

A Testing Tool for Introductory Programming Courses

Thesis A Seminar

Kyu-Sang Kim
z5208931

Supervised by Andrew Taylor (UNSW)
Assessed by John Shepherd (UNSW)

Term 1, 2022

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- 2 How much of the marking process can be automated via tools?
- 3 Will the automation tools remain viable as assessments change?

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- 5 Deeper exploration of architecture and implementation details in Background section of Seminar

Technical Debt

- 1 We approach technical debt as outlined in the framework defined within *An Exploration of Technical Debt*¹

¹Tom Edith, Aybüke Aurum and Richard Vidgen, ‘An Exploration of Technical Debt’ (2013) 86(6) *The Journal of systems and software* 1498

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- 3 How can we reconcile existing technical debt and ensure debt remains manageable in the future?

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Introducing all of these technical debt management solutions to the existing Andrew Taylor autotest software package has been determined to be infeasible due to the extensive refactoring required.

Thus, we propose that a new software package be created from a clean slate to minimise potential sources for both current and future technical debt from the ground up.

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- 5 Perform proving and performance tests on the new software package
- 6 Deprecate and replace the existing autotest used for introductory programming courses at UNSW CSE

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- 3 How can we eliminate or reduce these issues?

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Automated Testing & Marking Approaches

- 1 The earliest example of automated testing on student code was published in 1960 by Jack Hollingsworth of the Rensselaer Polytechnic Institute⁴

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 - Increasing enrolments for programming courses per teaching period becomes economically feasible

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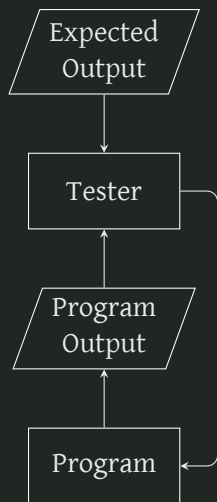
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 - Combination of above⁵
- 2 What are the specifics of these methodologies and what are some existing automated testing frameworks?

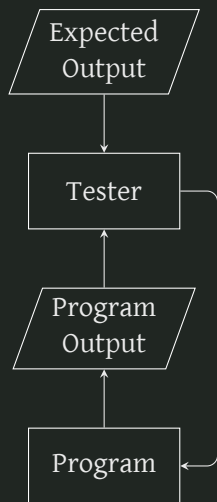
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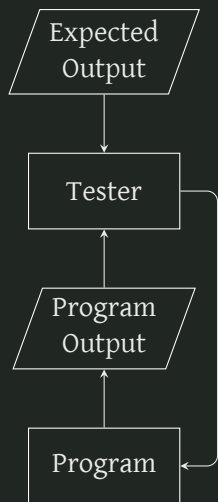
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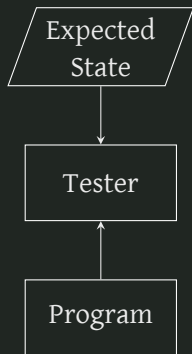
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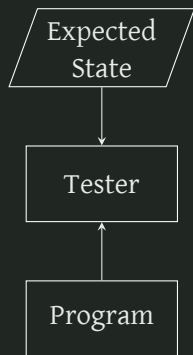
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- 2 This output can be **externally compared** with those pre-generated by a sample solution to determine whether expected behaviour has been achieved
- 3 Comparisons on side-effects after program execution allows for easier testing of complex programs with dependencies on multiple different components at the cost of storage space

Internal Program Unit Testing

- 1 Assume unit testing refers to the testing of **individual discrete code components** within the program by comparing internal program state to a known expected state pre-generated by a sample solution

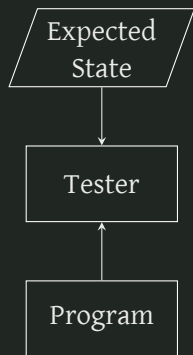


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- 2 Executing and collecting the results of the internal unit tests for the program can be used to determine whether expected behaviour has been achieved
- 3 Testing internal code components allow for more thorough determination of program correctness at the cost of difficulty in testing more complex programs which may not be able to share the same unit testing framework

Andrew Taylor autotest

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- 5 Current UNSW CSE automated general code testing tool utilised for lab and assessment marking in most introductory programming courses and at times, some higher level courses (COMP Level 2+)

Andrew Taylor autotest implementation details

Listing 1: autotest Example Test Cases

```
files=is_prime.c

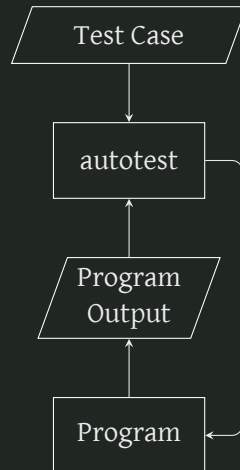
1 stdin="39" expected_stdout="39 is not prime\n"
2 stdin="42" expected_stdout="42 is not prime\n"
3 stdin="47" expected_stdout="47 is prime\n"
```

Listing 2: autotest Wrapper

```
#!/bin/sh

parameters="
default_compilers = {'c' : [['clang', '-Werror', '-std=gnu11', '-g', '-lm']]
upload_url = https://example.com/autotest.cgi
"

exec <path_to_autotest>/autotest.py --
exercise_directory <path_to_exercise_dir> --
parameters "$parameters" "$@"
```



Andrew Taylor autotest pros & cons

1 Pros:

- Proven to be *mostly* reliable at UNSW CSE
- Can support any programming language assuming autotest can detect and compare side-effects
- Extensive parameters exposed to manage test execution environment
- Test results on failure provide meaningful information on the differences between actual and expected output

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2 Cons:

- High levels of technical debt due to outdated use of technology and architecture
- Significant lack of documentation
- Difficult for first-time users to create tests and manage test execution environment

Harvard CS50 check50

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- 5 Current Harvard University CS50: Introduction to Computer Science automated general code testing tool for checking correctness of practical lab exercises

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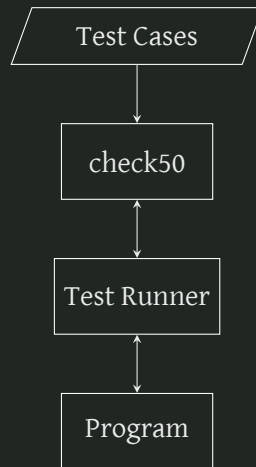
Listing 3: check50 tests

```
import check50
import check50.c

@check50.check()
def exists():
    """hello.c exists"""
    check50.exists("hello.c")

@check50.check(exists)
def compiles():
    """hello.c compiles"""
    check50.c.compile("hello.c", lcs50=True)

@check50.check(compiles)
def emma():
    """responds to name Emma"""
    check50.run("./hello").stdin("Emma").stdout("Emma").
    exit()
```



Harvard CS50 check50 Pros & Cons

1 Pros:

- Tests are very simple to create as a chain of functions
- Documentation is very extensive
- Testing results can be rendered to HTML via a module for easier viewing
- Supports running of tests on both local and remote machines (PaaS Support)
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2 Cons:

- As a result of design choice for simplicity, testing of complex programs can be challenging (may require Harnessing)
- No official support or implementations for programming languages outside of C and Python (Flask Supported)

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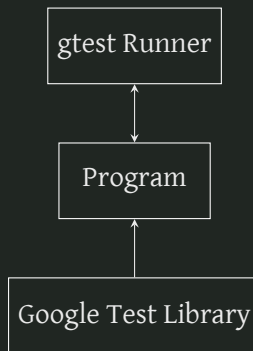
Google gtest

- 1 **Author(s) & Introduction:** Google - v1.0.0 released in 2008
- 2 **Testing Methodology:** Internal Program Unit Testing (Technically Supports External Program Side-effect Comparison)
- 3 **Language:** C++
- 4 **Maintained/Support:** Regularly maintained by Google and Open Source Community
- 5 Originally created by Google for internal use but has become one of the most popular C++ unit testing frameworks within the xUnit family of testing frameworks

Google gtest Implementation Details

Listing 4: gtest test cases

```
TEST(FactorialTest, Positive) {  
    EXPECT_EQ(1, Factorial(1));  
    EXPECT_EQ(2, Factorial(2));  
    EXPECT_EQ(6, Factorial(3));  
    EXPECT_EQ(40320, Factorial(8));  
}  
  
TEST(IsPrimeTest, Positive) {  
    EXPECT_FALSE(IsPrime(4));  
    EXPECT_TRUE(IsPrime(5));  
    EXPECT_FALSE(IsPrime(6));  
    EXPECT_TRUE(IsPrime(23));  
}
```



Google gtest Pros & Cons

1 Pros:

- Documentation is extensive with a large community
- Concurrent execution of tests is supported
- Performance benefits of C++

Google gtest Pros & Cons

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- Documentation is extensive with a large community
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2 Cons:

- Testing of complex systems can be difficult as per standard with Internal Program Unit Testing methodology
- Setting up test execution environment is not common for most users and can be difficult to configure based on testing needs

XUnit

- 1 **Author(s) & Introduction:** Kent Beck, Erich Gamma, David Saff, Kris Vasudevan - Initial Prototype in 1997⁷

⁷Martin Fowler, "Bliki: Xunit", *martinfowler.com* (Webpage, 2022)
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- 5 A very popular open source unit testing framework for Java applications within the xUnit family of testing frameworks

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BAGS - Basser Automatic Grading Scheme

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Kassandra

- 1 **Author(s) & Introduction:** Urs von Matt (ETH Zürich) - Earliest Documented in Winter term 1992/1993⁹

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- Design Requirements
- Proposed Design

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- 4 *Maintainable* - The new software package should be adequately documented and support ease of maintainability and possible extension of features via the appropriate architectural decisions

Exclusions

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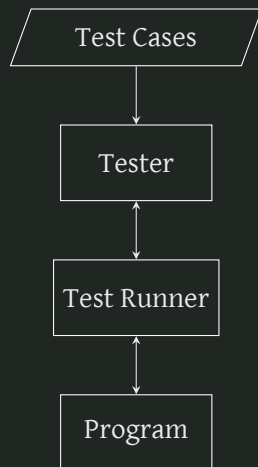
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- 4 Users of the existing Andrew Taylor autotest may elect to not utilise the new software package if the transition is less than convenient

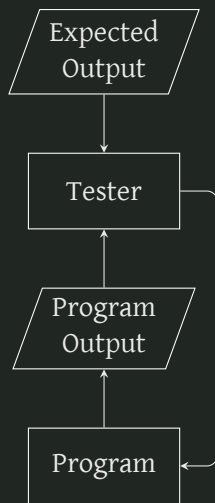
Approach 1

- 1 Architectural approach similar to Harvard University check50
- 2 check50 can be utilised as a “baseline” for both performance and correctness testing of the solution
- 3 Future Work and other relevant sections from the check50 paper can be utilised to inform implementation decisions for the solution
- 4 **Main methodology to determine correctness of tested program:**
External Program Side-effect
Comparison



Approach 2

- 1 Architectural approach similar to existing Andrew Taylor autotest which has been widely accepted for introductory programming courses at UNSW
- 2 autotest can be utilised as a “baseline” for both performance and correctness testing of the solution
- 3 **Main methodology to determine correctness of tested program:**
External Program Side-effect Comparison



Chosen Approach

- 1 We select **Approach 2** over the alternative as it more compatible with the outlined design requirements

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- 4 Regardless of approach, we will implement all aforementioned technical debt management procedures

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Thank you for attending! Questions?