Test Driven Development

CSCI 4448/5448: Object-Oriented Analysis & Design

Lecture 10

Acknowledgement & Materials Copyright

- I'd like to start by acknowledging Dr. Ken Anderson
- Ken is a Professor and the Chair of the Department of Computer Science
- Ken taught OOAD on several occasions, and has graciously allowed me to use his copyrighted material for this instance of the class
- Although I will modify the materials to update and personalize this class, the original materials this class is based on are all copyrighted © Kenneth M. Anderson; the materials are used with his consent; and this use in no way challenges his copyright

Quick look into Software Testing

Testing effectively may be just as important a part of designing and developing well, so let’s give it a bit of attention…

Definitions

- Verification – ensuring your code meets engineering requirements
- Validation – ensuring your code meets application expectations
- Testing – running a program on selected inputs and checking the results

- Formal verification – constructing a proof that a program is correct
- Z notation – a formal specification for describing and modeling business requirements for a program with relational algebra – allows code to be "correct by construction"

- Reference [1]

Software Quality Expectations

- 1 - 10 defects/kloc: Typical industry software
- 0.1 - 1 defects/kloc: High-quality validation - the Java libraries might achieve this level of correctness
- 0.01 - 0.1 defects/kloc: The very best, safety-critical validation, NASA
- Kloc = 1000 lines of code

So a 100,000 lines of typical industry source code (at the low end of 1 defect/kloc), it means you missed 100 bugs!

Reference [2]

Why Software Testing is Hard

- **Exhaustive testing** is infeasible. The space of possible test cases is generally too big to cover exhaustively. Imagine exhaustively testing a 32-bit floating-point multiply operation, a*b . There are 2^64 test cases!
- **Haphazard testing** ("just try it and see if it works") is less likely to find bugs, unless the program is so buggy that an arbitrarily-chosen input is more likely to fail than to succeed. It also doesn't increase our confidence in program correctness.
- **Random or statistical testing** doesn't work well for software. Other engineering disciplines can test small random samples (e.g. 1% of hard drives manufactured) and infer the defect rate for the whole lot. Physical systems can accelerate tests, e.g. opening a refrigerator 1000 times in 24 hours instead of 10 years. This assumes continuity or uniformity across the space of defects that's only true for physical artifacts.

Reference [2]

Why Software Testing is Hard

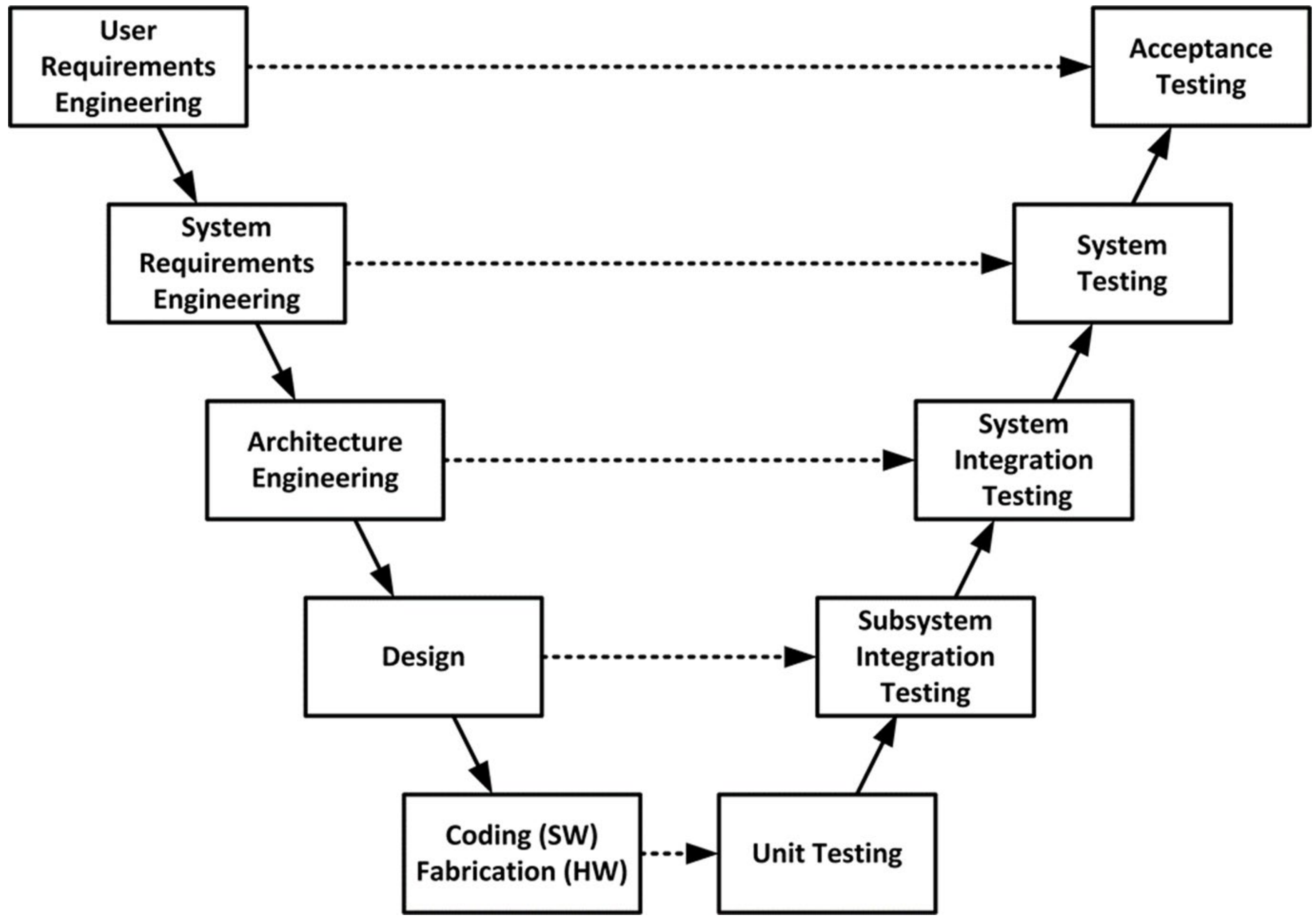
- Software behavior varies discontinuously and discretely across the space of possible inputs
  - The system may seem to work fine across a broad range of inputs, and then abruptly fail at a single boundary point
  - The famous Pentium division bug affected approximately 1 in 9 billion divisions
- In physical systems, there is often visible evidence that the system is approaching a failure point (cracks in a bridge) or failures are distributed probabilistically near the failure point
  - In a physical system, statistical testing will observe some failures even before the point is reached

Reference [2]

Multiple Levels of Testing for Systems

We have to consider how we will prove out our code at each level – from units, to sub systems, to integration, to full system tests, and to acceptance testing…

Reference [3]



Making Software Testing Work

- Test cases must be chosen carefully and systematically
- As a developer, our goal is to make the program work
- As a tester, you want to make it fail
- This is often a difficult transition for a developer
- Testers must identify and seek out vulnerabilities in order to eliminate them

- Reference [2]

Test-after/Test-with

- Often, we develop code in a “**test-after**” fashion. We develop the code, get it running, and then start to look for issues.
  - One of the issues with test-after goes back to the cost of finding and fixing defects, which increases as we get closer to finalizing our system
- A step improved from this is “**test-with**” development, where each element of code we write is written along with test cases to unit test that particular code.
  - At least here, we are taking the time to consider how the code should be tested and including some test infrastructure
  - We can also use these test cases in automated testing when new builds are made to see if changes to code have broken our expected behaviors

Test Driven Development

- A recognized best practice is "**test-first**" development, which is the basis of **Test Driven Development or TDD**
- In TDD, we start with a specification, develop tests that exercise that specification, and the write the code for the functionality – once your code passes the tests, you're done
- The specification indicates the input and output behavior of system elements
  - Types of parameters and any constraints
  - Type of return value and how inputs relate to that return value

- Reference [2]

Writing Tests Strengthens Specifications

- When you start to develop tests, you begin to question the specification
- Is anything incorrect, incomplete, ambiguous?
- Are there odd corner cases to consider?

- Writing a test early to prepare for and address these issues prevents wasted time implementing code from a buggy specification.

- Reference [2]

Partitioning for Test Cases

- Developing a test suite is in itself a challenging and interesting design problem – finding a small set of cases to run quickly that still validates the code
- One approach to this is dividing the input space into subdomains with sets of inputs
  - Our goal is to have subdomains that cover all of input space, so any possible input is present in at least one subdomain
  - This allows us to develop specific tests for each subdomain
  - This ensures testing coverage, that we're not missing parts of the input space that random tests might not reach
- In some cases, we may have to consider the subdomains of the output space as well to ensure coverage, but usually inputs are the focus
- Reference [2]

Subdomain example

- Consider a simple multiply function for two large integer values – a, b
- Typical partitions might include
  - a and b are positive
  - a and b are negative
  - one or the other are negative and positive
- Special cases might include a or b becoming 0, 1, or -1
- Should consider boundaries – a and b small, absolute value of a or b bigger than maximum integer sizes
- Covering the space of 7 variations for 2 parameters is 49 tests!

- Reference [2]

Black Box vs. White Box Testing

- Black Box testing – decisions are made only based on the specification; we do not consider any knowledge of how a function works
- White Box (aka Clear Box or Glass Box) testing – testing with knowledge of code internals
  - For instance, if you know certain combinations of inputs will force different algorithms or code sections to be visited, you should partition tests and subdomains to visit them as needed
  - Care should be taken not to test cases that are not part of the specification
- Reference [2]

Test Coverage

- Coverage - How thoroughly does a test set exercise a program
- Types (in increasing strength – i.e. takes more tests to achieve):
  - Statement coverage: is every statement run by some test case?
  - Branch coverage: for every if or while statement in the program, are both the true and the false direction taken by some test case?
  - Path coverage: is every possible combination of branches – every path through the program – taken by some test case?
- 100% path coverage is usually infeasible, requiring exponential-size test suites to achieve
- 100% statement coverage is rare due to unreachable defensive code (like “should never get here” assertions)
- 100% branch coverage is highly desirable

- Reference [2]

Test Coverage

- One standard approach to testing is to add tests until the test suite achieves adequate statement coverage
- That is, every reachable statement in the program is executed by at least one test case
- In practice, statement coverage is usually measured by a code coverage tool, which counts the number of times each statement is run by your test suite
- With such a tool, white box testing is easy; you just measure the coverage of your black box tests, and add more test cases until all important statements are logged as executed

- Reference [2]

Automated Tests, Regression Tests

- If you're using TDD, you will have suites of unit tests for your code that could be run at every build in your DevOps cycles – this is automated testing – of the test cases you and your team developed by hand
  - As opposed to automatic test generation which is a hard problem, and an subject of active computer science research
- Regression testing refers to test cases added to verify a modification was successful (to keep your code from regressing, i.e. getting worse)
- Suites of unit and regression tests grow as code matures
- The greatest value of these tests is when the tests are run often and automatically for builds

- Reference [2]

Three General Goals for Good Software

- Response to change
  - Readiness for change is supported by writing tests that depend on behavior in a specification
  - Automated regression testing helps keep bugs from coming back when changes are made
- Safe from bugs
  - Testing is about finding bugs in your code, and test-first programming is about finding them as early as possible, immediately when you introduced them
- Easy to understand
  - Readability, maintainability,…
  - More part of documentation, code standards, and code review

- Reference [2]

Test Frameworks

- Unit Test Harness
  - Software package to assess code – provides:
  - A common language to express test cases
  - A common language to express expected results
  - Access to the features of the production code programming language
  - A place to collect the unit test cases for the project, system, or subsystem
  - A mechanism to run the test cases, either in full or in partial batches
  - A concise report of the test suite success or failure
  - A detailed report of any test failures
- Reference [4]

Test Frameworks

- Mocks
  - The mock object (or simply the mock) is a test double
  - It allows a test case to describe the calls expected from one module to another
  - During test execution the mock checks that all calls happen with the right parameters and in the right order
  - The mock can also be instructed to return specific values in proper sequence to the code under test
  - A mock is not a simulator, but it allows a test case to simulate a specific scenario or sequence of events
- Reference [4]

Test Frameworks

- Frameworks for Java [5]
  - JUnit
  - JBehave
  - Serenity
  - TestNG
  - Selenide
- Frameworks for Python [6]
  - Robot
  - PyTest
  - UnitTest/PyUnit
  - Behave
  - Lettuce
  - Nose

```
import static org.junit.jupiter.api.Assertions.assertEquals;

import org.junit.jupiter.api.Test;

public class MyTests {

    @Test
    public void multiplicationOfZeroIntegersShouldReturnZero() {
        MyClass tester = new MyClass(); // MyClass is tested

        // assert statements
        assertEquals(0, tester.multiply(10, 0), "10 x 0 must be 0");
        assertEquals(0, tester.multiply(0, 10), "0 x 10 must be 0");
        assertEquals(0, tester.multiply(0, 0), "0 x 0 must be 0");
    }
}
```

From Tutorial at [7]

JUnit Notes

- Typical Method Annotations
  - @Test – makes a public method into a test case
  - @Before, @After – methods to run before/after every test case
  - @BeforeClass, @AfterClass – methods to run before/after any/all test cases run
- Typical Assertions
  - assertTrue(test), assertFalse(test) – check Boolean tests
  - assertEquals, assertSame, assertNotSame – check equality
  - assertNull, assertNotNull – check for null elements/objects
  - fail – force test to fail
- Best practices
  - Write the test to know EXACTLY what failed if test doesn't pass
  - Tests should be self contained and not dependent on each other
  - Focus on boundary, empty, and error cases and combined behavior

https://courses.cs.washington.edu/courses/cse331/11sp/sections/section4-cheat-sheet.pdf

Help for JUnit

- Junit.org is the home site for the tools (both 4 and 5):
  - https://junit.org/junit5/ or https://junit.org/junit4/
- I very much like this cycle of tutorials, presented step by step:
  - http://tutorials.jenkov.com/java-unit-testing/simple-test.html
  - These tutorials are for JUnit 4.8, JUnit 5.8 is also in use but has some minor differences – you can use either
    - Summary of JUnit 4 vs 5 here: https://howtodoinjava.com/junit5/junit-5-vs-junit-4/
    - Also a good tutorial: https://howtodoinjava.com/junit-5-tutorial/
- A nice best practice discussion
  - https://phauer.com/2019/modern-best-practices-testing-java/
- Another nice cheat sheet
  - https://www.jrebel.com/blog/junit-cheat-sheet
- Applying design patterns (observer, singleton, factory, template) to JUnit:
  - JUnit Recipes book - https://livebook.manning.com/book/junit-recipes/chapter-14/

- To clarify: For classroom use of JUnit, I'm really interested in your exploring the tool, not in comprehensive industrial strength test cases…
  - Having said that, how deep you go in using it past project requirements is up to you

Summary

- TDD is a learned approach, it’s not something most developers do by default
- If you can’t do “test-first” at least consider “test-with” where developing repeatable test cases for your code becomes part of your normal development
- Don’t be surprised to find an industry environment where TDD or test-with is part of the development cycle because of automated DevOps processes that want to apply tests to every build
- I will be requiring some test case development in your projects going forward, although I won’t be asking for as extensive a test suite as you might do in an industry environment

Test Frameworks References

[1] https://www.hillelwayne.com/post/why-dont-people-use-formal-methods/

[2] https://ocw.mit.edu/ans7870/6/6.005/s16/classes/03-testing/

[3] https://insights.sei.cmu.edu/sei_blog/2013/11/using-v-models-for-testing.html

[4] Test Driven Development for Embedded C, Grenning, 2011, Pragmatic Bookshelf

[5] https://dzone.com/articles/top-5-java-test-frameworks-for-automation-in-2019

[6] https://www.lambdatest.com/blog/top-5-python-frameworks-for-test-automation-in-2019/

[7] https://www.vogella.com/tutorials/JUnit/article.html