

CS1632: Unit Testing, part 2

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Mocks Allow True Unit Testing

By removing object dependencies from unit testing

Unit Testing Control.getInput() with Dependencies

System

```
class Game {  
    public static void main() {  
        control.getInput();  
        display.show();  
    }  
}
```

Subsystems

Unit Test

```
class Control {  
    public String getInput() {  
        mouse.getInput();  
        keyboard.getInput();  
    }  
}
```

```
class Display {  
    public void show() {  
        scenery.show;  
    }  
}
```

Modules

```
class Mouse {  
    public String getInput() {  
        ...  
    }  
}
```

```
class Keyboard {  
    public String getInput() {  
        ...  
    }  
}
```

```
class Scenery {  
    public void show() {  
        ...  
    }  
}
```

First, let's get rid of irrelevant classes

System

```
class Control {  
    public static void main()  
    {  
        control.getInput();  
        display.show();  
    }  
}
```

Subsystems

Unit Test

```
class Control {  
    public String getInput() {  
        mouse.getInput();  
        keyboard.getInput();  
    }  
}
```

```
class Display {  
    public void show() {  
        scenery.show();  
    }  
}
```

Modules

```
class Mouse {  
    public String getInput() {  
        ...  
    }  
}
```

```
class Keyboard {  
    public String getInput() {  
        ...  
    }  
}
```

```
class Scenery {  
    public void show() {  
        ...  
    }  
}
```

What should we do with dependencies?

System

Subsystems

Unit Test

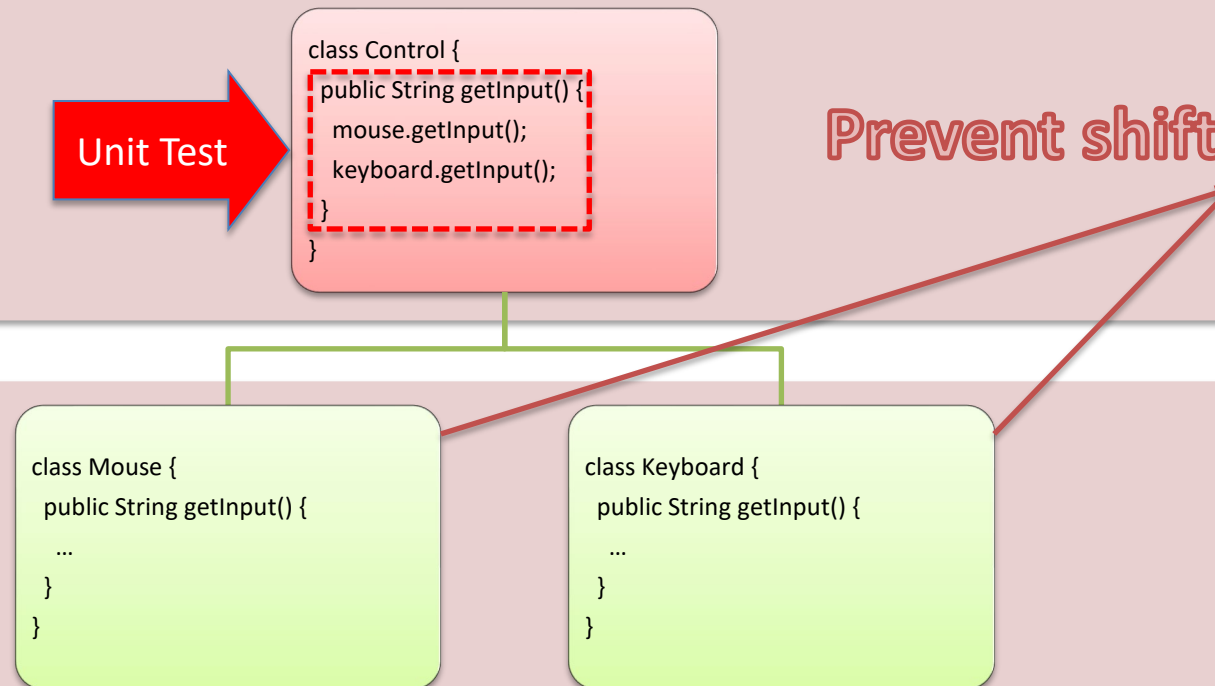
```
class Control {  
  public String getInput() {  
    mouse.getInput();  
    keyboard.getInput();  
  }  
}
```

Prevent shift-left testing!

Modules

```
class Mouse {  
  public String getInput() {  
    ...  
  }  
}
```

```
class Keyboard {  
  public String getInput() {  
    ...  
  }  
}
```



Answer: Replace dependencies with fake objects!

System

Subsystems

Unit Test

```
class Control {  
  public String getInput() {  
    mouse.getInput();  
    keyboard.getInput();  
  }  
}
```

Allows shift-left testing,
since no code is executed.

Modules

Fake Mouse

```
String getInput() {  
  // No code  
}
```

Fake Keyboard

```
String getInput() {  
  // No code  
}
```

Test Doubles (or mocks) fake the real object

- Goal: To **not execute code** in external classes as part of the unit test.
 - Means method can be **shift-left** tested.
 - Means if a defect is found, it is **localized**.
- Just like body doubles, **test doubles** pretend to be the real thing but aren't.
 - Also called **mocks**, since they are mock-ups of the real objects.
 - Mocks appear to be real objects, but without executing any code. How???
 - Hint: mock only needs to emulate behavior for the **given test scenario**.

Running Example: Rent-A-Cat System

```
class RentACat {
    HashMap<int, Cat> cats;

    public void addCat(int id, Cat cat) {
        cats.put(id, cat);
    }
    public void rentCat(int id, int days) {
        cats.get(id).rent(days * 100);
    }
    public String listCats() {
        String ret;
        for (Cat cat : cats.values()) {
            ret += cat.toString() + "\n";
        }
        return ret;
    }
}
```

```
class Cat {
    String name;
    int netWorth = 0;

    public Cat(String name) {
        this.name = name;
    }
    public void rent(int payment) {
        netWorth += payment;
    }
    public String toString() {
        return name + " " + netWorth;
    }
}
```


RentACat depends on Cat

```
class RentACat {  
    HashMap<int, Cat> cats;  
  
    public void addCat(int id, Cat cat) {  
        cats.put(id, cat);  
    }  
    public void rentCat(int id, int days) {  
        cats.get(id).rent(days * 100);  
    }  
    public String listCats() {  
        String ret;  
        for (Cat cat : cats.values()) {  
            ret += cat.toString() + "\n";  
        }  
        return ret;  
    }  
}
```

```
class Cat {  
    String name;  
    int netWorth = 0;  
  
    public Cat(String name) {  
        this.name = name;  
    }  
    public void rent(int payment) {  
        netWorth += payment;  
    }  
    public String toString() {  
        return name + " " + netWorth;  
    }  
}
```

How can we test RentACat w/o Cat code?

```
class RentACat {  
    HashMap<int, Cat> cats;  
  
    public void addCat(int id, Cat cat) {  
        cats.put(id, cat);  
    }  
    public void rentCat(int id, int days) {  
        cats.get(id).rent(days * 100);  
    }  
    public String listCats() {  
        String ret;  
        for (Cat cat : cats.values()) {  
            ret += cat.toString() + "\n";  
        }  
        return ret;  
    }  
}
```

"Fake" Cat

"Fake" void rent(int payment)

"Fake" String toString()

Mockito Framework

A popular Java framework for creating mock objects

Mock: A Fake Object with No Code

```
// Creates a mock cat of type Cat  
Cat cat = Mockito.mock(Cat.class);
```

Mockito: a framework for creating test doubles

- **Mockito**: a framework for creating mocks
 - Good for emulating mocks that exhibit simple behaviors
 - Uses Java Reflection + Bytecode Rewriting to override method behavior
 - Yes, method bytecode of mocks is literally rewritten during the test!
- In Mockito terminology:
 - Test double → **Mock**, Act of creating a mock → **Mocking**

A Mock Object does not execute your code!

```
Cat cat = new Cat("Tabby");
```

```
class Cat {  
    String name;  
    int netWorth = 0;  
  
    public Cat(String name) {  
        this.name = name;  
    }  
    public void rent(int payment) {  
        netWorth += payment;  
    }  
    public String toString() {  
        return name + " " + netWorth;  
    }  
}
```

```
Cat cat = Mockito.mock(Cat.class);
```

```
// No member variables  
// No constructor  
  
// Default code for rent  
void rent(int payment) {}  
// Default code for toString  
String toString() {  
    return "Mock for Cat, ...";  
}
```

Stub: A Fake Method with No Code

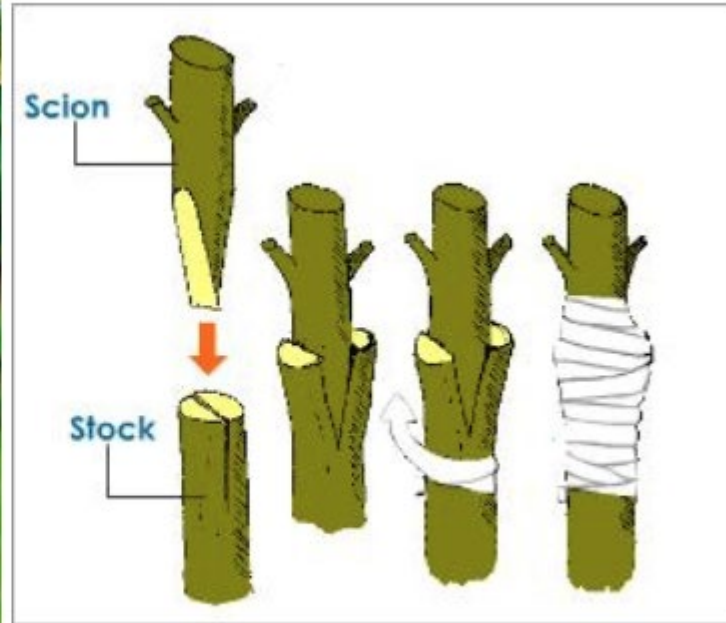
```
// Rewrites toString() stub to return "Tabby"  
Mockito.when(cat.toString()).thenReturn("Tabby");
```

Stubbing Getter Methods Emulates State

- OOP 101: objects have *data encapsulation*
 - *Data encapsulation*: private members are not visible from outside
 - Only way to query private state is through *getter* methods
 - *Getter*: a method that returns the value of a private member variable
- What if a **precondition** specifies a state for a mock object?
 - E.g. Cat has a name of “Tabby” and a net worth of 300 dollars.
 - Answer: rewrite *getter* methods to return specified state!

Stubbing sets up preconditions.

- In Mockito terminology:
 - Fake method → **Stub**, Act of changing method return value → **Stubbing**



Courtesy: Bainbridge Island Fruit Club

- Grafts apple tree limb to the stub of another tree.
- For all purposes, tree acts like an apple tree!
 - If precondition says red apples, stub red apples
 - If precondition says green apples, stub green apples

Creating a cat named "Tabby"

```
Cat cat = new Cat("Tabby");
```

```
Cat cat = Mockito.mock(Cat.class);
```

```
Mockito.when(cat.toString()).thenReturn("Tabby 0");
```

```
class Cat {  
    String name;  
    int netWorth = 0;  
  
    public Cat(String name) {  
        this.name = name;  
    }  
    public void rent(int payment) {  
        netWorth += payment;  
    }  
    public String toString() {  
        return name + " " + netWorth;  
    }  
}
```

```
void rent(int payment) {}  
  
// Now returns "Tabby 0"!  
String toString() {  
    return "Mock for Cat, ...";  
    return "Tabby 0";  
}
```

Creating a cat named “Tabby” with net worth 5

```
Cat cat = new Cat("Tabby");  
cat.rent(5);
```

```
Cat cat = Mockito.mock(Cat.class);  
Mockito.when(cat.toString()).thenReturn("Tabby 5");
```

```
class Cat {  
    String name;  
    int netWorth = 0;  
  
    public Cat(String name) {  
        this.name = name;  
    }  
    public void rent(int payment) {  
        netWorth += payment;  
    }  
    public String toString() {  
        return name + " " + netWorth;  
    }  
}
```

```
void rent(int payment) {}  
  
// Now returns "Tabby 5"!  
String toString() {  
    return "Mock for Cat, ...";  
    return "Tabby 5";  
}
```

Integration Testing listCats()

```
class IntegrationTest {
    @Test
    public void testListCats() {
        // Preconditions: System has a cat named "Tabby", net worth 300, ID 1.
        RentACat rentACat = new RentACat();
        Cat cat = new Cat("Tabby");
        rentACat.addCat(1, cat);
        rentACat.rentCat(1, 3);
        // Execution Steps: List all cats in the system.
        String str = rentACat.listCats();
        // Postconditions: "Tabby" is listed with net worth 300
        assertEquals("Tabby 300\n", str);
    }
}
```

Unit Testing listCats()

```
class RentACatUnitTest {
    @Test
    public void testListCats() {
        // Preconditions: System has a cat named "Tabby", net worth 300, ID 1.
        RentACat rentACat = new RentACat();
        Cat cat = Mockito.mock(Cat.class);
        Mockito.when(cat.toString()).thenReturn("Tabby 300");
        rentACat.addCat(1, cat);
        // Execution Steps: List all cats in the system.
        String str = rentACat.listCats();
        // Postconditions: "Tabby" is listed with net worth 300
        assertEquals("Tabby 300\n", str);
    }
}
```

Behavior Verification:

Allows postcondition checks on Mocks

```
// Verifies rent(300) has been called on cat  
Mockito.verify(cat).rent(300);
```

Mock state cannot (and should not) be checked

- What if a postcondition specifies a state for a mock object?
 - E.g. Cat has net worth of 300 dollars after being rented out for 3 days.
- First Answer: Cannot be done.
 - Mock cat has no state so there is nothing to check.
 - What if we emulated the state to check through stubbing?
`Mockito.when(cat.toString()).thenReturn("Tabby 300");`
`assertEquals("Tabby 300", cat.toString());`
This is called a *tautological test*, because it always passes regardless of defects.
- Second Answer: Should not be done.
 - You are checking something about Cat, which is beyond the scope of testing.

Modifications to Mock state *can* be checked

- What if postcondition specifies a modification to the state of a mock object?
 - E.g. Cat is given a rent payment of 300 dollars, after being rented out for 3 days.
- First Answer: Can be done.
 - Mockito framework keeps track of all calls to mock objects.
 - Can check that rent call has been made (once) with a certain payment argument:
`Mockito.verify(cat).rent(payment);`
`Mockito.verify(cat, Mockito.times(1)).rent(payment);`
- Second Answer: Should be done.
 - You are checking something about RentACat, that it initiates the modification.

Setter methods are targets of behavior verification

```
class RentACat {  
    HashMap<int, Cat> cats;  
  
    public void addCat(int id, Cat cat) {  
        cats.put(id, cat);  
    }  
    public void rentCat(int id, int days) {  
        cats.get(id).rent(days * 100);  
    }  
    public String listCats() {  
        String ret;  
        for (Cat cat : cats.values()) {  
            ret += cat.toString() + "\n";  
        }  
    }  
}
```

// No state to check

// Just stubs (no code)

void rent(int payment) {}

String toString() {
 return <stubbed value>;
}

**Mock Cat has no state to verify.
Instead, check that RentACat correctly pays the Cat.**

Getter methods are not targets of verification

```
class RentACat {  
    HashMap<int, Cat> cats;  
  
    public void addCat(int id, Cat cat) {  
        cats.put(id, cat);  
    }  
    public void rentCat(int id, int days) {  
        cats.get(id).rent(days * 100);  
    }  
    public String listCats() {  
        String ret;  
        for (Cat cat : cats.values()) {  
            ret += cat.toString() + "\n";  
        }  
        return ret;  
    }  
}
```

Verify?

// No state to check

// Just stubs (no code)

```
void rent(int payment) {}
```

```
String toString() {  
    return <stubbed value>;  
}
```

Testing is checking observed behavior == expected behavior.
Calling toString() doesn't result in changes to observed state.

Getter methods are not targets of verification

```
class RentACat {  
    ...  
    // New version of listCats()  
    public String listCats() {  
        String ret;  
        for (Cat cat : cats.values()) {  
            ret += cat.getName() + " " +  
                cat.getNetWorth() + "\n";  
        }  
        return ret;  
    }  
}
```

```
// New version of Cat  
void rent(int payment) {...}  
String toString() {...}  
String getName() {...}  
int getNetWorth() {...}
```

Verifying toString() fails even when RentACat behavior is same.

Integration Testing rentCat()

```
class IntegrationTest {
    @Test
    public void testRentCat() {
        // Preconditions: System has cat named "Tabby", net worth 0, ID 1.
        RentACat rentACat = new RentACat();
        Cat cat = new Cat("Tabby");
        rentACat.addCat(1, cat);
        // Execution Steps: Rent out "Tabby" for 3 days (100 USD / day).
        rentACat.rentCat(1, 3);
        // Postconditions: "Tabby" has net worth 300
        assertEquals("Tabby 300\n", rentACat.listCats());
    }
}
```

Unit Testing rentCat()

```
class RentACatUnitTest {  
    @Test  
    public void testRentCat() {  
        // Preconditions: System has cat named "Tabby", net worth 0, ID 1.  
        RentACat rentACat = new RentACat();  
        Cat cat = Mockito.mock(Cat.class);  
        Mockito.when(cat.toString()).thenReturn("Tabby 0");  
        rentACat.addCat(1, cat);  
        // Execution Steps: Rent out "Tabby" for 3 days (100 USD / day).  
        rentACat.rentCat(1, 3);  
        // Postconditions: "Tabby" is given payment of 300  
        Mockito.verify(cat).rent(300);  
    }  
}
```

Pitfall 1: Using Verify on a Getter Method

```
class RentACatUnitTest {
    @Test
    public void testListCats() {
        // Preconditions: System has cat named "Tabby", net worth 0, ID 1.
        RentACat rentACat = new RentACat();    Cat cat = Mockito.mock(Cat.class);
        Mockito.when(cat.toString()).thenReturn("Tabby 300");
        rentACat.addCat(1, cat);
        // Execution Steps: List all cats in the system.
        String str = rentACat.listCats();
        // Postconditions: The list consists of "Tabby" with net worth 300.
        Mockito.verify(cat).toString(); // Pointless. Nothing to do with outcome.
        assertEquals("Tabby 300\n", str); // This is what you should be testing!
    }
}
```

Pitfall 2: Using Mockito API on Real Objects

1. It does not work.
 - Mockito.when and Mockito.verify only work on mock objects.
 2. There is no reason to do it.*
 - Mockito.when: no reason to rewrite method for real object.
 - Mockito.verify: no reason to verify a real method has been called.
- * Mockito.spy allows creation of a “partial” mock object
- Part of the object is real, part of the object is rewritten using Mockito.when.
 - Per Mockito manual: “spies should be used **carefully and occasionally**”.
 - Outside this scope of this class (you will have no reason to use it).

Mocking has Uses Other than Unit Testing

- Robustness testing: for emulating hardware device failures
 - Hard to induce failures in real devices such as hard disks
 - Emulate failure in mock device to test how the system responds
- Repeatable testing: for controlling random number generation
 - Hard to test programs that rely on random number generators
 - Decide exactly what numbers get generated using mock generators

Limitations of Mockito

Mockito is not best for mocking complex behavior

Now rentCat cannot be tested using mock cats

```
class RentACat {
    HashMap<int, Cat> cats;

    public void addCat(int id, Cat cat) {
        cats.put(id, cat);
    }
    // Now cat displays two different states.
    // Can't stub 2 values on cat.toString().
    public String rentCat(int id, int days) {
        Cat cat = cats.get(id);
        String ret = cat.toString() + "\n";
        cat.rent(days * 100);
        ret += cat.toString() + "\n";
        return ret;
    }
}
```

```
class Cat {
    String name;
    int netWorth = 0;

    public Cat(String name) {
        this.name = name;
    }
    public void rent(int payment) {
        netWorth += payment;
    }
    public String toString() {
        return name + " " + netWorth;
    }
}
```

Create a Fake Class when Mocking doesn't work

```
class RentACatUnitTest {  
    @Test  
    public void testRentCat3Days() {  
        RentACat rentACat = new RentACat();  
  
        Cat cat = new FakeCat3Days("Tabby");  
        rentACat.addCat(1, cat);  
  
        String str = rentACat.rentCat(1, 3);  
  
        assertEquals("Tabby 0\nTabby 300\n", str);  
    }  
}
```

```
class FakeCat3Days extends Cat {  
    String ret = "Tabby 0";  
  
    public Cat(String name) {}  
  
    public void rent(int payment) {  
        ret = "Tabby 300";  
    }  
  
    public String toString() {  
        return ret;  
    }  
}
```

Another Fake Class for Another Test Case

```
class RentACatUnitTest {
    @Test
    public void testRentCat5Days() {
        RentACat rentACat = new RentACat();

        Cat cat = new FakeCat5Days("Tabby");
        rentACat.addCat(1, cat);

        String str = rentACat.rentCat(1, 5);

        assertEquals("Tabby 0\nTabby 500\n", str);
    }
}
```

```
class FakeCat5Days extends Cat {
    String ret = "Tabby 0";

    public Cat(String name) {}

    public void rent(int payment) {
        ret = "Tabby 500";
    }

    public String toString() {
        return ret;
    }
}
```

How to Create a Fake Class

- Inherit from class you want to fake
- Override methods to remove as much code as possible
- Insert minimum amount of code to emulate correct behavior

Now Please Read Textbook Chapter 14

- Also see sample_code/junit_example
 - Do “mvn test” or use VSCode Testing extension to run tests
 - See how Node objects are mocked and stubbed in @Before setUp()
 - See how Mockito.verify is used to perform behavior verification

- Mockito User Manual:

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