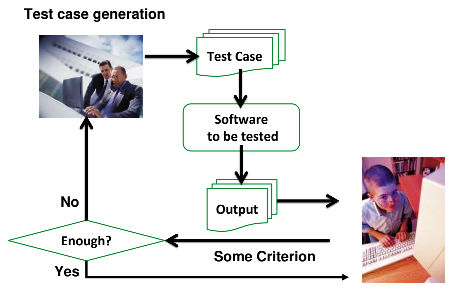
<u>**Week 1**</u>
Software testing: process of executing program/system with intent of finding errors
Fault: incorrect portions of code (can be missing as well as incorrect)
Failure: observable correct behaviour of program
Error: cause of fault, something bad programmer did (conceptual, typo, etc)
Bug: informal term for fault
Test case: set of test inputs, execution conditions, expected results developed for particular objective, such as to exercise particular program path ot verify compliance with specific requirement

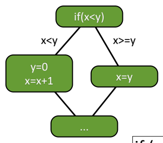
A Typical Software Testing Process



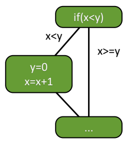
Testing: find inputs that cause failure of software, failure unknown, performed by testers
Debugging: process of finding & fixing fault given failure, failure is known, performed by devs
Black-Box/Functional Testing: identify functions & design test cases to check whether functions are correctly performed by software (formal & informal specs)
Equivalence partitioning: divide into partitions, select 1 test case from each partition, partitions must be disjointed (no input belongs to more than 1 partition) & all partitions must cover entire input domain
Equivalence partitioning examples: isEven then even & odd, password min 8 & max 12 characters then less than, valid, more than
Boundary-Value analysis: partition input domain, identify boundaries, select test data (for range $[R_1, R_2]$ less than R_1, equal to R_1, between, equal to R_2, greater than R_2, for unordered sets select in & not in, for equality select equal & not equal, for sets, lists select empty & not empty)
White box/structural testing: generate test cases based on program structure, abstract program to control flow graph (node is sequence of statements, edge is transfers of control)

CFG : The if statement

```
if (x < y)
{
  y = 0;
  x = x + 1;
}
else
{
  x = y;
}
...
```

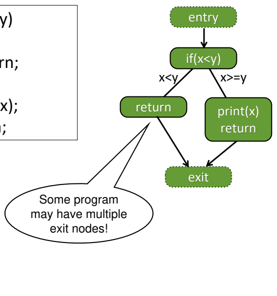


```
if (x < y)
{
  y = 0;
  x = x + 1;
}
...
```



CFG : The dummy nodes

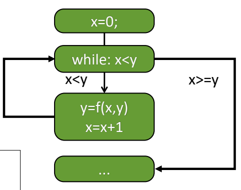
```
if (x < y)
{
  return;
}
print (x);
return;
```



CFG : while and for loops

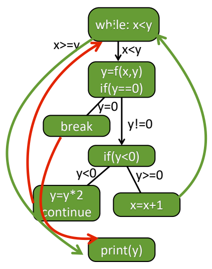
```
x=0;
while (x < y)
{
  y = f (x, y);
  x = x + 1;
}
...
```

```
for (x = 0; x < y; x++)
{
  y = f (x, y);
}
```



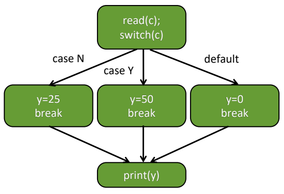
CFG: break and continue

```
while (x < y)
{
  y = f (x, y);
  if (y == 0) {
    break;
  } else if (y<0) {
    y = y*2;
    continue;
  }
  x = x + 1;
}
print (y);
```



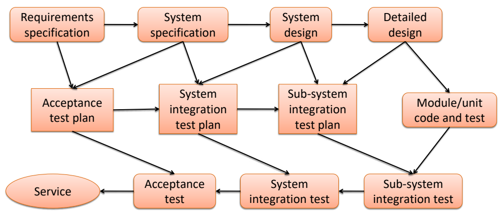
CFG: switch

```
read ( c ) ;
switch ( c )
{
  case 'N':
    y = 25;
    break;
  case 'Y':
    y = 50;
    break;
  default:
    y = 0;
    break;
}
print (y);
```



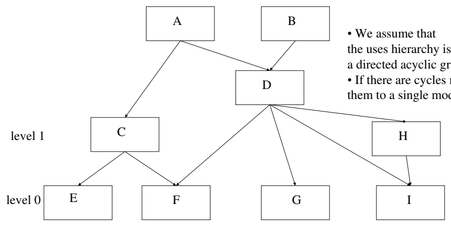
Coverage types: statement, branch, path (infinite if loop exists), strictly subsumes all beforehand
<u>**Week 2**</u>
Test oracle: expected output of software for given input, part of test case
Test driver: software framework that can load collection of test cases or test suite
Test suite: collection of test cases

The V-model of development


Requirements specification
System specification
System design
Detailed design
Acceptance test plan
System integration test plan
Sub-system integration test plan
Module/unit code and test
Service
Acceptance test
System integration test
Sub-system integration test

Testing types:
Unit/Module: test single module in isolated environment, use drivers & stubs for isolation
Integration: test parts of system by combining modules, integrated collection of modules tested as group or partial system
System: test system as a whole after integration phase
Acceptance: test system as a whole to find out if it satisfies requirements specifications
Driver: program that calls interface procedures of module being tested & reports results, simulates module that calls module currently being tested, also provides access to global variables for module under test
Stub: program that has same interface as module being used by module being tested but simpler, simulates module called by module being tested
Mock objects: create object that mimics behaviour needed for testing

Module Structure



- We assume that the uses hierarchy is a directed acyclic graph.
- If there are cycles merge them to a single module

- A uses C and D; B uses D; C uses E and F; D uses F, G, H and I; H uses I
- Modules A and B are at level 3; Module D is at level 2
Modules C and H are at level 1; Modules E, F, G, I are at level 0
- level 0 components do not use any other components
- level *i* components use at least one component on level *i*-1 and no component at a level higher than *i*-1

Integration types:
Bottom-Up: only terminal modules tested in isolation, requires drivers but not stubs (since lower levels are tested already)
Top-down: modules tested in isolation are modules at highest level, requires stubs but not drivers
Sandwich: begin both bottom-up & top-down, meet at predetermined point in middle
Big bang: every module unit tested, then integrate all at once, no driver or stub needed but may be hard to isolate bugs
System/Acceptance testing: can construct test case based on requirements specifications, main purpose is to assure that system meets requirements, alpha testing performed within development organisation, beta testing performed by select group of friendly customers
<u>**Week 3**</u>
Basis Path Testing: between branch & path coverage, fulfills branch testing & tests all independent paths that could be used to construct any arbitrary path through computer program
Independent path: includes some vertices/edges not covered in other path
Cyclomatic complexity: $e - n + 2p$, e is edges, n is nodes, p is number of connected components, or $1 + d$, d is loops or decision points, upper bound on number of test cases to guarantee coverage of all statements
Decision Coverage: executing true/false of decision
Condition Coverage: executing true/false of each condition
Condition/Decision Coverage: DC & CC, better than either
Multiple Condition Coverage: whether every possible combination of boolean sub-expressions occurs, test cases are truth table, 2^n test cases for n conditions
Modified C/DC: for each basic condition C, 2 test cases, values of all evaluated conditions except C are the same, compound decision as a whle evaluates to true for 1 & false for the other, subsumed by MCC & subsumes CC, DC, C/DC, stronger than statement & branch
MC/DC coverage: each entry & exit point invoked, each decision takes every possible outcome, each condition in a decision takes every possible outcome, each condition in decision is shown to independently affect outcome of decision, independence of condition is shown by proving that only one condition changes at a time

MC/DC: linear complexity

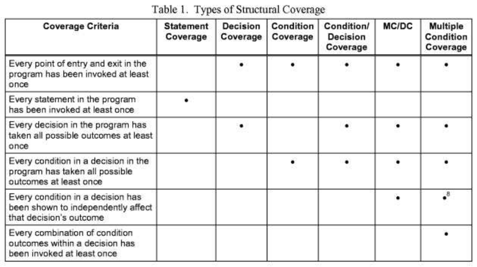
- N+1 test cases for N basic conditions

`(((a || b) && c) || d) && e`

Test Case	a	b	c	d	e	outcome
(1)	<u>true</u>	--	<u>true</u>	--	<u>true</u>	true
(2)	false	<u>true</u>	true	--	true	true
(3)	true	--	false	<u>true</u>	true	true
(4)	true	--	true	--	<u>false</u>	false
(5)	true	--	<u>false</u>	<u>false</u>	--	false
(6)	<u>false</u>	<u>false</u>	--	false	--	false

- Underlined values independently affect the output of the decision

Table 1. Types of Structural Coverage



Coverage Criteria	Statement Coverage	Decision Coverage	Condition Coverage	Condition/ Decision Coverage	MC/DC	Multiple Condition Coverage
Every point of entry and exit in the program has been invoked at least once		•	•	•	•	•
Every statement in the program has been invoked at least once	•					
Every decision in the program has taken all possible outcomes at least once		•		•	•	•
Every condition in a decision in the program has taken all possible outcomes at least once			•	•	•	•
Every condition in a decision has been shown to independently affect that decision's outcome					•	•[8]
Every combination of condition outcomes within a decision has been invoked at least once						•

<u>**Week 4**</u>
Dataflow Coverage: considers how data gets accessed & modified in system & how it can get corrupted
Common access-related bugs: using unde

fined/uninitializsed variable, deallocating/reinitialising variable before constructed/initialised/used, deleting collection object leaving members unaccessible
Variable definition: defined whenever value modified (LHS of assignment, input statement, call-by-reference)
Variable use: used whenever value read (RHS of assignment, call-by-value, branch statement predicate)
p-use: use in predicate of branch statement
c-use: any other use
Use & redefine in single statement: both sides of assignment, call-by-reference
du-pair: with respect to variable v is a pair (d, u) such that d is a node defining v, u is a node/edge using v (if p-use u is outgoing edge of predicate), there is a def-clear path with respect to v from d to u
Definition clear: with respect to variable v if no variable re-definition of v on path

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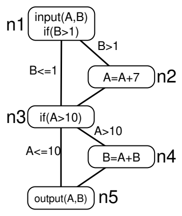
Identifying du-pairs – variable **A**

du-pair	path(s)
(1,2)	<1,2>
(1,4)	<1,3,4>
(1,5)	<1,3,4,5>
	<1,3,5>
(1,<3,4>)	<1,3,4>
(1,<3,5>)	<1,3,5>
(2,4)	<2,3,4>
(2,5)	<2,3,4,5>
	<2,3,5>
(2,<3,4>)	<2,3,4>
(2,<3,5>)	<2,3,5>



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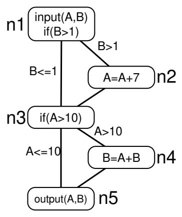
Identifying du-pairs – variable **B**

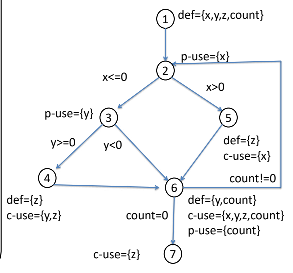
du-pair	path(s)
(1,4)	<1,2,3,4>
	<1,3,4>
(1,5)	<1,2,3,5>
	<1,3,5>
(1,<1,2>)	<1,2>
(1,<1,3>)	<1,3>
(4,5)	<4,5>



Dataflow test coverage criteria:
All-Defs: for every variable v, at least one def-clear path from every definition of v to at least one c-use or p-use of v must be covered
All-P/C-Uses: for every variable v, at least one def-clear path from every definition of v to every p/c-use of v must be covered
All-Uses: all du-pairs covered
Notations:
$d_1(x)$: definition of variable x in node i
$u_i(x)$: use of variable x in node i $dcu(d_i(x)) = dcu(x, i)$: set of c-uses with respect to $d_1(x)$
$dpu(d_i(x)) = dpu(x, i)$: set of p-uses with respect to $d_1(x)$

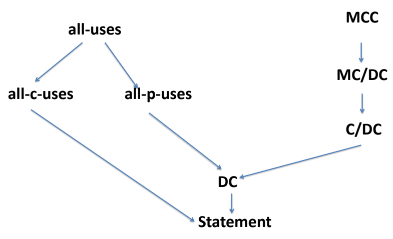
```
begin
    float x,y,z=0.0;
    int count;
    input(x,y,count);
    do{
      if(x≤0) {
        if(y≥0)  {
          z=y*z+1;
        }
      }
      else{
       z=1/x;
      }
      y=x*y+z;
      count=count-1;}
    while(count>0)
    output(z);
end
```

Another Example



All-C-Uses for above: $dcu(x, 1) + dcu(y, 1) + dcu(y, 6) + dcu(z, 1) + dcu(z, 4) + dcu(z, 5) + dcu(count, 1) + dcu(count, 6) = 2 + 2 + 2 + 3 + 3 + 3 + 1 + 1 = 17$
All-P-Uses for above: $dpu(x, 1) + dpu(y, 1) + dpu(y, 6) + dpu(z, 1) + dpu(z, 4) + dpu(z, 5) + dpu(count, 1) + dpu(count, 6) = 2 + 2 + 2 + 0 + 0 + 0 + 2 + 2 = 10$ (note this includes using the initial count definition even though it will always be redefined (-1) before the comparison)

Relationships among some of the coverage criteria



Week 5
Program mutation: create artificial bugs by injecting changes to statements of programs, simulate subtle bugs in real programs
Mutation testing: software testing technique based on program mutation, can be used to evaluate test effectiveness & enhance test suite, can be stronger than control/data-flow coverage, extremely costly since need to run whole test suite against each mutant
Mutation testing steps: applies artificial changes based on mutation operators to generate mutants (each mutant with ony one artificial bug), run test suite against each mutant (if any test fails mutant killed, else survives), compute mutation score
Symbolic execution/evaluation: analyse program to determine what inputs cause each part of program to execute, execute programs with symbols (track symbolic state rather than concrete input, when execute one path actually simulate many test inputs (since considering all inputs that can exercise same path))
Problems with symbolic execution:
Path explosion: 2^n paths for n branches, infinite paths for unbounded loops, calculate constraints for all paths is infeasible for real software
Constraint too complex: especially for large programs, also it is NP-complete
Input sub-domain: set of inputs satisfying path condition
Searching input to execute path: equivalent to solving associated path condition

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Example

```
y = read();               y=s, s is a symbolic variable for input
p = 1;                    p = 1, y = s
while(y < 10){            p = 1, y = s
      y = y + 1;           s<10, y = s + 1, p = 1
       if y >2
         p = p + 1;          2 < s + 1< 10, y = s + 1, p = 2
       else
         p = p + 2;        s + 1<=2, y = s + 1, p = 3
 }
 print (p);
```