

**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?

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 10
V&V Present	Week 06	Week of Oct 16
V&V Plan	Week 07	Oct 25
MG Present	Week 08	Week of Oct 30
MG	Week 09	Nov 8
MIS Present	Week 10	Week of Nov 13
MIS	Week 11	Nov 22
Impl. Present	Week 12	Week of Nov 27
Final Documentation	Week 13	Dec 6

Administrative Details: Presentation Schedule

- V&V Present
 - ▶ **Tuesday: Steven, Alexandre P., Alexander S.**
 - ▶ **Friday: Geneva, Jason, Yuzhi**
- MG Present
 - ▶ Tuesday: Xiaoye, Shusheng, Devi, Keshav, Alex P, Paul
 - ▶ Friday: Yuzhi, Jason, Geneva, Alex S, Isobel, Steven
- MIS Present
 - ▶ Tuesday: Isobel, Keshav, Paul
 - ▶ Friday: Shusheng, Xiaoye, Devi
- Impl. Present
 - ▶ Tuesday: Alexander S., Steven, Alexandre P.
 - ▶ Friday: Jason, Geneva, Yuzhi

Questions?

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

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;
```

**$\{\langle x = 2, y = -3 \rangle, \langle x = -13, y = 51 \rangle,$
 $\langle x = 97, y = 17 \rangle, \langle x = -1, y = -1 \rangle\}$**

covers all statements

$\{\langle x = -13, y = 51 \rangle, \langle x = 2, y = -3 \rangle\}$

is minimal

Weakness of the Criterion

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

$\{ \langle x = -3 \rangle \}$ 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

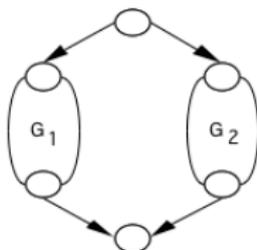
Edge-Coverage Criterion

- 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

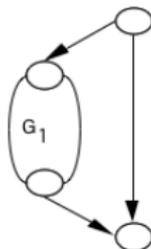
Control Graph Construction Rules



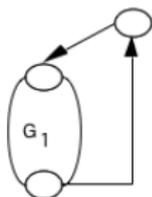
I/O, assignment,
or procedure call



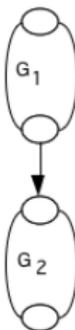
if-then-else



if-then



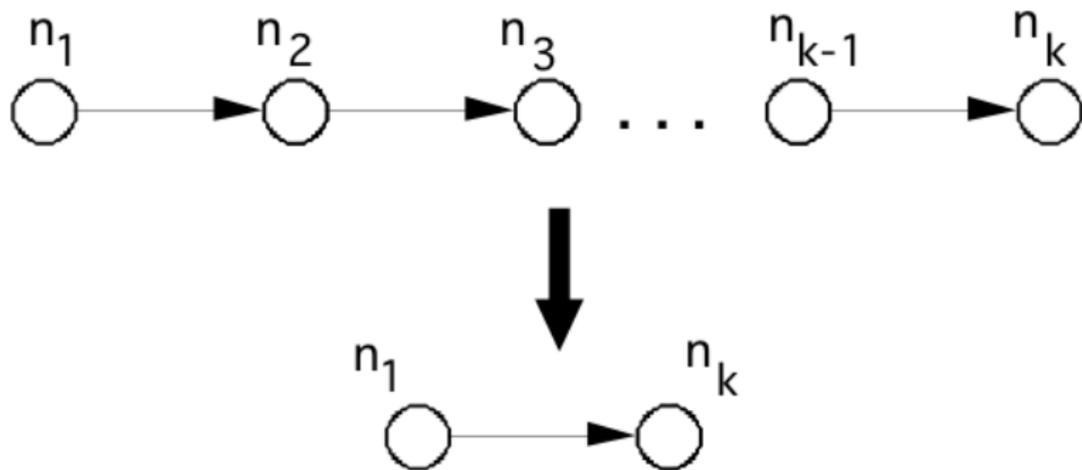
while loop



two sequential
statements

Simplification

A sequence of edges can be collapsed into just one edge



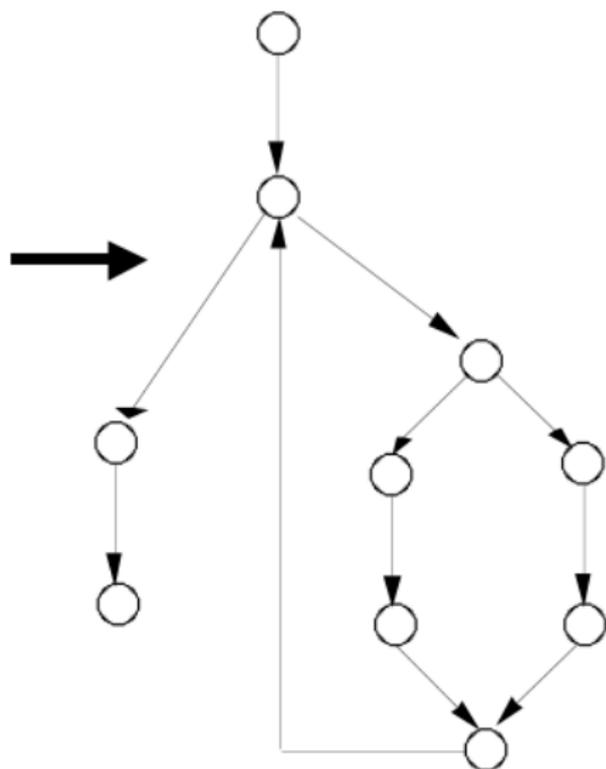
Example: Euclid's Algorithm

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



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
    found := true;
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  counter := counter + 1;
end loop;
if found then
  write ("the desired element is in the table");
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  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  $x \neq 0$  then
     $y := 5$ ;
else
     $z := z - x$ ;
end if;
if  $z > 1$  then
     $z := z / x$ ;
else
     $z := 0$ ;
end if;
```

$\{\langle x = 0, z = 1 \rangle, \langle x = 1, z = 3 \rangle\}$
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 P 's 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
 - ▶ Artificial 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)
 - ▶ 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 in [5]

- Compare to closed-form solutions
- Method of manufactured solutions [4]
- Interval arithmetic [2]
- Convergence studies
- Compare to other program (parallel testing)

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

Validation Testing Report for PMGT

- Prepared by Wen Yu
- 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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