

Test-Driven Development (TDD) with JUnit



EECS2030 B & G: Advanced
Object Oriented Programming
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Learning Outcomes



This module is designed to help you learn about:

- **Testing** the Solution to a Bounded Counter Problem
- Deriving **Test Cases** for a Bounded Variable
- Application of **Normal** vs. **Disrupted Execution Flows**
- **Intention** of a Test: **Exceptions Expected** vs. **Not Expected**
- **Test Driven Development (TDD)** via **Regression Testing**

Motivating Example: Two Types of Errors (1)



Consider two kinds of exceptions for a counter:

```
public class ValueTooLargeException extends Exception {  
    ValueTooLargeException(String s) { super(s); }  
}  
  
public class ValueTooSmallException extends Exception {  
    ValueTooSmallException(String s) { super(s); }  
}
```

Any thrown object instantiated from these two exception classes must be handled (**catch-or-specify requirement**):

- Either **specify** `throws ...` in the method header/API (i.e., **propagate** it to the immediate **caller** in the **call stack**)
- Or **handle** it in a `try-catch` block

Motivating Example: Two Types of Errors (2)



Approach 1 – Specify: Indicate in the method header/API that a specific exception might be thrown.

Example 1: Method that throws the exception

```
class C1 {  
    void m1(int x) throws ValueTooSmallException {  
        if(x < 0) {  
            throw new ValueTooSmallException("val " + x);  
        }  
    }  
}
```

Example 2: Method that calls another which throws the exception

```
class C2 {  
    C1 c1;  
    void m2(int x) throws ValueTooSmallException {  
        c1.m1(x);  
    }  
}
```

Motivating Example: Two Types of Errors (3)



Approach 2 – Catch: Handle the thrown exception(s) in a try-catch block.

```
class C3 {
    public static void main(String[] args) {
        Scanner input = new Scanner(System.in);
        int x = input.nextInt();
        C2 c2 = new C2();
        try {
            c2.m2(x);
        }
        catch(ValueTooSmallException e) { ... }
    }
}
```

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Exceptional Scenarios



- **Sound** Software Engineering Practice:
Design a **test strategy** even **before** code is completed.
- **Q:** Possible exceptional scenarios for such a counter?
 - An attempt to **increment** **above** the counter's upper bound.
 - An attempt to **decrement** **below** the counter's lower bound.

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A Simple Counter (1)



Consider a class for keeping track of an integer counter value:

```
public class Counter {
    public final static int MAX_VALUE = 3;
    public final static int MIN_VALUE = 0;
    private int value;
    public Counter() {
        this.value = Counter.MIN_VALUE;
    }
    public int getValue() {
        return value;
    }
    ... /* more later! */
}
```

- Access **private** attribute `value` using **public** accessor `getValue`.
- Two class-wide (i.e., static) constants (i.e., final) for lower and upper bounds of the counter value.
- Initialize the counter value to its lower bound.

Requirement :

The counter value must be within its lower and upper bounds.

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A Simple Counter (2)



```
/* class Counter */
public void increment() throws ValueTooLargeException {
    if(value == Counter.MAX_VALUE) {
        throw new ValueTooLargeException("value is " + value);
    }
    else { value++; }
}

public void decrement() throws ValueTooSmallException {
    if(value == Counter.MIN_VALUE) {
        throw new ValueTooSmallException("value is " + value);
    }
    else { value--; }
}
}
```

- Change the counter value via two mutator methods.
- Changes on the counter value may **trigger an exception**:
 - Attempt to **increment** when counter already reaches its **maximum**.
 - Attempt to **decrement** when counter already reaches its **minimum**.

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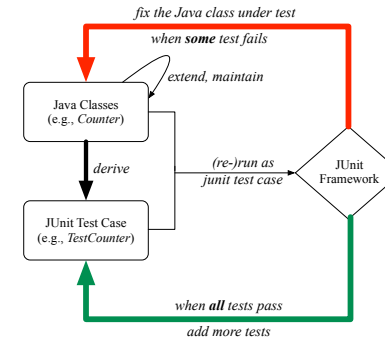
Components of a Test



- Manipulate the relevant object(s).
e.g., **Initialize a counter object *c*, then call *c.increment()*.**
e.g., **Initialize a counter object *c*, then call *c.decrement()*.**
- What do you **expect to happen**?
e.g., **value of counter is such that *Counter.MIN_VALUE + 1***
e.g., ***ValueTooSmallException* is thrown**
- What does your program **actually produce**?
e.g., **call *c.getValue()* to find out.**
e.g., **Use a *try-catch* block to find out** (to be discussed!).
- A test:
 - Passes** if **expected outcome** occurs.
 - Fails** if **expected outcome** does not occur.

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Test-Driven Development (TDD)



Maintain a collection of tests which define the **correctness** of your Java class under development (CUD):

- Derive and run tests as soon as your CUD is **testable**.
i.e., A Java class is testable when defined with method signatures.
- Red** bar reported: Fix the class under test (CUT) until **green** bar.
- Green** bar reported: Add more tests and Fix CUT when necessary.

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Why JUnit?



- Automate** the **testing of correctness** of your Java classes.
- Derive** the list of tests. **Transform** it into a **JUnit Test Class**.
- JUnit tests are **callers/clients** of your classes. Each **test** may:
 - Either attempt to use a method in a **legal** way (i.e., **satisfying** its precondition), and report:
 - Success** if the result is as expected
 - Failure** if the result is **not** as expected
 - Or attempt to use a method in an **illegal** way (i.e., **not satisfying** its precondition), and report:
 - Success** if the expected exception (e.g., *ValueTooSmallException*) occurs.
 - Failure** if the expected exception does **not** occur.
- Regression Testing**: Any **change** introduced to your software **must not compromise** its established **correctness**.

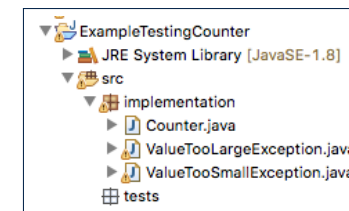
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How to Use JUnit: Packages



Step 1:

- In Eclipse, create a Java project `ExampleTestingCounter`
- Separation of concerns**:
 - Group classes for **implementation** (i.e., *Counter*) into package `implementation`.
 - Group classes for **testing** (to be created) into package `tests`.

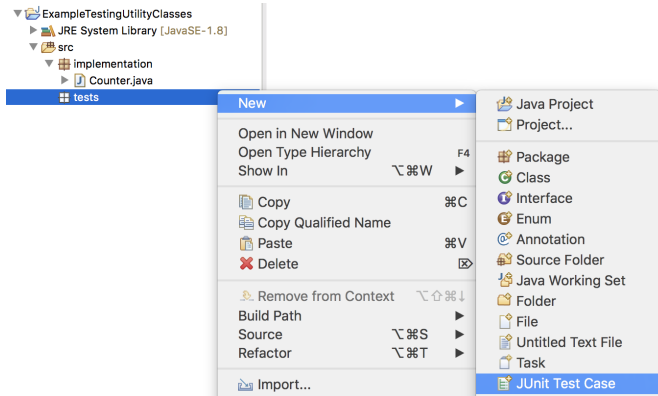


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How to Use JUnit: New JUnit Test Case (1)



Step 2: Create a new **JUnit Test Case** in `tests` package.



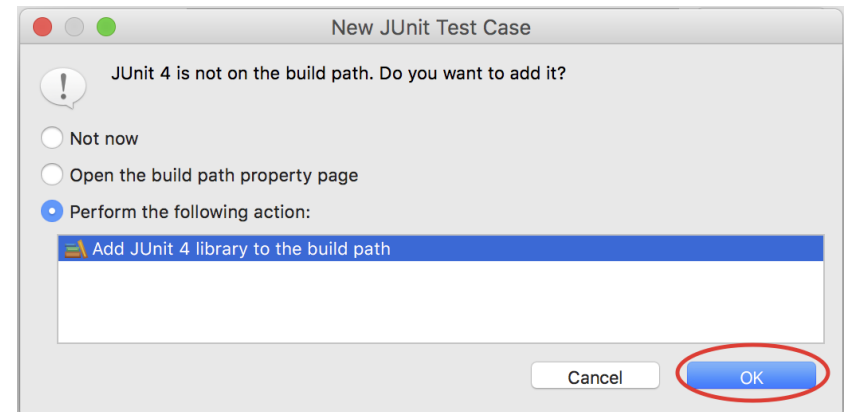
Create one JUnit Test Case to test one Java class only.
⇒ If you have *n Java classes to test*, create *n JUnit test cases*.

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How to Use JUnit: Adding JUnit Library



Upon creating the very first test case, you will be prompted to add the JUnit library to your project's build path.

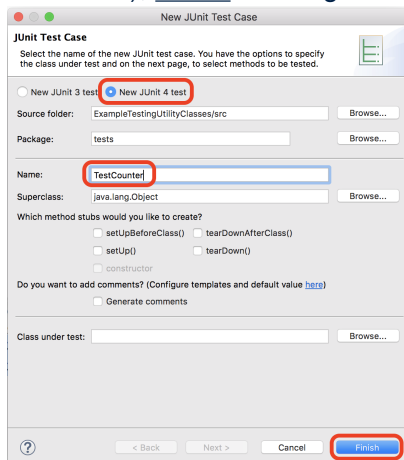


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How to Use JUnit: New JUnit Test Case (2)



Step 3: Select the version of JUnit (JUnit 4); Enter the name of test case (`TestCounter`); Finish creating the new test case.



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How to Use JUnit: Generated Test Case



```
TestCounter.java
1 package tests;
2 import static org.junit.Assert.*;
3 import org.junit.Test;
4 public class TestCounter {
5     @Test
6     public void test() {
7         fail("Not yet implemented");
8     }
9 }
```

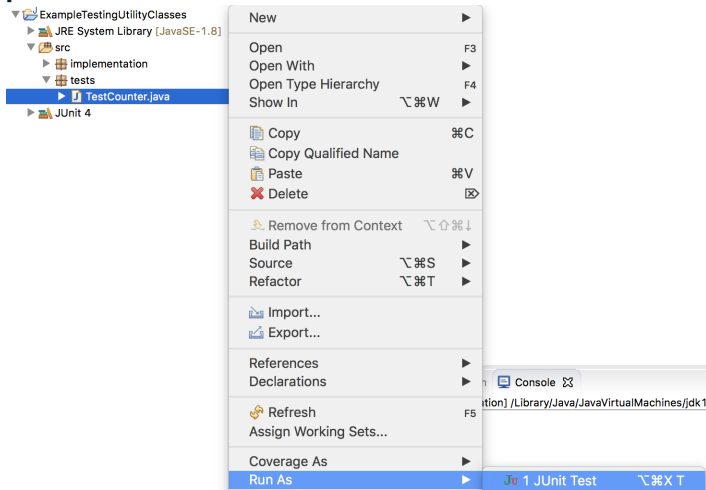
- Lines 6 – 8: `test` is just an **ordinary mutator method** that has a one-line implementation body.
- Line 5 is critical: Prepend the tag `@Test` verbatim, requiring that **the method is to be treated as a JUnit test**.
⇒ When `TestCounter` is run as a JUnit Test Case, only **those methods prepended by the `@Test` tags** will be run and reported.
- Line 7: By default, we deliberately fail the test with a message "Not yet implemented".

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How to Use JUnit: Running Test Case



Step 4: Run the `TestCounter` class as a JUnit Test.



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How to Use JUnit: Interpreting Test Report



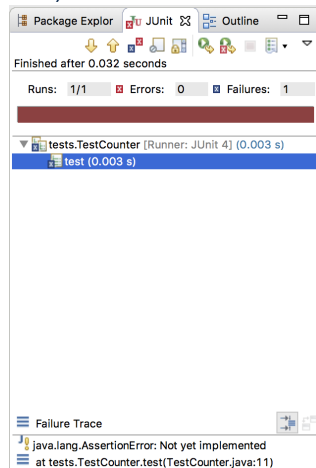
- A **test** is a method prepended with the `@Test` tag.
- The result of running a test is considered:
 - **Failure** if either
 - an **assertion failure** (e.g., caused by `fail`, `assertTrue`, `assertEquals`) occurs
 - an unexpected **exception** (e.g., `NullPointerException`, `ArrayIndexOutOfBoundsException`) thrown
 - **Success** if neither assertion failures nor (unexpected) **exceptions** occur.
- After running all tests:
 - A **green** bar means that **all** tests succeed.
⇒ Keep challenging yourself if **more tests** may be added.
 - A **red** bar means that **at least one** test fails.
⇒ Keep fixing the class under test and re-running all tests, until you receive a **green** bar.
- **Question:** What is the easiest way to making test a **success**?
Answer: Delete the call `fail("Not yet implemented")`.

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How to Use JUnit: Generating Test Report



A **report** is generated after running all tests (i.e., methods prepended with `@Test`) in `TestCounter`.



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How to Use JUnit: Revising Test Case



```
TestCounter.java
1 package tests;
2 import static org.junit.Assert.*;
3 import org.junit.Test;
4 public class TestCounter {
5     @Test
6     public void test() {
7         // fail("Not yet implemented");
8     }
9 }
```

Now, the body of `test` simply does nothing.
⇒ Neither assertion failures nor exceptions will occur.
⇒ The execution of `test` will be considered as a **success**.

∴ There is currently only one test in `TestCounter`.
∴ We will receive a **green** bar!

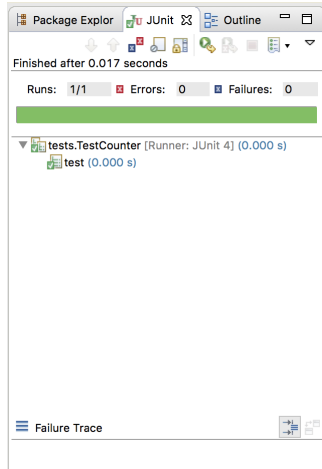
Caution: test which passes at the moment is **not useful** at all!

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How to Use JUnit: Re-Running Test Case



A new report is generated after re-running all tests (i.e., methods prepended with @Test) in TestCounter.



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How to Use JUnit: Common Assertions



- `void assertNull(Object o)`
- `void assertEquals(int expected, int actual)`
- `void assertEquals(double exp, double act, double epsilon)`
- `void assertEquals(expected, actuals)`
- `void assertTrue(boolean condition)`
- `void fail(String message)`

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JUnit Assertions: Examples (1)



Consider the following class:

```
public class Point {
    private int x; private int y;
    public Point(int x, int y) { this.x = x; this.y = y; }
    public int getX() { return this.x; }
    public int getY() { return this.y; }
}
```

Then consider these assertions. Do they **pass** or **fail**?

```
Point p;
assertNull(p); ✓
assertTrue(p == null); ✓
assertFalse(p != null); ✓
assertEquals(3, p.getX()); ✗ /* NullPointerException */
p = new Point(3, 4);
assertNull(p); ✗
assertTrue(p == null); ✗
assertFalse(p != null); ✗
assertEquals(3, p.getX()); ✓
assertTrue(p.getX() == 3 && p.getY() == 4); ✓
```

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JUnit Assertions: Examples (2)



- Consider the following class:

```
public class Circle {
    private double radius;
    public Circle(double radius) { this.radius = radius; }
    public int getArea() { return 3.14 * radius * radius; }
}
```

- How do we test `c.getArea()` ?
 - Mathematically: $3.4 \times 3.4 \times 3.14 = 36.2984$
 - However, base-10 numbers **cannot** be represented perfectly in the binary format.
 - When comparing fractional numbers, allow some **tolerance** :

$$36.2984 - 0.01 \leq c.getArea() \leq 36.2984 + 0.01$$

- Then consider these assertions. Do they **pass** or **fail**?

```
Circle c = new Circle(3.4);
assertEquals(36.2984, c.getArea(), 0.01); ✓
```

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More JUnit Assertion Methods



method name / parameters	description
<code>assertTrue(test)</code> <code>assertTrue("message", test)</code>	Causes this test method to fail if the given boolean test is not true.
<code>assertFalse(test)</code> <code>assertFalse("message", test)</code>	Causes this test method to fail if the given boolean test is not false.
<code>assertEquals(expectedValue, value)</code> <code>assertEquals("message", expectedValue, value)</code>	Causes this test method to fail if the given two values are not equal to each other. (For objects, it uses the equals method to compare them.) The first of the two values is considered to be the result that you expect; the second is the actual result produced by the class under test.
<code>assertNotEquals(value1, value2)</code> <code>assertNotEquals("message", value1, value2)</code>	Causes this test method to fail if the given two values are equal to each other. (For objects, it uses the equals method to compare them.)
<code>assertNull(value)</code> <code>assertNull("message", value)</code>	Causes this test method to fail if the given value is not null.
<code>assertNotNull(value)</code> <code>assertNotNull("message", value)</code>	Causes this test method to fail if the given value is null.
<code>assertSame(expectedValue, value)</code> <code>assertSame("message", expectedValue, value)</code> <code>assertNotSame(value1, value2)</code> <code>assertNotSame("message", value1, value2)</code>	Identical to <code>assertEquals</code> and <code>assertNotEquals</code> respectively, except that for objects, it uses the <code>==</code> operator rather than the <code>equals</code> method to compare them. (The difference is that two objects that have the same state might be equals to each other, but not <code>==</code> to each other. An object is only <code>==</code> to itself.)
<code>fail()</code> <code>fail("message")</code>	Causes this test method to fail.

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Testing: Correct vs. Incorrect Imp.



- The real value of a **test** is:
 - Not only to **reaffirm** when your implementation is **correct**,
 - But also to **reject** when your implementation is **incorrect**.
- What if the method `decrement` was implemented **incorrectly**?

```
class Counter {
    ...
    public void decrement() throws ValueTooSmallException {
        if (value < Counter.MIN_VALUE) {
            throw new ValueTooSmallException("value is " + value);
        }
        else { value --; }
    }
}
```

- A “good” test should **reject** such an **incorrect** implementation.

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Testing Strategy



- What is the complete list of cases for testing `Counter`?

<code>c.getValue()</code>	<code>c.increment()</code>	<code>c.decrement()</code>
0	1	ValueTooSmall
1	2	0
2	3	1
3	ValueTooLarge	2

- Let's turn the two cases in the 1st row into two JUnit tests:
 - Test for the **green** cell **succeeds** if:
 - No failures and exceptions occur; and
 - The new counter value is 1.
 - Tests for **red** cells **succeed** if the **expected exceptions** occur (`ValueTooSmallException` & `ValueTooLargeException`).

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Test Case 1: Increment from Min (1)



```
1 @Test
2 public void testIncAfterCreation() {
3     Counter c = new Counter();
4     assertEquals(Counter.MIN_VALUE, c.getValue());
5     try {
6         c.increment();
7         assertEquals(1, c.getValue());
8     }
9     catch (ValueTooLargeException e) {
10        /* Exception is not expected to be thrown. */
11        fail("ValueTooLargeException is not expected.");
12    }
13 }
```

- L3 sets `c.value` to 0.
- Line 6 requires a try-catch block ∴ potential `ValueTooLargeException`
- Lines 4, 7 11 are all assertions:
 - Lines 4 & 7 assert that `c.getValue()` returns the expected values.
 - Line 11: an **assertion failure** ∴ unexpected `ValueTooLargeException`
- Line 7 can be rewritten as `assertTrue(1 == c.getValue())`.

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Test Case 1: Increment from Min (2)

```

1  @Test
2  public void testIncAfterCreation() {
3      Counter c = new Counter();
4      assertEquals(Counter.MIN_VALUE, c.getValue());
5      try {
6          c.increment();
7          assertEquals(1, c.getValue());
8      }
9      catch (ValueTooLargeException e) {
10         /* Exception is not expected to be thrown. */
11         fail("ValueTooLargeException is not expected.");
12     }
13 }

```

At L6, if method decrement is implemented:

- **Correctly** ⇒ a ValueTooLargeException does not occur.
⇒ Execution continues to L7, L8, L13, then the program terminates.
- **Incorrectly** ⇒ an unexpected ValueTooLargeException occurs.
⇒ Execution jumps to L9, L10 – L11, then the test program terminates.

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Test Case 2: Decrement from Min (2)

```

1  @Test
2  public void testDecFromMinValue() {
3      Counter c = new Counter();
4      assertEquals(Counter.MIN_VALUE, c.getValue());
5      try {
6          c.decrement();
7          fail("ValueTooSmallException is expected.");
8      }
9      catch (ValueTooSmallException e) {
10         /* Exception is expected to be thrown. */
11     }
12 }

```

At L6, if method decrement is implemented:

- **Correctly** ⇒ a ValueTooLargeException occurs.
⇒ Execution jumps to L9, L10 – L12, then the program terminates.
- **Incorrectly** ⇒ expected ValueTooLargeException does not occur.
⇒ Execution continues to L7, then the test program terminates.

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Test Case 2: Decrement from Min (1)

```

1  @Test
2  public void testDecFromMinValue() {
3      Counter c = new Counter();
4      assertEquals(Counter.MIN_VALUE, c.getValue());
5      try {
6          c.decrement();
7          fail("ValueTooSmallException is expected.");
8      }
9      catch (ValueTooSmallException e) {
10         /* Exception is expected to be thrown. */
11     }
12 }

```

- L3 sets c.value to 0.
- Line 6 requires a try-catch block ∴ potential ValueTooSmallException
- Lines 4 & 7 are both assertions:
 - Lines 4 asserts that c.getValue() returns the expected value (i.e., Counter.MIN_VALUE).
 - Line 7: an **assertion failure** ∴ expected ValueTooSmallException not thrown

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Test Case 3: Increment from Max

```

1  @Test
2  public void testIncFromMaxValue() {
3      Counter c = new Counter();
4      try {
5          c.increment(); c.increment(); c.increment();
6      }
7      catch (ValueTooLargeException e) {
8          fail("ValueTooLargeException was thrown unexpectedly.");
9      }
10     assertEquals(Counter.MAX_VALUE, c.getValue());
11     try {
12         c.increment();
13         fail("ValueTooLargeException was NOT thrown as expected.");
14     }
15     catch (ValueTooLargeException e) {
16         /* Do nothing: ValueTooLargeException thrown as expected. */
17     }
18 }

```

- L4 – L9: a VTLE **is not** expected; L11 – 17: a VTLE **is** expected.

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Exercise: Console Tester vs. JUnit Test



Q. Can this **console tester** work like the **JUnit test** testIncFromMaxValue does?

```
1 public class CounterTester {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Current val: " + c.getValue());
5         try {
6             c.increment(); c.increment(); c.increment();
7             println("Current val: " + c.getValue());
8         }
9         catch (ValueTooLargeException e) {
10            println("Error: ValueTooLargeException thrown unexpectedly.");
11        }
12        try {
13            c.increment();
14            println("Error: ValueTooLargeException NOT thrown.");
15        } /* end of inner try */
16        catch (ValueTooLargeException e) {
17            println("Success: ValueTooLargeException thrown.");
18        }
19    } /* end of main method */
20 } /* end of CounterTester class */
```

A. Say one of the first 3 c.increment() **mistakenly** throws VTLE.

- After L10 is executed, flow of execution **still continues** to L12.
- This allows the 4th c.increment to be executed!

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Using Loops in JUnit Test Cases



Loops can make it effective on generating test cases:

```
1 @Test
2 public void testIncDecFromMiddleValues() {
3     Counter c = new Counter();
4     try {
5         for(int i = Counter.MIN_VALUE; i < Counter.MAX_VALUE; i++) {
6             int currentValue = c.getValue();
7             c.increment();
8             assertEquals(currentValue + 1, c.getValue());
9         }
10        for(int i = Counter.MAX_VALUE; i > Counter.MIN_VALUE; i--) {
11            int currentValue = c.getValue();
12            c.decrement();
13            assertEquals(currentValue - 1, c.getValue());
14        }
15    }
16    catch (ValueTooLargeException e) {
17        fail("ValueTooLargeException is thrown unexpectedly");
18    }
19    catch (ValueTooSmallException e) {
20        fail("ValueTooSmallException is thrown unexpectedly");
21    }
22 }
```

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Exercise: Combining catch Blocks?



Q: Can we rewrite testIncFromMaxValue to:

```
1 @Test
2 public void testIncFromMaxValue() {
3     Counter c = new Counter();
4     try {
5         c.increment();
6         c.increment();
7         c.increment();
8         assertEquals(Counter.MAX_VALUE, c.getValue());
9         c.increment();
10        fail("ValueTooLargeException was NOT thrown as expected.");
11    }
12    catch (ValueTooLargeException e) { }
13 }
```

No!

At Line 12, we would not know which line throws the VTLE:

- If it was any of the calls in L5 – L7, then it's **not right**.
- If it was L9, then it's **right**.

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Exercises



1. Run all 8 tests and make sure you receive a **green** bar.
2. Now, introduction an error to the implementation: Change the line value ++ in Counter.increment to --.
 - Re-run all 8 tests and you should receive a **red** bar. [Why?]
 - Undo **error injections** & Re-Run all 8 tests. [What happens?]

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Resources



- Official Site of JUnit 4:

<http://junit.org/junit4/>

- API of JUnit assertions:

<http://junit.sourceforge.net/javadoc/org/junit/Assert.html>

- Another JUnit Tutorial example:

<https://courses.cs.washington.edu/courses/cse143/11wi/>

[eclipse-tutorial/junit.shtml](#)

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Beyond this lecture...



Play with the source code `ExampleTestingCounter.zip`

Tip. Change input values so as to explore, in Eclipse *debugger*, possible (*normal* vs. *abnormal*) **execution paths**.

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