




}
```

(b) **[11 marks]** Complete the following makeRecommendation method which should return a Set of Products to recommend to the customer based on the products in the order. It should recommend a product if it is not in the order already and is a complement to any product in the order.

```
public Set<Product> makeRecommendation(Order order){
    Set<Product> ans = new HashSet<Product>();
    for (Item item : order.getItems()){
        Product product = allProducts.get(item.getProductID());
        for (String compID : product.getComplements()){
            Product compProduct = allProducts.get(compID);
            ans.add(compProduct);
        }
    }
    for (Item item : order.getItems()){
        Product product = allProducts.get(item.getProductID());
        ans.remove(product);
    }
    return ans;
OR
    Set<String> orderedIDs = new HashSet<String>();
    for (Item item : order.getItems()){orderedIDs.add(item.getProductID())};
    Set<Product> ans = new HashSet<Product>();
    for (String ordID : orderedIDs){
}       for (String compID : allProducts.get(ordID).getComplements()){
            if (!orderedIDs.contains(compID)){ans.add(allProducts.get(compID);}
    }}
    return ans;
```

(Question 2 continued on next page)

**SPARE PAGE FOR EXTRA ANSWERS**

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

**(Question 2 continued)**

(c) **[8 marks]** Complete the following sortItemList method that should sort the List of Items in an Order. Items with higher counts should come before Items with lower counts. Items with the same count should be sorted by their productID in standard String order.
Note that Items are not comparable. You may use a lambda or define a compareItems method.

```
    public void sortItemList (Order order){
        Collections.sort(order.getItems(), (Item it1, Item it2) ->{
                if (it1.getCount()>it2.getCount()) {return -1;}
                if (it1.getCount()<it2.getCount()) {return 1;}
                return it1.getProductID().compareTo(it2.getProductID());
        });
OR
        Collections.sort( list , this::compareByProductID));
    }
    public int compareItems(Item it1, Item it2){
        if (it1.getCount()==it2.getCount()){
            it1.getProductID().compareTo(it2.getProductID());
        }
        return (it2.getCount()-it1.getCount());
    }
```

**Question 3. Complexity: Big-O costs** **[24 marks]**

(a) **[8 marks]** The two fragments of code below are very similar, and print out the same elements of a list. Assume the size of the list is $n$.

For each fragment, work out the cost (in Big-O notation) by

- working out the cost of performing each line once.
- working out the number of times each line will be performed.
- computing the total cost.

Note the two highlighted differences in the second fragment.

```
for (int k = 0; k < list.size(); k++) {
    for (int j = 0; j < list.size(); j++) {
        if (k==j){                          // cost= O( 1 )   times= n^2
            UI.println( list.get(k));       // cost= O( 1 )   times= n
        }
    }
}
                                            // Total Cost = O( n^2 )
```

```
for (int k = 0; k < list.size(); k++) {
    for (int j = [k]; j < list.size(); j++) {
        if (k==j){                          // cost= O( 1 )   times= n
            UI.println( list.get(k));       // cost= O( 1 )   times= n
            [break];
        }
    }
}                                           // Total Cost = O( n )
```

(b) **[8 marks]** Assume that allWords is a Collection containing $n$ Strings. The following code fragment prints the Strings out in alphabetical order. Work out the cost in Big-O notation.

```
Queue<String> pq = new PriorityQueue<String>(); // cost= O( 1 )      times= 1
for (int i = allWords.size()-1; i>=0; i--){
    pq.offer(allWords.get(i));                  // cost= O( log(n) ) times= n
}
while ( ! pq.isEmpty()){                        // cost= O( 1 )      times= n
    String item = pq.poll();                    // cost= O( log(n) ) times= n
    outFile.println(item);                      // cost= O( 1 )      times= n
}
                                                // Total Cost = O( n log(n) )
```

(Question 3 continued on next page)

**(Question 3 continued)**

(c) **[4 marks]** A program uses an ArrayList to store all the words in a document.

When the List has 100,000 words, the program takes 12 microseconds to remove the first word from the list.

If the List had 10,000,000 words, how long would you expect the program to take to remove the first word? Explain why.

About 1200 microseconds = 1.2 milliseconds
Removing the first word means moving every remaining word down one position. There are 100 times as many words in the list, so the program will have to move down about 100 times as many words to find an item, so it should take about 100 times longer

(d) **[4 marks]** A program uses a HashSet to store all the *distinct* words in a document.

When the Set has 10,000 words, the program takes 120 nanoseconds to check whether the set contains a given word.

If the Set had 1,000,000 words, how long would you expect the program to take to check if the set contains a given word? Explain why.

About the same. A HashSet takes the same time to access an item, regardless of how large the set is.

**Question 4. Simulation with Collections** **[22 marks]**

Suppose you are writing a program to simulate passengers going through an airport security screening area. There are a set of queues, one for each X-ray machine. When a passenger arrives at the area, they join the shortest queue.

At each timestep, the program

- decides whether a passenger arrives, and adds them to the back of the shortest queue.
- advances the screening of the passenger at the front of each queue by one "tick".
- any passenger who has now completed their screening is removed from their queue.

You are to write the addPassenger and advanceAllScreening methods.

The Passenger class has the following constructor and methods:

```
Passenger class:
    public Passenger(int time);                 // make a new passenger, recording arrival time
    public void advanceScreeningByTick();       // removes 1 tick from remaining screening time
    public boolean completedScreening();        // true if passenger has completed screening
    public int getArrivalTime();                // returns time tick when passenger arrived
```

The SecuritySimulation class has the following field, constructor and run method.

```
public class SecuritySimulation {
    private Set<Queue<Passenger>> allLanes;

    public SecuritySimulation(){
        allLanes = new HashSet<Queue<Passenger>>();
        for(int i = 0; i<5; i++){                    // initialise queues
            allLanes.add(new ArrayDeque<Passenger>());
        }
    }

    public void run (){
        int time = 0;
        while (true){
            time++;
            if (Math.random()<0.05) {
                addPassenger(new Passenger(time));      // subquestion (a)
            }
            advanceAllScreening();                      // subquestion (b)
        }
    }
}
```

**Hint**: sketch a diagram of the content of allLanes.

(Question 4 continued on next page)

**(Question 4 continued)**

(a) **[11 marks]** Complete the following addPassenger method which should add the passenger to the shortest queue (fewest number of passengers) in allLanes:

```
public void addPassenger(Passenger p){
    Queue<Passenger> minQ = null;
    int min = Integer.MAX_VALUE;
    for (Queue<Passenger> queue : allLanes){
        if (queue.size() < min) {
            min = queue.size();
            minQ = queue;
        }
    }
    minQ.offer(p);




}
```

(b) **[11 marks]** Complete the following advanceAllScreening method which should

- advance the screening of each passenger at the head of a queue in allLanes by one tick
- dequeue any passenger who has completed their screening

```
public void advanceAllScreening(){
    for (Queue<Passenger> queue : allLanes){
        if (!queue.isEmpty()) {
            Passenger p =queue.peek();
            p.advanceScreeningByTick();
             if (p.completedScreening()){
                 queue.poll();
             }
        }
    }









}
```

**Question 5. Traversing General Trees** **[20 marks]**

In the lectures and assignment 6, we used a general tree implemented using GTNode to represent expressions for a calculator. The item in a GTNode was an operator or a number.

Note, this version of GTNode is **not** Iterable: You must use

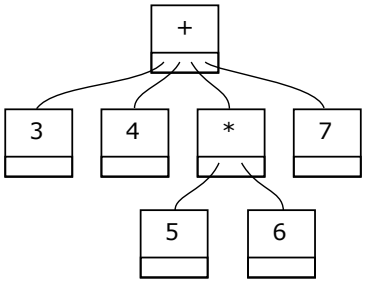
```
for ( int i=0; i<node.numChildren(); i++){... node.getChild(i) ...}|
```

to iterate through the children of a node.

```
class GTNode<E>
   public GTNode(E item);                          // constructor
   public E getItem();                             // return item in the node
   public int numChildren();                       // return number of children of the node
   public void addChild(GTNode<E> child);          // add a child
   public GTNode<E> getChild(int i);               // return i'th child
   public void removeChild(int i);                 // remove i'th child
```

(a) **[9 marks]** Complete the following printBRPN method which should print out an expression in "Bracketed Reverse Polish Notation", where every subtree is printed out with brackets around it, and each operator is printed *after* its arguments.

For example, the expression tree




should be printed as: `((3)(4)((5)(6)*)(7)+)`

```
public void printBRPN(GTNode<String> node){
    UI.print("(");
    for (int i=0; i<node.numChildren(); i++){
        printBRPN(node.getChild(i));
    }
    UI.print(node.getItem()+ ")");









}
```

(Question 5 continued on next page)

**(Question 5 continued)**

(b) **[11 marks]** An expression which has a + expression inside another + expression is a bit redundant. For example, the expression

```
(* 1 (+ 2 (+ 3 4) (+ 5 (+ 6 7) 8) 9) 10)
```

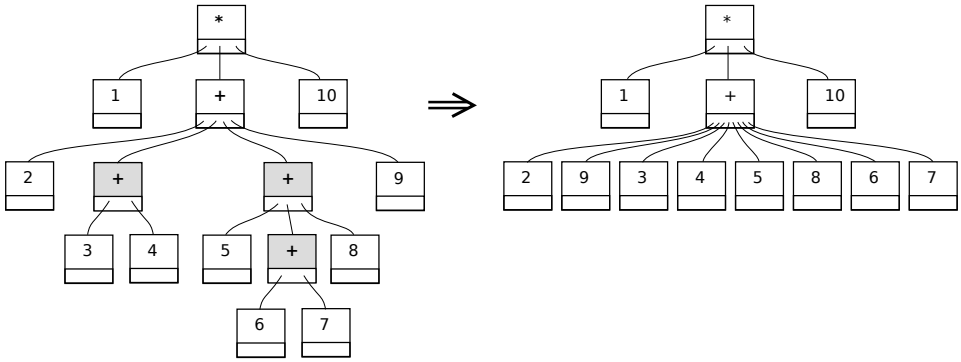
could be written more simply as

```
(* 1 (+ 2 3 4 5 6 7 8 9) 10)
```

or equivalently

```
(* 1 (+ 2 9 3 4 5 8 6 7) 10)
```

where the arguments of the lower three "+" nodes (shaded) have been moved up to the highest "+" node.




Complete the following fixNestedPlus method which should search an expression tree for nodes with a "+" operator which have a child node that also has a "+" operator. The method should remove the child node, and add all the children of the child node to the parent node. **Hint:** use a post-order traversal.

```
public void FixNestedPlus(GTNode<String> expr){
        for (int i=0; i<expr.numChildren(); i++){
            fixNestedPlus(expr.getChild(i));
         }
         if (expr.getItem().equals("+")){
             for (int i=0; i<expr.numChildren(); i++){
                 GTNode<String> child = expr.getChild(i);
                 if (child.getItem().equals("+")){
                     for (int j=0; j<child.numChildren(); j++){
                         expr.addChild(child.getChild(j));
                     }
                     expr.removeChild(i);
                     i--;
                 }
             }
         }




}
```

**Question 6. Traversing Graphs** **[10 marks]**

You are writing a program to set up temporary cellphone networks in disaster areas. A network consists of many small base stations, each of which is connected to several nearby base stations by cables or line-of-sight wireless links.

A critical property of such a network is that there should be a path through the network from every base station to every other base station. Your program needs a method for checking that.

Your program stores information about all the base stations in a List of BaseStation objects.

```
private List<BaseStation> allStations;    // List of all BaseStations in the network
```

Each BaseStation object contains a Set of its neighbours, and BaseStation is Iterable so that you can use a foreach loop to iterate through the neighbours of a BaseStation. You do not need to know any of the other fields or methods of the BaseStation class.

(a) **[5 marks]** Complete the following getConnected method which should return a Set of all the BaseStations to which a base is connected over the network (including itself).
**Note**: it uses a visited Set and returns the set at the end.

```
public Set<BaseStation> getConnected(BaseStation base){
    Set<BaseStation> visited = new HashSet<BaseStation>();
    getConnected(base, visited );
    return visited ;
}

public void getConnected(BaseStation base, Set<BaseStation> visited){
     visited .add(base);
     for (BaseStation neighbour : base){
         if (! visited .contains(neighbour)) {
             getConnected(neighbour, visited );
         }
     }
}
```

(Question 6 continued on next page)

**(Question 6 continued)**

(b) **[5 marks]** Complete the following checkNetwork() method which should use the allStations list and the getConnected method to check that every base station is connected to every other base station. For full marks, your method should be reasonably efficient and not do unnecessary work.

```
public boolean checkNetwork(){
    Set<BaseStation> fromFirst = getConnected(allStations.get(0));
    for (BaseStation base : allStations ){
        if (! fromFirst.contains(base) ){
            return false;
        }
    }
    return true;









}
```

* * * * * * * * * * * * * * *

**SPARE PAGE FOR EXTRA ANSWERS**

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

# Documentation for COMP 103 Exam

Brief, simplified specifications of some relevant Java collection types and classes.

**Note**: *E* stands for the type of the item in the collection.

---

```
interface Collection<E>
    public boolean isEmpty()                    // cost: O(1) for standard collection classes
    public int size()                           // cost: O(1) for standard collection classes
    public void clear()
    public boolean add(E item)
    public boolean contains(Object item)
    public boolean remove(Object element)
```

---

```
interface List<E> extends Collection<E>
    // Implementations: ArrayList
    public boolean isEmpty()
    public int size()
    public void clear()
    public E get(int index)                     // cost: O(1)
    public E set(int index, E element)          // cost: O(1)
    public boolean contains(Object item)        // cost: O(n)
    public void add(int index, E element)       // cost: O(n) (unless index close to end.)
    public E remove(int index)                  // cost: O(n) (unless index close to end.)
    public boolean remove(Object element)       // cost: O(n)
```

---

```
interface Set extends Collection<E>
    // Implementations: HashSet, TreeSet
    public boolean isEmpty()
    public int size()
    public void clear()
    public boolean add(E item)                  // cost: O(1)       for HashSet
                                                //       O(log(n))  for TreeSet
    public boolean contains(Object item)        // cost: O(1)       for HashSet
                                                //       O(log(n))  for TreeSet
    public boolean remove(Object element)       // cost: O(1)       for HashSet
                                                //       O(log(n))  for TreeSet
```

---

```
class Stack<E> implements Collection<E>
    public boolean isEmpty()
    public int size()
    pubic void clear()
    public E peek()                 // cost: O(1)
    public E pop()                  // cost: O(1)
    public E push(E element)        // cost: O(1)
    // (peek and pop return null if the queue is empty)
```

---

```
interface Queue<E> extends Collection<E>
   // Implementations: ArrayDeque, LinkedList, PriorityQueue
   public boolean isEmpty()
   public int size()
   public void clear()
   public E peek()                    // cost: O(1)      for ArrayDeque, LinkedList
                                      //       O(1)      for PriorityQueue
   public E poll()                    // cost: O(1)      for ArrayDeque, LinkedList
                                      //       O(log(n)) for PriorityQueue
   public boolean offer(E element)    // cost: O(1)      for ArrayDeque, LinkedList
                                      //       O(log(n)) for PriorityQueue
   // (peek and poll return null if the queue is empty)
```

```
interface Map<K, V>
   // Implementations: HashMap, TreeMap
   public V get(K key)                // cost: O(1)      for HashMap
                                      //       O(log(n)) for TreeMap
   public V put(K key, V value)       // cost: O(1)      for HashMap
                                      //       O(log(n)) for TreeMap
   public V remove(K key)             // cost: O(1)      for HashMap
                                      //       O(log(n)) for TreeMap
   public boolean containsKey(K key)  // cost: O(1)      for HashMap
                                      //       O(log(n)) for TreeMap
   public Set<K> keySet()             // cost: O(1)
   public Collection<V> values()      // cost: O(1)
   // get returns null if key not present; put & remove return the old value, if any)
```

```
class Collections
   public void sort(List<E> list);                          // cost = O(n log(n)) in general
                                                            //        O(n)        almost sorted
   public void sort(List<E> list, (E e1, E e2)->{..});      // cost = O(n log(n)) in general
                                                            //        O(n)        almost sorted
   public void swap(List<E> list, int i, int j);            // cost = O(1)
   public void reverse(List<E> list);                       // cost = O(n)
   public void shuffle(List<E> list);                       // cost = O(n)
```

```
interface Comparable<E>          // Items can be compared for sorting or a priority queue.
   public int compareTo(E other); // Comparable objects must have a compareTo method:
    // returns     -ve if this comes before other;
    //             +ve if this comes after other,
    //              0   if this and other are the same
```

```
interface Iterable<E>            // Can use a foreach loop on these items
   public Iterator<E> iterator(); // Iterable objects must have an iterator method:
```

```
Integer and Double constants:
   Integer.MAX_VALUE; Integer.MIN_VALUE;
   Double.MAX_VALUE; Double.NaN; Double.POSITIVE_INFINITY; Double.NEGATIVE_INFINITY;
```