White-Box Software Testing

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Presentation Outline

- *What is White-Box Testing?*
    - *Testing Focuses*
    - *Who Perform White-Box Testing?*
- *Basis-Path Program Testing*
- *Branch-Based Program Testing*
- *Data Flow Program Testing*
- *Syntax-Based Program Testing*
- *State-Based Program Testing*
- *Testing Coverage*

What is White-Based Software Testing?

What is white-box software testing?

--> White-box testing, also known as glass-box testing.
Basic idea is to test a program based on the structure of a program.

What do you need for white-box testing?

- A white-box testing model and test criteria
- A white-box test design and generation method
- Program source code

White-box testing methods can be classified into:

- Traditional white-box testing methods
- Object-oriented white-box testing methods
- Component-oriented white-box testing methods

White-Box Testing Objectives

The Major objective of white-box testing is to focus on internal program structure, and discover all internal program errors.

The major testing focuses:

- ***Program structures***
  - ***Program statements and branches***
  - ***Various kinds of program paths***
- ***Program internal logic and data structures***
- ***Program internal behaviors and states.***

Traditional White-Based Software Testing Methods

Test Model: control program chart (graph)

Test case design:

Various white-box testing methods generate test cases based on on a given control program graph for a program

The goal is to:

- Guarantee that all independent paths within a module have been exercised at least once.
- Exercise all logical decisions one their true and false sides.
- Execute all loops at their boundaries and within their operational bounds.
- Exercise internal data structures to assure their validity.
- Exercise all data define and use paths.

White-Box Software Testing Methods

Basic path testing (a white-box testing technique):

- First proposed by TomMcCabe [MCC76].
- Can be used to derive a logical complexity measure for a procedure design.
- Used as a guide for defining a basis set of execution path.
- Guarantee to execute every statement in the program at least one time.

Branch Testing:

Exercise predicate nodes of a program flow graph to make sure that each predicate node has been exercised at least once.

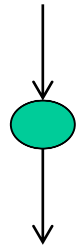
Loop Testing:

Exercise loops of a program to make sure that the inside and outside of loop body are executed.

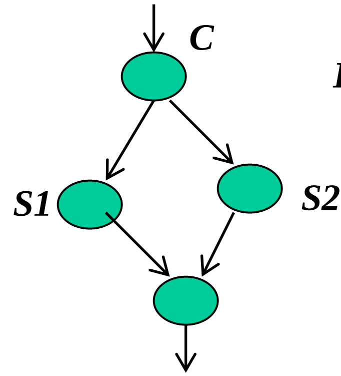
State-Based Testing:

Basic idea is to use a finite state machine as a test model to check the state behaviors of a program process.

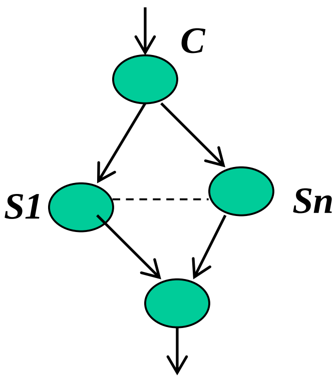
Program Flow Graph (Control Flow Diagram)



Sequential statement block

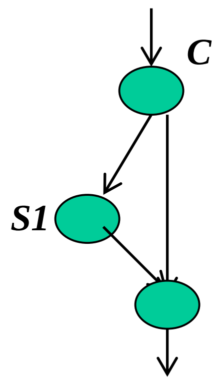


If C Then S1 else S2;



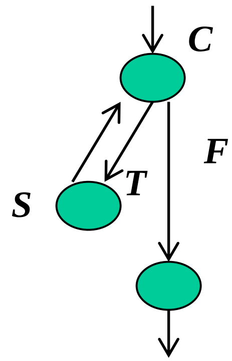
Case C of

L1: S1;
L2: S2;
…
Kn: Sn;
end;

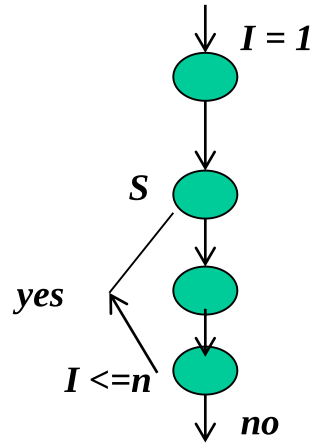


If C Then S1;

Program Flow Graph (Control Flow Diagram)

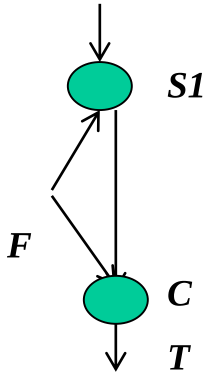


While C do S;



For loop:

for I = 1 to n do S;



Do loop:

do S1 until C;

Cyclomatic Complexity

Cyclomatic complexity is a software metric
-> provides a quantitative measure of the global complexity of a program.
When this metric is used in the context of the basis path testing, the value computed for cyclomatic complexity defines the number of independent paths in the basis set of a program.

Three ways to compute cyclomatic complexity:

- The number of regions of the flow graph correspond to the cyclomatic complexity.

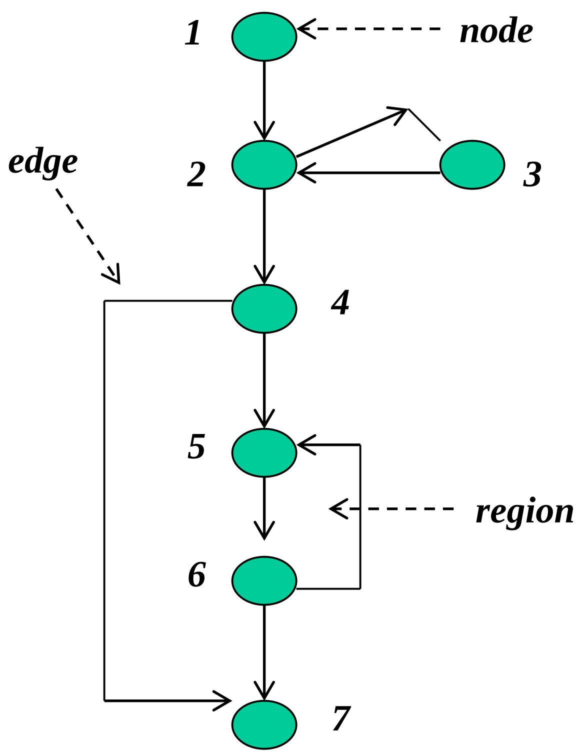
- Cyclomatic complexity, V(G), for a flow graph G is defined as

$$V(G) = E - N + 2$$

where E is the number of flow graph edges and N is the number of flow graph nodes.

- Cyclomatic complexity, V(G) = P + 1
where P is the number of predicate nodes contained in the flow graph G.

An Example



No. of regions = 4
(considering the universal region)

No. of edges = 9

No. of nodes = 7

No. of predicate nodes = 3

$V(G) = P + 1 = 3 + 1 = 4$

$V(G) = E - N + 2 = 9 - 7 + 2 = 4$

Deriving Test Cases

Step 1 : ***Using the design or code as a foundation, draw a corresponding flow graph.***

Step 2: ***Determine the cyclomatic complexity of the resultant flow graph.***

Step 3: ***Determine a minimum basis set of linearly independent paths.***

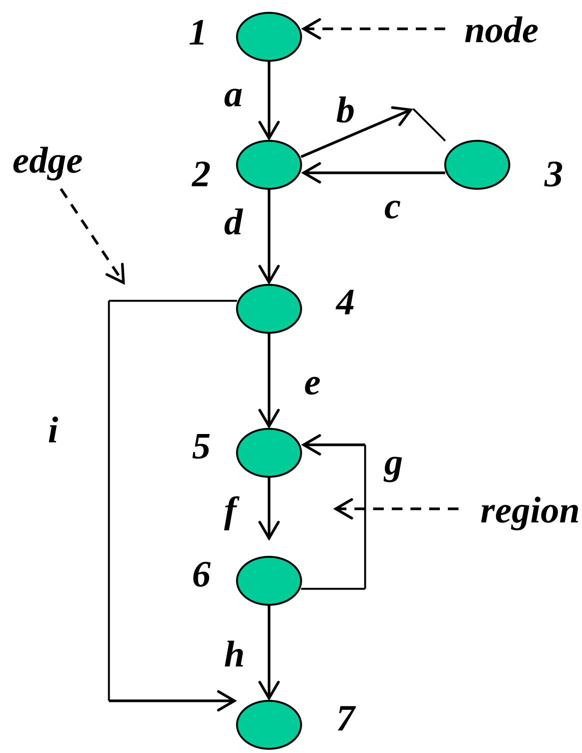
For example,

path 1: 1-2-4-5-6-7
path 2: 1-2-4-7
path 3: 1-2-3-2-4-5-6-7
path 4: 1-2-4-5-6-5-6-7

Step 4: ***Prepare test cases that will force execution of each path in the basis set.***

Step 5: ***Run the test cases and check their results***

An Example



	1	2	3	4	5	6	7
1		a					
2			b	d			
3		c					
4					e		i
5						f	
6					g		h
7							

	1	2	3	4	5	6	7	
1		1						1 - 1 = 0
2			1	1				2 - 1 =1
3		1						1 -1 = 0
4					1		1	2 - 1 =1
5						1		1 -1 = 0
6					1		1	2 -1 = 1
7								

----

3 +1 = 4

Data Flow Software Testing

Major Objective:

Focus data value definitions and its uses in a program control flow charts.

Major purpose:

Data flow test criteria is developed to improve the data test coverage of a program.

Basic idea:

For a given Var has been assigned the correct value at some point in the program if no test data cause the execution of a path from the assignment point to a usage point in a program flow chart.

Basic Test Model: *Program Control Flow Chart (Graph)*

Test Criteria: *Various data flow test criteria*

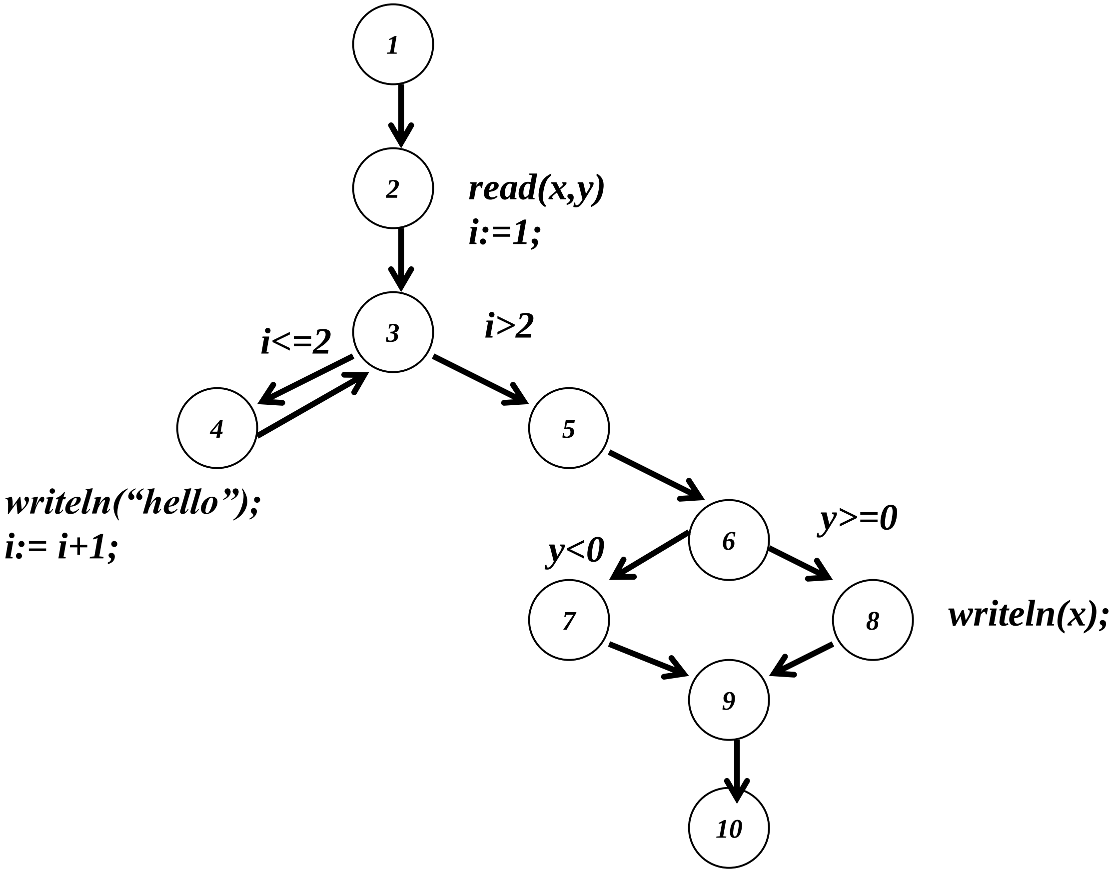
They are stronger than branch testing but weaker than path testing.

Data Flow Software Testing

Basic Definitions:

V	***= the set of variables.***
N	***= the set of nodes***
E	***= the set of edges***
def(i)	***= { x in V | x has a global definition in block I}***
c-use(i)	***= { x in V | x has a global c-use in block i }***
p-use(i,j)	***= { x in V } x has a p-use in edge (i,j) }***
dcu(x, j)	***= { j in N | x in c-use(j) and there is a def-clear path wrt x from i to j }***
dpu(x, j)	***= {(j,k) in E | x in p-use(j,k) and there is a def-clear path wrt x from i to (j,k) }***

Data Flow Software Testing

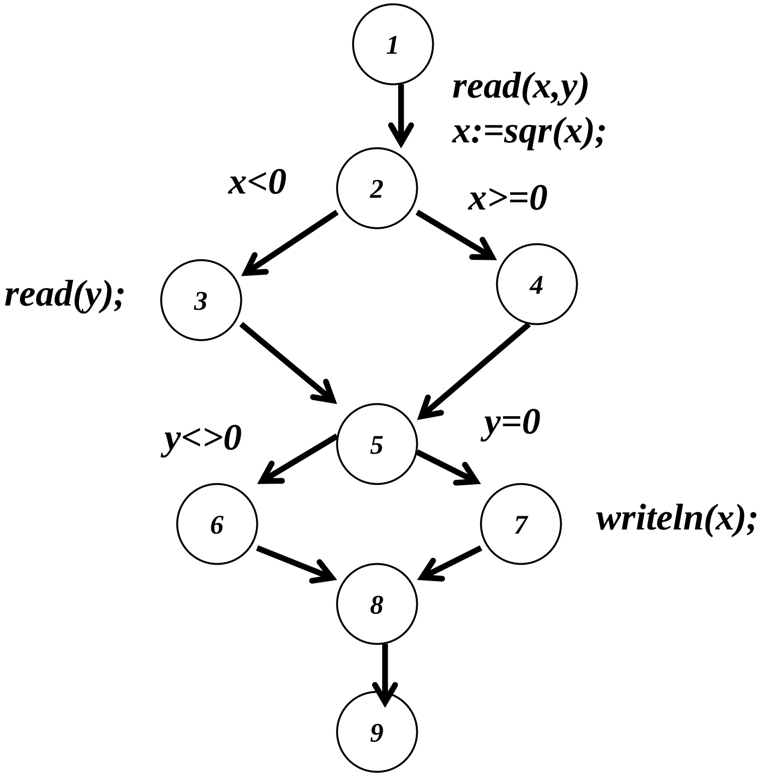


Data Flow Software Testing

Path	*With Respect to*	*Executable*
(1,2)	*input ^*	*Yes*
(2,3,4)	*i*	*Yes*
(2,3,5)	*i*	*No*
(4,3,4)	*i*	*Yes*
(4,3,5)	*i*	*Yes*
(2,3,5,6,7,9,10)	*input ^*	*No*
(2,3,5,6,8,9,10)	*input ^*	*No*

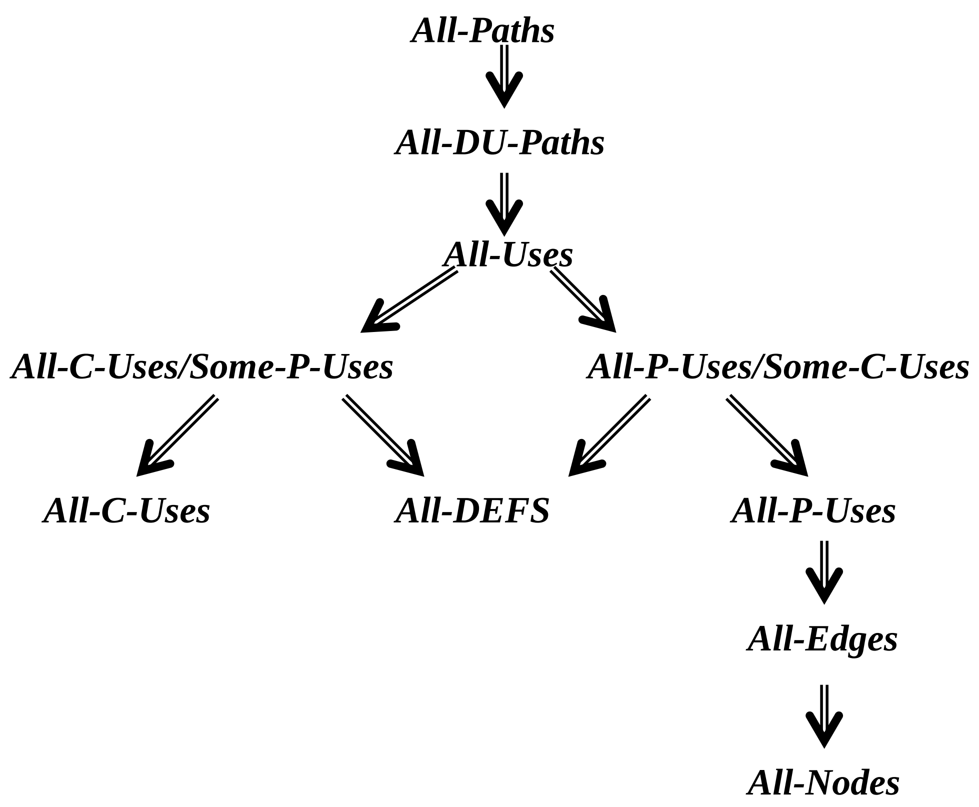
Program demonstrating that (all-du-paths)* fails to include the other criteria

Data Flow Software Testing



Program demonstrating that (all-p-uses) fails to include (all-edges)**

Relationships among the Data Flow Software Testing Criteria



Branch Testing

What is branch testing for software? (known as decision testing in programs)

Design test cases to exercise each branch-based path in a program flow graph.

Test focus is on: **Each branch in a program structure**

Test coverage: **For each decision in a program structure, each branch must be exercised at least once.**

Test model: **Program control flow graph**

Limitation:
- Treats a compound conditional as a single *statement*
- Ignores implicit paths that result from compound conditionals.

White-Box : Branch Testing

- Branch testing == decision testing
- Execute every branch of a program :

  each possible outcome of each decision occurs at least once
- Example:
  - IF b THEN s1 ELSE s2
  - IF b THEN s1; s2
  - CASE x OF

    1 : ....

    2 : ....

    3 : ....

Branch Testing Example

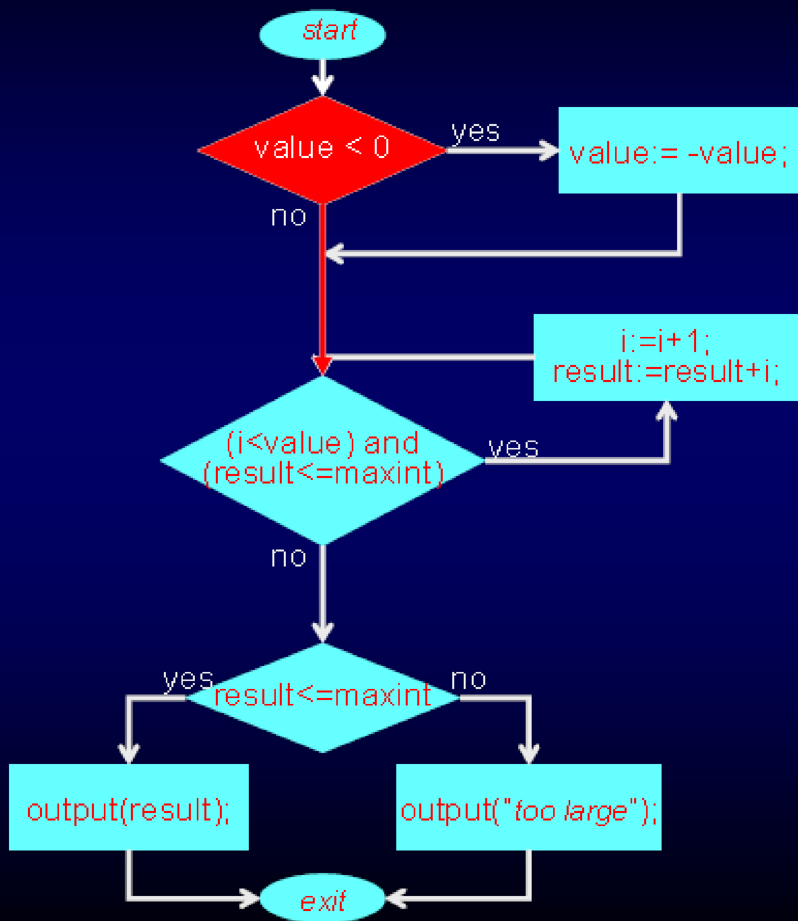
```
** Branch Testing Exercise
 * Create test cases using branch test method for this program
 */
 declare Length as integer
 declare Count as integer
READ Length;
READ Count;
WHILE (Count <= 6) LOOP
    IF (Length >= 100) THEN
          Length = Length - 2;
    ELSE
        Length = Count * Length;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

Branch	Possible outcome	T1	T2	T3
Count <=6	T	X	X	
	F			X
Length >=100	T	X		
	F		X	

Branch Testing Example

Test Case #	Input values - Count	Input values - Length	Expected Outcomes	Actual Outcomes
T1	5	101	594	
T2	5	99	493	
T3	7	99	99	

Example : Branch Testing



Tests for complete statement coverage:

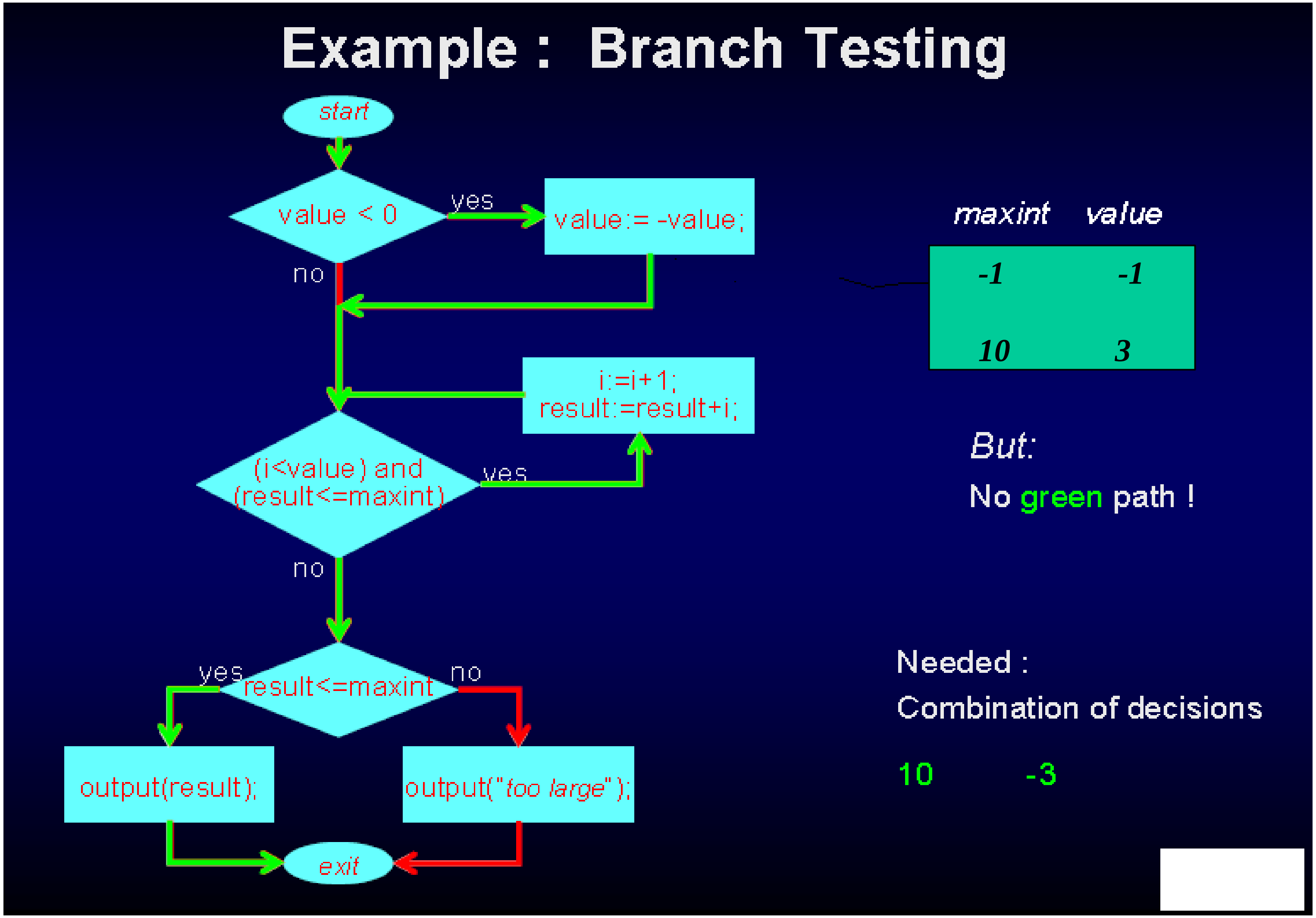
maxint	*value*
10	-1
0	-1

is not sufficient for branch coverage;

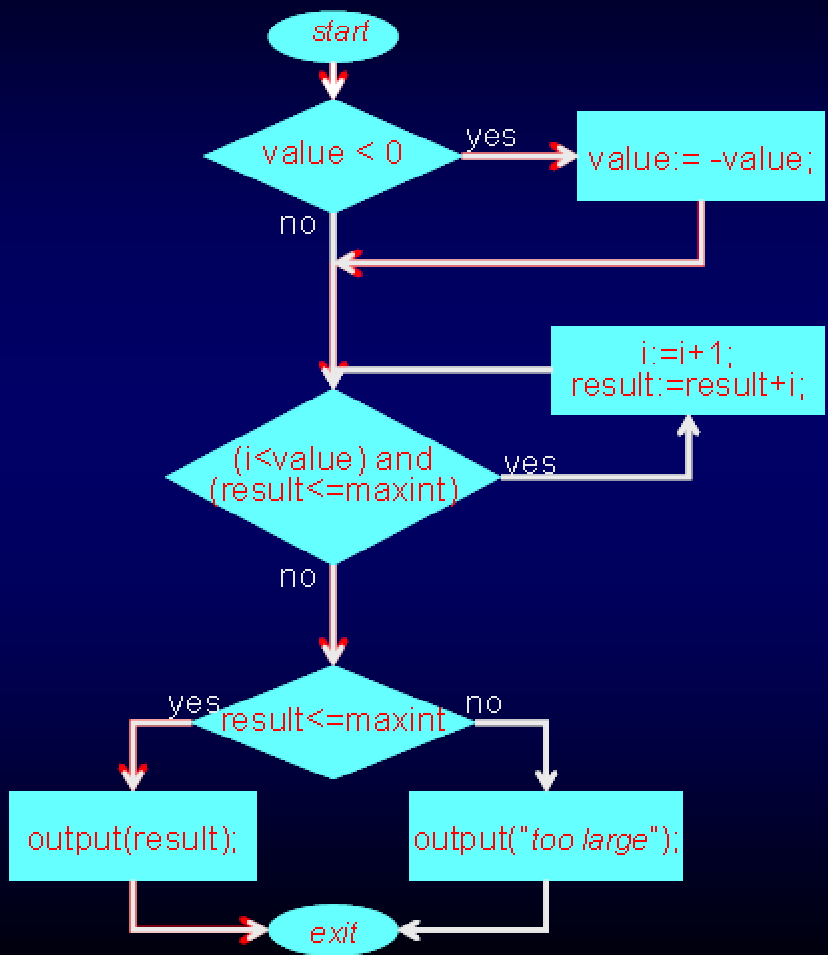
Take:

maxint	*value*
10	3
0	-1

for complete branch coverage


Example : Branch Testing
start
value < 0
yes
no
value:= -value;
i:=i+1;
result:=result+i;
(i<value) and
(result<=maxint)
yes
no
yes
result<=maxint
no
output(result);
output("too large");
exit
maxint value
-1 -1
10 3
But:
No green path !
Needed :
Combination of decisions
10 -3

Example : Branch Testing



Sometimes there are infeasible paths (infeasible combinations of conditions)

Condition Testing For Software

What is condition testing software?

Design test cases to exercise each logic condition in a program.

Test focus is on: incorrect logic in Boolean expressions of branch nodes.

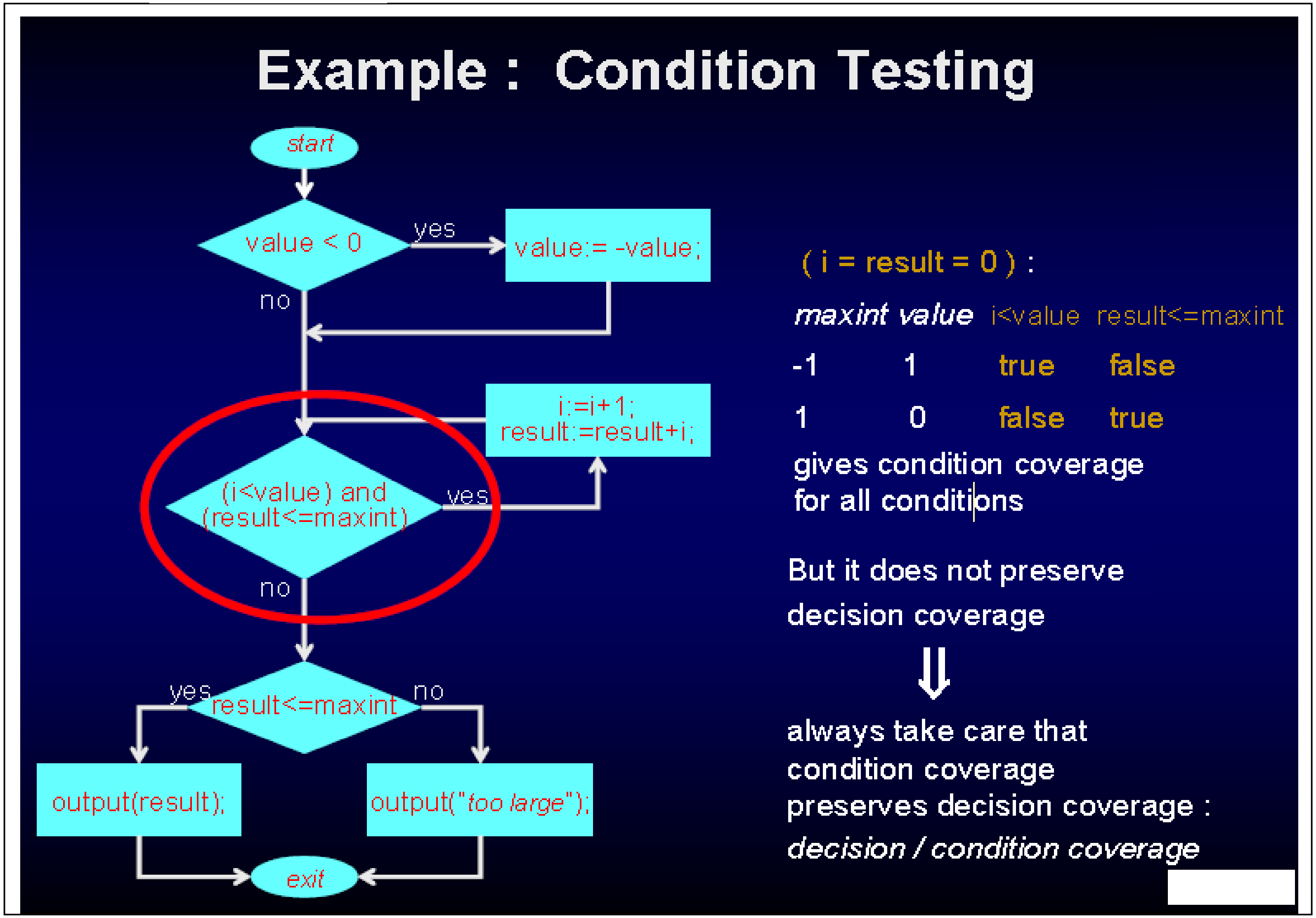
- **Boolean variable errors**
- **Boolean parenthesis errors**
- **Boolean operator errors**
- **Relational operator errors**
- **Arithmetic expression errors**

Test coverage:

For a compound condition C, the True and False branches of C and every simple condition in C need to be executed at least once.

White-Box : Condition Testing

- Design test cases such that each possible outcome of each condition in each decision occurs at least once
- Example:
  - decision (i < value) AND (result <= maxint)
    consists of two conditions : (i < value) AND (result <= maxint)
    test cases should be designed such that each gets value true and false at least once


Example : Condition Testing
start
value < 0
yes
value:= -value;
no
i:=i+1;
result:=result+i;
(i<value) and
(result<=maxint)
yes
no
yes
result<=maxint
no
output(result);
output("too large");
exit
(i = result = 0) :
maxint value i<value result<=maxint
-1 1 true false
1 0 false true
gives condition coverage
for all conditions
But it does not preserve
decision coverage
⇓
always take care that
condition coverage
preserves decision coverage :
decision / condition coverage

White-Box : Multiple Condition Testing

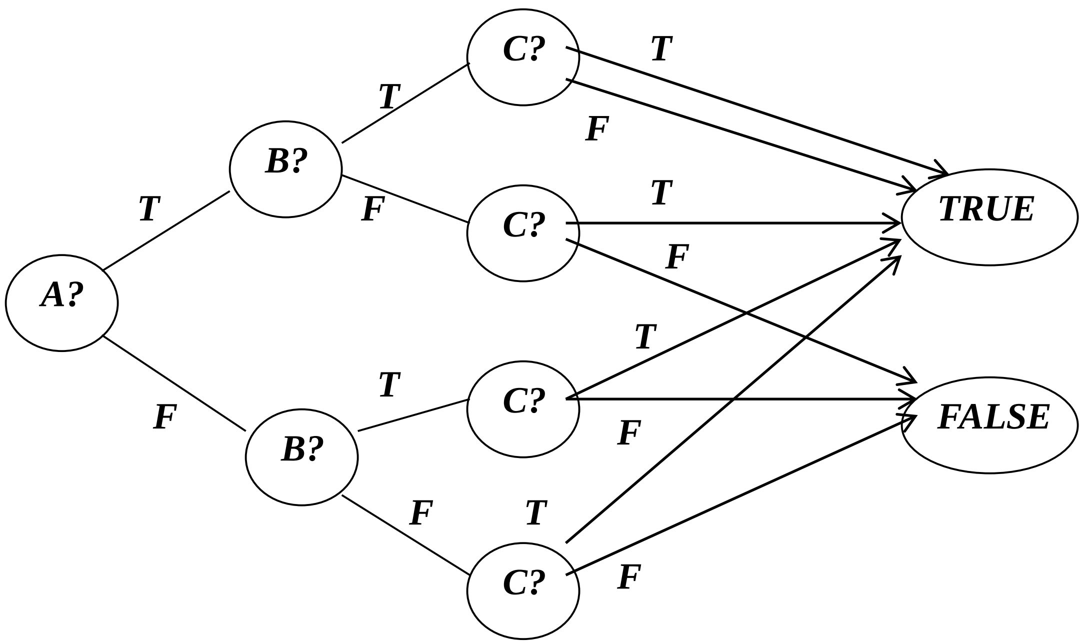
- Design test cases for each combination of conditions
- Example:
  - (i < value) | (result <= maxint)

(i < value)	(result <= maxint)
false	false
false	true
true	false
true	true

- Implies decision-, condition-, decision/condition coverage
- But : exponential blow-up
- Again : some combinations may be infeasible

Condition Testing for Software

Condition: (A AND B Or C)



Condition Testing For Software

A	*B*	*C*	*A&B or C*
TRUE	***TRUE***	***TRUE***	***TRUE***
TRUE	***TRUE***	***FALSE***	***TRUE***
TRUE	***FALSE***	***TRUE***	***TRUE***
TRUE	***FALSE***	***FALSE***	***FALSE***
FALSE	***TRUE***	***TRUE***	***TRUE***
FALSE	***TRUE***	***FALSE***	***FALSE***
FALSE	***FALSE***	***TRUE***	***TRUE***
FALSE	***FALSE***	***FALSE***	***FALSE***

Loop Testing For Software

Simple Loops, where *n is the maximum number of allowable passes through the loop.*

- Skip loop entirely
- Only one pass through loop
- Two passes through loop
- m passes through loop where m<n.
- (n-1), n, and (n+1) passes through the loop.

Nested Loops

- Start with inner loop. Set all other loops to minimum values.
- Conduct simple loop testing on inner loop.
- Work outwards
- Continue until all loops tested.

Concatenated Loops

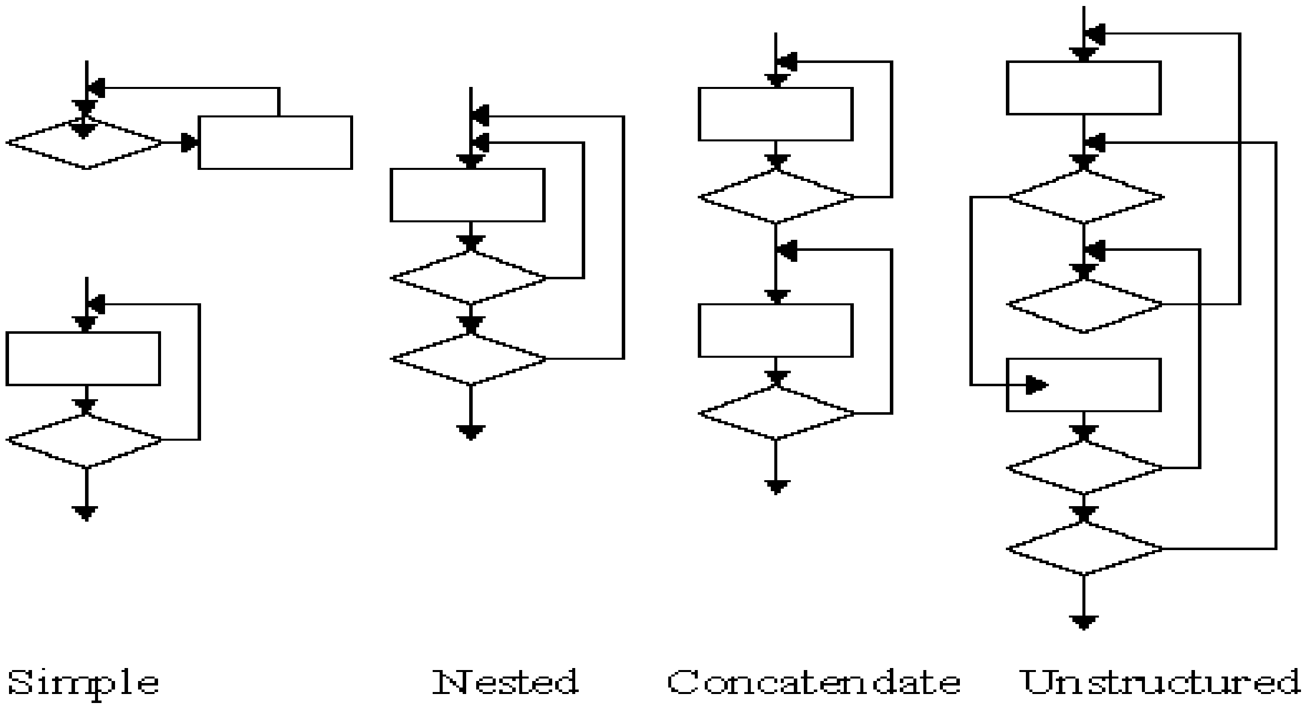
- If independent loops, use simple loop testing.
- If dependent, treat as nested loops.

Unstructured loops

- Don't test - redesign.

Loop Testing For Software

Examples:



Syntax-Based Software Testing

What is syntax testing?

Syntax testing is a powerful software testing technique for testing command-driven software and similar applications. There is a number of commercial tools.

Test model:

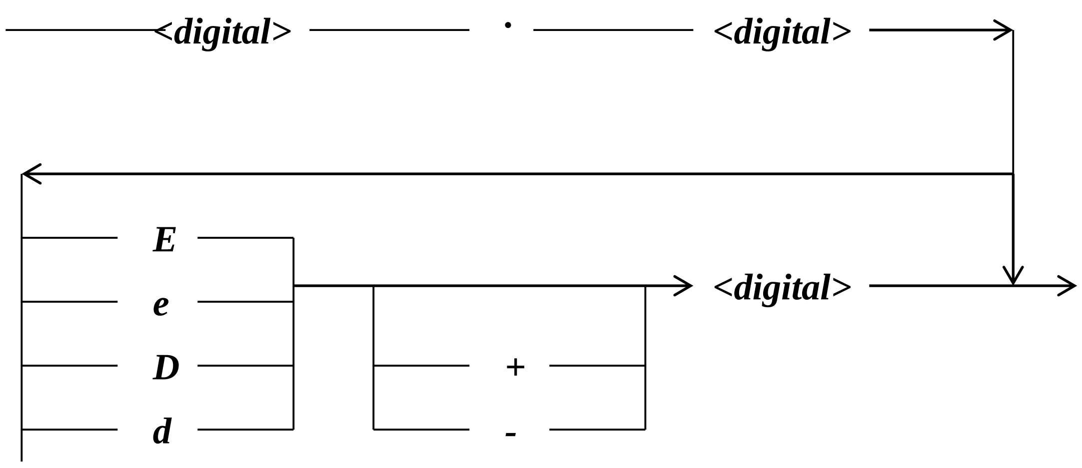
BNF-based graph is used as a test model to generate tests.

Test coverage:

- Node coverage - not very useful
- Link coverage - very important due to loops.

Syntax-Based Software Testing

Syntax Graph for <real_number>:



Syntax-Based Software Testing

Dirty Syntax Testing:

It includes twofold: ***a) to exercise a good sample of single syntactic errors in all commands in an attempt to break the software.***

b) to force every diagnostic message appropriate to that command to be executed.

Example test cases:

Try to come out test cases without loops:

.05, 1., 1.1e

Try to come out test cases with loops:

12345678901.1, 1.1234567890123, 1.1e1234

State-Based Software Testing

What is state-based software testing?

A software testing method in which a well-defined state machine (or a state graph) is used as a test model to check the state-based behavior of a program.

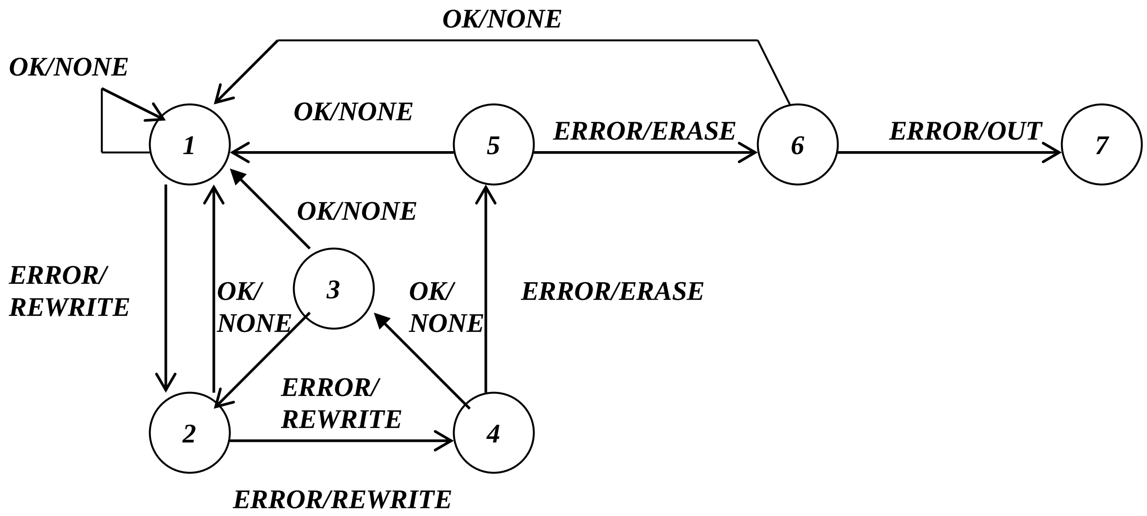
A state machine is used to define test cases and test criteria to uncover the incorrect state behavior of a program.

Coverage criteria:
- State node coverage
- Transition path coverage

Applications:
- Very useful to check protocol-based program communications.
- Good to check problems in state-driven or event-driven application programs.

State-Based Software Testing

A State Machine Example:



TAPE CONTROL RECOVERY ROUTINE STATE GRAPH

State-Based Software Testing

Making sure the correctness of your state graphs.

Checking the following problems in state machines:

- Dead lock state, a state can never be left.

- Non-reachable state, a state is not reachable from an initial state.

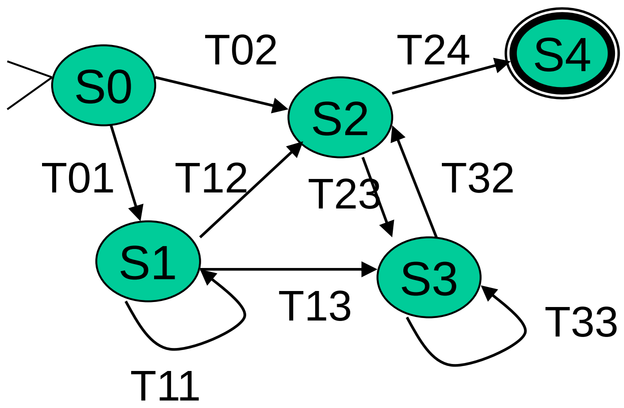
- Impossible and incorrect states.

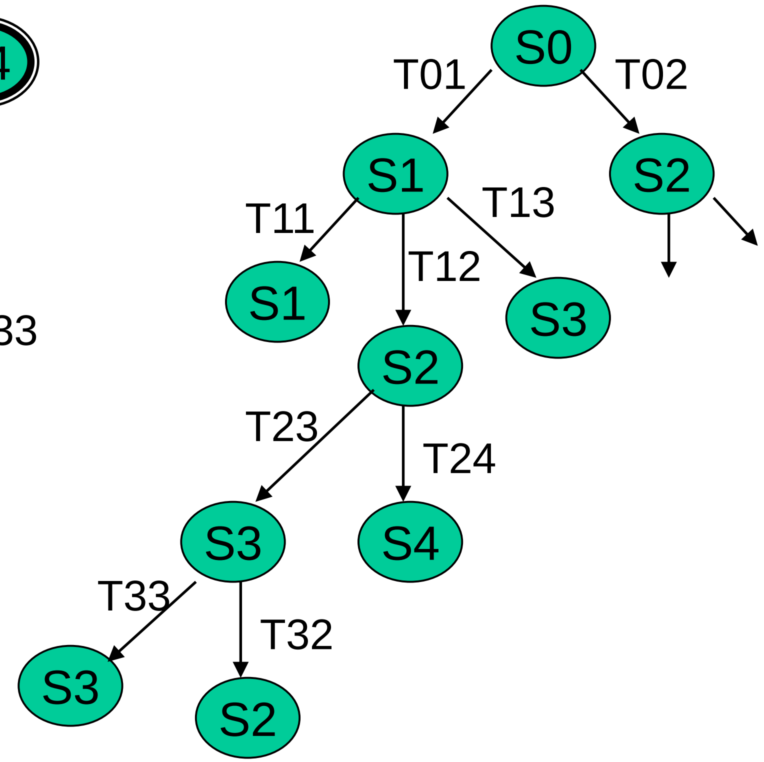
Some combinations of factors may appear to be impossible.

For example: (for a car)

GEAR	*R, N, 1, 2, 3, 4*	*= 6 factors*
DIRECTION	*FORWARD, REVERSE, STOPPED*	*= 3 factors*
ENGINE	*RUNNING, STOPPED*	*= 2 factors*
TRANSMISSION	*Okay, Broken*	*= 2 factors*
ENGINE	*Okay, Broken*	*= 2 factors*
Total		*= 144 states*

State-Based Test Generation





Test cases:

Level #1: S0->T01->S1
S0->T02>S2
Level #2: S0->T01->S1->T11->S1
S0->T01->S1->T12->S2
S0->T01->S1->T13->S3
…….

State-Based Software Testing

We can use the state-based testing method to uncover the following issues:

- ***Wrong number of states.***
- ***Wrong transition for a given state-input combination.***
- ***Wrong output for a given transition.***
- ***Pairs of states or sets of states that are inadvertently made equivalent (factor lost).***
- ***States or sets of states that are split to create inequivalent duplicates.***
- ***States or sets of states that have become dead.***
- ***States or sets of states that have become unreachable.***

State-Based Software Testing

Principles:

The starting point of state testing is:
• Define a set of covering input sequences that get back to the initial state when starting from the initial state.
•For each step in each input sequence, define the expected next state, the expected transition, and the expected output code.

A set of tests, then, consists of three sets of sequences:
1. Input sequences
2. Corresponding transitions of next state names.
3. Output sequences.

- ***Insist on a specification of transition and output for every combination of input and states.***
- ***Apply a minimum set of covering tests.***
- ***Instrument the transitions to capture the sequence of states and not just sequence of outputs.***
- ***Count the states.***

White-Box Software Testing Criteria

- Statement test coverage criteria
- Branch testing coverage criteria
- Condition test coverage criteria
- Basis-path test coverage criteria
- Loop test coverage criteria
- Dataflow testing coverage criteria
- Syntax testing coverage criteria
- State testing coverage criteria

Topic #1 – Software White-Box Testing

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Software Testing

TOPIC #1 – SOFTWARE WHITE-BOX TESTING

What Is White-Box Testing?

White-Box Testing Focuses

Why Is White-Box Testing Important?

Who Does White-Box Testing?

White-Box Testing Coverage

Software Testing

Topic #1 – Software White-Box Testing

What is software white-box testing?

White-box testing, also known as glass-box testing or program-based testing.

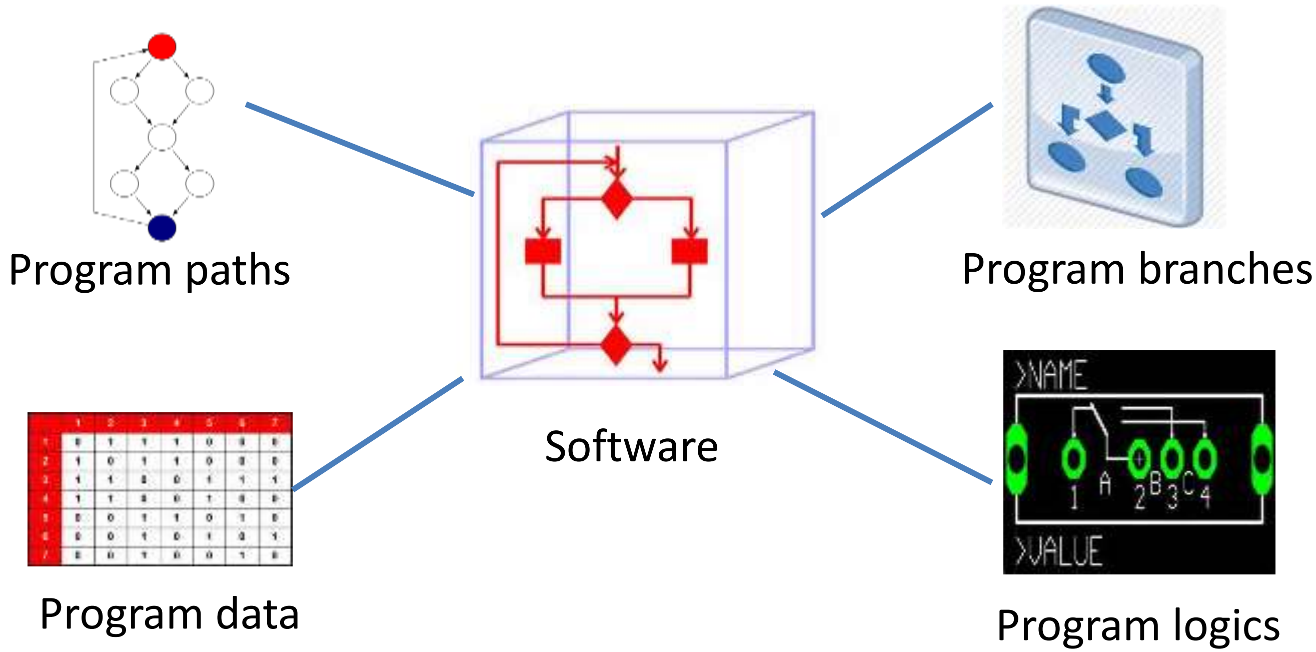
Definition: Software white-box testing refers to test design based on program source code structures, data, and internal program logics.

What do you need for white-box testing?

- A white-box testing model and test criteria 
- A white-box test design and generation method 

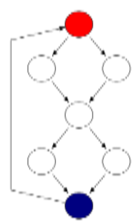
- Program source codes 

White-Box Testing Focuses

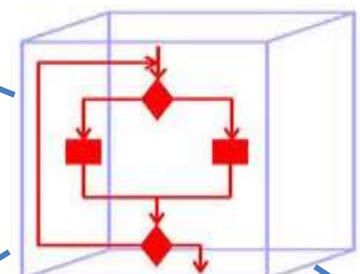


Why Is White-Box Program Testing Important?

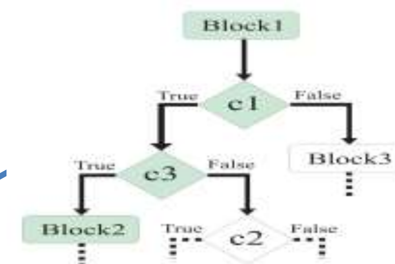
Answer: - Achieve certain program code coverage
- Assure software program-based test adequacy



Exercise program control flows



Software



Check program branches

	1	2	3	4	5	6	7
1	0	1	1	1	0	0	0
2	1	0	1	1	0	0	0
3	1	1	0	0	1	1	1
4	1	1	0	0	1	0	0
5	0	0	1	1	0	1	0
6	0	0	1	0	1	0	1
7	0	0	1	0	0	1	0

Cover different program data and their values

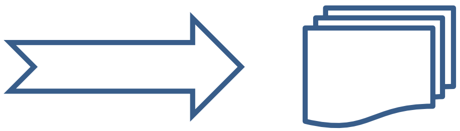
Discover deadlock codes

Who Does White-Box Program Testing?

Developers perform white-box program testing, not test engineers.

- They only target to software components/modules they created.
- They only use white-box testing methods and tools
- They need to use software program codes
- They must select and achieve white-box program code coverage

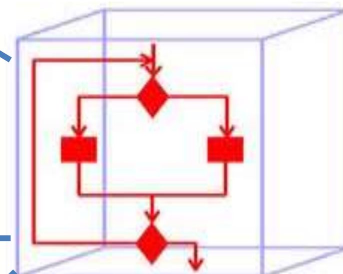
Source codes

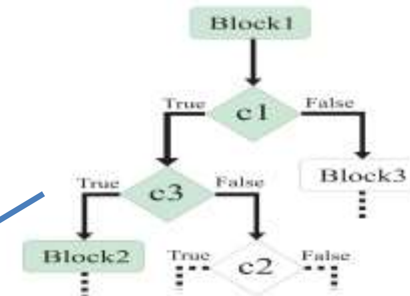


White-box Tests

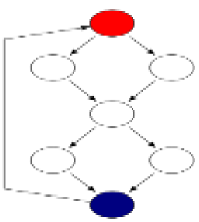
White-Box Program Coverage

Program Source
Code Line Coverage





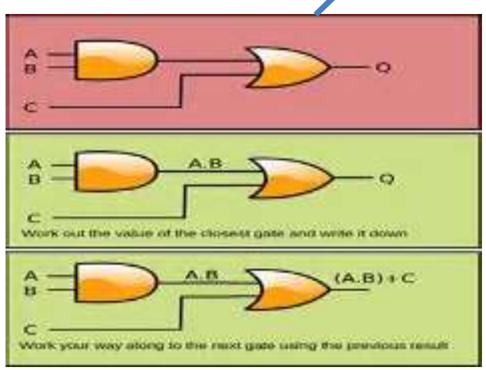
Program Branch
Coverage



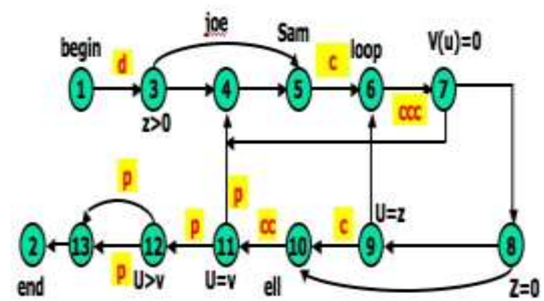
Program Control
Path Coverage

Program Source codes

Data Flow
Test Coverage



Program Logics
Coverage



Software Testing

MODULE #3 – SOFTWARE WHITE-BOX TESTING METHODS

Topic #2 – Software Basis Path Testing

Instructor: Jerry Gao, Ph.D., Professor
San Jose State University

TOPIC #2 – SOFTWARE BASIS PATH TESTING

- Flow Graph Model for White-Box Testing
- Cyclomatic Complexity
- Basis Path Testing Method
- Basis Path Testing Tips
- Basis Path Testing Coverage

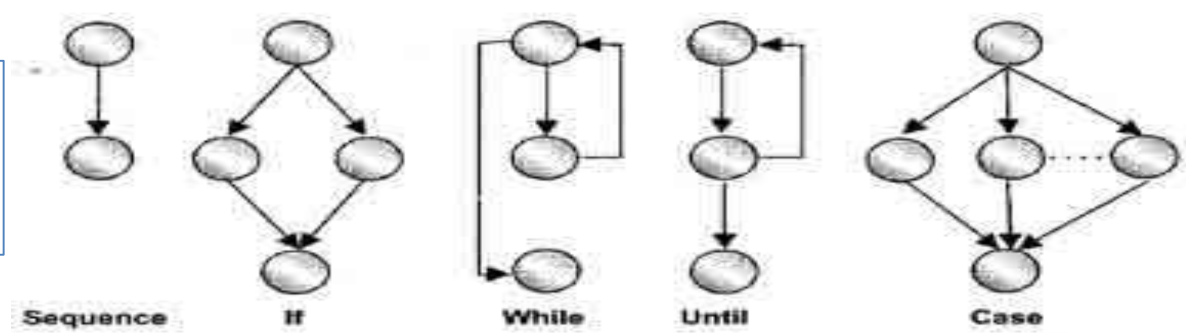
What is a program flow graph?

Definition:

--> A program flow is a graph model which is useful to present the control flows for a program. Each program flow graph consists of a set of nodes and edges (or links).

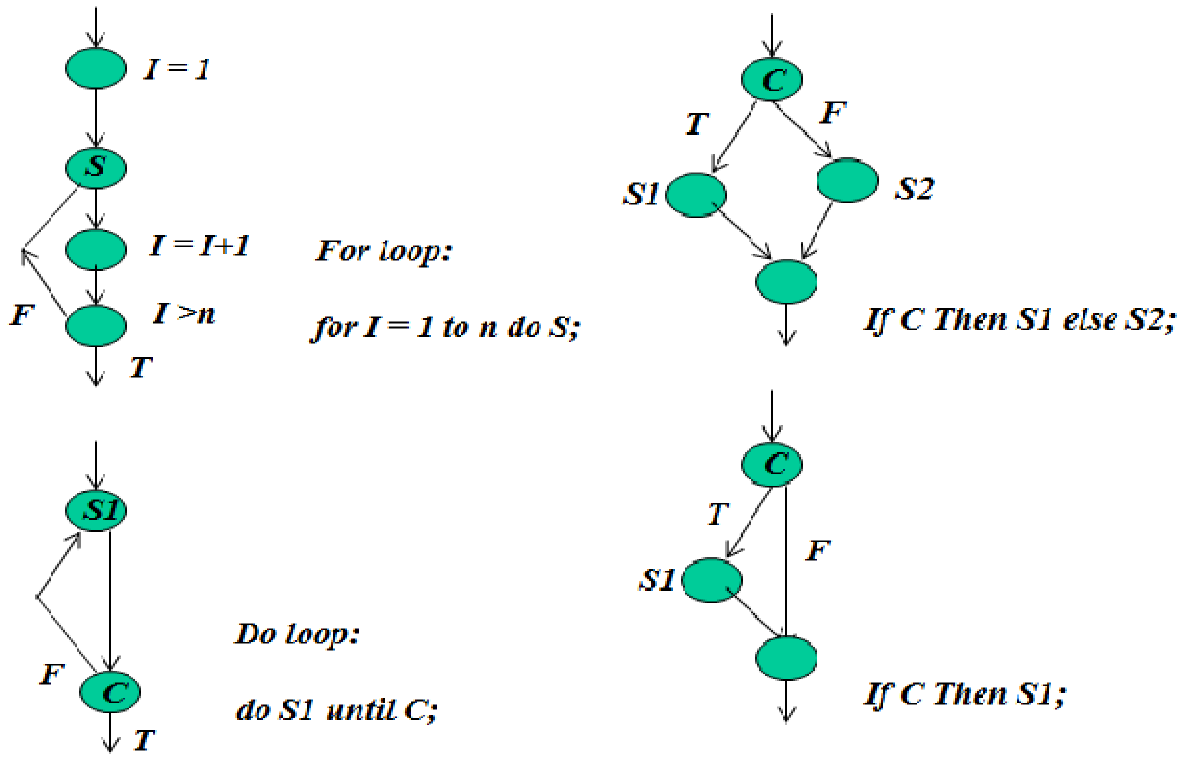
A program flow graph can be used as a test model for white-box program testing.

Typical example of program control structures



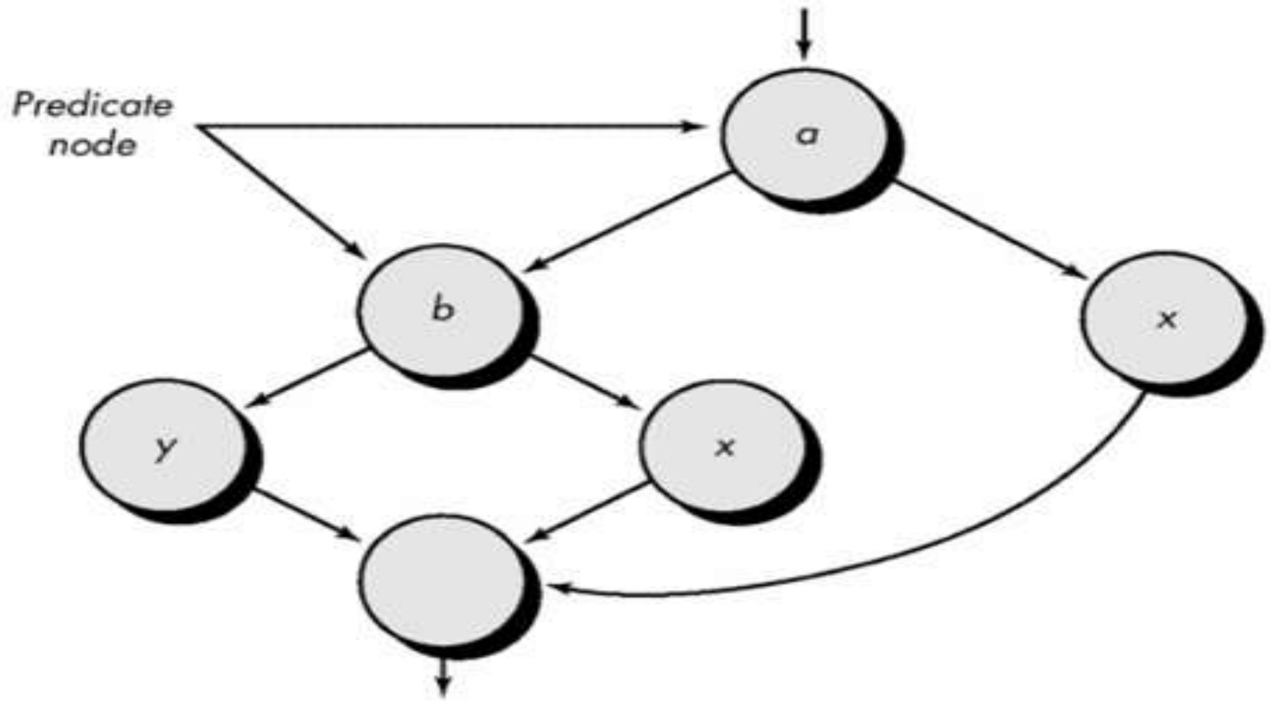
Flow Graph Notation

Typical Control Structures



Program Flow Graph Example

.
.
.
IF a OR b
then procedure x
else procedure y
ENDIF



Cyclomatic Complexity

What is Cyclomatic complexity?

Cyclomatic complexity is a software metric (developed by Thomas J. McCabe, Sr. in 1976) It is used to indicate the complexity of a program.

It is a quantitative measure of the complexity of programming instructions. It directly measures the number of linearly independent paths through a program's source code.

Cyclomatic complexity is computed using the control flow graph of a program.

One testing method, called Basis path testing (proposed by McCabe).

It is useful to test each linearly independent path through the program.

Cyclomatic Complexity

Cyclomatic complexity is computed using the control flow graph of a program.

Let M(G) represents the cyclomatic complexity of a program flow graph G.
N stands for the node set in G, and E stands for the edge set in G.
P stands for the predicate node set in G.

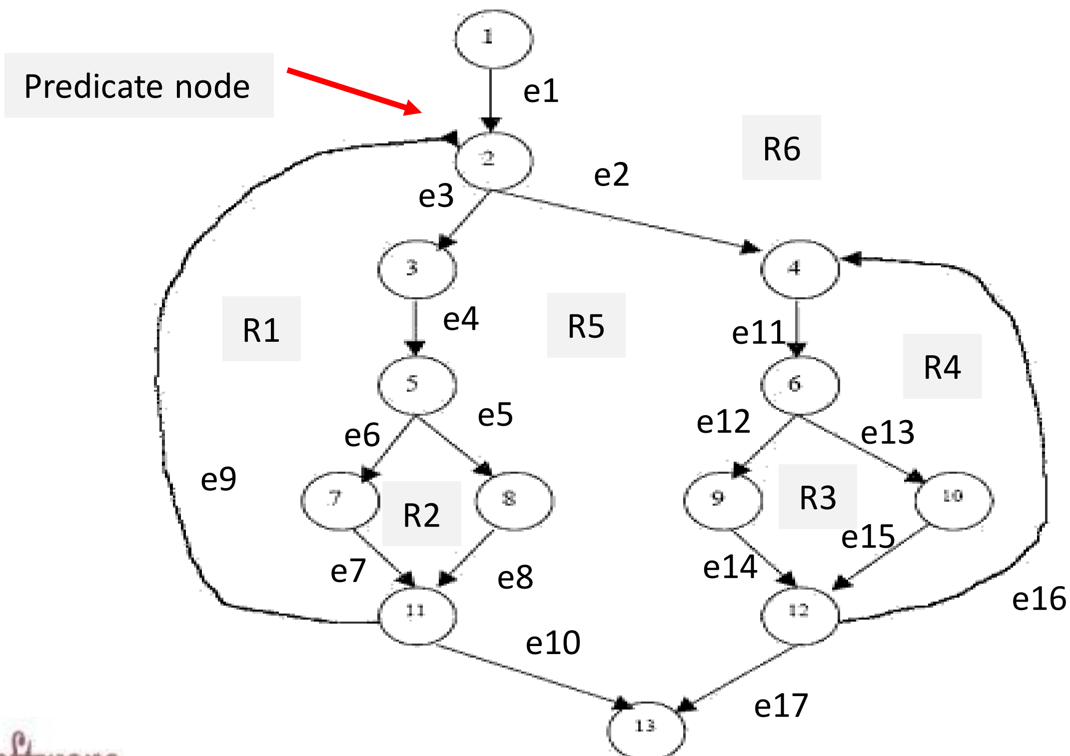
Three ways to compute cyclomatic complexity for a program:

#1: M(G) = No. of regions in G

#2: $M(G) = |E| - |N| + 2$
Where $|E|$ is the number of edges and $|N|$ is the number of nodes.

#3: $M(G) = |P| + 1$
Where $|P|$ is the number of predicate nodes in the flow graph G.

Cyclomatic Complexity Computation

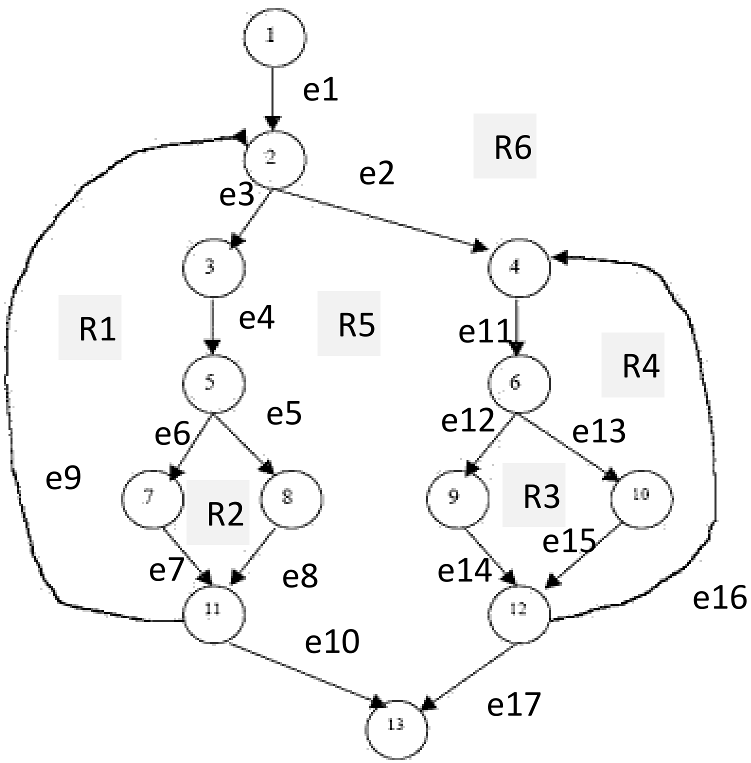


M(G) = 6 regions

M(G) = |E| - |N| +2
= 17 – 13 + 2 = 6

M(G) = |P| + 1
= 5 + 1 =6

Basis Path Testing Method



Step 1 : Draw a corresponding flow graph based on program codes

Step 2: Compute the cyclomatic complexity

Step 3: Determine a minimum basis set of linearly independent paths.

For example,

- path 1: 1-2-3-5-7-11-13
- path 2: 1-2-3-5-8-11-13
- path 3: 1-2-3-5-8-11-2-3-5-7-11-13
- path 4: 1-2-4-6-9-12-13
- path 5:1-2-4-6-10-12-13
- path 6: 1-2-4-6-10-12-4-6-9-12-13

Step 4: Prepare a test case for each path in the set.

Step 5: Run the test cases and check their results

Basis Path Testing Tips

Simple tips to form your basis path set:

1. Add your basis path incrementally. (one by one)

2. Check the redundant path whenever you add one path,

3. Make sure that new path has at least one new node or new link comparing with the rest paths in the set.

4. Make sure the total no. of basis paths in the set is equal to your cyclomatic complexity.

Simple tips to form your basis path test set:

1. Make sure each basis path is executable based on inputs.

2. Make sure to find the expected outputs based on your inputs for each test case.

Compute Cyclomatic Complexity Using Graph Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	
1	0	1	0	0	0	0	0	0	0	0	0	0	0	1-1=0
2	0	0	1	1	0	0	0	0	0	0	0	0	0	2-1=1
3	0	0	0	0	1	0	0	0	0	0	0	0	0	1-1=0
4	0	0	0	0	0	1	0	0	0	0	0	0	0	1-1=0
5	0	0	0	0	0	0	1	1	0	0	0	0	0	2-1=1
6	0	0	0	0	0	0	0	0	1	1	0	0	0	2-1=1
7	0	0	0	0	0	0	0	0	0	0	1	0	0	1-1=0
8	0	0	0	0	0	0	0	0	0	0	1	0	0	1-1=0
9	0	0	0	0	0	0	0	0	0	0	0	1	0	1-1=0
10	0	0	0	0	0	0	0	0	0	0	0	1	0	1-1=0
11	0	1	0	0	0	0	0	0	0	0	0	0	1	2-1=1
12	0	0	0	1	0	0	0	0	0	0	0	0	1	2-1=1
13	0	0	0	0	0	0	0	0	0	0	0	0	0	

|P| + 1 = 6

|P|=5

Basis Path Testing Coverage

Following the basis path testing method, we can achieve the following White-box program test coverage for each program.

1. **Source code node coverage:**
- For each node in a program flow graph, there will be at least one basis path test case exercise it.

2. ***Control link coverage***:
- For each edge in a program flow graph, there will be at least one basis path test case cover it.

3. ***Basis path coverage***:
- For each basis path in the basis path set, there will be at least one basis test case covering it.

4. Predicate node coverage:
- For each node, there will be at least one basis path test case covering it.

Topic #3 – Software Branch Testing

Instructor: **Jerry Gao, Ph.D., Professor**
San Jose State University

TOPIC #3 – SOFTWARE BRANCH TESTING

What Is Software Branch Testing?

Why Do We Need Branch Testing?

How To Conduct Branch Testing?

Branch Testing Example

Branch Testing Coverage

What is software branch testing?

Definition:

Software branch testing is one white-box test strategy and method. Engineers use this method to design test cases and data to validate each branch in the program flow graph of a given program's source codes.

Its test focuses:	**Every branch in a program flow graph**
Test model:	**Program flow graph model**
Limitation:	**Each Boolean condition is treated as a simple decision node with both "T" and "F" branches.**

Why Do We Need Branch Testing?

- **Software programs consist of many logic decisions (in Boolean expressions)**

- **Incorrect implementations of logic decisions lead to software errors**

- **The program code coverage is not enough to reach to the decision coverage (or the branch coverage)**

How to Conduct Software Branch Testing?

Step #1: Come out a program flow graph as a test model for a given program (i.e. a function in C++/Java).

Step #2: Identify predicate nodes in a program flow graph

Step #3: Create a branch table including all branches

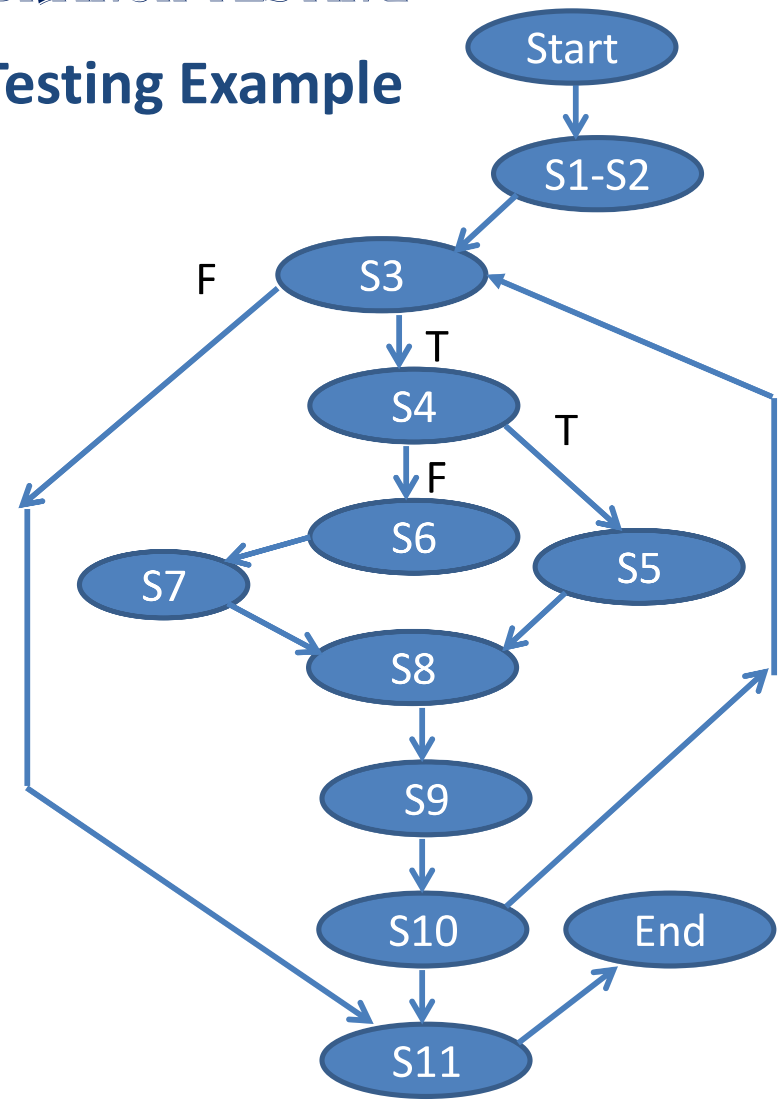
Step #4: Identify one independent executable path to cover one or more branches in the program flow graph from the starting node to the end node.

Step #5: Continue Step #4 until to cover all branches in the branch table in Step #3.

Software Branch Testing Example

Step #1: Create Program Flow Graph

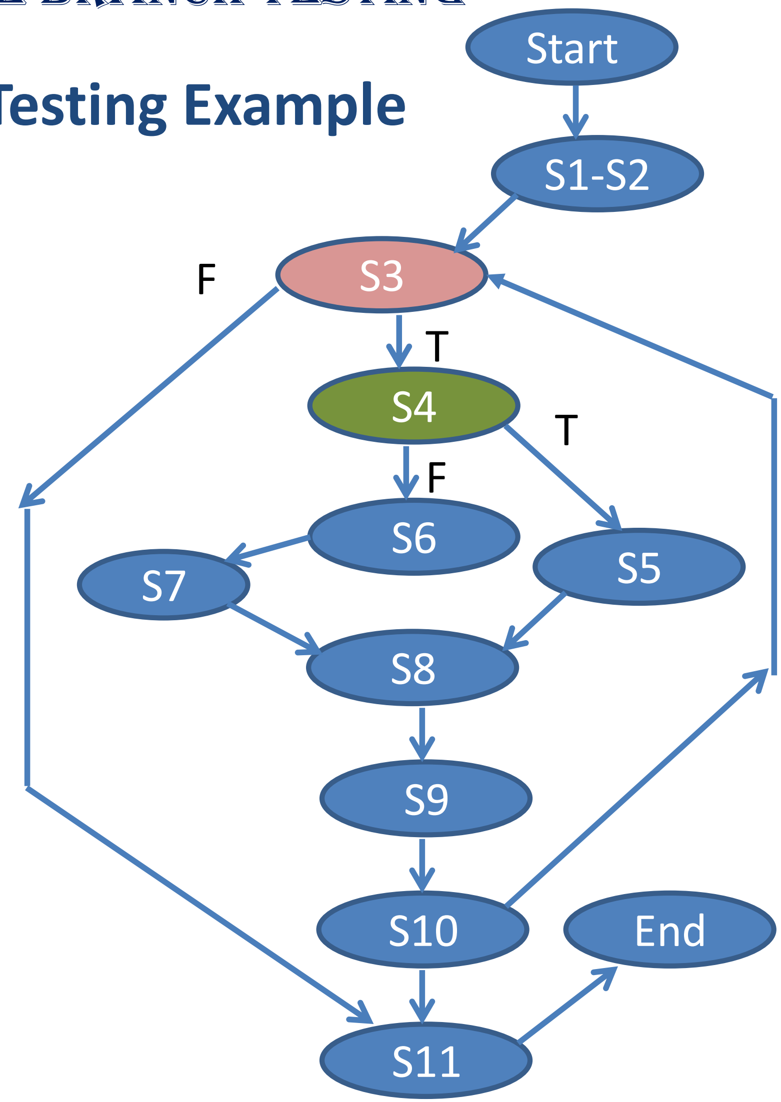
```
/*  Branch Testing Example*/
      declare Length as integer
      declare Count as integer
S1      READ Length;
S2      READ Count;

S3       WHILE (Count <= 6) LOOP
S4           IF (Length >= 100) THEN
S5               Length = Length - 2;
S6           ELSE
S7              Length = Count * Length;
S8           END IF
S9           Count = Count + 1;
S10     END LOOP;
S11     PRINT Length;
```



Software Branch Testing Example

Step #2: Create Decision Table

Predicate Node	Decision	Possible Outcome
S3	Count <= 6	T
		F
S4	Length >= 100	T
		F



Software Branch Testing Example

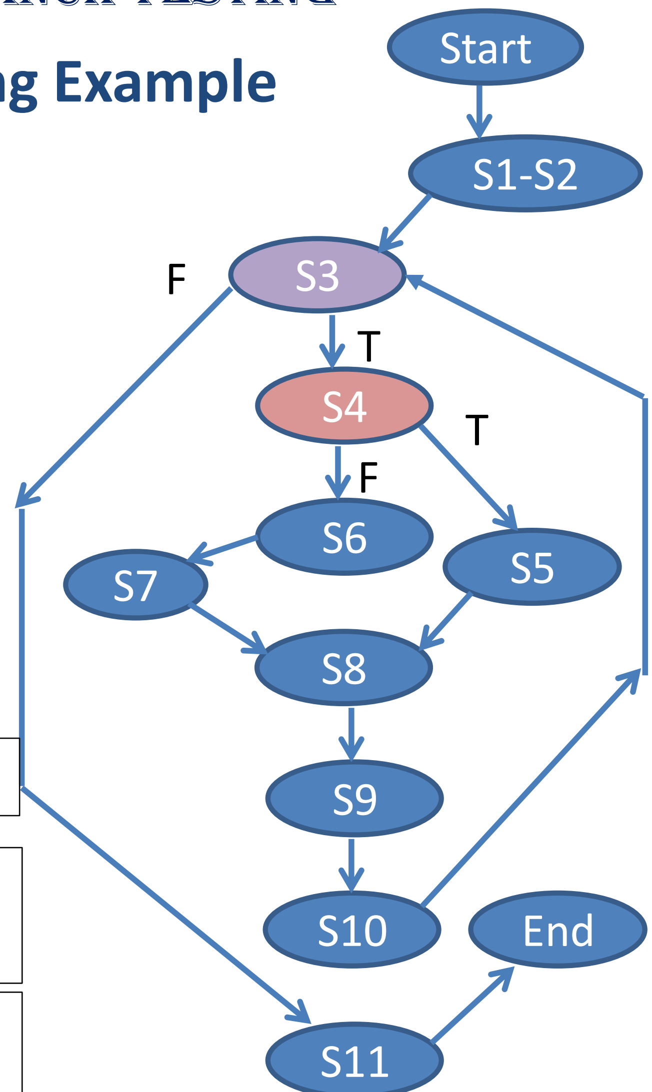
Step #3: Create one Independent Path for each decision's possible outcome.

Predicate Node	Decision	Possible Outcome	Path
S3	Count <= 6	F	P1
		T	P2. P3
S4	Length >= 100	T	P2
		F	P3

P1: Start→S1-S2→S3→S11→End

P2: Start→S1-S2→S3→S4→S5→S8
→S9→S10→S3→S11→End

P3: Start→S1-S2→S3→S4→S6→S7
->S8 →S9→S10→S3→S11→End



Software Branch Testing Example

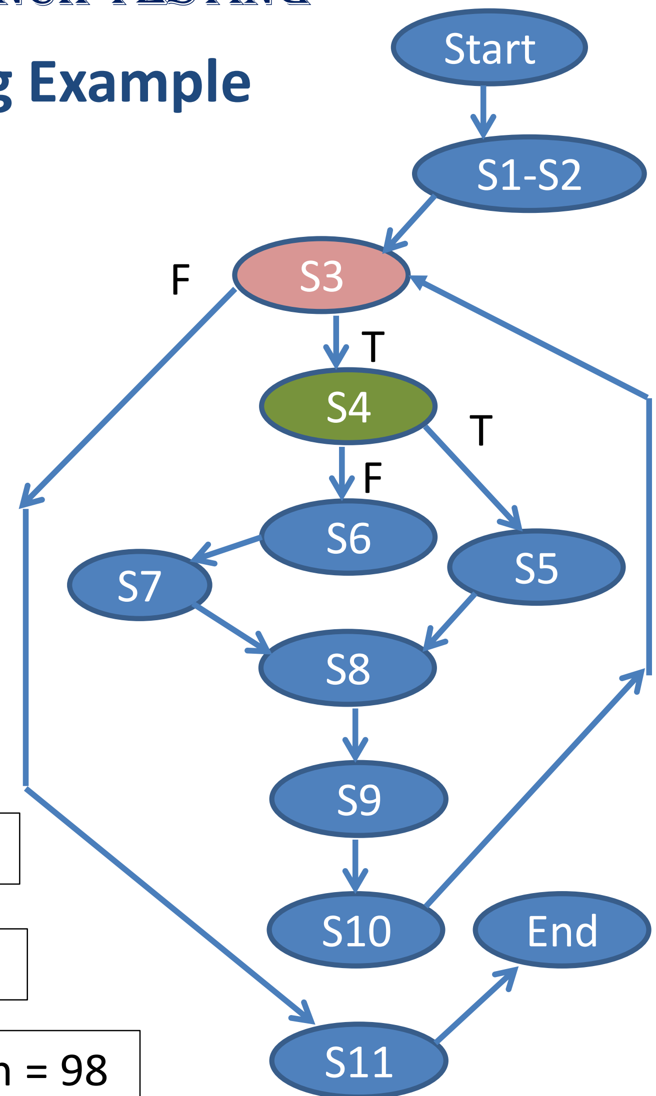
Step #3: Create one Independent Path for each decision's possible outcome.

Predicate Node	Decision	Possible Outcome	Path	T1	T2	T3
S3	Count <= 6	F	P1	X		
		T	P2. P3		X	X
S4	Length >= 100	T	P2		X	
		F	P3			X

T1- Inputs: (Count = 7, Length = 10) Outputs: Length = 10

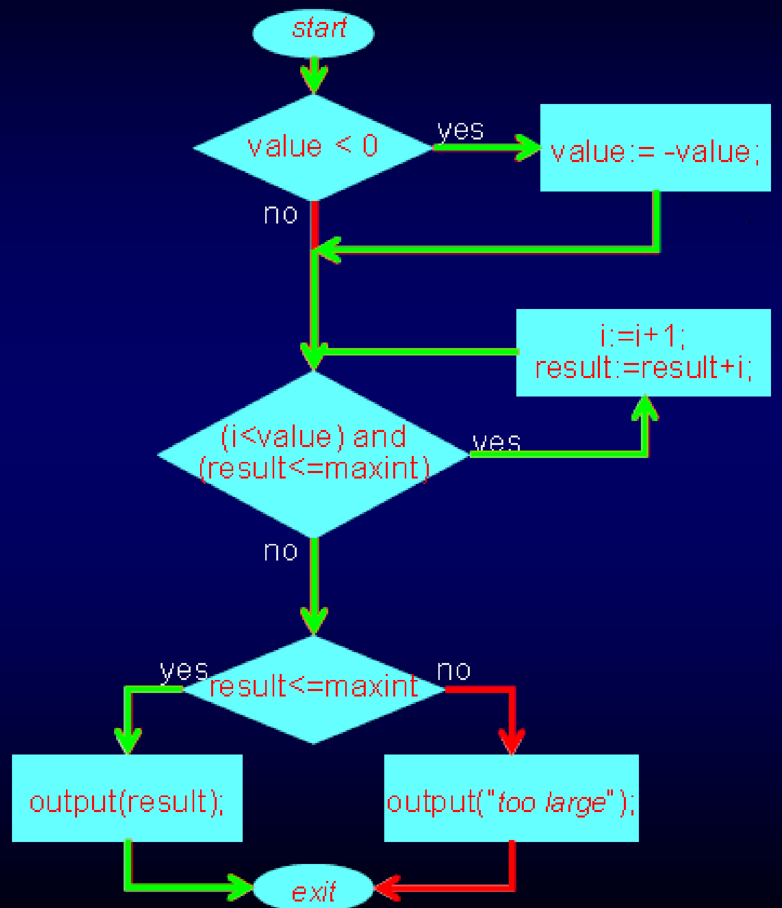
T2 - Inputs: (Count = 6, Length = 10) Outputs: Length = 60

T3 - Inputs: (Count = 6, Length = 100) Outputs: Length = 98



TOPIC #3 – SOFTWARE BRANCH TESTING

Example : Branch Testing



maxint	value
-1	-1
10	3

But:

No green path !

Needed :

Combination of decisions

10 -3

Software Branch Testing Coverage

What has been covered by Branch Testing?

- Cover each predicate node in a program flow graph.

- Cover each branch link (or edge) in a program flow graph.

- Cover each predicate node only in T/F value.

What has not been covered by Branch Testing?

- Diverse combinational cases from a compound Boolean expression

Topic #4 – Software Condition-Based Testing

Instructor: Jerry Gao, Ph.D., Professor
San Jose State University

Topic #3 – Software Condition-Based Testing

What Is Condition-Based Testing?

Why Is Condition-Based Testing Important?

How to Conduct Condition-Based Testing?

A Condition-Based Testing Example

Condition-Based Testing Coverage

What Is Condition-Based Testing?

Definition: Condition-based testing is one program-based software testing strategy in which engineers focus on compound Boolean conditions in predicate nodes.

Its major testing focuses are incorrect logics and implementations in complex Boolean expressions for predicate nodes. They include:

- Boolean variable errors
- Boolean parenthesis errors
- Boolean operator errors
- Relational operator errors
- Arithmetic expression errors

Test model: Program flow graph model

Why Do We Need Condition-Based Testing?

- Software programs consist of many logic decisions (in Boolean expressions). Some of them implemented with compound Boolean Conditions.

- Many incorrect implementations of compound Boolean conditions lead to software decision errors

- The program code coverage is not enough to reach to the decision coverage (or the branch coverage)

- Software branch testing can’t assure the adequate test coverage for each combined Boolean conditions and its outcomes for a predicate node in a program flow graph.

How to Conduct Software Condition-Based Testing?

Step #1: Come out a program flow graph as a test model for a given program (i.e. a function in C++/Java).

Step #2: Identify predicate nodes with a compound Boolean condition in a program flow graph. Identify an independent path for each predicate node and related branches.

Step #3: Create a T/F condition table for each compound Boolean condition, including all of possible outcomes with diverse combinational inputs.

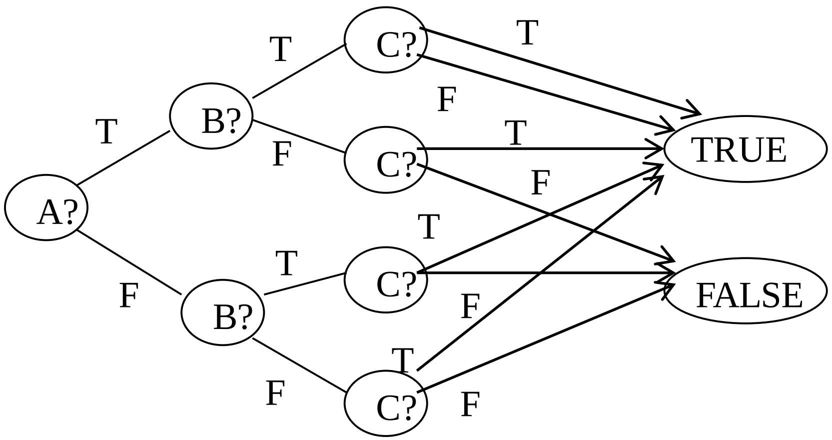
A compound condition:
→ A AND B or C

A	B	C	A AND B or C
TRUE	TRUE	TRUE	TRUE
TRUE	TRUE	FALSE	TRUE
TRUE	FALSE	TRUE	TRUE
TRUE	FALSE	FALSE	FALSE
FALSE	TRUE	TRUE	TRUE
FALSE	TRUE	FALSE	FALSE
FALSE	FALSE	TRUE	TRUE
FALSE	FALSE	FALSE	FALSE

How to Conduct Software Branch Testing?

A	B	C	A&B or C
TRUE	TRUE	TRUE	TRUE
TRUE	TRUE	FALSE	TRUE
TRUE	FALSE	TRUE	TRUE
TRUE	FALSE	FALSE	FALSE
FALSE	TRUE	TRUE	TRUE
FALSE	TRUE	FALSE	FALSE
FALSE	FALSE	TRUE	TRUE
FALSE	FALSE	FALSE	FALSE

A Compound Condition: (A AND B Or C)



Step #4: Identify one independent executable path to cover one target predicate node and its branch to cover one condition table entry.

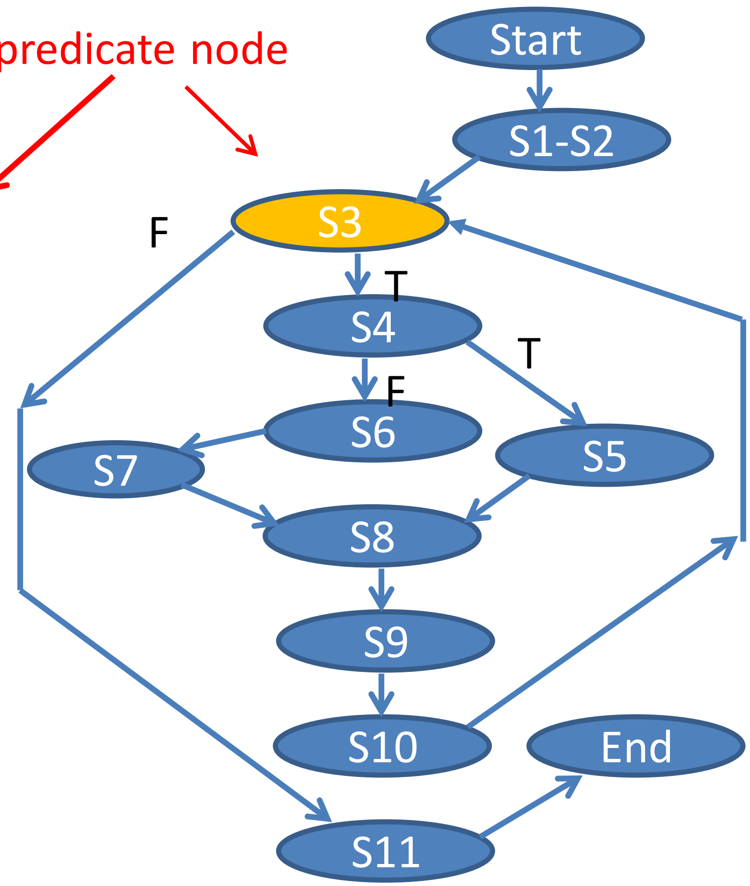
Step #5: Find test data and expected test result for this path. Continue Step #4 until covering the rest of condition table entries.

A Condition-Based Testing Example

Step #1: Create Program Flow Graph

A predicate node

```
/*  Condition Testing Example*/
S1    READ Length;
S2    READ Count;
S3    WHILE (Count < 6)AND (Length <200) LOOP
S4            IF (Length > 100) THEN
S5               Length = Length - 2;
S6            ELSE
S7               Length = Count * Length;
S8            END IF
S9        Count = Count + 1;
S10   END LOOP;
S11   PRINT Length;
```



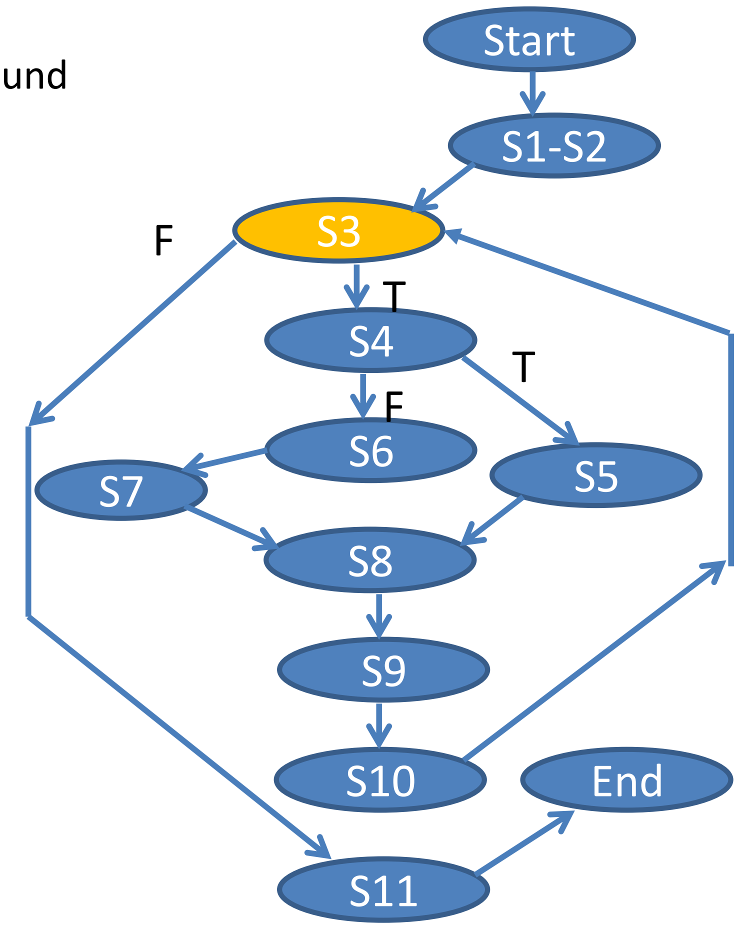
Software Condition-Based Testing Example

Step #2: Identify predicate nodes with a compound Boolean condition in a program flow graph.

Identify an independent path for each predicate node and related branches.

Compound Boolean Condition:
(Count < 6)AND (Length <200)

A= (Count < 6)
B= (Length < 200)
C= (Count < 6) AND (Length <200)

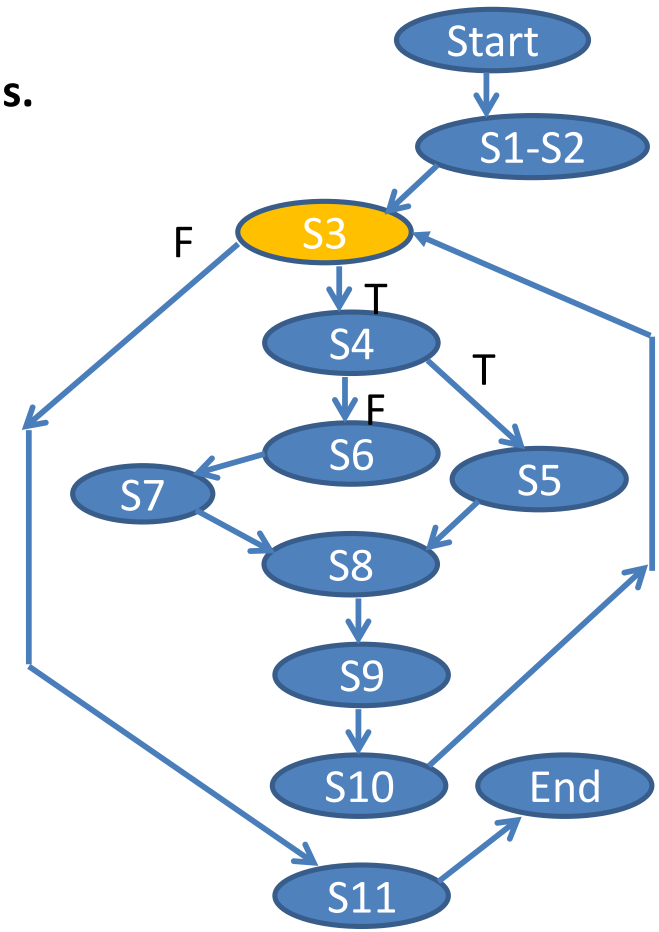


Software Condition-Based Testing Example

Step #3: Create one Independent Path for each predicate node with compound conditions.

Predicate Node	Decision	Possible Outcome	Path
S3	Count < 6 and Length<200	F	P1, P2
		T	P2

P1: Start→S1-S2→S3→S11→End
P2: Start→S1-S2→S3→S4→S5→S8
→S9→S10→S3→S11→End

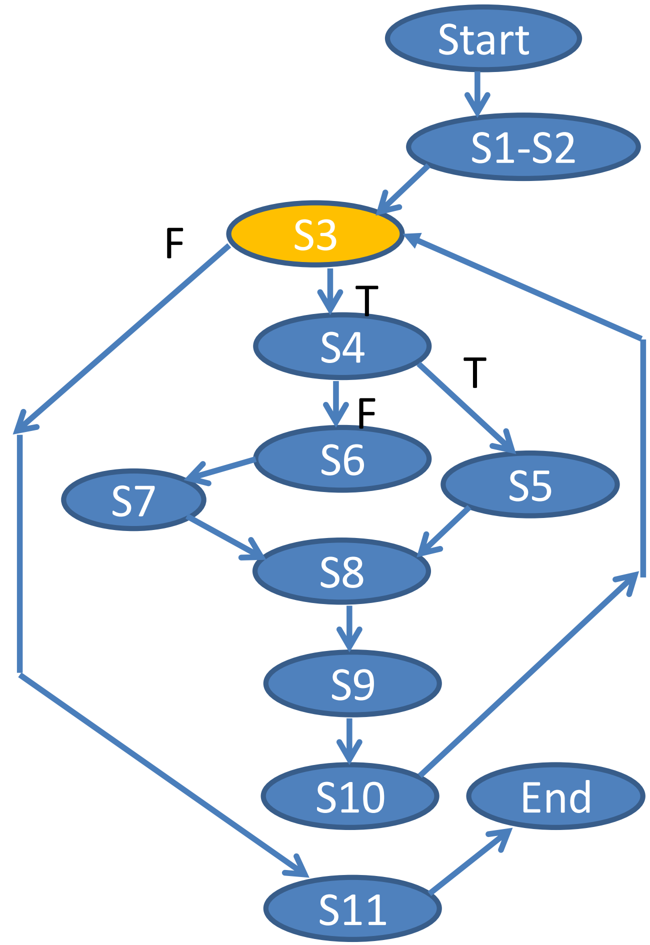


Software Condition-Based Testing Example

Step #4: Create a T/F Table for each compound condition

Predicate Node	Decision	Possible Outcome	Path
S3	Count < 6 and Length<200	F	P1, P2
		T	P2.

A: Count < 6	B: Length < 200	C: A AND B
TRUE	TRUE	TRUE
TRUE	TRUE	FALSE
TRUE	FALSE	FALSE
TRUE	FALSE	FALSE



Software Condition-based Testing Example

Step #5: Create a set of tests for each predicate with component conditions. Each test case covers one entry of the corresponding T/F Table.

Path ID	Test ID	Branch Outcome	Inputs	A: Count <6	B: Length <200	C: A and B	Expected Outputs
Path 1	T1	False	Count = 7 Length = 10	F	T	F	Length = 10
Path 1	T2	False	Count = 5 Length = 10	T	F	F	Length = 60
Path 2	T3	True	Count = 5 Length = 10	T	T	T	Length = 50
Path 1	T4	False	Count = 7 Length = 200	F	F	F	Length =200

Software Condition-Based Testing Coverage

What has been covered by Condition-Based Testing?

- Cover each predicate node in a program flow graph.

- Cover each branch link (or edge) in a program flow graph.

- Cover each combinational case in a compound Boolean condition of each predicate node in a program flow graph.

What has not been covered by Condition-Based Testing?

- This method can not assure the statement coverage (or known as node coverage) in a program.