Test-Driven Development (TDD) with JUnit

EECS2030 B & E: 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
- How Manual, Console Testers are Limited
- Deriving ***Test Cases*** for a Bounded Variable
- How Automated, JUnit Test Cases are Effective
- 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 classes must be handled (*catch-specify requirement*):

- Either *specify* `throws ...` in the method signature (i.e., propagating it to other caller)
- Or *handle* it in a `try-catch` block

Motivating Example: Two Types of Errors (2)

Approach 1 – Specify: Indicate in the method signature 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 between its lower and upper bounds.

Exceptional Scenarios

Consider the two possible exceptional scenarios:

- 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.
- To start with, we develop tests via a ***console tester*** class (i.e., with the `main` method).

Testing Counter via Console V1 (1.1)

```
1  public class CounterTester1 {
2    public static void main(String[] args) {
3      Counter c = new Counter();
4      println("Init val: " + c.getValue());
5      try {
6        c.decrement();
7        println("Error: ValueTooSmallException NOT thrown.");
8      }
9      catch (ValueTooSmallException e) {
10       println("Success: ValueTooSmallException thrown.");
11     }
12   } /* end of main method */
13 } /* end of class CounterTester1 */
```

- **L3** sets `c.value` to `0`.
- At **L6**, if method `decrement` is implemented:
  - ***Correctly*** ⇒ we expect a `ValueTooSmallException`.
    ⇒ Execution jumps to **L9**, **L10 – L12**, then the program terminates.
  - ***Incorrectly*** ⇒ expected `ValueTooSmallException` *wouldn't* occur.
    ⇒ Execution continues to **L7**, **L8**, **L12**, then the program terminates.

See the equivalent, automated JUnit test `testDecFromMinValue`.

Testing Counter via Console V1 (1.2)

```
1  public class CounterTester1 {
2    public static void main(String[] args) {
3      Counter c = new Counter();
4      println("Init val: " + c.getValue());
5      try {
6        c.decrement();
7        println("Error: ValueTooSmallException NOT thrown.");
8      }
9      catch (ValueTooSmallException e) {
10       println("Success: ValueTooSmallException thrown.");
11     }
12   } /* end of main method */
13 } /* end of class CounterTester1 */
```

- Say method `decrement` is implemented ***correctly***.
- **Lines 3 – 6, 9 – 11, 12** executed, giving the Console Output:

```
Init val: 0
Success: ValueTooSmallException thrown.
```


Testing Counter via Console V1 (1.3.1)

- The real value of a *test* is:
  - Not only to confirm when your implementation is ***correct***,
  - But also to reveal errors when your implementation is ***incorrect***.
- Say now 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 --; }
  }
}
```

- Is the same console tester able to *reveal* this ***incorrect*** implementation?

Testing Counter via Console V1 (1.3.2)


```
1  public class CounterTester1 {
2    public static void main(String[] args) {
3      Counter c = new Counter();
4      println("Init val: " + c.getValue());
5      try {
6        c.decrement();
7        println("Error: ValueTooSmallException NOT thrown.");
8      }
9      catch (ValueTooSmallException e) {
10       println("Success: ValueTooSmallException thrown.");
11     }
12   } /* end of main method */
13 } /* end of class CounterTester1 */
```

- Say method `decrement` is implemented ***incorrectly***.
- **Lines 3 – 6, 7 – 8, 12** executed, giving the Console Output:

```
Init val: 0
Error: ValueTooSmallException NOT thrown.
```


Testing Counter via Console V2 (2.1)


```
1  public class CounterTester2 {
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        try {
9          c.increment();
10         println("Error: ValueTooLargeException NOT thrown.");
11       } /* end of inner try */
12       catch (ValueTooLargeException e) {
13         println("Success: ValueTooLargeException thrown.");
14       } /* end of inner catch */
15     } /* end of outer try */
16     catch (ValueTooLargeException e) {
17       println("Error: ValueTooLargeException thrown unexpectedly.");
18     } /* end of outer catch */
19   } /* end of main method */
20 } /* end of CounterTester2 class */
```

See the equivalent, automated JUnit test `testIncFromMaxValue`.

Testing Counter via Console V2 (2.2)


```
1  public class CounterTester2 {
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        try {
9          c.increment();
10         println("Error: ValueTooLargeException NOT thrown.");
11       } /* end of inner try */
12       catch (ValueTooLargeException e) {
13         println("Success: ValueTooLargeException thrown.");
14       } /* end of inner catch */
15     } /* end of outer try */
16     catch (ValueTooLargeException e) {
17       println("Error: ValueTooLargeException thrown unexpectedly.");
18     } /* end of outer catch */
19   } /* end of main method */
20 } /* end of CounterTester2 class */
```

- Say method `increment` is implemented ***correctly***.
- **Lines 3 – 9, 12 – 15, 19** executed, with Console Output:

```
Current val: 0
Current val: 3
Success: ValueTooLargeException thrown.
```


Testing Counter via Console V2 (2.3.1)


```
1  public class CounterTester2 {
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        try {
9          c.increment();
10         println("Error: ValueTooLargeException NOT thrown.");
11       } /* end of inner try */
12       catch (ValueTooLargeException e) {
13         println("Success: ValueTooLargeException thrown.");
14       } /* end of inner catch */
15     } /* end of outer try */
16     catch (ValueTooLargeException e) {
17       println("Error: ValueTooLargeException thrown unexpectedly.");
18     } /* end of outer catch */
19   } /* end of main method */
20 } /* end of CounterTester2 class */
```

- **Exercise**: Give an ***incorrect*** method `increment`, so that
- **Lines 3 – 6, 16 – 18, 19** executed, with Console Output:

```
Current val: 0
Error: ValueTooLargeException was thrown unexpectedly.
```

Testing Counter via Console V2 (2.3.2)

```
1  public class CounterTester2 {
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        try {
9          c.increment();
10         println("Error: ValueTooLargeException NOT thrown.");
11       } /* end of inner try */
12       catch (ValueTooLargeException e) {
13         println("Success: ValueTooLargeException thrown.");
14       } /* end of inner catch */
15     } /* end of outer try */
16     catch (ValueTooLargeException e) {
17       println("Error: ValueTooLargeException thrown unexpectedly.");
18     } /* end of outer catch */
19   } /* end of main method */
20 } /* end of CounterTester2 class */
```

- **Exercise**: Give an ***incorrect*** method `increment`, so that
- **Lines 3 – 11, 15, 19** executed, with Console Output:

```
Current val: 0
Current val: 3
Error: ValueTooLargeException was NOT thrown.
```


Testing Counter via Console V2 (2.3.3)

Q. Can this alternative to `ConsoleTester2` work (without nested `try-catch`)?

```
1  public class CounterTester2 {
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     } /* end of inner catch */
19   } /* end of main method */
20 } /* end of CounterTester2 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!
- Constrast this with the structurally-similar JUnit test `testIncFromMaxValue`: here

Testing Counter via Console (V3)

```
import java.util.Scanner;
public class CounterTester3 {
  public static void main(String[] args) {
    Scanner input = new Scanner(System.in);
    String cmd = null; Counter c = new Counter();
    boolean userWantsToContinue = true;
    while(userWantsToContinue) {
      println("Enter \"inc\", \"dec\", or \"val\":");
      cmd = input.nextLine();
      try {
        if(cmd.equals("inc")) { c.increment(); }
        else if(cmd.equals("dec")) { c.decrement(); }
        else if(cmd.equals("val")) { println(c.getValue()); }
        else { userWantsToContinue = false; println("Bye!"); }
      } /* end of try */
      catch(ValueTooLargeException e){ println("Value too big!"); }
      catch(ValueTooSmallException e){ println("Value too small!"); }
    } /* end of while */
  } /* end of main method */
} /* end of class CounterTester3 */
```


Testing Counter via Console (V3): Test 1

Test Case 1: Decrement when the counter value is too small.

```
Enter "inc", "dec", or "val":
val
0
Enter "inc", "dec", or "val":
dec
Value too small!
Enter "inc", "dec", or "val":
exit
Bye!
```

Testing Counter via Console (V3): Test 2

Test Case 2: Increment when the counter value is too big.

```
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
val
3
Enter "inc", "dec", or "val":
inc
Value too big!
Enter "inc", "dec", or "val":
exit
Bye!
```


Limitations of Testing from the Console

- Do **Test Cases** 1 & 2 suffice to test `Counter`'s ***correctness***?
  - Is it plausible to claim that the implementation of `Counter` is *correct* because it passes the two test cases?
- What other test cases can you think of?

`c.getValue()`	`c.increment()`	`c.decrement()`
0	1	`ValueTooSmall`
1	2	0
2	3	1
3	`ValueTooLarge`	2

- So in total we need 8 test cases. ⇒ 6 more separate
  - `CounterTester` classes to create (like `CounterTester1`)!
  - Console interactions with `CounterTester3`!
- Problems? It is inconvenient and ***error-prone*** to:
  - Run each TC by executing `main` of a `CounterTester` and comparing console outputs ***with your eyes***.
  - *Re-run* ***manually*** all TCs whenever `Counter` is changed.

Regression Testing: Any **change** introduced to your software *must not compromise* its established ***correctness***.

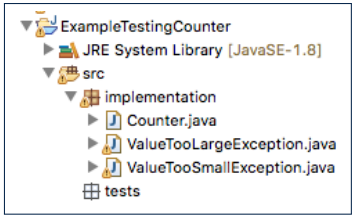
Why JUnit?

- *Automate* the ***testing of correctness*** of your Java classes.
- Once you derive the list of tests, translate it into a JUnit test case, which is just a Java class that you can execute upon.
- JUnit tests are *helpful callers/clients* of your classes, where 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.

How to Use JUnit: Packages

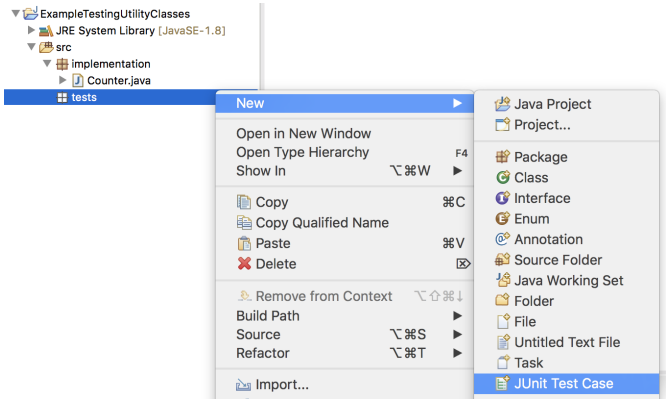
Step 1:

- 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.

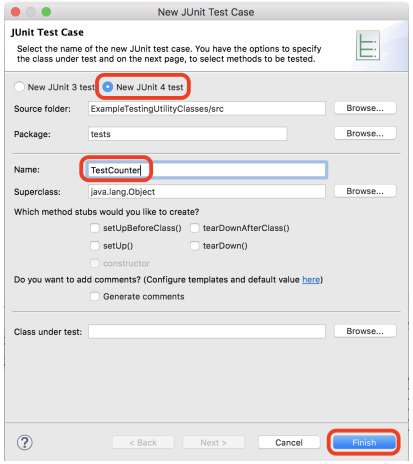


Create one JUnit Test Case to test one Java class only.

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

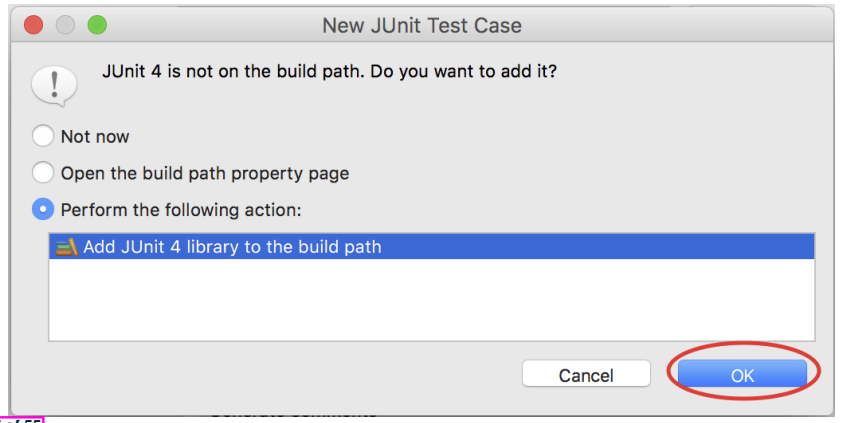
How to Use JUnit: New JUnit Test Case (2)

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

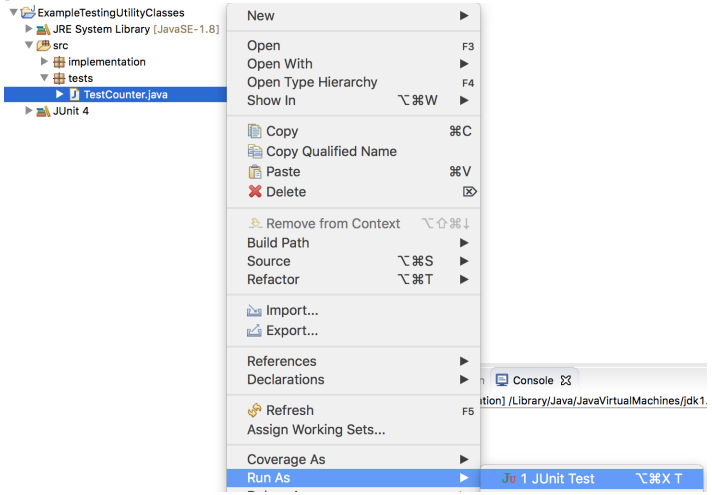
TestCounter.java

```
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.

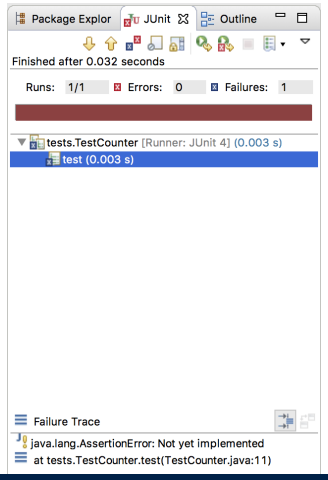


How to Use JUnit: Interpreting Test Report

- 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; or
    - an *unexpected* exception (e.g., `NullPointerException`, `ArrayIndexOutOfBoundException`) is 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-runing 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

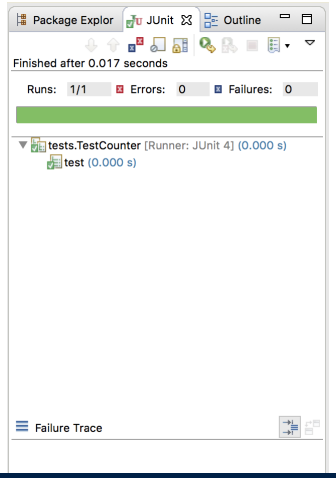
```
1 package tests;
2 import static org.junit.Assert.*;
3 import org.junit.Test;
4 public class TestCounter {
5     @Test
6     public void test() {
7 //      fail("Not yet implemented");
8     }
9 }
```

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: Adding More Tests (1)

- Recall 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`).
  - Common JUnit assertion methods:
    - `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*:

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

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

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

How to Use 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.

How to Use JUnit: Adding More Tests (2.1)

```
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(ValueTooBigException e) {
10     /* Exception is not expected to be thrown. */
11     fail("ValueTooBigException is not expected.");
12   }
13 }
```

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

How to Use JUnit: Adding More Tests (2.2)

- Don't lose the big picture!
- JUnit test in previous slide automates this console interaction:

```
Enter "inc", "dec", or "val":
val
0
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
val
1
Enter "inc", "dec", or "val":
exit
Bye!
```

- ***Automation*** *is exactly rationale behind using JUnit!*

How to Use JUnit: Adding More Tests (3.1)

```
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 }
```

- **Line 6** requires a try-catch block ∵ potential `ValueTooBigException`
- **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

See the equivalent, manual `ConsoleTester1`.

How to Use JUnit: Adding More Tests (3.2)

- Again, don't lose the big picture!

  Automation is exactly rationale behind using JUnit!
- JUnit test in previous slide automates `CounterTester1` and the following console interaction for `CounterTester3`:

```
Enter "inc", "dec", or "val":
val
0
Enter "inc", "dec", or "val":
dec
Value too small!
Enter "inc", "dec", or "val":
exit
Bye!
```


How to Use JUnit: Adding More Tests (4.1.1)


```
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.

See the equivalent, manual `ConsoleTester2`. Constrast with the alternative to `ConsoleTester2`.

How to Use JUnit: Adding More Tests (4.1.2)


```
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 }
```

Contrast with the structurally-similar console tester.

How to Use JUnit: Adding More Tests (4.2)

- JUnit test in previous slide *automates* `CounterTester2` and the following console interaction for `CounterTester3`:

```
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
inc
Enter "inc", "dec", or "val":
val
3
Enter "inc", "dec", or "val":
inc
Value too big!
Enter "inc", "dec", or "val":
exit
Bye!
```

How to Use JUnit: Adding More Tests (4.3)

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*.

How to Use JUnit: Adding More Tests (5)

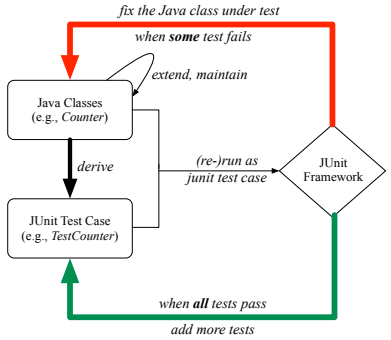
Loops can make it effective on generating test cases:

```
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 the ***injection of error***, and re-run all 8 tests. [What happens?]

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.

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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