Advanced Software Development: JUnit

CPSC 501: Advanced Programming Techniques
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Importance of Testing

- In large complex systems, **50%** of the systems development budget may be spent on testing
- Studies have shown that **virtually all non-trivial** software ships with errors!
- Thus, good testing is as important **(more?)** than programming
- We think if we're good, there will be no bugs.
- BUT everyone writes code with bugs
- Good programs have approximately 1 bug per 100 lines.
- So take the attitude that the more bugs you find, the BETTER programmer you are.

When to Test

- **Throughout** the development lifecycle, not just at the end.

- **Earlier** you find error **the better**

- Benefits:
  - **require less testing & debugging time**
  - **cost less**

Definitions

- **Exhaustive testing -** (testing every possible input), would be ideal, but clearly impossible

- **Blackbox Testing -** assumes you **know nothing** of the internals of a program
- **Whitebox Testing - look inside** at details of program to determine what to test

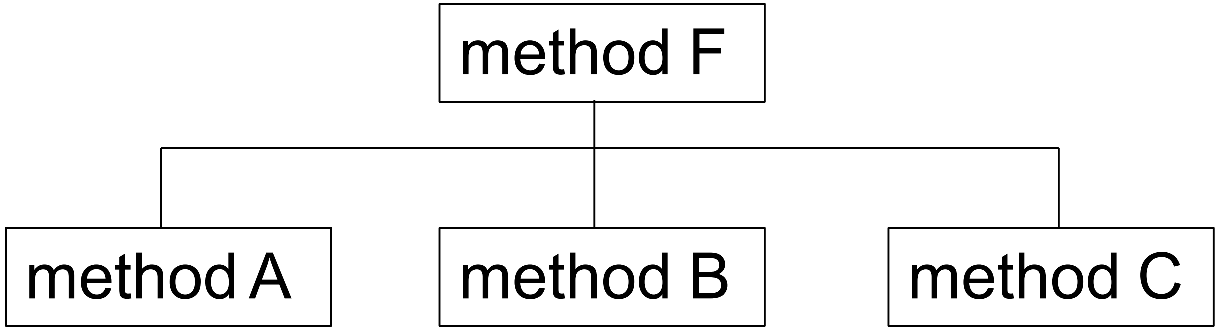
- For inputs states, divide into **equivalence classes** to make tests
- **Test Coverage** – Try to cover all **statements**, **conditionals**, or all **paths**
- **Boundary Testing** – errors occur most often on **border** of equivalence classes

Modular Testing

Modular Testing

- If you write whole 1000s of lines program and run it, and it doesn't work (e.g. infinite loop), it is very hard to find error
- **Better to test each module (100s of lines) separately** ---> much smaller bits of code to examine to find error.
- Most important concept: **test each module individually as you implement!**

Modular Testing (cont'd)



- Test & debug method A. (unit test)
- Test & debug method B. (unit test)
- Test & debug method C. (unit test)
- Finally, test method F. (integration test)
- If it fails the testing then you can be (mostly) sure that the error is in F, and not a sub-method.

Unit Testing

Unit Testing

- A **unit test** is a technique for testing the correctness of a module of source code
  - You create separate test cases for every nontrivial method in the module
  - Unlike most other tests, is done by developers as they code
  - Is a form of “bottom-up” testing

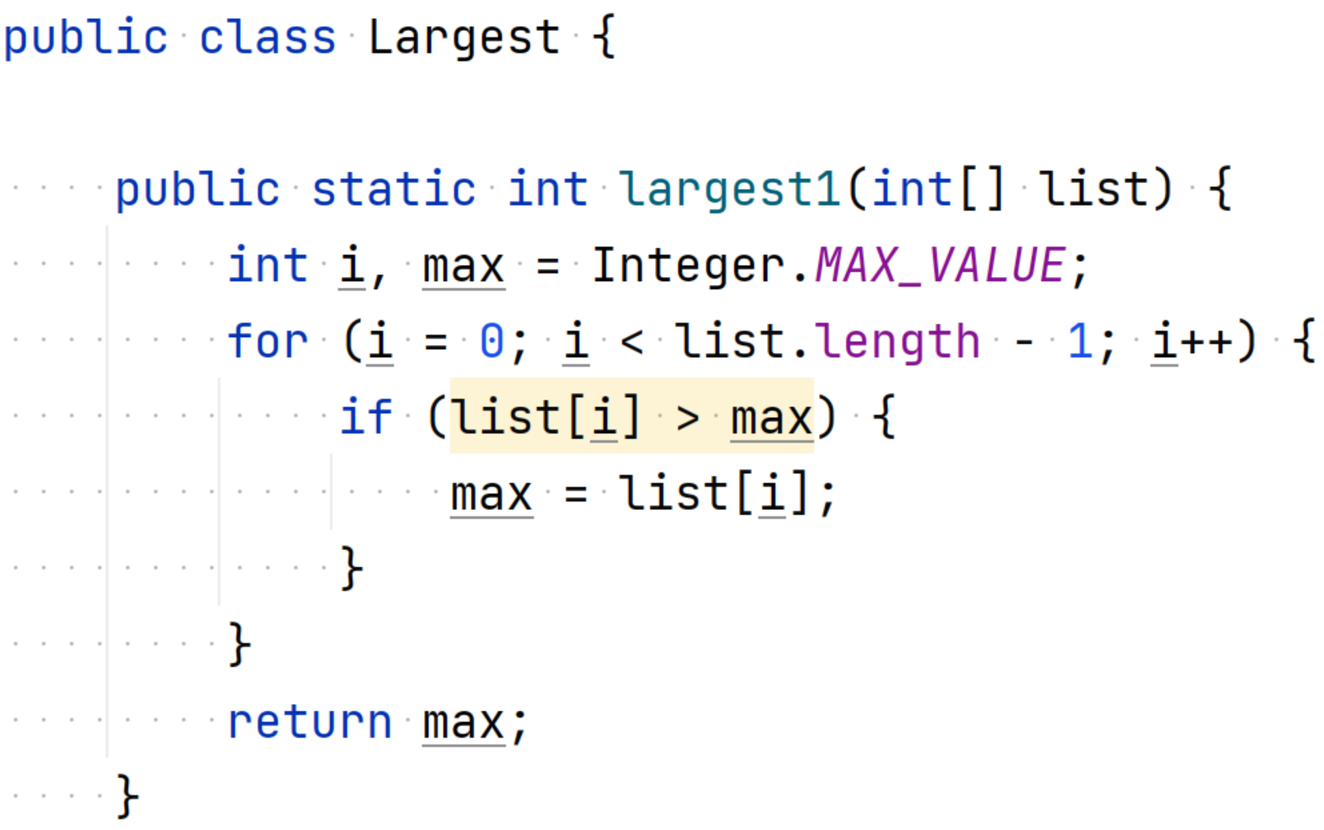
Benefits of Unit Testing

- Benefits of unit testing:
  - Reduces the time spent on debugging
  - **Catches bugs early**
  - Eases integration
    - Bottom-up testing allows you to build a large system on a reliable “foundation” of working low-level code
  - **Documents the intent of the code**
  - **Encourages refactoring**
    - Tests are rerun to make sure no new bugs are introduced
      - Is a form of regression testing

JUnit Example

JUnit Example – Largest Integer Method

- We will test the following method:
  - (Note: contains some bugs right now)

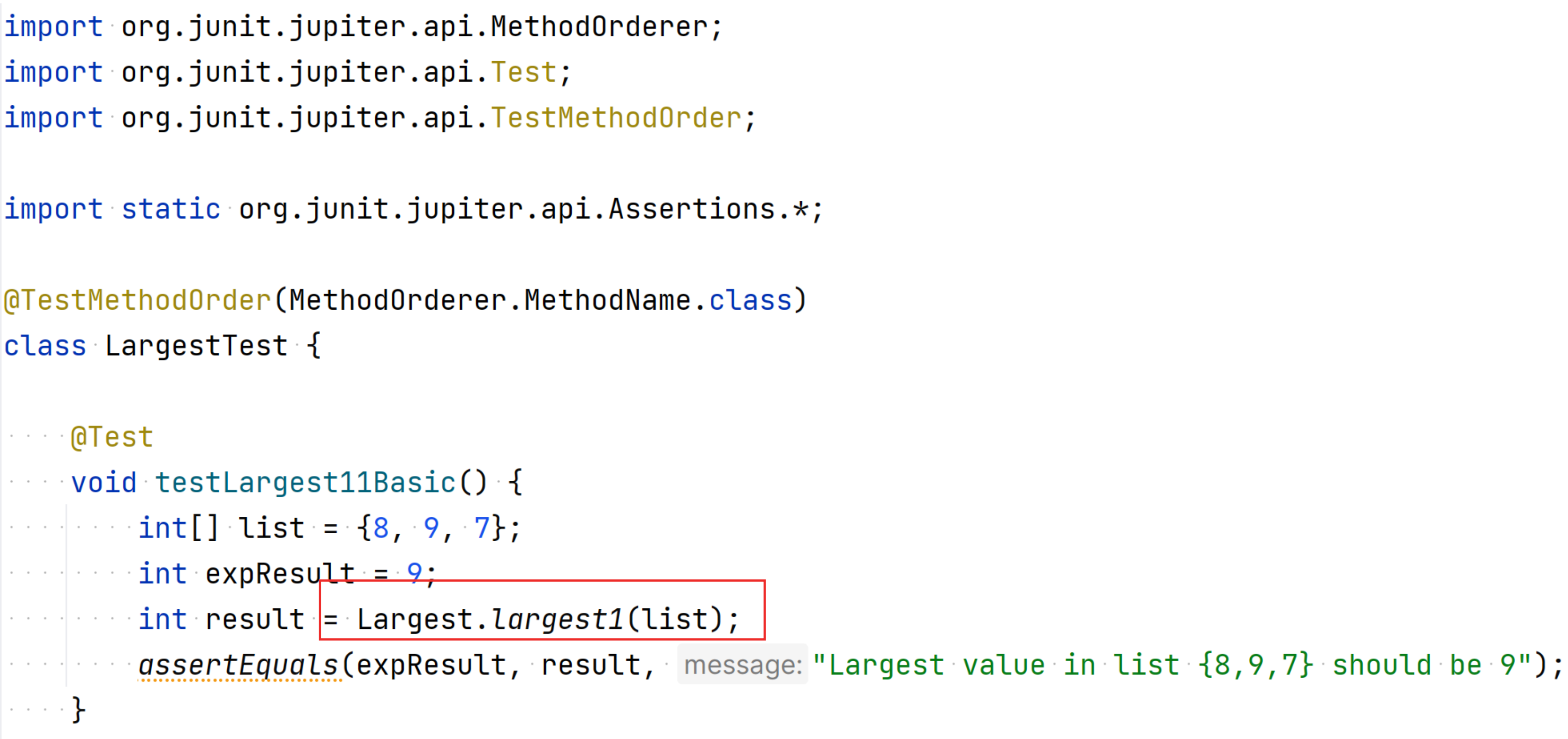


```java
public class Largest {

    public static int largest1(int[] list) {
        int i, max = Integer.MAX_VALUE;
        for (i = 0; i < list.length - 1; i++) {
            if (list[i] > max) {
                max = list[i];
            }
        }
        return max;
    }
```

JUnit Example – JUnit Test

- Create a test class with an initial test:



```
import org.junit.jupiter.api.MethodOrderer;
import org.junit.jupiter.api.Test;
import org.junit.jupiter.api.TestMethodOrder;

import static org.junit.jupiter.api.Assertions.*;

@TestMethodOrder(MethodOrderer.MethodName.class)
class LargestTest {

    @Test
    void testLargest11Basic() {
        int[] list = {8, 9, 7};
        int expResult = 9;
        int result = Largest.largest1(list);
        assertEquals(expResult, result, message: "Largest value in list {8,9,7} should be 9");
    }
```

JUnit Example - Details

- Your test class can be named anything
- Test methods must be annotated with **@Test**
  - Will be invoked automatically by the test runner
- The **assertEquals()** will abort if the **largest1()** method does not return a **9**
  - 9 is the largest element in the list 8, 9, 7
- Save the file
- Compile using: **javac *.java**

JUnit Asserts

- JUnit asserts
- https://junit.org/junit5/docs/current/api/org.junit.jupiter.api/org/junit/jupiter/api/Assertions.html
  - **assertEquals**(expected, actual, [String message])
    - message is optional
  - **assertEquals**(expected, actual, **tolerance**, [String message])
    - Useful for imprecise f.p. numbers
  - **assertNull**(Object object, [String message])
    - Asserts that the object is null
    - Also: assertNotNull()

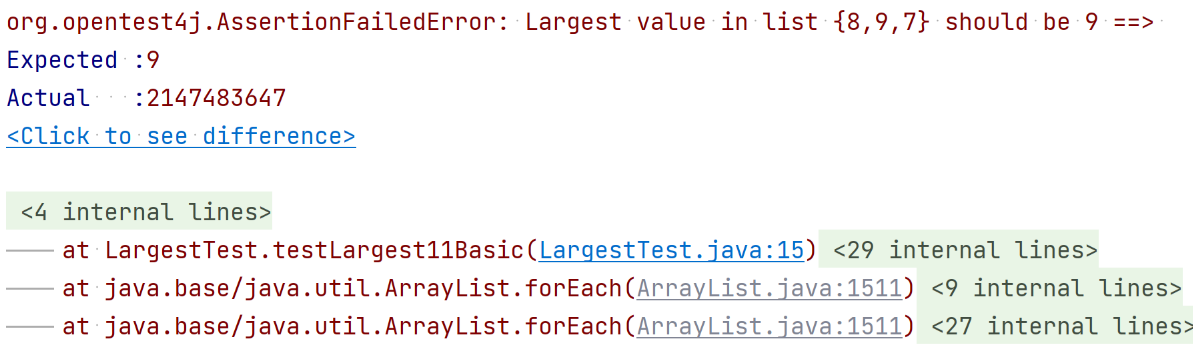
JUnit Asserts

- JUnit asserts:
  - **assertSame**(expected, actual, [String message])
    - Asserts that expected and actual **point to the same object**
    - Also: assertNotSame()
  - **assertTrue**(boolean condition, [String message])
    - Also: assertFalse()
  - **fail**([String message])
    - Fails the test immediately
    - Used to mark code that should not be reached

JUnit Example - Running

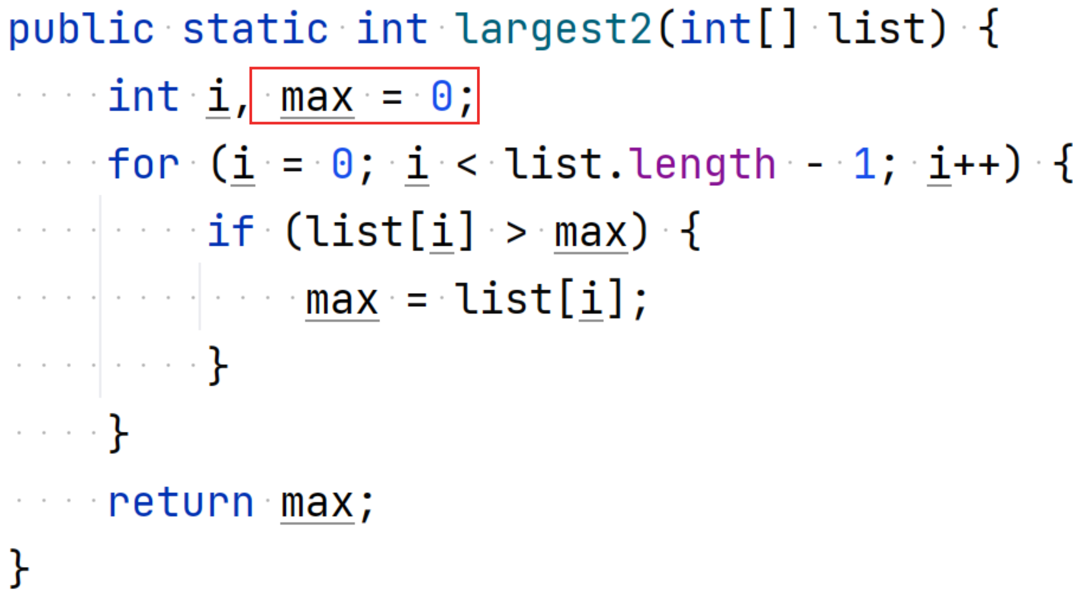
- Run the test
- Use: **java org.junit.runner.JUnitCore LargestTest**
    - The classpath must be set correctly for this to work
    - Is a textual UI
    - Most IDEs can run tests within their GUI

JUnit Example – Failing Test



```
org.opentest4j.AssertionFailedError: Largest value in list {8,9,7} should be 9 ==> 
Expected :9
Actual   :2147483647
<Click to see difference>

<4 internal lines>
── at LargestTest.testLargest11Basic(LargestTest.java:15) <29 internal lines>
── at java.base/java.util.ArrayList.forEach(ArrayList.java:1511) <9 internal lines>
── at java.base/java.util.ArrayList.forEach(ArrayList.java:1511) <27 internal lines>
```

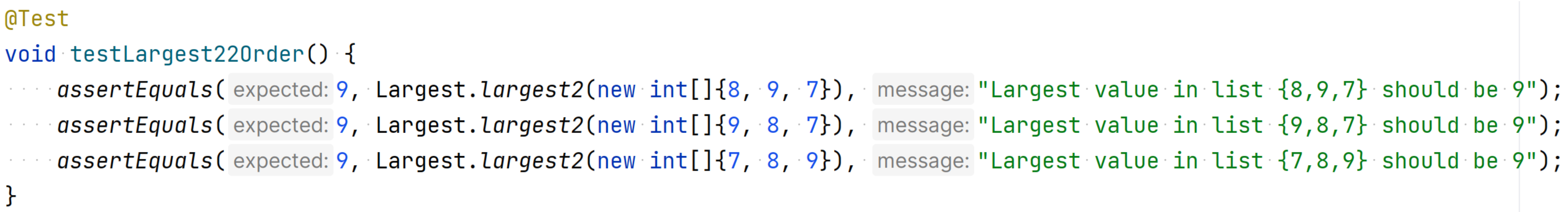


```java
public static int largest2(int[] list) {
    int i, max = 0;
    for (i = 0; i < list.length - 1; i++) {
        if (list[i] > max) {
            max = list[i];
        }
    }
    return max;
}
```

Let’s try max=0 instead

JUnit Example – Multiple Asserts

- Create a new test testOrder():

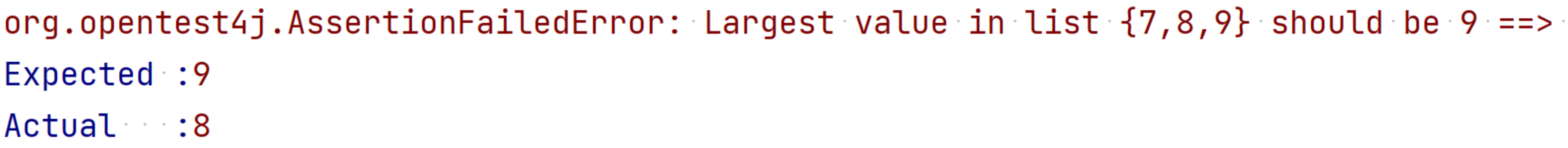


```
@Test
void testLargest22Order() {
    assertEquals( expected: 9, Largest.largest2(new int[]{8, 9, 7}),  message: "Largest value in list {8,9,7} should be 9");
    assertEquals( expected: 9, Largest.largest2(new int[]{9, 8, 7}),  message: "Largest value in list {9,8,7} should be 9");
    assertEquals( expected: 9, Largest.largest2(new int[]{7, 8, 9}),  message: "Largest value in list {7,8,9} should be 9");
}
```

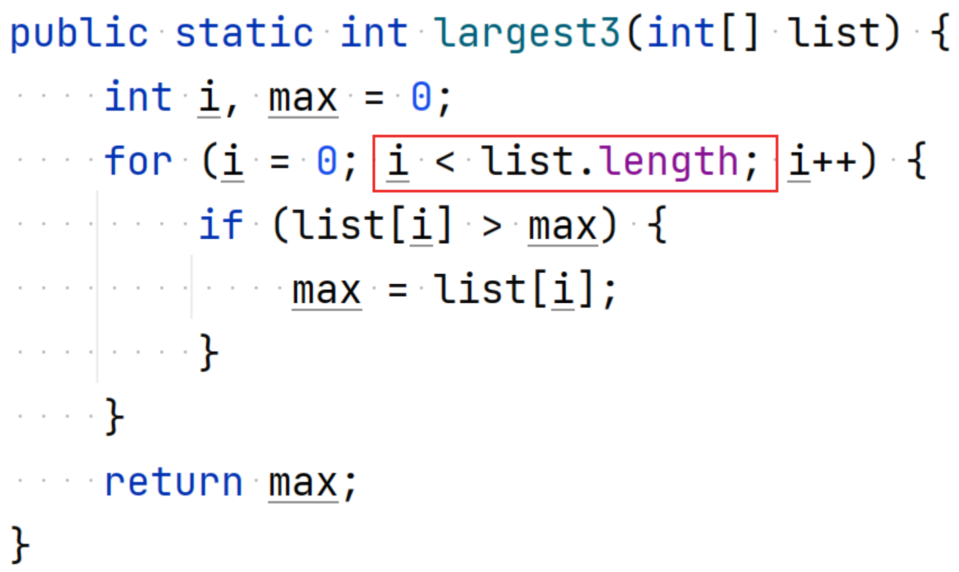
  - Tests for the largest element in all 3 positions
- Recompile and retest

- Not a good test! Why?
  - It tests 3 things at once?
    - When it fails we won’t immediately know which sub-test caused it to fail!

JUnit Example – Failing Again



```
org.opentest4j.AssertionFailedError: Largest value in list {7,8,9} should be 9 ==>
Expected :9
Actual   :8
```



```
public static int largest3(int[] list) {
    int i, max = 0;
    for (i = 0; i < list.length; i++) {
        if (list[i] > max) {
            max = list[i];
        }
    }
    return max;
}
```

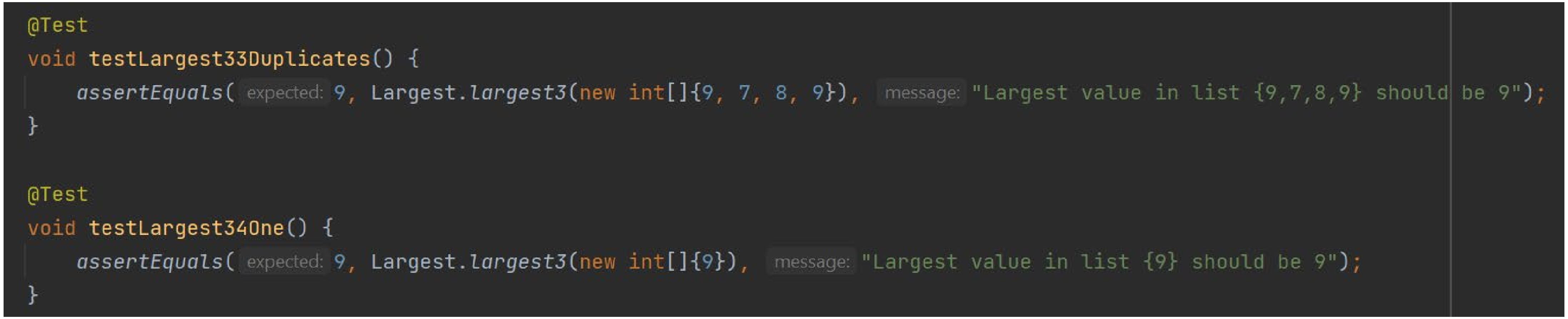
We had off by one error

JUnit Example – Fix Bug

- We find another error:
- Is an “off by one” bug:
    - Change loop for correct termination
- Recompile and retest
    - Should report: OK (2 tests)

JUnit Example – More Tests

- Add methods to test for duplicates and a list of size one:



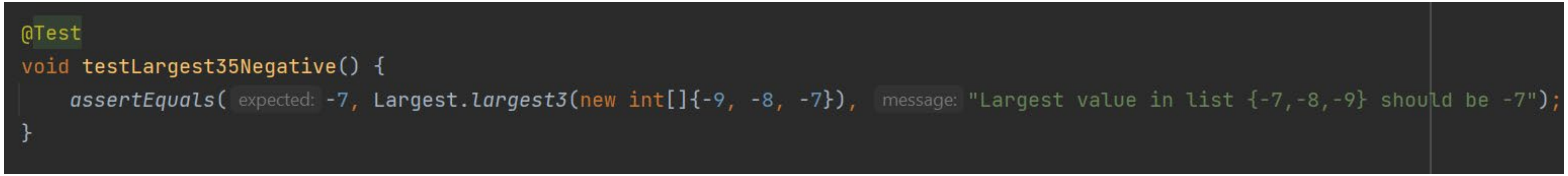
```
@Test
void testLargest33Duplicates() {
    assertEquals( expected: 9, Largest.largest3(new int[]{9, 7, 8, 9}),  message: "Largest value in list {9,7,8,9} should be 9");
}

@Test
void testLargest34One() {
    assertEquals( expected: 9, Largest.largest3(new int[]{9}),  message: "Largest value in list {9} should be 9");
}
```

- Recompile and retest
  - Should report: OK (4 tests)

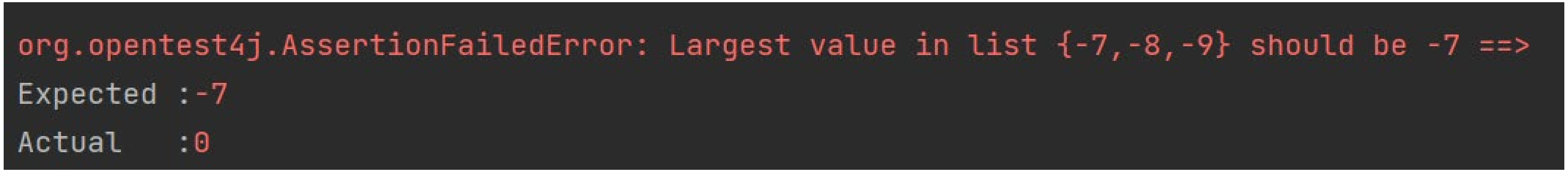
JUnit Example – Negative Numbers

- Add a method to test negative numbers:



```
@Test
void testLargest35Negative() {
    assertEquals( expected: -7, Largest.largest3(new int[]{-9, -8, -7}), message: "Largest value in list {-7,-8,-9} should be -7");
}
```

- Retesting reveals another bug:

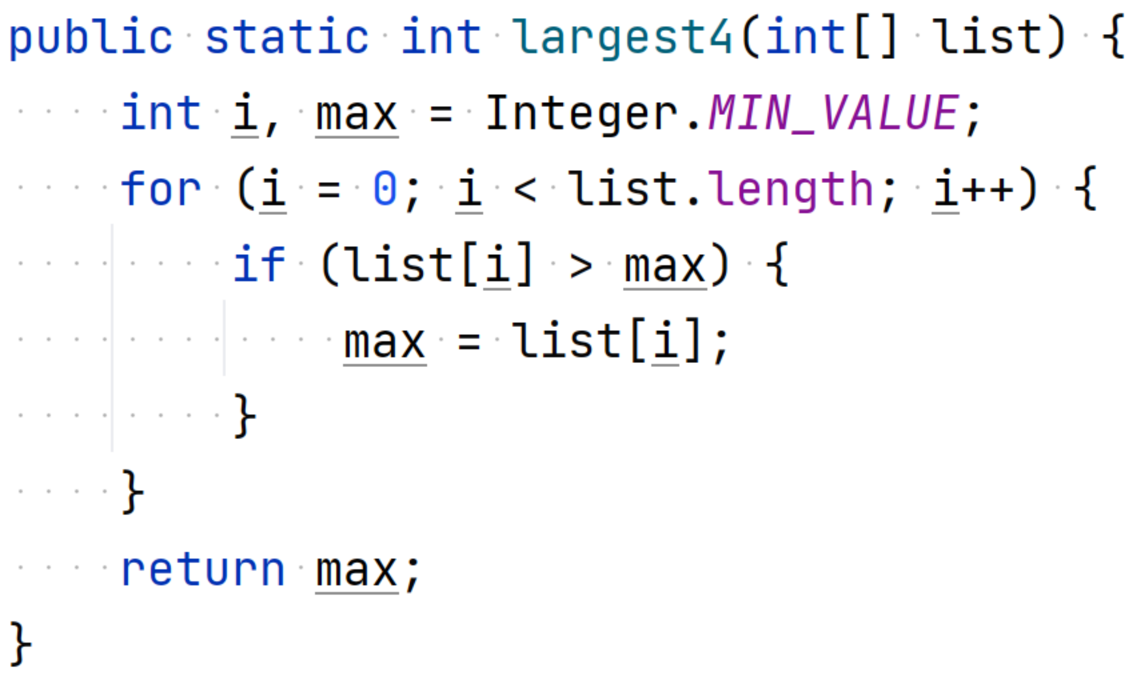


```
org.opentest4j.AssertionFailedError: Largest value in list {-7,-8,-9} should be -7 ==>
Expected :-7
Actual   :0
```

- Fix by initializing max = Integer.MIN_VALUE;
- Retest

Result

- Final Function



```java
public static int largest4(int[] list) {
    int i, max = Integer.MIN_VALUE;
    for (i = 0; i < list.length; i++) {
        if (list[i] > max) {
            max = list[i];
        }
    }
    return max;
}
```

JUnit Framework

JUnit Asserts

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JUnit Asserts

- JUnit asserts: (JUnit4 and JUnit5 will swap message front/end of parameters)
  - **assertSame**(expected, actual, [String message])
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    - Also: assertNotSame()
  - **assertTrue**(boolean condition, [String message])
    - Also: assertFalse()
  - **fail**([String message])
    - Fails the test immediately
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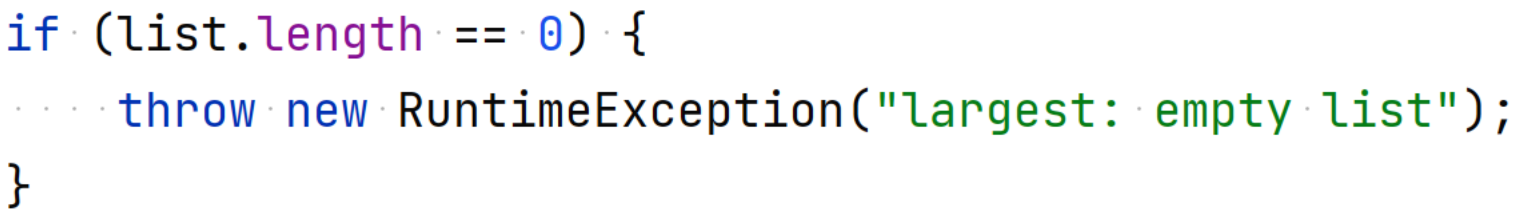
JUnit Exceptions

JUnit Example – Exceptions?

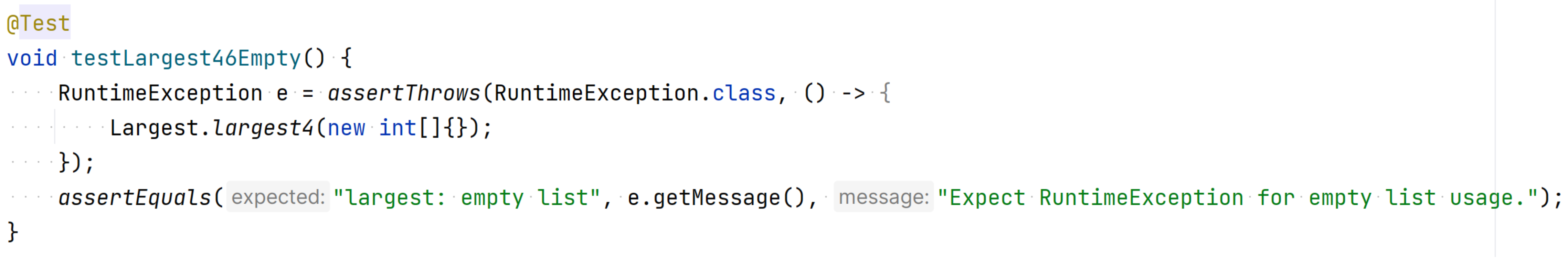
- What should happen if the list is empty?
    - Throw an exception



```java
if (list.length == 0) {
    throw new RuntimeException("largest: empty list");
}
```

JUnit Example – Exceptions Expected

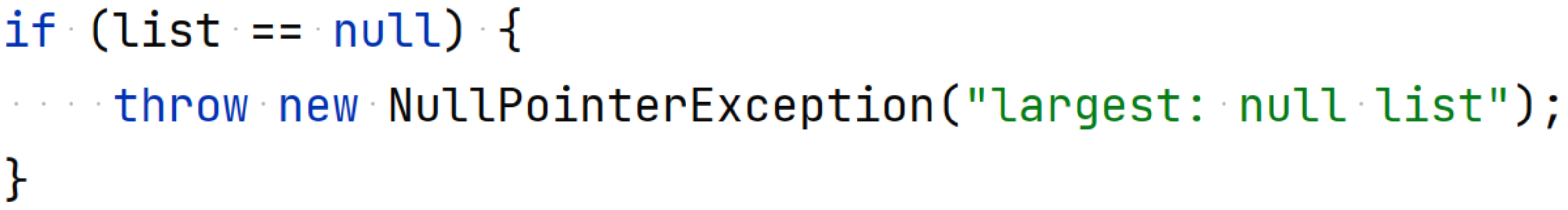
- Add a test for this



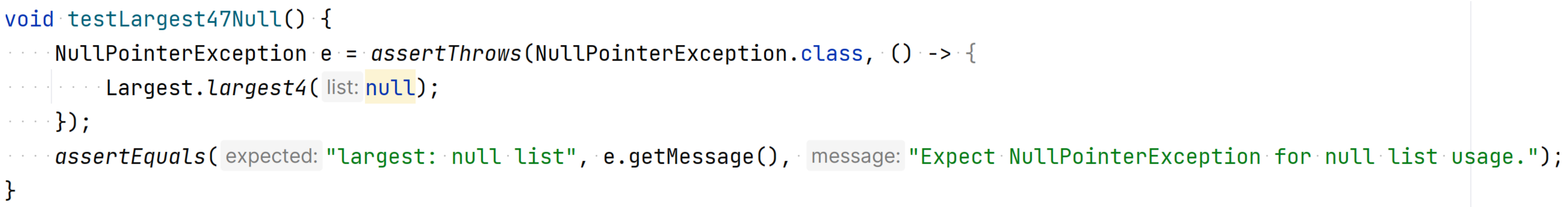
```
@Test
void testLargest46Empty() {
    RuntimeException e = assertThrows(RuntimeException.class, () -> {
        Largest.largest4(new int[]{});
    });
    assertEquals( expected: "largest: empty list", e.getMessage(), message: "Expect RuntimeException for empty list usage.");
}
```

JUnit Example – Null?

- What if our function should crash on null input?



```
if (list == null) {
    throw new NullPointerException("largest: null list");
}
```



```
void testLargest47Null() {
    NullPointerException e = assertThrows(NullPointerException.class, () -> {
        Largest.largest4( list: null);
    });
    assertEquals( expected: "largest: null list", e.getMessage(),  message: "Expect NullPointerException for null list usage.");
}
```

JUnit Before/After Examples

JUnit AfterAll/BeforeAll

- Use **@BeforeAll** to mark a method used to initialize the testing environment before every test in test class
  - E.g. Allocate resources, initialize state

- Use **@AfterAll** to mark a method used to clean up after every test in test class
  - E.g. Deallocate resources

- **Are invoked before and after EVERY test method is run**
- Incredibly useful to make objects re-used across multiple tests
- Tests should be designed to be run independently, and in any order
  - (JUnit DOES NOT follow your source code order)

JUnit AfterEach/BeforeEach

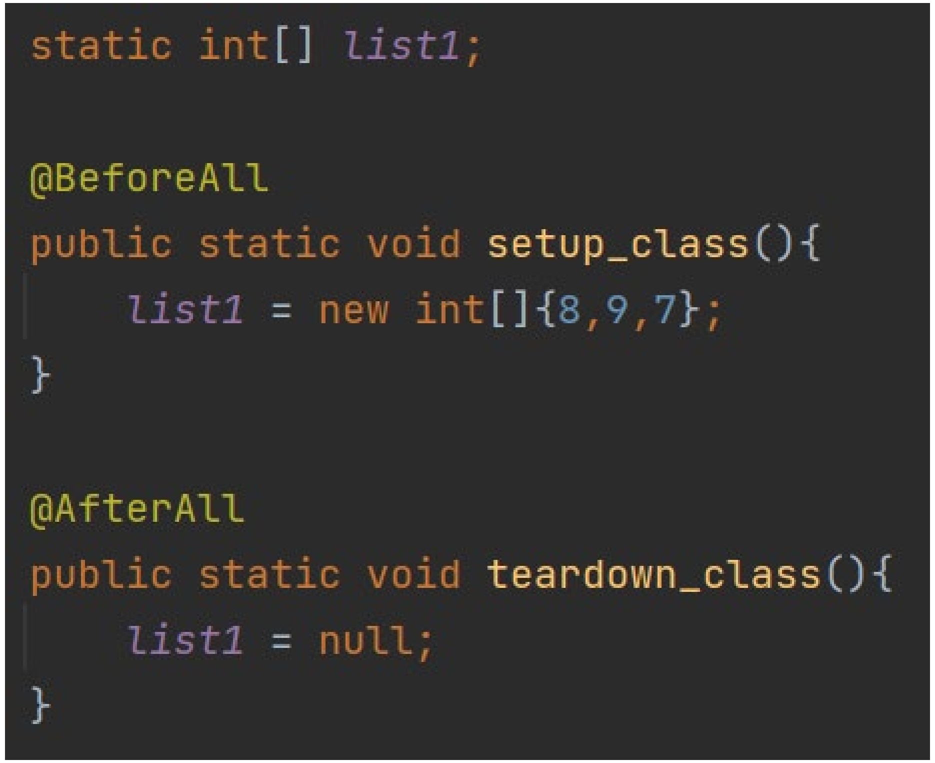
- Like @BeforeAll/@AfterAll, but once for the whole test class (instead of each function)
- Good for static setups, like database connections

- Use **@BeforeEach** to mark a method used to initialize the testing environment when test class is initialized
  - E.g. Allocate resources, initialize state

- Use **@AfterEach** to mark a method used to clean up after every test in test class is complete
  - E.g. Deallocate resources

Junit: Before and after

- **BeforeAll** – things you need for multiple tests (connections to resources, constants), shouldn’t be changed by tests
- **AfterAll** – cleanup things related to BeforeClass
- Issue here?



```
static int[] list1;

@BeforeAll
public static void setup_class(){
    list1 = new int[]{8,9,7};
}

@AfterAll
public static void teardown_class(){
    list1 = null;
}
```

Junit: Before and after

- **BeforeAll** – things you need for multiple tests (connections to resources, constants), shouldn't be changed by tests
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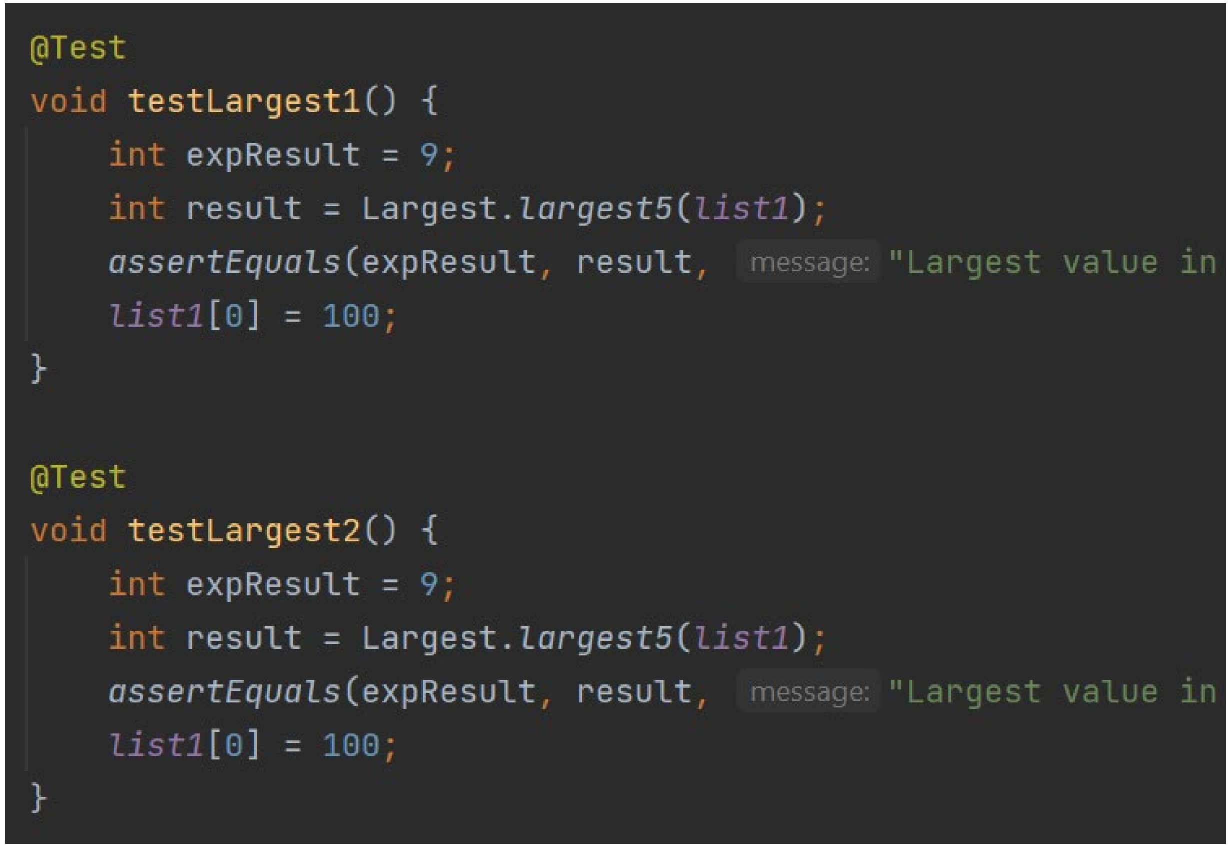
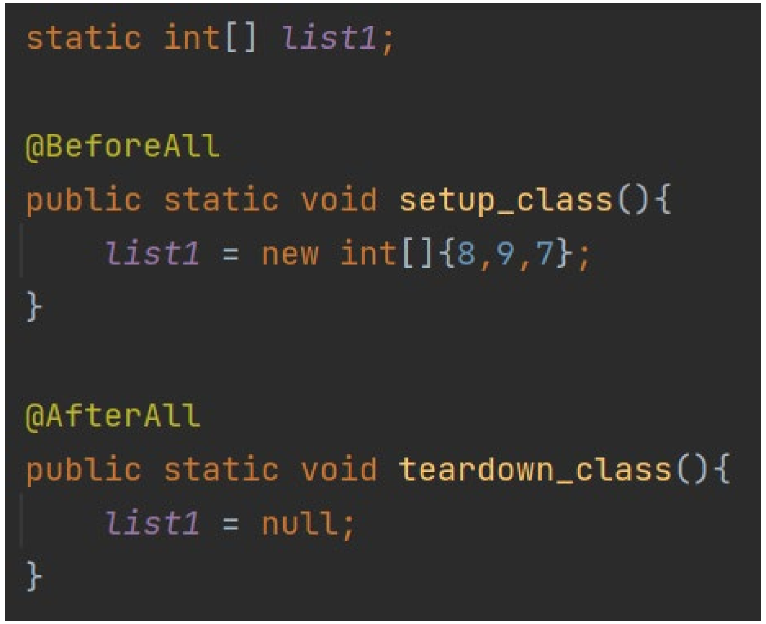


```
@Test
void testLargest1() {
    int expResult = 9;
    int result = Largest.largest5(list1);
    assertEquals(expResult, result, message: "Largest value in
    list1[0] = 100;
}

@Test
void testLargest2() {
    int expResult = 9;
    int result = Largest.largest5(list1);
    assertEquals(expResult, result, message: "Largest value in
    list1[0] = 100;
}
```



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Junit: Before and after

- **BeforeAll** – things you need for multiple tests (connections to resources, constants), shouldn't be changed by tests
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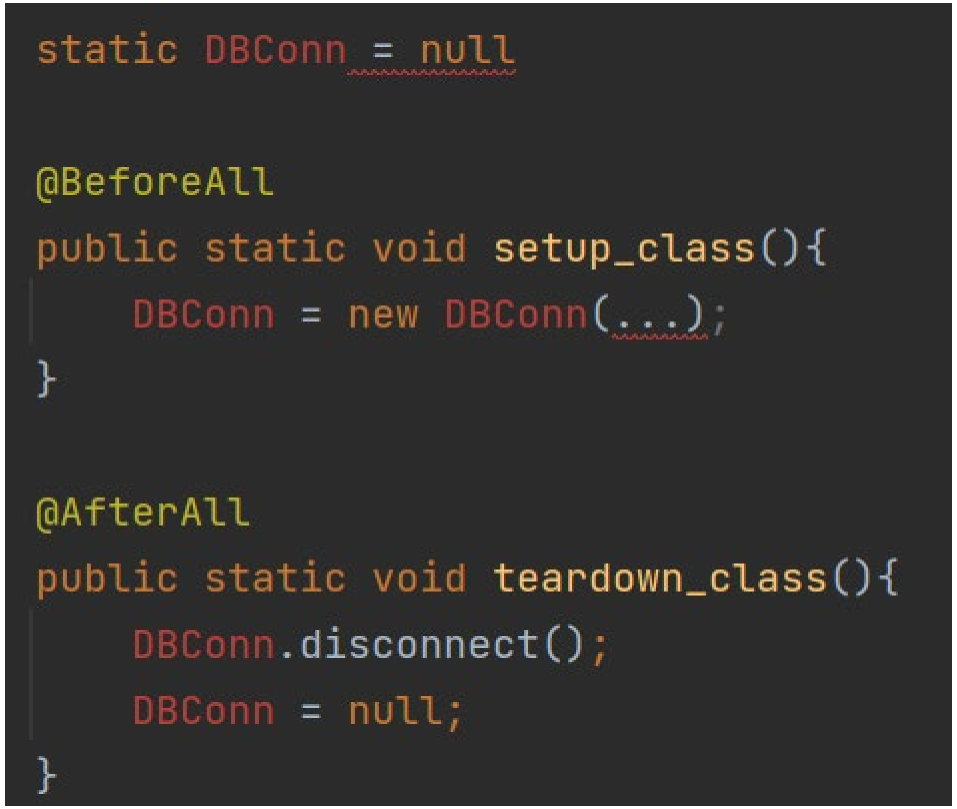
- Best used when you need some sort of infrastructure through-out the whole test, like a connection



```
static DBConn = null

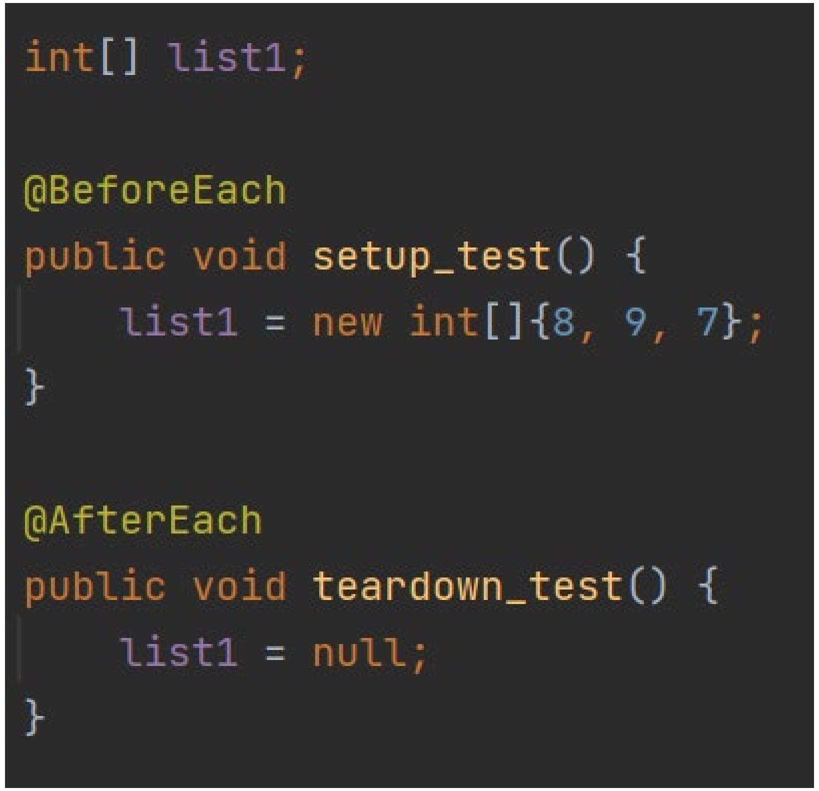
@BeforeAll
public static void setup_class(){
    DBConn = new DBConn(...);
}

@AfterAll
public static void teardown_class(){
    DBConn.disconnect();
    DBConn = null;
}
```

Junit: Before and after

- **BeforeEach** – things used for multiple tests, often changed by tests
- **AfterEach** – clean up stuff related to Before

- Proper usage for setting up an object, especially if you want to re-use it for multiple tests
- Great if you have a large amount of related classes to setup before a test can begin operating
- Ex. A lecture object connected with a list of student



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Junit: Before and after

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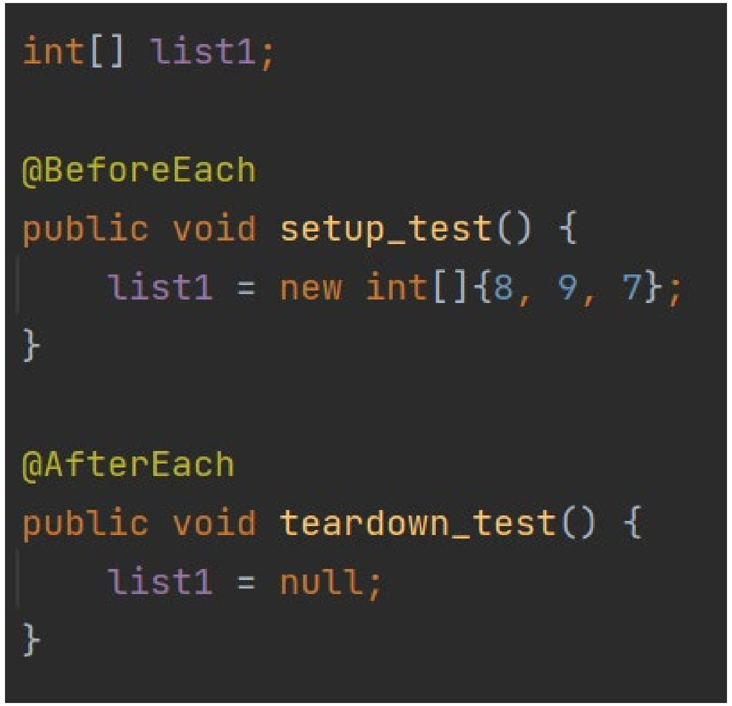

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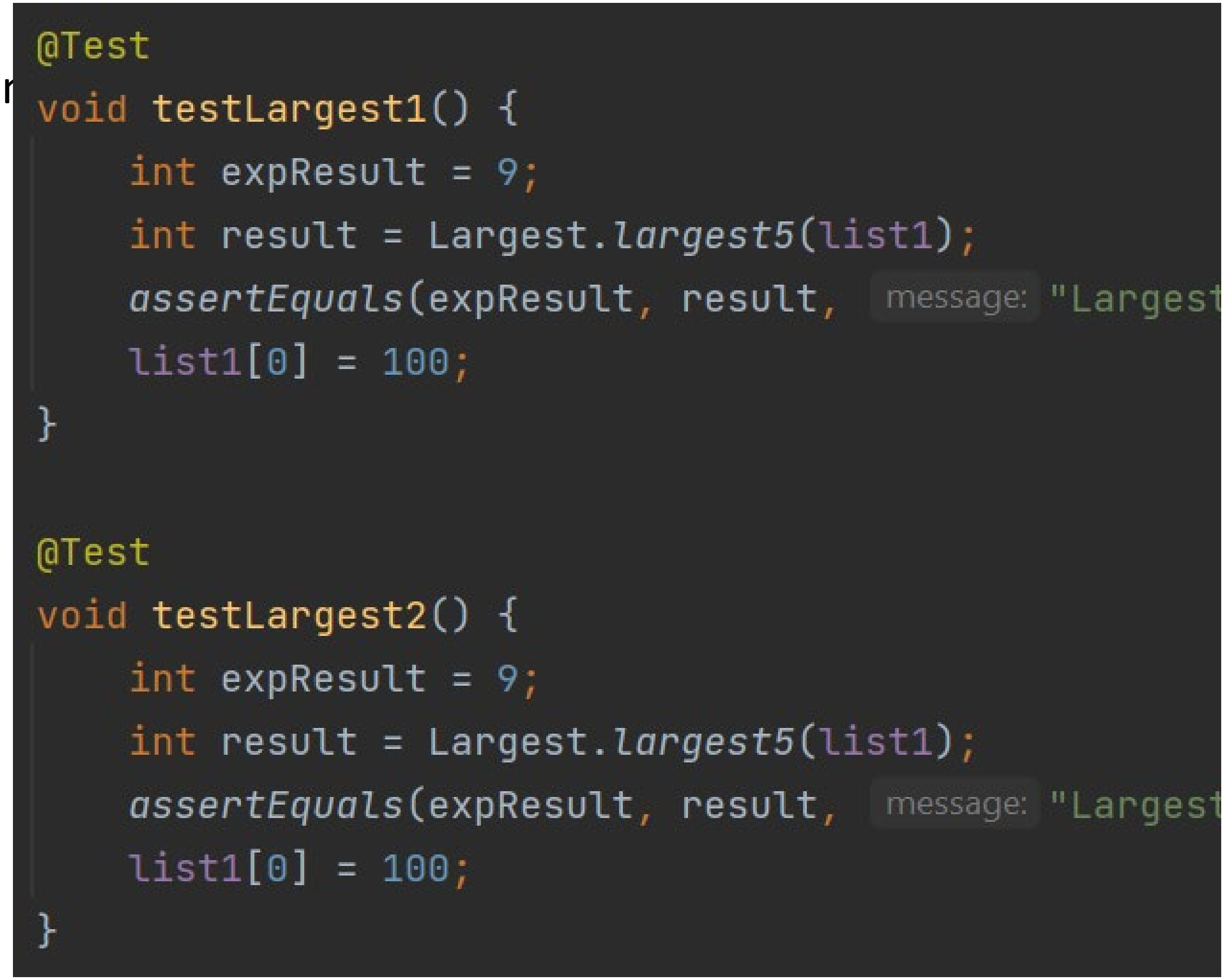
```



```
@Test
void testLargest1() {
    int expResult = 9;
    int result = Largest.largest5(list1);
    assertEquals(expResult, result, message: "Largest
    list1[0] = 100;
}

@Test
void testLargest2() {
    int expResult = 9;
    int result = Largest.largest5(list1);
    assertEquals(expResult, result, message: "Largest
    list1[0] = 100;
}
```

Onward to … refactoring.

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