Software Testing

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Testing

- Most common form of SW checking.
  - Run program on selected inputs.
  - Observe outputs.
  - Match outputs against expectation.
- Programmer's expectation of outputs.
  - May not capture program as a mathematical function.
    - Requires very deep understanding in the first place
  - But expected o/p for specific i/p

The trivial example

```
int factorial(int n)
{
   if (n == 1) return 1;
   else return n* fact(n-1);
}
```

Could capture programmer's expectation as

factorial(n) = n! for all n

Now find suitable *n*, and test the output of the factorial function against the expected output given by *n!*

Most of the times, this is not possible since the programmer does not have such a deep understanding of the program he/she is writing.

Programmer's expectation

- Often of the form
  - For input i==0, expect output o == 5, or
  - For input i == 0, expect output o > 0 , or
  - … in real-life, can be even of the form
    - Run program against input I == 0
    - Observe output
      - What is the observed output
      - Observed output o == 0
      - Doesn't look right, investigate
    - Debug program for its execution with input i==0

Why test software?

- Quote by Knuth (http://en.wikipedia.org/wiki/Donald_Knuth)
  - "Beware of bugs in this program. I have only proved it correct, not tried it."
- Quote by Dijkstra
  - "Testing only shows the presence of bugs, not their absence".
- *Which SW will you put in your mother's car?*
  - *Verified based on a model, but not tested.*
  - *``Thoroughly" tested, but not verified.*

A Trivial Exercise in Testing

- Function triangle takes three integers a,b,c which are the length of triangle sides; calculates whether the triangle is equilateral, isosceles, or scalene.
- Try to write down test cases for this function (due to Myers)

How thorough can we be?

- Do you have a test case for an equilateral triangle?
- Do you have a test case for an isosceles triangle?
- Do you have at least three test cases for isosceles triangles, where all permutations are considered? (e.g. (x,x,y), (x,y,x), (y,x,x))
- Do you have a test case for an admissible scalene triangle?
- Do you have a test case with one side zero?
- Do you have the test case (0,0,0)?
- Do you have a test case with negative values?
- Do you have a test case where the sum of two sides equals the third one?
- Do you have at least three test cases for such non-triangles, where all permutations of sides are considered?
- Do you have a test case where the sum of the two smaller inputs is greater than the third one?
- Do you have at least three such test cases, considering all permutations?
- Do you have test cases with very large integers (exceeding MAXINT) ?
- Do you have a test case with non-integer values but numbers?
- Do you have a test case with non-numbers e.g. strings, characters …
- Do you have a test case where 2 or 4 inputs are provided?

Testing isn't so trivial!

- Myers 1979: this example should demonstrate that testing even a trivial program is not an easy task. Consider the problem of testing an air traffic guidance system with 100.000 instructions, a compiler or just a payroll program.
- Windows Vista is 50 MLoC.

Why is testing important?

- As SW grows more complex
  - Less % of time in initial coding, modeling, requirements.
  - Greater % of time in testing & maintenance
    - Maintaining the SW as SW ages
    - Regression testing: testing a SW after changes, and see if any previously working functionality breaks.
    - Crucial in any large SW development project.

The high-level view

- Unit testing (we focus more on this now!)
  - Structural or Functional approaches
  - A unit can be a function or in the case of O-O programs, say a class
  - We will discuss control flow coverage criteria in details.
- Testing full programs
  - Integration testing
  - Regression testing (Check that the program still works after a feature is added to a tested program)
    - Discuss more in 3rd lecture
  - Stress testing (e.g. web-service with many users)

Common terminology

- Test case
  - A test input (or its execution trace)
- Test suite
  - Set of test cases
- Test purpose
  - A formal specification to guide testing
    - e.g. a regular expression which the test case should satisfy
- Coverage criterion
  - A guide to exhaustively cover program structure.
    - e.g. Statement coverage, Cond. coverage, Path coverage.

Structural vs. Functional Testing

- Functional (Black Box)
  - Boundary Value Testing
  - Equivalence Class Testing
  - Decision Table based Testing
- Structural (Glass Box or White Box)
  - Control flow Coverage Criteria
  - Data flow Coverage Criteria

Boundary value

Checking a "month" input variable for boundary values 0, 13

Can check for simple errors like

```
if (month >= 0) && (month < 13)
```

Need to get the boundary values by equivalence partitioning, or by general intuition (e.g. in the case of ``month" variable)

Equivalence Partitioning

- Name is suggestive
  - "month" variable --- <= 0, 1..12, > 12
  - Can have different handling for diff. values
    - `if (month >= 0) && (month < 13)`
      - `if (month < 4) { ...`
      - `}`
      - `else{    /* different financial year */ …`
      - `    }`
  - Partitions < =0, 1..3, 4..12, > 12
- Strictly speaking, a white box testing method

Decision Table based testing

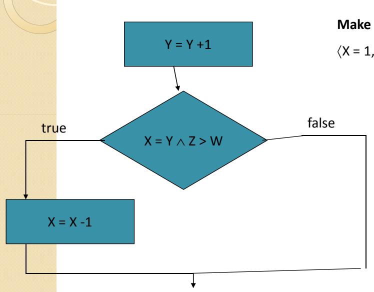
c1: a<b+c?	F	T	T	T	T	T	T	T	T	T	T
c2: b<a+c?	-	F	T	T	T	T	T	T	T	T	T
c3: c<a+b?	-	-	F	T	T	T	T	T	T	T	T
c4: a = b?	-	-	-	T	T	T	T	F	F	F	F
c5: a = c?	-	-	-	T	T	F	F	T	T	F	F
c6: b = c?	-	-	-	T	F	T	F	T	F	T	F
a1: Not a Triangle	X	X	X								
a2: Scalene											X
a3: Isosceles							X		X	X	
a4: Equilateral				X							
a5: Impossible					X	X		X			

Create such a decision table to check complex conditions.
Based on the tester's knowledge of what the program should do, rather than the structure of the program.

Now …

- Structural (White Box) Testing
  - Look inside the code
    - Discussion of control flow coverage criteria
      - Statement coverage
      - Branch coverage
      - …

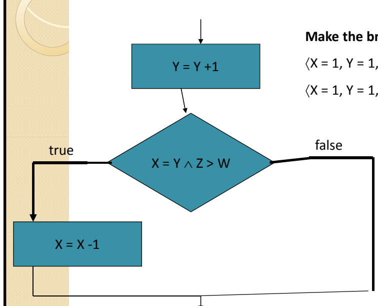
Statement coverage



Make the branch condition true

⟨X = 1, Y = 1, Z = 2, W = 1⟩

Edge coverage



Make the branch condition true/false

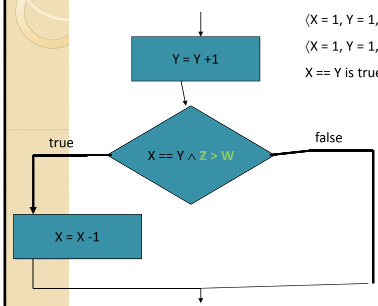
⟨X = 1, Y = 1, Z = 2, W = 1⟩

⟨X = 1, Y = 1, Z = 2, W = 2⟩

Condition coverage

- For each executable condition c
  - Check whether it can be both true or false
    - c could be unsatisfiable or valid in all pgm. executions
  - For all such conditions c, c should be true in at least one test in the test suite, and c should be false in at least one test in the test suite.

Condition coverage

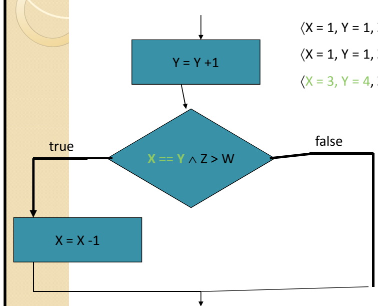


⟨X = 1, Y = 1, Z = 2, W = 1⟩

⟨X = 1, Y = 1, Z = 2, W = 2⟩

X == Y is true in both the test cases

Condition coverage



⟨X = 1, Y = 1, Z = 2, W = 1⟩

⟨X = 1, Y = 1, Z = 2, W = 2⟩

⟨X = 3, Y = 4, Z = 7, W = 5⟩

Path coverage

- Cover all paths in the program
  - Unboundedly many, unless loops can be bounded.
  - Lot of infeasible paths i.e. paths which do not form execution trace for any input.
    - Infeasible path detection will help test-suite construction.
- A technique to help exercise new paths with new tests
  - Attempts to achieve path coverage
  - Basic idea: concrete and *symbolic* execution at the same time.

Directed Automated Random Testing

- Start with a random input I.
- Execute program P with I
  - Suppose I executes path p in program P.
  - While executing p, collect a symbolic formula f which captures the set of all inputs which execute path p in program P.
- Minimally change f, to produce a formula f1
  - Solve f1 to get a new input I1 which executes a path p1 different from path p.

Example program

- if (Climb)
  - separation = Up;
- else
  - separation = Up + 100;
- if (separation > 150)
  - upward = 1;
- else
  - upward = 0;
- if (upward >0)
  - printf("Upward");
- else
  - printf("Downward");

Start with random input
(Climb == 0, Up == 457)

Example program

- if (Climb)
  - separation = Up;
- else — Climb == 0 $\wedge$
  - separation = Up + 100;
- if (separation > 150) — (Up + 100 > 150) $\wedge$
  - upward = 1;
- else
  - upward = 0;
- if (upward >0) — upward > 0
  - printf("Upward");
- else
  - printf("Downward);

Generating new tests

- The path condition calculated
  - Climb ==0 $\wedge$ Up + 100 > 150 $\wedge$ upward > 0
- Minimally modify the condition
  - Climb ==0 $\wedge$ Up + 100 > 150 $\wedge$ $\neg$(upward > 0)
- Corresponding to the path …

Infeasible path!!

- if (Climb)
  - separation = Up;
- else — Climb == 0 $\wedge$
  - separation = Up + 100;
- if (separation > 150) — (Up + 100 > 150) $\wedge$
  - upward = 1;
- else
  - upward = 0;
- if (upward >0)
  - printf("Upward");
- else — $\neg$ upward > 0
  - printf("Downward);

Generating new tests

- The path condition calculated
  - Climb ==0 $\wedge$ Up + 100 > 150 $\wedge$ upward > 0
- Minimally modify the condition
  - Climb ==0 $\wedge$ Up + 100 > 150 $\wedge$ $\neg$(upward > 0)
  - Corresponding to infeasible path!
- Modify a bit more
  - Climb == 0 $\wedge$ $\neg$ (Up + 100 > 150)
  - Corresponding to the path …

Feasible path

- if (Climb)
  - separation = Up;
- else — Climb == 0 $\wedge$
  - separation = Up + 100;
- if (separation > 150) — $\neg$ (Up + 100 > 150)
  - upward = 1;
- else
  - upward = 0;
- if (upward >0)
  - printf("Upward");
- else
  - printf("Downward);

Generating new tests

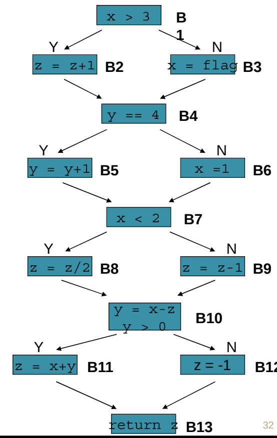
- The path condition calculated
  - Climb ==0 $\wedge$ Up + 100 > 150 $\wedge$ upward > 0
- Minimally modify the condition
  - Climb ==0 $\wedge$ Up + 100 > 150 $\wedge$ $\neg$(upward > 0)
  - Corresponding to infeasible path!
- Modify a bit more
  - Climb == 0 $\wedge$ $\neg$ (Up + 100 > 150)
  - Solve to get another test input
    - Climb == 0, Up == 0
- Continue in this fashion.

Structural Testing (continued)

- Coverage Criteria
  - Control flow based
    - Statement, Edge, Condition, Path
  - Data flow based
    - All defs, All uses etc
    - Why need it?
      - Control flow criteria (except path coverage) do not exercise the use of a variable definition and the data flow.

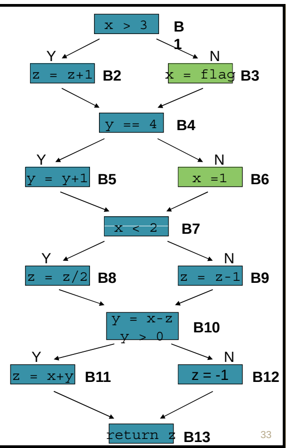

```
int P1( int flag ) {
    int x, y, z;

    if( x > 3 )
        z = z + 1;
    else
        x = flag;
    if( y == 4 )
        y = y + 1;
    else
        x = 1;
    if( x < 2 )
        z = z / 2;
    else
        z = z - 1;
    y = x - z;
    if( y > 0 )
        z = x + y;
    else
        z = -1;
    return z;
}
```



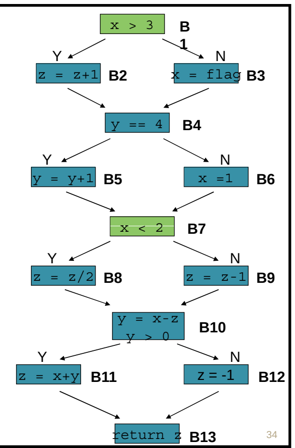
def(x)

Nodes where variable x is assigned



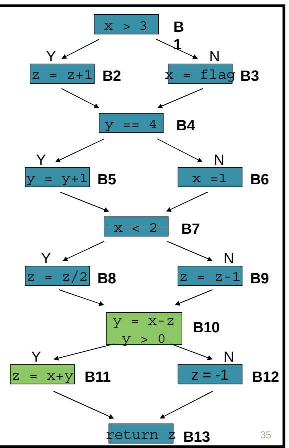
p-use(x)

Nodes where variable x is used in a predicate.



c-use(x)

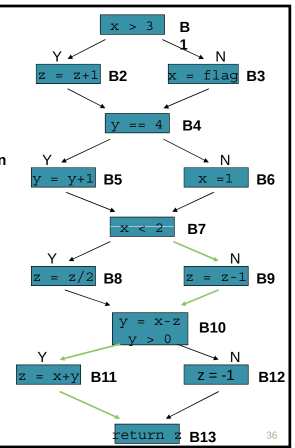
Nodes where variable x is used in any expression other than a predicate (say rhs of assignment)



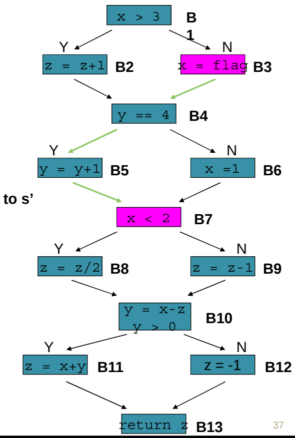
def-clear(x)

Set of paths which do not contain any node in def(x)

Typically consider acyclic paths



dpu(s,x)



Given variable x, and s ∊ def(x)

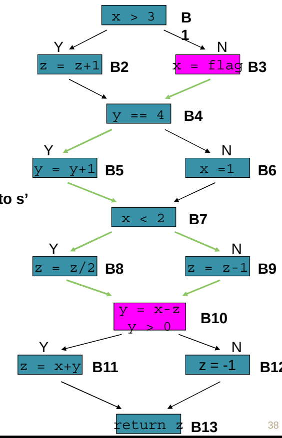
dpu(s,x) =

{ s' | ∃ def-clear(x) path from s to s'

and s' ∊ p-use(x)

}

dcu(s,x)



Given variable x, and s ∊ def(x)

dcu(s,x) =

{ s' | ∃ def-clear(x) path from s to s'

and s' ∊ c-use(x)

}

Coverage criteria

- All defs
  - For each variable x, and def. s ∊ def(x)
    - Include at least one def-clear(x) path from s to at least one node in dpu(s,x) ∪ dcu(s,x).
- All uses
  - For each variable x, and def. s ∊ def(x)
    - Include at least one def-clear(x) path from s to each node in dpu(s,x) and to each node in dcu(s,x).

Coverage criteria

- All du-paths
  - For each variable x, and def. s ∊ def(x)
    - Include all def-clear(x) path from s to each node in dpu(s,x) and to each node in dcu(s,x).
- In terms of power
  - All du-paths > All uses > All defs

Reading

- Most of the basic stuff is folklore.
- For a recent work on symbolic execution based testing see
  - http://srl.cs.berkeley.edu/~ksen/papers/dart.pdf
  - http://srl.cs.berkeley.edu/~ksen/slides/dart-fm.ppt
  - **This covers the portion on "Directed Automated Random Testing".**