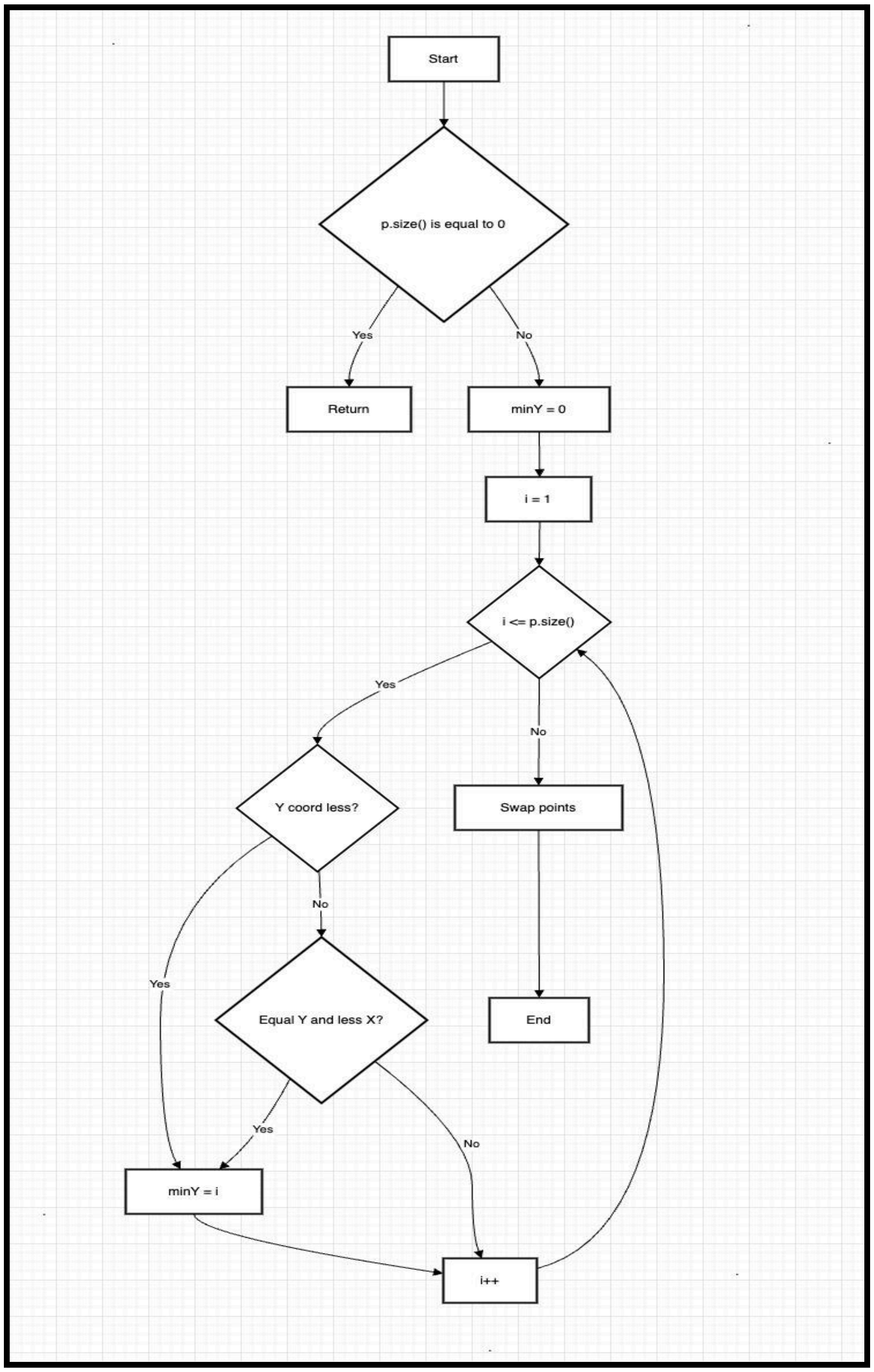
Q1. Convert the code comprising the beginning of the doGraham method into a control flow graph (CFG). You are free to write the code in any programming language.

Ans.

```
public class Point {
    double x;
    double y;
    public Point(double x, double y) {
        this.x = x;
        this.y = y;
    }
}
public class ConvexHull {
    public void doGraham(Vector<Point> p) {
        if (p.size() == 0) {
            return;
        }
        int minY = 0;
        for (int i = 1; i < p.size(); i++) {
            if (p.get(i).y < p.get(minY).y ||
               (p.get(i).y == p.get(minY).y && p.get(i).x <
p.get(minY).x)) {
                minY = i;
            }
        }
        Point temp = p.get(0);
        p.set(0, p.get(minY));
        p.set(minY, temp);
    }
}
Below is the Control Flow graph of above code
```



Q2. Construct test sets for your flow graph that are adequate for the following criteria:

a. Statement Coverage.
b. Branch Coverage.
c. Basic Condition Coverage.

Ans.

1).Statement Coverage

To achieve statement coverage, we need to ensure that each line of code is executed at least once.

Test Case:

- **Test 1**: Input vector p is empty (p.size() == 0)
  - Expected result: The function should return immediately without executing further.
- **Test 2**: Input vector p has at least one Point element.
  - Expected result: The function should proceed to find the Point with the minimum y-coordinate.

2).Branch Coverage

For branch coverage, we need to ensure that each decision (branch) in the code is evaluated as both true and false at least once.

Test Cases:

- **Test 1**: Empty vector p (p.size() == 0)
  - Expected result: if (p.size() == 0) branch is true, and the function returns immediately.
- **Test 2**: Vector p with one Point (e.g., Point(0, 0))

  - Expected result: if (p.size() == 0) branch is false, so the function proceeds to the for loop, which does not iterate as there's only one point.
- **Test 3:** Vector p with multiple Points where no point has a smaller y-coordinate than p[0]
  - Example: p = [Point(0, 0), Point(1, 1), Point(2, 2)]
  - Expected result: The if condition inside the for loop is always false, and minY remains 0.
- **Test 4:** Vector p with multiple Points where another point has a smaller y-coordinate than p[0]
  - Example: p = [Point(2, 2), Point(1, 0), Point(0, 3)]
  - Expected result: The if condition inside the for loop becomes true, updating minY.
  -

3).Basic Condition Coverage

For basic condition coverage, we need to test each condition independently within the branches.

Test Cases:

- **Test 1:** Empty vector p (p.size() == 0)
  - Expected result: if (p.size() == 0) is true.
- **Test 2:** Non-empty vector p (p.size() > 0)
  - Expected result: if (p.size() == 0) is false.
- **Test 3:** Multiple points where only p.get(i).y < p.get(minY).y is true
  - Example: p = [Point(1, 1), Point(0, 0), Point(2, 2)]

   - Expected result: The first condition p.get(i).y < p.get(minY).y is true, so minY is updated.
- **Test 4:** Multiple points where p.get(i).y == p.get(minY).y is true, and p.get(i).x < p.get(minY).x is also true
   - Example: p = [Point(1, 1), Point(0, 1), Point(2, 2)]
   - Expected result: Both conditions are true, so minY is updated.

Q3. For the test set you have just checked can you find a mutation of the code (i.e. the deletion, change or insertion of some code) that will result in failure but is not detected by your test set. You have to use the mutation testing tool.

Ans.1). Deletion Mutation

Mutation: Remove the assignment of minY to 0 at the beginning of the method.

```
public class ConvexHull {
    public void doGraham(Vector<Point> p) {
        if (p.size() == 0) {
            return;
        }
        for (int i = 1; i < p.size(); i++) {
            if (p.get(i).y < p.get(minY).y ||
               (p.get(i).y == p.get(minY).y && p.get(i).x <
p.get(minY).x)) {
                minY = i;
            }
        }
        Point temp = p.get(0);
        p.set(0, p.get(minY));
        p.set(minY, temp);
    }
}

Impact: This mutation causes minY to be uninitialized when
accessed, resulting in undefined behavior. Your test cases do
not check for proper initialization, which may lead to
undetected faults.

2). Insertion Mutation
Mutation: Insert a line that overrides minY incorrectly based on
a condition that should not occur.
public class ConvexHull {
    public void doGraham(Vector<Point> p) {
        if (p.size() == 0) {
            return;
        }
        int minY = 0;
        if (p.size() > 1) {
            minY = 1;
        }
        for (int i = 1; i < p.size(); i++) {
            if (p.get(i).y < p.get(minY).y ||
               (p.get(i).y == p.get(minY).y && p.get(i).x <
p.get(minY).x)) {
                minY = i;
            }
        }
        Point temp = p.get(0);
        p.set(0, p.get(minY));
        p.set(minY, temp);
    }
}
```

3). Modification Mutation
Mutation: Change the logical operator from || to && in the conditional statement.

```
public class ConvexHull {
    public void doGraham(Vector<Point> p) {
        if (p.size() == 0) {
            return;
        }
        int minY = 0;
        for (int i = 1; i < p.size(); i++) {
            if (p.get(i).y < p.get(minY).y &&
               (p.get(i).y == p.get(minY).y && p.get(i).x <
p.get(minY).x)) {
                minY = i;
            }
        }
        Point temp = p.get(0);
        p.set(0, p.get(minY));
        p.set(minY, temp);
    }
}
```

Analyzing Detection by Test Cases

1. **For Statement Coverage:**
   - The deletion of the initialization of minY might not be detected as it may not cause a direct exception depending on the surrounding logic.
2. **For Branch Coverage:**
   - The insertion that forces minY to 1 may lead to incorrect outcomes, but if no tests specifically check the positions of points after the execution, it may go unnoticed.
3. **For Basic Condition Coverage:**
   - Changing the logical operator from || to && does not cause a crash, and the test cases do not validate the correctness of minY updating under these conditions, so it may not be detected.

Q4. Create a test set that satisfies the path coverage criterion where every loop is explored at least zero, one or two times.

Ans. Test Case 1: Loop Explored Zero Times

- Input: An empty vector `p`.
- Test: `Vector<Point> p = new Vector<Point>();`
- Expected Result: The method should return immediately without any processing. This covers the condition where the vector size is zero, leading to the exit condition of the method.

Test Case 2: Loop Explored Once

- Input: A vector with one point.
- Test: `Vector<Point> p = new Vector<Point>(); p.add(new Point(0, 0));`
- Expected Result: The method should not enter the loop since `p.size()` is 1. It should swap the first point with itself, effectively leaving the vector unchanged. This test case covers the scenario where the loop iterates once.

Test Case 3: Loop Explored Twice

- Input: A vector with two points where the first point has a higher y-coordinate than the second.
- Test: `Vector<Point> p = new Vector<Point>(); p.add(new Point(1, 1)); p.add(new Point(0, 0));`
- Expected Result: The method should enter the loop and compare the two points, finding that the second point has a lower y-coordinate. Thus, `minY` should be updated to 1, and a

swap should occur, moving the second point to the front of the vector.

Test Case 4: Loop Explored More Than Twice

- Input: A vector with multiple points.
- Test: `Vector<Point> p = new Vector<Point>(); p.add(new Point(2, 2)); p.add(new Point(1, 0)); p.add(new Point(0, 3));`
- Expected Result: The loop should iterate through all three points. The second point will have the lowest y-coordinate, so `minY` will be updated to 1. The swap will place the point with coordinates (1, 0) at the front of the vector.

Lab Execution:-

Q1). After generating the control flow graph, check whether your CFG match with the CFG generated by Control Flow Graph Factory Tool and Eclipse flow graph generator.

Ans. Control Flow Graph Factory :- YES

Eclipse flow graph generator :- YES

Q2).Devise minimum number of test cases required to cover the code using the aforementioned criteria.

Ans. Statement Coverage: 3 test cases

1. Branch Coverage: 4 test cases

2. Basic Condition Coverage: 4 test cases
3. Path Coverage: 3 test cases

Summary of Minimum Test Cases:

- Total: 3 (Statement) + 4 (Branch) + 4 (Basic Condition) + 3 (Path) = 14 test cases

Q3) and Q4) Same as Part I