



EXAMINATIONS — 2008

END YEAR

COMP103
Introduction to
Data Structures and Algorithms
SOLUTIONS

Time Allowed: 3 Hours

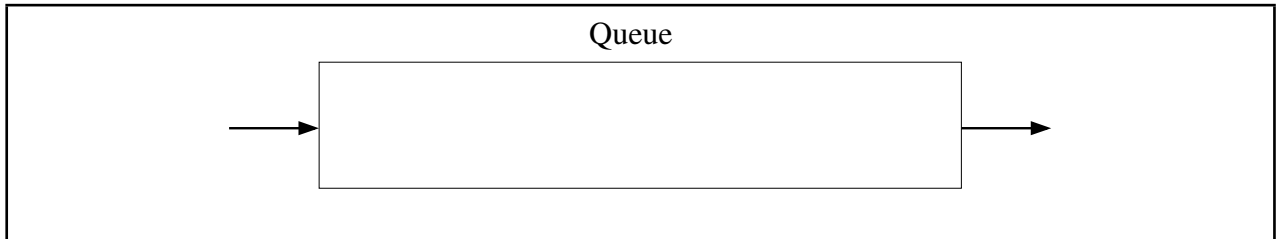
- Instructions:**
1. Attempt **all** of the questions.
 2. *Read each question carefully before attempting it.* (Suggestion: You do not have to answer the questions in the order shown. Do the questions you find easiest first.)
 3. This examination will be marked out of **180** marks, so allocate approximately 1 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 relevant Java classes and interfaces is at the end of the paper.

Questions	Marks
1. Basic Questions	[20]
2. Implementing Collections	[26]
3. Using Collections	[30]
4. Trees	[28]
5. Binary Search Trees	[20]
6. Partially Orderd Trees and Priority Queues	[23]
7. Hashing	[19]
8. Graphs	[14]

Question 1. Basic Questions

[20 marks]

(a) [2 marks] Suppose we start with an empty queue and carry out the following operations in order: offer(P), offer(Q), offer(R), poll(), offer(P). Draw the queue after these have been carried out.



(b) [2 marks] What is the *best*-case asymptotic ('big-O') cost of insertion sort?

$O(n)$

(c) [2 marks] What is the *average*-case asymptotic cost of selection sort?

$O(n^2)$

(d) [2 marks] Name the general strategy that enables both MergeSort and QuickSort to sort a list efficiently.

"Divide and conquer". (nb. Just 'recursion' is not good enough).

(e) [2 marks] How many comparisons are required to find a node in a binary search tree if it contains n items and is perfectly balanced?

$\log(n)$

(Question 1 continued on next page)

(Question 1 continued)

(f) [2 marks] Which kind of traversal will visit all the values in a Binary Search Tree in their natural order (smallest to largest)?

In-order Depth First Traversal

(g) [2 marks] If you were using a linked list to implement a Stack, would you make the top of the Stack be the first node of the list or the last node of the list? Explain why.

Make it the first node of the list. You always operate on the top of the stack, so if you make that the end of the list it'll take n steps every time you operate on the stack, compared to just one if the top of the stack is the front of the list.

(h) [2 marks] What is a leaf node of a tree?

A node with no children.

(i) [2 marks] State the property that must hold for each node in a Partially Ordered Tree.

The value in the node must be greater than the values in both its children. (Or every node must be less than its children, depending on the "direction" of the tree.)

(j) [2 marks] What is the difference between a directed graph and an undirected graph?

In a directed graph, the edges have a direction; in an undirected graph, the edges do not have a direction.

Question 2. Implementing Collections

[26 marks]

In lectures we considered the List implementation `ArrayList`, whose class definition would begin with the declaration of three fields:

```
public class ArrayList <E> extends AbstractList <E> {  
    private E[] data;  
    private int count=0;  
    private static final int INITIALCAPACITY=16;
```

(a) [3 marks] It would then continue by giving a constructor - complete the code for this.

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

(b) [12 marks] Complete the code for the following `add` method for the `ArrayList` class, which adds the specified element at the specified index. Remember to

- check whether the index is sensible: if it isn't, throw an `IndexOutOfBoundsException` exception.
- make appropriate use of (but don't write!) the `ensureCapacity()` method that `ArrayList` has.

```
public void add(int index, E item) {  
  
    if (index<0 || index>count)  
        throw new IndexOutOfBoundsException();  
    ensureCapacity();  
    for ( int i=count; i>index; i--) // move items up  
        data[i] = data[i-1];  
    data[index] = item; // inserts the new item  
    count++; // increment count  
  
}
```

(Question 2 continued on next page)

(Question 2 continued)

(c) [3 marks] Lists in java have a method called `addAll`, which adds all the items from another collection to a list.

`addAll` is required by the *List* interface, but it is *not* necessary to provide an implementation for it in the *ArrayList* class definition. Explain why not.

An implementation (in terms of multiple calls to `add`) is given in the *AbstractList* abstract class. This means `addAll` can be carried out provided we specify `add` in the *ArrayList* class.

(d) [4 marks] Write a version of `addAll` for the *ArrayList* class that adds all the items in a collection to the list.

```
public void addAll(Collection<E> other) {  
    for (E item : other)  
        add(item);  
  
}
```

(e) [4 marks] An efficient version of `addAll` for an *arrayList* would only expand the data array once, to be large enough to hold all the items from the collection. Explain why the efficient version would be considerably faster than a simple version that repeatedly called the `add` method.

If the collection being added was many times the size of the list, the simple version will have to double and copy many times, where as the efficient version could immediately increase the data array to be large enough to hold all the items and would therefore only have to copy each item (in each list) once instead of having to copy many of them twice or more.

Question 3. Using Collections

[30 marks]

(a) [10 marks] Complete the code for the following `reverseNums` method, which is passed a scanner to a file containing only integers. The method uses a stack and returns a list consisting of the integers from the file but in the reverse order.

You will need to create a stack, use the scanner to get the ints, and then build up a list to be returned.

```
public List <Integer> reverseNums(Scanner sc) {  
  
    // create stack  
    Stack <Integer> myNums = new Stack <Integer> ();  
  
    // use scanner to get the ints  
    while (sc.hasNextInt())  
        myNums.push(sc.nextInt());  
  
    // create and build up list  
    List <Integer> revNums = new ArrayList <Integer> ();  
    while (!myNums.isEmpty())  
        revNums.add(myNums.pop());  
  
    return revNums;  
  
}
```

(Question 3 continued on next page)

(Question 3 continued)

The rest of this question requires you to complete two methods for processing information about hotel bookings in Wellington.

Suppose you are given a file listing the hotels followed by strings indicating the different rooms they have available. For example:

```
HILTON  rm1  rm2  cheapo8 deluxe presidentialA  presidentialB
DUXTON  dux1 dux2 dux3    dux4    dux5  new1  new2
DAYTON  da1  da2
HOLIDAYINN  holA  holB    holC    holD  holE  holF  holG  holH
```

Assume that no two rooms are given the same name.

(b) [8 marks] Complete the `readRoomsAndHotels` method below, which is passed a `Scanner` to the above data file, and constructs a `Map` with rooms as the keys and hotel names as the values in the `roomHotelMap` field.

```
private Map <String, String> roomHotelMap;
```

Your method should initialise the `roomHotelMap` field appropriately.

```
public void readRoomsAndHotels(Scanner sc) {

    roomHotelMap = new HashMap <String, String> ();
    while (sc.hasNext()) {
        String hotelName = sc.next();
        String rooms = sc.nextLine();
        Scanner ln = new Scanner(rooms);
        while (ln.hasNext())
            roomHotelMap.put(ln.next(), hotelName);
    }

}
```

(Question 3 continued on next page)

(Question 3 continued)

(c) [12 marks] A second data file gives the bookings of hotel rooms around Wellington on a given day. Each line has a room and the name of the person who has booked it:

```
rm1 Bob Smith
dux4 Mary Jones
cheapo8 Helen Clarke
presidentialA Bob Smith
holB Barack Obama
holE John Key
da2 John McCain
```

From this file and the information in `roomHotelMap`, we would like to find the names of people who have booked rooms in each hotel.

Complete the `hotelsToGuests()` method on the facing page that is passed a `Scanner` to a bookings file (as above) and then prints out the set of all the people booked in each hotel. Note that a person might book more than one room in a hotel, but should only be listed at most once for each hotel.

For example, given the bookings file above, the method should print out

```
DUXTON      Mary Jones,
DAYTON      John McCain,
HOLIDAYINN  John Key, Barack Obama,
HILTON      Bob Smith, Helen Clarke,
```

Hint, you may want to construct a `Map`, with hotels as the keys, and sets of people as the values.

(Question 3 continued)

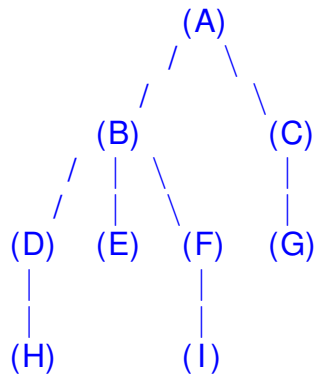
```
public void hotelsToGuests(Scanner sc) {
    Map <String, Set<String>> hotelBookings = new HashMap <String, Set<String>> ();
    while (sc.hasNext()) {
        String room = sc.next();
        String name = sc.nextLine().trim ();
        // get the hotel from the bed
        String hotel = roomHotelMap.get(room);
        if (hotelBookings.get(hotel)==null)
            hotelBookings.put(hotel, new HashSet<String>());
        hotelBookings.get(hotel).add(name);
    }
    for (String hotel : hotelBookings.keySet()){
        System.out.printf ("%12s ", hotel);
        for (String guest : hotelBookings.get(hotel))
            System.out.print(guest+" ", );
        System.out.println ();
    }
}
```

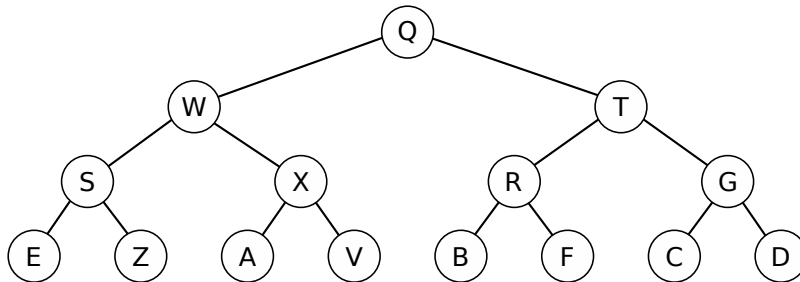
Question 4. Trees

[28 marks]

(a) [2 marks] Draw a tree with 9 nodes that is NOT a binary tree and has four levels of nodes.

There are many such trees, here is one.



(Question 4 continued)**(b)** [9 marks] Consider the following (binary) tree.

Show the order that the nodes would be visited by a

(i) [3 marks] Pre-order Depth First Traversal

QWSEZXAVTRBFGCD

(ii) [3 marks] in-order Depth First Traversal

ESZWA XVQBRFTCGD

(iii) [3 marks] Breadth First Traversal

QWTSXRGEZAVBFCD

(c) [3 marks] If a binary tree has n nodes, and every node either has two children or no children, how many leaves are there in the tree? (Hint: you may want to draw some examples). $(n + 1)/2$

(Question 4 continued on next page)

(Question 4 continued)

Consider the following `TreeNode` class that defines nodes for a general tree. Each node has a list of children. The class provides a constructor and two methods: `getValue`, and `getChildren`.

```
public class TreeNode <E> {  
  
    private E value;  
    private List<TreeNode<E>> children;  
  
    public TreeNode(E v){  
        value = v;  
        children = new ArrayList<TreeNode<E>>();  
    }  
    public E getValue(){  
        return value;  
    }  
    public List<TreeNode<E>> getChildren(){  
        return children;  
    }  
}
```

(d) [4 marks] Suppose a variable `myTree` contains a `TreeNode` that is the root of a large tree where the root of the tree has at least four children. Complete the following java statement that would print out the value in the third child of the root node.

```
System.out.println( myTree.getChildren().get(2).getValue());
```

(e) [6 marks] Complete the following `leftmost` method that will return the value in the leftmost node of a tree.

```
public E leftmost(TreeNode<E> tree){  
    if (tree!=null){  
        while (!tree.getChildren().isEmpty()){  
            tree = tree.getChildren().get(0);  
        }  
        return tree.getValue();  
    }  
}
```

(Question 4 continued on next page)

(Question 4 continued)

(f) [4 marks] Complete the following `printPostOrderDFT` method that will print out the values in the nodes of a tree using a post-order depth first traversal.

Hint: use a recursive method, not an iterative method.

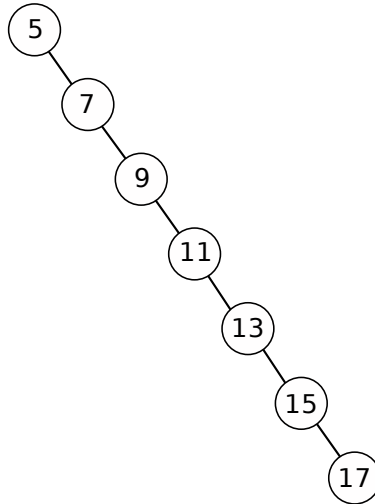
```
public void printPostOrderDFT(TreeNode<E> tree){  
    if (tree!=null){  
        for (TreeNode<E> child : tree.getChildren()) {  
            printPostOrderDFT(child);  
        }  
        System.out.println(tree.getValue());  
    }  
}
```

Question 5. Binary Search Trees

[20 marks]

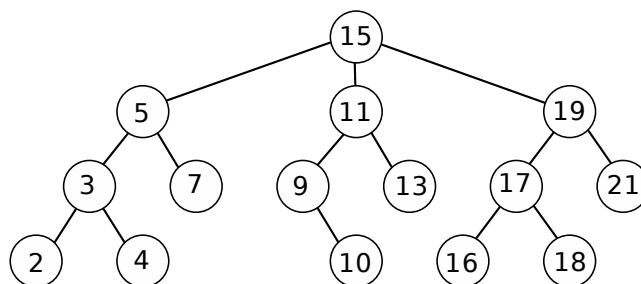
(a) [10 marks] For each of the following trees, say whether they are Binary Search Trees or not. If a tree is not, explain why not. The nodes contain integer values.

Tree (i):



Yes

Tree (ii):

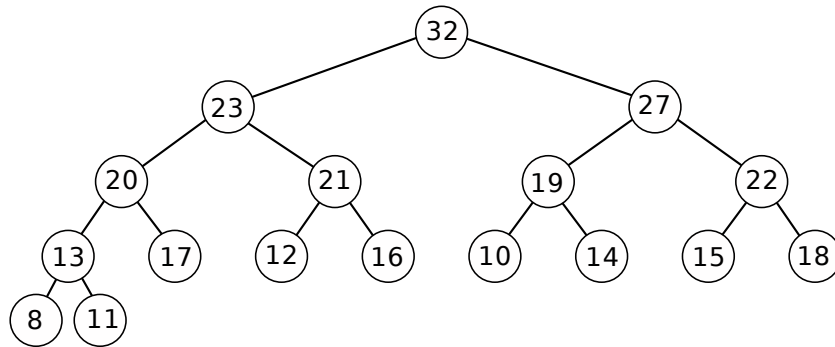


No, because it is not a binary tree (root has three children)

(Question 5 continued on next page)

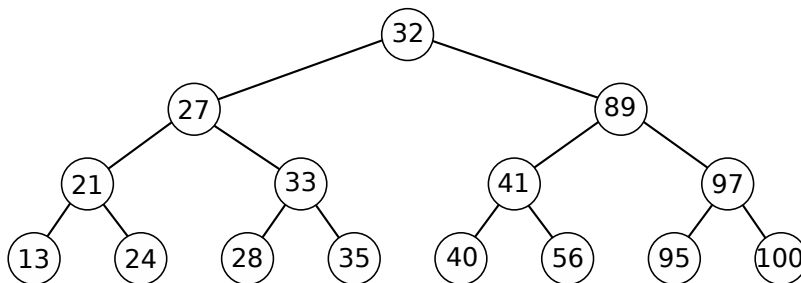
(Question 5 continued)

Tree (iii):



No, because it is not ordered for a BST: each node is larger than both subtrees, instead of larger than its left subtree and smaller than its right subtree

Tree (iv):



No, because 33 (and 35) is greater than 32, but it is in the left subtree under 32.

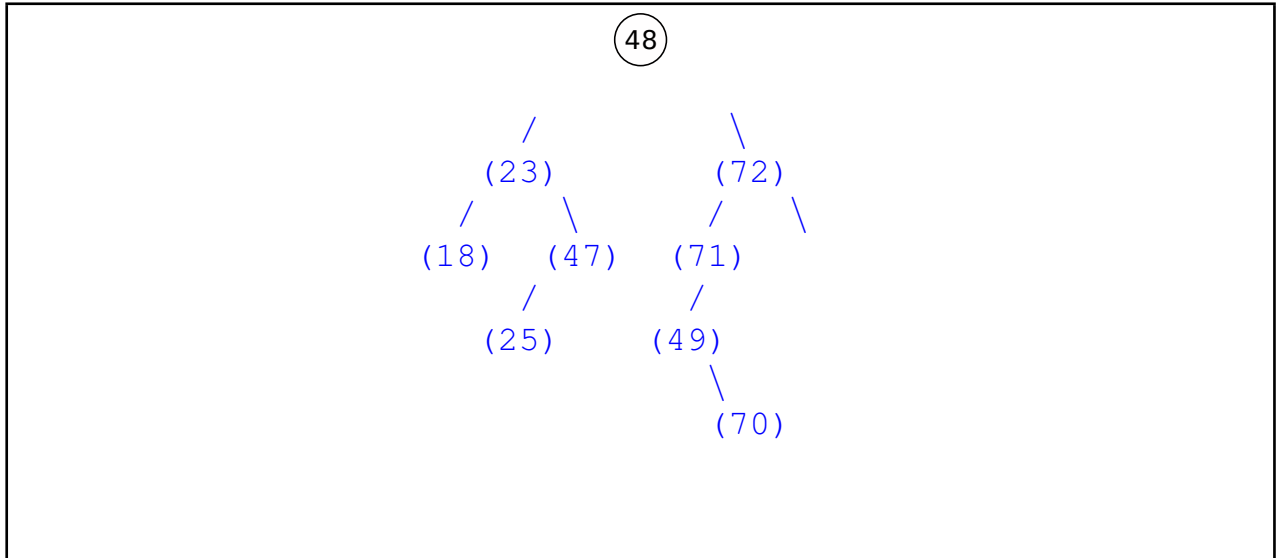
SPARE PAGE FOR EXTRA ANSWERS

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

(Question 5 continued)

(b) [4 marks] Show the tree that would be generated by inserting the following values (in order) into the Binary Search Tree below.

72, 71, 23, 47, 49, 70, 25, 18



(c) [3 marks] What is the average asymptotic (“Big-O”) cost of inserting an item into a well balanced Binary Search Tree containing n nodes? Briefly justify your answer.

$O(\log(n))$. In a well balanced binary tree with n nodes, the height of the tree will be $\log(n)$. Half the nodes are on the bottom level, which will require $\log(n)$ comparisons.

(d) [3 marks] What is the least number of comparisons that could possibly be required to insert an item into a BST tree that contains n nodes? Justify your answer by giving an example of a tree and an item leading to this case.

One. If the root had only one child, and the item being inserted needed to be the other child. The item would only need to be compared with the root value. For example, inserting H into the following tree:

```

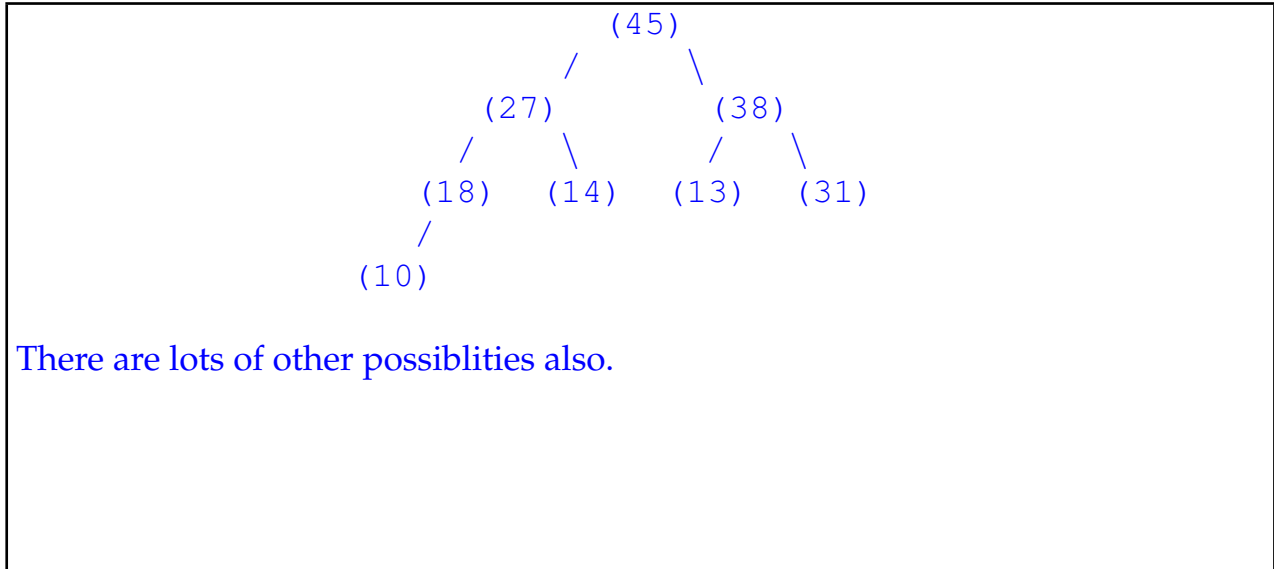
      (M)
       \
      (S)
     /  \
    (P)  (V)
   /  \  /  \
  etc ... (another n-4 nodes)
    
```

Question 6. Partially Ordered Trees and Priority Queues

[23 marks]

(a) [3 marks] Draw a balanced, partially ordered, binary tree containing the following values:

13 18 45 14 27 38 10 31



(Question 6 continued on next page)

(Question 6 continued)

(b) [6 marks] A heap is a partially ordered binary tree implemented in an array. Suppose a heap contains the following 13 values:

98	75	34	61	54	30	31	20	13	45	26	29
0	1	2	3	4	5	6	7	8	9	10	11

Show the sequence of changes to fix up the heap if the largest item (98) is removed from the heap. Each step should show the result after one swap. You may not need all the steps given.

step 1:	<table border="1" style="width: 100%; text-align: center; border-collapse: collapse;"> <tr> <td style="width: 20px;">29</td> <td style="width: 20px;">75</td> <td style="width: 20px;">34</td> <td style="width: 20px;">61</td> <td style="width: 20px;">54</td> <td style="width: 20px;">30</td> <td style="width: 20px;">31</td> <td style="width: 20px;">20</td> <td style="width: 20px;">13</td> <td style="width: 20px;">45</td> <td style="width: 20px;">26</td> <td style="width: 20px;">29</td> </tr> <tr> <td>0</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> <td>6</td> <td>7</td> <td>8</td> <td>9</td> <td>10</td> <td>11</td> </tr> </table>	29	75	34	61	54	30	31	20	13	45	26	29	0	1	2	3	4	5	6	7	8	9	10	11
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0	1	2	3	4	5	6	7	8	9	10	11														

(c) [4 marks] Suppose you need a Priority Queue for items whose priority can be any double value. Explain why a heap is a better data structure for implementing the Priority Queue than a sorted array or an array of ordinary Queues (one Queue for each priority).

A heap is very efficient in both time and space. It uses just enough space for the items, and it has $O(\log(n))$ time for enqueueing (“offer”) and dequeueing (“poll”). A sorted array would take $O(n)$ time to enqueue (though only $O(1)$ time to dequeue), and an array of Sets would take too much space — you could not make enough sets for all the possible priorities.

(Question 6 continued on next page)

(Question 6 continued)

(d) [10 marks] The POTree class below represents a Partially Ordered Tree using a binary tree structure. It contains one field for the root of the tree and a private class for the nodes:

```
public class POTree{  
  
    private POTNode root;  
  
    private class POTNode {  
        public int value;  
        public POTNode left;  
        public POTNode right;  
  
        public POTNode(int v){  
            value = v;  
        }  
    }  
}
```

Write a method called `check` for the POTree class that checks that the tree in the root field is a proper Partially Ordered Tree. `check` should return `true` if the tree is OK, and `false` otherwise. You may define helper methods if you wish.

Hint: do a recursive traversal of the tree, checking each node.

```
public boolean check(){  
    return check(root);  
}  
public boolean check(POTNode node){  
    if (node.left != null){  
        if (node.value < node.left.value || !check(node.left))  
            return false;  
    }  
    if (node.right != null){  
        if (node.value < node.right.value || !check(node.right))  
            return false;  
    }  
    return true;  
}
```

Question 7. Hashing

[19 marks]

(a) [4 marks] When two items hash to the same index of the data array, a Hash Set must resolve the collision in some way. Explain the difference between resolving the collision by probing and by using buckets.

With probing, the Hash Set will look for an alternative cell in the array to store the item. With buckets, it will store a set in each cell and simply add the item to the set in cell that it hashes to.

(b) [4 marks] A Hash Set with any kind of probing builds up “runs”, but quadratic probing is generally better than linear probing. Explain why quadratic probing is better than linear probing.

With linear probing, the runs join up to make long runs for all the cells in the run. Long runs make adding or finding expensive. With quadratic probing, the runs from different starting points do not join up since they each take a different sequence of steps. That means the runs do not get as long.

(c) [3 marks] Why is it important to ensure that a Hash Set using probing is not allowed to get too full?

If the hash set is too full, then the probing may take a long time to find an empty cell.

(Question 7 continued on next page)

(Question 7 continued)

(d) [8 marks] Suppose you are writing a program that needs to store a set of `Person` objects, and you have decided to use a `HashSet`. The fields of a `Person` object are shown below. The important information that identifies an individual is in the `name`, `dateOfBirth`, `countryOfBirth`, and `birthCertificateNumber` fields.

```
public class Person{  
    private final String name;  
    private final Date dateOfBirth;  
    private final String countryOfBirth;  
    private final long birthCertificateNumber;  
  
    private String currentAddress;    // may change  
    private long phoneNumber;        // may change  
    private String citizenship;      // may change  
  
    :
```

The other fields in a `Person` object (like `currentAddress`) may change over time without changing the identity of the person. The `hashCode` of a `Person` object should always be the same, even when these other fields change. Also, two `Person` objects that have the same values in the identifying fields should be considered to be the same person, and should therefore have the same `hashCode` (and be equal).

Complete the following `hashCode` and `equals` methods for the `Person` class. You may assume that the `String` and `Date` classes have appropriate `hashCode` functions.

```
public int hashCode(){  
    return ((name.hashCode()*1023+dateOfBirth.hashCode())*1023 +  
           countryOfBirth.hashCode()* 1023 + birthCertificateNumber;  
  
}
```

(Question 7 continued on next page)

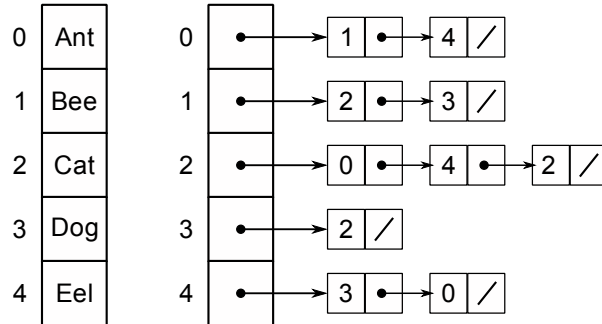
(Question 7 continued)

```
public boolean equals(Object obj){  
    if (! obj instanceof Person)  
        return false;  
    Person other = (Person) obj;  
    return (name.equals(other.name) &&  
            dateOfBirth.equals(other.dateOfBirth) &&  
            countryOfBirth.equals(other.countryOfBirth) &&  
            birthCertificateNumber == other.birthCertificateNumber);  
  
}
```

Question 8. Graphs

[14 marks]

(a) [4 marks] Draw a diagram (circles and lines) of the directed graph corresponding to the following adjacency list representation of a graph. The array on the left contains the node labels.



(Question 8 continued on next page)

(Question 8 continued)

(b) [4 marks] Draw a diagram (circles and lines) of the weighted undirected graph corresponding to the following adjacency matrix representation of a graph. The array on the left contains the node labels.

		0	1	2	3	4
0	Ant	0	18		43	
1	Bee	18		38	21	
2	Cat		38			
3	Dog	43	21			47
4	Eel				47	

(Question 8 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 8 continued)

(c) [6 marks] Complete the following `reachable` method that will return true if there is a path from one node to another node in a directed, unweighted graph represented by an adjacency list, and will return false if there is no such path. Assume the following declarations for two fields containing the graph:

```
private String[] nodes;
private List<Integer>[] edges;
```

Assume that the arrays have been constructed and filled.

```
public boolean reachable(int node1, int node2){

    boolean [ ] visited = new boolean [nodes.length];
    Queue<Integer> todo = new LinkedList<Integer>();
    todo.offer (node1);
    while (!todo.isEmpty()){
        int node = todo.poll ();
        if (node == node2)
            return true;
        visited [node] = true;
        for( int neighbour : edges[node]){
            if ( !visited [neighbour])
                todo.offer (neighbour);
        }
    }
    return false;

}
```

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.

(You may detach this page)

Appendices

Possibly useful formulas:

- $1 + 2 + 3 + 4 + \dots + k = \frac{k(k+1)}{2}$
- $1 + 2 + 4 + 8 + \dots + 2^k = 2^{k+1} - 1$
- $a + (a + b) + (a + 2b) + \dots + (a + kb) = \frac{(2a+kb)(k+1)}{2}$
- $a + as + as^2 + as^3 + \dots + as^k = \frac{as^{k+1}-a}{s-1}$

Table of base 2 logarithms:

n	1	2	4	8	16	32	64	128	256	512	1024	1,048,576
$\log_2(n)$	0	1	2	3	4	5	6	7	8	9	10	20

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

public class Random

```
public int nextInt(int n);           // return a random integer between 0 and n-1
public double nextDouble();        // return a random double between 0.0 and 1.0
```

public interface Iterator <E>

```
public boolean hasNext();
public E next();
public void remove();
```

public interface Iterable <E>

```
public Iterator <E> iterator();
```

// Can use in the "for each" loop

public interface Comparable <E>

```
public int compareTo(E o);
```

// Can compare this to another E

public interface Comparator <E>

```
public int compare(E o1, E o2);
```

// Can use this to compare two E's

DrawingCanvas **class**:

```
public void drawLine(int x, int y, int u, int v) // Draws line from (x, y) to (u, v)
public void drawOval(int x, int y, int wd, int ht) // Draws outline of oval
public void drawString(String str, int x, int y) // Prints str at (x, y)
```

```

public interface Collection<E>
    public boolean isEmpty();
    public int size ();
    public boolean contains(Object item);
    public boolean add(E item);           // returns false if failed to add item
    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(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); // returns element

```

```

public interface Map<K, V>
    // Implementations: HashMap, TreeMap, ArrayMap
    public V get(K key);       // returns null if no such key
    public V put(K key, V value); // returns old value, or null
    public V remove(K key);   // returns value removed, or null
    public boolean containsKey(K key);
    public Set<K> keySet();    // returns set of all keys in Map
    public Collection<V> values(); // returns collection of all values
    public Set<Map.Entry<K, V>> entrySet(); // returns set of (key–value) pairs

```

Scanner class:

```

public boolean hasNext()           // Returns true if there is more to read
public boolean hasNextInt()       // Returns true if the next token is an integer
public String next()              // Returns the next token (chars up to a space/line)
public String nextLine()          // Returns string of chars up to next newline
public int nextInt ()             // Returns the integer value of the next token

```