CAS 741 (Development of Scientific Computing Software)

Winter 2024

09 Verification and Validation

Dr. Spencer Smith

Faculty of Engineering, McMaster University

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Verification and Validation

- Administrative details
- Questions?
- 741 workflow
- Overview of testing
- Scientific software specific issues
- V&V examples
- V&V template

Administrative Details: Report Deadlines

System VnV Plan	Week 06	Feb 16
MG + MIS	Week 09	Mar 15
Final Documentation	Week 13	Apr 12

- The written deliverables will be graded based on the repo contents as of 11:59 pm of the due date
- If you need an extension for a **written** doc, please ask
- When ready, assign issues to your primary and secondary reviewers
- GitHub issues due two days after assignment deadlines
- From Drasil Code onward, Drasil projects no longer need to maintain traditional SRS

Administrative Details: Presentations

Syst. VnV	Week 06	Week of Feb 12
POC Demo	Week 07	Week of Feb 26
MG + MIS	Week 09	Week of Mar 11
MG + MIS	Week 09	Week of Mar 11
Unit VnV/Implement	Week 12	Week of Apr 3

- Specific schedule depends on final class registration
- Informal presentations with the goal of improving everyone's written deliverables
- Domain experts and secondary reviewers (and others) will ask questions

Presentation Schedule

- Syst V&V Plan Present (L11, L12) (20 min)
  - **Feb 13: Fasil, Hunter, Phil, Adrian**
  - **Feb 16: Gaofeng, AI, Seyed Ali, Xinyu**
- Proof of Concept Demonstrations (L14) (20 min)
  - Mar 1: Cynthia, Valerie, Waqar, Yi-Leng
- MG+MIS Present (L17, L18) (20 minutes)
  - Mar 12: Nada, Morteza, Kim Ying, Atiyeh
  - Mar 15: Fatemeh, Yiding, Tanya, Volunteer?

Presentation Sched Cont'd

- Implementation Present (L22–L25) (15 min each)
  - Mar 29: Fatemeh, Waqar, Al, Tanya, Atiyeh, Yi-Leng
  - Apr 2: Nada, Phil, Xinyu, Fasil, Seyed Ali, Kim Ying
  - Apr 5: Gaofeng, Morteza, Valerie, Hunter, Cynthia, Adrian
  - Apr 9: Yiding

Presentation Schedule

- 3 presentations each
  - SRS everyone
  - VnV and POC subset of class
  - Design subset of class
  - Implementation everyone
- If you will miss a presentation, please trade with someone
- Implementation presentation could be used to run a code review, or code walkthrough

Administrative Details

- SRS Presentation grades on Avenue
- Create GitHub issues for your colleagues (see next slide)
- Go ahead and address the colleague created issues
- No classes for Reading week

GitHub Reviews

- Project owners
  - "Domain Expert" and "Secondary Reviewer"
  - Find your reviewers in Repos.csv
  - Add your reviewers as collaborators
  - Assign review issues to myself and your reviewers
  - **separate** issue for each reviewer
- Reviewers
  - Provide at least 5 issues on the document
  - Grading
    - Not enough issues, or poor issues 0/2
    - Enough issues, but shallow 1/2
    - Enough issues and deep (not surface) 2/2
  - Issues are due 2 days after being assigned
- GitHub conventions (Writing Checklist (last sect.))
- How to give (and take) constructive criticism

Administrative Details: Drasil

- For some students, the SRS will be translated to Drasil
  - Due in place of design documentation
  - Forking Drasil (the last few instructions)
  - Creating a Project in Drasil

Administrative Details: VnV Presentations

- Not everyone will do VnV presentations
- Select 1 or 2 of the following:
  - **Specific** functional system test cases
  - **Specific** nonfunctional system test cases, such as
    - Performance profile
    - Usability testing
  - SRS verification plan
  - Automated testing and verification tools
    - Profiling tools
    - Continuous integration
    - Code coverage
    - Linters
  - Other related topic, etc.
- We would like a variety of topics presented
- If you are uncertain of your specific presentation plan, please ask

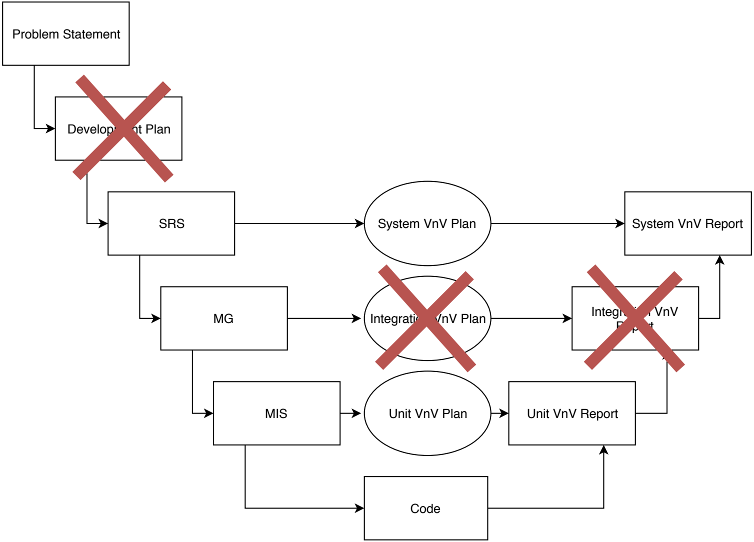
Proof of Concept (POC) Presentations

- Deepen your understanding by jumping into implementation
- A good idea, even if you aren't doing a POC
- Identify a risk with your code and implement enough to show you can resolve it
- Looking for an actual demo with running code
- Presentation
  - Explicitly identify your risk
  - Run your code
  - Discuss your implementation
- Simplify as much as necessary
- Do not use this code in your actual implementation

Questions?

- Questions about SRS?
- Questions about Soft Dev technology?
- Questions about the application of SE methods/tools/techniques/principles to research software?
- Questions about deliverables?

“Faked” Rational Design Process



Verification Plan Needs to Be Specific

- State exactly what your test cases are, give the actual input, and expected output
- State feasible plans for testing and inspection
- Decide what to emphasize, could include performance testing, or usability testing
- Give specific measures of error/performance/....
- How do you quantify error for a single scalar value?
- How do you quantify error for a vector value?

Outline of Verification Topics

- What are the goals of verification?
- What are the main approaches to verification?
  - What kind of assurance do we get through testing?
  - Can testing prove correctness?
  - How can testing be done systematically?
  - How can we remove defects (debugging)?
- What are the main approaches to software analysis?
- Informal versus formal analysis

Incorrect Version of Delete

Using `s = new T[MAX_SIZE]`, for some type `T`; `length` is a state variable

```
public static void del(int i)
{
  int j;

  for (j = i; j <= (length - 1); j++)
  {
    s[j] = s[j+1];
  }

  length = length - 1;
}
```

- What is the error?
- What test case would highlight the error?

Correct Version of Delete

```
public static void del(int i)
{
  int j;

  for (j = i; j < (length - 1); j++)
  {
    s[j] = s[j+1];
  }

  length = length - 1;
}
```

Avoids potential ArrayIndexOutOfBoundsException Exception

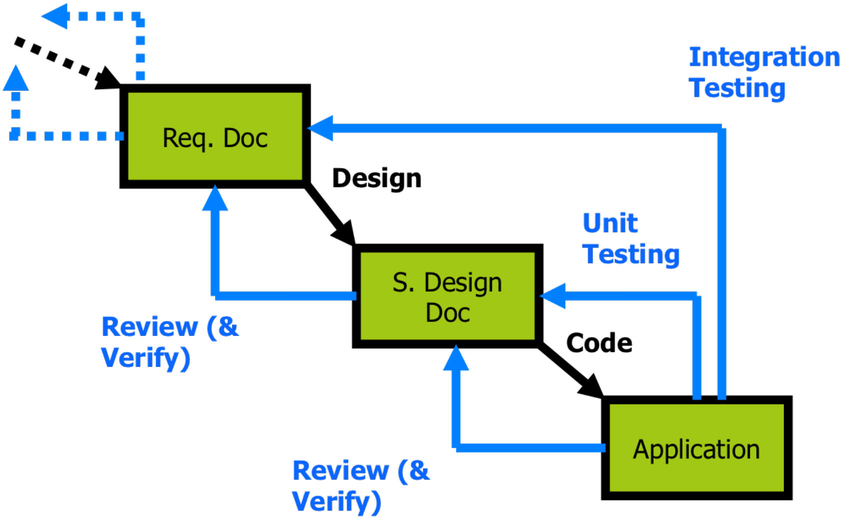
Verification Versus Validation

- What is the difference between verification and validation?

Verification Versus Validation

- Verification - Are we building the product right? Are we implementing the requirements correctly (internal)
- Validation - Are we building the right product? Are we getting the right requirements (external)
- According to Capability Maturity Model (CMM)
  - Software Verification: The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. [IEEE-STD-610]
  - Software Validation: The process of evaluating software during or at the end of the development process to determine whether it satisfies specified requirements. [IEEE-STD-610]
- We will focus on verification

Verification Activities



Testing Phases

1. Unit testing
2. Integration testing
3. System testing
4. Acceptance testing

Need for Verification

- Designers are fallible even if they are skilled and follow sound principles
- We need to build confidence in the software
- Everything must be verified, every required functionality, every required quality, every process, every product, every document
- For every work product covered in this class we have discussed its verification
- Even verification itself must be verified

Properties of Verification

From [1]

- May not be binary (OK, not OK)
  - Severity of defect is important
  - Some defects may be tolerated
  - Our goal is typically acceptable reliability, not correctness
- May be subjective or objective - for instance, usability, generic level of maintainability or portability
  - How might we make usability objective?
- Even implicit qualities should be verified
  - Because requirements are often incomplete
  - For instance robustness, maintainability
- What is better than implicitly specified qualities?

Approaches to Verification

- What are some approaches to verification?
- How can we categorize these approaches?

Approaches to Verification

- Experiment with behaviour of product
  - Sample behaviours via testing
  - Goal is to find "counter examples"
  - Dynamic technique
  - Examples: unit testing, integration testing, acceptance testing, white box testing, stress testing, etc.
- Analyze product to deduce its adequacy
  - Analytic study of properties
  - Static technique
  - Examples: Code walk-throughs, code inspections, correctness proof, etc.

Does our Engineering Analogy Fail?

- If a bridge can hold 512 kN, can it hold 499 kN?
- If our software works for the input 512, will it work for 499?

Verification in Engineering

- Example of bridge design
- One test assures infinite correct situations
- In software a small change in the input may result in significantly different behaviour
- There are also chaotic systems in nature, but products of engineering design are usually stable and well-behaved

Modified Version Works for 512, but not 499

```
procedure binary-search (key: in element;
                table: in elementTable; found: out Boolean) is
begin
  bottom := table'first; top := table'last;
  while bottom < top loop
    if (bottom + top) rem 2 ≠ 0 then
      middle := (bottom + top - 1) / 2;
    else
      middle := (bottom + top) / 2;
    end if;
    if key ≤ table (middle) then
      top := middle;
    else
      bottom := middle + 1;
    end if;
  end loop;
  found := key = table (top);
end binary-search
```

if we omit this the routine works if the else is never hit! (i.e. if size of table is a power of 2)

Testing and Lack of “Continuity”

- Testing samples behaviours by examining “test cases”
- Impossible to extrapolate behaviour of software from a finite set of test cases
- No continuity of behaviour - it can exhibit correct behaviour in infinitely many cases, but may still be incorrect in some cases

Goals of Testing

- If our code passes all test cases, is it now guaranteed to be error free?
- Are 5000 random tests always better than 5 carefully selected tests?

Goals of Testing

- To show the presence of bugs (Dijkstra, 1972)
- If tests do not detect failures, we cannot conclude that software is defect-free
- Still, we need to do testing - driven by sound and systematic principles
  - Random testing is often not a systematic principle to use
  - Need a test plan
- Should help isolate errors - to facilitate debugging

Goals of Testing Continued

- Should be repeatable
  - Repeating the same experiment, we should get the same results
  - Repeatability may not be true because of the effect of the execution environment on testing
  - Repeatability may not occur if there are uninitialized variables
  - Repeatability may not happen when there is nondeterminism
- Should be accurate
  - Accuracy increases reliability
  - Part of the motivation for formal specification
- Is a successful test case one that passes the test, or one that shows a failure?

Test (V&V) Plan

- Given that no single verification technique can prove correctness, the practical approach is to use ALL verification techniques. Is this statement True or False?

Test (V&V) Plan

- Testing can uncover errors and build confidence in the software
- Resources of time, people, facilities are limited
- Need to plan how the software will be tested
- You know in advance that the software is unlikely to be perfect
- You need to put resources into the most important parts of the project
- A risk analysis can determine where to put your limited resources
- A risk is a condition that can result in a loss
- Risk analysis involves looking at how bad the loss can be and at the probability of the loss occurring

White Box Versus Black Box Testing

- Do you know (or can you guess) the difference between white box and black box testing?
- What if they were labelled transparent box and opaque box testing, respectively?

White Box Versus Black Box Testing

- White box testing is derived from the program's internal structure
- Black box testing is derived from a description of the program's function
- Should perform both white box and black box testing
- Black box testing
  - Uncovers errors that occur in implementing requirements or design specifications
  - Not concerned with how processing occurs, but with the results
  - Focuses on functional requirements for the system
  - Focuses on normal behaviour of the system

White Box Testing

- Uncovers errors that occur during implementation of the program
- Concerned with how processing occurs
- Evaluates whether the structure is sound
- Focuses on abnormal or extreme behaviour of the system

Dynamic Testing

- Is there a dynamic testing technique that can guarantee correctness?
- If so, what is the technique?
- Is this technique practical?

Dynamic Versus Static Testing

- Another classification of verification techniques, as previously discussed
- Use a combination of dynamic and static testing
- Dynamic analysis
  - Requires the program to be executed
  - Test cases are run and results are checked against expected behaviour
  - Exhaustive testing is the only dynamic technique that guarantees program validity
  - Exhaustive testing is usually impractical or impossible
  - Reduce number of test cases by finding criteria for choosing representative test cases

Static Testing Continued

- Static analysis
  - Does not involve program execution
  - Testing techniques simulate the dynamic environment
  - Includes syntax checking
  - Generally static testing is used in the requirements and design stage, where there is no code to execute
  - Document and code walkthroughs
  - Document and code inspections

Manual Versus Automated Testing

- What is the difference between manual and automated testing?
- What are the advantages of automated testing?
- What is regression testing?

Manual Versus Automated Testing

- Manual testing
  - Has to be conducted by people
  - Includes by-hand test cases, structured walkthroughs, code inspections
- Automated testing
  - The more automated the development process, the easier to automate testing
  - Less reliance on people
  - Necessary for regression testing
  - Test tools can assist, such as Junit, Cppunit, CuTest etc.
  - Can be challenging to automate GUI tests
  - Test suite for Maple has 2 000 000 test cases, run on 14 platforms, every night, automated reporting

Continuous Integration Testing

- What is continuous integration testing?

Continuous Integration Testing

- Building and testing software on every push (see Fowler)
- Information available on Wikipedia
- Developers frequently integrate code into a shared repo
- Each integration is automatically accompanied by regression tests and other build tasks
- Build server
  - Unit tests
  - Integration tests
  - Static analysis
  - Profile performance
  - Extract documentation
  - Update project web-page
  - Portability tests
  - etc.
- Avoids potentially extreme problems with integration when the baseline and a developer's code greatly differ

Continuous Integration Tools

- Gitlab
- Jenkins
- Travis
- Shared Team's Video on Continuous Integration with extra material
- Docker
  - Eliminates the "it works on my machine" problem
  - Package dependencies with your apps
  - A container for lightweight virtualization
  - Not a full VM

Sample Nonfunctional System Testing

- Stress testing - Determines if the system can function when subject to large volumes
- Usability testing
- Performance measurement

Sample Functional System Testing

- Requirements: Determines if the system can perform its function correctly and that the correctness can be sustained over a continuous period of time
- Error Handling: Determines the ability of the system to properly process incorrect transactions
- Manual Support: Determines that the manual support procedures are documented and complete, where manual support involves procedures, interfaces between people and the system, and training procedures
- Parallel: Determines the results of the new application are consistent with the processing of the previous application or version of the application

Theoretical Foundations Of Testing: Definitions

- P (program), D (input domain), R (output domain)
  - P: D $\rightarrow$ R (may be partial)
- Correctness defined by OR $\subseteq$ D $\times$ R
  - P(d) correct if $\langle$ d, P(d) $\rangle \in$ OR
  - P correct if all P(d) are correct
- Failure
  - P(d) is not correct
  - May be undefined (error state) or may be the wrong result
- Error (Defect)
  - Anything that may cause a failure
    - Typing mistake
    - Programmer forgot to test "x=0"
- Fault
  - Incorrect intermediate state entered by program

Definitions Questions

- A test case t is an element of D or R?
- A test set T is a finite subset of D or R?
- How would we define whether a test is successful?
- How would we define whether a test set is successful?

Definitions Continued

- Test case t: An element of D
- Test set T: A finite subset of D
- Test is successful if P(t) is correct
- Test set successful if P correct for all t in T

Theoretical Foundations of Testing

- Desire a test set T that is a finite subset of D that will uncover all errors
- Determining and ideal T leads to several undecideable problems
- No algorithm exists:
  - To state if a test set will uncover all possible errors
  - To derive a test set that would prove program correctness
  - To determine whether suitable input exists to guarantee execution of a given statement in a given program
  - etc.

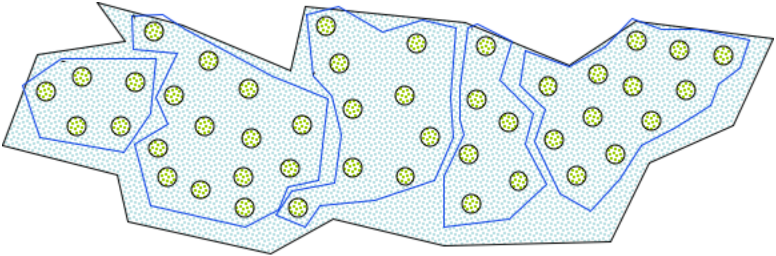
Empirical Testing

- Need to introduce empirical testing principles and heuristics as a compromise between the impossible and the inadequate
- Find a strategy to select significant test cases
- Significant means the test cases have a high potential of uncovering the presence of errors

Complete-Coverage Principle

- Try to group elements of D into subdomains D_1, D_2, ..., D_n where any element of each D_i is likely to have similar behaviour
- $D = D_1 \cup D_2 \cup ... \cup D_n$
- Select one test as a representative of the subdomain
- If $D_j \cap D_k = \emptyset$ for all $j \neq k$, (partition), any element can be chosen from each subdomain
- Otherwise choose representatives to minimize number of tests, yet fulfilling the principle

Complete-Coverage Principle



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