

# Test Plan for the Companion Cube Calculator ( $C^3$ ) Tool

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# 1 Revision History

Date	Version	Notes
November 13, 2017	1.0.1	Addition of missing test cases
October 25, 2017	1.0	Initial draft completed

## 2 Symbols, Abbreviations and Acronyms

Symbol	Description
$C^3$	Companion Cube Calculator
GUI	Graphical User Interface
IDE	Integrated Development Environment
SRS	Software Requirements Specification
T	Test

# Contents

<b>1</b>	<b>Revision History</b>	<b>i</b>
<b>2</b>	<b>Symbols, Abbreviations and Acronyms</b>	<b>ii</b>
<b>3</b>	<b>General Information</b>	<b>1</b>
3.1	Purpose . . . . .	1
3.2	Scope . . . . .	1
3.3	Overview of Document . . . . .	2
<b>4</b>	<b>Plan</b>	<b>3</b>
4.1	Software Description . . . . .	3
4.2	Test Team . . . . .	3
4.3	Automated Testing Approach . . . . .	3
4.4	Verification Tools . . . . .	4
4.5	Non-Testing Based Verification . . . . .	4
<b>5</b>	<b>System Test Description</b>	<b>6</b>
5.1	Tests for Functional Requirements . . . . .	6
5.1.1	Getting User Inputs . . . . .	6
5.1.2	Conditioning User Inputs . . . . .	12
5.1.3	Correctness of Component Calculations . . . . .	24
5.1.4	Composing Operators . . . . .	30
5.1.5	Presentation of Calculations to the User . . . . .	31
5.2	Tests for Non-Functional Requirements . . . . .	32
5.2.1	Usability . . . . .	32
5.3	Traceability Between Test Cases and Requirements . . . . .	34
<b>6</b>	<b>Unit Testing Plan</b>	<b>35</b>
<b>7</b>	<b>Appendix: Usability Testing</b>	<b>37</b>
7.1	Tasks . . . . .	37
7.2	Questionnaire . . . . .	37
7.2.1	Test Results (Round values as necessary) . . . . .	37
7.2.2	Software Usability . . . . .	38

## List of Tables

1	Traceability Matrix Showing the Connections Between Requirements and Test Suites . . . . .	34
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## List of Figures

1	Traceability Graph Showing the Connections Requirements and Test Suites . . . . .	35
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## 3 General Information

This document is a software test plan for the Companion Cube Calculator ( $C^3$ ), a mathematical tool which determines the range of a user-specified function given the domains of the function's variables. The calculations are performed using interval arithmetic.

### 3.1 Purpose

This document describes the software test plan for the  $C^3$  tool and is informed by its SRS documentation (version 2.0) and resulting implementation, including a description of automated testing approach, tools, and test cases. The purpose of documenting this information is to guide the product testing for the initial product release and to provide a basis for regression testing as further developments are made to the  $C^3$  tool.

This document is intended for readers who wish to test the initial version of the product, as well as those who want to refine and expand the tool. As changes are made to the  $C^3$  tool, these test cases will form the foundation of regression testing and will help ensure that any changes made to the product do not affect its original purpose or core functionality.

This test plan is intended to be used for version 1.0 of the  $C^3$  tool, and will only contain test information related to the product description in the product version's SRS documentation (version 2.0). Any functionality defined beyond the scope of the SRS document are not included in this version of the test plan.

All documentation and the associated release of the tool can be found at <https://github.com/GenevaS/CAS741>.

### 3.2 Scope

The  $C^3$  tool relies on interval arithmetic in the domain of real numbers ( $\mathbb{R}$ ), which means that many of its functions can be empirically tested. This plan contains testing for both specific and non-specific implementation aspects of the program. The implementation-specific tests are included to achieve 100% code coverage to ensure that all code paths are reachable and produce expected outcomes. Non-specific implementation testing focuses on the correctness of the program with respect to its original purpose and its adherence to the SRS document.

The purpose of this plan is to modularize testing of the  $C^3$  tool so that it is easy to maintain and improve. It also forms the foundation of the kinds of be-

haviours that the tool should exhibit when it encounters malformed user inputs and unexpected values during its calculations.

### **3.3 Overview of Document**

This document presents a general description of the  $C^3$  tool to establish the context of the test plan and a list of team members responsible for executing it. This background information is followed by a high-level description of the test plan, including the automated testing approach, verification tools, and non-testing based verification methods that will be used. The general plan outline is followed by a description of the system test which is designed to determine if the requirements from the associated SRS document are satisfied. The final section describes implementation-specific tests that were implemented to achieve 100% code coverage.

## 4 Plan

This section describes the test plan for the  $C^3$  tool from a high-level perspective, outlining the methodologies and tools that will be used during the verification process, and the team responsible for executing the plan.

### 4.1 Software Description

The  $C^3$  tool is a stand-alone application for calculating the mathematical range of a user-defined equation given the domains of the equation's component variables. Equation ranges and variable domains are represented by intervals, where intervals are defined as a set of consecutive values bounded by a minimum and maximum value. The minimum and maximum values for any given interval must be defined. To perform its calculations, the  $C^3$  tool uses interval arithmetic.

The purpose of this product is to produce accurate results when they can be found with respect to the host machine's floating-point precision. If a result cannot be found, the tool is expected to communicate the reason back to the user. Exact results are not required, as the tested equations are expected to be implemented in a software environment that has no impact on the external world. These tasks must be completed while presenting all communications to the user in standard function and interval notation.

### 4.2 Test Team

The test team assigned to implement this plan is Geneva Smith.

### 4.3 Automated Testing Approach

The  $C^3$  tool will almost exclusively rely on automated test approaches for its verification process, with the notable exceptions of the non-functional requirements for correctness, verifiability, usability and maintainability described in the SRS document (version 2.0). The verification of correctness cannot be tested by a machine because it relies on mathematical proofs and the remaining non-functional requirements of verifiability, usability, and maintainability are intended for a human audience. These types of verifications are best handled by manual tests and user studies.

The functional requirements tests (Section 5.1) focus on the behaviour that is expected at each stage of the  $C^3$  tool's work flow. Since these behaviours are inter-



nal to the tool and do not require human guidance, these behaviours can be tested automatically using a series of black box unit tests. Some of the non-functional requirements such as robustness (Section 5.2), can also be tested using automated approaches because they focus on empirically testable data, such as data constraints.

Many of the unit tests are designed to be used as part of integration testing, and the system will be progressively tested starting from the creation of data structures, to conversion processes, to input and output testing. Outputs include messages informing the user of erroneous behaviours or malformed inputs, and the calculated values and resulting equation tree if a no errors are detected.

The remaining unit tests are designed to test the correctness of the tool's calculation. Some of the tests check simple, two variable equations to ensure that the individual calculation types are behaving correctly. The remaining tests will ensure that equations with multiple operators are being decomposed correctly by comparing it to expected results. Once a set of equations has been selected for this task, regression testing becomes available to check further developments to the  $C^3$  tool.

## 4.4 Verification Tools

The C# programming language has been chosen for the development of the  $C^3$  tool because of its GUI building capabilities. The supporting IDE, Visual Studio 2017 (Enterprise Edition), comes with a number of built-in test tools, including:

- **A unit test framework and management system**

This forms the bulk of the automated testing approach and will be used for unit, integration, system, and regression testing. The IDE can be configured so that existing unit tests are run automatically when the program is compiled.

- **Code coverage tools**

The code coverage tools in Visual Studio is connected to the test management system and can help identify code that is not being run by any unit test.

## 4.5 Non-Testing Based Verification

There are a few non-functional requirements that cannot be tested automatically, but are still worth testing to verify their correctness:

- Correctness can be tested using mathematical proofs to verify the correctness of equation decomposition and order of operations.
- Verifiability, usability and maintainability can be verified using user studies tailored for each requirement. This plan specifically contains a user study description for the usability requirements (Appendix 7).

## 5 System Test Description

The system testing of the  $C^3$  tool will focus on inspecting and conditioning user inputs, verifying that the correct values are being produced by program calculations, and ensuring that the  $C^3$  tool is able to produce descriptive outputs for both valid and invalid inputs. These tests are divided into sections based on modules so that integration testing can arise naturally from the gradual addition of components.

### 5.1 Tests for Functional Requirements

The functional requirement tests are broken into four main groups. The “Getting User Inputs” tests (5.1.1) test to make sure that no syntactic errors exist in the user’s inputs that can be reasonably caught by the tool. The “Conditioning User Inputs” tests convert the user’s  $D(v)$ ,  $v \in V$  into internal data structures and parses  $f(V)$  into a semantically correct representation following BEDMAS rules. The “Composing Operators” tests help prove that the composition of individual operators will produce the correct solution  $R(f(V))$ . Finally, the “Presentation of Calculations to the User” tests ensure that the  $C^3$  tool follows the rules for significant figures and precision.

Each test group assumes that the groups preceding it have passed successfully, adding to the confidence in the product.

#### 5.1.1 Getting User Inputs

This test suite is designed to determine if the R1 (Accepting  $f(V)$  and  $D(v)$ ,  $v \in V$  as direct input or read from a file) functional requirement is satisfied and its associated data constraints from R3.

The initial test cases (User Inputs (As Expected)) are the white-box unit tests that start the integration testing. The tests that follow these assume that these tests have passed.

#### User Inputs (As Expected)

1. test-directinput

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 4], y = [3, 5]$

Output: Input received from direct input

How test will be performed: Unit Test

2. test-fileinput

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File containing:  $f(V) = x + y, x = [2, 4], y = [3, 5]$

Output: Input received from file

How test will be performed: Unit Test

**User Inputs (Bad File I/O)**

1. test-badFileInput

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File that cannot be read

Output: Error – File cannot be read

How test will be performed: Unit Test

**User Inputs (Function is a Constant Value)**

1. test-input\_functionAsConstant

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 34$

Output: Warning – Function  $f(V)$  does not contain any variables

How test will be performed: Unit Test

### **User Inputs (Extraneous Information)**

1. test-input\_variableNotInFunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [6, 7]$

Output: Warning – Function  $f(V)$  does not contain name  $z$  found in variable list -> ignoring domain of  $z$

How test will be performed: Unit Test

### **User Inputs (Missing Values)**

1. test-input\_noFunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Error – Could not find function  $f(V)$  with variables  $x, y$

How test will be performed: Unit Test

2. test-input\_noDomain

Type: Functional

Initial State: New Session

Input:  $f(X) = x + y$ ,  $x = [2, 4]$

Output: Error – No domain for variable  $y$

How test will be performed: Unit Test

## User Inputs (Incomplete Values)

1. test-input\_missingFunctionValue1  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x +$ ,  $x = [2, 4]$ ,  $y = [3, 5]$   
Output: Error – Function  $f(V)$  is missing an operand for “+” ->domain list contains unreferenced variable  $y$   
How test will be performed: Unit Test
2. test-input\_missingFunctionValue2  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x + *y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$   
Output: Error – Function  $f(V)$  is missing an operand between + and \*  
How test will be performed: Unit Test
3. test-input\_missingMinDomainValue  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x + y$ ,  $x = [, 4]$ ,  $y = [3, 5]$   
Output: Error – Missing min domain value for  $x$   
How test will be performed: Unit Test
4. test-input\_missingMaxDomainValue  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $\{f(V) = x + y, x = [2, 4], y = [3, ]\}$ ,  $\{f(V) = x + y, x = [2, 4], y = [3]\}$   
Output: Error – Missing max domain value for  $y$   
How test will be performed: Unit Test

### **User Inputs (Non-Numerical Value in Domains)**

1. test-input\_nonNumberInDomain

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [a, 5]$

Output: Error – Non-numerical value found in the domain for variable y

How test will be performed: Unit Test

### **Variable Names**

1. test-input\_simpleVariableName

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: N/A

How test will be performed: Unit Test

2. test-input\_multiCharacterVariableName1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_1 + y$ ,  $x_1 = [2, 4]$ ,  $y = [3, 5]$

Output: N/A

How test will be performed: Unit Test

3. test-input\_multiCharacterVariableName2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_- + y$ ,  $x_- = [2, 4]$ ,  $y = [3, 5]$

Output: N/A

How test will be performed: Unit Test

4. test-input\_multiCharacterVariableName3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_1 + y$ ,  $x_1 = [2, 4]$ ,  $y = [3, 5]$

Output: N/A

How test will be performed: Unit Test

5. test-input\_multiCharacterVariableName4

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_i + y$ ,  $x_i = [2, 4]$ ,  $y = [3, 5]$

Output: N/A

How test will be performed: Unit Test

6. test-input\_multiCharacterVariableName5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x'' + y$ ,  $x'' = [2, 4]$ ,  $y = [3, 5]$

Output: N/A

How test will be performed: Unit Test

7. test-input\_multiCharacterVariableName6

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = xy + y$ ,  $xy = [2, 4]$ ,  $y = [3, 5]$



Output: N/A

How test will be performed: Unit Test

8. test-input\_multiCharacterVariableName7

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = xy$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Warning – Found variable  $xy$  that does not exist in the domain list for  $f(V)$  ->expanding to multiplication  $x * y$

How test will be performed: Unit Test

9. test-input\_multiCharacterVariableName8

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x* + y$ ,  $x* = [2, 4]$ ,  $y = [3, 5]$

Output: Error – Variable names cannot contain the characters  $\{+, -, *, ^, (, )\}$

How test will be performed: Unit Test

### 5.1.2 Conditioning User Inputs

This test suite is designed to determine if the R2 (Converting each  $D(v)$  into DD1) and R4 (Decomposing  $f(V)$  into two-operand equations following BED-MAS rules) functional requirements and the associated data constraints from R3 are satisfied.

The tests that follow these assume that the user input tests (5.1.1) have passed.

#### Unexpected Domain Ordering

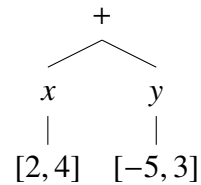
1. test-parse\_domainOrder

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 4], y = [3, -5]$

Output: Warning – Domain for variable  $y$  is ordered highest to lowest; re-ordering values to be smallest to highest



How test will be performed: Unit Testing

### Addition, Subtraction, and Multiplication

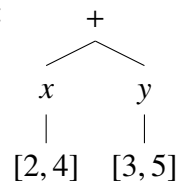
#### 1. test-parse\_addition

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 4], y = [3, 5]$

Output:



How test will be performed: Unit Testing

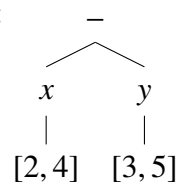
#### 2. test-parse\_subtraction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x - y, x = [2, 4], y = [3, 5]$

Output:



How test will be performed: Unit Testing

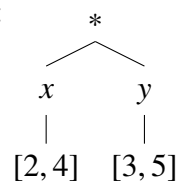
3. test-parse\_multiplication1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y, x = [2, 4], y = [3, 5]$

Output:



How test will be performed: Unit Testing

## Division

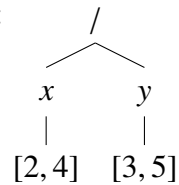
1. test-parse\_divisionPositiveDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y, x = [2, 4], y = [3, 5]$

Output:



How test will be performed: Unit Testing

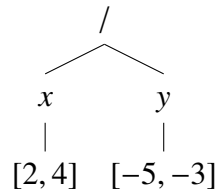
2. test-parse\_divisionNegativeDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y, x = [2, 4], y = [-5, -3]$

Output:



How test will be performed: Unit Testing

3. test-parse\_divisionMixedIntervalDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, 5]$

Output: Error – Cannot perform division with a mixed interval divisor

How test will be performed: Unit Testing

4. test-parse\_divisionMixedIntervalDivisorZero1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, 0]$

Output: Error – Cannot perform division with a mixed interval divisor

How test will be performed: Unit Testing

5. test-parse\_divisionMixedIntervalDivisorZero2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [0, 3]$

Output: Error – Cannot perform division with a mixed interval divisor

How test will be performed: Unit Testing

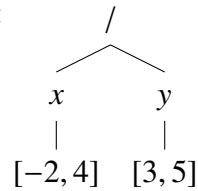
6. test-parse\_divisionMixedIntervalQuotient

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [-2, 4]$ ,  $y = [3, 5]$

Output:



How test will be performed: Unit Testing

### Intervals as Exponents

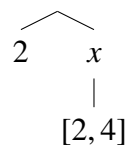
1. test-parse\_intervalAsExponents

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 2^x$ ,  $x = [2, 4]$

Output:  $B^x$



How test will be performed: Unit Testing

2. test-parse\_intervalAsExponentsInvalidBase

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 1^x$ ,  $x = [2, 4]$

Output: Error – Cannot perform operation with an interval exponent when the base number  $(B) \leq 1$

How test will be performed: Unit Testing

## Intervals as Base Numbers

### 1. test-parse\_intervalWithExponent

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [2, 4]$

Output:

$$\begin{array}{c} x^N \\ \swarrow \quad \searrow \\ x \quad 2 \\ | \\ [2, 4] \end{array}$$

How test will be performed: Unit Testing

### 2. test-parse\_intervalWithInvalidExponent1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^{2.1}$ ,  $x = [2, 4]$

Output: Warning – Cannot perform operation with an exponent that is not a whole number; the exponent has been rounded to 2

$$\begin{array}{c} x^N \\ \swarrow \quad \searrow \\ x \quad 2 \\ | \\ [2, 4] \end{array}$$

How test will be performed: Unit Testing

### 3. test-parse\_intervalWithInvalidExponent2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^{-1}$ ,  $x = [2, 4]$

Output: Error – Cannot perform operation exponentiation with an exponent  $(N) < 0$

How test will be performed: Unit Testing

### Intervals-Only Exponentiation

1. test-parse\_intervalsOnlyExponentiation

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Error – Cannot perform exponentiation when the base number ( $B$ ) and the exponent ( $N$ ) are intervals

How test will be performed: Unit Testing

### Constant Values

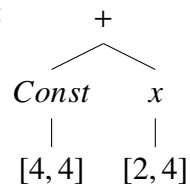
1. test-parse\_constantValue1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 4 + x$ ,  $x = [2, 4]$

Output:



How test will be performed: Unit Testing

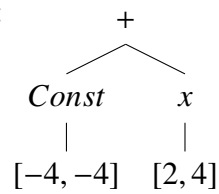
2. test-parse\_constantValue2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = -4 + x$ ,  $x = [2, 4]$

Output:



How test will be performed: Unit Testing

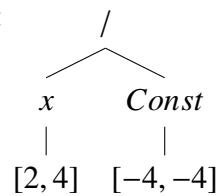
3. test-parse\_constantValue3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x / -4, x = [2, 4]$

Output:



How test will be performed: Unit Testing

4. test-parse\_constantValue4

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x / 0, x = [2, 4]$

Output: Error – No support for division by zero

How test will be performed: Unit Testing

5. test-parse\_constantValue5

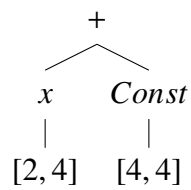
Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + 4, x = [2, 4]$



Output:



How test will be performed: Unit Testing

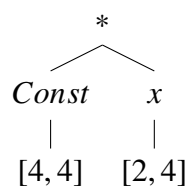
#### 6. test-parse\_implicitMultiplication

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 4x$ ,  $x = [2, 4]$

Output:



How test will be performed: Unit Testing

### Precedence of Brackets

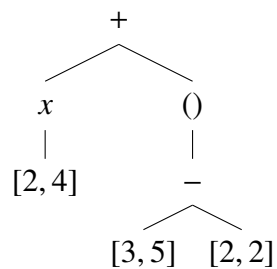
#### 1. test-parse\_brackets1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + (y - z)$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output:



How test will be performed: Unit Testing

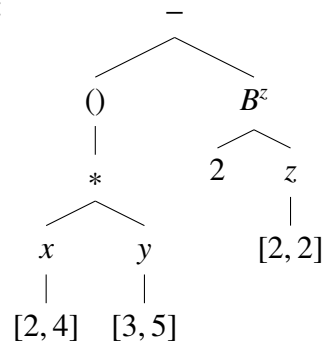
2. test-parse\_brackets2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = (x * y) - 2^z$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output:



How test will be performed: Unit Testing

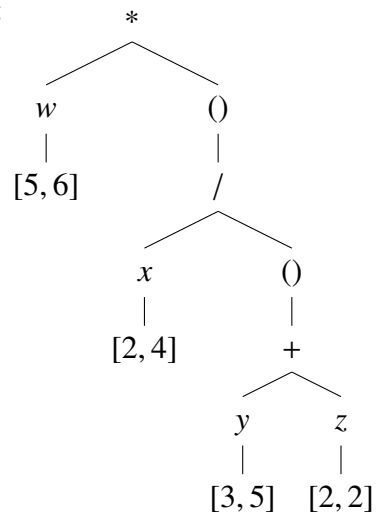
3. test-parse\_brackets3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = w * (x / (y + z))$ ,  $w = [5, 6]$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output:



How test will be performed: Unit Testing

## Open Brackets

### 1. test-parse\_openLeftBracket

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y - z$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output: Error – Missing “(” in  $f(V)$

How test will be performed: Unit Testing

### 2. test-parse\_openRightBracket

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + (y - z)$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output: Error – Missing “)” in  $f(V)$

How test will be performed: Unit Testing

## Operational Precedence Tests

### 1. test-parse\_commutativityOfAdditionSubstraction

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y - z == f(V) = (x + y) - z$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output: True

How test will be performed: Unit Testing

2. test-parse\_commutativityOfMultiplicationDivision

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x * y / z == f(V) = (x * y) / z, x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

How test will be performed: Unit Testing

3. test-parse\_precedenceOfOperators1

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y * z == x + (y * z), x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

How test will be performed: Unit Testing

4. test-parse\_precedenceOfOperators2

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = 2^x * y == (2^x) * y, x = [2, 4], y = [3, 5]$

Output: True

How test will be performed: Unit Testing

5. test-parse\_precedenceOfOperators3

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x^2 * y == (x^2) * y, x = [2, 4], y = [3, 5]$

Output: True

How test will be performed: Unit Testing

6. test-parse\_precedenceOfOperators4

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x * (y + z)$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output: [10, 28]

How test will be performed: Unit Testing

### 5.1.3 Correctness of Component Calculations

This test suite is designed to determine if the R5 (Solving each component equation in  $f(V)$ ) and R7 (Ensuring that the calculated result is represented in closed, interval form) functional requirements, and the associated data constraints from R8 are satisfied.

The tests that follow these assume that the user input tests (5.1.1) and input conditioning tests (5.1.2) have passed.

#### Correctness of Addition, Subtraction, and Multiplication

1. test-calculate\_addition

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: [5, 9]

How test will be performed: Unit Testing

2. test-calculate\_subtraction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x - y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: [-1, -1]

How test will be performed: Unit Testing

3. test-calculate\_multiplication1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:  $[6, 20]$

How test will be performed: Unit Testing

4. test-calculate\_multiplication2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$ ,  $x = [-1, 3]$ ,  $y = [-3, 5]$

Output:  $[-9, 15]$

How test will be performed: Unit Testing

5. test-calculate\_multiplication3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$ ,  $x = [-3, -1]$ ,  $y = [-5, -2]$

Output:  $[2, 15]$

How test will be performed: Unit Testing

### **Correctness of Division**

1. test-calculate\_divisionPositiveDivisor1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:  $[0.4, 1.3333333333333333]$

How test will be performed: Unit Testing

2. test-calculate\_divisionPositiveDivisor2  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [0, 4]$ ,  $y = [3, 5]$   
Output:  $[0, 1.3333333333333333]$   
How test will be performed: Unit Testing
3. test-calculate\_divisionPositiveDivisor3  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-1, 4]$ ,  $y = [3, 5]$   
Output:  $[-0.333333333333, 0.8]$   
How test will be performed: Unit Testing
4. test-calculate\_divisionPositiveDivisor4  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-2, -1]$ ,  $y = [3, 5]$   
Output:  $[-0.666666666666, -0.2]$   
How test will be performed: Unit Testing
5. test-calculate\_divisionPositiveDivisor5  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-2, 0]$ ,  $y = [3, 5]$   
Output:  $[-0.666666666666, 0]$   
How test will be performed: Unit Testing

6. test-calculate\_divisionNegativeDivisor1  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, -5]$   
Output:  $[-0.8, -0.6666666666]$   
How test will be performed: Unit Testing
7. test-calculate\_divisionNegativeDivisor2  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [0, 4]$ ,  $y = [-3, -5]$   
Output:  $[-0.8, 0]$   
How test will be performed: Unit Testing
8. test-calculate\_divisionNegativeDivisor3  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-1, 4]$ ,  $y = [-3, -5]$   
Output:  $[-0.8, 0.2]$   
How test will be performed: Unit Testing
9. test-calculate\_divisionNegativeDivisor4  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-2, 0]$ ,  $y = [-3, -5]$   
Output:  $[0, 0.4]$   
How test will be performed: Unit Testing



10. test-calculate\_divisionNegativeDivisor5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [-2, -1]$ ,  $y = [-3, -5]$

Output:  $[0.333333333333, 0.4]$

How test will be performed: Unit Testing

11. test-calculate\_mixedDivisorComponent

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/(y * z)$ ,  $x = [-2, -1]$ ,  $y = [3, 5]$ ,  $z = [-1, 1]$

Output: Error – Cannot complete operation because a mixed interval was calculated for a divisor  $\rightarrow R(f(V)) = R([-2, -1]/[-5, 5])$

How test will be performed: Unit Testing

### Correctness of Intervals as Exponents

1. test-calculate\_intervalAsExponents

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 2^x$ ,  $x = [2, 4]$

Output:  $[4, 16]$

How test will be performed: Unit Testing

### Correctness of Intervals as Base Numbers

1. test-parse\_intervalWithExponent1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^3, x = [2, 4]$

Output:  $[8, 64]$

How test will be performed: Unit Testing

2. test-parse\_intervalWithExponent2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2, x = [2, 4]$

Output:  $[4, 16]$

How test will be performed: Unit Testing

3. test-parse\_intervalWithExponent3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2, x = [0, 4]$

Output:  $[0, 16]$

How test will be performed: Unit Testing

4. test-parse\_intervalWithExponent4

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2, x = [-2, 4]$

Output:  $[0, 16]$

How test will be performed: Unit Testing

5. test-parse\_intervalWithExponent5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [-4, -2]$

Output:  $[4, 16]$

How test will be performed: Unit Testing

#### 5.1.4 Composing Operators

This test suite is designed to determine if the R6 (Recomposing the results from the component equations of  $f(V)$ ) and R7 (Ensuring that the calculated result is represented in closed, interval form) functional requirements, and the associated data constraints from R8 are satisfied.

The tests that follow these assume that the user input tests (5.1.1), input conditioning tests (5.1.2), and component equation calculation tests (5.1.3) have passed.

#### Correctness of Operator Composition

1. test-parse\_multipleOperatorsInFX

Type: Static, Manual, Unit

Initial State: New Session

Input:  $R(f(V)) = R(f_1(V)) < op > R(f_2(V))$ , where  $R(f_1(V))$ ,  $R(f_2(V))$  exist

Output:  $R(f(V)) = R(f_1(V)) < op > R(f_2(V))$  by induction

How test will be performed: Induction

2. test-parse\_multipleOperatorsInFX

Type: Static, Manual, Unit

Initial State: New Session

Input:  $R(f(V)) = R(f_1(V)) < op > R(f_2(V))$ , where  $R(f_1(V))$  or  $R(f_2(V))$  do not exist

Output:  $R(f(V)) \neq R(f_1(V)) < op > R(f_2(V))$  by induction

How test will be performed: Induction

Note: This case should only apply to cases where there is a mixed interval divisor for the division operator

### 5.1.5 Presentation of Calculations to the User

This test suite is designed to test that the final functional requirements, R9 (Showing the results to the user or an error if a result cannot be found) and R?? (Representing  $R(f(V))$  with the most precise number of significant decimal figures), are satisfied. It is assumed that any inputs that do not produce a viable result have been caught previously and an appropriate error or warning message was presented to the user.

The tests that follow these assume that the user input tests (5.1.1), input conditioning tests (5.1.2), component equation calculation tests (5.1.3), and operator composition tests (5.1.4) have passed.

#### Rounding For Significant Figures

1. test-equalSignificantFigures

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2.5, 4.3]$ ,  $y = [3.5, 5.5]$

Output:  $[6.0, 9.8]$

How test will be performed: Unit Testing

2. test-unequalSignificantFigures

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2.5, 4.33]$ ,  $y = [3.45, 5.555]$

Output:  $[6.0, 9.9]$

How test will be performed: Unit Testing

3. test-significantFiguresFloatingPoint

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2.5343...3, 4.3333...34]$ ,  $y = [3.5343...3, 5.5343...3]$

Output: [6.0686...6, 9.8676...6]

Warning – Precision of domain boundaries exceeds the floating point representation on this machine ->rounded to the most significant figure available

How test will be performed: Unit Testing

**Note:** Numerical values for input and output are for illustrative purposes only

## 5.2 Tests for Non-Functional Requirements

Some of the non-functional requirements can be tested using the same tests as their associated functional requirements. This includes correctness and verifiability (5.1.4), robustness (applicable at every process stage), and reliability (5.1.5). This leaves the non-functional requirements of usability and maintainability to test separately.

Due to the intended audience for the initial version of the  $C^3$  tool and the size of the test team, maintainability testing will not be covered.

### 5.2.1 Usability

The tests for usability focus on the notation used to represent  $f(V)$  and  $D(v)$ ,  $v \in V$  and the user's ability to use the tool intuitively without external guidance or instruction.

[Great to see usability testing! Could you please give some more detail on how the tests will be run. How many participants? How will they be recruited? What documentation will they be given? etc. What specific task or tasks will they be asked to perform? How will the results of the usability tests be summarized? —SS]

### Use of Standard Mathematical Notation

#### 1. test-enteringFV

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user is given a series of  $f(V)$  to enter into the tool; the  $f(V)$  chosen will be taken from the functional requirement tests (5.1)

Result: The user should be able to enter in the  $f(V)$  with no guidance

How test will be performed: User study (7)

## 2. test-enteringDv

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user is given a series of  $D(v)$  to enter into the tool; the  $D(v)$  chosen will be taken from the same functional requirement tests (5.1) as the  $f(V)$  usability test (Test ID: test-enteringFV)

Result: The user should be able to enter in the  $D(v)$  with no guidance

How test will be performed: User study (7)

## GUI Presentation and Organization

### 1. test-GUIPresentationInputs

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user will be given an input set  $\{f(V), D(v) | v \in V\}$  and asked to enter them into the GUI

Result: The user should be able to find and enter the data into the GUI with no guidance

How test will be performed: User study (7)

### 2. test-GUIWorkflow

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user will be shown a GUI that has an input set  $\{f(V), D(v) | v \in V\}$  already entered and ask them to tell the tool to compute the result

Result: The user should be able to prompt the tool to begin processing with no guidance

How test will be performed: User study (7)

### 3. test-GUIPresentationOutputs

Type: Non-Functional, Manual, System

Initial State: End Session

Condition: The user will be shown a GUI that has finished its calculations

Result: The user should be able to find and understand the system's outputs from the GUI with no guidance

How test will be performed: User study (7)

## 5.3 Traceability Between Test Cases and Requirements

The purpose of the traceability matrix (Table 1) and graph (Figure 1) is to provide easy references between the test suite and the requirements from the SRS (version 2.0). In the table, the test suites that verify a requirement are marked with an “X” in the requirement's column. In the graph, tests appear at the tail of an arrow and requirements appear at the head.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	NF: Usability
5.1.1	X		X							
5.1.2		X	X	X						
5.1.3					X		X	X		
5.1.4						X	X	X		
5.1.5									X	
5.2.1										X

Table 1: Traceability Matrix Showing the Connections Between Requirements and Test Suites

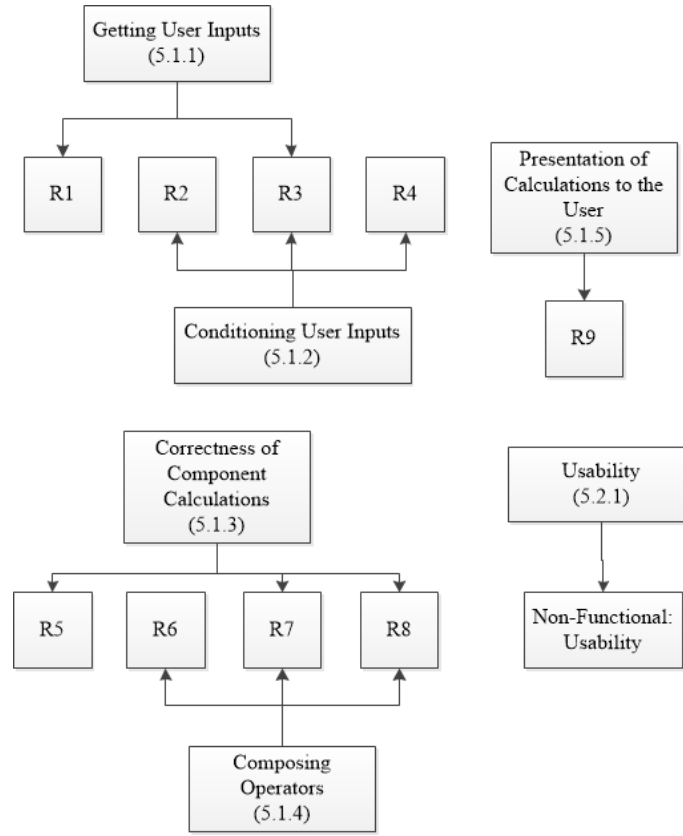


Figure 1: Traceability Graph Showing the Connections Requirements and Test Suites

## 6 Unit Testing Plan

As shown by the system test description (Section 4), the system and integration testing of the  $C^3$  tool can be divided into several unique steps. This also has implications for specific function unit tests.

The general plan for unit testing is to use the same tests from the functional requirements (Section 5.1) except that the expected inputs are provided by the human tester rather than the module that produces those values as outputs. For example if the  $f(V)$  parsing function is expecting an error-checked  $f(V)$  from the input module, the error-checked  $f(V)$  would be provided by the human tester instead. If a manually synthesised input produces incorrect behaviours from a



function, debugging strategies can be employed, including debugging statements and visual code inspections.

The unit testing stage is also the point where code coverage tools can be used to ensure that most lines of code are being tested by the integration and system tests. The goal is to have 100% code coverage. If code is not covered by the tests, it should be analysed to determine its usefulness and accessibility to the rest of the program.

Once a section of tests have been completed and there do not appear to be any immediate problems, the modules can be used in the functional requirement tests.

## 7 Appendix: Usability Testing

An informal user study was conducted as part of the Companion Cube Calculator test suite, where participants were recruited from the examiner's lab. Participants were sent a compressed file containing the program, user manual, and instructions and asked to complete it on their own time. The instructions file contained a URL to the associated study questionnaire.

The instructions that were sent to participants can be found at:

<https://github.com/GenevaS/CAS741/tree/master/Doc/TestReport/UserStudy>

### 7.1 Tasks

User study participants were asked to complete two tasks given the information:

$$\frac{2(x+y)^2}{3^z}$$

where

$$x = [1, 2], y = [3, 4], z = [5, 6]$$

The first task was to input the information directly into the GUI and the second task was to load the information into the program via a file.

Participants were free to access the program user guide as they saw fit.

### 7.2 Questionnaire

This survey were designed to accompany the user study. The questionnaire was distributed as a Google Form.

#### 7.2.1 Test Results (Round values as necessary)

1. (Long Answer) What range value did you calculate in Task 1?
2. (Long Answer) What was the resulting equation tree from Task 1?
3. (Long Answer) What range value did you calculate in Task 2?
4. (Long Answer) What was the resulting equation tree from Task 2?

### **7.2.2 Software Usability**

#### **Task 1: Entering values directly into the GUI**

1. (Likert Scale) I found it easy to find the input mechanism for entering the equation into the GUI.
2. (Likert Scale) I found it easy to use the function input mechanism.
3. (Likert Scale) I found it easy to find the input mechanism for entering variable domains into the GUI.
4. (Likert Scale) I found it easy to use the variable domain input mechanism.

#### **Task 2: Loading values into the program from a file**

1. (Likert Scale) I found it easy to find the option to load from a file.

#### **Understanding the Results**

1. (Likert Scale) I found it easy to find the calculated range in the GUI.
2. (Likert Scale) I found it easy to understand the calculated range.
3. (Likert Scale) I found it easy to understand the sequence of steps required to use the software.
4. (Long answer) Describe any interactions with the program that confused you during the tasks.
5. (Long answer) Do you have any suggestions for improving the process flow of the tool?