

# CAS 741, CES 741 (Development of Scientific Computing Software)

Fall 2019

## 09 Verification and Validation

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# Verification and Validation

- Administrative details
- Questions?
- 741 workflow
- Testing from SE perspective
- Testing from SC perspective
- V&V template
- V&V examples
  - ▶ SWHS
  - ▶ Mesh Gen
  - ▶ Rogue Reborn

# Administrative Details

- SRS Presentation grades on Avenue
- GitHub issues for colleagues
  - ▶ `Repos.xlsx` reviewer assignments now up to date
  - ▶ When SRS is complete, assign myself and your two reviewers issues to review
  - ▶ Provide at least 5 issues on their SRS
  - ▶ 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 your colleague assigns your issue
- Reading week next week, no 741 classes
- Work on your VnV plan during reading week

# Administrative Details

- VnV (and other deliverables) for families
  - ▶ You do not have to test and implement the entire family
  - ▶ At the end of your CA, list the selected values for your variabilities and their binding time
  - ▶ I will explicitly add a section to the template for this

# Administrative Details: Report Deadlines

<b>SRS</b>	Week 06	Oct 7
System VnV Plan	Week 08	Oct 28
MG + MIS	Week 10	Nov 25
Final Documentation	Week 14	Dec 9

- 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, please ask
- Two days after each major deliverable, your GitHub issues will be due
- Domain expert code due 1 week after MIS deadline

# Administrative Details: Presentations

Syst. VnV Present	Week 07	Week of Oct 21
MG + MIS Syntax Present	Week 9	Week of Nov 4
MIS Semantics Present	Week 11	Week of Nov 18
Unit VnV or Impl. Present	Week 12/13	Week of Nov 28

- Informal presentations with the goal of improving everyone's written deliverables
- Domain experts and secondary reviewers (and others) will ask questions (listed in Repos.xlsx file)

# Administrative Details: Presentation Schedule

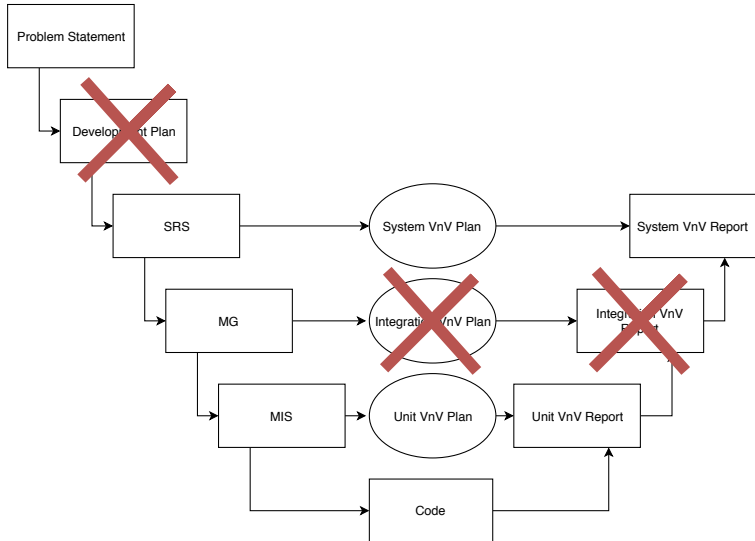
- Syst V&V Plan Present
  - ▶ **Monday: Deema, Peter**
  - ▶ **Thursday: Sharon, Ao**
- MG + MIS Syntax Present
  - ▶ Monday: Deema, Bo
  - ▶ Thursday: Sasha
- MIS Syntax + Semantics Present
  - ▶ Monday: Zhi, Peter
  - ▶ Thursday: Sharon, Ao
- Unit VnV Plan or Impl. Present
  - ▶ Monday: Bo, Sasha
  - ▶ Thursday: Zhi, Peter, Ao

# Questions?

- Questions about SRS?



# "Faked" Rational Design Process



# 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`

```
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

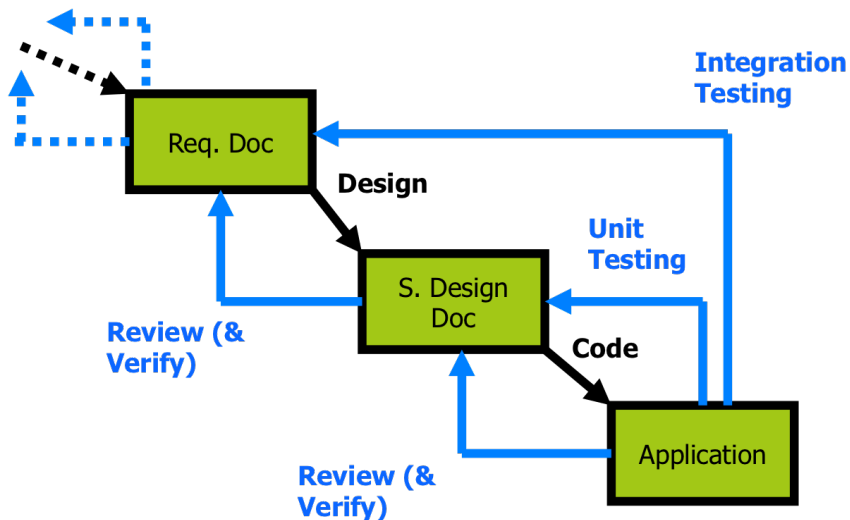
# Verification Versus Validation

- 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  $\neq$  0 then  
      middle := (bottom + top - 1) / 2;  
    else  
      middle := (bottom + top) / 2;  
    end if;  
    if key  $\leq$  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

- Information available on [Wikipedia](#)
- Developers integrate their code into a shared repo frequently (multiple times a day)
- 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
  - ▶ Example at [Rogue Reborn](#)
- Jenkins
- Travis
- 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 an ideal  $T$  leads to several **undecidable 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

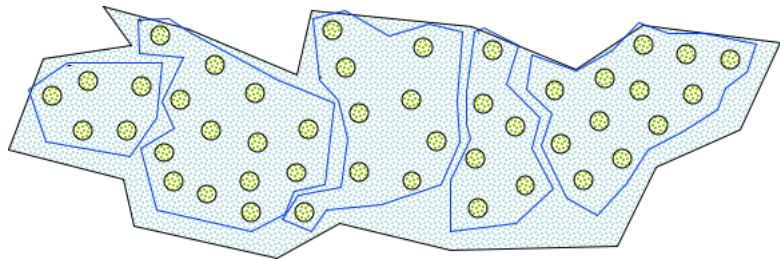
- Need to introduce empirical testing principles and heuristics as a compromise between the impossible and the inadequate
- Find a strategy to select **significant** test cases
- Significant means the test cases have a high potential of uncovering the presence of errors

# Complete-Coverage Principle

- Try to group elements of  $D$  into subdomains  $D_1, D_2, \dots, D_n$  where any element of each  $D_i$  is likely to have similar behaviour
- $D = D_1 \cup D_2 \cup \dots \cup D_n$
- 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



# References I



Carlo Ghezzi, Mehdi Jazayeri, and Dino Mandrioli.

*Fundamentals of Software Engineering.*

Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition,  
2003.