Program Testing

(Lecture 8)

Organization of this Lecture

- Introduction to Testing.
- White-box testing:
  - statement coverage
  - path coverage
  - branch testing
  - condition coverage
  - Cyclomatic complexity
- Summary

Black-box Testing

- Test cases are designed using only functional specification of the software:
  - Without any knowledge of the internal structure of the software.
- For this reason, black-box testing is also known as functional testing.

White-Box Testing

- Designing white-box test cases:
  - Requires knowledge about the internal structure of software.
  - White-box testing is also called structural testing.

Black-Box Testing

- Two main approaches to design black box test cases:
  - Equivalence class partitioning
  - Boundary value analysis

White-Box Testing

If a stronger testing has been performed, then a weaker testing need not be carried out.

Fault-based testing

A fault-based testing strategy targets to detect certain types of faults. An example of a fault-based strategy is mutation testing, which is discussed later in this section.

Coverage-based testing

A coverage-based testing strategy attempts to execute (or cover) certain elements of a program. Popular examples of coverage-based testing strategies are statement coverage, branch coverage, multiple condition coverage, and path coverage-based testing.

The set of specific program elements that a testing strategy targets to execute is called the *testing criterion* of the strategy.

A white-box testing strategy is said to be stronger than another strategy, if the stronger testing strategy covers all program elements covered by the weaker testing strategy, and the stronger strategy additionally covers at least one program element that is not covered by the weaker strategy.

Stronger versus weaker testing

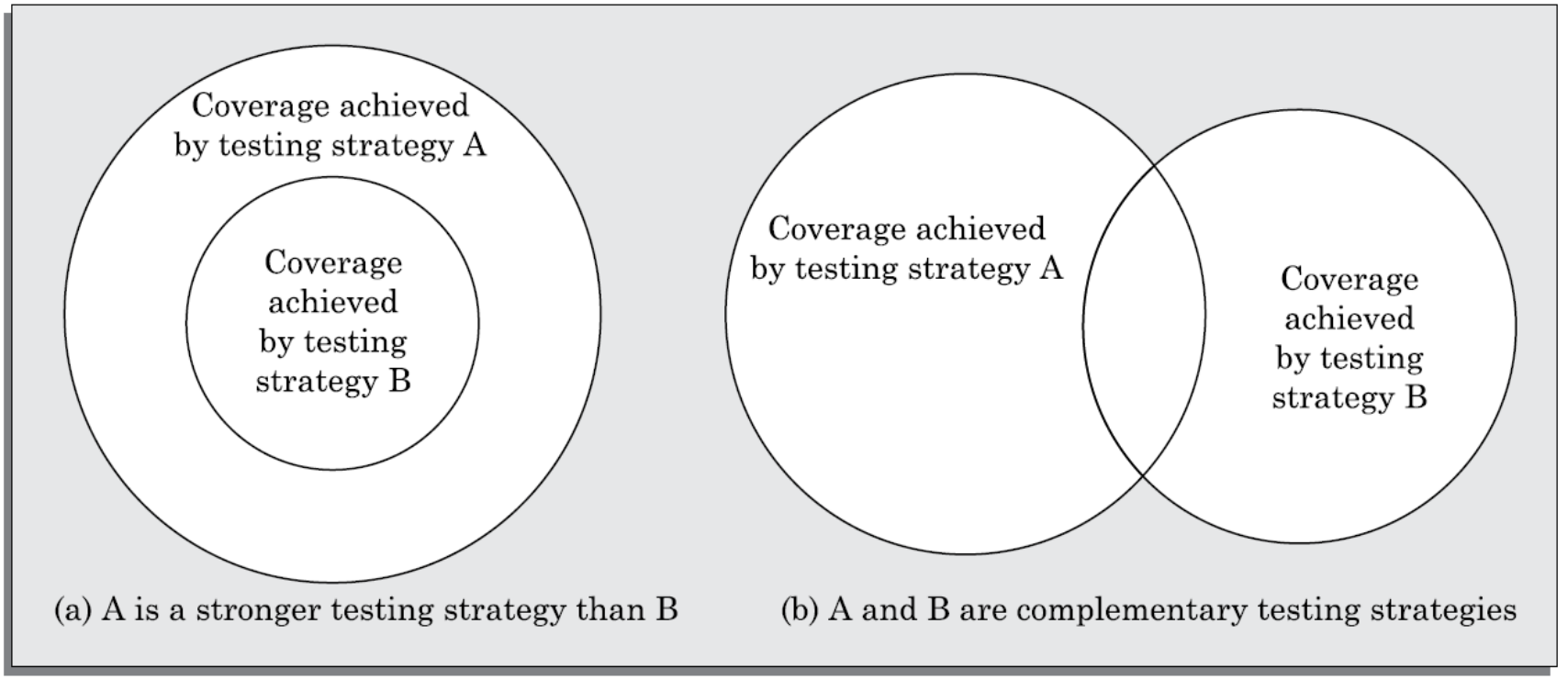


FIGURE 10.6 Illustration of stronger, weaker, and complementary testing strategies.

White-Box Testing

- There exist several popular white-box testing methodologies:
  - Statement coverage
  - Branch coverage
  - Path coverage
  - Condition coverage
  - Mutation testing
  - Data flow-based testing

Statement Coverage

- Statement coverage methodology:
  - Design test cases so that every statement in the program is executed at least once.

Coverage-Based Testing Versus Fault-Based Testing

- Idea behind coverage-based testing:
  - Design test cases so that certain program elements are executed (or covered).
  - Example: statement coverage, path coverage, etc.
- Idea behind fault-based testing:
  - Design test cases that focus on discovering certain types of faults.
  - Example: Mutation testing.

Statement Coverage

- The principal idea:
  - Unless a statement is executed,
  - We have no way of knowing if an error exists in that statement.

Statement Coverage Criterion

- Observing that a statement behaves properly for one input value:
  - No guarantee that it will behave correctly for all input values.

Example

```
int f1(int x, int y){
1 while (x != y){
2     if (x>y) then
3           x=x-y;
4     else y=y-x;
5 }
6 return x;          }
```

Euclid's GCD Algorithm

Euclid's GCD Computation Algorithm

- By choosing the test set {(x=3,y=3),(x=4,y=3), (x=3,y=4)}
  - All statements are executed at least once.

Branch Coverage

- Test cases are designed such that:
  - Different branch conditions
    - Given true and false values in turn.

Branch Coverage

- Branch testing guarantees statement coverage:
  - A stronger testing compared to the statement coverage-based testing.

Stronger Testing

- Test cases are a superset of a weaker testing:
  - A stronger testing covers at least all the elements of the elements covered by a weaker testing.

Example

```
. int f1(int x,int y){
. 1 while (x != y){
. 2     if (x>y) then
. 3           x=x-y;
. 4     else y=y-x;
. 5 }
. 6 return x;          }
```

Example

- Test cases for branch coverage can be:
- {(x=3,y=3),(x=3,y=2), (x=4,y=3), (x=3,y=4)}

- Let us take one example to explain Branch coverage:
- IF "A > B"
- PRINT A is greater than B
- ENDIF
- So the Test Set for 100% branch coverage will be:
- Test Case 1: A=5, B=2 which will return true.
- Test Case 2: A=2, B=5 which will return false.
- So in your case, both the test cases 1 and 2 are required for Branch coverage.
- With only Test cases1, it will be statement coverage.

Theorem 10.1 Branch coverage-based testing is stronger than statement coverage-based testing.

Proof: We need to show that (a) branch coverage ensures statement coverage, and (b) statement coverage does not ensure branch coverage.

(a) Branch testing would guarantee statement coverage since every statement must belong to some branch (assuming that there is no unreachable code).

(b) To show that statement coverage does not ensure branch coverage, it is sufficient to give an example of a test suite that achieves statement coverage, but does not cover at least one branch. Consider the following code, and the test suite {5}.

```
if(x>2)  x+=1;
```

The test suite would achieve statement coverage. However, it does not achieve branch coverage, since the condition ($x > 2$) is not made false by any test case in the suite.

```
/**  Branch Testing Exercise
 *   Create test cases using branch test method for this program
 */
      declare Length as integer
      declare Count as integer
      READ Length;
      READ Count;
      WHILE (Count <= 6) LOOP
         IF (Length >= 100) THEN
            Length = Length - 2;
         ELSE
            Length = Count * Length;
         END IF
         Count = Count + 1;
      END;
      PRINT Length;
```

Decision	Possible Outcomes	Test Cases 1	2	3	4	5	6	7	8	9	10
Count <= 6	T	X	X								
	F			X							
Length >= 100	T	X									
	F		X								

Case #	Input Values		Expected Outcomes	Actual Outcomes
	Count	Length		
1	5	101	594	
2	5	99	493	
3	7	99	99	
4				

Condition Coverage

- Test cases are designed such that:
  - Each component of a composite conditional expression
    - Given both true and false values.

Example

- Consider the conditional expression
  - ((c1.and.c2).or.c3):
- Each of c1, c2, and c3 are exercised at least once,
  - i.e. given true and false values.

Branch Testing

- Branch testing is the simplest condition testing strategy:
  - Compound conditions appearing in different branch statements
    - Are given true and false values.

Branch testing

- Condition testing
  - Stronger testing than branch testing.
- Branch testing
  - Stronger than statement coverage testing.

Condition coverage

- Consider a boolean expression having n components:
  - For condition coverage we require 2^n test cases.
- Condition coverage-based testing technique:
  - Practical only if n (the number of component conditions) is small.

Path Coverage

- Design test cases such that:
  - All linearly independent paths in the program are executed at least once.
- Defined in terms of
  - Control flow graph (CFG) of a program.

A control flow graph describes the sequence in which the different instructions of a program get executed.

Path Coverage-Based Testing

- To understand the path coverage-based testing:
  - we need to learn how to draw control flow graph of a program.
- A control flow graph (CFG) describes:
  - the sequence in which different instructions of a program get executed.
  - the way control flows through the program.

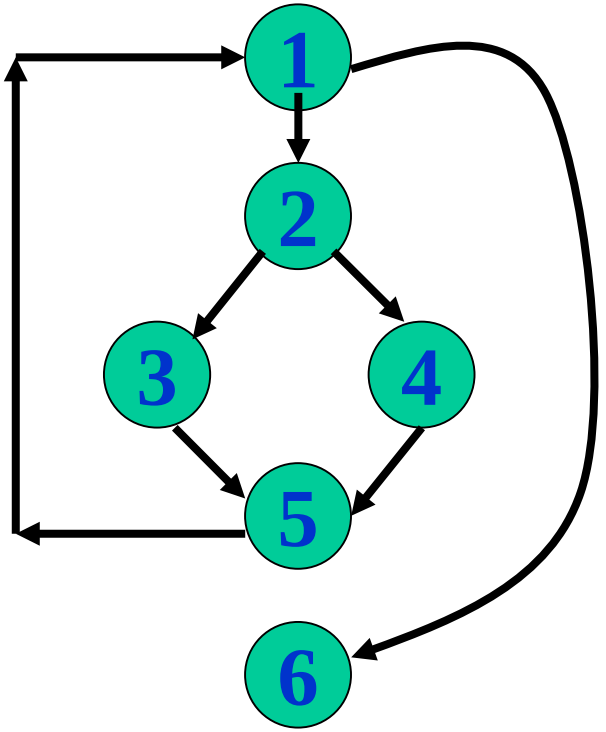
How to Draw Control Flow Graph?

- Number all the statements of a program.
- Numbered statements:
  - Represent nodes of the control flow graph.
- An edge from one node to another node exists:
  - If execution of the statement representing the first node
    - Can result in transfer of control to the other node.

Example

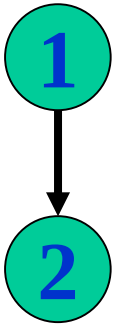
```
int f1(int x,int y){
1 while (x != y){
2     if (x>y) then
3           x=x-y;
4     else y=y-x;
5 }
6 return x;          }
```

Example Control Flow Graph



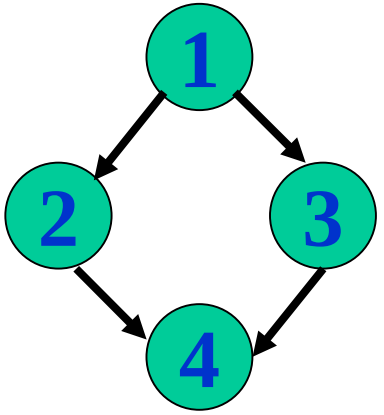
How to draw Control flow graph?

- Sequence:
  - 1 a=5;
  - 2 b=a*b-1;



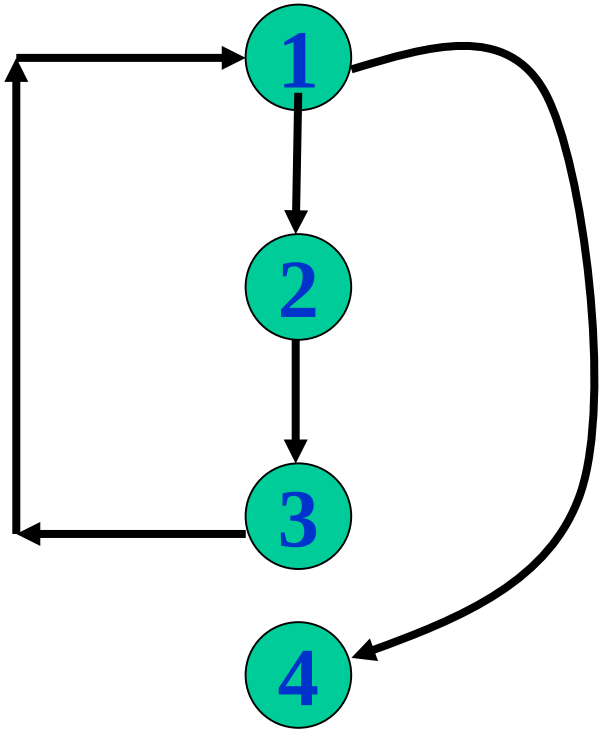
How to draw Control flow graph?

- Selection:
  - 1 if(a>b) then
  - 2 c=3;
  - 3 else c=5;
  - 4 c=c*c;



How to draw Control flow graph?

- Iteration:
  - 1 while(a>b){
  - 2 b=b*a;
  - 3 b=b-1;}
  - 4 c=b+d;



Path

- A path through a program:
  - A node and edge sequence from the starting node to a terminal node of the control flow graph.
  - There may be several terminal nodes for program.

Linearly Independent Path

- Any path through the program:
  - Introducing at least one new edge:
    - That is not included in any other independent paths.

If a set of paths is linearly independent of each other, then no path in the set can be obtained through any linear operations (i.e., additions or subtractions) on the other paths in the set.

Independent path

- It is straight forward:
  - To identify linearly independent paths of simple programs.
- For complicated programs:
  - It is not so easy to determine the number of independent paths.

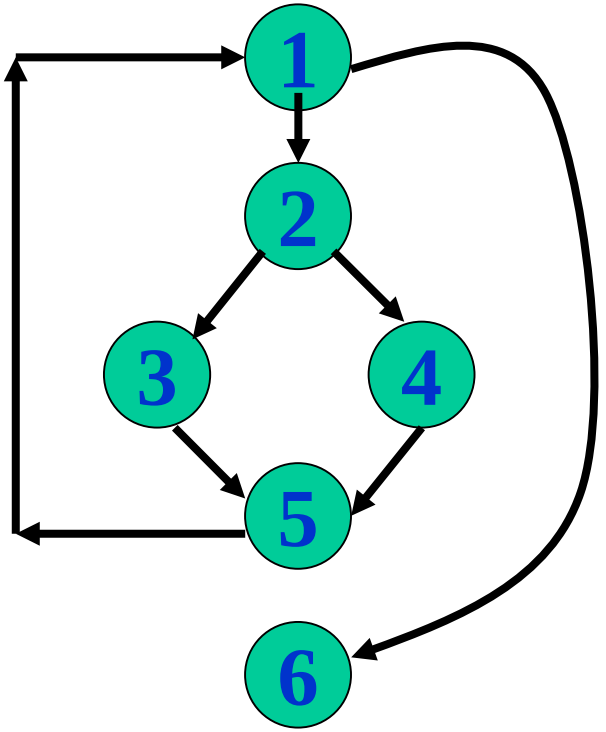
McCabe's Cyclomatic Metric

- An upper bound:
  - For the number of linearly independent paths of a program
- Provides a practical way of determining:
  - The maximum number of linearly independent paths in a program.

McCabe's Cyclomatic Metric

- Given a control flow graph G, cyclomatic complexity V(G):
  - V(G)= E-N+2
    - N is the number of nodes in G
    - E is the number of edges in G

Example Control Flow Graph

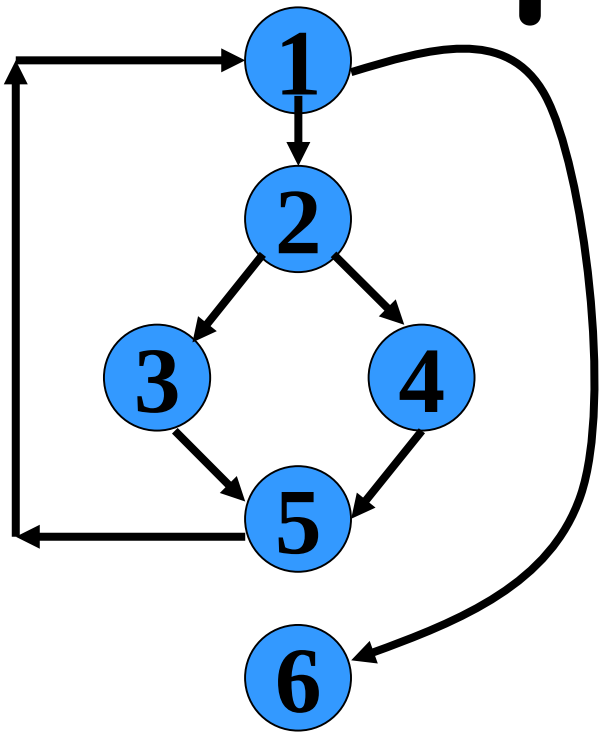


Cyclomatic complexity = 7-6+2 = 3.

Cyclomatic Complexity

- Another way of computing cyclomatic complexity:
  - inspect control flow graph
  - determine number of bounded areas in the graph
- V(G) = Total number of bounded areas + 1
  - Any region enclosed by a nodes and edge sequence.

Example Control Flow Graph



Example

- From a visual examination of the CFG:
  - the number of bounded areas is 2.
  - cyclomatic complexity = 2+1=3.

Cyclomatic complexity

- McCabe's metric provides:
  - *A quantitative measure of testing difficulty and the ultimate reliability*
- Intuitively,
  - Number of bounded areas increases with the number of decision nodes and loops.

Cyclomatic Complexity

- The first method of computing V(G) is amenable to automation:
  - You can write a program which determines the number of nodes and edges of a graph
  - Applies the formula to find V(G).

Cyclomatic complexity

- The cyclomatic complexity of a program provides:
  - A lower bound on the number of test cases to be designed
  - To guarantee coverage of all linearly independent paths.

Cyclomatic Complexity

- Defines the number of independent paths in a program.
- Provides a lower bound:
  - for the number of test cases for path coverage.

Cyclomatic Complexity

- Knowing the number of test cases required:
  - Does not make it any easier to derive the test cases,
  - Only gives an indication of the minimum number of test cases required.

Path Testing

- The tester proposes:
  - An initial set of test data using his experience and judgement.
- A dynamic program analyzer is used:
  - To indicate which parts of the program have been tested
  - The output of the dynamic analysis
    - used to guide the tester in selecting additional test cases.

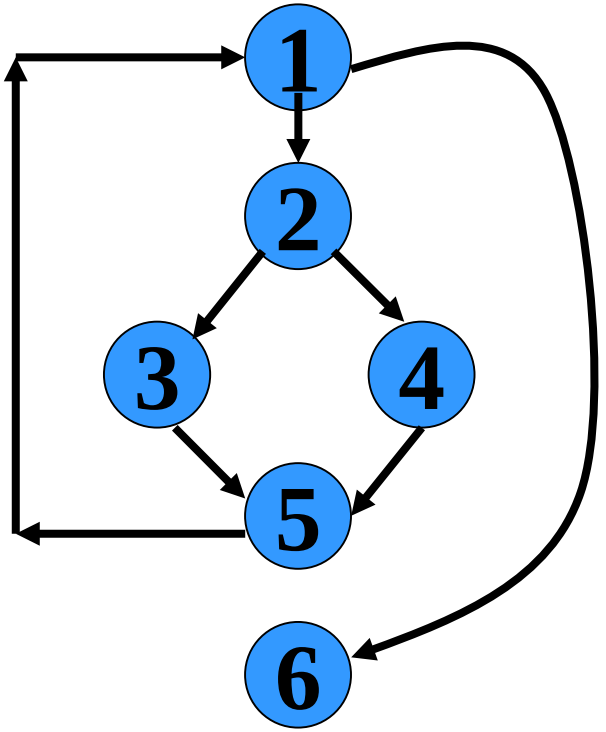
Derivation of Test Cases

- Let us discuss the steps:
  - to derive path coverage-based test cases of a program.
- Draw control flow graph.
- Determine V(G).
- Determine the set of linearly independent paths.
- Prepare test cases:
  - to force execution along each path.

Example

```
. int f1(int x,int y){
. 1 while (x != y){
. 2     if (x>y) then
. 3           x=x-y;
. 4     else y=y-x;
. 5 }
. 6 return x;          }
```

Example Control Flow Diagram



Derivation of Test Cases

- Number of independent paths: 3
  - 1,6 test case (x=1, y=1)
  - 1,2,3,5,1,6 test case(x=1, y=2)
  - 1,2,4,5,1,6 test case(x=2, y=1)

An interesting application of cyclomatic complexity

- Relationship exists between:
  - McCabe's metric
  - The number of errors existing in the code,
  - The time required to find and correct the errors.

Cyclomatic Complexity

- Cyclomatic complexity of a program:
  - Also indicates the psychological complexity of a program.
  - Difficulty level of understanding the program.

Cyclomatic Complexity

- From maintenance perspective,
  - limit cyclomatic complexity
    - of modules to some reasonable value.
  - Good software development organizations:
    - restrict cyclomatic complexity of functions to a maximum of ten or so.

Summary

- Exhaustive testing of non-trivial systems is impractical:
  - We need to design an optimal set of test cases
    - Should expose as many errors as possible.
- If we select test cases randomly:
  - many of the selected test cases do not add to the significance of the test set.

Summary

- There are two approaches to testing:
  - black-box testing and
  - white-box testing.
- Designing test cases for black box testing:
  - does not require any knowledge of how the functions have been designed and implemented.
  - Test cases can be designed by examining only SRS document.

Summary

- White box testing:
  - requires knowledge about internals of the software.
  - Design and code is required.
- We have discussed a few white-box test strategies.
  - Statement coverage
  - branch coverage
  - condition coverage
  - path coverage

Summary

- A stronger testing strategy:
  - provides more number of significant test cases than a weaker one.
  - Condition coverage is strongest among strategies we discussed.
- We discussed McCabe's Cyclomatic complexity metric:
  - provides an upper bound for linearly independent paths
  - correlates with understanding, testing, and debugging difficulty of a program.