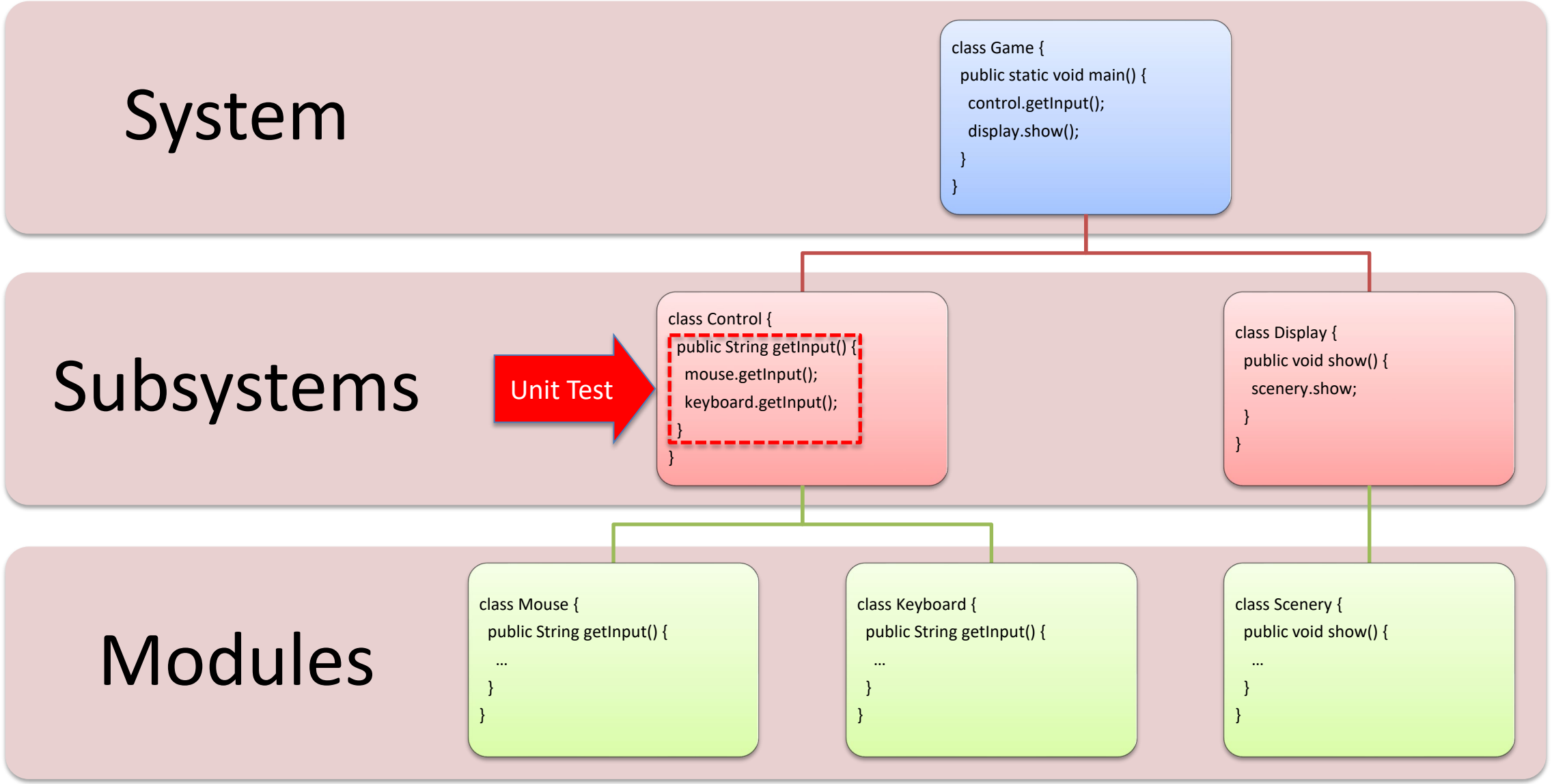
CS1632:
Unit Testing, part 2

Wonsun Ahn

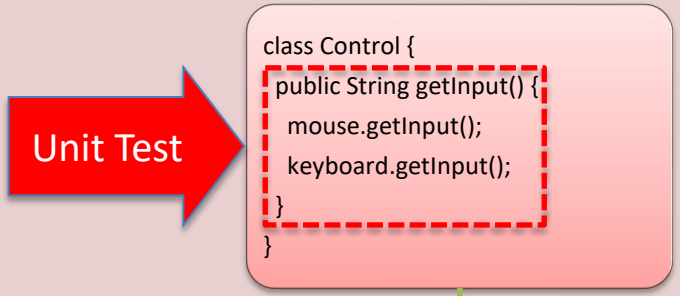
Unit Testing Control.getInput() with Dependencies



Let’s first get rid of irrelevant classes

System

Subsystems



Modules

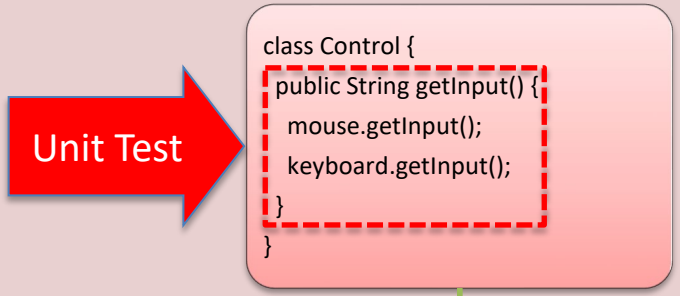
```
class Mouse {
  public String getInput() {
    …
  }
}
```

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

Unit Test using Fake Objects for Dependencies

System

Subsystems



Modules

Fake Mouse

Emulates behavior of mouse.getInput() without executing any code.

Fake Keyboard

Emulates behavior of keyboard.getInput() without executing code.

Fake Objects are called Test Doubles

- Just like body doubles, **test doubles** pretend to be the real thing, but aren't.

- Goal: To **not execute code** in external classes as part of the unit test.
  - Means if a defect is found, it is **localized** to within the tested method.
  - Means method can be tested with dependent classes still under development.

- Test double *appears* like the real thing to tested method
  - Even if double does not execute code in the external class
  - Double emulates the real object's behavior in 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;
  }
}
```

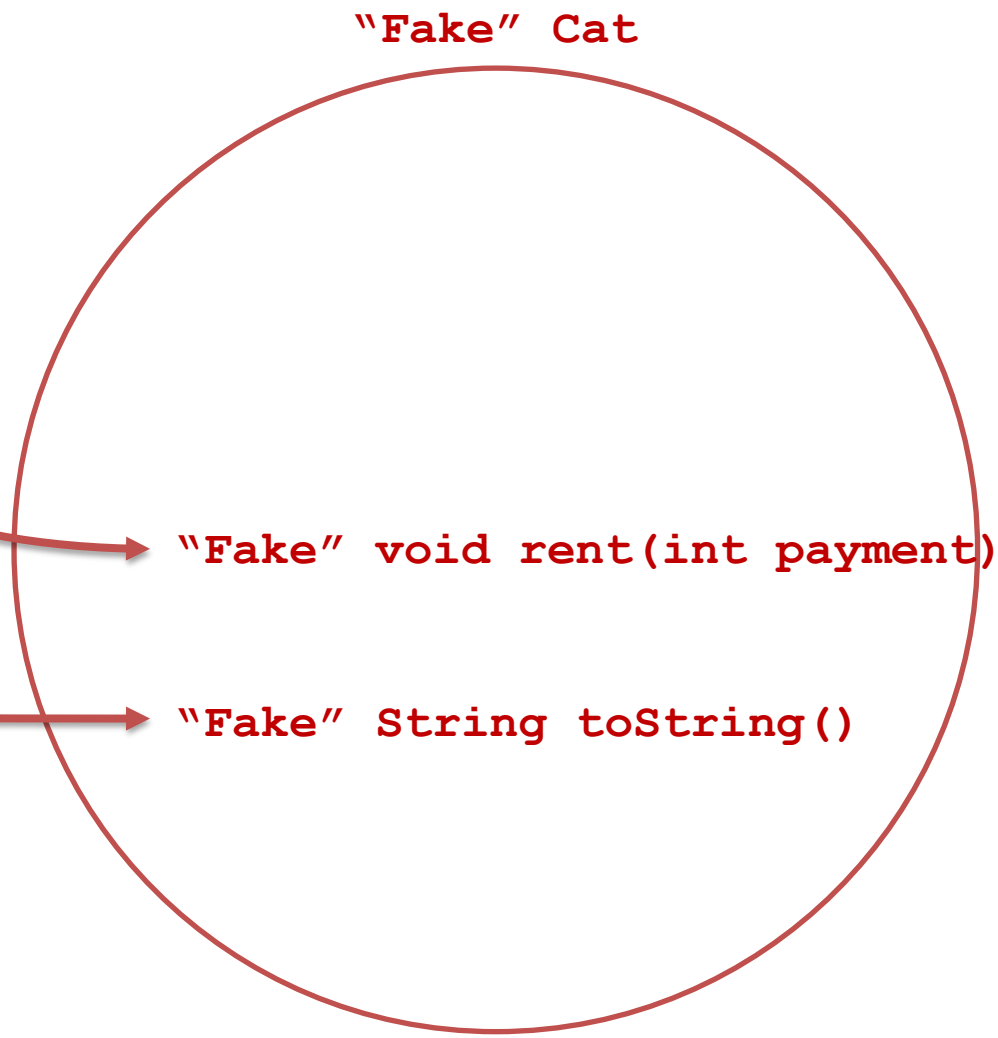
```
class Cat {
  String name;
  int netWorth = 0;

  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;
  }
}
```



Mocking: Creates Fake Object with No Code

```
fake = Mockito.mock(fake.class);
```

Mockito: a framework for creating test doubles

- **Mockito**: a framework for creating test doubles
  - Good for emulating test doubles that exhibit simple behaviors
  - Uses Java Reflection + Bytecode Rewriting to override method behavior

- In Mockito terminology:
  - Test double → **Mock**, Act of creating a mock → **Mocking**

A Mock Object contains No 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

// Void methods: No code
void rent(int payment) {}
// Value returning methods:
// Returns a default value
// (e.g. null, 0, false)
String toString() {
  return <default value>;
}
```

Stubbing: Allows Mocks to Emulate State

```
Mockito.when(mock.method()).thenReturn(<value>);
```

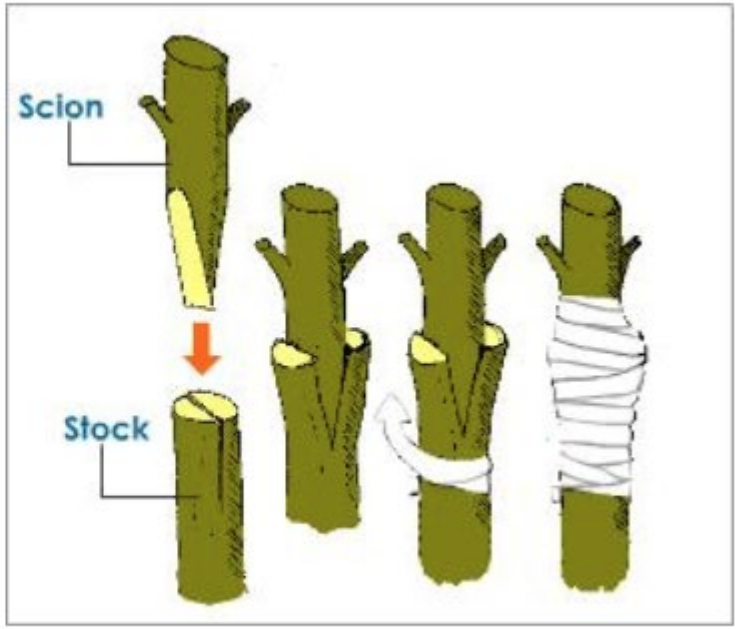
Emulating Getter Methods Emulates State

- What if a precondition specifies a state for a mock object?
  - E.g. Cat has a name of “Tabby” or a net worth of 300 dollars.
  - Wait… we learned mocks are completely devoid of state or code.
  - Answer: manipulate *getter* methods to return specified state!

- Java 101: all objects should have proper *data encapsulation*
  - *Data encapsulation*: when all member variables are declared private
  - Then only way to query internal state is through *getter* methods
  - *Getter*: a method that returns the value of a private member variable

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

Stubbing cat with name “Tabby” and net worth 0

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

```
void rent(int payment) {}

// Now returns “Tabby 0”!
String toString() {
  return “Tabby 0”;
}
```

Stubbing cat with name “Tabby” and net worth 5

```
Cat cat = new Cat(“Tabby”);
cat.rent(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;
  }
}
```

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

```
// No Member variables

// No Constructor

// Only Stubs (no code)
void rent(int payment) {}

String toString() {
  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 UnitTest {
  @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

```
Mockito.verify(mock).method(arg1, arg2, …);
```

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 verfication

```
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 IntegrationTest {
  @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);
}
```

Using Verify on a Getter is Pointless

```
class UnitTest {
  @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 toString() method has been called on "Tabby"
    Mockito.verify(cat).toString(); // Pointless. Nothing to do with outcome.
  }
}
```

Mockito API can and should only be used on Mocks

- Mockito.when and Mockito.verify only work on methods in mock objects.
- You should feel no need to use them on real methods to begin with.
  - Real methods = tested method + “helper” methods within tested object
- No need to use Mockito.when (stubbing) on real methods.
  - Real methods are the target of testing. Why stub to change behavior?
- No need to use Mockito.verify (behavior verification) on real methods.
  - Tested method is getting called (to test, of course) so no need to check
  - Whether “helper” methods are called has nothing to do with correctness.

Limitations of Mocking

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 IntegrationTest {
  @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[] arr = new String[] {
    "Tabby 0", "Tabby 300"};
  int calls = 0;

  public Cat(String name) {}

  public void rent(int payment) {}

  public String toString() {
    return arr[calls++];
  }
}
```

Another Fake Class for Another Test Case

```
class IntegrationTest {
  @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[] arr = new String[] {
    "Tabby 0", "Tabby 500"};
  int calls = 0;

  public Cat(String name) {}

  public void rent(int payment) {}

  public String toString() {
    return arr[calls++];
  }
}
```

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

Discussion and Summary

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

- Reproducible 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

JUnit is not the only unit test framework out there

- xUnit frameworks for each programming language
  - C++: CPPunit
  - JavaScript: JSUnit
  - PHP: PHPUnit
  - Python: PyUnit

- Ideas should apply to other testing frameworks easily

Unit Testing cannot replace Integration Testing

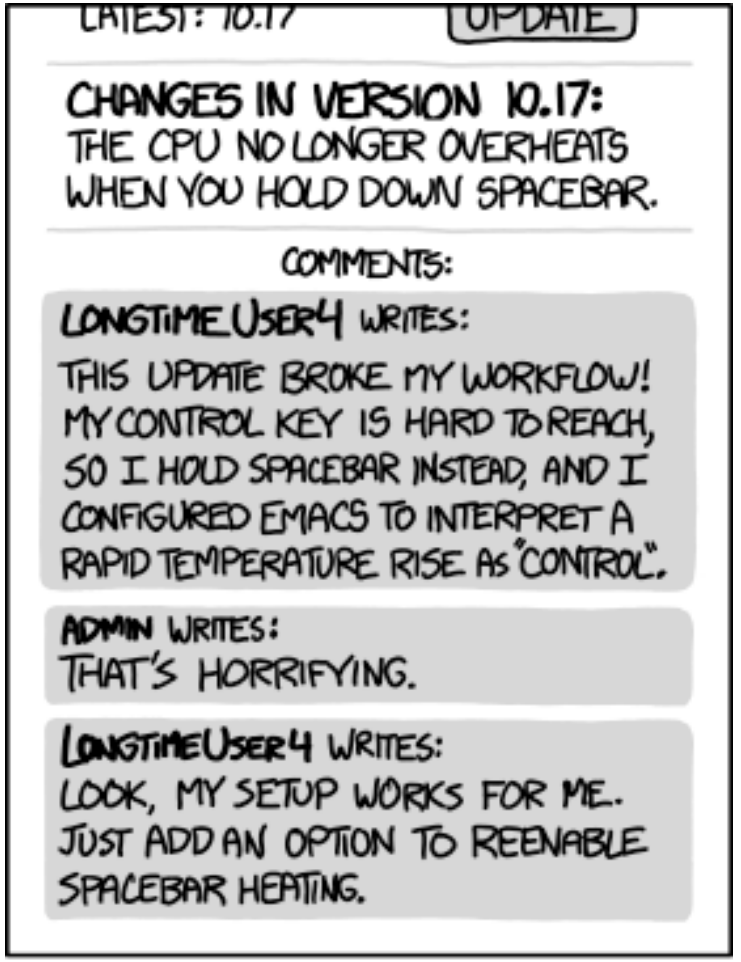
- A proper testing process includes both:
  - Unit tests to detect local errors within units of code
  - Integration tests to check that units work together correctly

- Units often have hidden undocumented dependencies between them
  - Since they are undocumented, they are not unit tested
  - Defects arising from these dependencies only surface when units are integrated

Hyrum's Law

"With a sufficient number of users of an API, it does not matter what you promise in the contract: all observable behaviors of your system will be depended on by somebody."

--- Hyrum Wright



Courtesy https://www.hyrumslaw.com/

Courtesy https://xkcd.com/1172/

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