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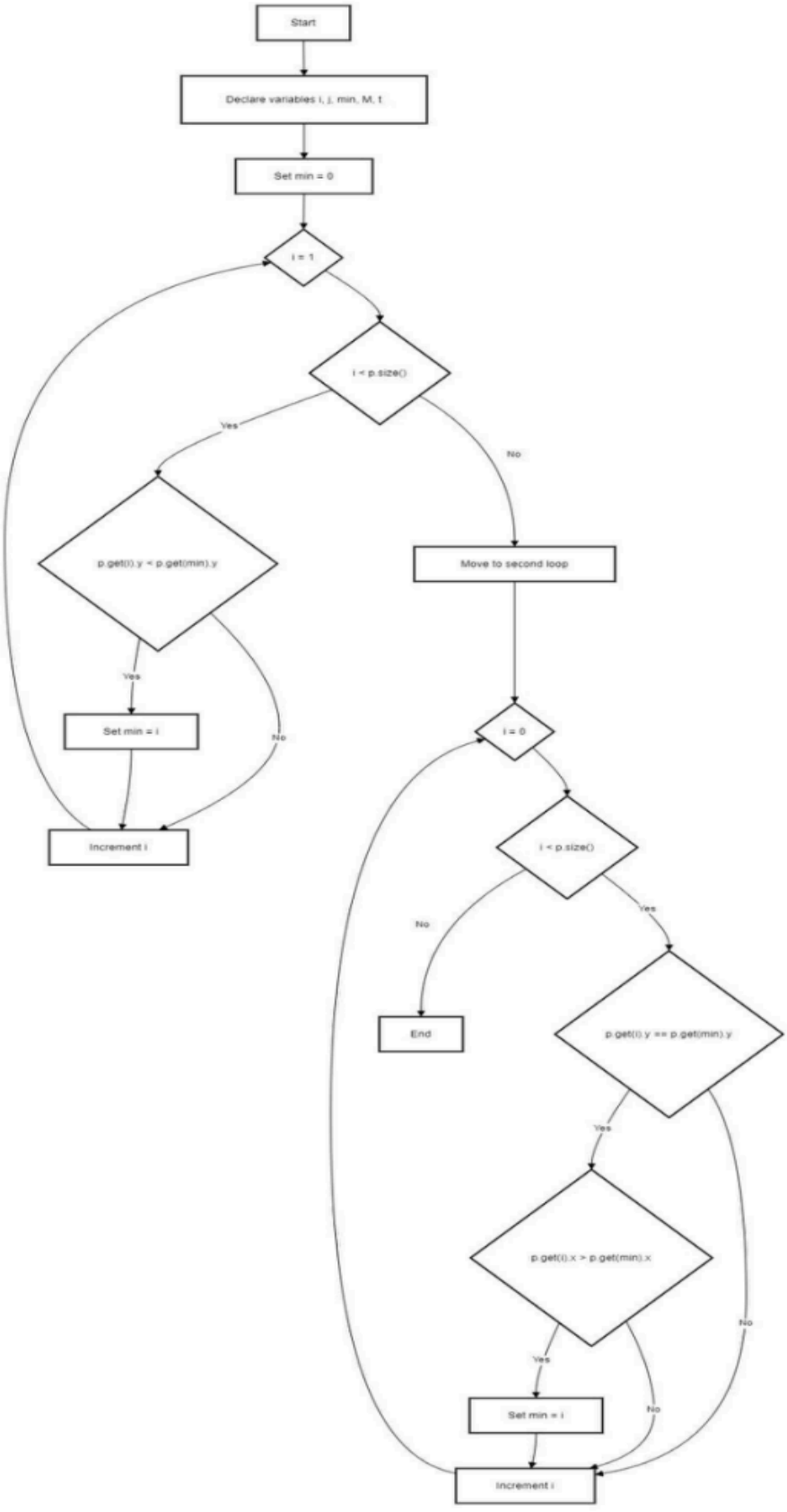
Lab 9 : Mutation Testing

Q.1. The code below is part of a method in the ConvexHull class in the VMAP system. The following is a small fragment of a method in the ConvexHull class. For the purposes of this exercise, you do not need to know the intended function of the method. The parameter p is a Vector of Point objects, p.size() is the size of the vector p, (p.get(i)).x is the x component of the ith point appearing in p, similarly for (p.get(i)).y. This exercise is concerned with structural testing of code, so the focus is on creating test sets that satisfy some particular coverage criteria.

```
Vector doGraham(Vector p) {
        int i,j,min,M;

        Point t;
        min = 0;

        // search for minimum:
        for(i=1; i < p.size(); ++i) {
            if( ((Point) p.get(i)).y <
                        ((Point) p.get(min)).y )
            {
                min = i;
            }
        }

        // continue along the values with same y component
        for(i=0; i < p.size(); ++i) {
            if(( ((Point) p.get(i)).y ==
                        ((Point) p.get(min)).y ) &&
                 (((Point) p.get(i)).x >
                        ((Point) p.get(min)).x ))
            {
                 min = i;
            }
        }
```

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.

ANS :


Start
Declare variables i, j, min, M, t
Set min = 0
i = 1
i < p.size()
Yes
No
p.get(i).y < p.get(min).y
Yes
No
Set min = i
Increment i
Move to second loop
i = 0
i < p.size()
No
Yes
End
p.get(i).y == p.get(min).y
Yes
No
p.get(i).x > p.get(min).x
Yes
No
Set min = i
Increment i

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

Statement Coverage:

- **Objective:** Ensure every line of code is executed at least once.
- **Requirements:**
  - The check for an empty vector (`if (p.size() == 0)`) must be executed.
  - The `for` loop should be entered and iterated.
- **Test Cases:**
  - **Test Case 1:** p is empty (e.g., `p = new Vector<Point>();`)
    - *Expected Outcome:* Method returns immediately without performing any operations.
  - **Test Case 2:** p contains multiple points with different y values (e.g., `p = new Vector<>(Arrays.asList(new Point(1, 2), new Point(2, 3), new Point(3, 1)));`)
    - *Expected Outcome:* The point with the smallest y-coordinate is moved to the first position.
  - **Additional Test Cases:**
    - Test Case 3: p has at least two points with distinct y values.
    - Test Case 4: p has multiple points with the same y but different x values.

Branch Coverage:

- **Objective:** Test each branch of every decision (e.g., `if` statements).
- **Requirements:**
  - Test `if (p.size() == 0)` condition with an empty vector and a non-empty vector.
  - Test both conditions within the loop: `(p.get(i).y < p.get(minY).y)` and `(p.get(i).y == p.get(minY).y && p.get(i).x < p.get(minY).x)`.
- **Test Cases:**
  - **Test Case 1:** Empty vector (`p = new Vector<Point>();`)
    - *Expected Outcome:* Method returns immediately.

    - **Test Case 2:** Non-empty vector with unique y values (e.g., `p = new Vector<>(Arrays.asList(new Point(1, 2), new Point(3, 3), new Point(2, 1)));`)
        - *Expected Outcome:* Point with smallest y-value moves to the first position.
    - **Test Case 3:** Non-empty vector with points sharing the same y-value (e.g., `p = new Vector<>(Arrays.asList(new Point(1, 2), new Point(2, 2), new Point(0, 2)));`)
        - *Expected Outcome:* Among points with the same y, the one with the smallest x moves to the first position.

Basic Condition Coverage:

- **Objective:** Test each condition within compound conditions for both true and false outcomes.
- **Requirements:**
    - `(p.get(i).y < p.get(minY).y)` being true and false.
    - `(p.get(i).y == p.get(minY).y)` being true, and `(p.get(i).x < p.get(minY).x)` being true and false.
- **Test Cases:**
    - **Test Case 1:** Non-empty vector where `(p.get(i).y < p.get(minY).y)` is true (e.g., `p = new Vector<>(Arrays.asList(new Point(3, 4), new Point(1, 2)));`)
        - *Expected Outcome:* Point with the smallest y-value is moved to the first position.
    - **Test Case 2:** Non-empty vector where `(p.get(i).y == p.get(minY).y)` is true, and `(p.get(i).x < p.get(minY).x)` is also true (e.g., `p = new Vector<>(Arrays.asList(new Point(3, 2), new Point(1, 2)));`)
        - *Expected Outcome:* Point with smallest x among points with the same y moves to the first position.
    - **Test Case 3:** Non-empty vector where `(p.get(i).y == p.get(minY).y)` is true, and `(p.get(i).x < p.get(minY).x)` is false (e.g., `p = new Vector<>(Arrays.asList(new Point(1, 2), new Point(3, 2)));`)

- *Expected Outcome:* The first point remains in position since it has the smallest `x`.

Test Case 4: For `if ((Point) p.get(i)).y < ((Point) p.get(min)).y`:

1: y value of `p.get(i)` < y value of `p.get(min)` (True case).

2: y value of `p.get(i)` >= y value of `p.get(min)` (False case).

Test Case 5: For `if ((Point) p.get(i)).y == ((Point) p.get(min)).y && ((Point) p.get(i)).x < ((Point) p.get(min)).x`:

1: y values are equal and `x` value of `p.get(i)` < `x` value of `p.get(min)` (True case).

2: y values are equal and `x` value of `p.get(i)` >= `x` value of `p.get(min)` (False case).

3. 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

Mutation Testing

- Mutation testing involves modifying the code slightly to check if the test cases detect errors.

Examples of Mutation

- **Deletion**: Remove the assignment `min = i;` in either loop to see if the test cases detect the error.
- **Insertion**: Insert an additional condition or statement that affects `min` calculation, e.g., `min = 0;` after the loops.
- **Modification**: Change the < comparison to <= or the && to `||` in the if conditions.

Mutation 1: Change Comparison Operator in `p.get(i).y < p.get(minY).y`

- **Mutation**: Change `p.get(i).y < p.get(minY).y` to `p.get(i).y <= p.get(minY).y`.
- **Explanation**: This change would mean that the algorithm would potentially select the last instance of the smallest y instead of the first, which could impact the correctness of the hull.
- **Analysis**: Our current tests with points having unique y values and points with the same y but different x values might not catch this mutation directly because:
    - We have no test where two points have both equal x and y values.
    - We assume a strict less-than comparison.
- **New Test Case**:
    - **Input**: `p = new Vector<>(Arrays.asList(new Point(1, 2), new Point(1, 2), new Point(0, 2)))`
    - **Expected Outcome**: The first occurrence of (1, 2) should stay at the front.
    - **Reasoning**: This will ensure the code behaves correctly under strict y ordering.

Mutation 2: Removing the `if (p.size() == 0)` Check

- **Mutation**: Delete the check `if (p.size() == 0)`, allowing the function to proceed even if the vector is empty.
- **Explanation**: Without this check, calling the method with an empty vector would result in an `IndexOutOfBoundsException` when attempting to access elements in the empty list.
- **Analysis**: Our current test set would catch this mutation, as Test Case 1 is an empty vector test, which would fail with this mutation.

Mutation 3: Removing or Swapping the First Element Swap Operation

- **Mutation**: Remove or incorrectly swap `p.set(0, p.get(minY));` and `p.set(minY, temp);`.
- **Explanation**: This mutation would result in an incorrect ordering of the points, as the point with the smallest y (or smallest x if y values are equal) might not be placed in the first position.
- **Analysis**: Our current test set should catch this mutation, as Test Case 2 requires the smallest y point to move to the first position, and it would fail if this didn't occur correctly.

Mutation 4: Changing Condition to Only Consider x Without y

- **Mutation**: Change the compound condition to consider only x values without regard to y, e.g., change `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))` to `if (p.get(i).x < p.get(minY).x)`.
- **Explanation**: This mutation would ignore the y ordering completely, leading to incorrect results if points differ in y but not in x.
- **Analysis**: Our current tests might miss this mutation because we lack tests where:
  - The smallest x isn't necessarily the smallest y.
  - We have cases where x changes without y changes.
- **New Test Case**:
  - **Input**: `p = new Vector<>(Arrays.asList(new Point(3, 2), new Point(1, 3), new Point(2, 1)))`
  - **Expected Outcome**: The point (2, 1) should be placed first, as it has the smallest y, rather than the point with the smallest x alone.

Mutation Testing Pit Test Report

Pit Test Coverage Report

Package Summary

default

Number of Classes	Line Coverage		Mutation Coverage		Test Strength	
1	100%	9/9	30%	3/10	30%	3/10

Breakdown by Class

Name	Line Coverage		Mutation Coverage		Test Strength	
ConvexHull.java	100%	9/9	30%	3/10	30%	3/10

Report generated by PIT 1.15.8

```
1   import java.util.Vector;
2
3   class ConvexHull {
4       Vector<Point> doGraham(Vector<Point> p) {
5           int i, j, min, M;
6           Point t;
7           min = 0;
8
9           // search for minimum:
10 2        for (i = 1; i < p.size(); ++i) {
11 2            if (p.get(i).y < p.get(min).y) {
12                  min = i;
13              }
14          }
15
16          // continue along the values with the same y component
17 2        for (i = 0; i < p.size(); ++i) {
18 3            if ((p.get(i).y == p.get(min).y) && (p.get(i).x > p.get(min).x)) {
19                  min = i;
20              }
21          }
22
23 1        return p; // Placeholder return; actual return might vary
24      }
25  }
```

Mutations

10	1. changed conditional boundary → KILLED 2. negated conditional → SURVIVED
11	1. negated conditional → SURVIVED 2. changed conditional boundary → SURVIVED
17	1. changed conditional boundary → KILLED 2. negated conditional → SURVIVED
18	1. negated conditional → SURVIVED 2. changed conditional boundary → SURVIVED 3. negated conditional → SURVIVED
23	1. replaced return value with null for ConvexHull::doGraham → KILLED

Active mutators

- CONDITIONALS_BOUNDARY
- EMPTY_RETURNS
- FALSE_RETURNS
- INCREMENTS
- INVERT_NEGS
- MATH
- NEGATE_CONDITIONALS
- NULL_RETURNS
- PRIMITIVE_RETURNS
- TRUE_RETURNS
- VOID_METHOD_CALLS

Tests examined

- ConvexHullTest.[engine:junit-jupiter]/[class:ConvexHullTest]/[method:testDoGraham_ConditionCoverage_YEqualAndXLargerThanMinX()] (0 ms)
- ConvexHullTest.[engine:junit-jupiter]/[class:ConvexHullTest]/[method:testDoGraham_StatementCoverage()] (2 ms)
- ConvexHullTest.[engine:junit-jupiter]/[class:ConvexHullTest]/[method:testDoGraham_BranchCoverage_SameYValues()] (2 ms)
- ConvexHullTest.[engine:junit-jupiter]/[class:ConvexHullTest]/[method:testDoGraham_ConditionCoverage_YSmallerThanMinY()] (2 ms)
- ConvexHullTest.[engine:junit-jupiter]/[class:ConvexHullTest]/[method:testDoGraham_BranchCoverage_DifferentYValues()] (75 ms)

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

Ans:

Test Set for Path Coverage Criterion

- To achieve path coverage for the `doGraham` method, we need to cover paths that:
  - Skip the loop entirely.
  - Enter the loop once.
  - Enter the loop multiple times (specifically twice, as per the criterion).
- **Test Case 1: Empty Vector (Loop is Skipped)**
  - **Input**: An empty vector, `p = new Vector<Point>();`
  - **Expected Outcome**: The method returns immediately without entering the loop.
  - **Reasoning**: This case covers the path where `p.size() == 0`, so the for loop is skipped entirely.
- **Test Case 2: Vector with One Point (Loop Executes Zero Times)**
  - **Input**: A vector with one point, e.g., `p = new Vector<>(Arrays.asList(new Point(1, 1)));`
  - **Expected Outcome**: The method should handle this without errors, and no swapping should occur.
  - **Reasoning**: Since there is only one point, the for loop initializes but does not execute any iterations, as `i = 1` exceeds `p.size() - 1`.
- **Test Case 3: Vector with Two Points (Loop Executes Once)**
  - **Input**: A vector with two points, e.g., `p = new Vector<>(Arrays.asList(new Point(2, 3), new Point(1, 2)));`
  - **Expected Outcome**: The point with the lowest y value (or lowest x if y values are the same) is moved to the first position.
  - **Reasoning**: This case covers the path where the for loop executes exactly once.

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

Ans:

- Statement Coverage: 2 test cases
- Branch Coverage: 3 test cases
- Basic Condition Coverage: 3 test cases
- Path Coverage: 3 test cases

Total: 2 (Statement) + 3 (Branch) + 3 (Basic Condition) + 3 (Path) = 11 test cases