EECS1022 Winter 2021
OOP Notes
Tracing *Point*, *PointCollector*, and *PointCollectorTester*

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Contents

1 Class **Point**

```
1  class Point {
2    private double x;
3    private double y;

4    public Point(double x, double y) {
5      this.x = x;
6      this.y = y;
7    }

8    public double getX() { return this.x; }
9    public double getY() { return this.y; }
10 }
```

Figure 1: Template for Two-Dimensional Points

- Figure 1 (page 2) shows the complete definition of class `Point`, which is a template for entities (i.e., points) on a two-dimensional plane. The common attributes (Lines 2 and 3) of all points are the x-coordinate and y-coordinate:

```
2    private double x;
3    private double y;
```

- To create an instance of the above `Point` class, you need to make a call to its (in this case, the only) constructor (Lines 4 to 7) by giving two argument values whose types match the types of the constructor's two parameters.

```
4    public Point(double x, double y) {
5      this.x = x;
6      this.y = y;
7    }
```

  For example, the call `Point(3, 4)` is valid, because the first argument value `3` matches the type of the first parameter `x`, and the second argument value should `4` matches the type of the second parameter `y`.

  There are occurrences of name clashes of variables in the above constructor: input parameters `x` and `y` clash with, respectively, attributes `x` and `y`.

  – There are **no** compilation errors, but both sources (RHS) of the variable assignments at Line 5 and Line 6 (i.e., `x` and `y`) reference the input parameters `x` and `y` (rather than the attributes). This phenomenon is called **variable shadowing**.

  – The use of "`this.`" preceding both targets (LHS) of the variable assignments (Line 5 and Line 6) are *necessary* for disambiguating references to the attributes `x` and `y`.

- To retrieve values of the two private attributes `x` and `y` of a `Point` object, one must invoke the two public accessor methods:

```
8    public double getX() { return this.x; }
9    public double getY() { return this.y; }
```

2 Class PointCollector

```
1  public class PointCollector {
2    private Point[] points;
3    private int nop; /* number of points */

4    public PointCollector() {
5      this.points = new Point[100];
6    }

7    public void addPoint(double x, double y) {
8      this.points[this.nop] = new Point(x, y);
9      this.nop ++;
10   }

11   public Point[] getPointsInQuadrantI() {
12     Point[] ps = new Point[this.nop];
13     int count = 0; /* number of points in Quadrant I */
14     for(int i = 0; i < this.nop; i ++) {
15       Point p = points[i];
16       if(p.getX() > 0 && p.getY() > 0) {
17         ps[count] = p;
18         count ++;
19       }
20     }
21     Point[] q1Points = new Point[count];
22     /* ps contains null if count < nop */
23     for(int i = 0; i < count; i ++) {
24       q1Points[i] = ps[i]
25     }
26     return q1Points;
27   }

28   public int getNumberOfPoints() {
29     return this.nop;
30   }
31 }
```

Figure 2: Template for Entities which Collect Points

2.1 Attributes of PointCollector

Figure 2 (page 3) shows the complete definition of class `PointCollector`, which is a template for entities (i.e., collectors of points), each of which collecting a list of points on the two-dimensional plane. The common attributes (Lines 2 and 3) of all point collectors are:

– **Line 2**: An array of `points`, which is of type `Point[]`. Declaring the attribute

```
private Point[] points;
```

means that at runtime, each point collector has an array named `points`, where each slot stores the address (which may be `null`) of some `Point` object.

– **Line 3**: An integer counter named `nop` (standing for number of points), which serves two purposes:

1. Records how many points have been collected (i.e., added to the `points` array) so far. Notice that the value of `nop` should start with `0`, and get incremented by one as each new `Point` object is collected, until it reaches `points.length`.
2. Indicates where in `points` (i.e., an index value between `0` and `points.length - 1`). When the value of `nop` reaches its maximum `points.length`, meaning that all slots of the `points` array are occupied by addresses of `Point` objects, this maximum value also means that storing a next `Point` object is not possible (because the value `points.length` is out of the index bounds for array `points`).

– **Lines 28 – 30**: To retrieve values of the private attribute `nop` of a `PointCollector` object, one must invoke the public accessor method:

```
28  public int getNumberOfPoints() {
29    return this.nop;
30  }
```

2.2 Constructor of `PointCollector`

To create an instance of the above `PointCollector` class, you need to make a call to its (only) constructor (Lines 4 to 6) by giving zero argument values. For example, consider the the following line

```
PointCollector pc = new PointCollector();
```

where

Step 1:

The RHS (i.e., `new PointCollector()`) creates a new object of type `PointCollector`.

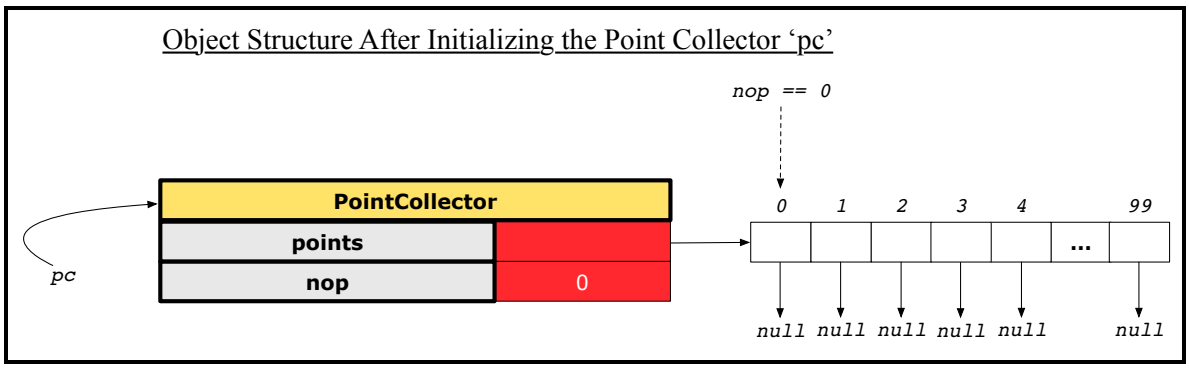
Step 2:

The LHS (i.e., `PointCollector pc`) declares a variable `pc` which, at runtime, stores only an address of some `PointCollector` object.

Step 3:

The middle equal sign (=) assigns (i.e., stores) the address of the new `PointCollector` object (created in **Step 1**) to the `PointCollector` address placeholder (declared in **Step 2**).

Here is a visual summary of the effect of executing the above three steps (where we use an addition dashed arrow to make it explicit that the value of `nop` can be seen as pointing to a position in array `pc.points`):



where

– The path `pc.nop` (where `pc` is the *context object*) brings us to the value of attribute `nop` of the specific `PointCollector` instance `pc`.

– The path `pc.ponts` (where `pc` is the `context object`) brings us to the value of attribute `points`. That is, `pc.points` denotes the address of an array object, whose each slot stores the address of some `Point` object.

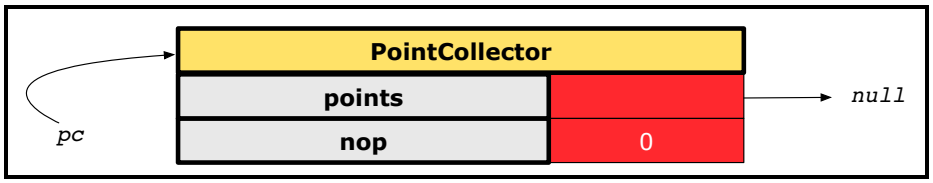
Why is it the case that `pc.nop` has the value `0` and `pc.points` has the value of an array whose each slot stores the `null` (i.e., unknown address) value? Inspect the definition of the constructor in class `PointCollector` (Lines 5 to 6 in Figure 2, page 3):

```
4  public PointCollector() {
5    this.points = new Point[100];
6  }
```

– When each instance of type `PointCollector` is created, it is critical to initialize the `points` array that it possesses (so that subsequent method calls on each `PointCollector` object can access/modify its `points` array without triggering a `NullPointerException`). That is, here is a wrong implementation of the constructor of `PointCollector`:

```
public PointCollector() { /* wrong implementation of the constructor */
  /* points array is implicitly initialized to null */
}
```

where the `points` array is not explicitly initialized to certain length, so it is implicitly assigned to the default value of reference types: `null`. Here is a visual summary of the effect of the above wrong implementation of constructor:



Why is it wrong? Try access contents of the `points` array, for example, calling `pc.points[0]`, then it will trigger a `NullPointerException`, because `pc.points` is `null` and calling `pc.points[0]` is equivalent to calling `null.points[0]`, which simply does not make sense.

– Line 5 initializes `points` as an array of size `100` (just for this example as the assumed maximum number of points that each `PointCollectr` may collect). We only initializes the array `points` with a fixed size, without storing in any of its slots addresses of `Point` (simply because initially no points have been collected yet), so all slots in `points` store values `null` only.

– Since there is no explicit assignments that given an initial value to the attribute `nop`, it is initialized (implicitly) with the default value of integers: `0`.

Remark: The above digram shows a sensible configuration of objects: **1)** `pc.points.length` is `100`, meaning that we can in the future store at most `100` objects of type `Point` into it; and **2)** `pc.nop` is `0`, meaning that so far we have collected zero points, and that the next (i.e., very first) point object to be stored will be stored at `pc.points[0]`.

2.3 Mutator Method `addPoint` of `PointCollector`

The mutator method `void addPoint(double x, double y)` (Lines 7 to 10, page 3) defines how a new point with coordinate values `x` and `y` can be added to the point collector.

```
7  public void addPoint(double x, double y) {
8    this.points[this.nop] = new Point(x, y); /* store the new point at index 'nop' of 'points' */
9    this.nop++; /* increment # of points collected, update index for storing next point */
10 }
```

There are two steps involved:

Step 1 (Line 8):

```
8  this.points[this.nop] = new Point(x, y);
```

Step 1.1: The RHS (i.e., `new Point(x, y)`) creates a new `Point` object, by calling the constructor of `Point`: the parameter values `x` and `y` of method `addPoint` are used as argument values for the call to the constructor call `Point(x, y)`.

Step 1.2: The LHS (i.e., `this.points[this.nop]`) brings us to the specific slot at index `nop` in array `points`.

Step 1.3: The middle equal sign (=) assigns/stores the address of the new `Point` object (created in **Step 1.1**) at index `nop` in array `points`. Remember that one of the purposes of counter `nop` is that it indicates where a new `Point` to be collected should be stored.

Step 2 (Line 9):

```
9  this.nop++;
```

Now that from **Step 1** we already store a new `Point` object at index `nop` of array `points`, this line updates (by incrementing) the value of `nop` so that it still serves its purpose well. For example, if in **Step 1** the value of `nop` is `2`, that means so far the slots `points[0]`, `points[1]`, `points[2]` are all occupied by addresses of some `Point` object. So to make sure that

- value of `nop` correctly records the number of `Point` objects collected so far (which should be `3` rather than `2`), and that
- value of `nop` indicates the position for storing the next new `Point` to be collected (which should be `points[3]` rather than `points[2]`),

we increment the value of `nop` by `1`.

2.4 Accessor Method `getPointsInQuadrantI` of `PointCollector`

The accessor method `Point[] getPointsInQuadrantI()` (Lines 11 to 27, page 3) defines, out of the `Point` objects collected so far, how to return an array containing only those points which are located at the first quadrant (i.e., those points whose both coordinates are positive).

First of all, we need to understand that simply returning `points` (which is also of type `Point[]`) is not acceptable, because: **1)** if `nop < points.length`, there are `points.length - nop` slots storing `null` values; and **2)** even if `nop == points.length`, not necessarily all points collected so far are all located in the first quadrant. Therefore, this accessor method `getPointsInQuadrantI` is supposed to return an array of `Point` objects, whose length corresponds to exactly the number of collected points that are located in the first quadrant.

There are three steps involved:

Step 1 (Lines 12 to 20):

```
12 Point[] ps = new Point[this.nop];
13 int count = 0; /* number of points in Quadrant I (Q1) */
14 for(int i = 0; i < this.nop; i ++) {
15   Point p = this.points[i]; /* store the current point under consideration into p */
16   if(p.getX() > 0 && p.getY() > 0) { /* the point being considered is in 1st quadrant */
17     ps[count] = p; /* copy what's stored in 'p' to slot at index 'count' of 'ps' */
18     count ++; /* increment # of Q1 points, update index for storing next Q1 point */
19   }
20 }
```

- Line 12 initializes an array of size `nop`, indicating that might be up to `nop` points that we have collected are located in the first quadrant. Why? Given that so far we have collected `nop` (rather than `points.length`) `Point` objects in the point collector, the maximum number of `Point` that are located in the first quadrant is simply `nop` (i.e., when all points collected are located in the first quadrant).

– As we iterate through the `points` array (slots `points[0]`, `points[1]`, ..., `points[nop - 1]`) some collected points might be located in the first quadrant, and some might not be. As a result, we need a separate counter `count` that records exactly how many points are located in the first quadrant. How `count` is used (Lines 17 and 18, Figure 2, page 3) to keep track of how many collected `Point` objects are located in the first quadrant is analogous to how `nop` is used (Lines 8 and 9, Figure 2, page 3) to keep track of how many `Point` objects are collected so far.

Step 2 (Lines 21 to 25):

```
21 Point[] q1Points = new Point[count];
22 /* ps contains null if count < nop */
23 for(int i = 0; i < count; i ++) {
24   q1Points[i] = ps[i]
25 }
```

– From **Step 1**, we have updated the integer variable `count` so that it records the number of collected points that are located in the first quadrant, and that the `count` slots `ps[0]`, `ps[1]`, ..., `ps[count - 1]` store addresses of such first-quadrant points. Notice that it is the case that `count <= nop`:

Case 1) if `count == nop`, then all slots of array `ps` (whose length is `nop` as can be seen in Line 12 in Figure 2, page 3) are occupied;

Case 2) if `count < nop`, then at at least one slots of array `ps` (i.e., `ps[count]`, `ps[count + 1]`, ..., `ps[nop]`) store the `null` points (simply because not all points collected happen to be in the first quadrant).

If the above **Case 2** is true, meaning that there are `null` values in array `ps`, then we cannot simply return `ps` as the return value for method `getPointsInQuadrantI`.

– Therefore:

* In Line 21 we initialize an array `q1Points` whose length corresponds the exact number of first-quadrant points (i.e., the value of `count`).
* In Lines 23 to 25, we copy addresses of all such first-quadrant (stored in `ps[0]`, `ps[1]`, ..., `ps[count - 1]`) to their corresponding positions in array `q1Points` to be returned: `q1Points[0]`, `q1Points[1]`, ..., `q1Points[count - 1]`.

Step 3 (Line 26):

```
26 return q1Points;
```

Now that the previous two steps store addresses of all first-quadrant points (no more, and no less) into the array `q1Points`, we return it as the return value of method `getPointsInQuadrantI` (whose return type is `Point[]`).

3 Class PointCollectorTester

After understanding the descriptions of the attributes and methods of the classes `Point` (Section 1) and `PointCollector` (Section 2) from the previous two sections, let us learn how objects of these two classes may interact.

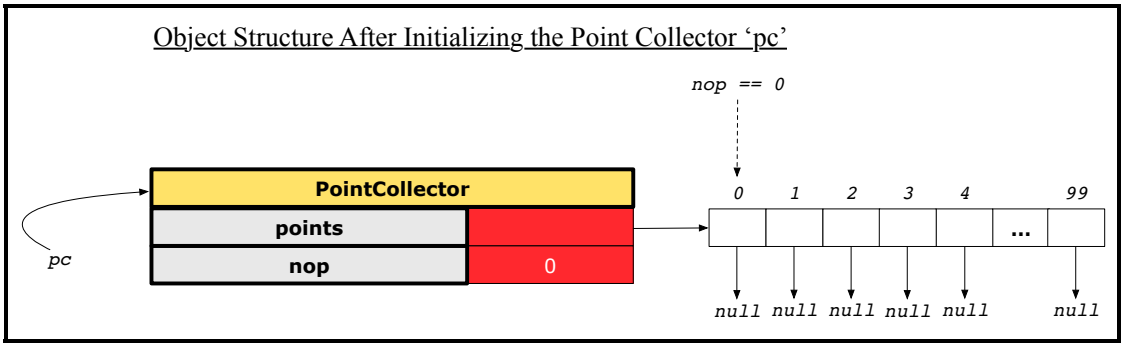
```
1  public class PointCollectorTester {
2    public static void main(String[] args) {
3      PointCollector pc = new PointCollector();
4      System.out.println(pc.getNumberOfPoints()); /* 0 */

5      pc.addPoint(3, 4);
6      System.out.println(pc.getNumberOfPoints()); /* 1 */

7      pc.addPoint(-3, 4);
8      System.out.println(pc.getNumberOfPoints()); /* 2 */

9      pc.addPoint(-3, -4);
10     System.out.println(pc.getNumberOfPoints()); /* 3 */

11     pc.addPoint(3, -4);
12     System.out.println(pc.getNumberOfPoints()); /* 4 */

13     Point[] ps = pc.getPointsInQuadrantI();
14     System.out.println(ps.length); /* 1 */
15     System.out.println("(" + ps[0].getX() + ", " + ps[0].getY() + ")"); /* (3, 4) */
16   }
17 }
```

Figure 3: Tester for Instances of `Point` and `PointTester`

- **Line 3** of `PointTester`:

```
PointCollector pc = new PointCollector();
```

As explained in the constructor of `PointCollector` (Section 2, page 3), the above line results in the following object structure:



Therefore, executing the print statement `System.out.println(pc.getNumberOfPoints())` in Line 4 of `PointCollector` outputs `0` to the console.

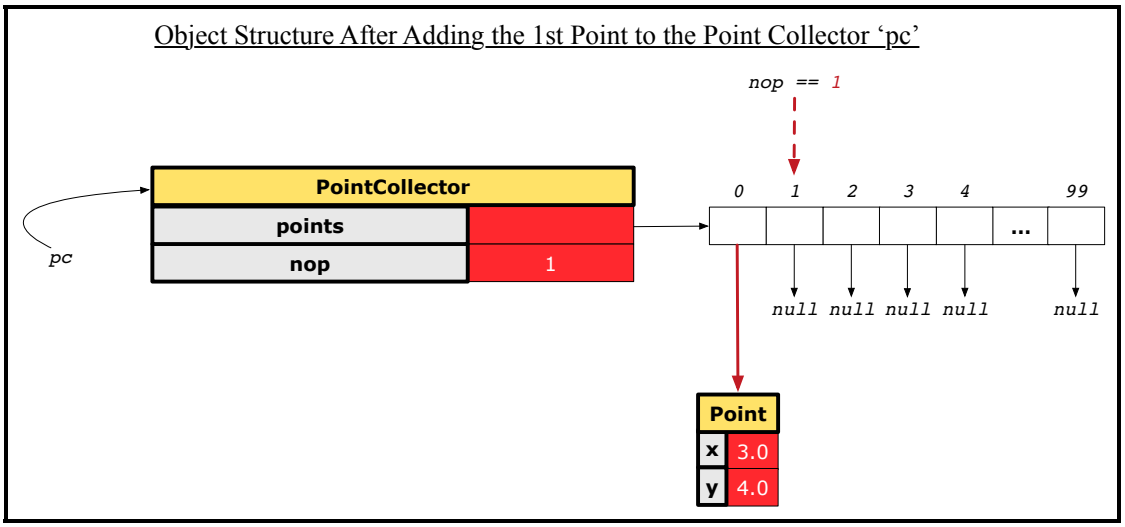
- **Line 5** of `PointTester`:

```
pc.addPoint(3, 4);
```

This method call has the context object `pc`, declared as an address holder of some `PointCollector` object, and the mutator method `void addPoint(double x, double y)` (defined in Lines 7 to 10 in Figure 2, Section 2, page 3) is instantiated (by substituting `this` by `pc`, `x` by `3` and `y` by `4`) as:

```
public void addPoint(3, 4) {
  /* current value of nop is 0 */
  pc.points[pc.nop] = new Point(3, 4);
  pc.nop++;
  /* current value of nop is 1 */
}
```

Executing the above method call results in the following object structure:



Therefore, executing the print statement `System.out.println(pc.getNumberOfPoints())` in Line 6 of `PointCollector` outputs `1` to the console.

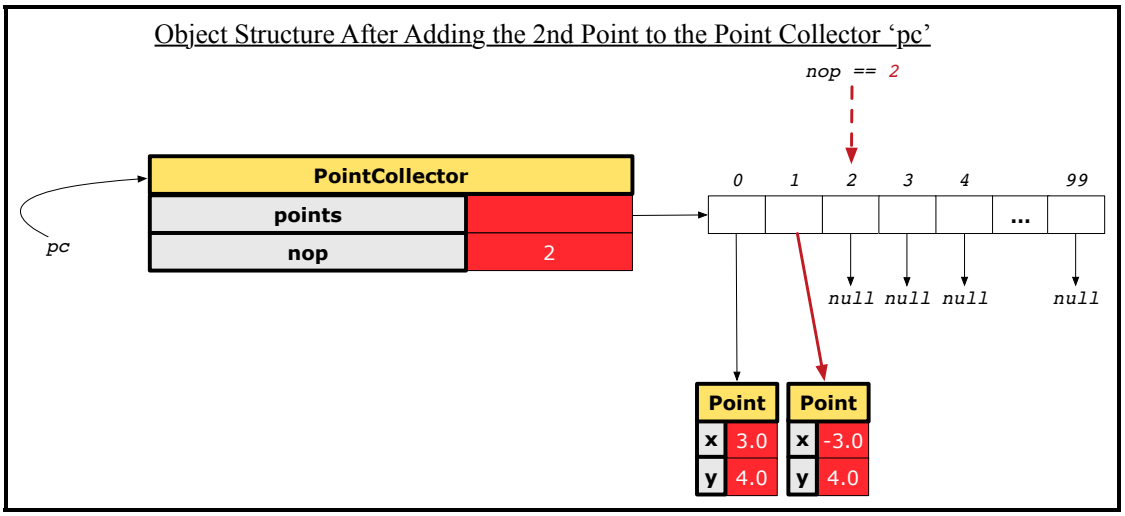
- **Line 7** of `PointTester`:

```
pc.addPoint(-3, 4);
```

This method call has the context object `pc`, declared as an address holder of some `PointCollector` object, and the mutator method `void addPoint(double x, double y)` (defined in Lines 7 to 10 in Figure 2, Section 2, page 3) is instantiated (by substituting `this` by `pc`, `x` by `-3` and `y` by `4`) as:

```
public void addPoint(-3, 4) {
  /* current value of nop is 1 */
  pc.points[pc.nop] = new Point(-3, 4);
  pc.nop++;
  /* current value of nop is 2 */
}
```

Executing the above method call results in the following object structure:



Therefore, executing the print statement `System.out.println(pc.getNumberOfPoints())` in Line 8 of `PointCollector` outputs `2` to the console.

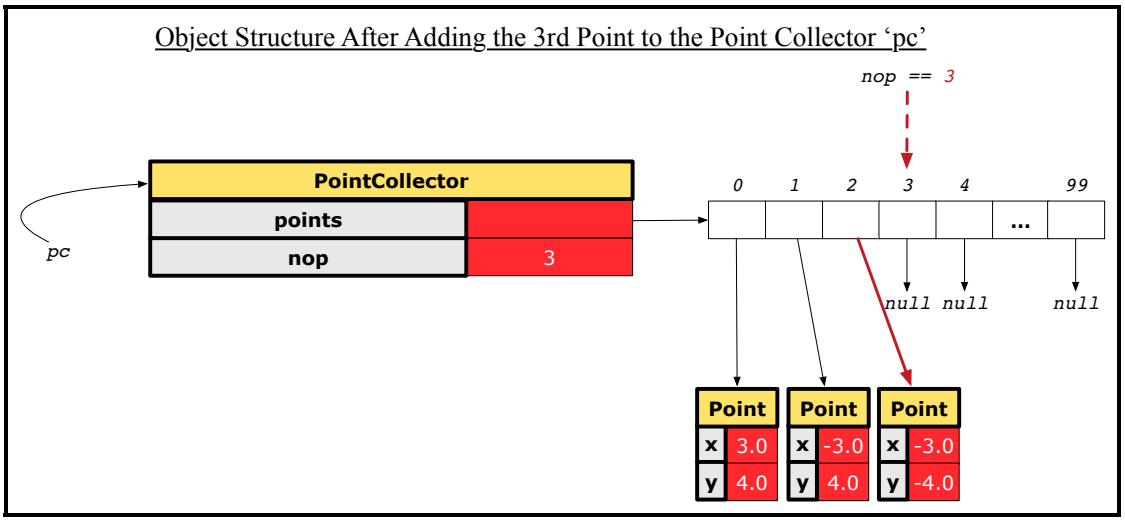
- **Line 9** of `PointTester`:

```
pc.addPoint(-3, -4);
```

This method call has the context object `pc`, declared as an address holder of some `PointCollector` object, and the mutator method `void addPoint(double x, double y)` (defined in Lines 7 to 10 in Figure 2, Section 2, page 3) is instantiated (by substituting `this` by `pc`, `x` by `-3` and `y` by `-4`) as:

```
public void addPoint(-3, -4) {
  /* current value of nop is 2 */
  pc.points[pc.nop] = new Point(-3, -4);
  pc.nop++;
  /* current value of nop is 3 */
}
```

Executing the above method call results in the following object structure:



Therefore, executing the print statement `System.out.println(pc.getNumberOfPoints())` in Line 10 of `PointCollector` outputs `3` to the console.

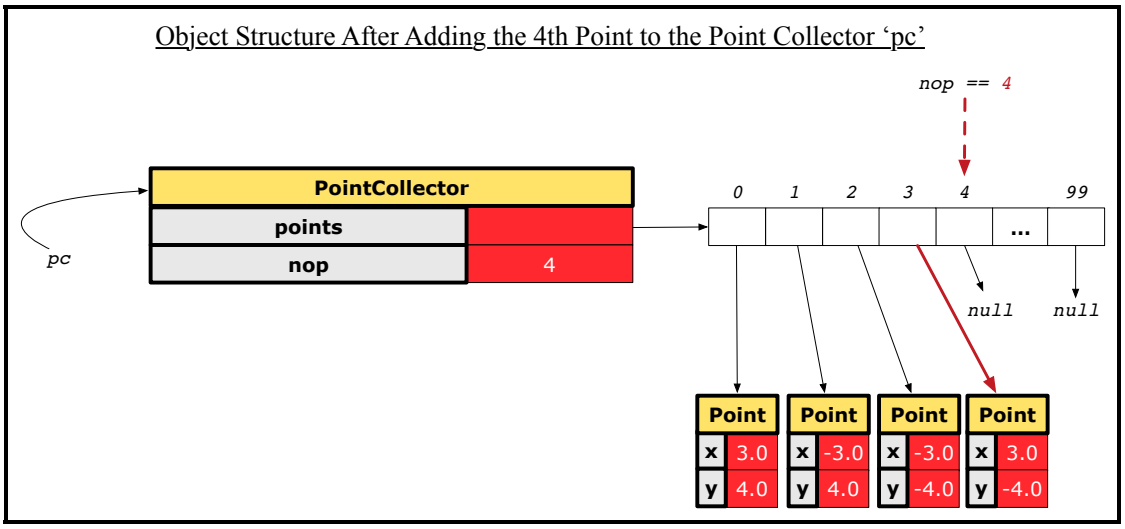
- **Line 11** of `PointTester`:

```
pc.addPoint(3, -4);
```

This method call has the context object `pc`, declared as an address holder of some `PointCollector` object, and the mutator method `void addPoint(double x, double y)` (defined in Lines 7 to 10 in Figure 2, Section 2, page 3) is instantiated (by substituting `this` by `pc`, `x` by `3` and `y` by `-4`) as:

```
public void addPoint(3, −4) {
  /* current value of nop is 3 */
  pc.points[pc.nop] = new Point(3, −4);
  pc.nop++;
  /* current value of nop is 4 */
}
```

Executing the above method call results in the following object structure:



Therefore, executing the print statement `System.out.println(pc.getNumberOfPoints())` in Line 12 of `PointCollector` outputs `4` to the console.

Pause and think: Up to this point, `nop == 4` indicates that there have been four points collected in the `points` array of the point collector object `pc`. We observe that out of these four points collected, only the points stored at `pc.points[0]` is located in the first quadrant. Therefore, we would expect the return value from a subsequent (accessor) method call `pc.getPointsInQuadrantI()` to be an array of length **1**.

- **Line 13** of `PointTester`:

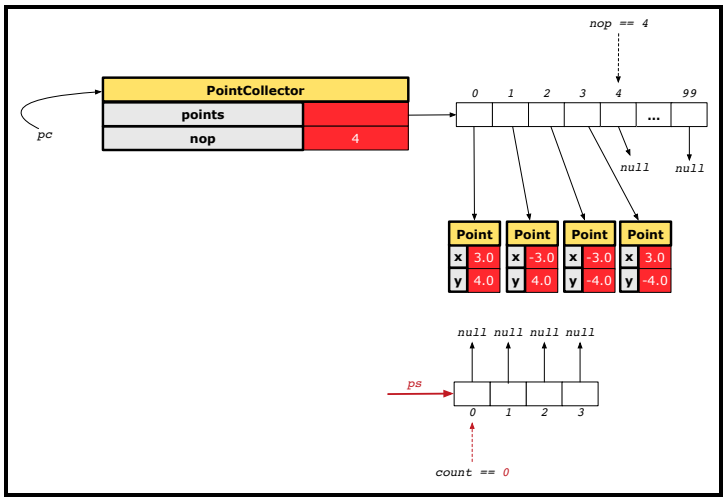
```
Point[] ps = pc.getPointsInQuadrantI();
```

This method call has the context object `pc`, declared as an address holder of some `PointCollector` object, and the accessor method `Point[] getPointsInQuadrantI()` (defined in Lines 11 to 27 in Figure 2, Section 2, page 3) is executed (by substituting `this` by `pc`, `nop` by its current value `4` and `points` by the array above where the first four slots are occupied) as:

– **Lines 12 to 20** of `PointCollector`:

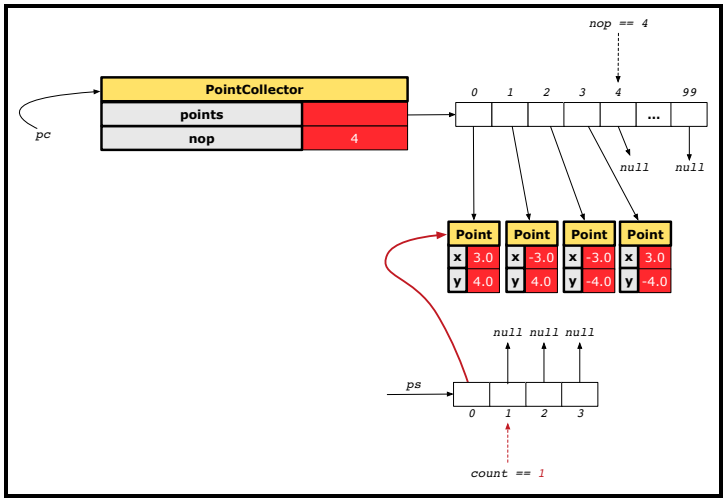
```
12  Point[] ps = new Point[pc.nop]; /* current value of nop is 4 */
13  int count = 0; /* number of points in Quadrant I */
14  for(int i = 0; i < pc.nop; i ++) {
15    Point p = points[i];
16    if(p.getX() > 0 && p.getY() > 0) {
17      ps[count] = p;
18      count ++;
19    }
20  }
```

Right after Line 13, we initialize an array `ps` of size `nop` (whose current value is 4, meaning that at most the four points collected are all located in the first quadrant) and a counter `count` (whose job is to keep track of out of those points collected so far, how many of them are located in the first quadrant). Here is a visual summary of the object structure after right after executing Line 13:



Then, the `for` loop in Lines 14 to 20 is executed to iterate through `pc.points[0]`, `pc.points[1]`, `pc.points[2]`, and `pc.points[3]`, and store whichever that is located in the first quadrant into slots in `ps`. Only the first iteration (when `i == 0`) which inspects `pc.points[0]` would pass the condition in Line 16, store the address of the point object $(3, 4)$ into `ps`, and update the `count` value accordingly; all later three iterations (when `i` is `1`, `2`, and `3`), the condition in Line 6 evaluates to $false$, so none of those three points would be stored in `ps` and the value of `count` would not be incremented any further.

Here is a visual summary of the object structure after right after executing Line 20:



Remarks. It is important to notice that in Line 14, the value of `nop` (which is currently 4), rather than the value of `pc.points.length` (which has remained 100 since it was first created), is used as the upper bound of the loop counter. What if `i < pc.points.length` was used instead as the stay condition of the `for` loop? Unfortunately, when the value of loop counter `i` reaches `4` (which corresponds to the first, left-most index at which `pc.points` stores a `null` value), we would still pass this (wrong) stay condition `i < pc.points.length` and enter the body of the `for` loop. Consequently, executing Line 15 assigns `null` to variable `p`, and when the execution reaches Line 16, executing `p.getX()` and `p.getY()` is equivalent to executing `null.getX()` and `null.getY()`, which would trigger a `NullPointerException`.

– **Lines 21 to 25** of `PointCollector`:

```
21  Point[] q1Points = new Point[count];
22  /* ps contains null if count < nop */
23  for(int i = 0; i < count; i ++) {
24    q1Points[i] = ps[i]
25  }
```

From Lines 12 to 20, we have updated the values of `count` (which is now `1`) and `ps`, so that array `ps` now has `1` non-`null` slot and `3` (calculated through `ps.length - count`, where `ps.length == nop && nop == 4`) `null` slots. We cannot simply return array `ps` as the return value for method `getPointsInQuadrantI`, as it contains `null` slots. As a result, we execute Lines 21 to 25 to initialize an array `q1Points` whose length corresponds to exactly those (indicated by the value of `count`) collected points that are located in the first quadrant, and we simply copy over the addresses of the first-quadrant points to slots in array `q1Points`.

Figure 4 summarizes the object structure after right after executing Line 25:

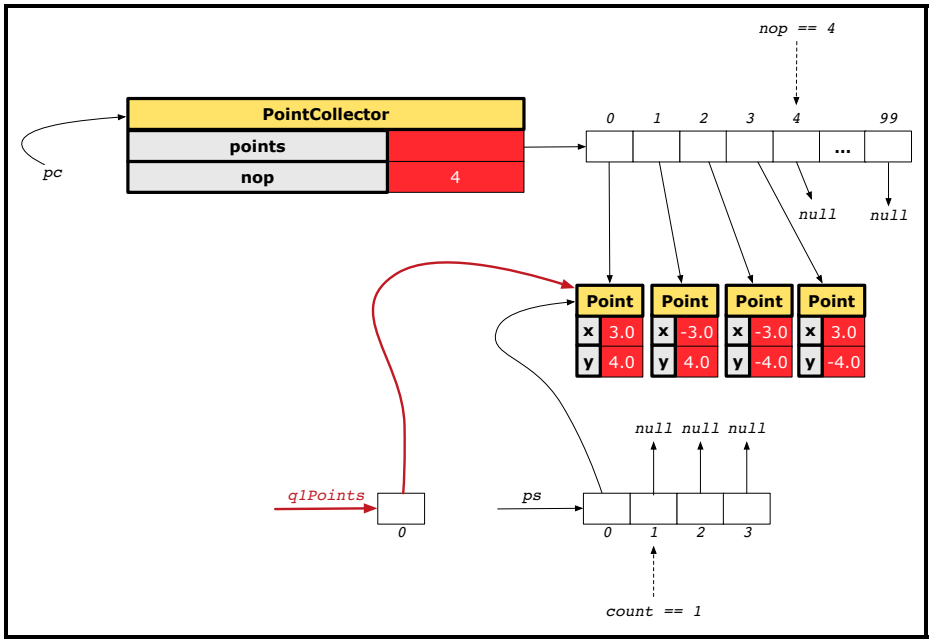


Figure 4: Final Object Structure from Executing `PointCollectorTester`

Again, it is important to notice that in Line 23, the value of `count` (which is currently 1), rather than the value of `nop` (which is 4), is used as the upper bound of the loop counter. What if `i < nop` was used instead as the stay condition of the `for` loop? Unfortunately, when the value of loop counter `i` reaches `1`, we would still pass this (wrong) stay condition `i < nop` and enter the body of the `for` loop. Consequently, executing the expression `q1Points[i]` in Line 24 would trigger an `ArrayIndexOutOfBoundException` because the array `q1Points` was created in Line 21 to have length `count` (which is 1).

– **Line 26** of `PointCollector`:

```
26   return q1Points;
```

Up to now, there are three candidate objects (whose types all match the return type `Point[]` of the accessor method `getPointsInQuadrantI`) that can be the return values:

1. `pc.points`
   This should not be returned, since it contains `pc.points.length - nop` slots that store `null` values, and even for those slots that store addresses of `Point` objects, some of them are actually not located in the first quadrant.
2. `ps`
   This should not be returned, since it contains `nop - count` slots that store `null` value.
3. `q1Points`
   This should be returned, since it contains exactly those collected points that are located in the first quadrant, and there are no `null`-slots in this array.

Therefore, we return `q1Points` (which stores the address of the array of size 1) as the return value of accessor method `getPointsInQuadrantI`. This return value is stored, from Line 13 of `PointCollectorTester` (Figure 3, page 8), into variable `ps`. Consequently:

* In Line 14 of `PointCollectorTester`, the print statement `System.out.println(ps.length)` outputs `1` to the console.
* In Line 15 of `PointCollectorTester`, the print statement `System.out.println("(" + ps[0].getX() + ", " + ps[0].getY() + ")")` outputs `(3, 4)` to the console.

- **Exercise.** Figure 3 (page 8) above shows declarations and manipulations in the context of a console application. As an exercise, convert it into a JUnit test method. For example, Line 3 and 4 may be converted to:

```
@Test
public void test() {
  PointCollector pc = new PointCollector();
  assertEquals(0, pc.getNumberOfPoints());
}
```