Software Testing

CS2: Data Structures and Algorithms
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Topics

- Software Testing
- Black Box Testing
- Unit Testing with JUnit
- Test Driven Development
- White Box Testing
- Software Debugging

Faults and reliability

- ***Software Faults (aka bugs and defects):*** inevitable in a complex software system.
  - 10-50 faults per 1000 lines of code in industry!
  - Faults can be known or remain hidden.
  - Either way, they can cause software to fail.
- ***Software Reliability***: probability of failure of a software system over time. Measured using
  - mean time between failures, crash statistics, uptime versus downtime.

Common faults in programs

- Incorrect logical conditions
- Calculation performed in wrong place
- Non-terminating loop or recursion
- Incorrect preconditions for an algorithm
- Not handling null conditions
- Off-by-one errors
- Operator precedence errors

Faults in numerical programs

- Overflow and underflow - Not using enough bits
- Not using enough digits, especially places before or after the decimal point
- Assuming a floating point value will be exactly equal to some other value
- Ordering numerical operations poorly so errors build up

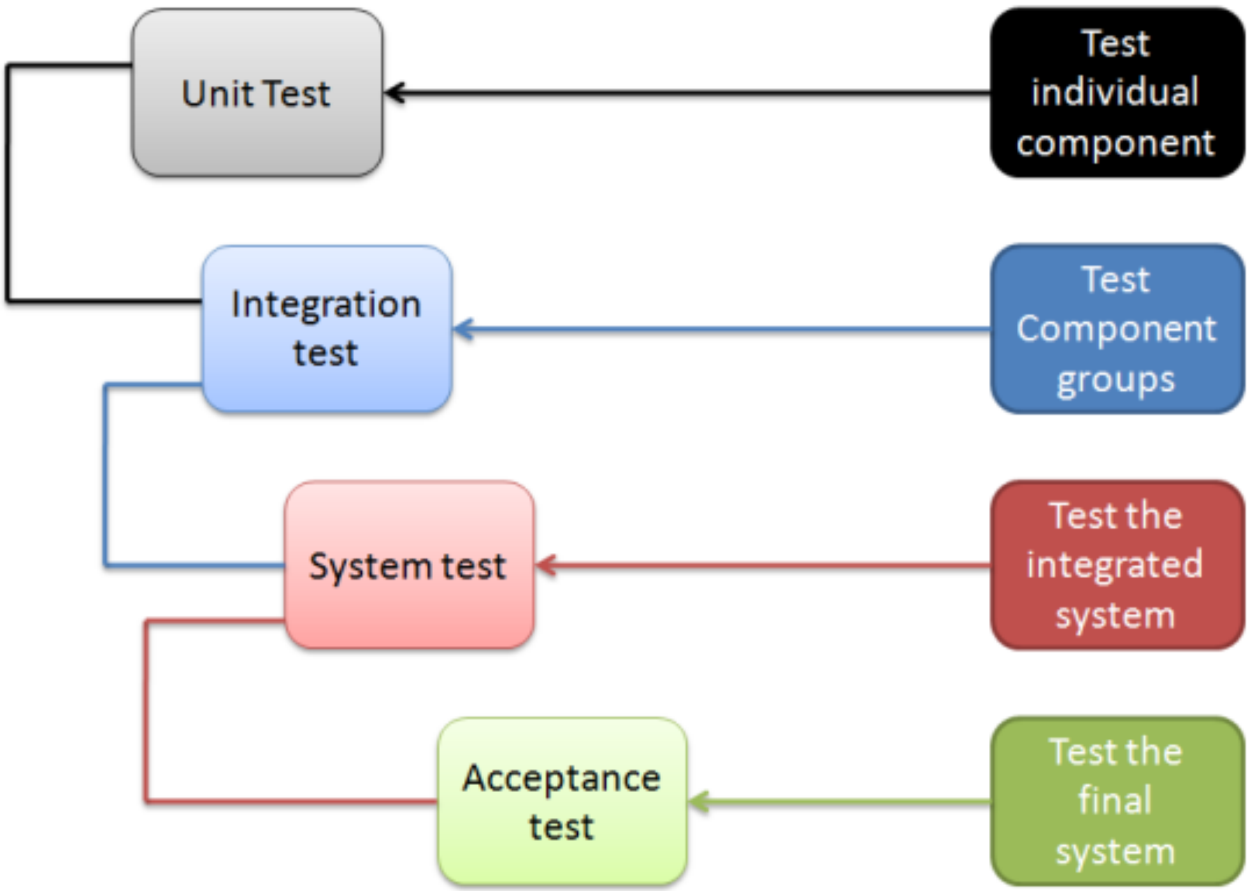
Definitions

- ***Software Testing*** is a systematic attempt to reveal faults in software by running test programs or scripts (interactively or automated).
- Test case is a test input along with its expected output
  - FAILING TEST: a fault was demonstrated in the software under test.
  - PASSING TEST: no fault was found (even if it existed).
- Dijkstra said: “Program testing can be used to show the presence of bugs, but never to show their absence!”

Software Testing

- Types
  - **Functional**, Usability, Performance, ...
- Levels
  - **Unit** (Method/Class), Integration, System, Acceptance
- Test case creation methods
  - **Black-box, white-box**
- Processes
  - **Test-Driven Development**, **Coverage Testing**, Regression Testing, …

Functional Testing



Exhaustive Testing?

- We consider a program to be *correct* if it produces the expected output **for all inputs**.
- Domain of input values can be very large, e.g. 2^{32} values for an integer or float:

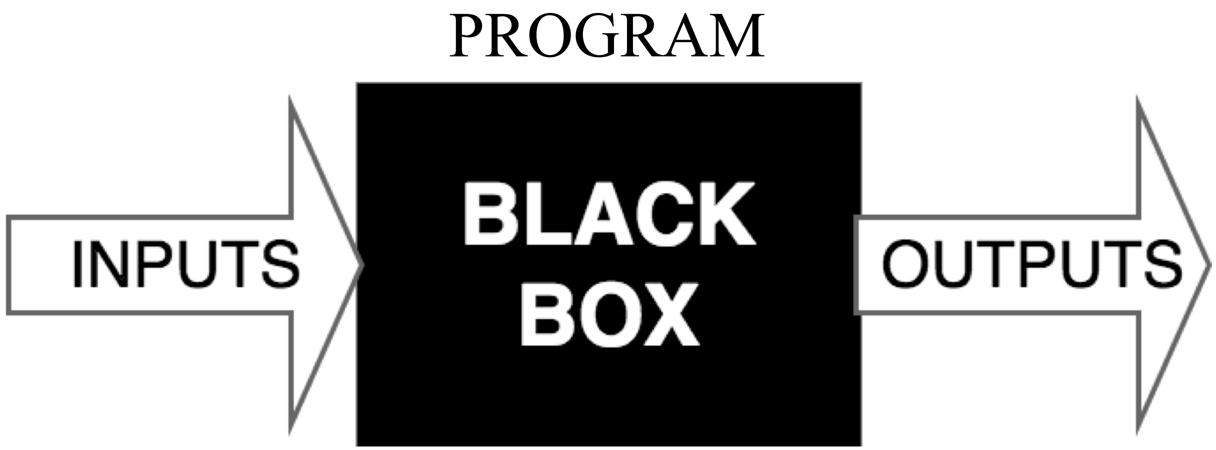
```
int divide (int operand1, int operand2);
```

- $2^{32} * 2^{32} = 2^{64}$, a large number, so we clearly cannot test exhaustively!
- And that is just for one method, in one class, in one package, and relatively simple.
- Thus, exhaustive testing isn't feasible. Need smart ways to select test inputs!

Test case creation methods

- Black-box testing
  - Code, design or internal documents unavailable
  - Test inputs obtained from specifications
  - Expected outputs also obtained from specifications
- White-box testing
  - Code, design, and internal documents available
  - Test inputs obtained from code structure
  - Expected outputs obtained from specifications

Black-box Testing



- Divide large input domain into a small number of equivalence classes
- Also consider boundaries of equivalence classes

Equivalence classes

- Groups or partitions of inputs to be treated similarly
- Must be complete and disjoint
- Strategy selected is based on the problem to be solved
- Partitioning integers based on
  - Sign:
    - Classes are {positive ints}, {negative int}, {0}
    - Choose 4, -6, and 0 as inputs
  - Even or odd
    - Classes are {even ints}, {odd ints}
    - Choose 6 and 3 as inputs

Examples of equivalence classes

- Months represented as ints: (Red is invalid input)
  - Partitions: [-∞..0], [1..12], [13..∞]
  - Representative values: -4, 5, 15
- Months represented as strings:
  - Each partition is a single value: “Jan”, “Feb”, “Mar”, “Apr”, “May”, “Jun”, “Jul”, “Aug”, “Sep”, “Oct”, “Nov”, “Dec”, any other 3 character string.
- Month numbers grouped by number of days:
  - Partitions {1,3,5,7,8,10,12}, {4,6,9,11}, {2}

Equivalence partition testing

- Test at least one value of every equivalence class for each individual input.
- Test all combinations where one input is likely to affect the interpretation of another input.
- Test random combinations of equivalence classes.

Boundary value testing

- Expand equivalence classes to test values at extremes of each equivalence class.
- Number ranges:
  - minimum, slightly above minimum, nominal or median value, slightly below maximum, and maximum values
  - values slightly and significantly outside the range
- Testing array of length 10:
  - Using partitions {0}, {positive}, select indices 0, 4
  - Using boundary values, select indices -1, 9, 10

Boundary value testing example

Test boundaries of the parameter value domain:

```
// Boundary testing of Math.floor
System.out.println(Math.floor(Double.MIN_VALUE));
System.out.println(Math.floor(Double.MAX_VALUE));
System.out.println(Math.floor(-987654321.123456789));
System.out.println(Math.floor(-1.999999));
System.out.println(Math.floor(-1.000001));
System.out.println(Math.floor(-1.0));
System.out.println(Math.floor(-0.0));
System.out.println(Math.floor(+0.0));
System.out.println(Math.floor(+1.0));
System.out.println(Math.floor(1.000001));
System.out.println(Math.floor(1.999999));
System.out.println(Math.floor(987654321.123456789));
```

How to specify expected outputs?

- Find the exact expected answer by using the specification (e.g., gcd(4,6) = 2)
  - gcd(p,0) (p!=0) = Math.abs(p)
  - gcd(0,q) (q!=0) = Math.abs(q)
  - gcd(0,0) = 0
  - gcd(p,q) (p!=0 and q!=0) = d (d>0 and d largest int such that d divides p and d divides q)
- Find a suitable condition involving the variables (e.g., gcd(p, q) >= 0)
- Use stronger checks as much as possible to write more powerful test cases

JUnit

- Simple, open source framework to write and run repeatable tests.
- Commonly used in industry for unit testing.
- Typical workflow inside a test case (or test method):
  - Set up the objects involved in the test with appropriate values
  - Call the method under test with appropriate parameters
  - Capture the method return value and/or state information on the object of interest
  - Write assertions about the return value and/or the state information

Citation: JUnit testing framework (http://www.junit.org/)

Starting to use JUnit

- Eclipse project contains a file called GCD.java in package junitintro
- Click on File → New → JUnit Test Case to create a file called GCDTest that tests GCD
- Remember to include the JUnit 5 library
- A JUnit test class is created with the following declarations:

```
import static org.junit.jupiter.api.Assertions.*;
import org.junit.jupiter.api.Test;
class GCDTest {
    @Test
    void test() {
        fail("Not yet implemented");
    }
}
```

This test will fail because nothing is implemented yet

Selecting inputs for greatest common divisor (gcd)

- gcd takes two ints
- What is a good partitioning strategy?
  - positive/negative useful
  - even/odd NOT useful
- Use domain knowledge: presence or absence of common factors in the numerator/denominator
  - No common factor: 11, 13. Expected result 1
  - Some common factor: 16, 20. Expected result 4

Writing JUnit methods

```
public class GCD {
  public int gcd (int p, int q) {
    int a = Math.abs(p), b = Math.abs(q);
    if(b==0)  return a;
    else if (a==0) return b;

    int rem=1, result=1;
    while(rem!=0) {
        rem = a % b;
        if(rem==0) result=b;
        a = b;   b = rem;
    }
    return result;
  }
}
```

```
@Test
void testNoCommonFactors() {
    GCD g = new GCD();
    int result = g.gcd(11, 13);
    assertEquals(result, 1);
}

@Test
void testSomeCommonFactors() {
    GCD g = new GCD();
    int result = g.gcd(16, 20);
    assertTrue(result==4);
}

@Test
void
testNegativeNegativeNoCommonFactor() {
    GCD g = new GCD();
    int result = g.gcd(-13, -20);
    assertEquals(result,1,
                      "Expected 1");
}
```

More JUnit value assertions

```
assertTrue( 'a' < 'b' , "message");
assertFalse( 'b' < 'a' );

assertEquals( 1+1, 2 );

assertEquals( 22.0d/ 7.0d, 3.14159, 0.001 );

assertEquals( "cs165" , "cs165" );
```

Citation: JUnit testing framework (http://www.junit.org/)

JUnit array assertions

```
int[] array1 = { 1, 2, 3 };
int[] array2 = { 1, 2, 3 };

assertNull( null );
assertNotNull( array1 );

assertNotSame( array1, array2 );

assertArrayEquals( array1, array2 );
```

Citation: JUnit testing framework (http://www.junit.org/)

Two Kinds of Tests

- Tests that find defects after they occur
  - Often written by other developers/testers
  - Or as an afterthought
- Tests that prevent defects
  - Help you think about coding specific types of cases/conditions while you are coding
  - Often used in modern software development

Test Driven Development

- Goal: Clean code that works!
- Drive development with automated tests
  - Write new code only if tests fail
  - Eliminate duplication
- Implies a different order of tasks
  1. Write a test that fails first
  2. Make the test work in the code

Citation: Test Driven Development, Kent Beck

Using TDD: Creating a simple constructor

```
public class Rational {
      private int numerator, denominator;
}
```

- Develop the constructor and toString code
  - Let the constructor handle integers of the form p/q where p and q are positive and have no common factors
  - toString returns a string in the form of p/q

First step: Simple constructor

```java
public class RationalTest {

@Test
void testNoCommonFactor() {
    Rational r = new Rational(3, 5);
    String result = r.toString();
    assertEquals(result, "3/5");
}

}
```

```java
public class Rational {
private int numerator, denominator;

public Rational(int n, int d) {
    numerator = n;
    denominator = d;
}

public String toString() {
    return new String(numerator +
                      "/" + denominator);
}

}
```

Using TDD: Handle zero denominator

- Let the constructor also handle integers of the form p/q where p>0 and q==0
- This needs to throw an exception because the number is not valid
- Since such a number can't be created, toString doesn't need to handle this case

Second step: Handle zero denominator

```java
public class RationalTest {

@Test
void testNoCommonFactor() {
    Rational r = new Rational(3, 5);
    String result = r.toString();
    assertEquals(result, "3/5");
}

@Test
void testZeroDenominator() {
    try {
    Rational r = new Rational(3, 0);
    fail("Did not throw an
          arithmetic exception");
    } catch (ArithmeticException e) {
    }
}
}
```

```java
public class Rational {

private int numerator, denominator;

public Rational(int n, int d) {
    if (d==0)
    throw new ArithmeticException();

    numerator = n;
    denominator = d;
}

public String toString() {
    return new String(numerator +
                  "/" + denominator);
}

}
```

Using TDD: Handle special cases

- Let the constructor handle integers of the form p/q where p and q are any integers but have no common factors
  - If numerator is 0, then the denominator is stored as 1
  - The sign is stored in the numerator.
  - The denominator is always positive.
- toString doesn't need to handle this case any differently because the constructor takes care of the representation

Third step: Handle special cases

```
@Test
void testPositiveNegative() {
    Rational r = new Rational(3, -5);
    String result = r.toString();
    assertEquals(result, "-3/5");
}
@Test
void testNegativePositive() {
    Rational r = new Rational(-3, 5);
    String result = r.toString();
    assertEquals(result, "-3/5");
}
@Test
void testNegativeNegative() {
    Rational r = new Rational(-3, -5);
    String result = r.toString();
    assertEquals(result, "3/5");
}
@Test
void testZeroNumerator() {
    Rational r = new Rational(0, -5);
    String result = r.toString();
    assertEquals(result, "0/1");
}
```

```
public class Rational {
private int numerator, denominator;

public Rational(int n, int d) {
   if (d==0) throw new
                 ArithmeticException();
   if (n==0) {
      numerator = 0;
      denominator = 1;
   } else {
      denominator = Math.abs(d);
      numerator = (d > 0)? n: -n;
   }
}
public String toString() {
    return new String(numerator +
                  "/" + denominator);
}
}
```

Using TDD: Handle common factors

- Let the constructor handle integers of the form p/q where p and q are positive but have common factors
- We need to normalize (i.e., reduce p and q to the lowest common denominator)
- toString doesn't need to handle this case any differently because the constructor takes care of the reduction

Fourth step: Handle common factors

```
@Test
void testCommonFactorPositivePositive() {
    Rational r = new Rational(16, 20);
    String result = r.toString();
    assertEquals(result, "4/5");
}
@Test
void testCommonFactorPositiveNegative() {
    Rational r = new Rational(16, -20);
    String result = r.toString();
    assertEquals(result, "-4/5");
}
@Test
void testCommonFactorNegativePositive() {
    Rational r = new Rational(-16, 20);
    String result = r.toString();
    assertEquals(result, "-4/5");
}
@Test
void testCommonFactorNegativeNegative() {
    Rational r = new Rational(-16, -20);
    String result = r.toString();
    assertEquals(result, "4/5");
}
```

```
public class Rational {
private int numerator, denominator;

public Rational(int n, int d) {
    if (d==0) throw new ArithmeticException();
    if (n==0) {
        numerator = 0;  denominator = 1;
    } else {
        denominator = Math.abs(d);
        numerator = (d > 0)? n: -n;
        reduce();
    }
}
private void reduce () {
    int common = gcd(numerator, denominator);
    numerator = numerator / common;
    denominator = denominator / common;
}

// code for toString not shown…
}
```

Using TDD: String representation for special cases

- Modify toString to print special cases
  - When the numerator is 0, print 0
  - When the denominator is 1 in the reduced form, just print the numerator.

Fifth step: String representation for special cases

```
public class RationalTest {

// include all the previous tests
// May need to adapt prior tests
// that has zero numerator

@Test
void testNumeratorZero() {
    Rational r = new Rational(0, 20);
    String result = r.toString();
    assertEquals(result, "0");
}
@Test
void testDenominatorOne() {
    Rational r = new Rational(-16, 1);
    String result = r.toString();
    assertEquals(result, "-16");
}
```

```
public class Rational {
private int numerator, denominator;

// include other methods

public String toString() {
    if (numerator==0 || denominator==1)
        return new
           Integer(numerator).toString();
    else
        return new String(numerator + "/"
                                 + denominator);
}


}
```

Using TDD: Ability to check equality of numbers

- Add an equals method
- Needed if you further implement add, subtract, multiple, and divide operations and must check their results
- Since the constructor takes care of normalizing, we can just compare the numerators and denominators.
- Several test cases:
  - Two numbers with the same numerator and denominator
  - Two numbers with different numerator and denominators
  - With and w/o gcd > 1

Sixth step: Adding the equals method

```
@Test void testTwoEqualRationalNumbers() {
  Rational r1 = new Rational (16, 20);
  Rational r2 = new Rational (20, 25);
  assertEquals(r1, r2);
}
@Test void
testTwoEqualRationalNumbersDifferentSigns() {
  Rational r1 = new Rational (-16, 20);
  Rational r2 = new Rational (20, -25);
  assertEquals(r1, r2);
}
@Test void testTwoIdenticalRationalNumbers()
{
  Rational r1 = new Rational (16, 20);
  Rational r2 = new Rational (16, 20);
  assertEquals(r1, r2);
}
@Test void testTwoUnequalRationalNumbers() {
  Rational r1 = new Rational (16, 20);
  Rational r2 = new Rational (6, 10);
  assertNotEquals(r1, r2);
}
```

```
public class Rational {
private int numerator, denominator;

// include other methods

public boolean equals (Object other) {
    if(other instanceof Rational) {
       return (
    numerator ==
    ((Rational)other).getNumerator()
    &&
    denominator ==
    ((Rational)other).getDenominator());
    } else {
        return false;
}

}
```

White Box Testing

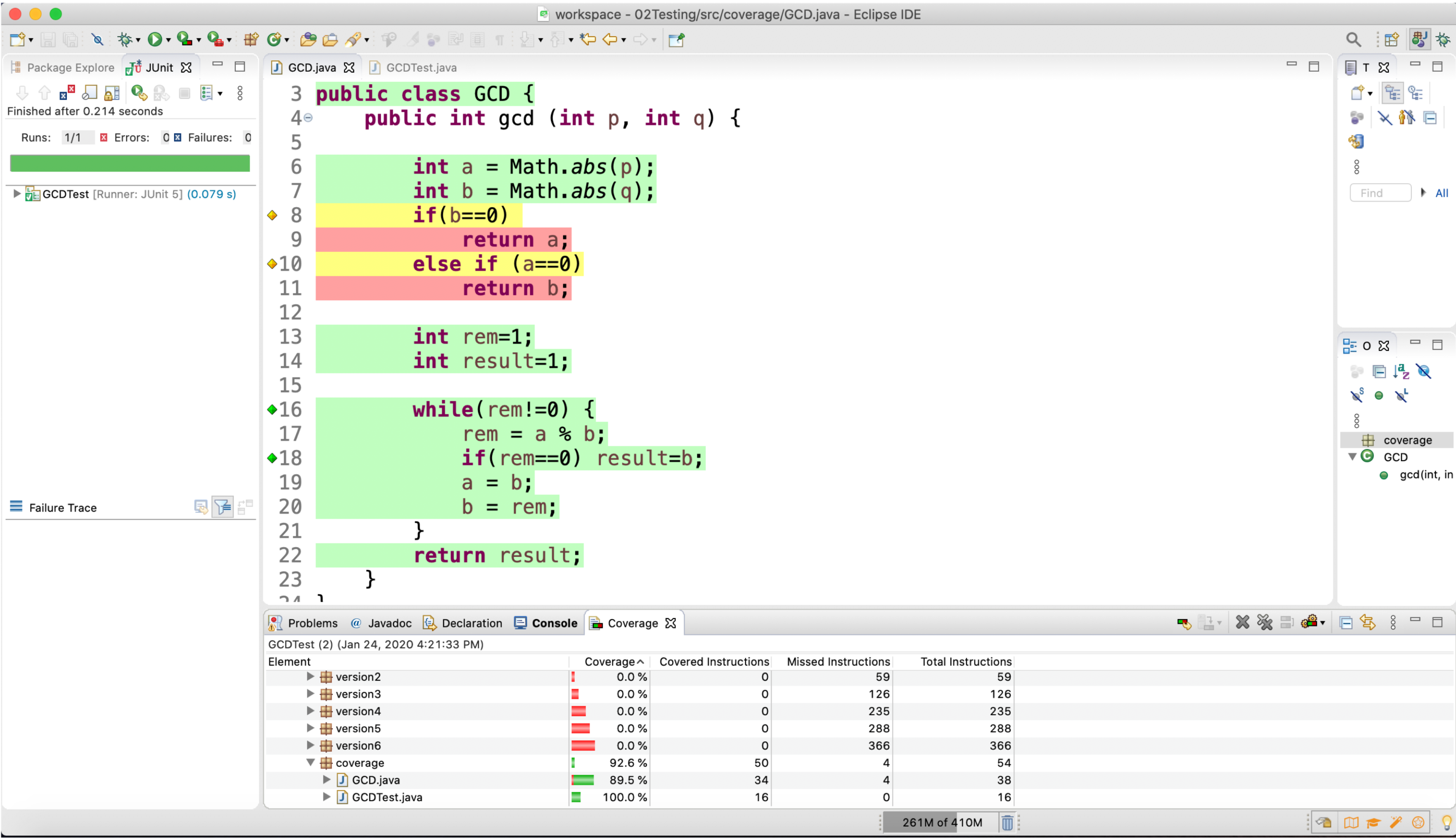
- Goal is to "cover" the code to gain confidence and detect defects.
- Statement Coverage (most common)
  - Requires all statements to be executed
- Branch Coverage
  - Require decisions evaluate to true and false at least once
  - Implies statement coverage

Doing white box testing on gcd

- Often parts of the implementation are not executed by the test cases you have written using blackbox strategies
- Run Eclipse coverage tool (EclEmma) using the same JUnit test cases as before
- What is not covered? Suggest test inputs to cover those statements and branches

Code Coverage

Green = executed, Yellow = partial branch, Red = not executed



Software Debugging

- Possible methods for debugging:
  - Examine code by hand
  - Look at stack trace if program crashed with an exception to find out where the last method call happened.
  - Use *Print* statements to show intermediate values
  - Use built-in debugger in eclipse

Print Debugging

```
public static void readFile (String filename) {

    try {
        Scanner reader = new Scanner(new File(filename));
        while (reader.hasNextLine()) {
            String line = reader.nextLine();
            System.out.println(line); // debug print
            contents.add(line);
            reader.close(); // code defect
        }
    } catch (IOException e) {
        System.out.println(e.getMessage());
    }
}
```

Debugging a faulty program

- Use the Data.java file in the debugging package.
- The bubblesort method in the Data.java file has a fault but the programmer doesn't know that.
- Some tests pass but others fail.
- Let's debug the failing tests.
- Set a debug configuration in eclipse.
- Put a breakpoint at the bubblesort declaration.

Debugging in Eclipse

Breakpoint