Software Design and Construction 2 SOFT3202 / COMP9202 Advanced Testing Techniques (1)

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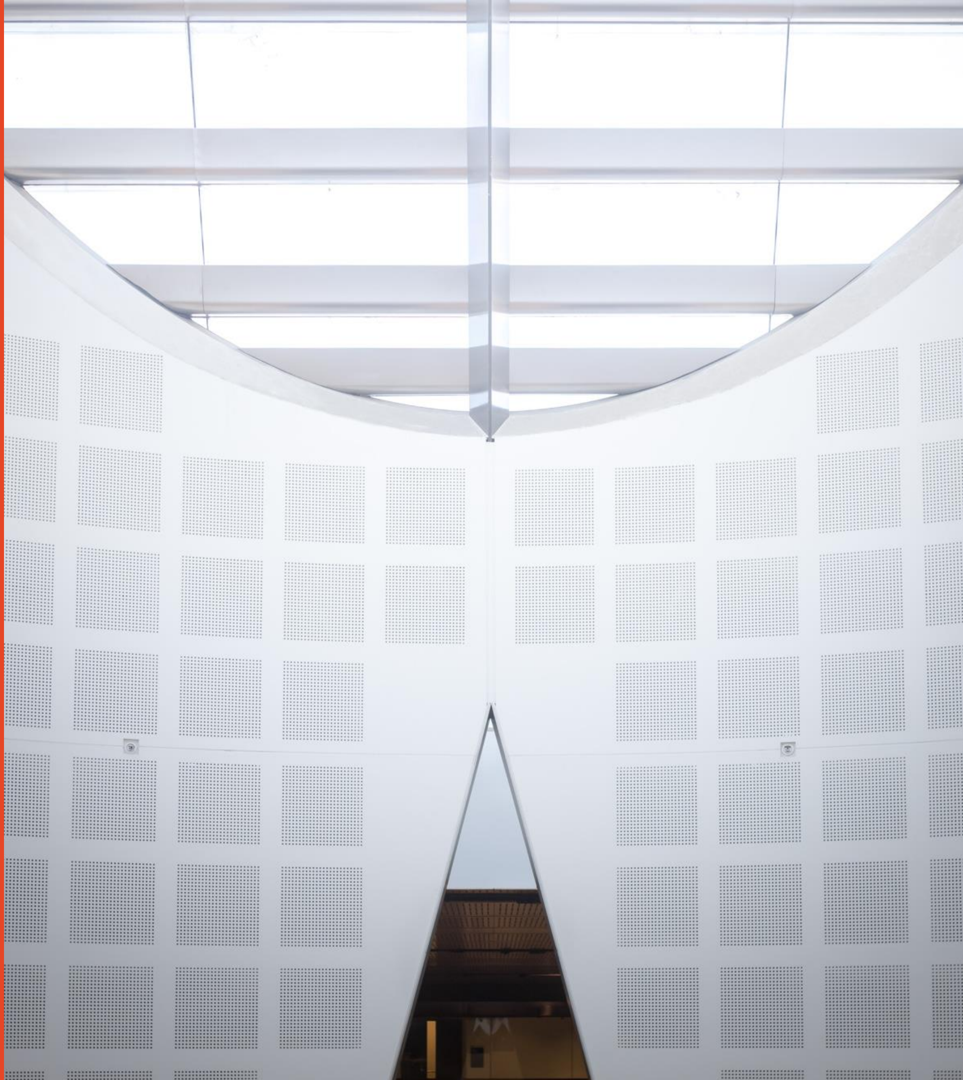

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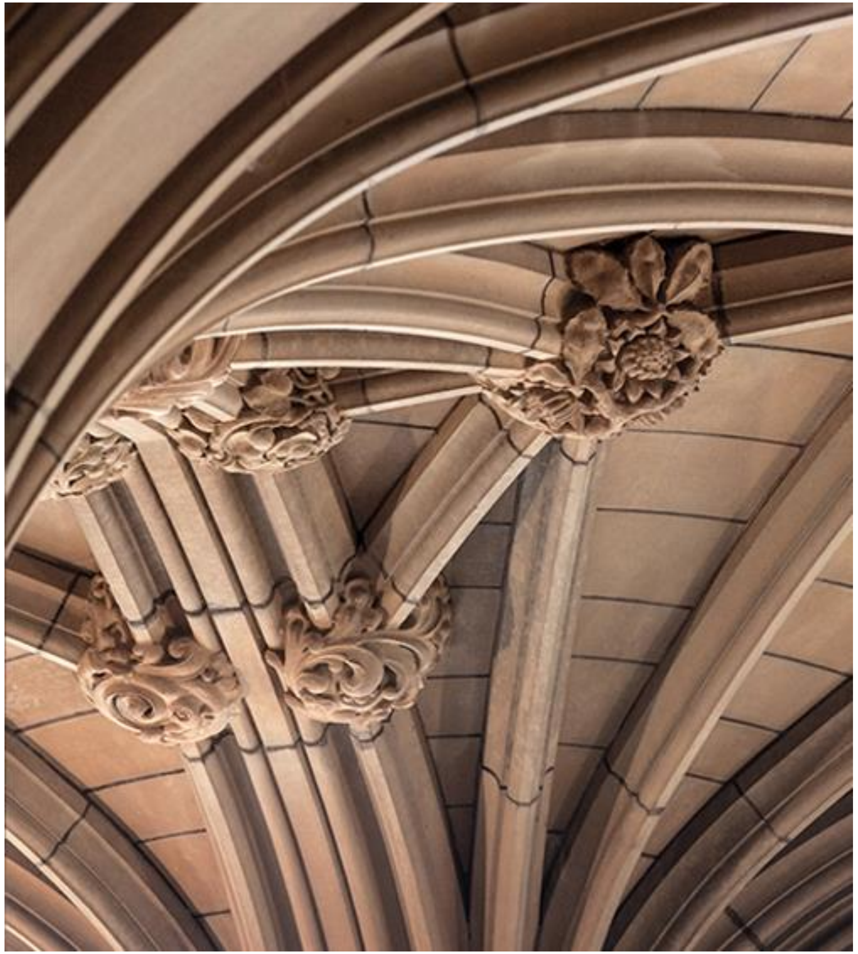
Agenda

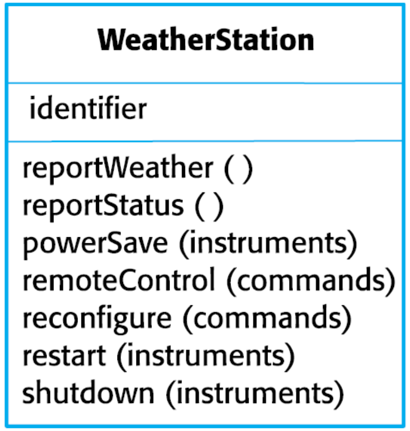
- Testing Types
  - Integration Testing, Regression Testing
- Advanced Testing Techniques
  - Test doubles (Dummies, Fakes, Stubs, Spies, Mocks)
  - Contract Test
- Testing Frameworks
  - Mockito

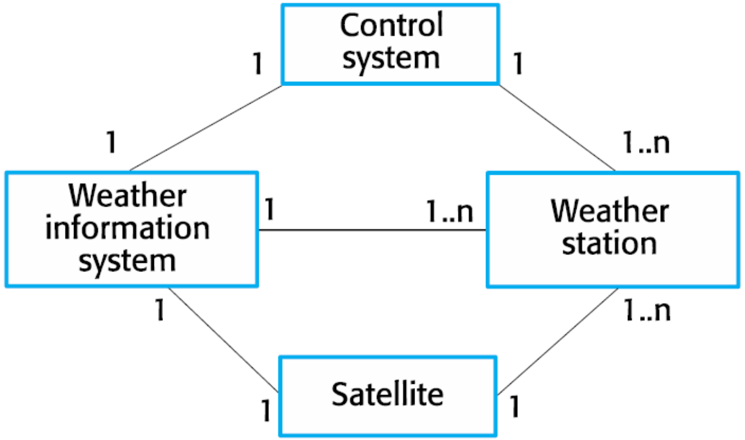
Advanced Testing Types

Integration testing, regression testing



Software Components/Sub-systems





Integration Testing

- The process of verifying interactions/communications among software components behave according to its specifications

- Independently developed (and tested) units may not behave correctly when they interact with each other

- Activate corresponding components and run high-level tests

- Incremental integration testing vs. “Big Bang” testing

Interaction Errors

- Parameter interfaces
  - Methods in objects have a parameter interface
- Procedural interfaces
  - Objects and reusable components
- Message passing interfaces
  - One component encapsulates a service from another component by passing a message to it
- Shared memory interfaces
  - Interfaces in which block of memory is shared between components (e.g., embedded systems)

Your Testing Exposed Bugs

- What would you do when your testing reveal bugs/errors?
- You fixed the discovered bugs, what should happen next?
- You extended one class with additional functionality (new feature), what should happen next?

Regression Testing

- Verifies that the software behaviour has not changed by incremental changes to the software
  - Bug fixes, code extension, code enhancements

- Modern software development processes are iterative/incremental

- Changes may be introduced which may affect the validity of previous tests

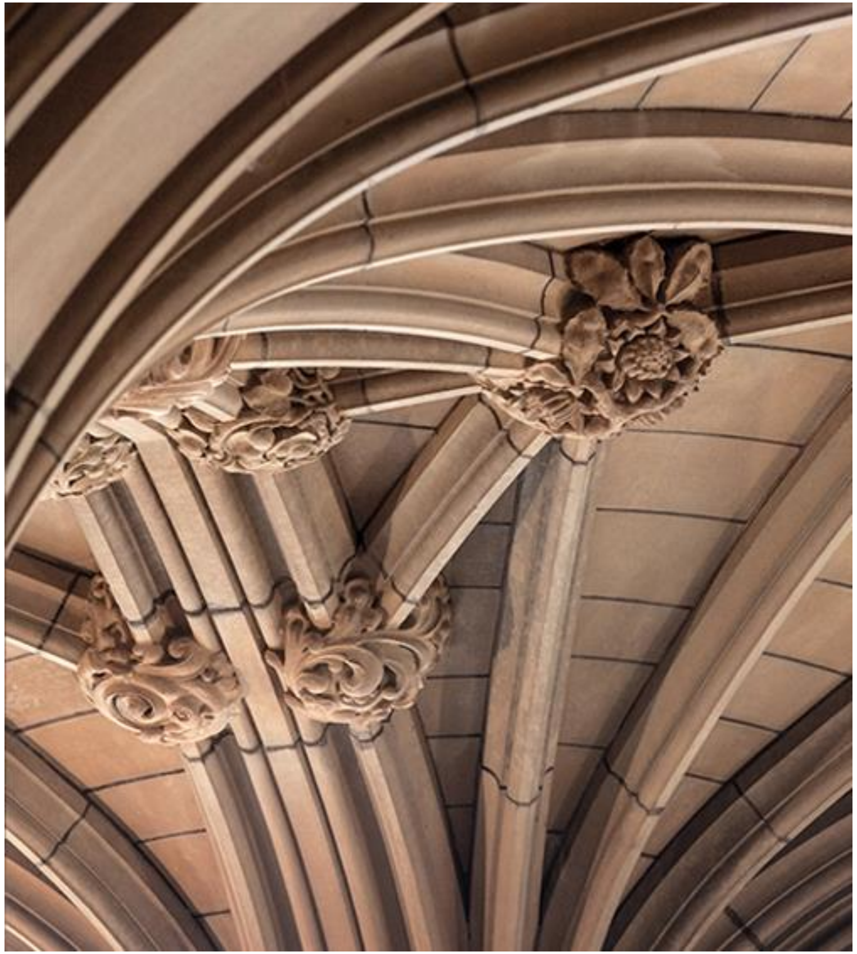
- Regression testing is to verify
  - Pre-tested functionality (and non-functional properties) still working as expected
  - No new bugs are introduced

Regression Testing – Techniques

Type	Description
Retest All	Re-run all the test cases in a test suit
Test Selection	Re-run certain test cases based on the changes in the code
Test case prioritization	Re-run test cases in order of its priority; high, medium, low. Priority determined by how criticality and impact of test cases on the product
Hybrid	Re-run selected test cases based on it's priority

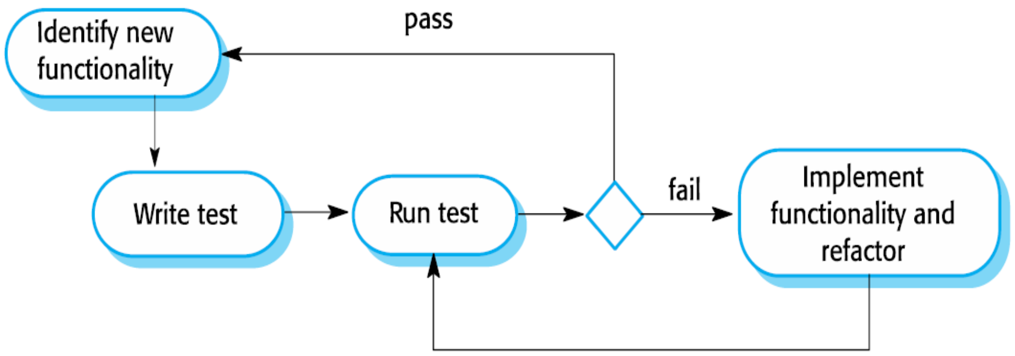
. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.5875&rep=rep1&type=pdf

Test-Driven Development



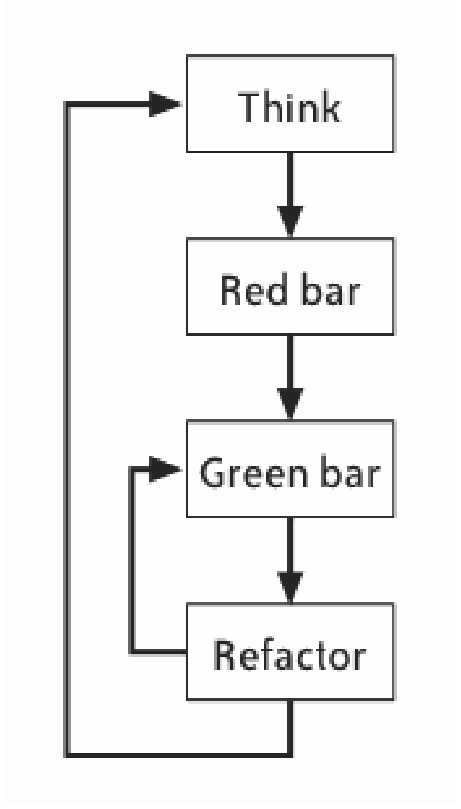
Test-driven Development

- A software development approach for developing the code incrementally along with a set of tests for that increment
  - Write tests before code
- All tests must pass before starting the next increment
- Introduced in the XP agile development method


pass
Identify new functionality
fail
Write test
Run test
Implement functionality and refactor

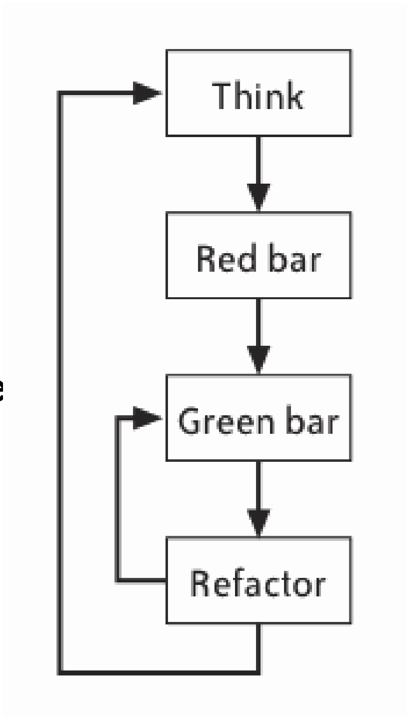
TDD Cycle

- “A rapid cycle of testing, coding, and refactoring” – Kent Beck
- “Every few minutes, TDD provides proven code that has been tested, designed, and coded”
- **Red, Green, Refactor cycle**



TDD Cycle – Think

- **Think** of a behavior you want your code to have (small increment; few lines of code)
- **Think** of a test (few lines of code) that will fail unless the behavior is present
- Pair programming helps
  - Driver and navigator



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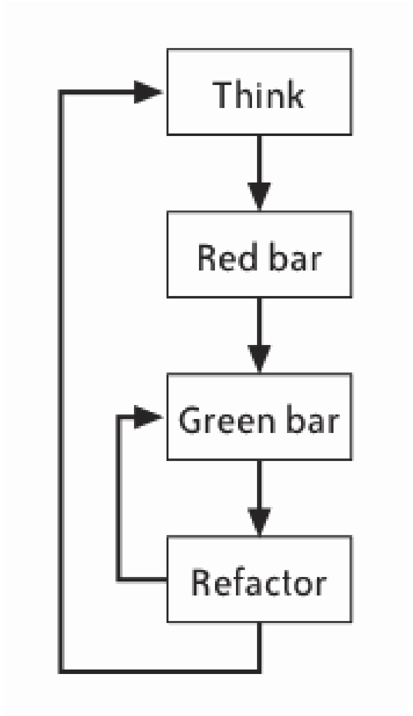
TDD Cycle – Red (Run the Test)

- Write the tests – only enough code for the current increment of behavior
  - Typically less than 5 lines of code

- Code for the class behavior and its public interface (encapsulation)
  - Tests use method and class names do not exist yet

- Run your entire suite of tests and enjoy the test failure

- Results in Red progress bar (testing tools)



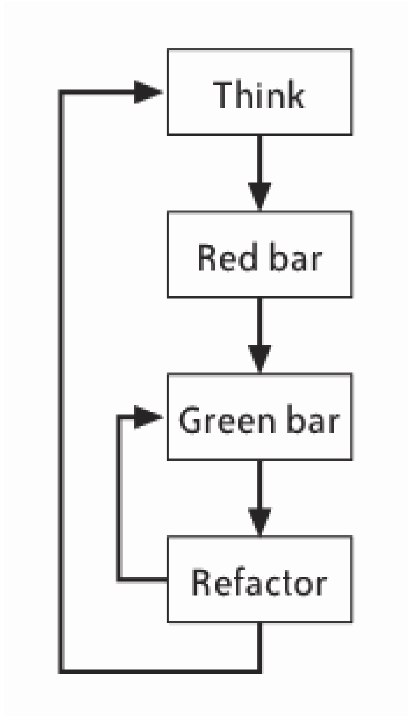
https://www.jamesshore.com/Agile-Book/test_driven_development.html

TDD Cycle – Green (Write Code)

- Write the code; just enough to get the test to pass
  - Less than 5 lines
  - It's okay to hard code, you'll refactor

- Run your tests again, and enjoy the tests passing

- Results in <u>Green</u> progress bar (testing tools)



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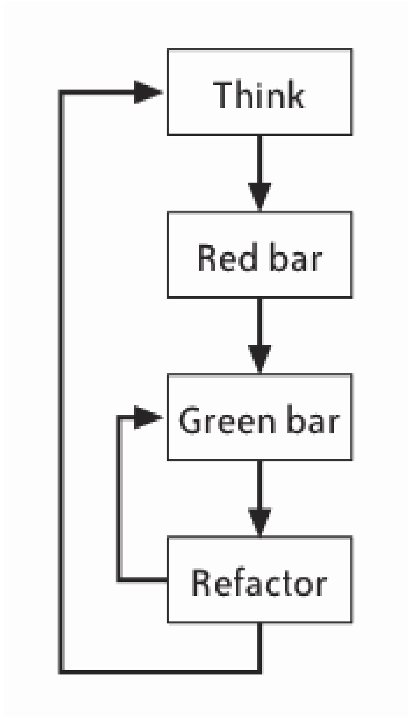
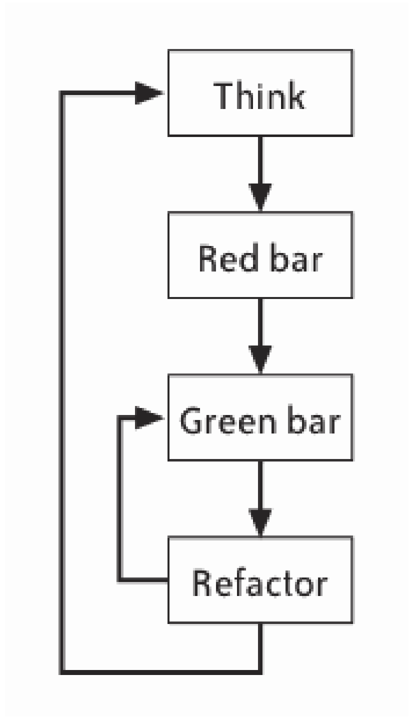
TDD Cycle – Refactor

- Review the code and look for possible improvements
  - Ask your navigator if they made any notes
- Series of very small refactorings
  - 1-2 minutes each, no longer than 5 minutes
- Run the tests after each refactoring
  - Should always be green (pass!)
  - Test failed and no obvious answer, get back to good code
- Refactor many times, improve design
  - Refactoring isn't about changing behavior



TDD Cycle – Repeat

- Repeat to add new behavior, start the cycle over again
- Tiny bit of well-tested, well-designed code will be incrementally created
- Typically, run through several cycles very quickly, then spend more time on refactoring
- Do not skip any step, especially refactoring, to speed up!



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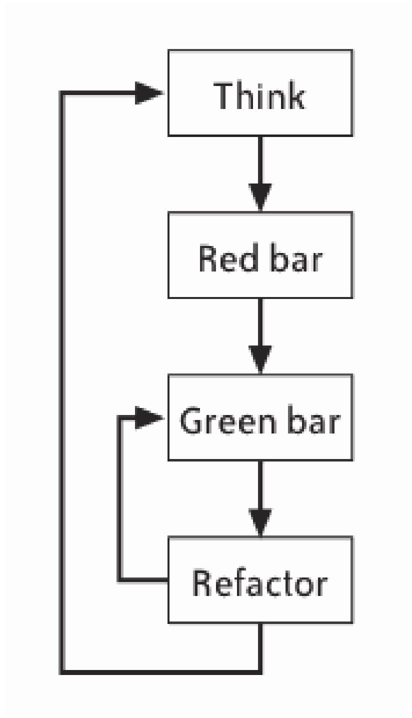
TDD – Red, Green, Refactor

- Use Red, Green, Refactor cycle to impalement TDD
- **Think** of a code behavior, then choose a small increment and then a test
- Write the test for the current increment code and run the entire suit of tests – should fail (**Red bar**)
- Write just enough code to get the test pass and run the tests again – should pass (**Green bar**)
- Review the code and look for improvements – small set of refactoring and run the tests after each (**Refactor**)



https://www.jamesshore.com/Agile-Book/test_driven_development.html

TDD – Example

- Java class to parse HTTP query string (name-value pair)
  - E.g., http://example.com/page/to/page?title=Central+Park&where=US
- Think
  - “class to separate name/value pairs into a HashMap” or “class to put one name/value pair into a HashpMap”? Why?

  - Class *QueryString* won’t return a HashMap, but a method (valueFor(name)) to access the name-value pairs. Shall you proceed with writing the test?
  - Count() method instead to return total number of name-value pairs (more suitable for one increment)
  -

https://www.jamesshore.com/Agile-Book/test_driven_development.html

TDD Example – Red Bar

```
public void testOneNameValuePair() {
    QueryString qs = new QueryString("name=value");
    assertEquals(1, qs.count());
 }

public class QueryString {
    public QueryString(String queryString) {}
    public int count() { return 0; }
 }
```

..

TDD Example – Green Bar & Refractor

```
public int count() { return 1; }
```

Refactor

Change the QueryString name to HttpQuery() – noted for next cycle

Another test to try

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TDD Example – Repeat

Thinking

- Remove the hard-coded line but not time yet to deal with multiple query string
- Testing an empty string would require coding the count() properly

```
public void testNoNameValuePairs() {
      QueryString qs = new QueryString("");
      assertEquals(0, qs.count());
 }
```

Emerging thoughts (noted for later cycles)

- Test the case of a null argument to the QueryString constructor
- Deal with the tests duplication tests that needed refactoring

..

TDD Example – Green & Refactor

```
public class QueryString {
      private String _query

      public QueryString(string queryString) {
          _query = queryString;
      }
      public int count() {
          if ("".equals(_query)) return 0;
          else return 1;
      }
  }
```

Refactor (notes):

- Rename QuerySting
- **testNull()**
- Refactor duplicate tests

..

TDD Example – testNull()

- Test the case when the query string is null
- Red Bar – think of the behavior when the value is null
- Through an exception (Null is illegal) – simple design

```
public void testNull() {
      try {
          QueryString qs = new QueryString(null);
          fail("Should throw exception");
      }
      catch (NullPointerException e) {
          // expected
      }
  }
```

```
 public QueryString(String queryString) {
        if (queryString == null) throw new
NullPointerException();

        _query = queryString;
    }
```

..

TDD Example – valueFor()

- Implement valueFor() method to return the associated value give a name/value pair
- Emerging thoughts: test for a name doesn’t exist (noted)

```
 public void testOneNameValuePair() {
      QueryString qs = new
QueryString("name=value");
      assertEquals(1, qs.count());
      assertEquals("value",
qs.valueFor("name"));
  }
```

```
 public String valueFor(String name) {
      String[] nameAndValue =
_query.split("=");
      return nameAndValue[1];
  }
```

..

TDD Example – Repeat

- Code passed the tests, but it was incomplete
- Multiple name/value pairs …
- Repeat …

..

TDD – Benefits

- Help developers to understand the requirements and write better code
- Simplify debugging
  - Easier to find and fix mistakes in small code chunks
- Reduce cost of regression testing
- Improved design and code quality
  - Research shows TDD substantially reduces the incidence of defects
- Reuse tests as the software grow, and use it as documentation

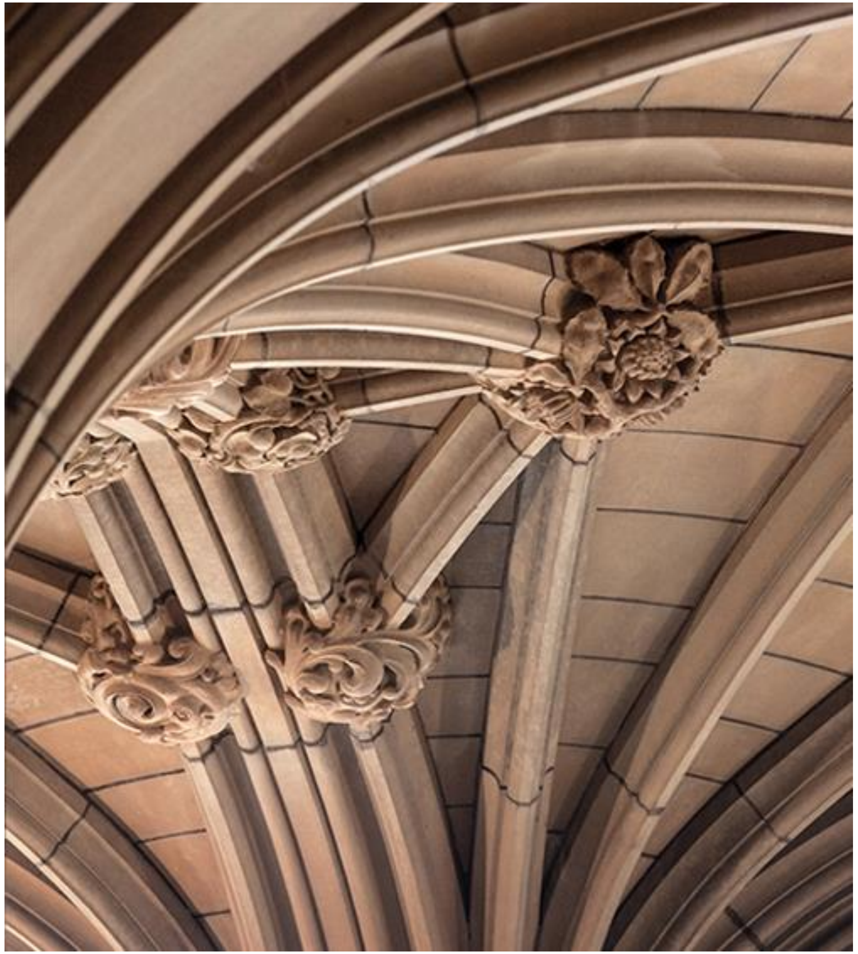
Refactoring

- “*Refactoring* is the process of changing the design of your code without changing its behavior” – Kent Beck
- Change the *how* not the *what*
- Refactoring is reversible!
- Analyze the design of existing code and improve it
- Code improvements can be identified with *code smells*

How to Refactor

- Refactor constantly in a series of small transformations
- Learn from in-depth catalog of refactoring
- Refactor intuitively through learning the mindset behind refactoring
- Learn how to refactor manually
  - Development frameworks/tools can help automating some refactoring
- Use continuous integration practices and automation tools
  - Version control system, build and test automation, IDEs

Test Double



Movie – "Stunt Double"

https://i.ytimg.com/vi/xm7kzxXHF38/maxresdefault.jpg
http://cdn.kickvick.com/wp-content/uploads/2014/07/celebrity-stunt-doubles.jpg
https://amp.businessinsider.com/images/525328ce6bb3f78e7afdcbb2-750-563.jpg

Test Double

- *“A **test double** is an object that can stand in for a real object in a **test**, similar to how a **stunt double** stands in for an actor in a movie” – Google Testing Blog*
  - Includes stubs, mocks and fakes
  - Commonly referred to as “mocks”, but they have different uses!
- Why test double?
  - Dependency on components that cannot be used
  - Reduce complexity, test indecently

https://testing.googleblog.com/2013/07/testing-on-toilet-know-your-test-doubles.html

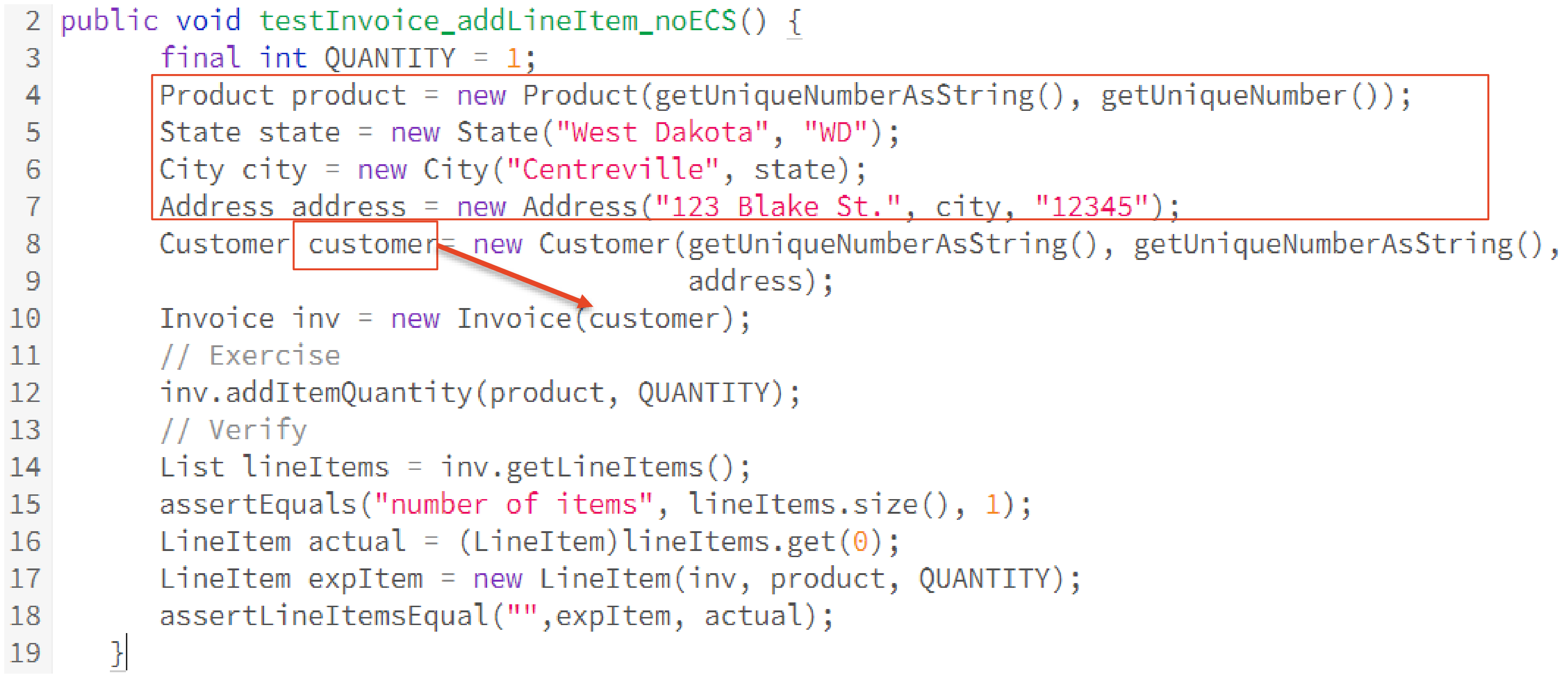
Test Double – Types

Type	Description
Dummy	Pass object(s) that never actually used (to fill parameter list)
Stub	Test-specific object(s) that provide indirect inputs into SUT
Spy	Capture indirect output calls made by the SUT to another component for later verification
Fake	Objects to provide simpler implementation of a heavy component
Mock	Object(s) that verify indirect output of the tested code

Dummy Object

- Dummy, dummy parameter/value
- Pass object with no implementation (dummy) and never actually used
  - E.g., Fill in parameter lists
- SUT's methods to be called often take objects stored in instance variables
  - Those objects, or some of its attributes, will never be used in the testing
- Preparing the SUT into right state (conform to the signature of some methods need to be called)

Dummy Object – Example

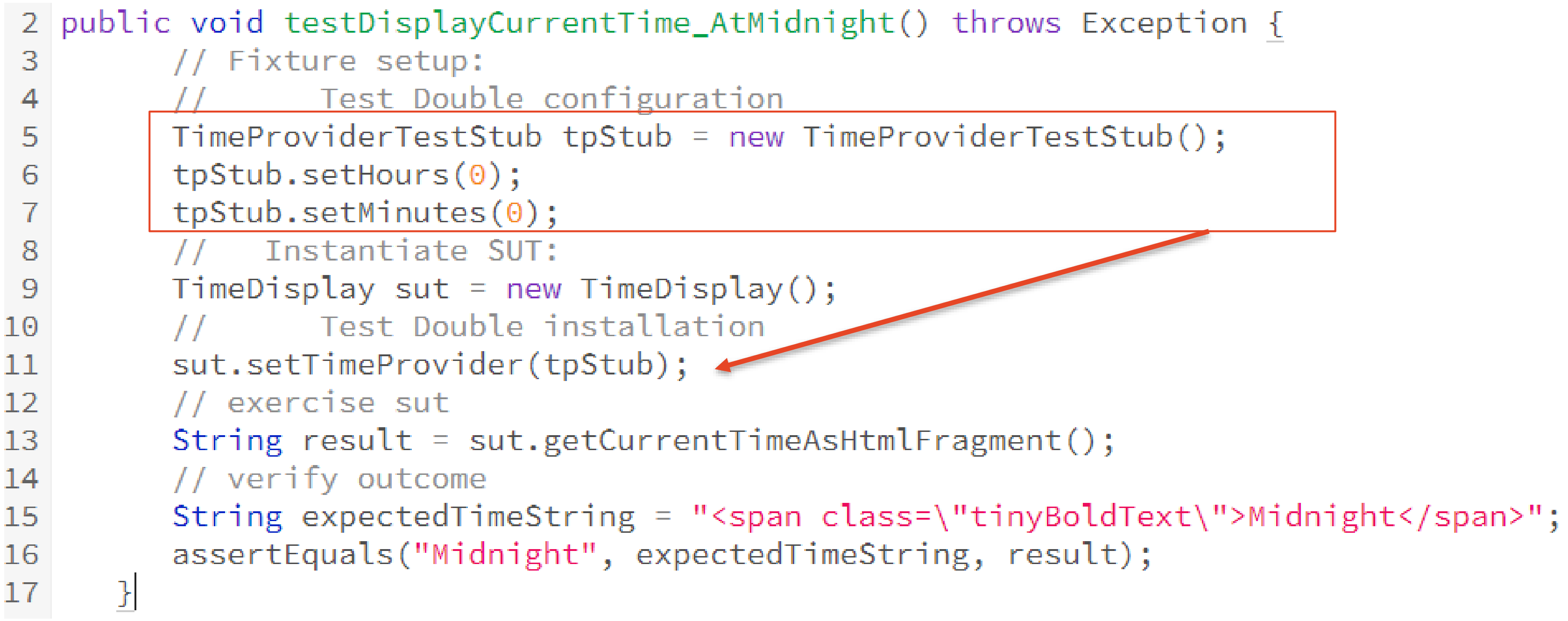


```
public void testInvoice_addLineItem_noECS() {
        final int QUANTITY = 1;
        Product product = new Product(getUniqueNumberAsString(), getUniqueNumber());
        State state = new State("West Dakota", "WD");
        City city = new City("Centreville", state);
        Address address = new Address("123 Blake St.", city, "12345");
        Customer customer= new Customer(getUniqueNumberAsString(), getUniqueNumberAsString(),
                                        address);
        Invoice inv = new Invoice(customer);
        // Exercise
        inv.addItemQuantity(product, QUANTITY);
        // Verify
        List lineItems = inv.getLineItems();
        assertEquals("number of items", lineItems.size(), 1);
        LineItem actual = (LineItem)lineItems.get(0);
        LineItem expItem = new LineItem(inv, product, QUANTITY);
        assertLineItemsEqual("",expItem, actual);
    }
```

(Test) Stub

- A test-specific object that provides indirect inputs during tests
  - E.g., Object requires data from a database to answer a method call
- Used to verify logic independently when it depends on inputs from other components
- Verify indirect inputs of the SUT
- It does not deal with indirect outputs of the system

(Test) Stub – Example



```java
public void testDisplayCurrentTime_AtMidnight() throws Exception {
      // Fixture setup:
      //      Test Double configuration
      TimeProviderTestStub tpStub = new TimeProviderTestStub();
      tpStub.setHours(0);
      tpStub.setMinutes(0);
      //   Instantiate SUT:
      TimeDisplay sut = new TimeDisplay();
      //      Test Double installation
      sut.setTimeProvider(tpStub);
      // exercise sut
      String result = sut.getCurrentTimeAsHtmlFragment();
      // verify outcome
      String expectedTimeString = "<span class=\"tinyBoldText\">Midnight</span>";
      assertEquals("Midnight", expectedTimeString, result);
   }
```

(Test) Spy

- Capture output calls made by the SUT to another component for later verification
  - Verify indirect outputs of the SUT

- Get enough visibility of the outputs generated by the SUT (observation point)

- E.g., email service that records no. of messages sent

(Test) Spy

- Capture output calls made by the SUT to another component for later verification
  - Verify indirect outputs of the SUT

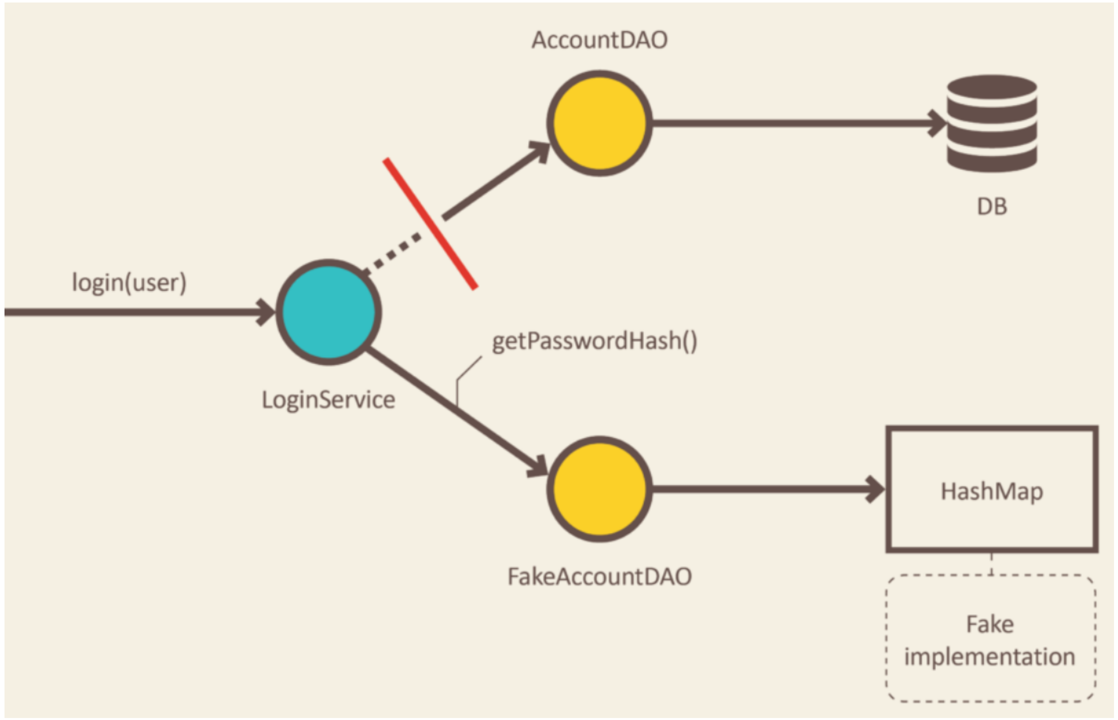
- Get enough visibility of the outputs generated by the SUT (observation point)

- E.g., email service that records no. of messages sent

Fake (Object)

- Objects to provide simplified implementation of a heavy (real) component
  - E.g., in-memory implementation of repository using simple collection to store data
- SUT depends on other components that are unavailable or make testing complex or slow
  - Run tests faster
- Should not be used when want to control inputs to SUT or outputs of SUT

Fake (Object) – Example



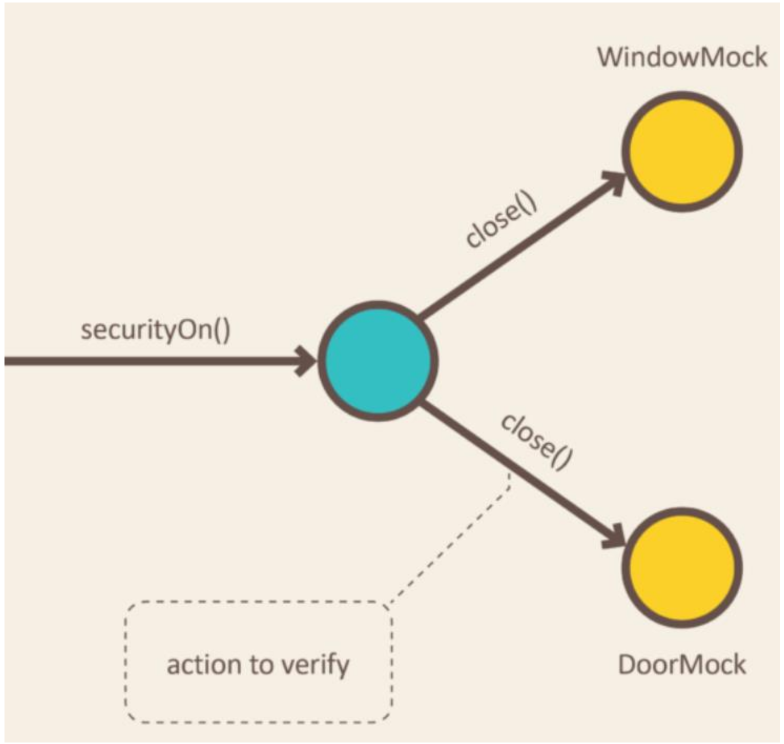
Mock (Object)

- Object(s) that verify indirect output of the SUT
  - E.g., function that calls email sending service, not to really send emails but to verify that email sending service was called

- Calling real implementation during testing is tedious, or the side effect is not the testing goal

- Unlike all doubles, mocks verify correctness against expectations

Mock (Object) – Example



Mock (Object)

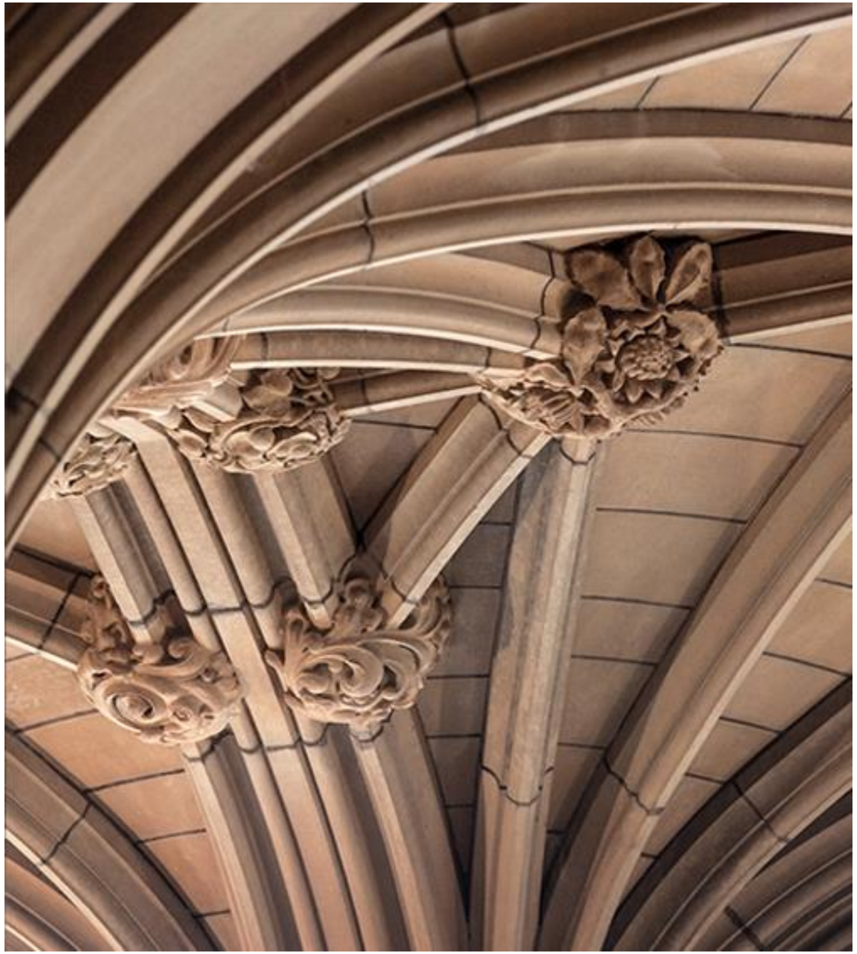
```java

public class SecurityCentral {
    private final Window window;
    private final Door door;

    public SecurityCentral(Window window, Door door) {
        this.window = window;
        this.door = door;
    }

    void securityOn() {
        window.close();
        door.close();
    }
}
```

```java

public class SecurityCentralTest {
    Window windowMock = mock(Window.class);
    Door doorMock = mock(Door.class);

    @Test
    public void enabling_security_locks_windows_and_doors() {
        SecurityCentral securityCentral = new SecurityCentral(windowMock, doorMock);
        securityCentral.securityOn();
        verify(doorMock).close();
        verify(windowMock).close();
    }
}
```

Test Doubles

- Understand the differences carefully and use the one that serve the verification type and purpose and how it should be run
- Don't be fooled by the mocking frameworks terminology – focus on the verification purpose
- Read Fowler's Mocks aren't Stubs
- Check xUnit Test Patterns for more advanced details

Contract Test



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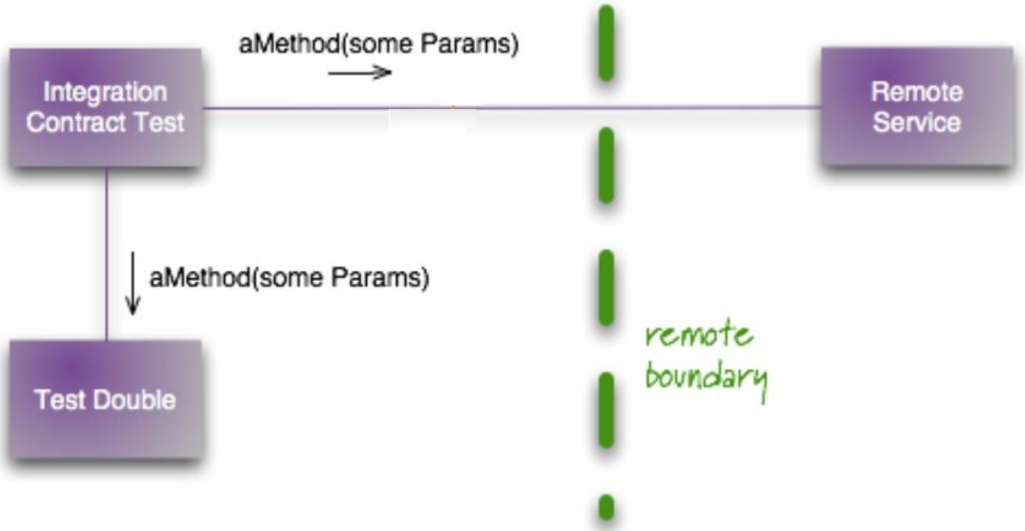
Test Double – External Services

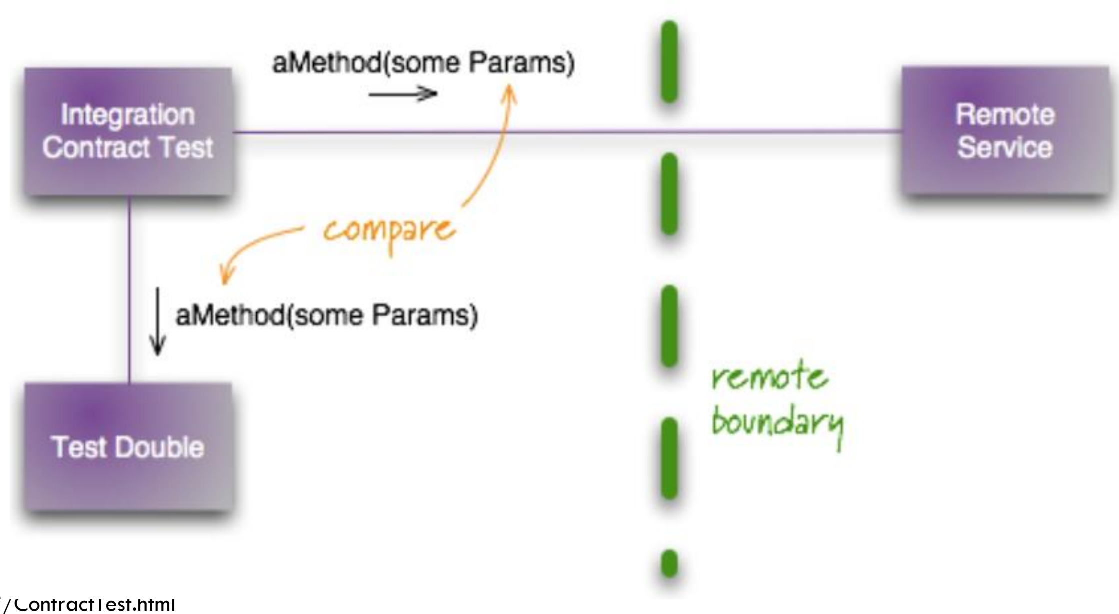
- Test double to interact with external/remote service
  - How accurate/reliable is a test double?



https://martinfowler.com/bliki/ContractTest.html

Test Double – External Services

- Service reliability
- Service contract changes

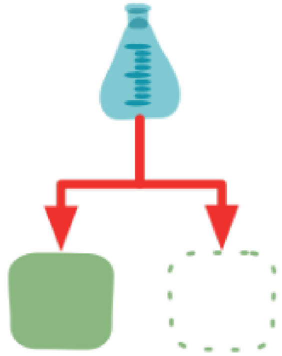


https://martinfowler.com/bliki/ContractTest.html

Contract Test

- The process of running periodic tests against real components to check the validity of test doubles results

- How?
  - Run your own test against the double
  - Periodically run separate contract tests (real tests to call the real service)
  - Compare the results
  - Check the test double in case of results inconsistency/failures
  - Also, consider service contract changes



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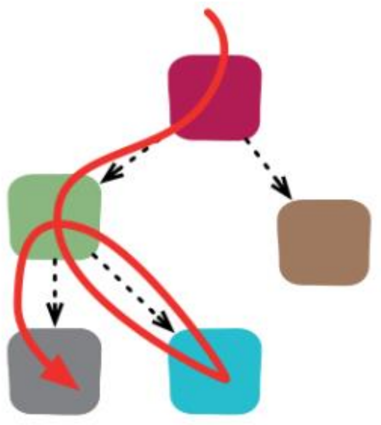
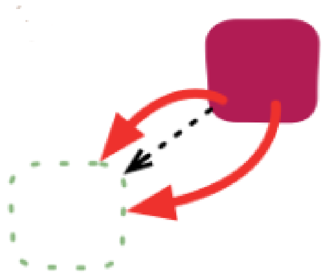
Integrated (Broad) Tests



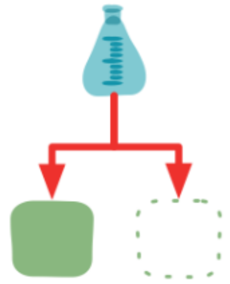
"Broad tests done with many modules active" – ***integrated*** *testing*

Read more for further discussion - https://martinfowler.com/bliki/IntegrationTest.html

Collaborative (Narrow) Tests



“*Narrow tests of interaction with individual test doubles*” – **Collaboration Tests**

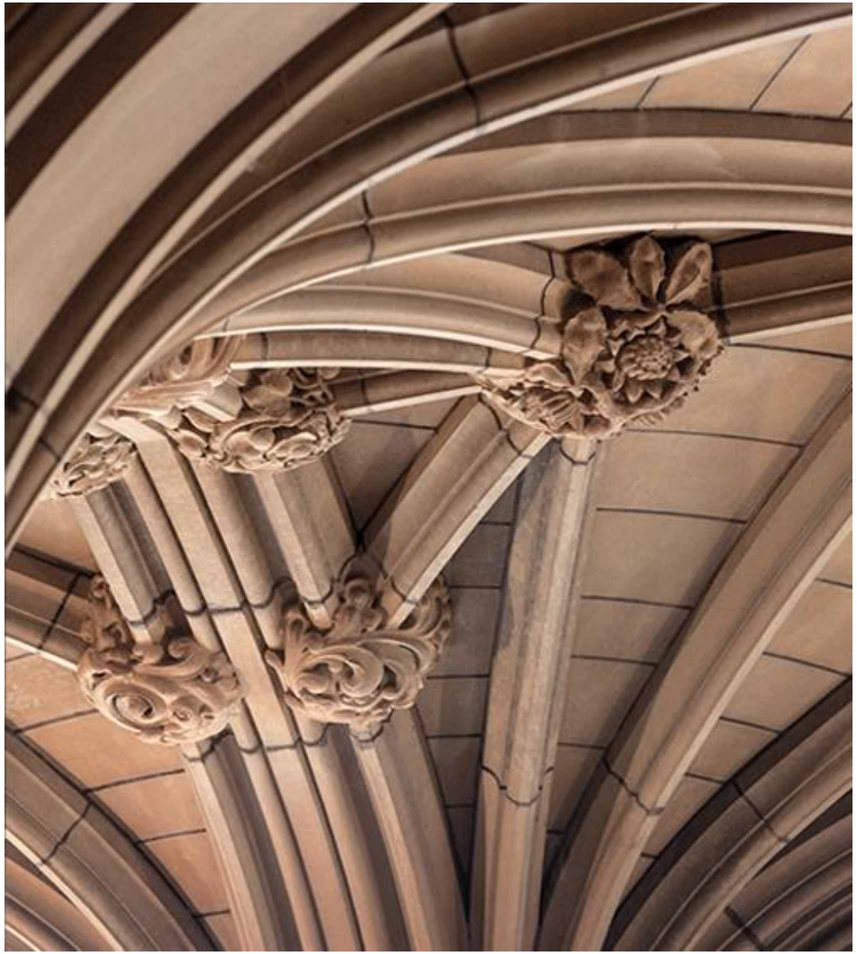


“supported by ***Contract Tests*** to ensure the faithfulness of the double” – Contract Tests

Read more for further discussion - https://martinfowler.com/bliki/IntegrationTest.html

Integration Testing Frameworks

Mockito



Mocking Frameworks

- Mockito
- JMock
- EasyMock
- Mountebank
- Others …

http://www.mbtest.org/
http://jmock.org/
http://easymock.org/

Mockito

- An open source testing (test spy) framework for Java
  - It has a type called 'spy' which is partial mock[1]
- Verify interactions after executing tests (what you want)
  - Not expect-run-verify (look for irrelevant interactions)
  - Interaction among objects/components not unit testing
- Allows to specify order of verification (not all interactions)

https://github.com/mockito/mockito/wiki/FAQ

Mockito – Constructs

Mockito Features	Description
mock(), @Mock or Mokito.mock()	Different ways to create a mock
Answer or MockSettings	Interfaces to specify how a mock should behave (optional)
when()	Specify the mock to return a value when a method is called
Spy() or @Spy	Caution: creates a (partial mock) for a given object
@InjectMocks	automatically inject mcoks/spies annotated with @Mock() or @Spy()
verify()	Check methods were called with given arguments

Note: call MockitoAnnotations.initMocks(testClass) (usually in a @Before method) to get the annotations to work. Alternatively, use MockitoJUnit4Runner as a JUnit runner

http://static.javadoc.io/org.mockito/mockito-core/2.24.0/org/mockito/Mockito.html

Mockito Example

```java

public class GradesService {
    private final Gradebook gradebook;

    public GradesService(Gradebook gradebook) {
        this.gradebook = gradebook;
    }

    Double averageGrades(Student student) {
        return average(gradebook.gradesFor(student));
    }
}
```

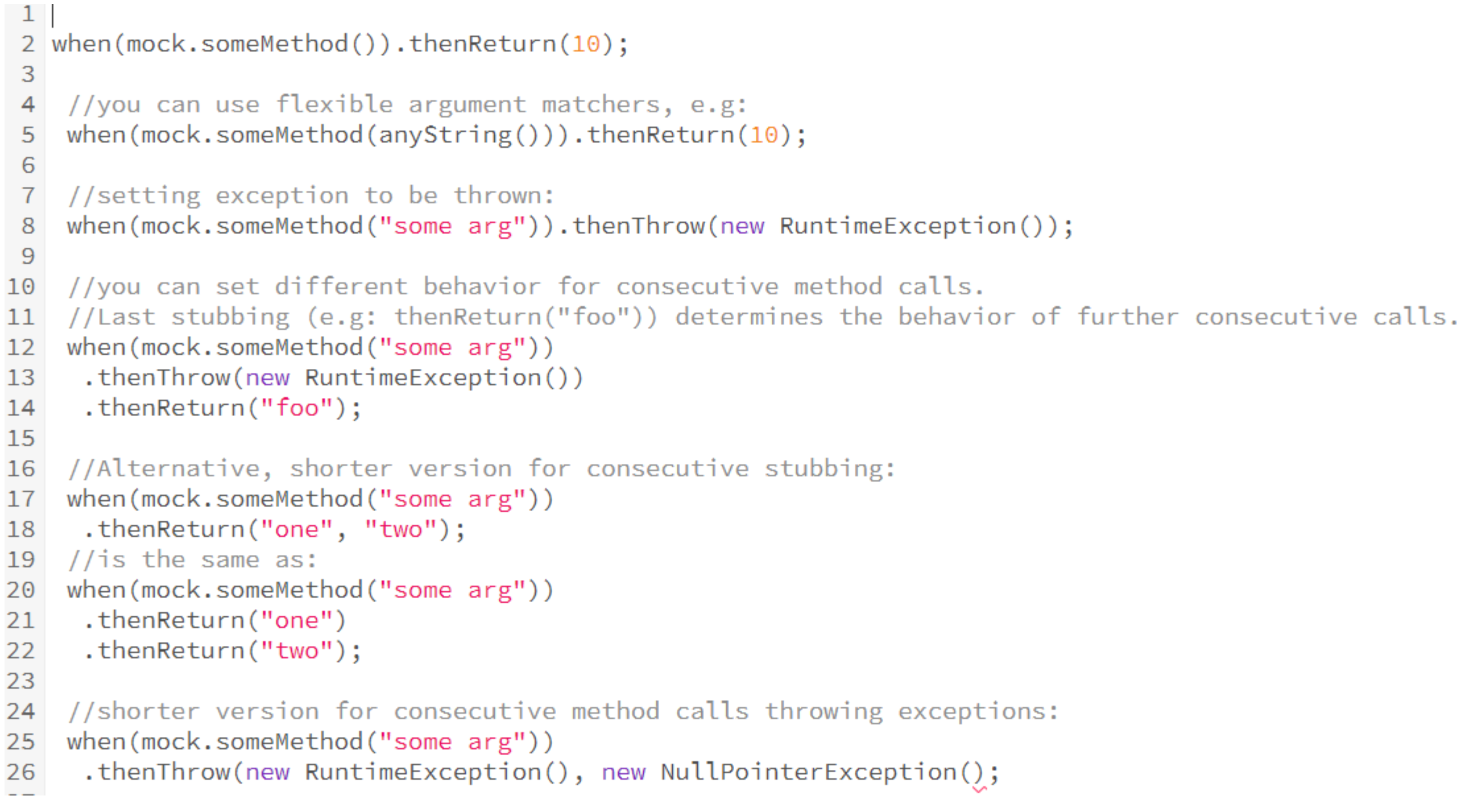
```java

public class GradesServiceTest {
    private Student student;
    private Gradebook gradebook;

    @Before
    public void setUp() throws Exception {
        gradebook = mock(Gradebook.class);
        student = new Student();
    }

    @Test
    public void calculates_grades_average_for_student() {
        when(gradebook.gradesFor(student)).thenReturn(grades(8, 6, 10)); //stubbing gradebook
        double averageGrades = new GradesService(gradebook).averageGrades(student);
        assertThat(averageGrades).isEqualTo(8.0);
    }
}
```

Mockito – Method Call

- Use Mockito.when() and thenRturn() to specify a behavior when a method is called
- Example of methods supported in Mockito

Method	Purpose
thenReturn(valueToBeReturned)	Return a given value
thenThrow(Throwable tobeThrown)	Throws given exception
Then(Answer answer)	User created code to answer

Mockito – 'When' Example



```

when(mock.someMethod()).thenReturn(10);

 //you can use flexible argument matchers, e.g:
 when(mock.someMethod(anyString())).thenReturn(10);

 //setting exception to be thrown:
 when(mock.someMethod("some arg")).thenThrow(new RuntimeException());

 //you can set different behavior for consecutive method calls.
 //Last stubbing (e.g: thenReturn("foo")) determines the behavior of further consecutive calls.
 when(mock.someMethod("some arg"))
  .thenThrow(new RuntimeException())
  .thenReturn("foo");

 //Alternative, shorter version for consecutive stubbing:
 when(mock.someMethod("some arg"))
  .thenReturn("one", "two");
 //is the same as:
 when(mock.someMethod("some arg"))
  .thenReturn("one")
  .thenReturn("two");

 //shorter version for consecutive method calls throwing exceptions:
 when(mock.someMethod("some arg"))
  .thenThrow(new RuntimeException(), new NullPointerException();
```

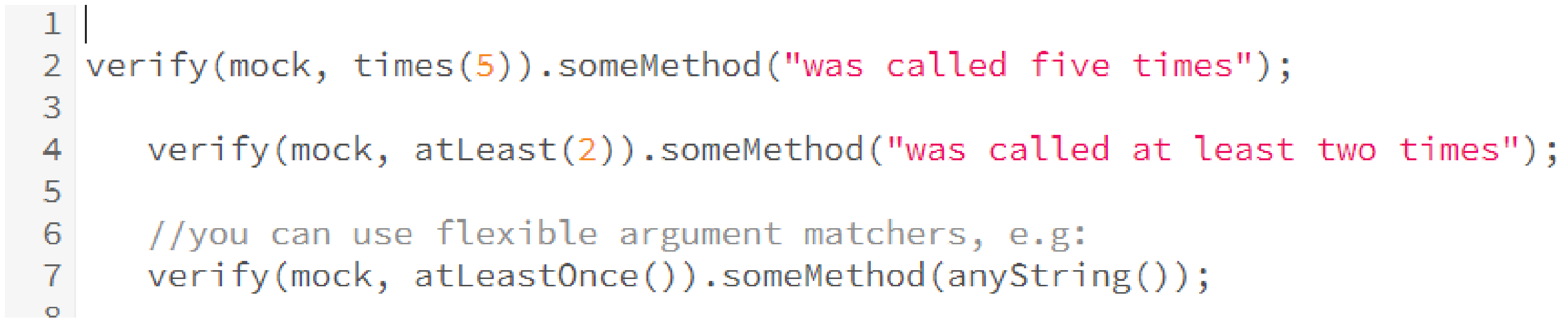
http://static.javadoc.io/org.mockito/mockito-core/2.24.0/org/mockito/Mockito.html#when-T-

Mockito – Verifying Behavior

- *Mockito.verify (T mockTobeVerified, verificationMode mode)*
  - Verifies certain behavior happened at least once (default) – e.g., a method is called once
  - Different verification modes are available

Verification Mode	Description
Times(int wantedNoCalls)	Called exactly n times, default = 1
atMost(in maxNoOfCalls)	Called at most n times
atLeast(int minNoOfCalls)	Called at least n times
never()	Never called
Timeout (int milliseconds)	Interacted in a specified time range

Mockito – Verifying Behavior Example



```

verify(mock, times(5)).someMethod("was called five times");

   verify(mock, atLeast(2)).someMethod("was called at least two times");

   //you can use flexible argument matchers, e.g:
   verify(mock, atLeastOnce()).someMethod(anyString());
```

- Default mode is times (1) which can be omitted
- Argument passed are compared suing equals() method

Mockito – Verifying Order of Calls

- InOrder (mocks) allows verifying mocks in order
  - *verify(mock)*: verifies interactions happened once in order
  - *verify(mock, VerificationMode mode)*: verifies interactions in order

```java

InOrder inOrder = inOrder(firstMock, secondMock);

 inOrder.verify(firstMock).add("was called first");
 inOrder.verify(secondMock).add("was called second");
```

```java

InOrder inOrder = inOrder(firstMock, secondMock);

 inOrder.verify(firstMock, times(2)).someMethod("was called first two times");
 inOrder.verify(secondMock, atLeastOnce()).someMethod("was called second at least once");
```

http://static.javadoc.io/org.mockito/mockito-core/2.24.0/org/mockito/InOrder.html

Writing Good Tests

Writing Good Tests

- Reliable
  - Free of bugs, defects or errors
- Fast
  - Should not be counterproductive, will be run very frequently
- Keep it compact and readable
  - Lots of refactoring
  - Follow recommended coding practices (e.g., naming conventions, documentation)
- Cover wide range to show positive cases and errorenous code paths

https://github.com/mockito/mockito/wiki/How-to-write-good-tests

Writing Good Tests

- Do not mock everything
  - It's anti-pattern
- Understand mocking framework's capabilities
  - Mock syntax vs. actual purpose of mocking
  - Read Fowler's Mocks aren't Stubs
- Do not mock type you do not own
  - Third-party library or API – owner change the signature and behavior of the API
  - Contract test ?
- Do not mock value objects
  - Instantiating an object is too painful – not a valid reason
  - Can be a sign that the code needs some serious refactoring or use builders for the value objects (some tools such as Lombok can help)

https://github.com/mockito/mockito/wiki/How-to-write-good-tests

Next Lecture/Tutorial

W4 Lecture: Advanced Testing Techniques 2

W4 Tutorial + quiz

References

- Ian Sommerville. 2016. Software Engineering (10th ed.) Global Edition. Pearson
- James Shore and Shane Warden. 2007. The Art of Agile Development
- Martin Fowler, various testing articles. https://martinfowler.com/
- Gerard Meszaros, xUnit Test Patterns: Refactoring Test Code. Addison-Wesley
- Martin Fowler, Mocks Arent Stubs, [https://martinfowler.com/articles/mocksArentStubs.html]
- Gaurav Duggal, Bharti Suri, Understanding Regression Testing Techniques. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.5875&rep=rep1&type=pdf
- Bernd Bruegge and Allen, H. Dutoit. 2009. Object-Oriented Software Engineering Using Uml, Patterns, and Java (3rd ed.). Pearson
- Michal Lipski, Pragmatists: Test doubles: Fakes, Mocks and Stubs. https://blog.pragmatists.com/test-doubles-fakes-mocks-and-stubs-1a7491dfa3da