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

Fall 2017

10 Verification and Validation Continued

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Verification and Validation Continued

- Administrative details
- Questions?
- Finish what started last day
  - Nonfunctional software testing
  - Theoretical foundations of testing
  - Complete coverage principle
- White box testing
- Oracle problem
- SCS Specific Ideas
- Overview of template

Administrative Details

- GitHub issues for colleagues
  - Assigned 1 colleague (see `Repos.xlsx` in repo)
  - Provide at least 5 issues on their SRS
- Reading week, no 741 classes
- V&V template updated in repo

Administrative Details: Deadlines

SRS Issues	Reading week	Oct 9
Syst. VnV Present	Week 06	Week of Oct 15
System VnV Plan	Week 07	Oct 22
MG Present	Week 08	Week of Oct 29
MG	Week 09	Nov 5
MIS Present	Week 10	Week of Nov 12
MIS	Week 11	Nov 19
Unit VnV or Impl. Present	Week 12	Week of Nov 26
Unit VnV Plan	Week 13	Dec 3
Final Doc	Week 14	Dec 10

Administrative Details: Presentation Schedule

- Syst V&V Plan Present
  - Wednesday: Malavika, Robert
  - Friday: Hanane
- MG Present
  - Wednesday: Karol, Malavika, Robert, Hanane
  - Friday: Brooks, Vajiheh, Olu, Jennifer
- MIS Present
  - Wednesday: Malavika, Robert
  - Friday: Hanane, Jennifer
- Unit VnV Plan or Impl. Present
  - Wednesday: Brooks, Vajiheh
  - Friday: Olu, Karol

Questions?

- Questions about SRS?
- Questions about V&V?

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

- 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.

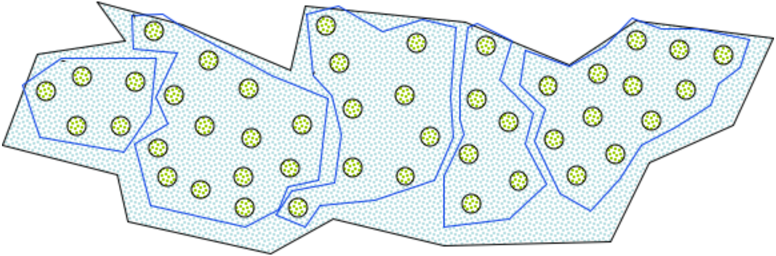
Empirical Testing

- 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



White-box Testing

- Intuitively, after running your test suites, what percentage of the lines of code in your program should be exercised?

White-box Coverage Testing

- (In)adequacy criteria - if significant parts of the program structure are not tested, testing is inadequate
- Control flow coverage criteria
  - Statement coverage
  - Edge coverage
  - Condition coverage
  - Path coverage

Examples that follow are from [1]

Statement-Coverage Criterion

- Select a test set T such that every elementary statement in P is executed at least once by some d in T
- An input datum executes many statements - try to minimize the number of test cases still preserving the desired coverage

Example

```
read (x); read (y);
if x > 0 then
        write ("1");
else
        write ("2");
end if;
if y > 0 then
        write ("3");
else
        write ("4");
end if;
```

How would you write a test case?

What is the minimum number of test cases?

Example

```
read (x); read (y);
if x > 0 then
        write ("1");
else
        write ("2");
end if;
if y > 0 then
        write ("3");
else
        write ("4");
end if;
```

{<x = 2, y = -3>, <x = - 13, y = 51>, <x = 97, y = 17>, <x = - 1, y = - 1>} covers all statements

{<x = - 13, y = 51>, <x = 2, y = - 3>} is minimal

Weakness of the Criterion

```
if x < 0 then
        x := -x;
end if;
z := x;
```

{<x=-3>} covers all statements. Why is this not enough?

Weakness of the Criterion

```
if x < 0 then
        x := -x;
end if;
z := x;
```

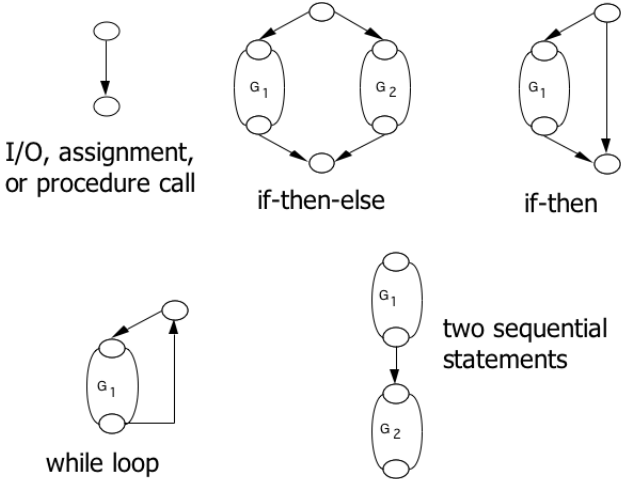
{<x=-3} covers all statements

it does not exercise the case when x is positive and the then branch is not entered

Edge-Coverage Criterion

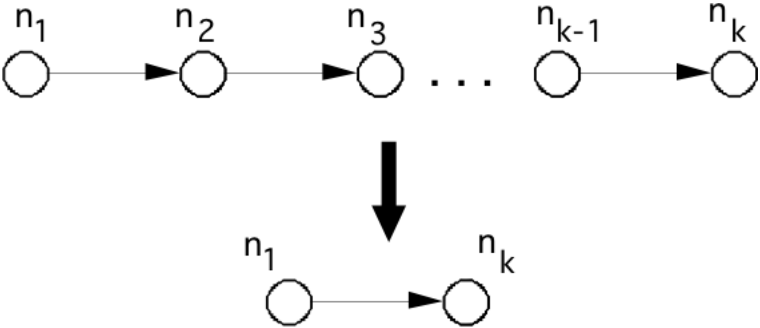
- Select a test set T such that every edge (branch) of the control flow is exercised at least once by some d in T
- This requires formalizing the concept of the control graph and how to construct it
  - Edges represent statements
  - Nodes at the ends of an edge represent entry into the statement and exit

Control Graph Construction Rules



Simplification

A sequence of edges can be collapsed into just one edge



Example: Euclid's Algorithm

```
begin
        read (x); read (y);
        while x ≠ y loop
                if x > y then
                        x := x - y;
                else
                        y := y - x;
                end if;
        end loop;
        gcd : = x;
end;
```

Draw the control flow graph

Example: Euclid's Algorithm

```
begin
        read (x); read (y);
        while x ≠ y loop
                if x > y then
                        x := x - y;
                else
                        y := y - x;
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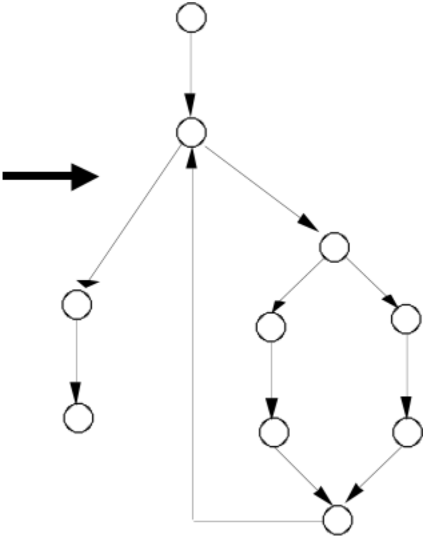

Weakness

```
found := false; counter := 1;
while (not found) and counter < number_of_items loop
        if table (counter) = desired_element then
                found := true;
        end if;
        counter := counter + 1;
end loop;
if found then
        write ("the desired element is in the table");
else
        write ("the desired element is not in the table");
end if;
```

test cases: (1) empty table, (2) table with 3 items, second of which is the item to look for

Weakness

```
found := false; counter := 1;
while (not found) and counter < number_of_items loop
        if table (counter) = desired_element then
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        end if;
        counter := counter + 1;
end loop;
if found then
        write ("the desired element is in the table");
else
        write ("the desired element is not in the table");
end if;
```

test cases: (1) empty table, (2) table with 3 items, second of which is the item to look for

Do not discover the error ($<$ instead of $\leq$)

```
if c1 and c2 then
   st;
else
   sf;

// equivalent to

if c1 then
   if c2 then
      st;
   else
      sf;
else
   sf;
```

Condition-Coverage Criterion

- Select a test set T such that every edge of P's control flow is traversed and all possible values of the constituents of compound conditions are exercised at least once
- This criterion is finer than edge coverage

Weakness

```
if x ≠ 0 then
        y := 5;
else
        z := z - x;
end if;
if z > 1 then
        z := z / x;
else
        z := 0;
end if;
```

{<x = 0, z = 1>, <x = 1, z = 3>} causes the execution of all edges, but fails to expose the risk of a division by zero

Path-Coverage Criterion

- Select a test set T that traverses all paths from the initial to the final node of Ps control flow
- It is finer than the previous kinds of coverage
- However, number of paths may be too large, or even infinite (see while loops)
- Loops
  - Zero times (or minimum number of times)
  - Maximum times
  - Average number of times

The Infeasibility Problem

- Syntactically indicated behaviours (statements, edges, etc.) are often impossible
- Unreachable code, infeasible edges, paths, etc.
- Adequacy criteria may be impossible to satisfy
  - Manual justification for omitting each impossible test case
  - Adequacy "scores" based on coverage - example 95 % statement coverage

Further Problem

- What if the code omits the implementation of some part of the specification?
- White box test cases derived from the code will ignore that part of the specification!

Testing Boundary Conditions

- Testing criteria partition input domain in classes, assuming that behavior is “similar” for all data within a class
- Some typical programming errors, however, just happen to be at the boundary between different classes
  - Off by one errors
  - $<$ instead of $\leq$
  - equals zero

Criterion

- After partitioning the input domain D into several classes, test the program using input values not only "inside" the classes, but also at their boundaries
- This applies to both white-box and black-box techniques
- In practice, use the different testing criteria in combinations

The Oracle Problem

When might it be difficult to know the "expected" output/behaviour?

The Oracle Problem

- Given input test cases that cover the domain, what are the expected outputs?
- Oracles are required at each stage of testing to tell us what the right answer is
- Black-box criteria are better than white-box for building test oracles
- Automated test oracles are required for running large amounts of tests
- Oracles are difficult to design - no universal recipe

The Oracle Problem Continued

- Determining what the right answer should be is not always easy
  - Scientific computing
  - Machine learning
  - Artifical intelligence

The Oracle Problem Continued

What are some strategies we can use when we do not have a test oracle?

Strategies Without An Oracle

- Using an independent program to approximate the oracle (pseudo oracle)
- Method of manufactured solutions
- Properties of the expected values can be easier than stating the expected output
  - Examples?

Strategies Without An Oracle

- Using an independent program to approximate the oracle (pseudo oracle)
- Method of manufactured solutions
- Properties of the expected values can be easier than stating the expected output
  - Examples?
  - List is sorted
  - Number of entries in file matches number of inputs
  - Conservation of energy or mass
  - Expected trends in output are observed (metamorphic testing [5, 4, 6])
  - etc.

Challenges Specific to Scientific Computing

- Unknown solution
- Approximation of real numbers
- Nonfunctional requirements
- Parallel computation

Mutation Testing for SC

- Generate changes to the source code, called mutants, which become code faults
- Mutants include changing an operation, modifying constants, changing the order of execution, etc.
- The adequacy of a set of tests is established by running the tests on all generated mutants
- Need to account for floating point approximations
- See [3]

Specific SC V&V Approaches

Summary of most points below in [10]

- Compare to closed-form solutions
- Method of manufactured solutions [8]
- Interval arithmetic [2]
- Convergence studies
- Compare to other program (parallel testing)
- Can also consider using code inspection
  - [7, 9]
  - Sample checklists

Specific SC V&V NonFunctional

- Installability, consider VMs
- Portability, consider VMs, Docker, CI
- Describe (rather than specify) impact of changing inputs
  - Accuracy
  - Performance
  - Relative comparison
- Usability
  - Fairly simple standard survey
  - Example

Validation Testing Report for PMGT

- Prepared by Wen Yu (here)
- Do not know the correct solution, but know properties of the correct solution
- Automated correctness validation tests
  - The area of each element is greater than zero
  - The boundary of the mesh is closed
  - Vertices in a clockwise order
  - $nc + nv - ne = 1$
  - ...
- Visual correctness validation tests
  - No vertex outside the input domain
  - No vertex inside a cell
  - No dangling edges
  - All cells connected
  - The mesh is conformal

Validation Testing Report for PMGT (Continued)

- List and description of test cases
- Test cases are labelled and numbered
- Traceability to SRS requirements
- Traceability to MG
- Summary of results
- Analysis of results
  - Focus on nonfunctional requirements
  - Speed

Test Plan From BlankProjectTemplate

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