Introduction to Software Engineering (ISAD1000)

Lecture 8: White-Box Testing & Test Fixtures

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Discipline of Computing
School of Electrical Engineering, Computing and Mathematical Sciences (EECMS)

Outline

Inputs and Outputs

Files

Exceptions

Test Fixtures

White Box Testing

Testing So Far

- So far, our discussion of testing has focused on parameters and return values.
- We see the range of possible parameter values, and divide (partition) them into categories.
  - Equivalence partitioning and boundary value analysis.
  - But we *haven't* looked *inside* the method/function. We've treated it as a black box.
- For the return values, we obtain them the actual value, and compare to what we expected.
  - We've *assumed* that methods/functions are like mathematical functions: transforming one or more parameters into a single return value.

Generalising

- Unit testing can get more complicated.
- We *do still* have the following basic ingredients:
  - Test cases;
  - For each test case: test data, production code call, expected results, and actual results.
- But:
  - We can also do "white-box" testing, where we find test cases based on the code.
  - In either white- or black-box testing, we sometimes need additional "setting up" for each test case.
  - Some test data are *not* provided via parameters.
  - Some test results are *not* obtained via return values.
  - There can be multiple results per test case, and hence multiple assertions.

Input (Sources of Data)

- Methods/functions can get data from various sources:
  - Parameter values;
  - User input;
  - Fields (variables outside the method/function);
  - Files on disk;
  - Databases;
  - The operating system;
  - Other running programs on the same computer;
  - Online services.
- Testing must account for *all* the data a method/function uses.
- Test code must control and mimick these sources of data.
  - e.g. We need to fool the production code into accepting fake "user input" that really comes from the test code.

Output (Actions)

- Methods/functions can also send data to many different places:
  - Return value;
  - Exceptions;
  - The screen/console;
  - Fields;
  - Files;
  - Databases;
  - Other running programs;
  - Online services.

Called *"side effects"*, though they're often the main purpose of a method/function.

- Testing must check that all of these are as expected.
  - e.g., if you're writing a file, your test code must ensure that actually happens properly.
- We need to capture these outputs and run them all through assertion statements.

Input/Output is String-Based

- We'll consider how to test methods/functions that:
  - Take user input (console input);
  - Display output (console output);
  - Read text files (file input);
  - Write text files (file output);
  - Generate exceptions.
- The first four of these have something in common:
- Everything is a string!
  - Reading console input? The user enters *a string*.
    - If you ask for an integer, the user enters a string containing digit characters. Then you calculate what integer they form.
  - Writing real numbers to a file? You're writing a string.
    - You take each number, and generate a string that contains various digit characters and a ".".

New Lines (“\n”) in Input/Output

- The string-iness of input/output goes a bit further.
- You can think of *all* console input as just *one big string* put together.
  - And, similarly, all console output is another big string.
  - And an entire text file is really just a single string.
- To make sense of this, you need to understand the “newline” character “\n”.
  - It’s written backslash-n, though it doesn’t really *look* like anything.
  - But it can be part of any string, just like a letter or digit.
  - It represents a line break; a point at which one line of text ends and another begins.
  - It’s the ENTER key, when pressed by the user.

New Lines ("\n") in Input/Output

- The newline character "\n" lets us think of multiple inputs or outputs as all being one string.
- Say you write a program that asks the user some questions, and they answer like this:

```
Enter an integer: 50
Enter another integer: -71
Enter a word: calculator
```

- You can represent the input as the string `"50\n-71\ncalculator\n"`.
  - That's the string the user has actually typed in.
- An aside: to represent an actual backslash, you must write "\\". (For two backslashes, write "\\\\", etc.)

GUIs

- Another aside...
- For programs that display *windows*, *buttons*, *scroll-bars*, etc., and respond to mouse clicks or touch-based input, these things are *not* strings.
- Testing this is outside the scope of this unit.
- It can be quite tricky:
  - How many different ways are there to move the mouse?
  - How many different positions on the screen can windows and buttons occupy?
  - Nonetheless, there are mechanisms to automate GUI input; e.g. `java.awt.Robot`.

Simulating User Input

- To test a method/function that takes console input:
  - Our test data will be a string representing that input.
  - We have to set things up so that the production code *thinks* this string is actual input.
- And remember: the production code still has to work as normal.
  - We can't change it to make this work.
  - Everything we do to test it must be in the test code.
- Fortunately, languages like Java and Python provide a couple of tricks to help. . .

Simulating Console Input

Java

```
import java.io.*;  // Test code:
...
String simInput = "abc";
System.setIn(new ByteArrayInputStream(
    simInput.getBytes()));
... // call production code
```

- We decide what the simulated input should be (e.g. “abc”)
- We create an “object” that behaves like a source of input, but actually just gives you back what you put into it.
  - Java “ByteArrayInputStream”
  - Python “io.StringIO”
- We tell the system to read from this, instead of the console.

Simulating Console Input

Python

```
import sys, io  # Test code:
...
simInput = "123"
sys.stdin = io.StringIO(simInput)
... # call production code
```

- We decide what the simulated input should be (e.g. "abc")
- We create an "object" that behaves like a source of input, but actually just gives you back what you put into it.
  - Java "ByteArrayInputStream"
  - Python "io.StringIO"
- We tell the system to read from this, instead of the console.

Using Simulated Input

- Say your test code sets up some simulated input; specifically, a value of "abc".
- Your test code then calls the production code.
- The production code tries to read some console input.

  Java: `String val = scanner.nextLine();`

  Python: `val = input()`
- The production code receives the simulated input; i.e., `val` becomes equal to "abc".
  - The production code assumes the user has entered this value.
  - It can't tell the difference between real and simulated input, which is the point.
- The test code uses this to check what happens for different kinds of input.

Using Simulated Input: Example Test Code

- Remember "max()"? Say we also have "inputMax()".
- Instead of importing two numbers, it *inputs* them.
- Here's how we might test it:

Java
```java
public static void testInputMax()
{
    System.setIn(
        new ByteArrayInputStream("10\n15".getBytes()));
    assert 15 == MyUtils.inputMax();

    System.setIn(
        new ByteArrayInputStream("10\n-10".getBytes()));
    assert 10 == MyUtils.inputMax();
    ... // One other test case
}
```

Using Simulated Input: Example Test Code

- Remember "`max()`"? Say we also have "`inputMax()`".
- Instead of importing two numbers, it *inputs* them.
- Here's how we might test it:

Python

```python
def testInputMax():
    sys.stdin = io.StringIO("10\n15")
    assert 15 == MyUtils.inputMax()

    sys.stdin = io.StringIO("10\n-10")
    assert 10 == MyUtils.inputMax()
    ... # One other test case
```

Capturing Output

- A "mirror image" of the problem of simulating input.
- If production code *displays* something, test code must be able to check it.
    - But, *normally*, your code cannot see its own output. Only the user can.
    - We must do something to *capture* it, before it is actually displayed.

Capturing Console Output

Java

```java
import java.io.*;
...
ByteArrayOutputStream capOut = new ByteArrayOutputStream();
System.setOut(new PrintStream(capOut));
... // call production code
String actualOutput = capOut.toString();
```

- Create an "object" that can receive output, but *stores* it instead of displaying it.
  - Java "`ByteArrayOutputStream`"
  - Python "`io.StringIO`" (same as for input)
- Tell the system to use this, instead of the console.
- Afterwards, retrieve the text that was "displayed".

Capturing Console Output

Python

```
import sys, io
...
capOut = io.StringIO()
sys.stdout = capOut
... // call production code
actualOutput = capOut.getvalue()
```

- Create an "object" that can receive output, but *stores* it instead of displaying it.
  - Java "ByteArrayOutputStream"
  - Python "io.StringIO" (same as for input)
- Tell the system to use this, instead of the console.
- Afterwards, retrieve the text that was "displayed".

Capturing Output: Example Test Code

- Say we have another variation of `max()` called `outputMax()`.
- Instead of returning the result, it *outputs* it.
- Here's how we might test it:

Java
```
public static void testOutputMax()
{
    ByteArrayOutputStream capOut =
        new ByteArrayOutputStream();
    System.setOut(new PrintStream(capOut));
    MyUtils.outputMax(10, 15); // Production code call
    assert "15".equals(capOut.toString());

    ... // Other test cases
}
```

Capturing Output: Example Test Code

- Say we have another variation of `max()` called `outputMax()`.
- Instead of returning the result, it *outputs* it.
- Here's how we might test it:

Python

```
def testOutputMax():
    capOut = io.StringIO()
    sys.stdout = capOut
    MyUtils.outputMax(10, 15) # Production code call
    assert "15" == capOut.getvalue()

    ... # Other test cases
```

Simulating Input *and* Capturing Output

- What about inputOutputMax()?
- We can simulate input and capture output at the same time:

```java
public static void testInputOutputMax()
{
    ByteArrayOutputStream capOut =
        new ByteArrayOutputStream();
    System.setOut(new PrintStream(capOut));
    System.setIn(
        new ByteArrayInputStream("10\n15".getBytes()));

    MyUtils.inputOutputMax(); // Production code call
    assert "15".equals(capOut.toString());
    ... // Other test cases
}
```

Java

Simulating Input *and* Capturing Output

- What about `inputOutputMax()`?
- We can simulate input and capture output at the same time:

Python

```python
def testInputOutputMax():
    capOut = io.StringIO()
    sys.stdout = capOut
    sys.stdin = io.StringIO("10\n15")

    MyUtils.inputOutputMax() # Production code call
    assert "15" == capOut.getvalue()
    ... # Other test cases
```

Testing with Files

- If the production code deals reads/writes data files, the test code must also deal with them.
- *Conceptually* this is quite similar to console IO, but the fine details a bit different.
- To test a method/function that reads an input file:
  - The test code must setup (i.e. write) the input file beforehand.
- To test a method/function that writes an output file:
  - The test code must verify (i.e. read) the output file afterwards.

File Reading and Writing Syntax

- The following slides show code for reading/writing files.
  - In Java, we'll use `PrintWriter` and `Scanner`.
  - In Python, we'll use the "`with`" statement, and `open()`, `write()` and `read()`.
- There are other valid ways to do this.
- There's nothing particularly special about these particular reading/writing approaches.
  - Except that they're reasonably short and easy to put into slide form.
- The most important thing is that you understand the *concept* of what is happening.

Testing with Input Files

```java
public static void testInputFileMax()
{
    PrintWriter inputFile = new PrintWriter("inputfile.txt");
    inputFile.println("10\n15"); // <-- The test data
    inputFile.close();

    assert 15 == MyUtils.inputFileMax("inputfile.txt");
    ... // Other test cases
}
```

- First, we create a file containing test data.
- Then, we call the production code, which (in theory) reads that file and thus gets the test data.
- Let's assume the production code takes a filename parameter.
  - If so, this must be the same as the file we created.

Testing with Input Files

Python

```
def testInputFileMax():
    with open("inputfile.txt", mode = "w") as inputFile:
        inputFile.write("10\n15") # <-- The test data

    assert 15 == MyUtils.inputFileMax("inputfile.txt")
    ... # Other test cases
```

- First, we create a file containing test data.
- Then, we call the production code, which (in theory) reads that file and thus gets the test data.
- Let's assume the production code takes a filename parameter.
  - If so, this must be the same as the file we created.

Testing with Output Files

Java

```java
public static void testOutputFileMax()
{
    MyUtils.outputFileMax(10, 15, "outputfile.txt");

    Scanner outputFile = new Scanner("outputfile.txt");
    String actual = outputFile.nextLine(); // <-- Actual
    assert "15".equals(actual);            //     result

    ... // Other test cases
}
```

- First, we call the production code, which (in theory) creates a file and writes a result to it.
- Then, the test code reads that file, gets the result, and runs it through an assertion.

Testing with Output Files

```python
def testOutputFileMax():
    MyUtils.outputFileMax(10, 15, "outputfile.txt")

    with open("outputfile.txt") as outputFile:
        actual = outputFile.read().strip() # <-- Actual
        assert "15" == actual              #     result

    ... # Other test cases
```

- First, we call the production code, which (in theory) creates a file and writes a result to it.
- Then, the test code reads that file, gets the result, and runs it through an assertion.

Exceptions During Testing

Exceptions during testing occur because:

- The production code gave the wrong result.
- The production code unexpectedly threw an exception.
  - The test fails, but before we even get to the `assert` statement.
- The test code itself is broken.
  - Maybe the "expected result" is incorrect.
  - Maybe you didn't set up a test input file properly.
- **The production code *expectedly* threw an exception.**
  - Often the production code *must* throw an exception, under certain circumstances.
  - So, the test code must check that it does.
  - Such a test should fail in the *absence* of an exception.

Handling Unexpected Exceptions

- You could use a `try-catch`/`except` statement.
- But *in test code*, it's simpler to just pass-on the exception.
- This will be interpreted as a test failure, as it should be.
- Python: nothing additional needs to be done!
- Java: add a `throws` clause:

```
public static void testThing() throws ExceptionType
{
    ...
}
```

ExceptionType is the particular kind of exception that the production code might generate.

Handling *Expected* Exceptions

- Remember `formatTime()`?
- It returned `"error"` when passed invalid hours/minutes.
  - i.e., if we write "`actual = MyUtils.formatTime(12, -10)`", we should expect `actual` to be `"error"`.
- But, in the real world, it's more likely to be designed to throw an exception.
  - In this case, there is no string value at all, and by default the exception means a test failure.
  - But *this* exception means the code actually works!
    - i.e. it successfully identifies invalid values, and takes appropriate action.
  - The test should only fail if there *isn't* an exception.
  - How do we test for this?

Handling Expected Exceptions

- We need to use a try statement to sort this out.
- The test passes only if an exception makes the code jump to the catch/except block.

Java

```java
public static void testFormatTime()
{
    try
    {
        String actual = MyUtils.formatTime(12, -10);
        assert false; // Test fails if it reaches this point
    }
    catch(IllegalArgumentException e) {} // Do nothing.

    ... // Other test cases
}
```

Handling Expected Exceptions

- We need to use a try statement to sort this out.
- The test passes only if an exception makes the code jump to the catch/except block.

```python
def testFormatTime():
    try:
        actual = MyUtils.formatTime(12, -10)
        assert False # Test fails if it reaches this point

    except ValueError:
        pass # Do nothing.

    ... # Other test cases
```

Test Fixtures

- We're now seen various situations where test cases are written like this:
  1. Perform setting up.
  2. Call production code.
  3. Compare results.
- And there's one more step we sometimes have:
  4. Tear down: restore everything to its original state.

  For instance:
  - If the test code (or production code) created a file, we should delete it afterwards.
  - If the test code redirected console input or output, it should set it back afterwards.
- The "setting up" and "tearing down" defines a *test fixture*:
  - A set of things in-place to make the test case work, and to isolate the test case from external factors.

Common Setting-Up and Tearing-Down

- Multiple test cases often require at least some of the same setting-up and tearing-down.
  - Some of the setting-up may be separate from providing the test data.
  - Perhaps *all* test cases require the same console input, just to make the production code work.
  - Or perhaps they all require the same file to exist.
- Reuse applies to test code too! We don't want to repeat ourselves.
- So, the convention is to have `setUp()` and `tearDown()` helper method/functions.
  - These do all the *common* work to establish a test fixture.
  - `setUp()` will be called immediately before *every* test method/function.
  - `tearDown()` will be called immediately after.

Text Fixture Example – *Without* a Test Framework

Java

```java
public class TestSuite
{
    public static void main(String[] args)
    {
        setUp();
        testMethod1();
        tearDown();
        setUp();
        testMethod2();
        tearDown();
    }

    public static void setUp() { ... }
    public static void testMethod1() { ... }
    public static void testMethod2() { ... }
    public static void tearDown() { ... }
}
```

Text Fixture Example – *Without* a Test Framework

Python

```python
def setUp(): ...
def testFunction1(): ...
def testFunction2(): ...
def tearDown(): ...

if __name__ == "__main__":
    setUp()
    testMethod1()
    tearDown()
    setUp()
    testMethod2()
    tearDown()
```

Test Fixtures in JUnit/`unittest`

- JUnit understands methods that have `@Before` and `@After` annotations.
  - It doesn't actually care what the names are.
- Python's `unittest` module looks for methods specifically called `setUp()` and `tearDown()`.
- In either case, the framework will automatically:
  - Call the `@Before`/`setUp()` method before *each* test method.
  - Call the `@After`/`tearDown()` method after each test method.

Test Fixture Example – *With* a Test Framework

Java

```java
@RunWith(JUnit4.class)
public class TestSuite
{
    @Before
    public void setUp() { ... }

    @Test
    public void testMethod1() { ... }

    @Test
    public void testMethod2() { ... }

    @After
    public void tearDown() { ... }
}
```

Test Fixture Example – *With* a Test Framework

Python

```
import unittest

class TestSuite(unittest.TestCase):
    def setUp(self): ...
    def testMethod1(self): ...
    def testMethod2(self): ...
    def tearDown(self): ...
```

White-Box Testing

- Let's leave the implementation details now, and go back to *test design*.
  - i.e., how to decide which test cases we need in the first place.
- In "Black Box" testing:
  - We design test cases *without* looking at the code.
  - We just look at the parameters, return type, and documentation.
  - This is what Equivalence Partitioning and Boundary Value Analysis are doing.
- In "White Box" (or "Clear Box") testing, test cases are based on the *paths* through a method/function.

Paths

- A "path" is (roughly speaking) one possible way to "get through" a method/function, from start to end.
- There's always at least one path, but there are often more.
- Different paths are created by conditional statements, like `if`.
    - When there are multiple choices, this translates to multiple paths.
    - Multiple paths are also created by `switch`, `while`, `do-while`, `for` and `try-catch`/`except`.
        - (Not all of these exist in Python.)
- White-box testing ensures that we test each path – each possible way through the production code.
    - Each path becomes a test case!

if Statement Paths

- if statements have two paths.
- 1st path:

Java

```java
double abs(double n)
{
  if(n < 0)
  {
    n = -n;
  }
  return n;
}
```

Python

```python
def myAbs(n):
  if n < 0:
    n = -n
  return n
```

if Statement Paths

- if statements have two paths.
- 2nd path:

Java

```
double abs(double n)
{
  if(n < 0)
  {
      n = -n;
  }
  return n;
}
```

Python

```
def myAbs(n):
  if n < 0:
      n = -n
  return n
```

White Box Test Design – `if` statements

- In drawing up our test design, we work with paths instead of equivalence categories.
- We still need to pick test data and expected results:

Test design for abs:

Path	Test Data	Expected Result
1. Enter the `if`	$n = -5$	5
2. DO NOT enter the `if`	$n = 10$	10

if-else Paths

- if-else statements also have two paths.
- 1st path:

Java

```java
void printMax(int x, int y)
{
    if(x > y)
    {
        System.out.println(x);
    }
    else
    {
        System.out.println(y);
    }
    return n;
}
```

Python

```python
def printMax(x, y):
    if x > y:
        print(x)
    else:
        print(y)
```

if-else Paths

- if-else statements also have two paths.
- 2nd path:

Java

```
void printMax(int x, int y)
{
    if(x > y)
    {
        System.out.println(x);
    }
    else
    {
        System.out.println(y);
    }
    return n;
}
```

Python

```
def printMax(x, y):
    if x > y:

        print(x)

    else:

        print(y)
```

`if-else` Test Design

Path	Test Data	Expected Result
1. Enter the `if` part	$x = 10, y = 5$	output: `"10"`
2. Enter the `else` part	$x = 10, y = 20$	output: `"20"`

Loop Paths

- How does the concept of a "path" apply to loops?
  - `while`, `do-while`, `for`.
- It may seem like a loop should have *many* paths.
  - You can go around a `while` loop *any number* of times, for instance.
- In fact, loops have exactly two paths, just like `if` statements.
  1. The path that never enters the loop.
     - (Or, for Java's `do-while` loop, never repeats the loop.)
  2. A path that *does* enter the loop.
- Whether the loop repeats twice, or a million times, it's considered the same path.

while Paths

1st path:

Java

```java
int readPositive()
{
  int val = ...; // Input

  while(val <= 0) {

      System.out.println(
          "Not positive");
      val = ...; // Input
  }
  return val;
}
```

Python

```python
def readPositive():
  val = int(input())

  while val <= 0:

      print(
        "Not positive")
      val = int(input())

  return val
```

while Paths

2nd path:

Java

```java
int readPositive()
{
  int val = ...; // Input

  while(val <= 0) {

    System.out.println(
        "Not positive");
    val = ...; // Input
  }
  return val;
}
```

Python

```python
def readPositive():
    val = int(input())

    while val <= 0:

        print(
            "Not positive")
        val = int(input())

    return val
```

while Test Design

Path	Test Data	Expected Result
1. Enter loop	input: "-5\n10"	val = 10, output: "Not positive"
2. Skip loop	input: "5"	val = 5, output: ""

do-while Paths

- do-while loops don't exist in Python, so this is just FYI.
- 1st path (no iteration):

Java

```java
void userAdd() {
    int val1, val2;
    System.out.println("Enter two positive numbers");
    do {

        val1 = ...; // Input

        val2 = ...; // Input

    }
    while(val1 <= 0 || val2 <= 0);

    System.out.println(val1 + val2);
}
```

do-while Paths

- do-while loops don't exist in Python, so this is just FYI.
- 2nd path (some iteration):

Java

```java
void userAdd() {
    int val1, val2;
    System.out.println("Enter two positive numbers");
    do {

        val1 = ...; // Input

        val2 = ...; // Input

    }
    while(val1 <= 0 || val2 <= 0);

    System.out.println(val1 + val2);
}
```

try-catch/except Paths

- This construct is intended for exception handling.
  - Java has a `try-catch` statement.
  - Python has a `try-except` statement.
  - Same thing (but the names of exceptions are different).
- You'd have one path for "success", where no exception occurs.
- You'd have one additional path for each `catch`/`except` clause.
  - i.e., for each different kind of exception that you're handling.

try-catch/except Paths

1st path (success):

Java

```java
void convertF2C() {
    Scanner sc = ...;
    try {

        double f = sc.nextDouble();

        System.out.println(
            (f - 32.0) / 1.8);
    }
    catch(InputMismatchException e)
    {
        System.out.println(e);
    }

}
```

Python

```python
def convertF2C():
    try:
        f = float(input())

        print((f - 32.0)
                     / 1.8)

    except ValueError as e:

        print(e)
```

try-catch/except Paths

2nd path (invalid, non-numerical input):

Java

```
void convertF2C() {
  Scanner sc = ...;
  try {

    double f = sc.nextDouble();

    System.out.println(
        (f - 32.0) / 1.8);
  }
  catch(InputMismatchException e)
  {
    System.out.println(e);
  }

}
```

Python

```
def convertF2C():
    try:
        f = float(input())

        print((f - 32.0)
              / 1.8)

    except ValueError as e:

        print(e)
```

Other Control Statements and Combinations

- `for` loops are like specialised `while` loops.
- `if-else-if-...-else` sequences create several paths.
  - Two paths for the first `if`.
  - One additional path for each additional `else-if`/`elif`.
- `switch` statements (in Java) create several paths.
  - One for each case, plus one for the default (even if the default is not specified).
  - These do not exist in Python.
- Everything can occur in combinations.
  - Think about control constructs as *splitting* one path into two (or more).
  - A single `if` gives you two paths.
  - *Another* nested `if` will split one of paths into *two more* paths, giving you three.

Nested ifs

1st path:

Java

```java
void zeroOrLargest(int x, int y) {
    if(y > 0) {
        if(x > y) {
            System.out.println(x);
        }
        else {

            System.out.println(y);
        }
    }
    else {

        System.out.println(0);
    }

}
```

Python

```python
def zeroOrLargest(x, y):
    if y > 0:

        if x > y:

            print(x)

        else:

            print(y)

    else:

        print(0)
```

Nested ifs

2nd path:

Java

```java
void zeroOrLargest(int x, int y) {
    if(y > 0) {
        if(x > y) {
            System.out.println(x);
        }
        else {
            System.out.println(y);
        }
    }
    else {
        System.out.println(0);
    }
}
```

Python

```python
def zeroOrLargest(x, y):
    if y > 0:
        if x > y:
            print(x)
        else:
            print(y)
    else:
        print(0)
```

Nested ifs

3rd path:

Java

```java
void zeroOrLargest(int x, int y) {
    if(y > 0) {
        if(x > y) {
            System.out.println(x);
        }
        else {

            System.out.println(y);
        }
    }
    else {

    System.out.println(0);
    }

}
```

Python

```python
def zeroOrLargest(x, y):
    if y > 0:

        if x > y:

            print(x)

        else:

            print(y)

    else:

        print(0)
```

Nested `if`s Test Design

Path	Test Data	Expected Result
1. Enter both `if` parts	$y = 5, x = 10$	output: `"10"`
2. Enter inner `else` part	$y = 5, x = 2$	output: `"5"`
3. Enter outer `else` part	$y = -5$	output: `"0"`

- Notice that we've omitted x in the 3rd test case.
  - We must provide *some* x value when calling `zeroOrLargest()`, but the value is irrelevant to the test design.
- In a *black box* design, we would have *four* test cases instead:
  1. $y > 0, x > y$ (equivalent to 1 above);
  2. $y > 0, x \leq y$ (equivalent to 2 above);
  3. $y \leq 0, x > y$;
  4. $y \leq 0, x \leq y$.

Black Box or White Box?

- Why choose one over the other?
- Number of paths (in white-box testing) may differ from the number of equivalence categories (in black-box testing).
- Black Box testing:
  - Test cases can be designed *before* the production code exists.
  - You can change algorithms without changing the test code.
- White Box testing:
  - You can better understand the different behaviours that the production code should have.
    - What decisions must the production code make?
    - In black-box testing, you take an educated guess.
    - In white-box testing, you can *see* the decisions.
  - Changes to production code usually mean changes to test code.
  - However, your test code may be more up-to-date as a result.

That's all for now!