Name : Patel Naisargi
ID : 202201291
Lab : 09

1. 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.

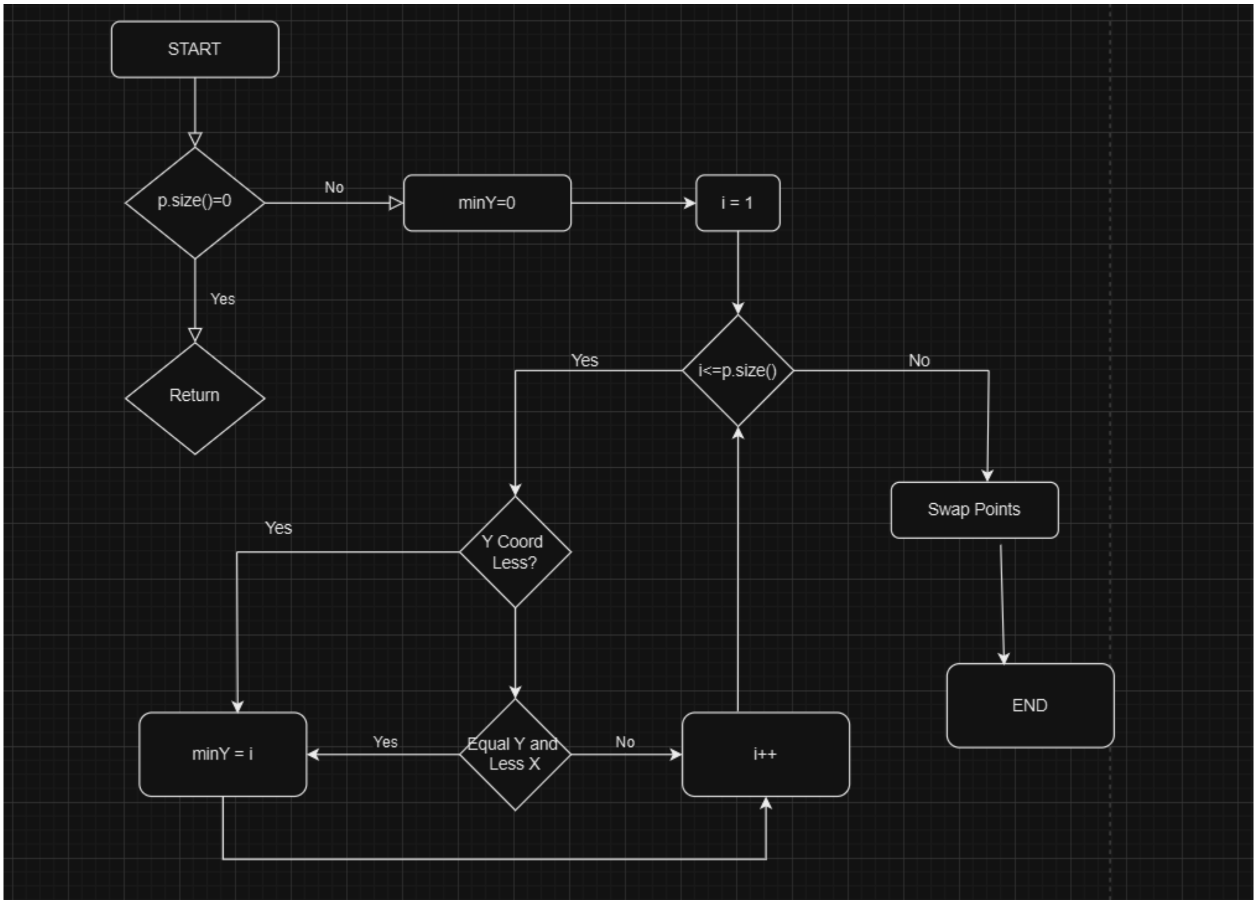
```
public class Point {
double x;
double y;
public Point(double x, double y) {
this.x = x;
this.y = y;
}
}
public class ConvexHull {
public void doGraham(Vector<Point> p) {
if (p.size() == 0) {
return;
}
int minY = 0;
for (int i = 1; i < p.size(); i++) {
if (p.get(i).y < p.get(minY).y ||
(p.get(i).y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

-Control Flow graph of above code



Q2. Develop test sets for your flow graph that fulfill the following criteria:

a. Statement Coverage

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

Test Cases:

- **Test Case 1:** Provide an empty vector p (i.e., p.size() == 0).
  Expected Outcome: The function should terminate immediately without further execution.
- **Test Case 2:** Use a vector p that contains at least one Point element.
  Expected Outcome: The function should continue to locate the Point with the minimum y-coordinate.

b. Branch Coverage

For branch coverage, it's essential that every decision (branch) in the code is

evaluated as both true and false at least once.
Test Cases:

- **Test Case 1:** An empty vector p (i.e., p.size() == 0).
  Expected Outcome: The condition if (p.size() == 0) evaluates to true, causing the function to return immediately.
- **Test Case 2:** A vector p containing one Point (e.g., Point(0, 0)).
  Expected Outcome: The condition if (p.size() == 0) evaluates to false, leading the function to enter the for loop, which does not iterate due to the presence of only one point.
- **Test Case 3:** A vector p with multiple Points where none has a y-coordinate less than that of p[0].
  Example: p = [Point(0, 0), Point(1, 1), Point(2, 2)].
  Expected Outcome: The if condition inside the loop remains false, resulting in minY staying at 0.
- **Test Case 4:** A 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 Outcome: The if condition within the loop becomes true, leading to an update of minY.

c. Basic Condition Coverage
To ensure basic condition coverage, we must test each condition independently within the branches.
Test Cases:

- **Test Case 1:** An empty vector p (i.e., p.size() == 0).
  Expected Outcome: The condition if (p.size() == 0) is true.
- **Test Case 2:** A non-empty vector p (i.e., p.size() > 0).
  Expected Outcome: The condition if (p.size() == 0) is false.
- **Test Case 3:** Multiple points where only the condition p.get(i).y < p.get(minY).y holds true.
  Example: p = [Point(1, 1), Point(0, 0), Point(2, 2)].
  Expected Outcome: The first condition p.get(i).y < p.get(minY).y is true, prompting an update to minY.
- **Test Case 4:** Multiple points where both p.get(i).y == p.get(minY).y and p.get(i).x < p.get(minY).x are true.
  Example: p = [Point(1, 1), Point(0, 1), Point(2, 2)].

Expected Outcome: Both conditions evaluate to true, leading to an update of minY.

Q3. Can you identify a mutation of the code (such as the deletion, modification, or addition of code) that could lead to failure but would not be detected by the provided test set? Use a mutation testing tool to assist with this.

1. Deletion Mutation
Mutation: Eliminate 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;
        }

        // minY initialization removed
        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 results in minY being uninitialized upon access, potentially leading to undefined behavior. The existing test cases do not verify the proper initialization of minY, allowing such faults to go unnoticed.

2. Insertion Mutation

Mutation: Add a line that incorrectly overrides minY based on an irrelevant condition.

```
public class ConvexHull {
    public void doGraham(Vector<Point> p) {
        if (p.size() == 0) {
            return;
        }

        int minY = 0;
        if (p.size() > 1) {
            minY = 1; // Insertion mutation
        }

        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 sets minY to 1 without justifiable conditions. If the tests do not specifically check the final arrangement of points after execution, this error might remain undetected.

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 && // Modification mutation
                (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: The alteration of the logical operator may not result in an immediate crash, and the current test cases do not validate whether minY updates correctly under these modified conditions, potentially allowing this error to go unnoticed.

Q4. Design a test set that meets the path coverage criterion, ensuring that every loop is explored at least zero, one, or two times.

To satisfy the path coverage criterion and ensure that every loop is explored zero, one, or two times, the following test cases will be created:

Test Case 1: Zero Iterations
Input: An empty vector p.
Description: This scenario confirms that no iterations of either loop occur.
Expected Outcome: The function should handle this gracefully (ideally returning an empty result or a specific value indicating that no points are present).

Test Case 2: One Iteration (First Loop)
Input: A vector containing a single point p (e.g., [(3, 4)]).
Description: This ensures that the first loop runs exactly once since the minimum point is the only one present.
Expected Outcome: The function should return the sole point in p.

Test Case 3: One Iteration (Second Loop)
Input: A vector with two points sharing the same y-coordinate but differing x-coordinates (e.g., [(1, 2), (3, 2)]).
Description: This case guarantees that the first loop identifies the minimum point, while the second loop runs once to compare the x-coordinates.
Expected Outcome: The function should return the point with the maximum x-coordinate: (3, 2).

Test Case 4: Two Iterations (First Loop)
Input: A vector with multiple points, ensuring at least two have the same y-coordinate (e.g., [(3, 1), (2, 2), (5, 1)]).
Description: This test ensures that the first loop identifies the minimum y-coordinate (first iteration for (3, 1)) and continues to the second loop.
Expected Outcome: The function should return (5, 1) as it has the highest x-coordinate among the points sharing the same y-coordinate.

Test Case 5: Two Iterations (Second Loop)
Input: A vector with multiple points where more than one point has the same minimum y-coordinate
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.
- 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.
-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 Q4 and Q4 Same as Part I)