CSE 470 –Control Flow Graph (Path Based Testing)

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Control Flow Graph: Introduction

- An abstract representation of a structured program/function/method.
- Consists of two major components:
  - *Node*:
    - Represents a stretch of sequential code statements with no branches.
  - *Directed Edge* (also called *arc*):
    - Represents a branch, alternative path in execution.
- Path:
  - A collection of *Nodes* linked with *Directed Edges.*

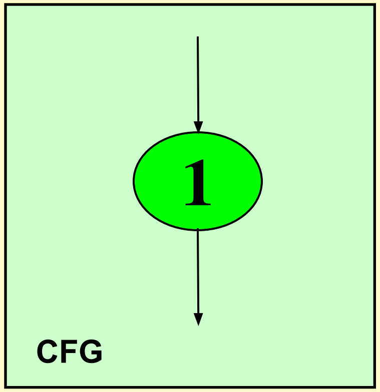
Notation Guide for CFG

- A CFG should have:
  - 1 entry arc (known as a directed edge, too).
  - 1 exit arc.
- All nodes should have:
  - At least 1 entry arc.
  - At least 1 exit arc.
- **A Logical Node** that does not represent any actual statements can be added as a joining point for several incoming edges.
  - Represents a logical closure.
  - Example:
    - Node 4 in the `if-then-else` example in next slides

Simple Examples

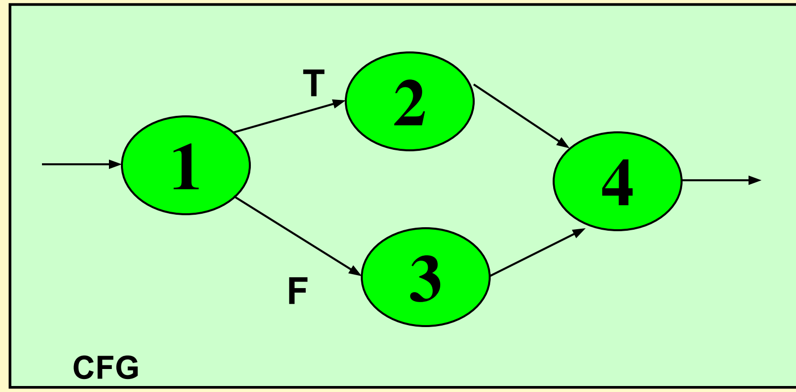
```
Statement1;
Statement2;
Statement3;
Statement4;
```

Can be represented as **one** node as there is no branch.

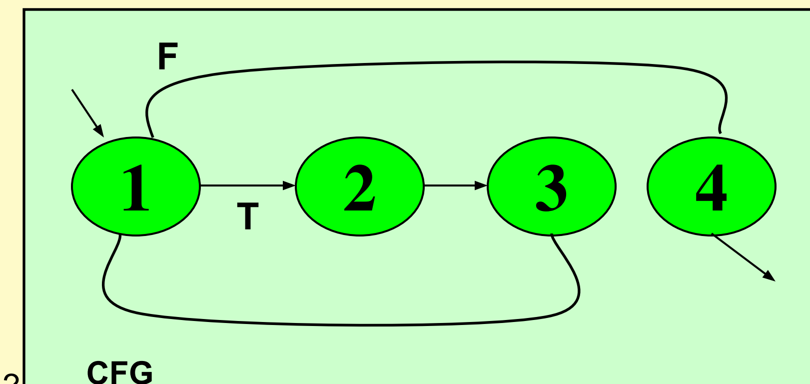


More Examples

```
if X > 0 then          1
    Statement1;        2
else
    Statement2;        3
```




```
while X < 10 {         1
    Statement1;        2
    X++; }             3
```

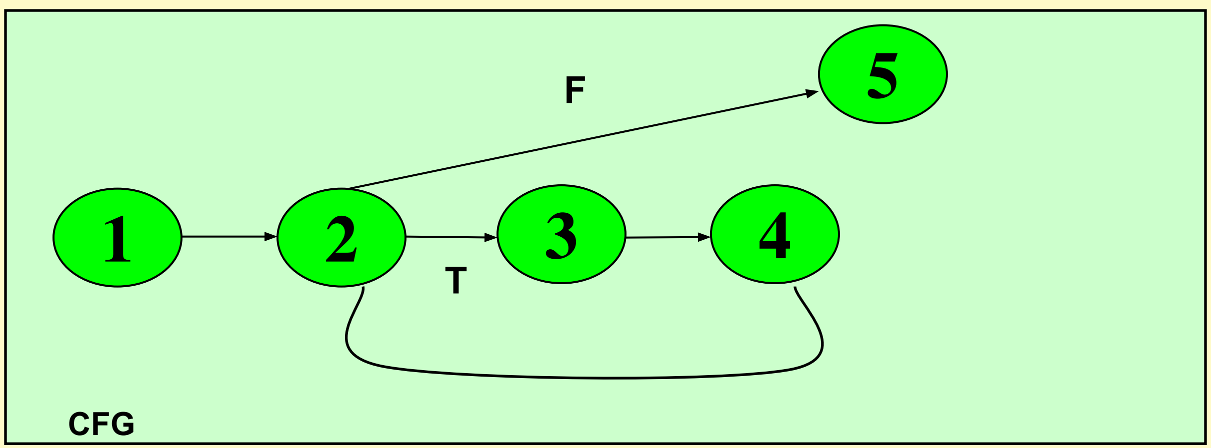


Question: Why is there a node **4** in both CFGs?

Answer: A logical node

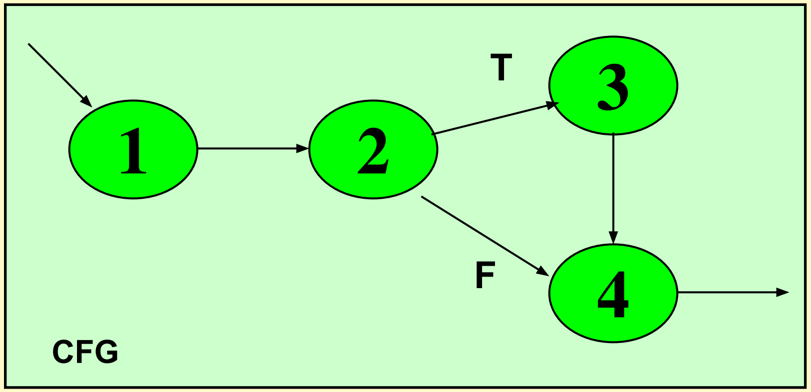
More Examples

```
           1             2           4
for (int I = 0; I < 10 ; I ++){
    Statement1;
    Statement2;           3
    Statement3;
  }
Statement4;               5
```



Combined Examples

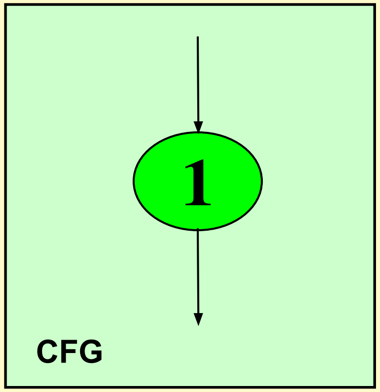
```
Statement1;
Statement2;                1

if x < 10 then             2
    Statement3;            3

Statement4;                4
```



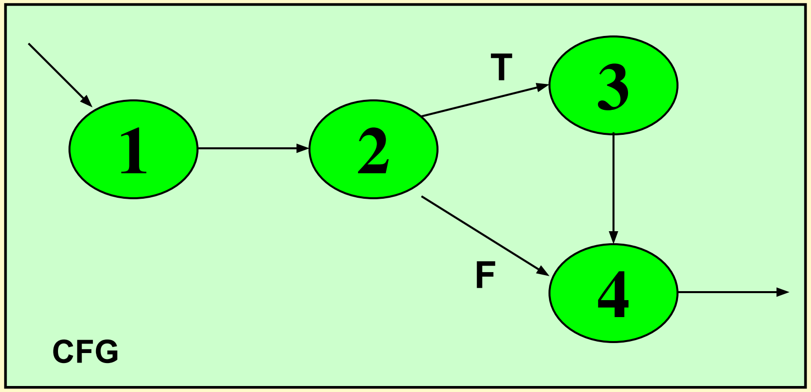
Number of Paths through CFG

- Given a program, how do we exercise all statements and branches at least once?
- Translating the program into a CFG, an equivalent question is:
  - Given a CFG, how do we cover all arcs and nodes at least once?
- Since a path is a trail of nodes linked by arcs, this is similar to ask:
  - Given a CFG, what is the set of paths that can cover all arcs and nodes?

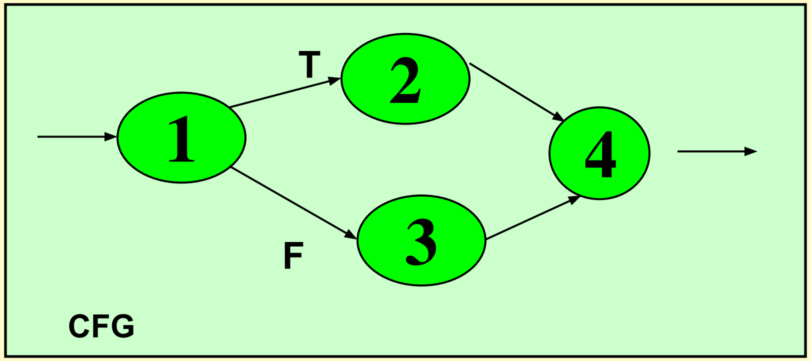
Example



- Only **one** path is needed:
  - [1]



- **Two** paths are needed:
  - [1 – 2 – 4]
  - [1 – 2 – 3 – 4]



- **Two** paths are needed:
  - [1 – 2 – 4]
  - [1 – 3 – 4]

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White Box Testing: Path Based

- A generalized technique to find out the number of paths needed (known as *cyclomatic complexity*) to cover all arcs and nodes in CFG.
- Steps:
  1. Draw the CFG for the code fragment.
  2. Compute the *cyclomatic complexity number* ***C***, for the CFG.
  3. Find at most ***C*** paths that cover the nodes and arcs in a CFG, also known as **Basic Paths Set;**
  4. Design test cases to force execution along paths in the **Basic Paths Set.**

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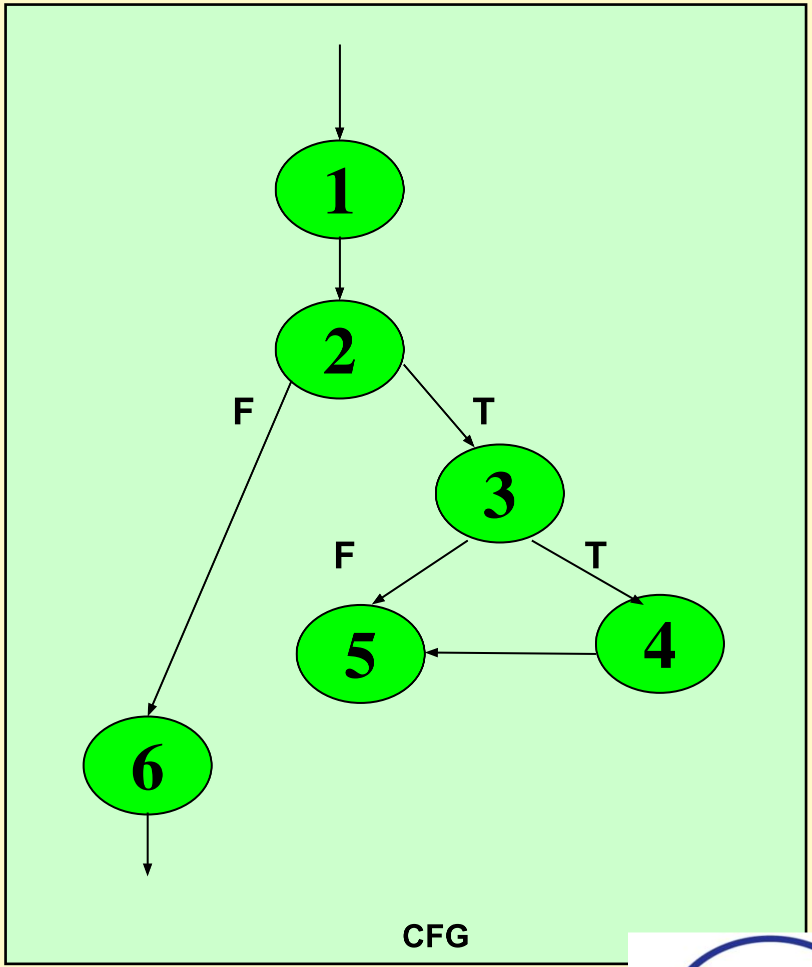
Path Based Testing: Step 1

```
min = A[0];
I = 1;

while (I < N) {
  if (A[I] < min)
        min = A[I];
   I = I + 1;
}
print min
```

1 (lines `min = A[0];` and `I = 1;`)
2 (`while (I < N) {`)
3 (`if (A[I] < min)`)
4 (`min = A[I];`)
5 (`I = I + 1;`)
6 (`print min`)



Path Base Testing: Step 2

1. The complexity M is then defined as

$$\mathbf{M = R + 1},$$

where R = the number of regions in the graph.

2. The complexity M is then defined as

$$\mathbf{M = P + 1},$$

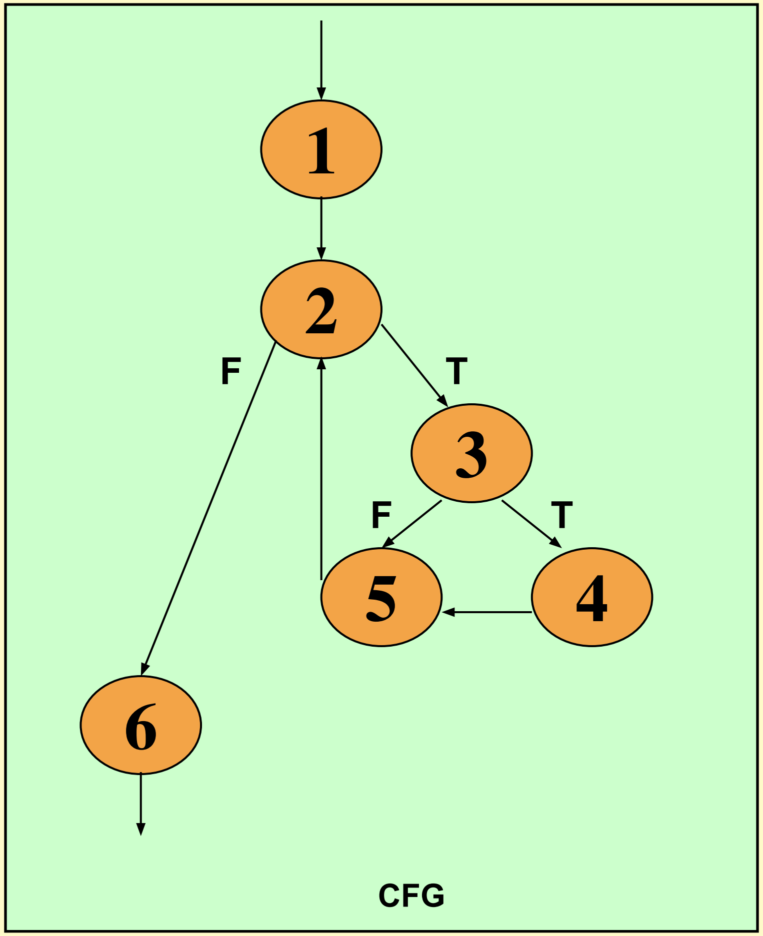
where P = the number of predicate nodes in the graph.

3. The complexity M is then defined as

$$\mathbf{M = E - N + 2P}, \text{where}$$

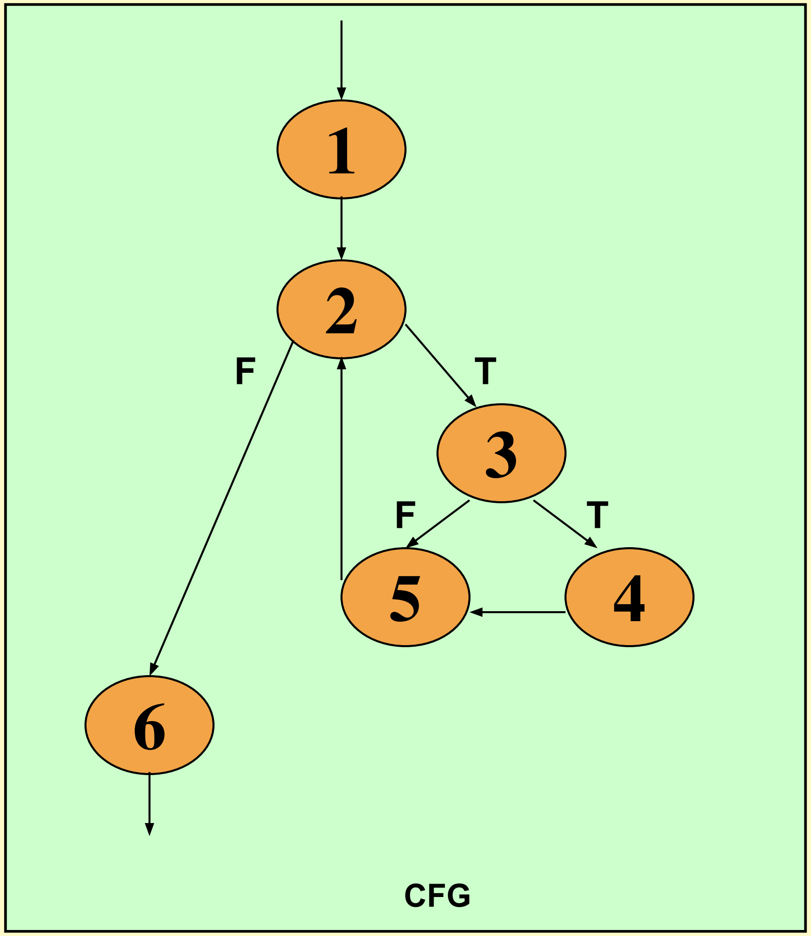
- E = the number of edges of the graph.
- N = the number of nodes of the graph.
- P = the number of connected components.

Path Base Testing: Step 2



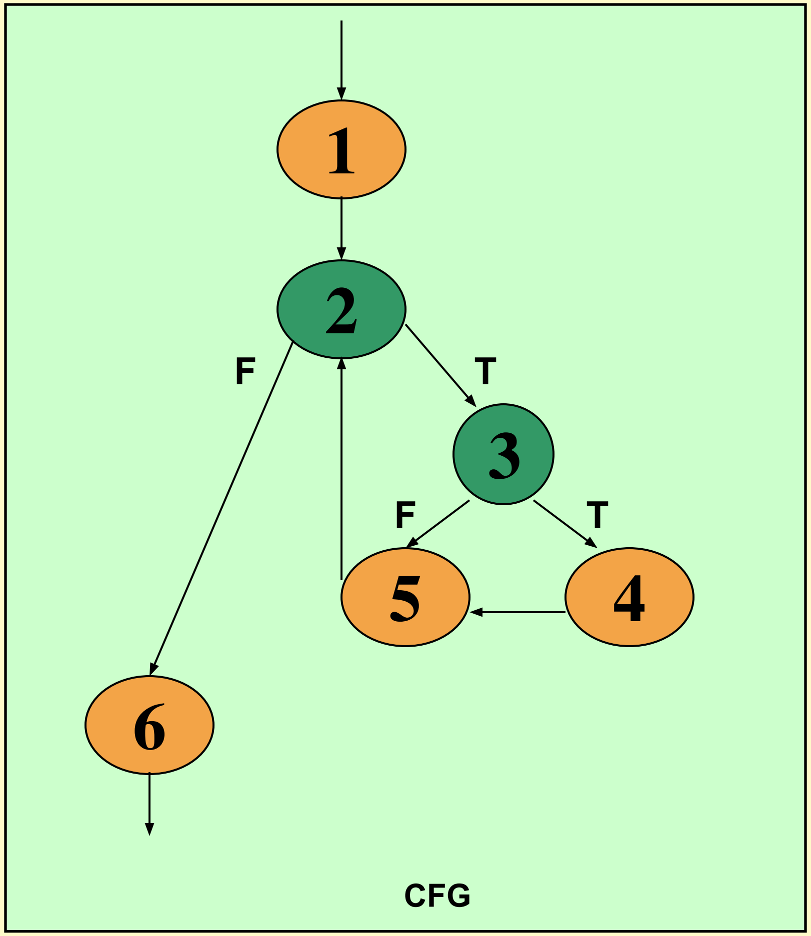
- Cyclomatic complexity =
  - The number of 'regions' in the graph(R) + 1
  - **M = R + 1**
  -

Path Base Testing: Step 2



- Cyclomatic complexity, M =
  - The number of 'regions' in the graph(R) + 1
  - = 2 +1 = 3

Path Base Testing: Step 2



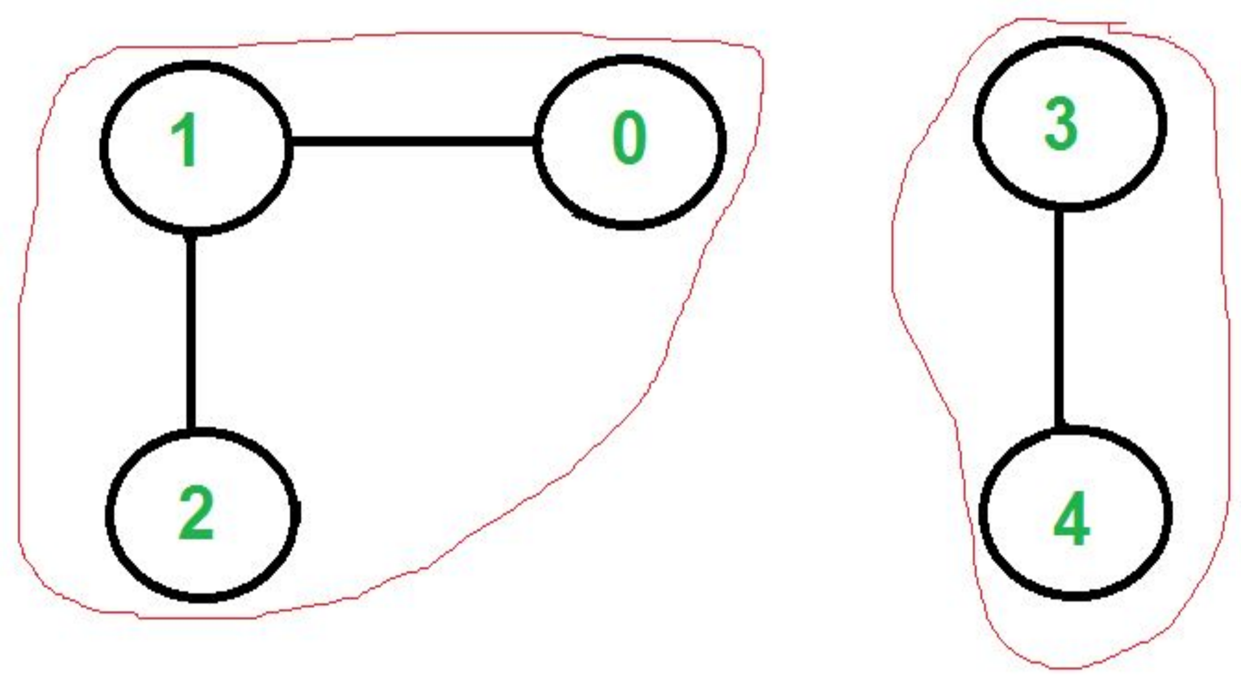
- M = Number of 'predicate' node (P) + 1
- In this example:
  - Predicates, P = 2
    - (Node 2 and 3)
  - Cyclomatic Complexity, M

    = 2 + 1

    = 3

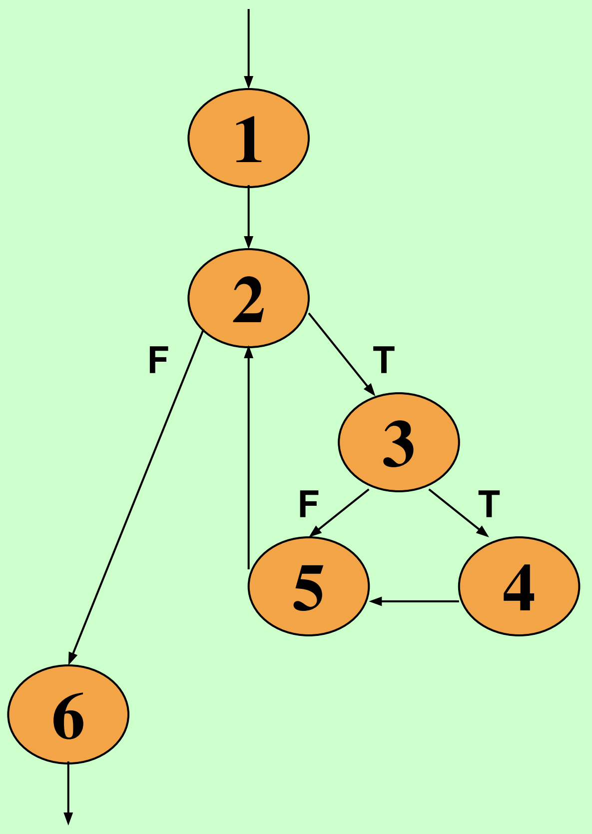
Path Base Testing: Step 2

Connected Components in a Graph



There are two connected components in above undirected graph
0 1 2
3 4

Path Base Testing: Step 2



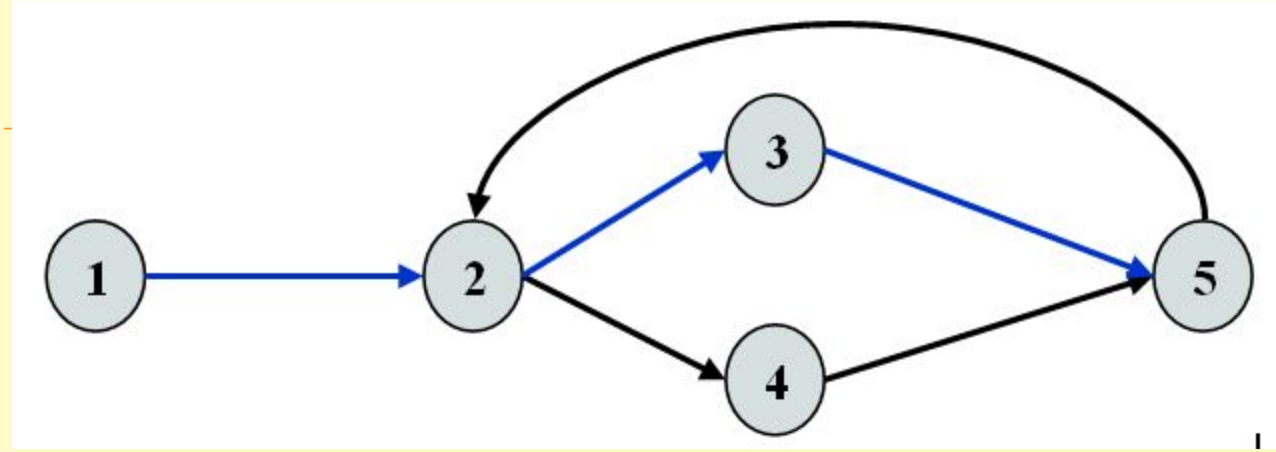
CFG

- Cyclomatic complexity, M = **E − N + 2P**
- E, edges = 7
- N, nodes = 6
- P, connected components = 1
- = 7 – 6 + (2x1)
- = 3

Path Base Testing: Step 3

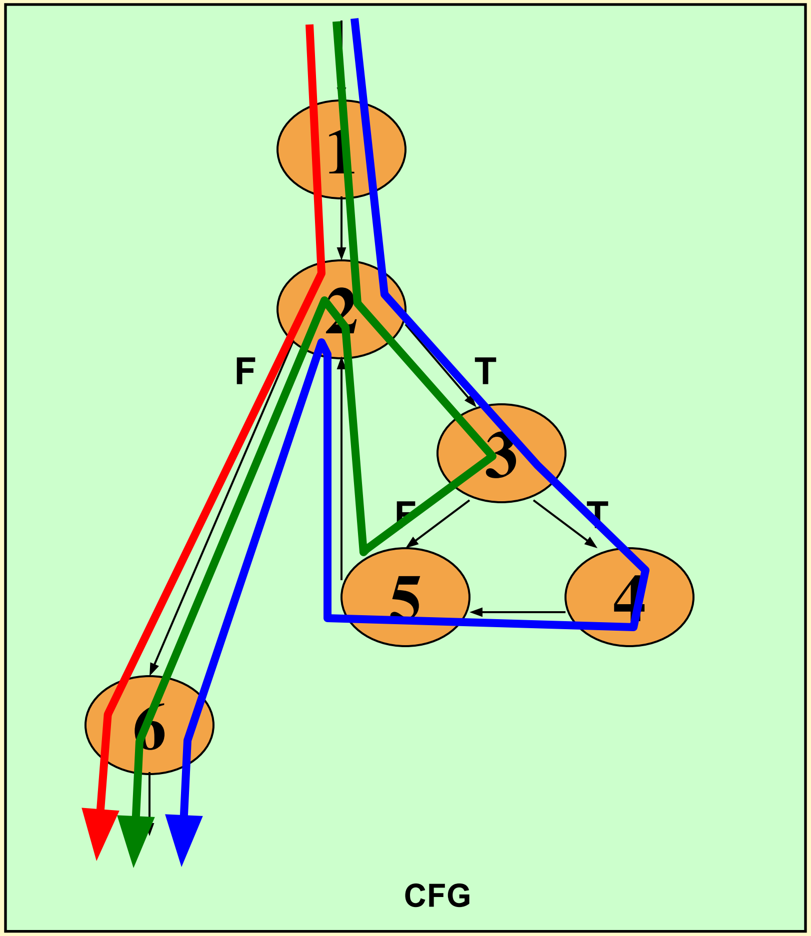
- Independent path:
  - An **executable** or **realizable path** through the graph from the start node to the end node that has not been traversed before.
  - **Must** move along **at least one arc** that has not been yet traversed (an unvisited arc).
  - The objective is to cover all statements in a program by independent paths.
- The number of independent paths to discover <= Cyclomatic complexity number, M
- The set of Independent paths is called **Basic Path Set**

Example



- M = Regions + 1 = 2 + 1 = 3
- 1-2-3-5 can be the first independent path; 1-2-4-5 is another; 1-2-3-5-2-4-5 is one more.
- Alternatively, if we had identified 1-2-3-5-2-4-5 as the first independent path, there would be no more independent paths.
- The number of independent paths therefore can vary according to the order we identify them.

Path Base Testing: Step 3



- Cyclomatic complexity = 3.
- Need at most **3** independent paths to cover the CFG.
- In this example:
  - [1 – 2 – 6]
  - [1 – 2 – 3 – 5 – 2 – 6]
  - [1 – 2 – 3 – 4 – 5 – 2 – 6]

Path Base Testing: Step 4

- Prepare a test case for each independent path.
- In this example:
  - Path: [1 – 2 – 6]
    - Test Case: A = { 5, …}, N = 1
    - Expected Output: 5

```
min = A[0];                 1
I = 1;

while (I < N) {             2
 if (A[I] < min)            3
         min = A[I];        4
     I = I + 1;             5
}
print min                   6
```

Try to verify that the test cases actually force execution along a desired path.

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