Data Flow Coverage 2

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Coverage: the point, revisited

- We are attempting to decide what makes a good test.
  i.e judge the **adequacy** of our test suite.
- Surely an **adequate** test suite will show our software is correct?
  Impossible. Same as proving the software is correct.
- So can we say some test suites are better than others?
  Yes, if we can define effective, testable **adequacy criteria**. Such as?
  - Statement coverage = 1
    But if our test doesn't exercise all statements, surely it's no good?
  - Branch coverage = 1
    But if our test doesn't exercise all branches, surely it's no good?
  - Path coverage = 1
    But if our test doesn't exercise all paths, surely it's no good? (!)
- So they are actually really **inadequacy criteria**

Subsumption

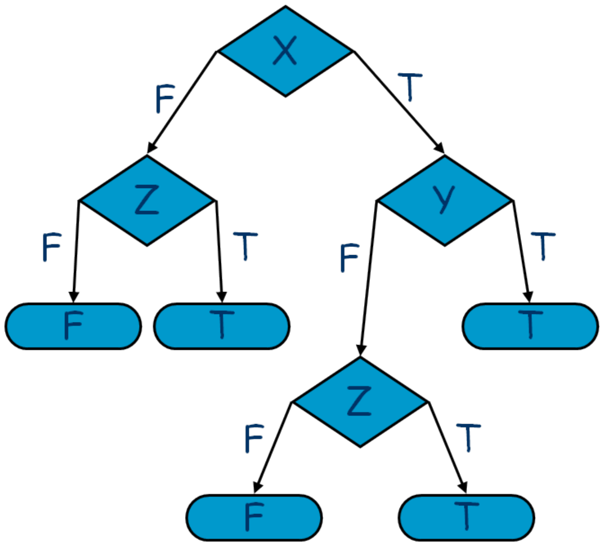
- So really, no tests are as good as we'd want. But some are provably worse than others, e.g. branch coverage necessarily includes statement coverage.
- **Definition:** *test coverage criterion A subsumes test coverage criterion B if and only if, for every program P, every test set satisfying A with respect to P also satisfies B with respect to P.*
- If you have branch coverage, you also always have statement coverage — Branch coverage subsumes statement coverage.
- If criterion A subsumes criterion B, and a test suite satisfying B is guaranteed to find a fault, then a suite satisfying A will also find that fault.
  - But these criteria provide no guarantees.
  - And with no guarantee that B will find a fault, we have no guarantee for A either.

Adequacy review 1

- **Statement adequacy:** all statements have been executed by at least one test case.
- **Branch adequacy:** all branches have been executed by at least one test case.
- **Basic condition adequacy:** each basic condition evaluates to true in at least one test case, and to false in at least one test case.
- **Compound condition adequacy (simplistic definition):** each combination of truth values of basic conditions must be visited by at least one test case.

X	Y	Z	(X&Y)|Z
F	F	F	F
F	F	T	T
F	T	F	F
F	T	T	T
T	F	F	F
T	F	T	T
T	T	F	T
T	T	T	T

Good definitions are important: basic condition



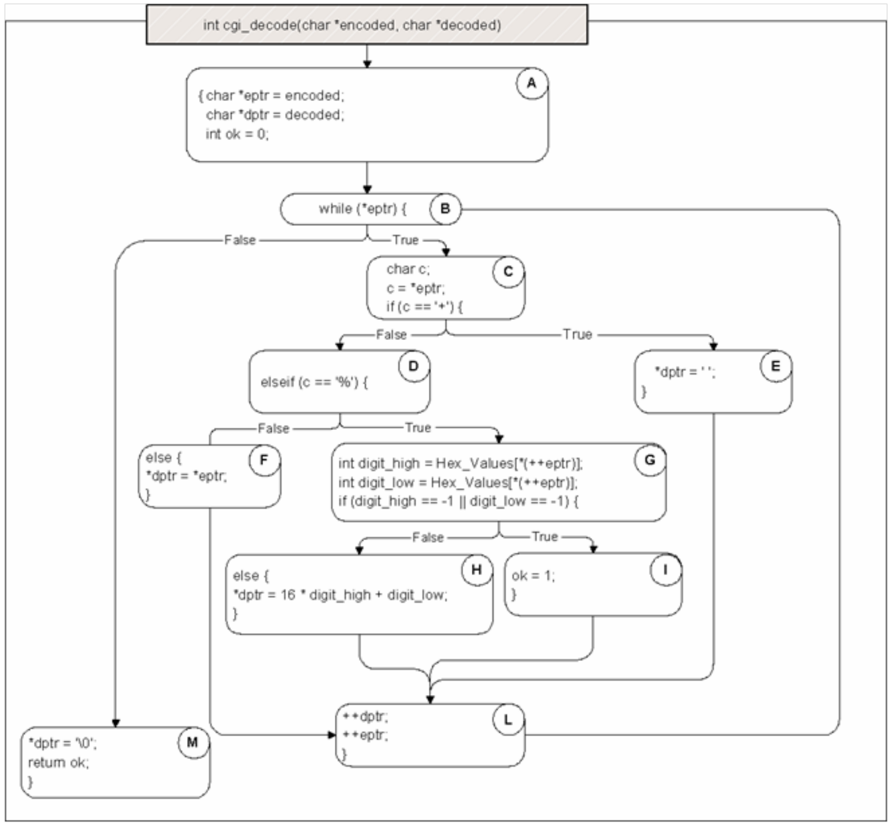
X	Y	Z	(X&Y)|Z
F	F	F	F
F	F	T	T
F	T	F	F
F	T	T	T
T	F	F	F
T	F	T	T
T	T	F	T
T	T	T	T

- (X=Y=Z=F); (X=Y=Z=T) appears to achieve B.C.A., but condition Y is never evaluated in the first case, nor Z in the second.
- Need, e.g. (X=F, Y=?, Z=T); (X=T, Y=Z=F); (X=Y=T, Z=?) (? = don't care, because it's never evaluated).

Test suite adequacy 1

- T_0 = { " ", "test", "test+case%1Dadequacy" }
- T_1 = { "adequate+test%0Dexecution
- T_2 = { "%3D", "%A", "a+b", "test" }
- T_3 = { " ", "+%0D+%4J" }
- T_4 = { "first+test%9Ktest%K9" }

Coverage Criterion	T0	T1	T2	T3	T4
Statement					
Branch					
Basic Condition					
Compound Condition					



[P&Y p.213-214, Figures 12.1 & 12.2]

Test suite adequacy 1

- T2 uncovers a bug in the program. What bug?
- Branch coverage appears the same as statement coverage here. Suggest a code construct which would show branch coverage to be superior to statement coverage.
- Basic condition coverage clearly doesn't subsume branch coverage.
- While T4 technically satisfies basic condition coverage, you can argue that it doesn't. How?
- You can also argue that compound condition coverage is impossible for this code fragment, for a similar reason. This might lead us to modify our definitions of basic and compound condition coverage, to make them more practical. How?
- Can you suggest enhancements to each test in order to achieve compound condition coverage?

Adequacy review 2

- Test suite T satisfies the path adequacy criterion for program P iff for each path p of P there exists at least one test case in T that causes the execution of p.

- **Loop boundary adequacy criterion:** test cases exist such that each loop is executed zero times, exactly once, and many times.

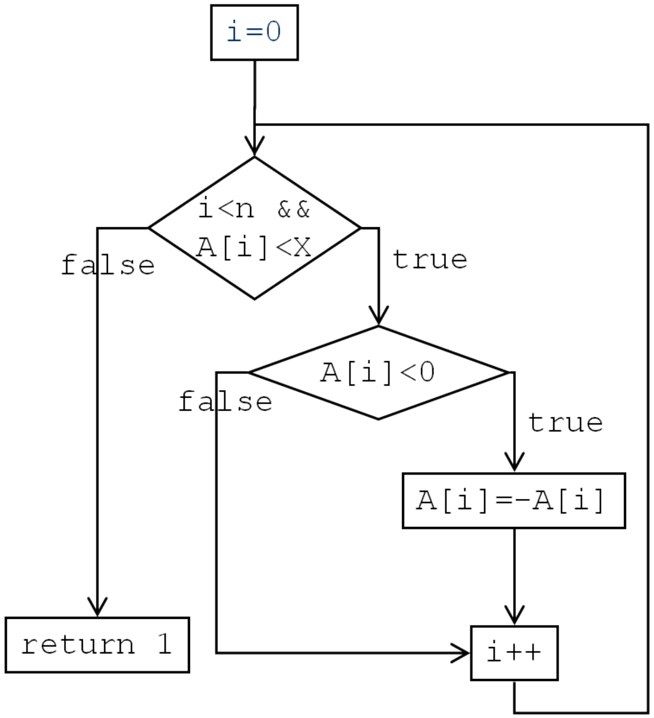
  Some common sense necessary in application: Some loops have a fixed number of iterations. How many is 'many'?

Test suite adequacy 2

- This routine loops through elements 0 to n-1 of array A (stopping if it finds an element that's greater than or equal to X). As it does so, it replaces any negative entries in A with their absolute (positive) value.

- Generate a test suite (in the form of some suggested values for array A, e.g. [1, 2], [3, 4]) which satisfies the path adequacy criterion for this program. Assume $n = |A|$.

- Generate a test suite which satisfies the loop boundary adequacy criterion.



Test suite adequacy 2

- Path adequacy is impossible, even for this trivial example!

- Consider the below code fragment. On the surface there are four paths through it, but a little attention makes it clear that no test suite could ever exercise one of those paths:

```
if(a < 0)
    a = 0;
if(a > 10)
    a = 10;
```

- So, realistically, we must settle for less than 100% coverage.

Adequacy review 3: data flow basics

- Data flow criteria are concerned with **definition-clear paths** from definition to use of individual variables.
- Context is a graph representation of the program, with vertices being basic blocks.
- A **definition-use pair** (**DU pair**) is a pairing of definition and use of a variable, with at least one def-clear path between them (there could be many).
- $dcu(x, v)$ is the set of vertices v' which use variable x in $computations$, and could be directly affected by a definition of x at v (i.e. there is a def-clear path from v to v').
- $dpu(x, v)$ is the set of edges (v', v'') which use variable x in their predicates (conditions/branches), and could be directly affected by a definition of x at v (i.e. there is a def-clear path from v to v').

Data flow basics

- Identify DU pairs for c (your answer will be a list of pairs of line numbers).
- Identify DU pairs for `digit_high`.
- Identify the def-predicate uses in your answers.
- Identify the def-computation uses in your answers.
- What is **dcu(ok,34)**?
- What is **dpu(ok,20)**?
- What is **dpu(digit_high, 30)**?

```
-17: int cgi_decode(char *encoded, char *decoded) {
-18:   char *eptr = encoded;
-19:   char *dptr = decoded;
*20:   int ok=0;
*21:   while (*eptr) {
-22:     char c;
*23:     c = *eptr;
-24:     /* Case 1: '+' maps to blank */
*25:     if (c == '+') {
*26:       *dptr = ' ';
*27:     } else if (c == '%') {
-28:       /* Case 2: '%xx' is hex for character xx */
-29:
*30:       int digit_high = Hex_Values[*(++eptr)];
*31:       int digit_low = Hex_Values[*(++eptr)];
*32:       if ( digit_high == -1 || digit_low == -1 ) {
-33:         /* *dptr='?'; */
*34:         ok=1; /* Bad return code */
-35:       } else {
*36:         *dptr = 16* digit_high + digit_low;
-37:       }
-38:
-39:       /* Case 3: All other chars map to themselves */
*40:     } else {
*41:       *dptr = *eptr;
-42:     }
*43:     ++dptr;
*44:     ++eptr;
-45:   }
*46:   *dptr = '\0'; /* Null terminator for string */
*47:   return ok;
-48: }
```


Adequacy review 4: data flow criteria

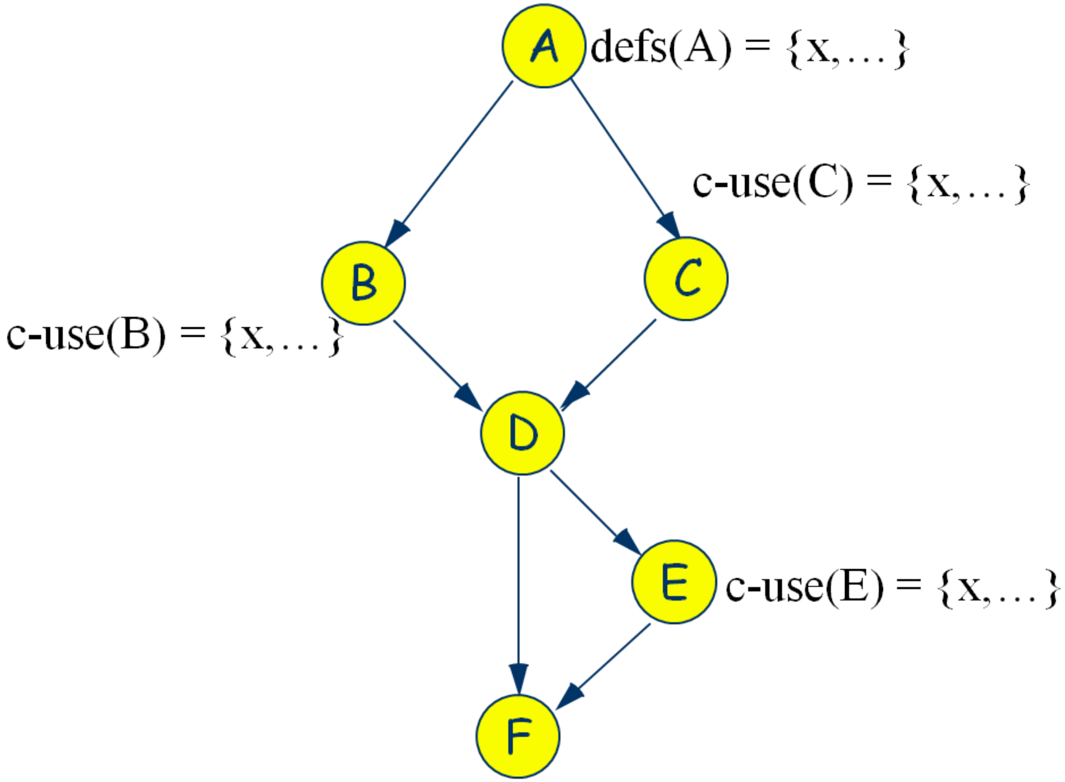
- **All-defs** requires that test T exercises each definition in program P at least once. This means not just executing the definition, but using its result in at least one computation or predicate.
- **All-p-uses** requires exercise of all **DU pairs** culminating in **predicates**. Note pairs, not paths: only one def-clear path needed per DU pair.
- **All-c-uses** requires exercise of all DU **pairs** culminating in **computations**. Note pairs, not paths.
- **All-p-uses/some-c-uses** and **all-c-uses/some-p-uses** expand the above two by requiring that all-defs hold as well.
- **All-uses** requires that both all-p-uses and all-c-uses hold.
- **All-du-paths** expands on all-uses by requiring that **all def-clear paths** between each DU pair are exercised, modulo loops.

Data flow criteria

- Suggest a set of path(s) which satisfy **all-defs**.

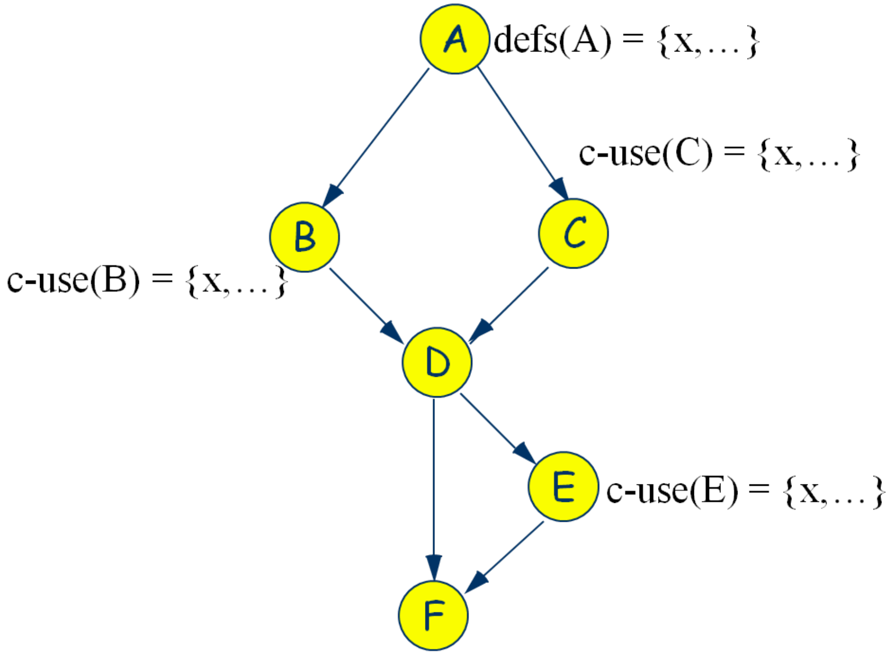
- Suggest a set of path(s) which satisfy **all-c-uses**.

- Suggest a set of path(s) which satisfy **all-du-paths**.



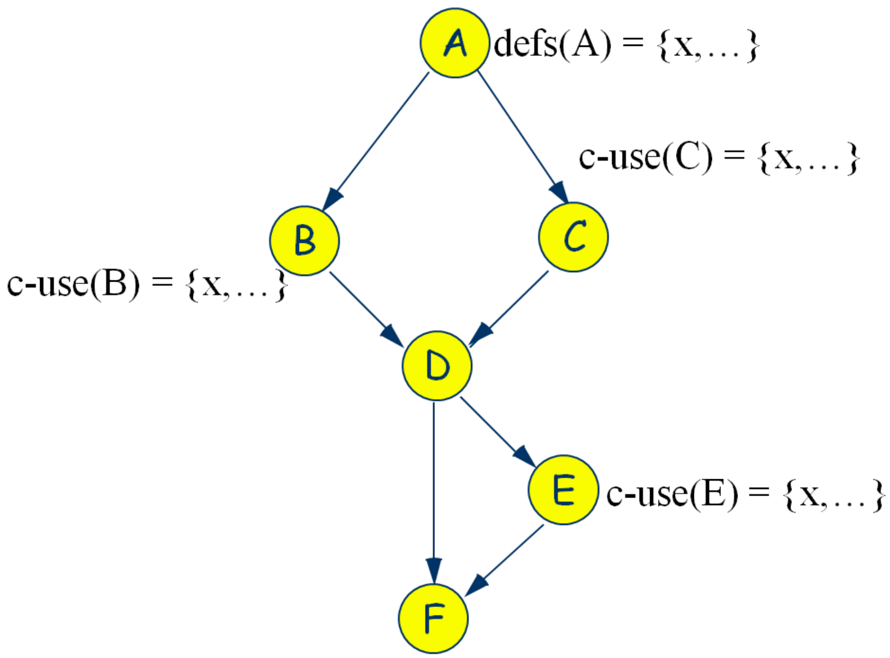
All-Defs Coverage Criterion

- We require to use all definitions.
- Here we assume we only use the variable x.
- We require to use each def.
- So the path A,B,D,F is OK.
- Suppose we defined a variable y in C and used it in E what would be a suitable test set?



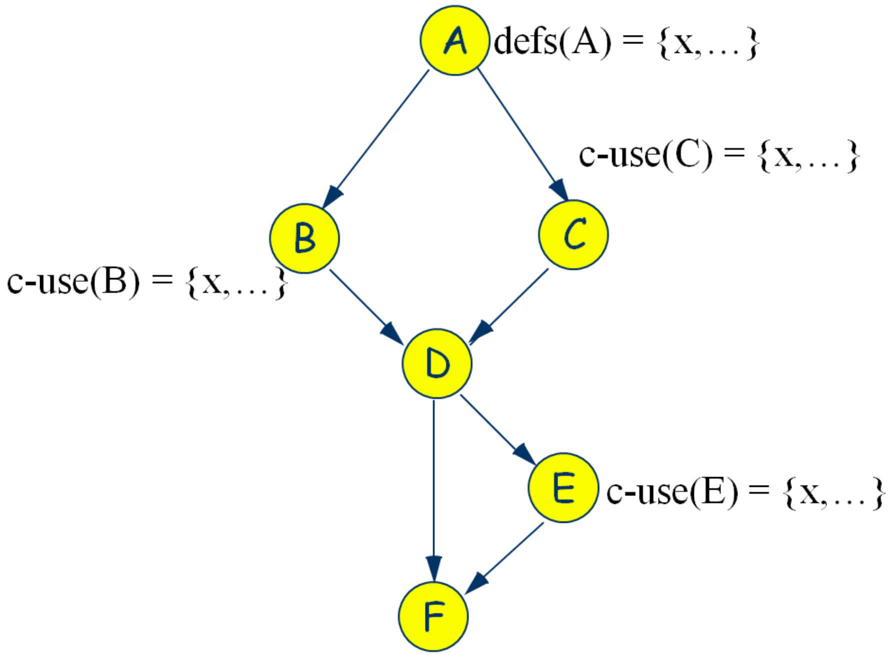
All-Uses Coverage Criterion

- We need to ensure we exercise every use.
- So we need the set of test paths to include:
  - A to B
  - A to C
  - A to E
- So a satisfactory test set is:
  - A,B,D,F
  - A,C,D,E,F



All DU-paths Coverage Criterion

- Here we need to consider all loop-free paths between A and vertices that use x.
- So we need to include:
  - A,B
  - A,C
  - A,B,D,E
  - A,C,D,E
- So the following test set satisfies the coverage criterion:
  - A,B,D,E,F
  - A,C,D,E,F

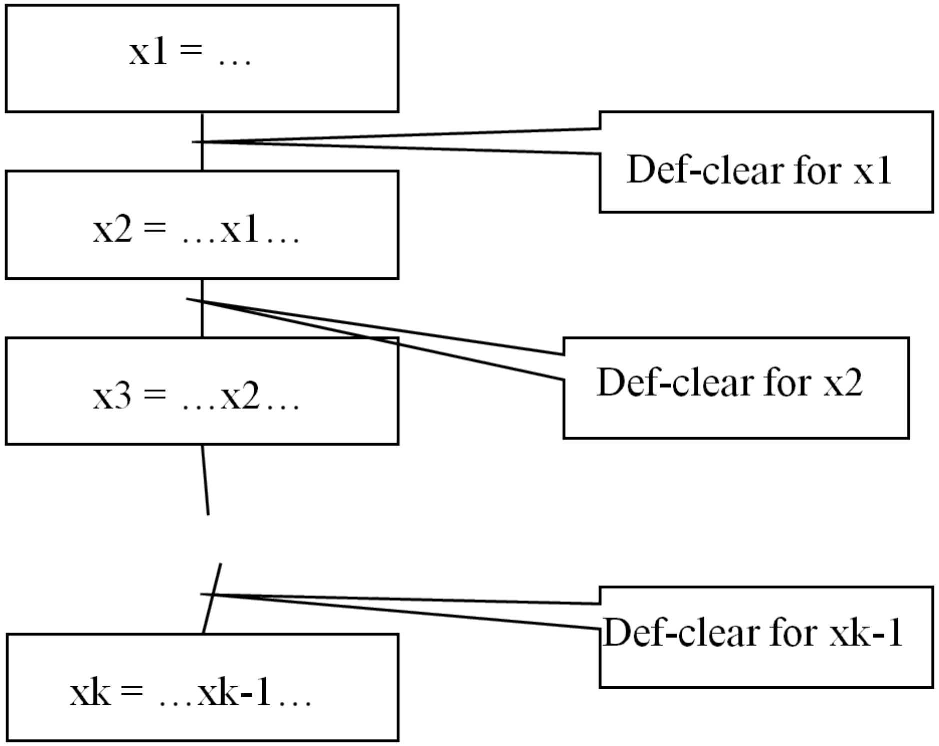


More Complex Data Flow Criteria

- Ntafos proposed a generalisation of the original data-flow criteria to allow iteration of definition/use chains

- Foundation:
  - Chains of alternating definitions and uses linked by definition-clear subpaths (k-dr interactions)
  - i^{th} definition reaches i^{th} use,
  - which defines i^{th+1} definition
  - k is number of iterations

k-dr Interactions



Wrapping up

- So we can argue that certain criteria are less bad than others. Where does this get us?
- Not terribly far unfortunately: most of the theoretical research seems to indicate you cannot conclude much about test effectiveness from your adequacy criteria.
- But there is empirical evidence that at very high levels of coverage, stronger criteria are worth pursuing.
- It does not seem surprising though that writing ten times as many tests in order to satisfy a stronger criterion gives you better results. The question then is whether these extra criterion-driven tests are better than extra random ones.
- Research now seems to be heading in this more empirical direction, rather than focusing on theoretical adequacy comparisons.

Readings

Required Readings

- **Textbook (Pezzè and Young):** Chapter 9, Test Case Selection and Adequacy

