

CS1632, Lecture 9: Unit Testing, part 2

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How would you Unit Test this Method?

```
public class Example {  
    public static int doubleMe(int x) {  
        return x * 2;  
    }  
}
```

Perhaps something like this...

```
@Test
public void zeroTest() {
    assertEquals(Example.doubleMe(0), 0);
}
@Test
public void positiveTest() {
    assertEquals(Example.doubleMe(10), 20);
}
@Test
public void negativeTest() {
    assertEquals(Example.doubleMe(-4), -8);
}
```

OK, how about this?

```
public class DoALot {  
    public void quackALot(Duck duck, int num) {  
        for (int j=0; j < num; j++) {  
            duck.quack();  
        }  
    }  
}
```

1. There is no return value! What should we test then?!
 - ☛ Test the behavior: somehow test `quack()` is called `num` times
2. We are testing `Duck` class along with `DoALot` class. How do we avoid this?
 - `Duck` may not even be implemented yet
 - Even if it were, we don't want to test `Duck` code --- we want tests *localized*
 - ☛ Use a “body double” for `Duck` that fakes a real duck

Advance Unit Testing Techniques

- Removing Class Dependencies
 - Test Doubles
 - Stubs
- Behavior Verification
 - Mocks

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Test Doubles

- “Fake” objects used in place of real objects to test the target class method
 - These are objects of external classes that the target class method references (e.g. Method parameters, member variables, etc.)
- Goal: To *not execute code* in the real object as part of the test
 - Means target class can be tested without external classes having been implemented
 - Means if a defect is found, it is *localized* to within the target class
 - Means any changes in external classes will not impact the test
- Caveat: Double should *appear* like the real thing to target class
 - Even if double does not execute code in the external class
 - Double should emulate the real object in some state according to the test scenario

Test Double Examples

1. Doubled database object: for testing without a DB installation
 - Double doesn't actually connect to a database
 - Double returns pre-determined database entries for testing
2. Doubled file object: for emulating failures hard to do with a real file
 - Double doesn't actually read a file from the hard disk
 - Double emulates file read failures that are hard to trigger in a real hard disk
3. Doubled RandomNumberGenerator: for reproducible testing
 - Double doesn't actually generate random numbers
 - Double returns pre-determined numbers to make SW deterministic

Double External Classes (NOT the Tested Class)

- Double objects of external classes that the tested class depends on
- Don't double the tested class!
 - If you double it, you would be testing the faked object and not the real one
 - Defeats the entire purpose of doing the test

JUnit Example without Test Double

```
public class LinkedListUnitTest {  
    @Test  
    public void testDeleteFrontOneItem() {  
        LinkedList<Integer> ll = new LinkedList<Integer>();  
        ll.addToFront(new Node<Integer>());  
        ll.deleteFront();  
        assertEquals(ll.getFront(), null);  
    }  
}
```

- We want to test `LinkedList`; we don't want to test `Node`
- But a defect in `Node` may cause test to fail → not a true unit test!

JUnit Example with Test Double

```
public class LinkedListUnitTest {  
    @Test  
    public void testDeleteFrontOneItem() {  
        LinkedList<Integer> ll = new LinkedList<Integer>();  
        ll.addToFront(Mockito.mock(Node.class));  
        ll.deleteFront();  
        assertEquals(ll.getFront(), null);  
    }  
}
```

- Test double Node with Mockito.mock API
- Do not double LinkedList because that is the target class for testing

What does Mockito.mock(Node.class) create?

new Node

```
// Member variables
Node nextNode;
int data;

// Member methods
void setData(int d) {
    data = d;
}
int getData() {
    return data;
}
...
```

Mockito.mock(Node.class)

```
// Member variables
// NONE!

// Empty methods (stubs)
void setData(int d) {

}
int getData() {
    return 0;
}
...
```

Advance Unit Testing Techniques

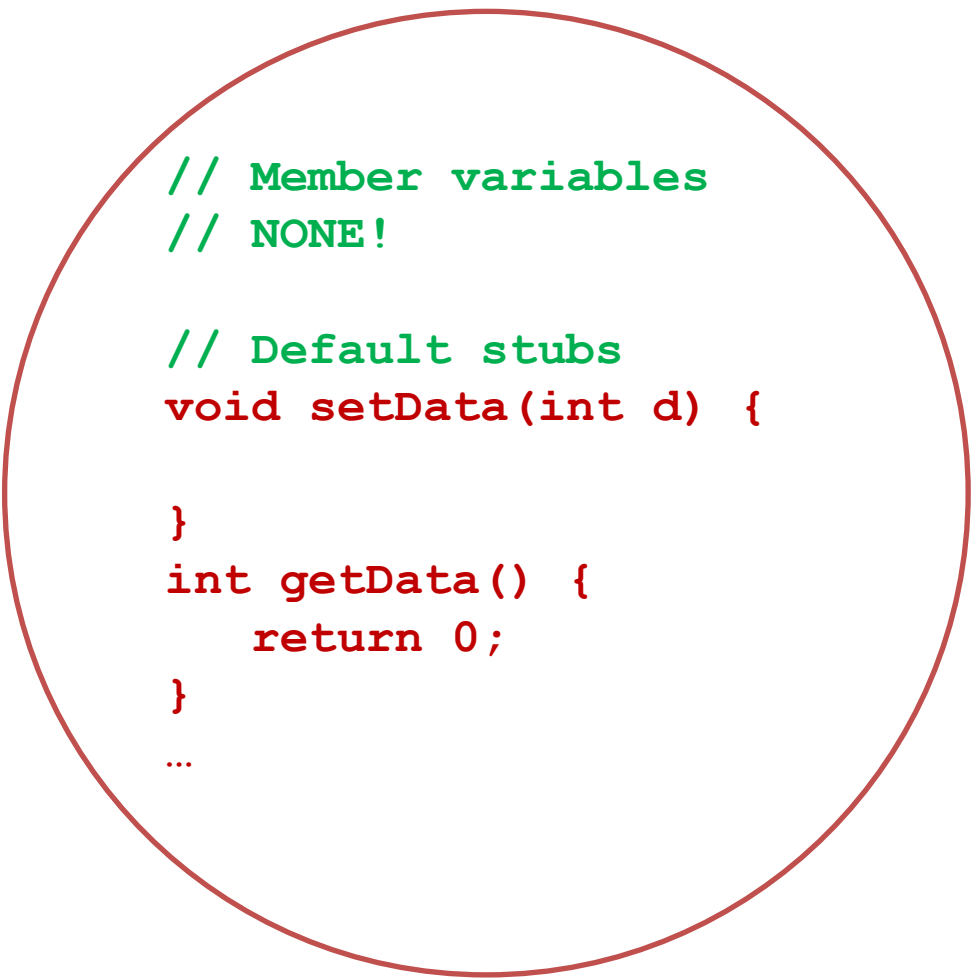
- Removing Class Dependencies
 - Test Doubles
 - Stubs
- Behavior Verification
 - Mocks

Stubs

- Test doubles are “fake objects”
- Stubs are “fake methods” for the “fake objects”

Test Doubles are Born with Default Stubs

`Mockito.mock(Node.class)`



```
// Member variables
// NONE!

// Default stubs
void setData(int d) {

}
int getData() {
    return 0;
}
...
```

- Default stubs are empty methods
 - Return type `void`: Does nothing
 - Return type `int`: returns 0
 - Return type `boolean`: returns `false`
 - Return type `Object`: returns `null`
 - Code of original class is never executed
- You can modify these default stubs
 - Modified stubs will still be empty
 - But can have it return a different value (E.g. have it return 1 instead of 0)
 - Make double behave the way you want it

Stub Example

```
public class DoALot {  
    public int quackALot(Duck duck, int num) {  
        int numQuacks = 0;  
        for (int j=0; j < num; j++) {  
            numQuacks += duck.quack();  
        }  
        return numQuacks;  
    }  
}
```

- First, mock Duck to localize test to DoALot
- Then, stub duck.quack() to make it return the desired value

Stubbing quack () to Return 1

```
public class TestDoALot {  
    @Test  
    public void testQuackALot100() {  
        DoALot doALot = new DoALot();  
        Duck mockDuck = mock(Duck.class);  
        when(mockDuck.quack()).thenReturn(1);  
        int val = doALot.quackALot(mockDuck, 100);  
        assertEquals(val, 100);  
    }  
}
```

- Made the mocked Duck quack once per quack () by stubbing it

Stubbing quack () to Return 2

```
public class TestDoALot {  
    @Test  
    public void testQuackALot100() {  
        DoALot doALot = new DoALot();  
        Duck mockDuck = mock(Duck.class);  
        when(mockDuck.quack()).thenReturn(2);  
        int val = doALot.quackALot(mockDuck, 100);  
        assertEquals(val, 200);  
    }  
}
```

- See if quackALot still works well when quack () returns 2

Stubs Enables Control of Mocked Objects

- Remember, mocked objects have no state; trick is to *appear* to have state

- Given the following class:

```
public class Node {  
    private int data;  
    public void setData(int d) { data = d; }  
    public int getData() { return data; }  
    public int getDouble() { return data*2; }  
}
```

- Which methods would you stub to have Node appear to have 10 as data?
- Hint: Not `setData(int d)`. Since it doesn't have return value, cannot stub!

Stub “get” Methods to Emulate Real Objects

Real Object

```
// Member variables
int data;
// Member methods
void setData(int d) {
    data = d;
}
int getData() {
    return data;
}
int getDouble() {
    return data*2;
}
```

Mocked Object (for when data == 10)

```
// Member variables
// NONE!
// Member methods
void setData(T d) {
    // Cannot stub
}
int getData() {
    return 10; // Stubbed
}
int getDouble() {
    return 20; // Stubbed
}
```

Stub “get” Methods to Emulate Real Objects

Real Object

```
// Member variables
int data;
// Member methods
void setData(int d) {
    data = d;
}
int getData() {
    return data;
}
int getDouble() {
    return data*2;
}
```

Mocked Object (for when data == 20)

```
// Member variables
// NONE!
// Member methods
void setData(T d) {
    // Cannot stub
}
int getData() {
    return 20; // Stubbed
}
int getDouble() {
    return 40; // Stubbed
}
```

Incorrect Stubbing Results in Incorrect Object

Real Object

```
// Member variables
int data;
// Member methods
void setData(int d) {
    data = d;
}
int getData() {
    return data;
}
int getDouble() {
    return data*2;
}
```

Mocked Object (stubbed incorrectly)

```
// Member variables
// NONE!
// Member methods
void setData(T d) {
    // Cannot stub
}
int getData() {
    return 2; // data==2?
}
int getDouble() {
    return 2; // data==1?
}
```

What if Behavior is Too Complex to Stub?

```
public class Duck {
    private boolean alive = true;
    public void shoot(int distance) {
        boolean hit = ...; // complex trajectory calculation
        if( hit ) alive = false;
    }
    public String toString() {
        return alive ? "alive!" : "dead!";
    }
}

public HuntingTrip {
    public String hunt(Duck duck, int distance) { // Tested method
        String ret = duck.toString(); // duck.toString() returns "alive!"
        duck.shoot(distance); // duck.alive == false in test case
        return ret + duck.toString(); // duck.toString() returns "dead!"
    }
}
```

- We want to mock duck. But impossible to stub `duck.toString()` to emulate real duck.

Attempt to Stub with “alive!” (Fail)

```
@Test
public void testShootDuck10Yards() {
    HuntingTrip trip = new HuntingTrip();
    // Create a mock Duck and stub
    Duck mockDuck = Mockito.mock(Duck.class);
    when(mockDuck.toString()).thenReturn("alive!");
    // Duck should be hit since it's only 10 yards away
    String ret = trip.hunt(mockDuck, 10);
    // Expected behavior is "alive!dead!"
    assertEquals("alive!dead!", ret);
}
```

- Fail because `ret == "alive!alive!"` at the end of execution

Attempt to Stub with “dead!” (Fail)

```
@Test
public void testShootDuck10Yards() {
    HuntingTrip trip = new HuntingTrip();
    // Create a mock Duck and stub
    Duck mockDuck = Mockito.mock(Duck.class);
    when(mockDuck.toString()).thenReturn("dead!");
    // Duck should be hit since it's only 10 yards away
    String ret = trip.hunt(mockDuck, 10);
    // Expected behavior is "alive!dead!"
    assertEquals("alive!dead!", ret);
}
```

- Fail because `ret == "dead!dead!"` at the end of execution
- Unable to stub because object state must change in the middle of the test

Create a “Fake” Instead

```
@Test
public void testShootDuck10Yards() {
    HuntingTrip trip = new HuntingTrip();
    // Create a “fake” Duck that is near us
    Duck fakeDuck = new FakeDuckNear();
    // Duck should be hit since it's only 10 yards away
    String ret = trip.hunt(fakeDuck, 10);
    assertEquals("alive!dead!", ret);
}

// A simplified Duck with no complex trajectory calculation
public class FakeDuckNear extends Duck {
    // private boolean alive; inherited from Duck
    // Always hits, emulating a Duck that is close by
    public boolean shoot(int distance) { alive = false; }
}
```

- *Fake*: a test double that is a simplified version of the original object

Create a Different Fake for a Different Scenario

```
@Test
public void testShootDuck1000Yards() {
    HuntingTrip trip = new HuntingTrip();
    // Create a "fake" Duck that is far away from us
    Duck fakeDuck = new FakeDuckFar();
    // Duck should not be hit since it's a 1000 yards away
    String ret = trip.hunt(fakeDuck, 1000);
    assertEquals("alive!alive!", ret);
}

// A simplified Duck with no complex trajectory calculation
public class FakeDuckFar extends Duck {
    // private boolean alive; inherited from Duck
    // Always misses, emulating a Duck that is far away
    public boolean shoot(int distance) { alive = true; }
}
```

- Yes, we could have used a mocked Duck for this test case. But you get the point.

Advance Unit Testing Techniques

- Removing Class Dependencies
 - Test Doubles
 - Stubs
- Behavior Verification
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Original Problematic Example

```
public class DoALot {  
    public void quackALot(Duck duck, int num) {  
        for (int j=0; j < num; j++) {  
            duck.quack();  
        }  
    }  
}
```

1. There is no return value! What should we test then?!
 - ☛ Test the behavior: somehow test `quack()` is called `num` times
2. We are testing Duck along with DoALot. How do we avoid this?

Behavior Verification

- No relation to "verification" in "verification and validation"
- *State Verification vs. Behavior Verification*
 - *State Verification*: Tests the state of the program
 - Whether state changes correctly as a result of method call(s)
 - Done through **assertions** on **postconditions** (what we've done so far)
 - *Behavior Verification*: Tests the behavior of code
 - Whether certain methods have been called a certain number of times
 - Whether methods have been called with the correct parameters
 - Done through **verify** in Mockito

Why do Behavior Verification?

- In the end, we are interested in *state* not *behavior*
 - Whether method returns correct value → state verification
 - Whether method updates heap object correctly → state verification
 - Whether method outputs correct message → state verification
 - We are less interested in what methods were called internally
- Given a choice, always do *state* over *behavior* verification
- But what if you need to verify state within a mocked object?
 - Remember, mocked objects don't have any state to begin with!
 - This is when you need to do behavior verification

When State Verification does not Work

```
public class Duck {
    private int quacks = 0;
    public void quack() { quacks++; }
    public int getQuacks() { return quacks; }
}

public class DoALot {
    public void quackALot(Duck duck, int num) {
        for (int j=0; j < num; j++) {
            duck.quack(); // doesn't do duck.quacks++ (it's a mocked object)
        }
    }
}

@Test public void testQuackALot() {
    DoALot doALot = new DoALot();
    Duck mockDuck = Mockito.mock(Duck.class);
    int quack = doALot.quackALot(mockDuck, 5);
    assertEquals(5, mockDuck.getQuacks()); // returns 0, stub for getQuacks()
}
```


Behavior Verification to the Rescue!

```
@Test public void testQuackALot() {  
    DoALot doALot = new DoALot();  
    // Make a mocked Duck, stub quack()  
    Duck mockDuck = mock(Duck.class);  
    // Call quackALot, which calls mockDuck.quack() 5 times  
    doALot.quackALot(mockDuck, 5);  
    // Verifies quack called 5 times on mockDuck  
    Mockito.verify(mockDuck, times(5)).quack();  
    // Note no assertions! Assertions built in to verify.  
}
```

- `Mockito.verify` does not directly check that `mockDuck` has the correct state
- But, had a real duck with correct code been used, it would have the correct state

Mock

- *Mock*: A test double which uses behavior verification
- Many frameworks uses the same API for doubles and mocks
 - `Mockito.mock` is used to create both doubles and mocks
 - If mocked object later uses behavior verification, it's a mock
 - If object happens to not use behavior verification, it's a double
- But technically, a mock is a specific kind of test double.

More JUnit / Mockito Examples

- `sample_code/ junit_example/LinkedListUnitTest.java`
 - Replica of `LinkedListTest.java` we saw in Part 1 but using Mockito
 - `LinkedListTest`: not a true unit test due to testing `Node` alongside `LinkedList`
 - `LinkedListUnitTest`: true unit test that mocks all `Node` instances
- Above uses `Mockito.verify` to check method call parameters
 - That `Node` methods are called properly from `LinkedList`
 - `ll.addToFront(existingNode);`
`ll.addToFront(testNode);`
`Mockito.verify(testNode).setNext(existingNode);`
 - ☛ **Checks** `testNode.setNext(existingNode)` **is called in** `addToFront`

Unit Testing Summary

What does a Good Unit Test Look Like?

- Reproducible on every run
- Independent of other tests
- Is localized (tests only the unit)
- Tests one test case at a time

Good Unit Test:

Reproducible on Every Run

- Tests should either always pass or always fail. Otherwise:
 - When a test fails, it may be hard to reproduce the defect for debugging
 - When a test passes, there is no guarantee defect will not resurface later
- That means ...
 - All preconditions must be precise and complete
 - There can be no random factor in the execution steps
 - No randomness in the test itself (e.g. testing a random input value)
 - No randomness internal to the program (e.g. game with a die roll)
- How do we remove randomness internal to the program?!
 - Don't worry, we will learn when we talk about Writing Testable Code 😊

Good Unit Test:

Independent of Other Tests

- Tests should not depend on other tests to run. **Why?**
 - We may choose to run a subset of tests in a test suite
 - We may choose to run tests in a different order (e.g. in parallel)
 - That other test may fail (which will cause this test to fail also)
- We learned how to create a test fixture using @Before, @After

Good Unit Test:

Localized (Tests only the unit)

- In other words, mock external classes and stub the methods
- We talked enough about this so no need to belabor

Good Unit Test:

Tests one thing at a time

- Do not test different test cases in a single test. **Why?**
 - If a test case fails (assertion fires), remaining test cases aren't tested
 - On test failure, hard to tell which test case failed
- Means you should try to call only one method from test
 - The one that you are testing
 - Except when you need to call other methods to set up preconditions
 - Except when you need to call other methods to check postconditions

JUnit is not the only unit test framework out there!

- Not even for Java!
- But xUnit frameworks are common and easy to understand
 - C++: CPPunit
 - JavaScript: JSUnit
 - PHP: PHPUnit
 - Python: PyUnit
- Ideas should apply to other testing frameworks easily

Unit Testing != System Testing

- The manual tests that you've done for Exercise 1 is a system test
 - Checks that the whole system works
- The automated tests that you will do for Exercise 2 are unit tests
 - Checks that each unit of functionality individually works
- A proper testing process includes both
 - Unit tests to detect local errors within units of code
 - System tests to check that all pieces of code work together correctly

My advice

- Try to add tests as soon as possible.
 - Ideally, write tests before coding
 - Will cover in our next chapter “Test Driven Development”.
- Develop in a way to make it easy for others to test.
 - E.g. if you create an external object inside a method, much harder to mock

```
public class RentACat {  
    public void addCat() {  
        Cat cat = new Cat(1, "cat"); // How can we mock this?  
        list.add(cat);  
    }  
}
```
 - Will cover in our next, next chapter “Writing Testable Code”

Now Please Read Textbook Chapter 14

- In addition, look at code using Mockito in our JUnit example:
sample_code/junit_example/LinkedListUnitTest.java

- Mockito User Manual:

<https://javadoc.io/static/org.mockito/mockito-core/3.2.4/org/mockito/Mockito.html>