Is Unit Testing Worth The Trouble?

Nima Seyedtalebi

University of Kentucky

November 7, 2018

Background

- The IEEE Software Engineering Body of Knowledge (SWEBOK) provides a concise definition of software testing: "Software testing consists of the *dynamic* verification that a program provides *expected* behaviors on a *finite* set of test cases, suitably *selected* from the usually infinite execution" [12]
- Key points:
  - Dynamic: Input and source code are not always enough to determine behavior
    - Examples: I/O, SLF4J
  - Expected: We must be able to define expected behavior to test for it
  - Finite: The set of possible test cases is practically infinite, so we must choose a finite subset
  - Selected: Test cases can vary in usefulness considerably, so the choice is important

Different Kinds of Testing

- Testing can be classified by target or objective
- Classifying by target gives three levels:
  - Unit Testing: Small pieces of software testable in isolation
  - Integration Testing: Interactions between software components
  - System Testing: An entire system
- Classifications by objective:
  - Regression testing
  - Acceptance testing
  - Security testing
  - Performance testing
  - Stress testing

What is Unit Testing?

- From the SWEBOK: "Unit testing verifies the functioning in isolation of software elements that are separately testable." [12]
  - What constitutes a unit? It depends on context
  - Developers may have differing ideas about what constitutes a unit
- Usually performed by the developer of the unit or someone with programming skills and access to the source code
- Surveys suggest unit testing is an important testing method that sees widespread use
- Unit testing is sometimes conflated with other kinds of testing
  - E.g. a "unit test" that relies on a database connection is not a unit test under the definition given

Testing Terms and Software Metrics

- Failure: An undesired behavior
- Fault: The cause of a failure
- Defect: A fault or failure
- General software measures:
  - Code size (lines of code)
  - Number of independent paths through code (cyclomatic complexity)
  - Degree of nesting
  - Average number of parameters
  - Fan-out, or how many classes does this class use?
  - Fan-in, or how many classes use this class?
- Survey data are used to measure things that are difficult to measure objectively

Challenges in Software Testing

- Tests that are written without referring to some external specification can only suggest that the code does what the developer intended
- Exhaustive testing is impractical at best and impossible at worst. Consider a program similar to "echo" in Unix that takes a Unicode string argument:
  - With Unicode 11, 137374^n permutations of length n are possible[3]
- Some tests are more useful than others. How do we choose the best set of tests?
- How do we know if we have enough tests?
- How do we know if testing is effective?
- Testing always involves a trade-off. More tests may find more problems, but tests take time to write and maintain

Common Techniques for Choosing a Test Set

- Ad-hoc: Choose test inputs based on intuition and experience
- Boundary-value Analysis: Choose inputs close to boundaries in the input domain e.g. largest and smallest possible values for numerical datatypes
- Code-based analysis techniques:
  - Control Flow Analysis: Choose tests that follow a subset of the possible control flow paths through the code
  - Data Flow Analysis: Choose tests that follow a subset of the possible data flow paths through the code
  - Mutation Analysis: Choose tests that fail when the program under test is changed slightly
- The code-based techniques are often used to assess test sufficiency

Control-Flow and Data-Flow Analysis

- Units contain assignment statements and conditional statements
- Units have well-defined entry and exit points
- A *path* is a sequence of instructions
- Conditional statements determine control flow
- Assignment statements determine data flow
- Control-flow and data-flow analysis both involve selecting tests so their execution follows different paths through the code
- They differ in perspective and how paths are selected:
  - Control flow analysis considers paths between the entry and exit points
  - Data flow analysis considers paths that start with an assignment statement and end with the last use of the variable

Coverage Metrics

- Coverage metrics assess how many execution paths are tested versus how many are possible
- Metrics are based on desired level of coverage
- More complete coverage means exploring a larger portion of the possible execution paths
- Path selection criteria for control-flow analysis:
  - Statement Coverage: All statements are executed at least once
  - Branch Coverage: Every branch is taken at least once
  - Predicate Coverage: Every combination of truth value for every conditional is tried at least once
  - All-Paths Coverage: Every execution path is tried at least once
- Path selection criteria for data-flow analysis are based on when variables are defined and used

Mutation Analysis

- Mutation score comes from mutation analysis, first proposed in a 1978 article "Hints on Test Data Selection" [5]
- Key insights:
  - Programmers usually write software that is "almost correct"
  - Finding simple errors uncovers complex errors
- Used to assess test data sufficiency
- Mutation analysis involves making small, syntactically-legal changes to the unit under test, producing *mutants*
  - If the mutant causes some test to fail, it is said to be *dead*
  - If the mutant does not cause any tests to fail, it is said to be *alive*,*killable*, or *stubborn*
  - Mutants are killed when the test set is sufficiently sensitive to detect the mutation
- Mutation score is the number of mutants killed divided by the total number of mutants

What Does a Good Test Look Like?

- Bowes et al.[2] wrote a paper called "How Good Are My Tests" that contained fifteen principles to follow when writing unit tests
- Some of them include:
  - "Simplicity"
  - "Readability and Comprehension"
  - "Single-responsibility" (fail for one reason)
  - "Avoid over-protectiveness" (e.g. redundant assertions)
  - "Test behavior (not implementation)"
  - "Tests should not dictate the code"
  - A test should fail. Tests that never fail are useless
  - "Reliability", and no nondeterminism
  - "Happy vs. sad tests"
    - "Happy" tests verify system behavior
    - "Sad" tests break the system
    - Both are useful, but confirmation bias creeps in and causes us to favor "happy" tests

Arguments for Unit Testing

- Helps uncover defects early in the development process
- Allows developers to refactor with confidence because breaking changes will cause the tests to fail
- Can encourage good software design
  - Unit testing requires the unit under test (UUT) to be isolated
  - Tightly-coupled units require more effort to test
  - Tightly-coupled units are less robust
  - Difficulty or undue effort in testing indicates suggest code needs refactoring to reduce coupling
- Tests serve as a form of documentation

Arguments Against, or Unit Testing Considered Harmful

- Unit testing does not positively affect code quality in practice
  - Most tests only assess whether the code does what the developer intended
  - Developers write lower-quality code to meet coverage-based requirements
- Low-quality tests are worse than no tests at all since they must be maintained
- Unit tests provide a false sense of security
- Unit testing costs more time than it saves
- Integration and system testing are more effective at uncovering defects

What Does the Research Say?

- No correlation found yet between unit testing and code quality[7]
- No correlation found between coverage-based methods for determining test sufficiency quality and code quality[7]
- Developers need a better understanding of what makes a unit test good[4]
- Test-Driven Development (TDD), of which unit testing is an integral part, seems to measurably improve software quality in some cases[11],[8]
- Automated test generation is in use, but mostly used in cases where specifications are not required[4]

What About Test-Driven Development?

- Test-driven development (TDD) is a development style built around two rules:[1]
  - "Write new code only if you first have a failing automated test"
  - "Eliminate duplication"
- Important points:
  - Test: Unit tests are written before new code
  - Failing: The test must fail at first
  - Automated: Tools are used to run tests and collect results
- "The goal is clean code that works..." [1]
  - Clean code has the smallest possible number of dependencies
  - Empirical studies of TDD use different measures
  - The ambiguity was probably intentional[1]

[1] *Test-Driven Development By Example* says,"TDD is an awareness of the gap between decision and feedback during programming,and techniques to control that gap"

...and the Research?

- A 2008 article [8] found modest improvements in code size and complexity but not in coupling or cohesion
- A 2013 meta-analysis[11] of 27 empirical studies found that TDD "results in a small improvement in quality but results on productivity are inconclusive."
- A recent (July 2018) article[9] called "What Do We (Really) Know About Test-Driven Development?" offers the following:
  - Use of TDD is uncommon in practice
  - TDD does appear to improve some measures of quality in some cases
  - Evidence for the effects of TDD on productivity is inconclusive
  - The order of testing is not the important part of TDD
  - Using a short development cycle had much more impact on quality than the order of testing (test-first versus test-last)

Conclusions

- Unit testing *can* be worth the trouble, but it is not sufficient by itself to improve software quality
- An iterative development process with short, gradual steps seems to improve software quality
- Unit testing and TDD are tools. Like other tools, they work best in the hands of those that know how to use them
- Test quality is very important since we are limited to a very small subset of possibilities when testing
- Testing is a balancing act
  - Test selection is an important problem
  - Tests are not free to maintain, even if a machine writes them for you
- Automation and tool support is a poor substitute for thinking about design

So What Can Be Done?

- "A Survey On Unit Testing Practice and Problems" [4] suggests:
  - Developers need help identifying what to test and whether a given test is good or not
  - Automatic test generation helps with the "how" of testing but not the "what"
  - The question of "what" is shared across all types of testing
  - Tests should be realistic
- Furthermore:
  - Software design is a skill that must be learned and practiced
  - Though part of design, testing is a distinct skill that must be learned and practiced

References:


Kent Beck.
Test-Driven Development By Example.
Addison-Wesley Professional, 2003.


David Bowes, Tracy Hall, Jean Petrić, Thomas Shippey, and Burak Turhan.
How good are my tests?
In *Proceedings of the 8th Workshop on Emerging Trends in Software Metrics*, WETSoM '17, pages 9–14, Piscataway, NJ, USA, 2017. IEEE Press.


The Unicode Consortium.
The Unicode Standard Version 11.0 - Core Specification.
The Unicode Consortium, 2018.


E. Daka and G. Fraser.
A survey on unit testing practices and problems.
In *2014 IEEE 25th International Symposium on Software Reliability Engineering*, pages 201–211, Nov 2014.


R. A. DeMillo, R. J. Lipton, and F. G. Sayward.

Hints on test data selection: Help for the practicing programmer.
Computer, 11(4):34–41, April 1978.


D. Fucci, H. Erdogmus, B. Turhan, M. Oivo, and N. Juristo.
A dissection of the test-driven development process: Does it really matter to test-first or to test-last?
IEEE Transactions on Software Engineering, 43(7):597–614, July 2017.


L. Gren and V. Antinyan.
On the relation between unit testing and code quality.
In *2017 43rd Euromicro Conference on Software Engineering and Advanced Applications (SEAA)*, pages 52–56, Aug 2017.


D. Janzen and H. Saiedian.
Does test-driven development really improve software design quality?
IEEE Software, 25(2):77–84, March 2008.


I. Karac and B. Turhan.
What do we (really) know about test-driven development?

IEEE Software, 35(4):81–85, July 2018.


Kshirasagar Naik and Priyadarshi Tripathy.
Software testing and quality assurance: theory and practice.
John Wiley & Sons, 2011.


Y. Rafique and V. B. Mišić.
The effects of test-driven development on external quality and productivity: A meta-analysis.
IEEE Transactions on Software Engineering, 39(6):835–856, June 2013.


IEEE Computer Society, Pierre Bourque, and Richard E. Fairley.
Guide to the Software Engineering Body of Knowledge (SWEBOK(R)): Version 3.0.
IEEE Computer Society Press, Los Alamitos, CA, USA, 3rd edition, 2014.