A Testing Tool for Introductory Programming Courses

Thesis A Seminar

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

Term 1, 2022

Contents

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1. How can courses feasibly start/continue utilising practical assessments without automation tools as the staff to student ratio decreases?
2. How much of the marking process can be automated via tools and 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]

[1] Tom 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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4. Perform proving and performance tests on the new software package
5. 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

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

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Automated Testing & Marking Approaches

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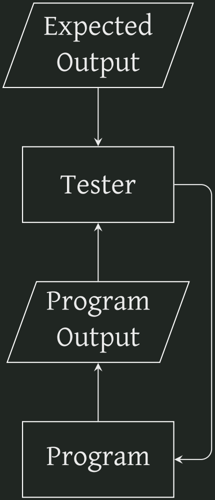
External Program Side-effect Comparison



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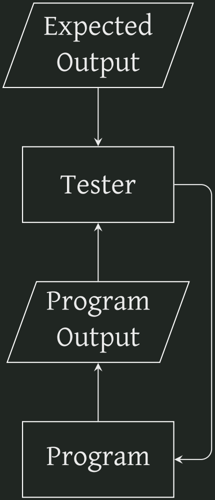

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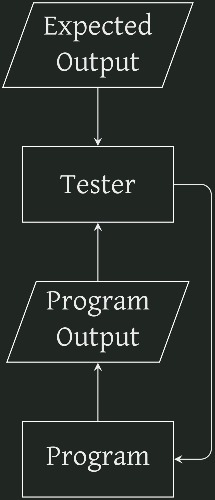

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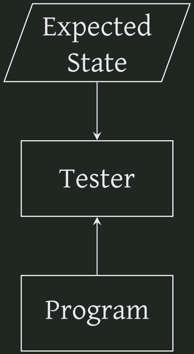
3. Comparisons on side-effects after program execution allows for easier testing of complex programs with dependencies on multiple different components at the cost of storage space

Internal Program Unit Testing



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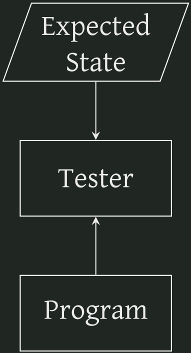

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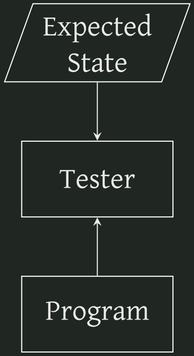

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2. Executing and collecting the results of the internal unit tests for the program can be used to determine whether expected behaviour has been achieved
3. Testing internal code components allow for more thorough determination of program correctness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

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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+)

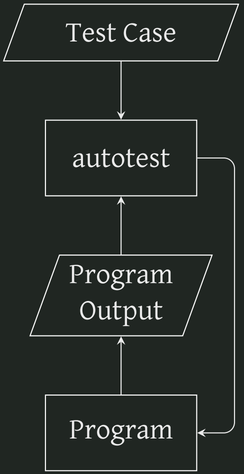
Andrew Taylor autotest implementation details

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 Uni CS50 check50

1. **Author(s) & Introduction:** Chad Sharp (Harvard University) - 2012[6]

[6] Chad Sharp et al, 'An Open-Source, API-Based Framework for Assessing the Correctness of Code in CS50' in *Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education* (ACM, 2020) 487

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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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Harvard Uni CS50 check50 implementation details

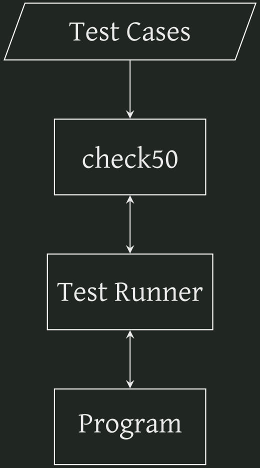
Listing 3: check50 tests

```
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 Uni 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)
   - Concurrent running of tests is supported

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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)

Google gtest

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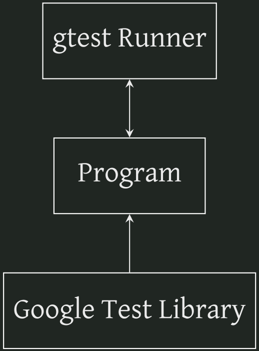
5. Originally created by Google for internal use but has become one of the most popular C++ unit testing frameworks within the xUnit family of testing frameworks

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));
}
```



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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

JUnit

1. **Author(s) & Introduction:** Kent Beck, Erich Gamma, David Saff, Kris Vasudevan - Initial Prototype in 1997[7]

[7] Martin Fowler, "Bliki: Xunit", *martinfowler.com* (Webpage, 2022) <https://martinfowler.com/bliki/Xunit.html>

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4. *Maintainable* - The new software package should be adequately documented with architectural decisions to increase ease of maintainability and possible extension of features

Exclusions

1. *Security* - We assume security to be out of scope as this is not a consideration in the existing Andrew Taylor autotest software package

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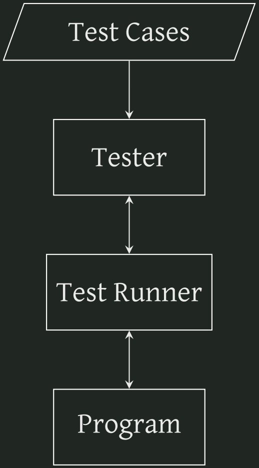
4. Users of the existing Andrew Taylor autotest may elect to not utilise the new software package if the transition is less than convenient

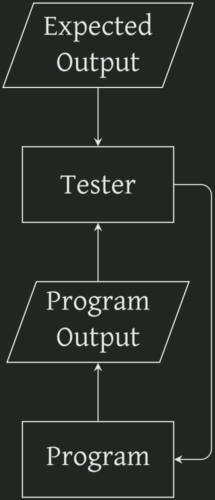
Approach 1

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



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1. We select **Approach 2** over the alternative as it more compatible with the outlined design requirements
2. We note that solutions implementing Approach 1 are more feature rich than Approach 2 but it must be considered that uptake of the solution is of higher importance than the features it provides
3. Features present from Approach 2 can also be added or removed in the interest of time but Approach 1 will provide a good starting point

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1. Rest of thesis A:
   - Continue inspection of Andrew Taylor autotest implementation

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   - Run correctness and performance testing on Parser and Runner

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   - Run correctness and performance testing on complete package and make final adjustments

Summary

We have covered:

- Student enrolments in Introductory Programming courses at UNSW, Andrew Taylor autotest, Technical Debt

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Thank you for attending! *Questions?*