Test-Driven Development (TDD) with JUnit

EECS2030 E: Advanced
Object Oriented Programming
Summer 2025

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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) { ... }
  }
}
```


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.

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.

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**.

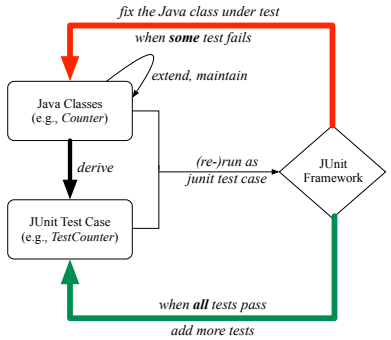
Components of a Test

- 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.

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***.

Test-Driven Development (TDD)



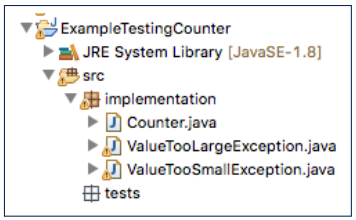
Maintain a collection of tests which define the ***correctness*** of your Java class under development (CUD):

- 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.

How to Use JUnit: Packages

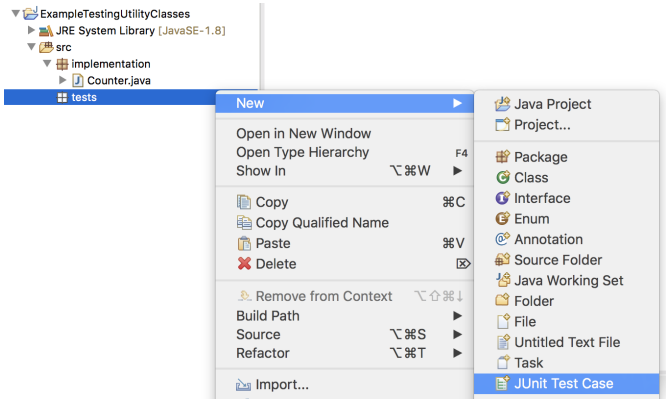
Step 1:

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



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

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

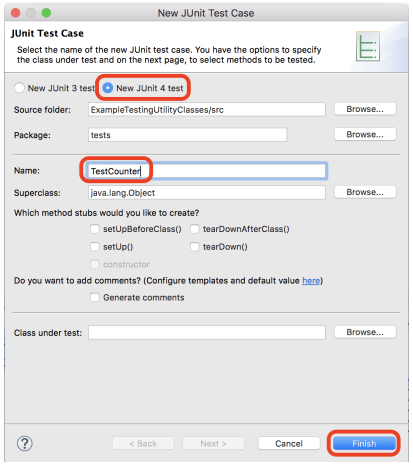


Create one JUnit Test Case to test one Java class only.

⇒ If you have *n Java classes to test*, create *n JUnit test cases*.

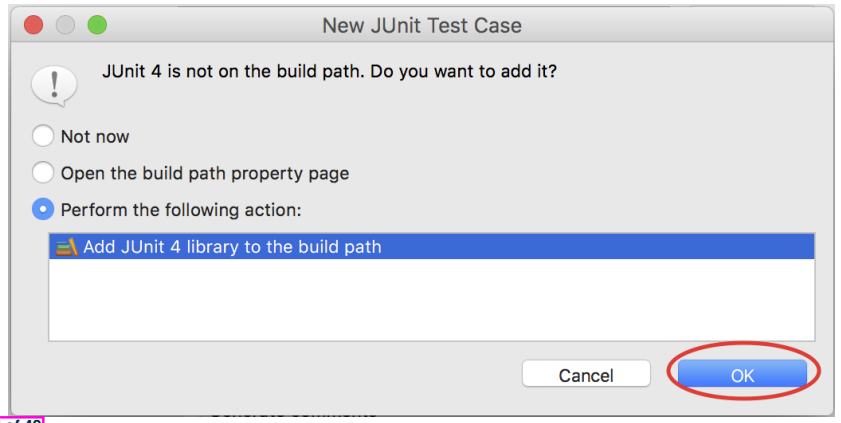
How to Use JUnit: New JUnit Test Case (2)

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



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.



How to Use JUnit: Generated Test Case

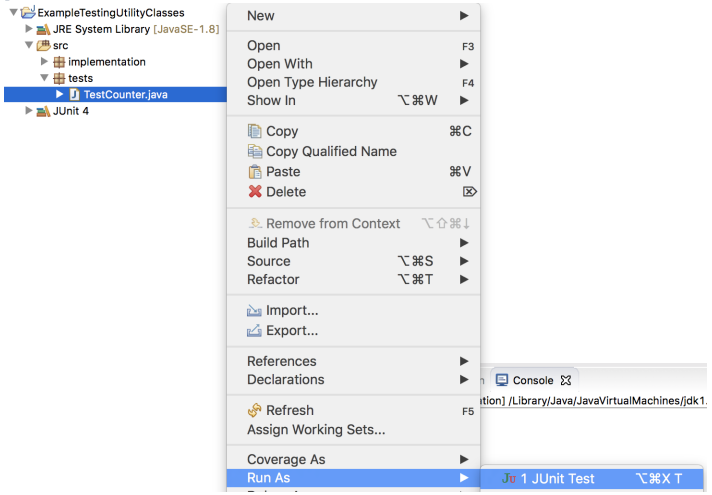
TestCounter.java

```
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".

How to Use JUnit: Running Test Case

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

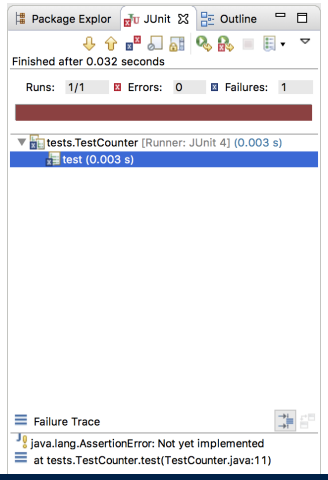


How to Use JUnit: Interpreting Test Report

- 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`, `ArrayIndexOutOfBoundException`) 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")`.

How to Use JUnit: Generating Test Report

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



How to Use JUnit: Revising Test Case

TestCounter.java

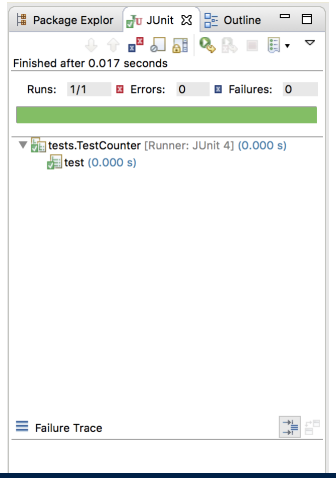
```
1 package tests;
2 import static org.junit.Assert.*;
3 import org.junit.Test;
4 public class TestCounter {
5     @Test
6     public void test() {
7 //      fail("Not yet implemented");
8     }
9 }
```

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!

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`.



How to Use JUnit: Commons Assertions

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

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);  ✓
```


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*:

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

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

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

More JUnit Assertion Methods

method name / parameters	description
`assertTrue(`*`test`*`)` `assertTrue(`*`"message", test`*`)`	Causes this test method to fail if the given `boolean` test is not `true`.
`assertFalse(`*`test`*`)` `assertFalse(`*`"message", test`*`)`	Causes this test method to fail if the given `boolean` test is not `false`.
`assertEquals(`*`expectedValue, value`*`)` `assertEquals(`*`"message", expectedValue, value`*`)`	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.
`assertNotEquals(`*`value1, value2`*`)` `assertNotEquals(`*`"message", value1, value2`*`)`	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.)
`assertNull(`*`value`*`)` `assertNull(`*`"message", value`*`)`	Causes this test method to fail if the given value is not `null`.
`assertNotNull(`*`value`*`)` `assertNotNull(`*`"message", value`*`)`	Causes this test method to fail if the given value *is* `null`.

`assertSame(`*`expectedValue, value`*`)`
`assertSame(`*`"message", expectedValue, value`*`)`
`assertNotSame(`*`value1, value2`*`)`
`assertNotSame(`*`"message", value1, value2`*`)`
	Identical to `assertEquals` and `assertNotEquals` respectively, except that for objects, it uses the `==` operator rather than the `equals` method to compare them. (The difference is that two objects that have the same state might be `equals` to each other, but not `==` to each other. An object is only `==` to itself.)

`fail()` `fail(`*`"message"`*`)`	Causes this test method to fail.

Testing Strategy

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

`c.getValue()`	`c.increment()`	`c.decrement()`
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`).

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.

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())`.

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.

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

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.

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.

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!

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***.

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 }
```


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?]

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`

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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