INFO6205 Assignment 2 (3-SUM)

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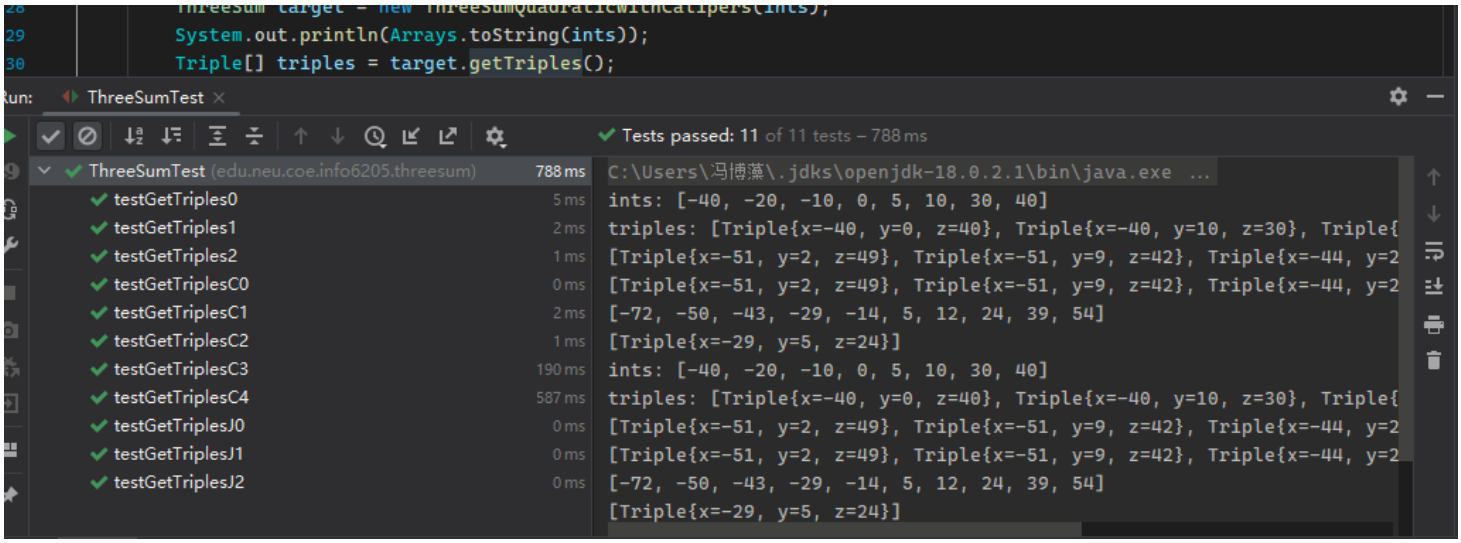
Repository: https://github.com/fengb3/INFO6205

Assignment02 Three Sum

a) Screenshots of unit testing code and test pass

```java
    xiaohuanlin
    @Test
    public void testGetTriples2() {
        Supplier<int[]> intsSupplier = new Source( N: 10,  M: 15,  seed: 3L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadratic(ints);
        System.out.println(Arrays.toString(ints));
        Triple[] triples = target.getTriples();
        System.out.println(Arrays.toString(triples));
        assertEquals( expected: 1, triples.length);
        assertEquals( expected: 1, new ThreeSumCubic(ints).getTriples().length);
    }

    xiaohuanlin
    @Ignore // Slow
    public void testGetTriples3() {
        Supplier<int[]> intsSupplier = new Source( N: 1000,  M: 1000).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadratic(ints);
        Triple[] triplesQuadratic = target.getTriples();
        Triple[] triplesCubic = new ThreeSumCubic(ints).getTriples();
        int expected1 = triplesCubic.length;
        assertEquals(expected1, triplesQuadratic.length);
    }

    xiaohuanlin
    @Ignore // Slow
    public void testGetTriples4() {
        Supplier<int[]> intsSupplier = new Source( N: 1500,  M: 1000).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadratic(ints);
        Triple[] triplesQuadratic = target.getTriples();
        Triple[] triplesCubic = new ThreeSumCubic(ints).getTriples();
        int expected1 = triplesCubic.length;
        assertEquals(expected1, triplesQuadratic.length);
    }

    xiaohuanlin
    @Test
    public void testGetTriplesC0() {
        int[] ints = new int[]{30, -40, -20, -10, 40, 0, 10, 5};
        Arrays.sort(ints);
        System.out.println("ints: " + Arrays.toString(ints));
        ThreeSum target = new ThreeSumQuadratic(ints);
        Triple[] triples = target.getTriples();
        System.out.println("triples: " + Arrays.toString(triples));
        assertEquals( expected: 4, triples.length);
        assertEquals( expected: 4, new ThreeSumCubic(ints).getTriples().length);
    }

    xiaohuanlin +1
    @Test
    public void testGetTriplesC1() {
        Supplier<int[]> intsSupplier = new Source( N: 20,  M: 20,  seed: 1L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
        Triple[] triples = target.getTriples();
        assertEquals( expected: 4, triples.length);
        System.out.println(Arrays.toString(triples));
        Triple[] triples2 = new ThreeSumCubic(ints).getTriples();
        System.out.println(Arrays.toString(triples2));
        assertEquals( expected: 4, triples2.length);
    }

    xiaohuanlin +1
    @Test
    public void testGetTriplesC2() {
        Supplier<int[]> intsSupplier = new Source( N: 10,  M: 15,  seed: 3L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
```


ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
System.out.println(Arrays.toString(ints));
Triple[] triples = target.getTriples();
Run: ThreeSumTest
Tests passed: 11 of 11 tests – 788 ms
ThreeSumTest (edu.neu.coe.info6205.threesum) 788 ms
testGetTriples0 5 ms
testGetTriples1 2 ms
testGetTriples2 1 ms
testGetTriplesC0 0 ms
testGetTriplesC1 2 ms
testGetTriplesC2 1 ms
testGetTriplesC3 190 ms
testGetTriplesC4 587 ms
testGetTriplesJ0 0 ms
testGetTriplesJ1 0 ms
testGetTriplesJ2 0 ms
C:\Users\冯博藻\.jdks\openjdk-18.0.2.1\bin\java.exe ...
ints: [-40, -20, -10, 0, 5, 10, 30, 40]
triples: [Triple{x=-40, y=0, z=40}, Triple{x=-40, y=10, z=30}, Triple{
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
[-72, -50, -43, -29, -14, 5, 12, 24, 39, 54]
[Triple{x=-29, y=5, z=24}]
ints: [-40, -20, -10, 0, 5, 10, 30, 40]
triples: [Triple{x=-40, y=0, z=40}, Triple{x=-40, y=10, z=30}, Triple{
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
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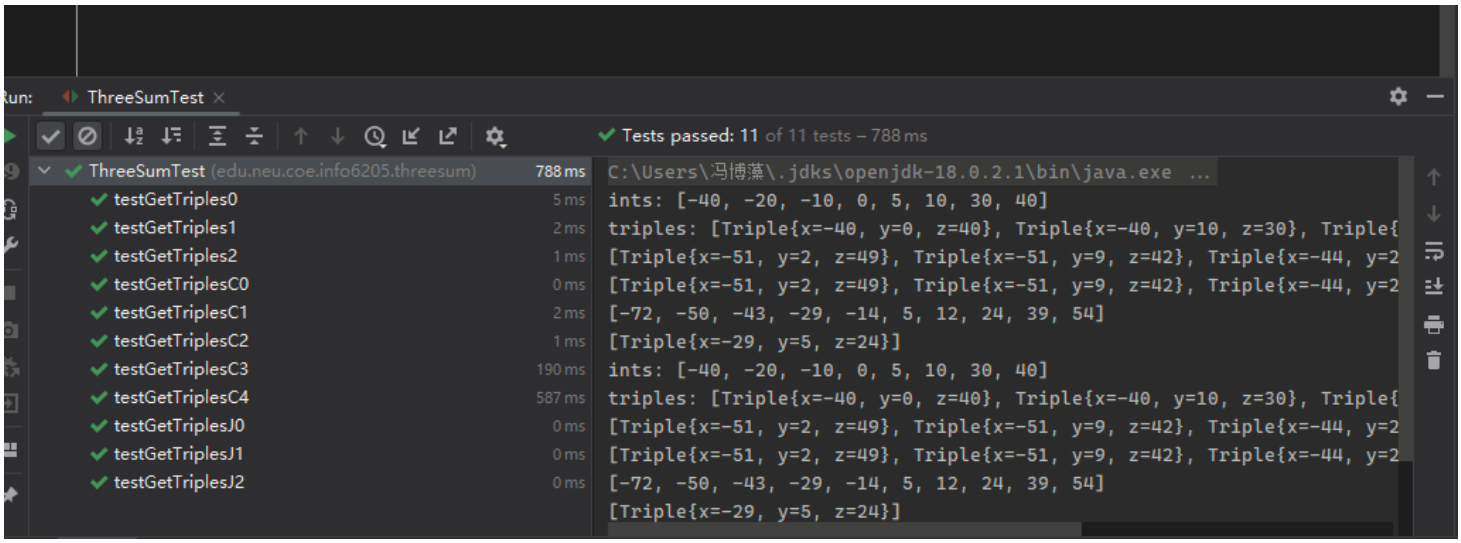
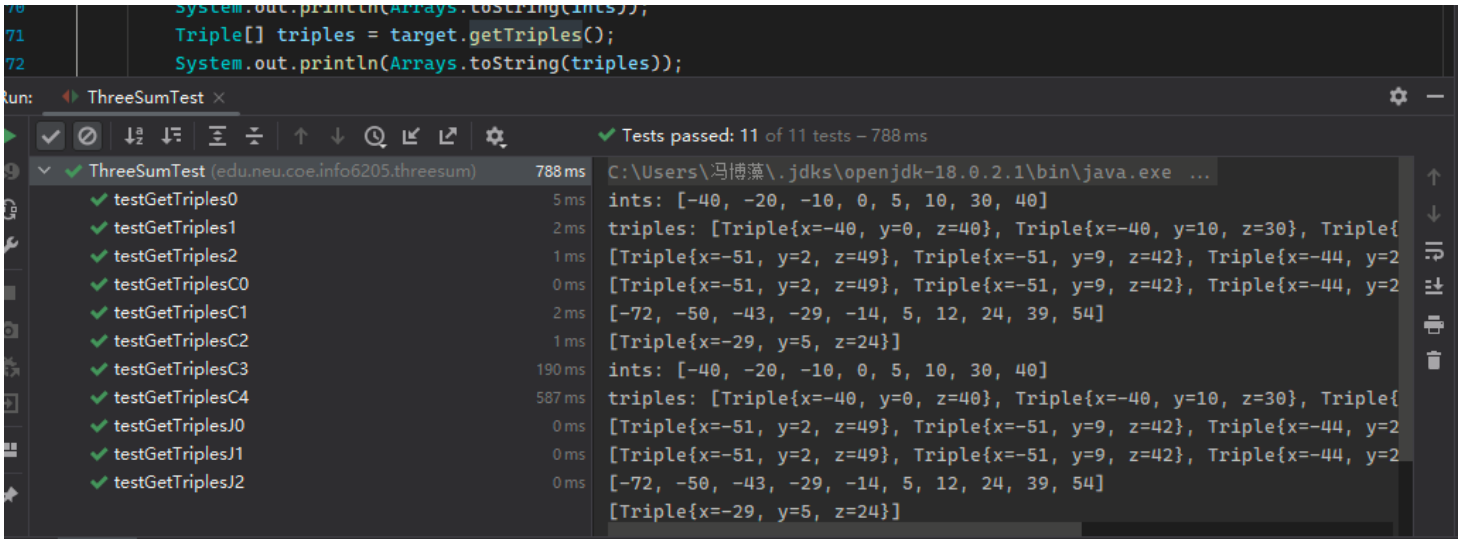
[-72, -50, -43, -29, -14, 5, 12, 24, 39, 54]
[Triple{x=-29, y=5, z=24}]

```
        int expected1 = triplesCubic.length;
        assertEquals(expected1, triplesQuadratic.length);
    }

    xiaohuanlin
    @Test
    public void testGetTriplesC0() {
        int[] ints = new int[]{30, -40, -20, -10, 40, 0, 10, 5};
        Arrays.sort(ints);
        System.out.println("ints: " + Arrays.toString(ints));
        ThreeSum target = new ThreeSumQuadratic(ints);
        Triple[] triples = target.getTriples();
        System.out.println("triples: " + Arrays.toString(triples));
        assertEquals( expected: 4, triples.length);
        assertEquals( expected: 4, new ThreeSumCubic(ints).getTriples().length);
    }

    xiaohuanlin +1
    @Test
    public void testGetTriplesC1() {
        Supplier<int[]> intsSupplier = new Source( N: 20,  M: 20,  seed: 1L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
        Triple[] triples = target.getTriples();
        assertEquals( expected: 4, triples.length);
        System.out.println(Arrays.toString(triples));
        Triple[] triples2 = new ThreeSumCubic(ints).getTriples();
        System.out.println(Arrays.toString(triples2));
        assertEquals( expected: 4, triples2.length);
    }

    xiaohuanlin +1
    @Test
    public void testGetTriplesC2() {
        Supplier<int[]> intsSupplier = new Source( N: 10,  M: 15,  seed: 3L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
        System.out.println(Arrays.toString(ints));
        Triple[] triples = target.getTriples();
        System.out.println(Arrays.toString(triples));
        assertEquals( expected: 1, triples.length);
        assertEquals( expected: 1, new ThreeSumCubic(ints).getTriples().length);
    }

    xiaohuanlin +1
    @Test
    public void testGetTriplesC3() {
        Supplier<int[]> intsSupplier = new Source( N: 1000,  M: 1000).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
        Triple[] triplesQuadratic = target.getTriples();
        Triple[] triplesCubic = new ThreeSumCubic(ints).getTriples();
        assertEquals(triplesCubic.length, triplesQuadratic.length);
    }

    xiaohuanlin +1
    @Test
    public void testGetTriplesC4() {
        Supplier<int[]> intsSupplier = new Source( N: 1500,  M: 1000).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadraticWithCalipers(ints);
        Triple[] triplesQuadratic = target.getTriples();
        Triple[] triplesCubic = new ThreeSumCubic(ints).getTriples();
        assertEquals(triplesCubic.length, triplesQuadratic.length);
    }

}
```


Run:
ThreeSumTest
Tests passed: 11 of 11 tests – 788 ms
ThreeSumTest (edu.neu.coe.info6205.threesum) 788 ms
testGetTriples0 5 ms
testGetTriples1 2 ms
testGetTriples2 1 ms
testGetTriplesC0 0 ms
testGetTriplesC1 2 ms
testGetTriplesC2 1 ms
testGetTriplesC3 190 ms
testGetTriplesC4 587 ms
testGetTriplesJ0 0 ms
testGetTriplesJ1 0 ms
testGetTriplesJ2 0 ms
C:\Users\冯博藻\.jdks\openjdk-18.0.2.1\bin\java.exe ...
ints: [-40, -20, -10, 0, 5, 10, 30, 40]
triples: [Triple{x=-40, y=0, z=40}, Triple{x=-40, y=10, z=30}, Triple{
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
[-72, -50, -43, -29, -14, 5, 12, 24, 39, 54]
[Triple{x=-29, y=5, z=24}]
ints: [-40, -20, -10, 0, 5, 10, 30, 40]
triples: [Triple{x=-40, y=0, z=40}, Triple{x=-40, y=10, z=30}, Triple{
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
[Triple{x=-51, y=2, z=49}, Triple{x=-51, y=9, z=42}, Triple{x=-44, y=2
[-72, -50, -43, -29, -14, 5, 12, 24, 39, 54]
[Triple{x=-29, y=5, z=24}]

```java
package edu.neu.coe.info6205.threesum;

import ...

xiaohuanlin +1
public class ThreeSumTest {

    xiaohuanlin
    @Test
    public void testGetTriplesJ0() {
        int[] ints = new int[]{-2, 0, 2};
        ThreeSumQuadratic target = new ThreeSumQuadratic(ints);
        List<Triple> triples = target.getTriples( j: 1);
        assertEquals( expected: 1, triples.size());
    }

    xiaohuanlin
    @Test
    public void testGetTriplesJ1() {
        int[] ints = new int[]{30, -40, -20, -10, 40, 0, 10, 5};
        Arrays.sort(ints);
        ThreeSumQuadratic target = new ThreeSumQuadratic(ints);
        List<Triple> triples = target.getTriples( j: 3);
        assertEquals( expected: 2, triples.size());
    }

    xiaohuanlin
    @Test
    public void testGetTriplesJ2() {
        Supplier<int[]> intsSupplier = new Source( N: 10,  M: 15,  seed: 2L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSumQuadratic target = new ThreeSumQuadratic(ints);
        List<Triple> triples = target.getTriples( j: 5);
        assertEquals( expected: 1, triples.size());
    }

    xiaohuanlin
    @Test
    public void testGetTriples0() {
        int[] ints = new int[]{30, -40, -20, -10, 40, 0, 10, 5};
        Arrays.sort(ints);
        System.out.println("ints: " + Arrays.toString(ints));
        ThreeSum target = new ThreeSumQuadratic(ints);
        Triple[] triples = target.getTriples();
        System.out.println("triples: " + Arrays.toString(triples));
        assertEquals( expected: 4, triples.length);
        assertEquals( expected: 4, new ThreeSumCubic(ints).getTriples().length);
    }

    xiaohuanlin
    @Test
    public void testGetTriples1() {
        Supplier<int[]> intsSupplier = new Source( N: 20,  M: 20,  seed: 1L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadratic(ints);
        Triple[] triples = target.getTriples();
        assertEquals( expected: 4, triples.length);
        System.out.println(Arrays.toString(triples));
        Triple[] triples2 = new ThreeSumCubic(ints).getTriples();
        System.out.println(Arrays.toString(triples2));
        assertEquals( expected: 4, triples2.length);
    }

    xiaohuanlin
    @Test
    public void testGetTriples2() {
        Supplier<int[]> intsSupplier = new Source( N: 10,  M: 15,  seed: 3L).intsSupplier( safetyFactor: 10);
        int[] ints = intsSupplier.get();
        ThreeSum target = new ThreeSumQuadratic(ints);
```



b) Spread sheet showing timing observations

N	ThreeSumQuadratic	ThreeSumQuadrithmic	ThreeSumCubic
250	1.95	2.17	8.57
500	2.01	3.7	21.94
1000	4.87	14.18	135.8
2000	15.74	56.7	952.79
4000	57.1	241.13	7306.84

c) Explanation of why quadratic method works

code :

```
public Triple[] getTriples() {
    List<Triple> result = new ArrayList<>();
    int length = a.length;

    // check validation
    if(a == null || length < 3)
        return result.toArray(new Triple[0]);

    // sort the array
    Arrays.sort(a);

    // first loop from start to end of the array
    for(int i = 0; i < length - 2; i++)
    {
        // science the array is sorted, there is not a chance that sum is 0, if we loop to a
        if(a[i]>0)
            break;

        // skip if we meet duplicate number
        if(i > 0 && a[i] == a[i - 1])
            continue;

        // 2 pointers that loop from start and end to the center
        int left = i + 1;
        int right = length - 1;

        // second loop
        while(left < right)
        {
            int sum = a[i] + a[left] + a[right];

            // check the sum
            if(sum == 0)
            {
                // if the sum is 0, which is what we want, remember it
                result.add(new Triple(a[i], a[left], a[right]));

                // then move 2 pointer one step the the center
                left++;
                right--;

                // skip duplicate numbers
                while(left < right && a[left] == a[left - 1])
                    left++;

                while(left < right && a[right] == a[right + 1])
                    right--;
            }
            // if the sum is smaller than 0, we need to move left pointer, to make the sum b
            else if(sum < 0)
```

```
                    left++;

                // similarly, move the right pointer to make the sum small to approach 0
                else
                    right--;
            }
        }

        return result.stream().distinct().toArray(Triple[]::new);
    }
```

The quadratic method is basicly an optimized version of cubic method.

In cubic method, we have three layer of loops to find 3 numbers.

In quadratic method, we combine second and thrid layer loops into a 2 pointer check to find second and third number we want.

In first layer we loop the array from the start to end, the check **i** th number in array.

We set up 2 pointers (**Left** and **right**) at both sides of the rest of the array.

Then we check the sum of **i**, **left** and **right**

There are 3 diffent situation in our 2 pointer check :

- if the sum is smaller than 0, we apply `left++` .
- if the sum is greater than 0, we apply `right++` .
- is the sum is equal than 0, we found one of the answer, add it to the list.

until the **left** is equal to **right**

Then we can start the next iteration of the first layer loop to find other answers

Time complexity

sort the array : $O(n * Logn)$,
iterate over array : $O(n)$,
2 pointer search : $O(n)$,
total : $O(n * logn) + O(n) * O(n)$ => $O(n^2)$

Space complexity

we are not using extra space so the space conplexity is $O(1)$