# SENG3320/6320:
# Software Verification and Validation

School of Electrical Engineering and Computing

Semester 1, 2020

# Basis Path Coverage

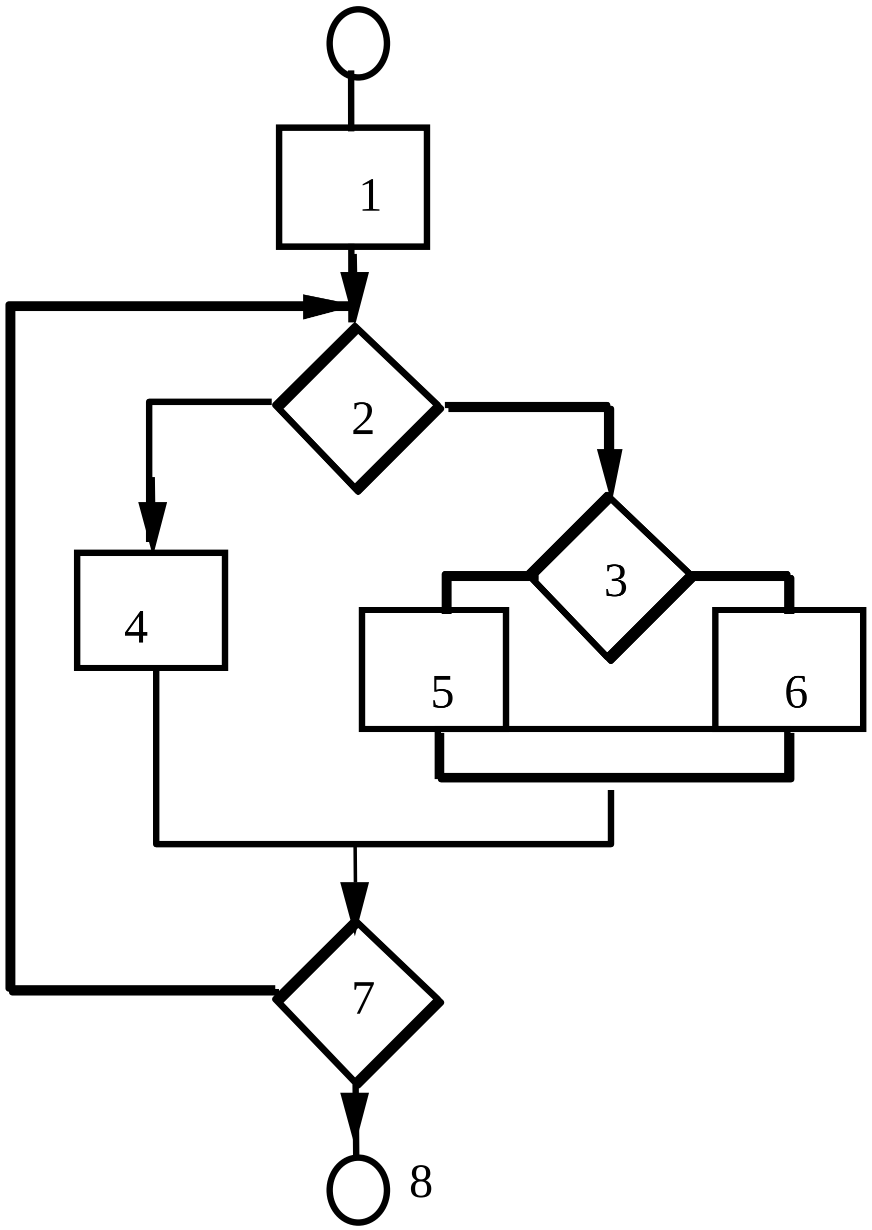
# Basis Path Testing

- A testing mechanism proposed by McCabe.
- A testing criterion between branch coverage and all path coverage.
- Basis Path testing is a software testing that fulfills the requirements of branch testing & also tests all of the **independent paths** that could be used to construct **any arbitrary path** through the computer program. [NIST]

Arthur H. Watson and Thomas J. McCabe (1996). "Structured Testing: A Testing Methodology Using the Cyclomatic Complexity Metric". NIST Special Publication 500-235.

Thomas J. McCabe: A Complexity Measure. IEEE Trans. Software Eng. 2(4): 308-320 (1976)

# Independent Path




A path through the system is independent from other paths only if it includes some vertices or edges that are not covered in the other path.

Path 1: 1,2,3,6,7,8
Path 2: 1,2,3,5,7,8
Path 3: 1,2,4,7,8
Path 4: 1,2,4,7,2,4,...7,8

# Cyclomatic Complexity

- A program's complexity can be measured by the cyclomatic number of the program flowgraph
- For a program with the program flowgraph *G*, the cyclomatic complexity *v(G)* is measured as:

$$\boldsymbol{v(G) = e - n + 2p}$$

  - *e* : number of edges
    - Representing branches and cycles
  - *n* : number of nodes
    - Representing block of sequential code
  - *p* : number of connected components
    - For a single component, *p=1*

# Simplified Complexity Calculation

- For a program with the program flowgraph $G$, the cyclomatic complexity $v(G)$ is measured as:

  $$v(G) = 1 + d$$

  - $d$ : number of predicate nodes (i.e., nodes with out-degree other than 1)
    - $d$ represents number of loops in the graph

      or number of decision points in the program

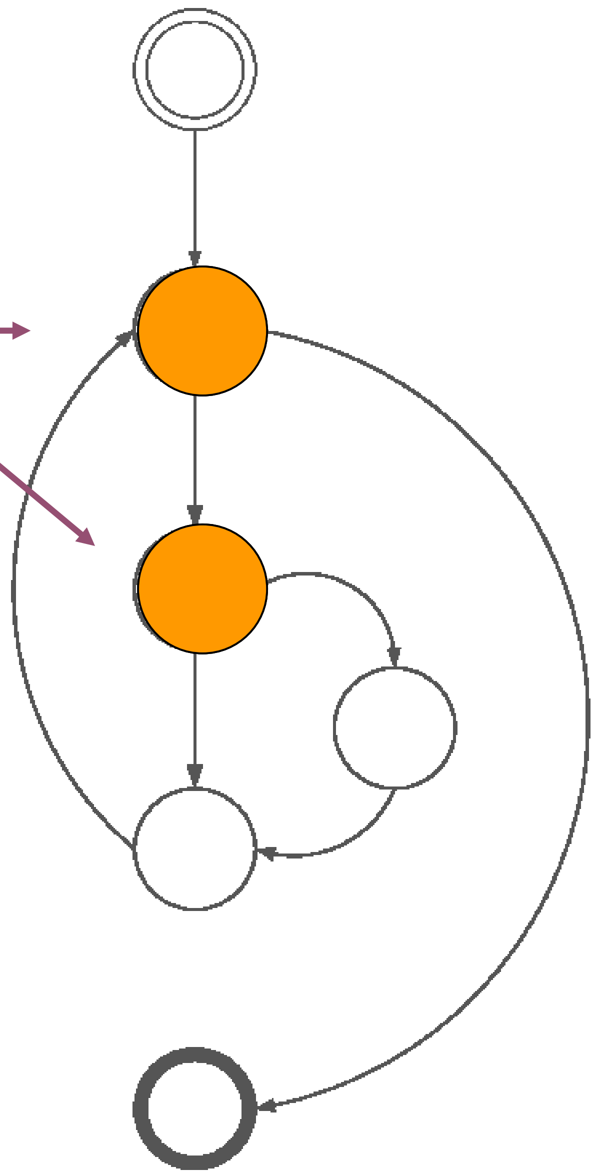
# Example 1

$$v(G) = e - n + 2p$$
$$= 7 - 6 + 2 \times 1$$
$$= 3$$

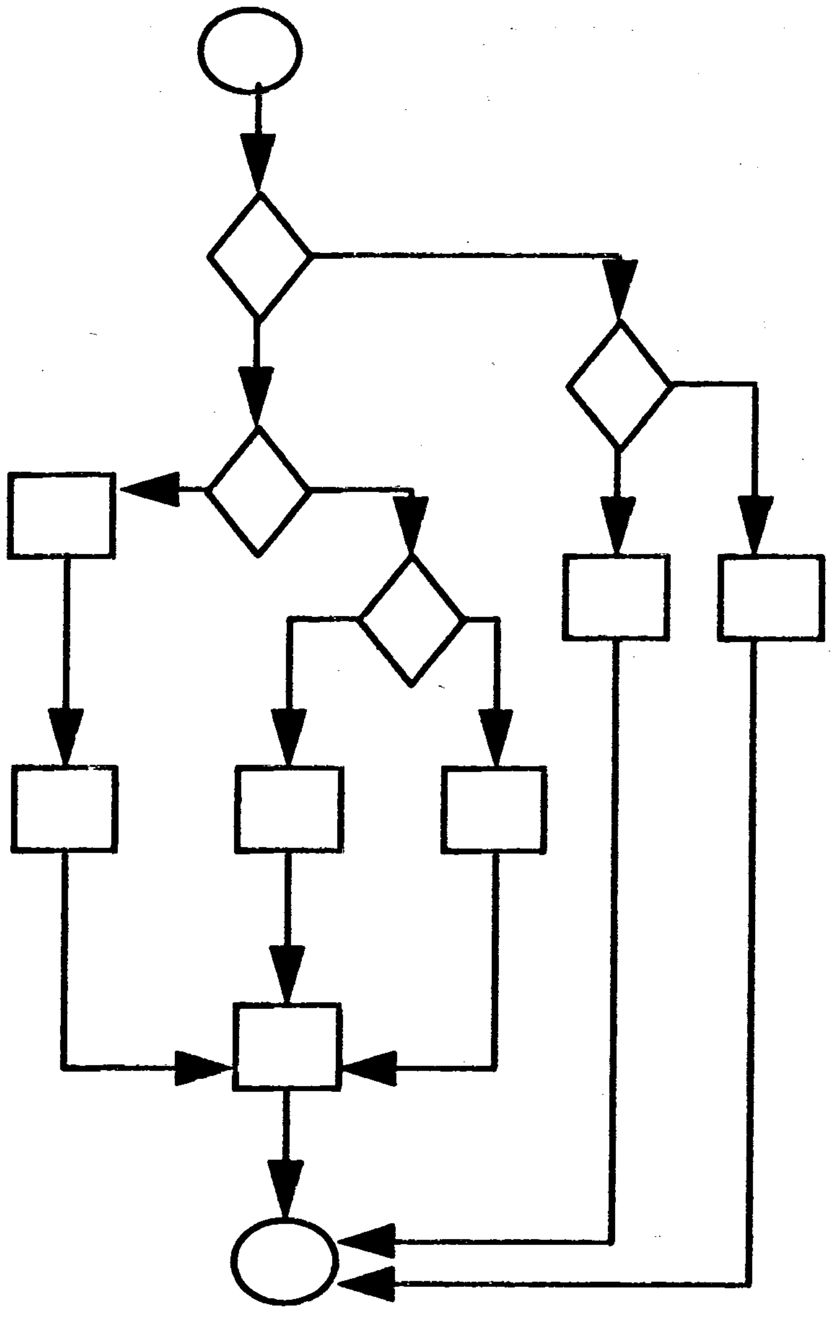
**Or**

$$v(G) = 1 + d$$
$$= 1 + 2 = 3$$

Predicate nodes (decision points)



# Example 2



***v(G) = 16 – 13 + 2 = 5***

***or***

***v(G) = 4 +1 = 5***

# Cyclomatic Complexity: Usage

- **A useful indicator of software quality**
  - McCabe (1976) suggested that a module may be problematic if *v(G)* exceeds 10.
  - Grady (1994) concluded that 15 should be maximum value of *v(G)*
  - Bennett (1994) suggested that a modules be rejected if its *v(G)* exceeds 20.
- **Useful in white-box testing**
  - It provides an upper bound on the number of test cases that will be required to guarantee coverage of all program statements.

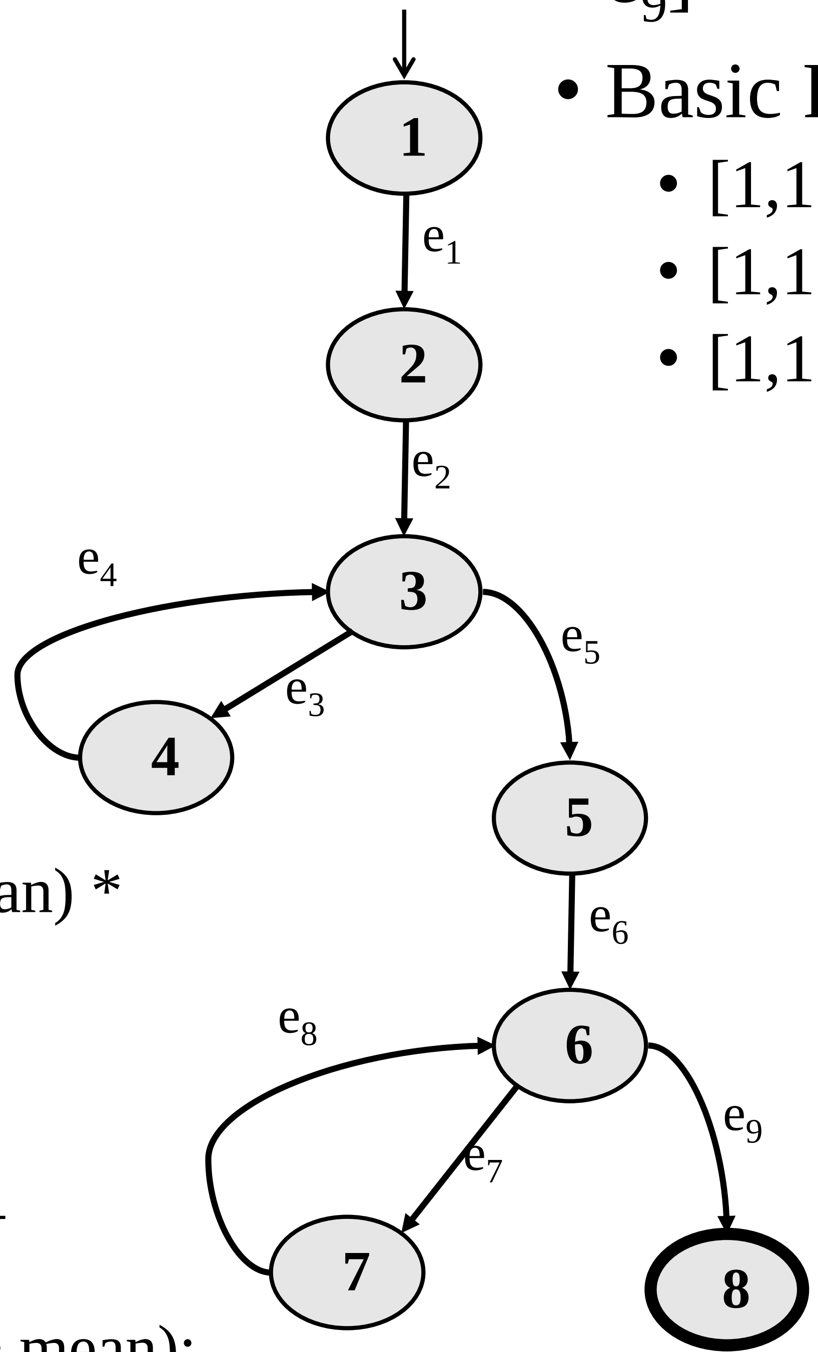
# **McCabe’s** Basis Path Testing

1. Generate control flow graph
2. Compute cyclomatic complexity
3. Determine a basis set of linearly independent paths
4. Generate tests for the basis paths

*All Path Testing>=Basis Path Testing>=Branch Testing*

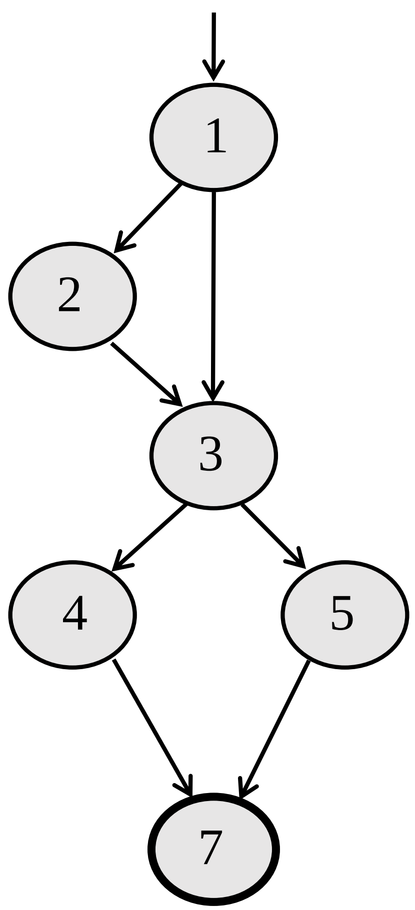
# Basis Path Testing

```
public static void CSta (int [ ] numbers)
{
    int length = numbers.length;
    double var, mean, sum, varsum;

    sum = 0.0;
    for (int i = 0; i < length; i++)
    {
        sum += numbers [ i ];
    }
    mean = sum / (double) length;

    varsum = 0.0;
    for (int i = 0; i < length; i++)
    {
        varsum = varsum  + ((numbers [i] - mean) * 
(numbers [i] - mean));
    }
    var = varsum / ( length - 1.0 );

    System.out.println ("length:                    " + 
length);
    System.out.println ("mean:                      " + mean);
    System.out.println ("variance:                  " + var);
}
```

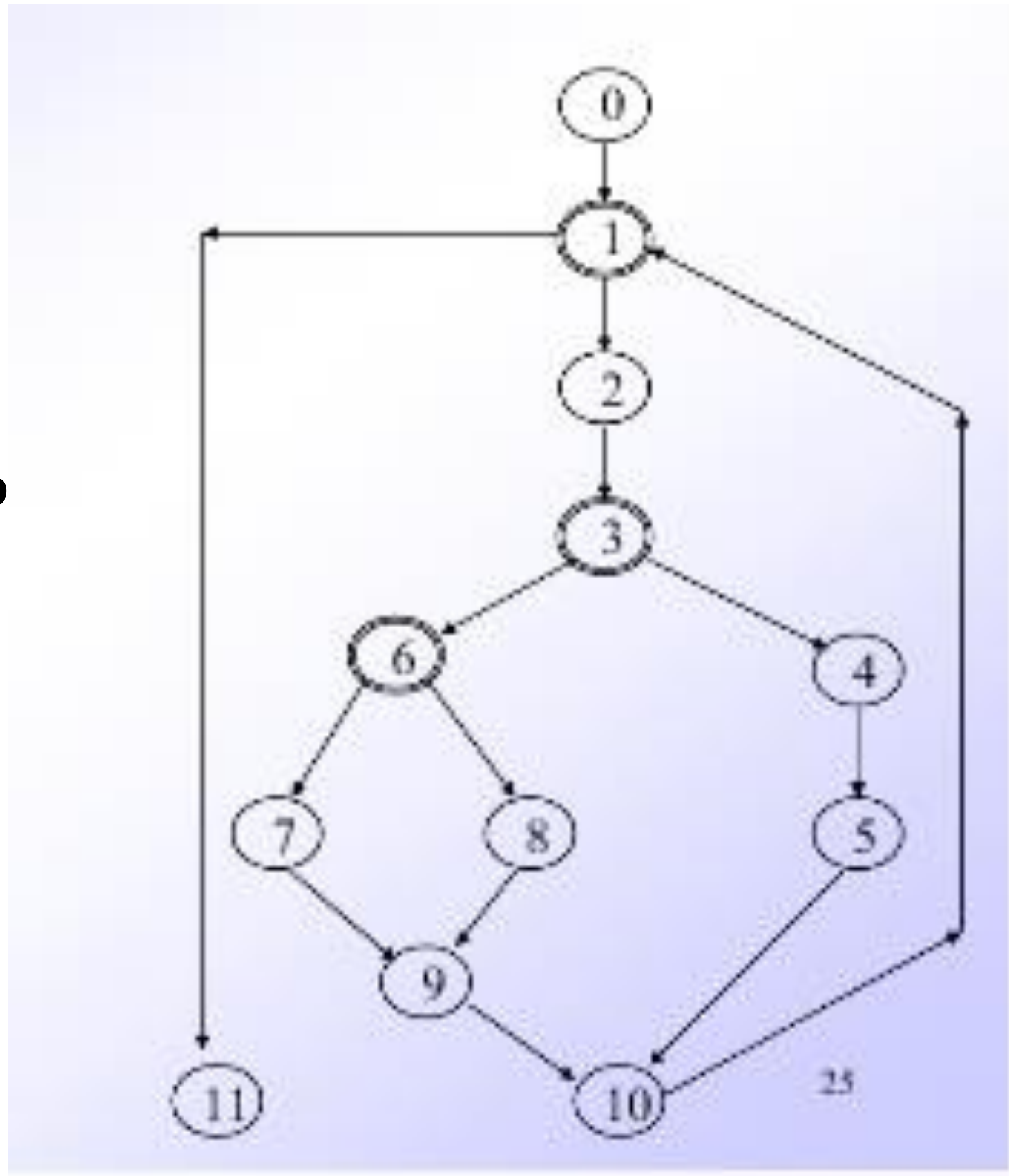



- V(g) = 9-8+2=3
- [$e_1$, $e_2$, $e_3$, $e_4$, $e_5$, $e_6$, $e_7$, $e_8$, $e_9$]
- Basic Path Set
  - [1,1,0,0,1,1,0,0,1]
  - [1,1,1,1,1,1,0,0,1]
  - [1,1,0,0,1,1,1,1,1]

# Quiz




Basis Path Set ?



# Quiz

```
#include <stdio.h>
main()
{
int a ;
scanf (“%d”, &a);
if ( a >= 10 )
 if ( a < 20 )
    printf ("10 < a< 20 %d\n" , a);
 else
    printf ("a >= 20    %d\n" , a);
else
  printf ("a <= 10    %d\n" , a);
}
```

Basis Path Set ?

# Decision and Condition Coverage

# Logic in Program

((x>5) && (y>0))

Decision

Condition

# Decision Coverage

- Decision Coverage (DC):
  Executing *true* and *false* of decision.
- Also called Branch Decision Coverage

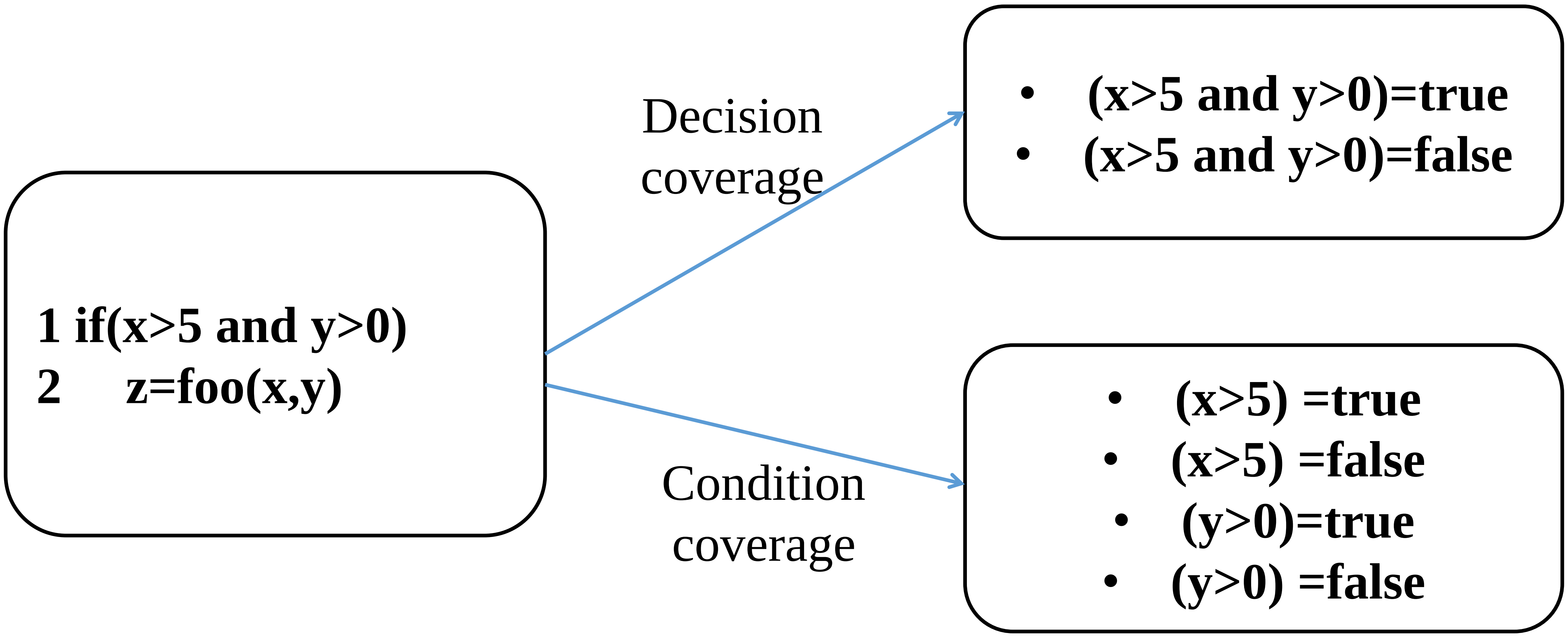
Example: ((x>5) && (y>0)): *true* and *false*

```
// {(6, 1), (1,1)} --- 100% Decision Coverage
int foo(int x, int y) {
        int z = y;
        if ((x>5) && (y>0)) {
                z = x;
        }
        return x*z;
}
```

# Condition Coverage

- Condition Coverage (CC):
  Executing *true* and *false* of each condition
- (x>5)： *true* and *false*
- (y>0)： *true* and *false*

```
// {(6, 0), (0,1)} --- 100% Condition Coverage
int foo(int x, int y) {
        int z = y;
        if ((x>5) && (y>0)) {
                z = x;
        }
        return x*z;
}
```


1 if(x>5 and y>0)
2 z=foo(x,y)
Decision coverage
• (x>5 and y>0)=true
• (x>5 and y>0)=false
Condition coverage
• (x>5) =true
• (x>5) =false
• (y>0)=true
• (y>0) =false

# An Example

```
begin
    int x,y,z;
    input(x,y);
    if(x<0 and y<0)
      z=foo1(x,y)
    else
      z=foo2(x,y);
    output(z);
end
```

**$T=\{t_1:<x=-3,y=-2>,\ \ t_2:<x=-4,y=2>\}$**

- **Decision coverage?**
- **Condition coverage?**

- **100% Condition coverage does not mean 100% Decision coverage**

```
begin
    int x,y,z;
    input(x,y);
    if(x<0 and y<0)
      z=foo1(x,y)
    else
      z=foo2(x,y);
    output(z);
end
```

**$T=\{t_1:<x=-3,y=2>,\ \ t_2:<x=4,y=-2>\}$**

- **Decision coverage?**
- **Condition coverage = 100%**

- **100% Decision coverage does not mean 100% Condition coverage**

```
begin
   int x,y,z;
   input(x,y);
   if(x<0 and y<0)
     z=foo1(x,y)
   else
      z=foo2(x,y);
   output(z);
end
```

$T=\{t_1:<x=-3,y=-2>,t_2:<x=-4,y=2>\}$

- **Decision coverage = 100%**
- **Condition coverage?**

# Condition/Decision Coverage

- Condition/Decision Coverage (C/DC): Combing DC and CC.
- Overcomes the limitation of Decision Coverage (DC) and Condition Coverage (CC)
  - C/DC $\geq$ CC
  - C/DC $\geq$ DC

```
begin
    int x,y,z;
    input(x,y);
    if(x<0 and y<0)
      z=foo1(x,y)
    else
       z=foo2(x,y);
    output(z);
end
```

$T=\{t_1:<x=-3,y=-2>,t_2:<x=4,y=2>\}$

- **Decision coverage = 100%**
- **Condition coverage = 100%**

# Multiple Condition Coverage

- Multiple condition coverage (MCC) reports whether every possible combination of Boolean sub-expressions occurs.
- The test cases required for full multiple condition coverage of a condition are essentially given by the logical operator truth table for the condition.

# D=(A<B) or (A>C)

| | A<B | A>C | D |
|---|---|---|---|
| 1 | true | true | true |
| 2 | true | false | true |
| 3 | false | true | true |
| 4 | false | false | false |

**T={t1:<A=2,B=3,C=1>, t2:<A=2,B=1,C=3>}**

- **Covers all decisions and conditions**
- **Covers only two combinations of Boolean sub-expressions.**

# An Example

- Requirements for a program:

*Given three integers A, B, and C, produce S according to the following table:*

| | A<B | A>C | S |
|---|---|---|---|
| **1** | **true** | **true** | **f1(A,B,C)** |
| **2** | **true** | **false** | **f2(A,B,C)** |
| **3** | **false** | **true** | **f3(A,B,C)** |
| **4** | **false** | **false** | **f4(A,B,C)** |

```
1 begin
2     int A,B,C,S=0;
3     input(A,B,C);
4     if(A<B and A>C)
      S=f1(A,B,C);
5     if(A<B and A≤C)
      S=f2(A,B,C);
6     if(A≥B and A≤C)
      S=f4(A,B,C);
7     output(S);
9 end
```

| | A<B | A>C | S |
|---|---|---|---|
| 1 | true | true | f1(A,B,C) |
| 2 | true | false | f2(A,B,C) |
| 3 | false | true | f3(A,B,C) |
| 4 | false | false | f4(A,B,C) |

A buggy implementation！

```
1 begin
2     int A,B,C,S=0;
3     input(A,B,C);
4     if(A<B and A>C)
      S=f1(A,B,C);
5     if(A<B and A≤C)
      S=f2(A,B,C);
6     if(A≥B and A≤C)
      S=f4(A,B,C);
7     output(S);
9 end
```

| | A<B | A>C | S |
|---|---|---|---|
| 1 | true | true | f1(A,B,C) |
| 2 | true | false | f2(A,B,C) |
| 3 | false | true | f3(A,B,C) |
| 4 | false | false | f4(A,B,C) |

$T=\{t_1:<A=2,B=3,C=1>, t_2:<A=2,B=1,C=3>\}$

- 100% condition coverage
- Bug not found

```
begin
    int A,B,C,S=0;
    input(A,B,C);
    if(A<B and A>C) S=f1(A,B,C);
    if(A<B and A≤C) S=f2(A,B,C);
    if(A≥B and A≤C) S=f4(A,B,C);
    output(S);
end
```

| | A<B | A>C | S |
|---|---|---|---|
| 1 | true | true | f1(A,B,C) |
| 2 | true | false | f2(A,B,C) |
| 3 | false | true | f3(A,B,C) |
| 4 | false | false | f4(A,B,C) |

**T={$t_1$:<A=2,B=3,C=1>,**
**$t_2$:<A=2,B=1,C=3>,**
**$t_3$:<A=2,B=3,C=5>}**

- **100% condition coverage**
- **100% decision coverage**
- **Bug not found**

```
begin
    int A,B,C,S=0;
    input(A,B,C);
    if(A<B and A>C) S=f1(A,B,C);
    if(A<B and A≤C) S=f2(A,B,C);
    if(A≥B and A≤C) S=f4(A,B,C);
    output(S);
end
```

**T={$t_1$:<A=2,B=3,C=1>,**
**$t_2$:<A=2,B=1,C=3>,**
**$t_3$:<A=2,B=3,C=5>,**
**$t_4$:<A=2,B=1,C=1>}**

- 100% Multiple Condition Coverage
- **Bug found**

| | A<B | A>C | T | A<B | A≤C | T | A≥B | A≤C | T |
|---|---|---|---|---|---|---|---|---|---|
| 1 | true | true | t1 | true | true | t3 | true | true | t2 |
| 2 | true | false | t3 | true | false | t1 | true | false | t4 |
| 3 | false | true | t4 | false | true | t2 | false | true | t3 |
| 4 | false | false | t2 | false | false | t4 | false | false | t1 |

# Quiz – C/DC

How to achieve 100% condition/decision coverage?

```
// ??
int foo(int x, int y) {
        int z = y;
        if ((x>5) && (y>0)) {
                z = x; }
        return x*z;
}
```

# Quiz- MCC

How to achieve 100% multiple condition coverage?

```
// ??
int foo(int x, int y) {
         int z = y;
        if ((x>5) && (y>0)) {
                 z = x; }
        return x*z;
}
```

# Limitation of MCC

- Assuming n conditions, $2^n$ test cases are required.
- Assuming each test case needs 1ms to execute:

| Conditions<br>n | Test cases<br>$2^n$ | Test case execution time |
|---|---|---|
| 1 | 2 | 2ms |
| 4 | 16 | 16ms |
| 8 | 256 | 256ms |
| 16 | 65536 | 65.5s |
| 32 | 4294967296 | 49.5 days |

# Modified condition/decision (MC/DC)

- Motivation: Effectively test important combinations of conditions, without exponential blowup in test suite size
  - "Important" combinations means: Each basic condition independently affects the outcome of each decision
  - MC/DC $\geq$ C/DC
- Requires:
  - For each basic condition C, two test cases,
  - values of all evaluated conditions except C are the same
  - compound condition as a whole evaluates to true for one and false for the other

# Modified condition/decision (MC/DC)

- **MC/DC coverage:**
  - Each entry and exit point is invoked
  - Each decision takes every possible outcome
  - Each condition in a decision takes every possible outcome
  - Each condition in a decision is shown to independently affect the outcome of the decision.
  - Independence of a condition is shown by proving that only one condition changes at a time.
- MC/DC is used in avionics software development guidance DO-178B and DO-178C to ensure adequate testing of the most critical (Level A) software.

https://en.wikipedia.org/wiki/Modified_condition/decision_coverage

# MC/DC

- ((x>5) && (y>0)) Decision

| | | |
|---|---|---|
| T | T | T |
| T | F | F |
| F | T | F |
| F | F | F |

```
// ??
int foo(int x, int y) {
        int z = y;
        if ((x>5) && (y>0)) {
                z = x; }
        return x*z;
}
```

# Comparison on the number of test cases

| | |
|---|---|
| • DC | 2 |
| • CC | 2**n* |
| • C/DC | 2*n+1 |
| • MC/DC | 2*n+1 |
| • MCC | $2^n$ |

- To test `if (A xor B)`

| | | | |
|---|---|---|---|
| A: | T | T | F |
| B: | T | F | T |

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 | | | | | | • |

# References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- Jones, J. and Harrold, M. "**Test-Suite Reduction and Prioritization for Modified Condition/Decision Coverage**", *Proceedings of the IEEE International Conference on Software Maintenance ( ICSM'01), Florence, Italy, 7-9 November 2001, pp. 92--101.*
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- Lecture Materials from Dan Hao, Zhenyu Chen, Mauro Pezzè & Michal Young.
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Thanks!


Testing
Software
development
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People
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team
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life