Test-Driven Development (a.k.a. Design to Test)

CSE219, Computer Science III

Stony Brook University

http://www.cs.stonybrook.edu/~cse219

Man-hours

- Labor is sometimes measured in man-hours, man-months, or man-years.
  - Example: Doom3 took 5 years and more than 100 man-years of labor to develop
    - Company Spokesman: "It will be ready when it's done"
  - Why not double the size of the team and halve the *lead time* (concept date to release date)?

Man-hours: The Mythical Man-Month

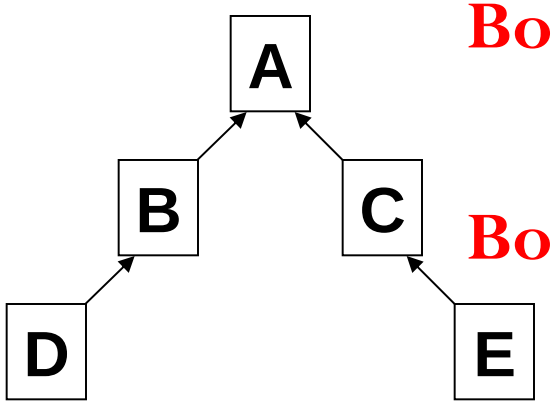
- Assume that a software program might take one expert programmer a year to develop = 12 man-months
- Market pressures might be such that we want to get the program finished in a month, rather than a year
- 1 programmer * 12 months = 12 programmers * 1 month?
  - When you throw additional programmers at a project that is late, you are likely to make it *more late!*
  - ***Remove promised-but-not-yet-completed features, rather than multiplying workers bees.***
  - ***Also, at least one team member must have detailed knowledge of the entire system (all the modules).***

Design to Implementation

- Assume a modular design has been completed
  - Can all the modules be developed in parallel?
    - most likely not - due to dependencies
  - division of work within a module may also be necessary
    - can classes within a module be developed in parallel?
      - most likely not - due to dependencies
      - division of work within a class may also be necessary
        - can methods within a class be developed in parallel?
        - Again most likely not - due to dependencies

Bottom-Up Development

- Traditional approach:
  - All modules used by module M are implemented and tested before M is implemented.
- Requires the use of drivers (i.e., testers).
- Example of Module dependencies:

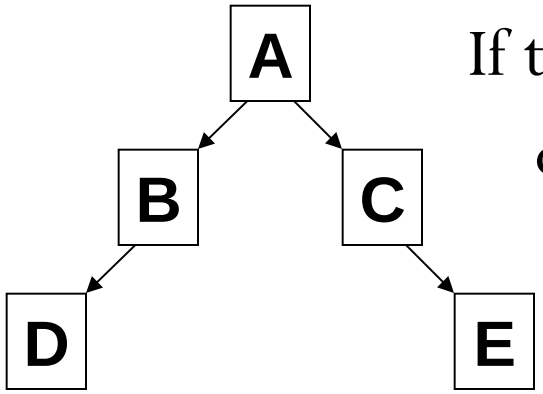


Bottom-up development can place less of a load on system resources.

Bottom-up development can lead to earlier completion of useful subsystems.

Top-Down Development

- All modules that use module M are implemented and tested before M is implemented.
  - Modules themselves will probably use bottom-up development
- Requires the use of stubs.
- Testing procedures are important
  - Example of module dependencies:



If the design contains a type hierarchy, top-down development is required.

The Development Strategy

- Should be defined explicitly before implementation begins
- Should be primarily top-down, with bottom-up used mainly for modules that are easier to implement than to simulate
- Advantages of top-down outweigh bottom-up
  - simplifies system integration & test
  - makes it possible to produce useful partial versions of the system
  - allows critical high-level design errors to be caught early
- Bottom-up development may be used for each module
  - we'll see this with module testing as well

What is design to test?

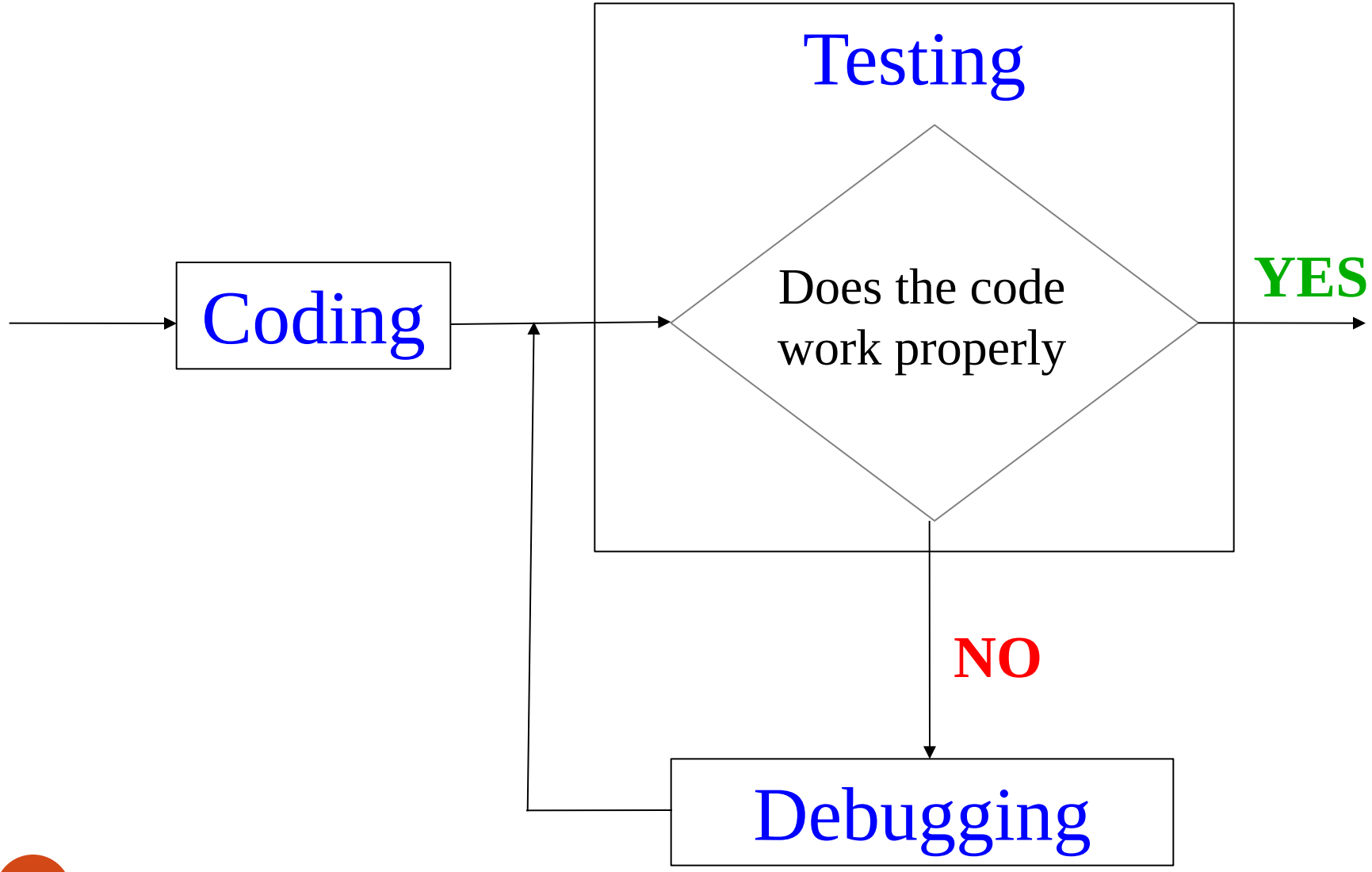
- Approach to implementation
  - design modular classes and methods
  - before coding:
    - determine what needs to be tested
    - design test cases for those important methods
  - test incrementally, as you implement your solution

Don't Design to Fail

$$\text{Design to Test} = \frac{1}{\text{Design to Fail}}$$

- Things to avoid:
  - coding without a design
  - not planning on how a design will be tested
  - creating large amounts of untested code
  - coding very large methods
  - lack of modularity can doom an implementation

Testing vs. Debugging



Important Definitions

- Testing
  - a process of running a program on a set of test cases and comparing the actual results with expected results
- Verification
  - a formal or informal argument that a program works as intended for all possible inputs
- Validation
  - a process designed to increase confidence that a program works as intended
    - performed through verification or testing
- Defensive Programming
  - writing programs in a way designed to ease the process of validation and debugging

Kinds of Testing

- Unit Testing
  - Test each module in a program separately.
- Integration Testing
  - Test interfaces between modules.
  - Much more difficult than unit testing
- Regression Testing
  - Test programs after modifications to ensure correct behavior of the original program is preserved.
- System Testing
  - Test overall system behavior.

Aspects of Testing

- How do we generate test cases?
  - Exhaustive
    - Consider all possible combinations of inputs.
    - Often infeasible – why?
    - Is it feasible with your project?
  - Sampled
    - A small but representative subset of all input combinations.
      - Black-box testing - Test cases generated from program specifications and not dependent on the implementation
      - Glass-box testing - Test cases generated from program's code

Black-box testing

- It is the best place to start when attempting to test a program thoroughly
- Test cases based on program's specification, not on its implementation (see the homework grading sheets)
- Test cases are not affected by:
  - Invalid assumptions made by the programmer
  - Implementation changes
    - Use same test cases even after program structures has changed
- Test cases can be generated by an "independent" agent, unfamiliar with the implementation.
- Test cases should cover all paths (not all cases) through the specification, including exceptions.

Boundary Conditions

- A boundary condition is an input that is "one away" from producing a different behavior in the program code
- Such checks catch 2 common types of errors:
  - Logical errors, in which a path to handle a special case presented by a boundary condition is omitted
  - Failure to check for conditionals that may cause the underlying language or hardware system to raise an exception (ex: arithmetic overflow)

Glass-box testing

- Black-box testing is generally not enough.
- For Glass-box testing, the code of a program being tested is taken into account
- Path-completeness:
  - Test cases are generated to exercise each path through a program.
  - May be insufficient to catch all errors.
  - Can be used effectively only for a program fragment that contains a reasonable number of paths to test.

Testing paths through specification

- Examine the method specifications (preconditions) & all paths through method to generate unique test cases for testing.

```
/* REQUIRES: x >= 0 && y >= 10 */

public static int calc(int x, int y) { ... }
```

- Translate paths to test cases:

```
x =  0, y = 10  (x == 0 && y == 10)
x =  5, y = 10  (x >  0 && y == 10)
x =  0, y = 15  (x == 0 && y >  10)
x =  5, y = 15  (x >  0 && y >  10)
x = -1, y = 10  (x <  0 && y == 10)
x = -1, y = 15  (x <  0 && y >  10)
x = -1, y =  9  (x <  0 && y <  10)
x =  0, y =  9  (x == 0 && y <  10)
x =  1, y =  9  (x >  0 && y <  10)
```

JUnit

- Unit-test framework for Java programs
  - open source software
  - hosted on SourceForge: http://junit.sourceforge.net/javadoc
    - Moved to http://junit.org (for JUnit 4 and later)
  - not in the standard JDK:

```
import junit.framework.*;
                          //for JUnit 3.8 and earlier
import org.junit.*; //for JUnit 4 and later
```

- Associate a Test class with each unit
  - one or more classes

http://blog.takipi.com/we-analyzed-30000-github-projects-here-are-the-top-100-libraries-in-java-js-and-ruby research survey performed in 2013 across 30,000 GitHub projects found that 40-50% of all projects use an automatic testing framework (**JUnit** in Java and **RSpec** in Ruby)

JUnit

- The test class has a set of test methods

```
public void testX()
```

where **X** is the method to be tested

- The test methods use "assertions" to perform the tests, ex:

```
Assert.assertTrue(c)
Assert.assertEquals(x,y)
Assert.assertSame(obj1, obj2)
```

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.

JUnit

Calculator.java

```
public class Calculator {
  public int evaluate(String expression) {
    int sum = 0;
    for (String summand: expression.split("\\+"))
      sum += Integer.valueOf(summand);
    return sum;
  }
}
```

JUnit

CalculatorTest.java

```
import static org.junit.Assert.assertEquals;
import org.junit.Test;

public class CalculatorTest {
  @Test
  public void evaluatesExpression() {
    Calculator calculator = new Calculator();
    int sum = calculator.evaluate("1+2+3");
    assertEquals(6, sum);
  }
}
```

JUnit

```
java -cp .:junit-4.12.jar:hamcrest-core-
    1.3.jar org.junit.runner.JUnitCore
    CalculatorTest

JUnit version 4.12

Time: 0,006

OK (1 test)
```

JUnit

Calculator.java

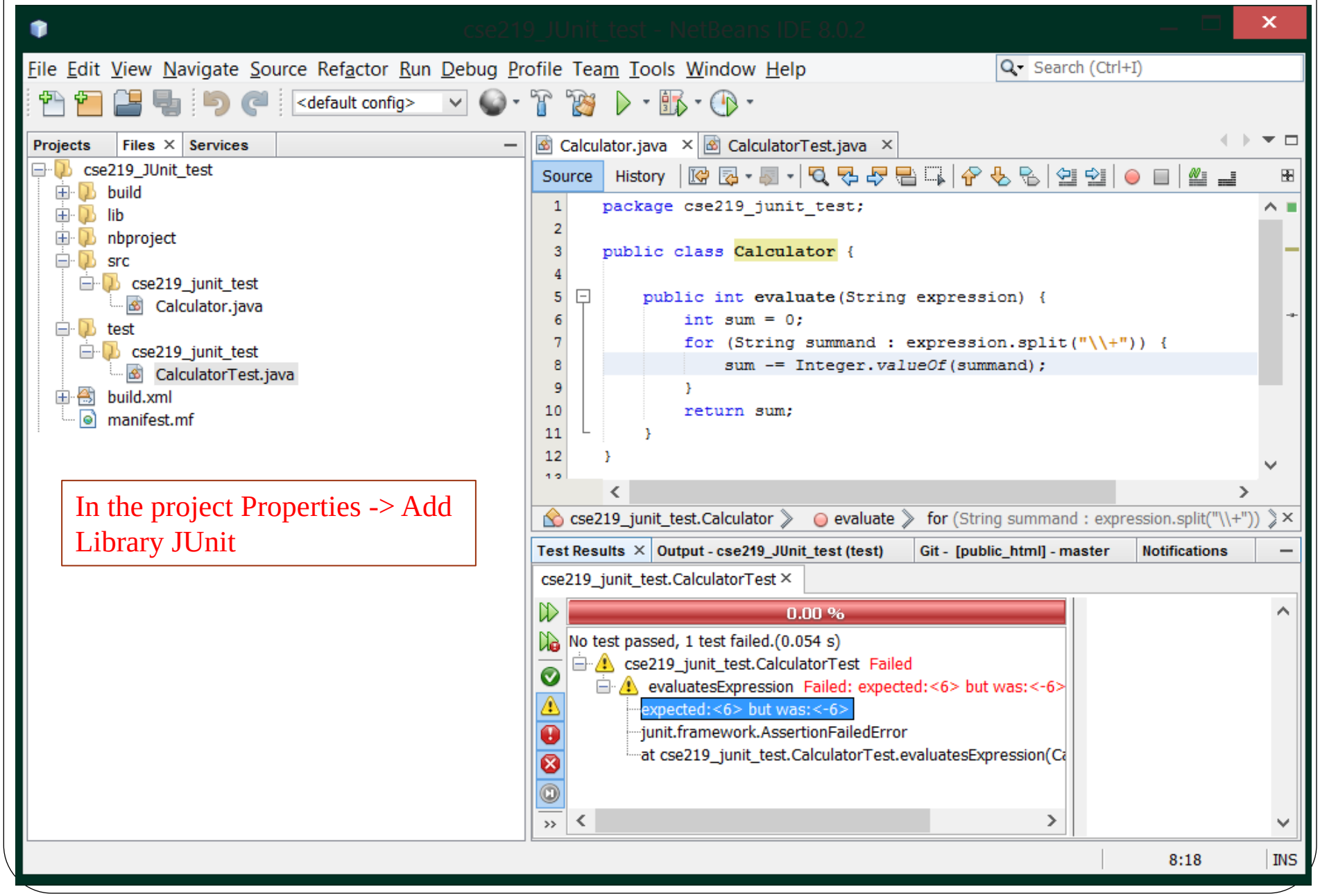
```
public class Calculator {
  public int evaluate(String expression) {
    int sum = 0;
    for (String summand: expression.split("\\+"))
      sum -= Integer.valueOf(summand);
    return sum;
  }
}
```

JUnit

```
java -cp .:junit-4.12.jar:hamcrest-core-
    1.3.jar org.junit.runner.JUnitCore
    CalculatorTest
JUnit version 4.12
.E
Time: 0,007
There was 1 failure:
1) evaluatesExpression(CalculatorTest)
java.lang.AssertionError: expected:<6> but was:<-6>
  at org.junit.Assert.fail(Assert.java:88)
  ...
FAILURES!!!
Tests run: 1,  Failures: 1
```

Netbeans IDE

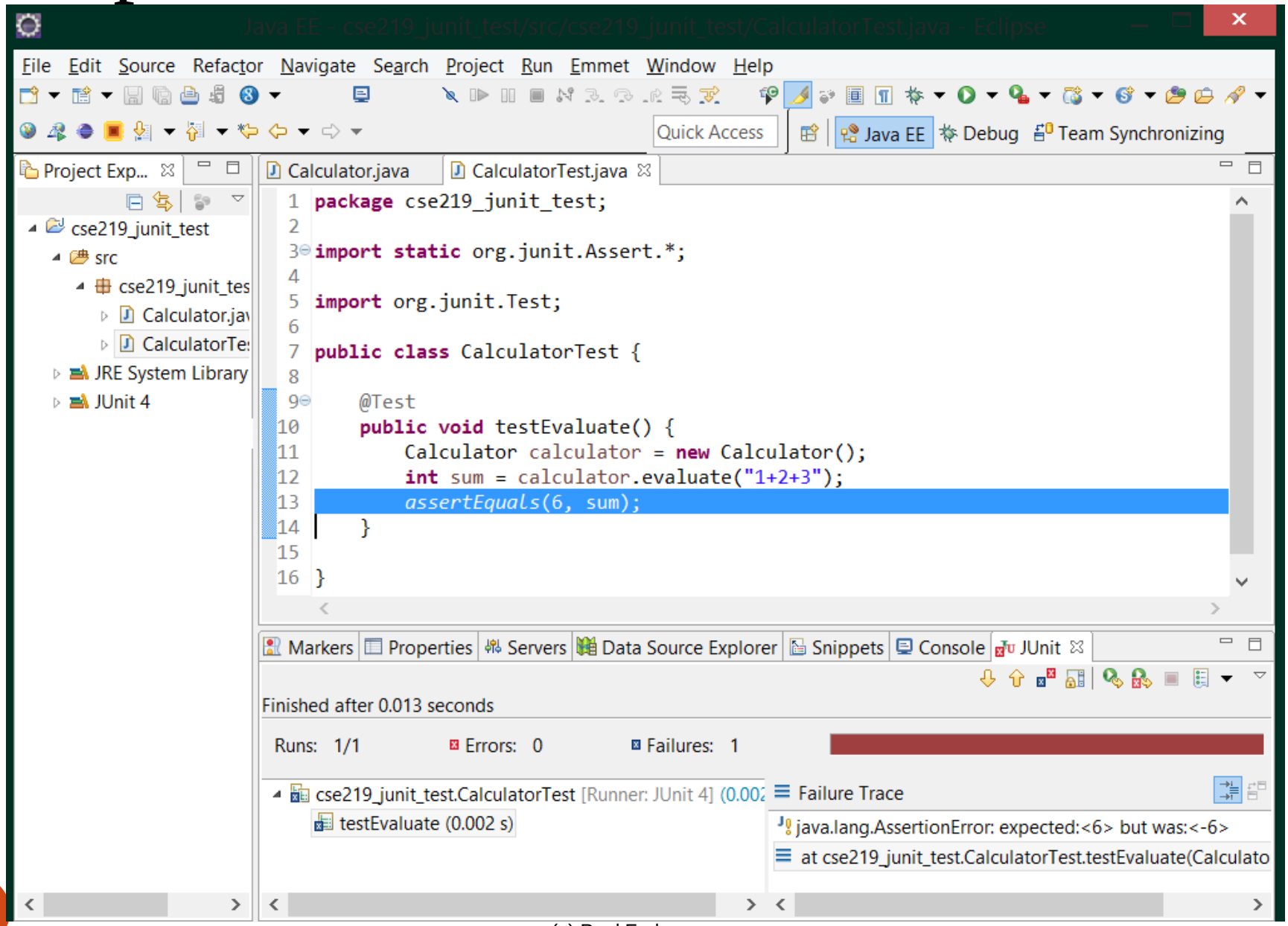
Right-click Calculator.java and choose Tools > Create Tests.



In the project Properties -> Add Library JUnit

Eclipse IDE

Open the New wizard (**File > New > JUnit Test Case**).



Building unit tests with JUnit

- Initialize any instance variables necessary for testing in the test object
- Define tests for emptiness, equality, boundary conditions, …
- Define test suites, if necessary, to group tests.
- Use Assert methods to perform tests

JUnit 3.8 vs. 4

- JUnit 4: all test methods are annotated with @Test.
  - Unlike JUnit3 tests, you do not need to prefix the method name with "test“.
- JUnit 4 does not have the test classes extend junit.framework.TestCase (directly or indirectly).
  - Usually, tests with JUnit4 do not need to extend anything (which is good, since Java does not support multiple inheritance).

JUnit Example – StatCompiler.java

```
public class StatCompiler {

   /**
     * a, b, & c must all be positive
     **/
   public static int averageOfPosInts(int a, int b, int c)
                  throws IllegalArgumentException{
      if ((a < 0) || (b <0) || (c < 0))
          throw new IllegalArgumentException("No neg values");
      int sum = a + b + c;
      return sum/3;
    }

    public static int median(int a, int b, int c){
        if ( (a >=b) && (a <=c))     return a;
        else if ((a >= b) && (a >=c))   return b;
        else                  return c;
    }

}
```

StatCompilerTest_3_8.java

```
import junit.framework.*;
          // JUnit 3.8
public class StatCompilerTest extends TestCase {

    public StatCompilerTest(java.lang.String testName) {
        super(testName);
    }

    public void testAverageOfPosInts() {
      System.out.println("testAverageOfPosInts");
      Assert.assertEquals(StatCompiler.averageOfPosInts(1, 2, 3), 2);
      try{
          StatCompiler.averageOfPosInts(-1, 2, 3);
          fail("Exception should have been thrown");
      } catch (IllegalArgumentException iae) {}
    }

    public void testMedian() {
       System.out.println("testMedian");
       Assert.assertEquals(2, StatCompiler.median(1, 2, 3));
       Assert.assertEquals(2, StatCompiler.median(3, 2, 1));
    }
}
```

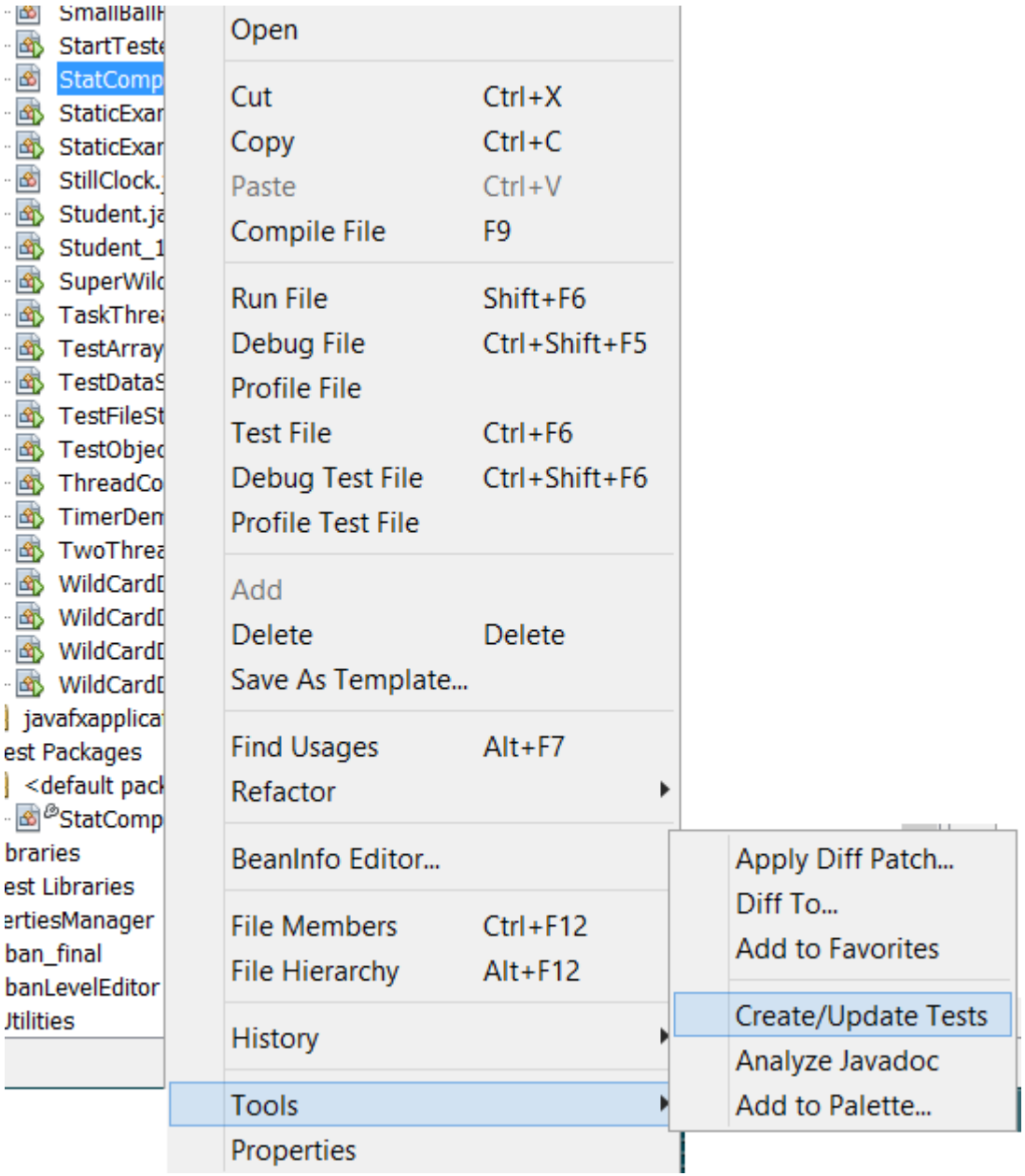
Run JUnit version 3.8

```
Junit version 3.8
testAverageOfPosInts
testMedian
=============================================
Errors logged for the StatCompilerTest test:
        No errors.
=============================================
Failures logged for the StatCompilerTest test:
        Total failures: 1
Test case testMedian(StatCompilerTest) failed with "expected:<2>
but was:<3>" at
StatCompilerTest.testMedian(StatCompilerTest.java:42)
=============================================

Summary of StatCompilerTest test:
        Result: Failed

        Run:              2
        Failures:         1
        Errors:           0
        Elapsed time:     0.01
```

StatCompilerTest_4.java

```
import org.junit.Test;
import static org.junit.Assert.*;
public class StatCompilerTest {
    @Test
    public void testAverageOfPosInts() {
        System.out.println("averageOfPosInts");
        int a = 1;
        int b = 2;
        int c = 3;
        int expResult = 2;
        int result = StatCompiler.averageOfPosInts(a, b, c);
        assertEquals(expResult, result);
    }
    @Test
    public void testMedian() {
        System.out.println("median");
        int a = 3;
        int b = 2;
        int c = 1;
        int expResult = 2;
        int result = StatCompiler.median(a, b, c);
        assertEquals(expResult, result);
    }

}
```

NetBeans and Junit: Download the Junit library and add it in the path. The Junit plugin is installed.



Run JUnit version 4

```
Run: java org.junit.runner.JUnitCore [test class name]

JUnit version 4.11
.testAverageOfPosInts
.testMedian
Time: 0.005
There was 1 failure:
1) testMedian(JUnit_test_01)
java.lang.AssertionError: expected:<2> but was:<3>

FAILURES!!!
Tests run: 2,  Failures: 1
```

Notes on Static import

- Static import is a feature introduced in the Java programming language that allows members (fields and methods) defined in a class as public static to be used in Java code without specifying the class in which the field is defined.
- The mechanism can be used to reference individual members of a class:

```
import static java.lang.Math.PI;
import static java.lang.Math.pow;
```

- or all the static members of a class:

```
import static java.lang.Math.*;
```

Static import example

```
import static java.lang.Math.*;
// OR
// import static java.lang.Math.PI;
// import static java.lang.Math.pow;

import static java.lang.System.out;

public class HelloWorld {
    public static void main(String[] args) {
        out.println("Hello World!");
        out.println("A circle with a diameter of 5 cm has:");
        out.println("A circumference of " + (PI * 5) + " cm");
        out.println("And an area of " + (PI * pow(2.5,2))
           + " sq. cm");
    }
}
```

Notes on Assertions

- An assertion is a Java statement that enables you to assert an assumption about your program.
- An assertion contains a Boolean expression that should be true during program execution.
- Assertions can be used to assure program correctness and avoid logic errors.

Declaring Assertions

- An assertion is declared using the Java keyword **`assert`** in JDK 1.5 as follows:

```
assert assertion;   //OR
assert assertion : detailMessage;
```

where assertion is a Boolean expression and detailMessage is a primitive-type or an Object value.

Executing Assertions Example

```
public class AssertionDemo {
  public static void main(String[] args) {
    int i; int sum = 0;
    for (i = 0; i < 10; i++) {
      sum += i;
    }
    assert i==10;
    assert sum>10 && sum<5*10 : "sum is " + sum;
  }
}
```

Executing Assertions

- When an assertion statement is executed, Java evaluates the assertion.
  - If it is false, an AssertionError will be thrown.
  - The AssertionError class has a no-arg constructor and seven overloaded single-argument constructors of type int, long, float, double, boolean, char, and Object.
  - For the first assert statement with no detail message, the no-arg constructor of AssertionError is used.
  - For the second assert statement with a detail message, an appropriate AssertionError constructor is used to match the data type of the message.
  - Since AssertionError is a subclass of Error, when an assertion becomes false, the program displays a message on the console and exits.

Running Programs with Assertions

- By default, the assertions are disabled at runtime. To enable it, use the switch –enableassertions, or –ea for short, as follows:

java –ea AssertionDemo

```
public class AssertionDemo {
  public static void main(String[] args){
    int i; int sum = 0;
    for (i = 0; i < 10; i++) {
      sum += i;
    }
    assert i!=10;
  }
}
```

```
Exception in thread "main" java.lang.AssertionError
at AssertionDemo.main(AssertionDemo.java:7)
```

Running Programs with Assertions

- Assertions can be selectively enabled or disabled at class level or package level.
  - The disable switch is –disableassertions or –da for short.
  - For example, the following command enables assertions in package package1 and disables assertions in class Class1.

```
java –ea:package1 –da:Class1 AssertionDemo
```

Using Exception Handling or Assertions?

- Assertion should not be used to replace exception handling.
  - Exception handling deals with unusual circumstances during program execution.
  - Assertions are to assure the correctness of the program.
  - Exception handling addresses robustness and assertion addresses correctness.
  - Assertions are used for internal consistency and validity checks.
  - Assertions are checked at runtime and can be turned on or off at startup time.

Using Exception Handling or Assertions?

- Do not use assertions for argument checking in public methods:
  - Valid arguments that may be passed to a public method are considered to be part of the method's contract.
  - The contract must always be obeyed whether assertions are enabled or disabled.
  - For example, the following code in the Circle class should be rewritten using exception handling:

```
public void setRadius(double newRadius) {
  assert newRadius >= 0;
  radius =  newRadius;
}
```

Using Exception Handling or Assertions?

- Use assertions to reaffirm assumptions.
  - This gives you more confidence to assure correctness of the program.
  - A common use of assertions is to replace assumptions with assertions in the code.
  - A good use of assertions is place assertions in a switch statement without a default case. For example:

```
switch (month) {
  case 1: ... ; break;
  case 2: ... ; break;
  ...
  case 12: ... ; break;
  default: assert false : "Invalid month: " + month;
}
```