CS3300 Introduction to Software Engineering

Lecture 17: White-Box Testing

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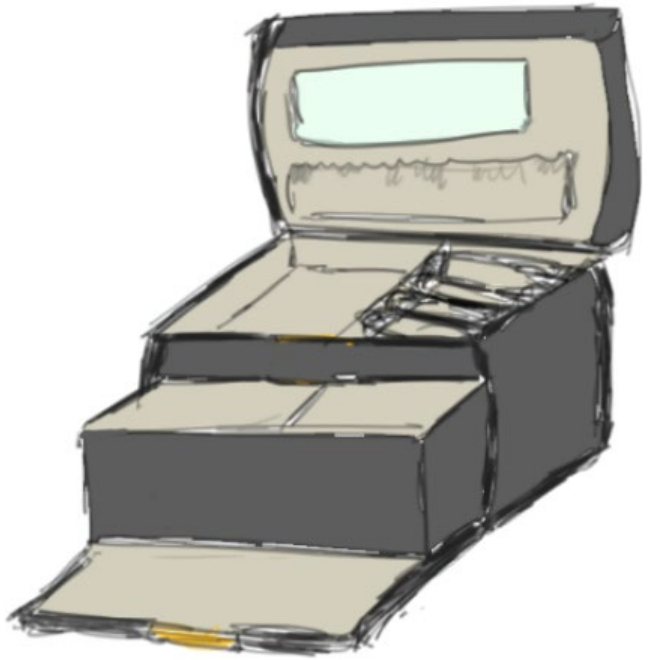
Slides adapted from Alessandro Orso

White- Box Testing



Basic Assumption

Executing the faulty statement is a necessary condition for revealing a fault

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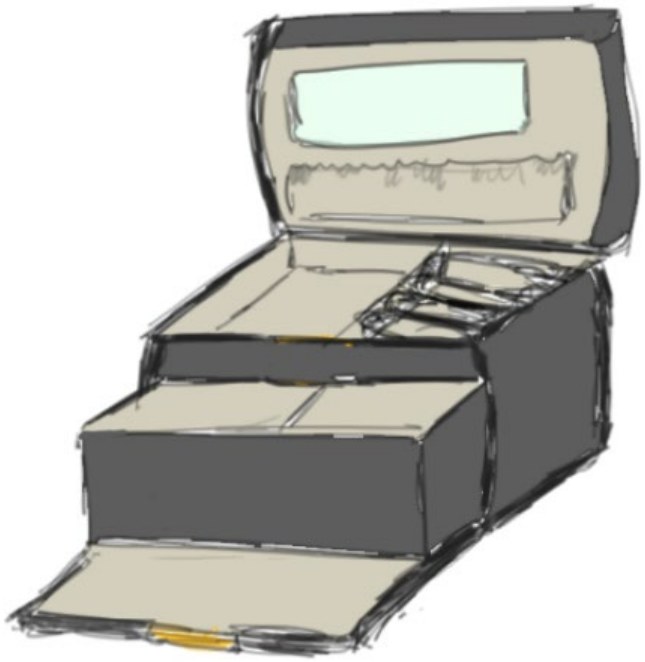
White- Box Testing



Different Kinds

- Control-Flow Based
- Data-flow based
- Fault based

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Coverage Criteria

Defined in terms of

Test requirements - Elements/entities in the code that we need to execute

We can Compute

Coverage Measure

Result in

Test specifications

Test cases

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Coverage Criteria: Statement Coverage

Test Requirements	Statements in the program
Coverage Measure	$\frac{\text{Number of executed Statements}}{\text{Total number of Statements}}$

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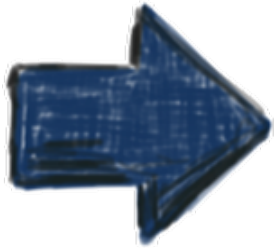
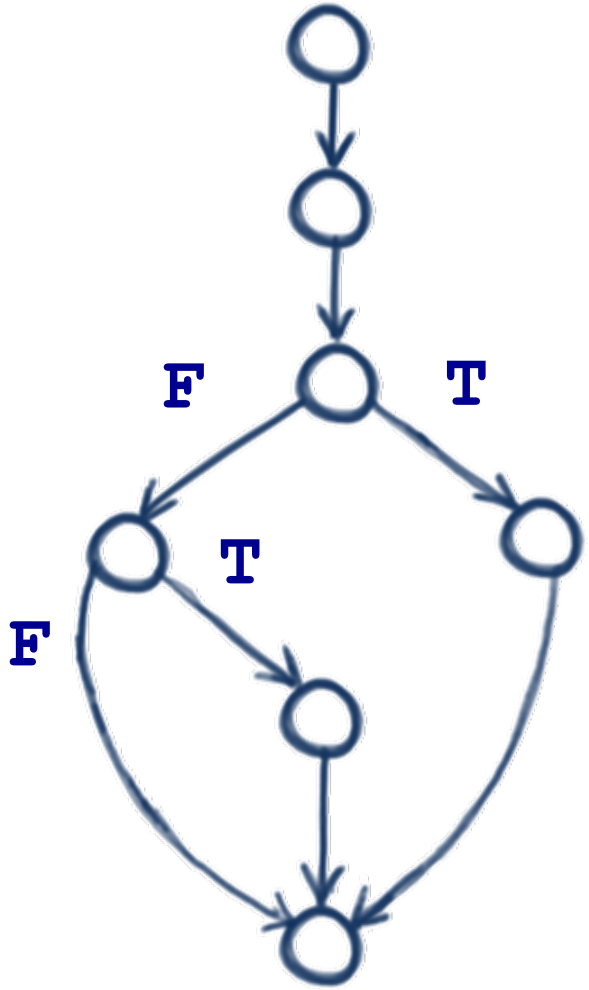
Control Flow Graphs

Representation for the code that is very convenient when we run our reason about the code and its structure.

Represents statement with nodes and the flow of control within the code with edges.

```
1. printSum (int a, int b){
2.    int result = a+b;
3.    if (result>0)
4.       printcol("red", result);
5.    else if (result<0)
6.       printcol("blue", result);
      [else doNothing]
7. }
```





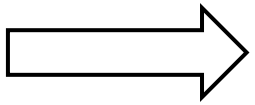
Coverage Criteria: Branch Coverage

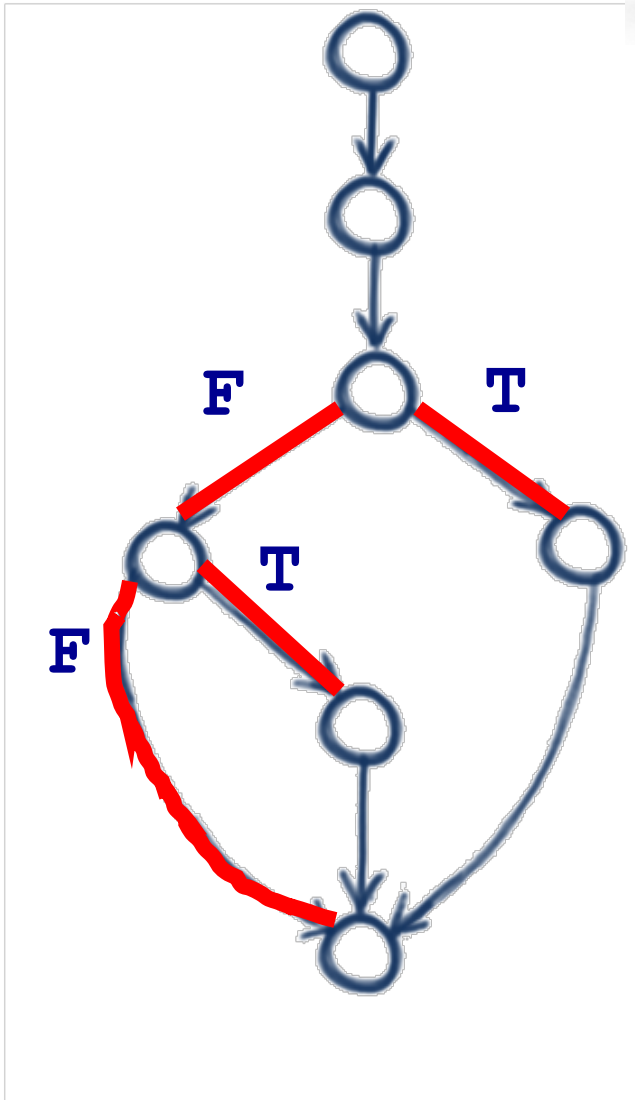
Test Requirements	Branches in the program: outgoing edges from a decision point
Coverage Measure	$\frac{\text{Number of executed Branches}}{\text{Total number of Branches}}$

Slide adapted from Alessandro Orso

printSum: Branch coverage

```
1.  printSum (int a, int b) {
2.      int result = a+b;
3.      if (result > 0)
4.          printcol("red", result);
5.      else if (result < 0)
6.          printcol("blue", result);
7.      [else DO NOTHING]
8.  }
```



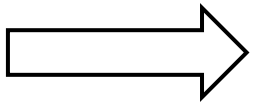


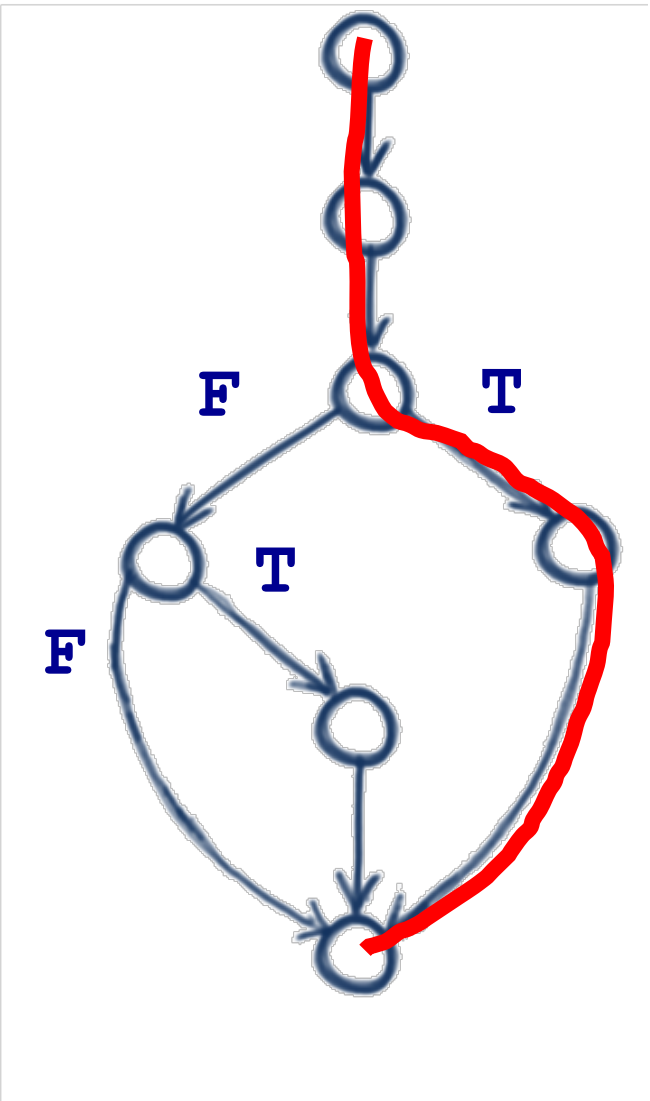
How many branches? [4]

printSum: Branch coverage

TC #1
a == 5
b == -4

```
1.  printSum (int a, int b) {
2.      int result = a+b;
3.      if (result > 0)
4.          printcol("red", result);
5.      else if (result < 0)
6.          printcol("blue", result);
7.      [else DO NOTHING]
8.  }
```





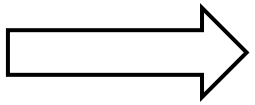
Coverage [25 %]

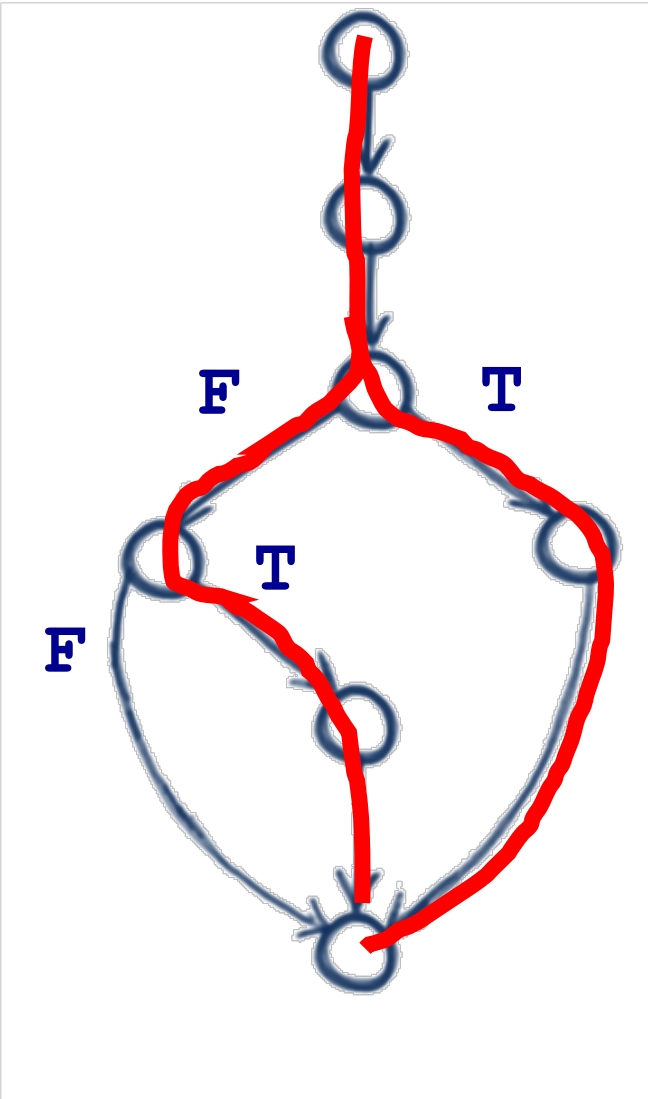
printSum: Branch coverage

TC #1	TC #2
a == 5	a == 0
b == -4	b == -1

```
1.  printSum (int a, int b) {
2.      int result = a+b;
3.      if (result > 0)
4.          printcol("red", result);
5.      else if (result < 0)
6.          printcol("blue", result);
7.      [else DO NOTHING]
8.  }
```

Coverage [75 %]

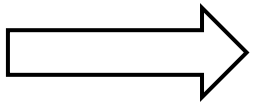


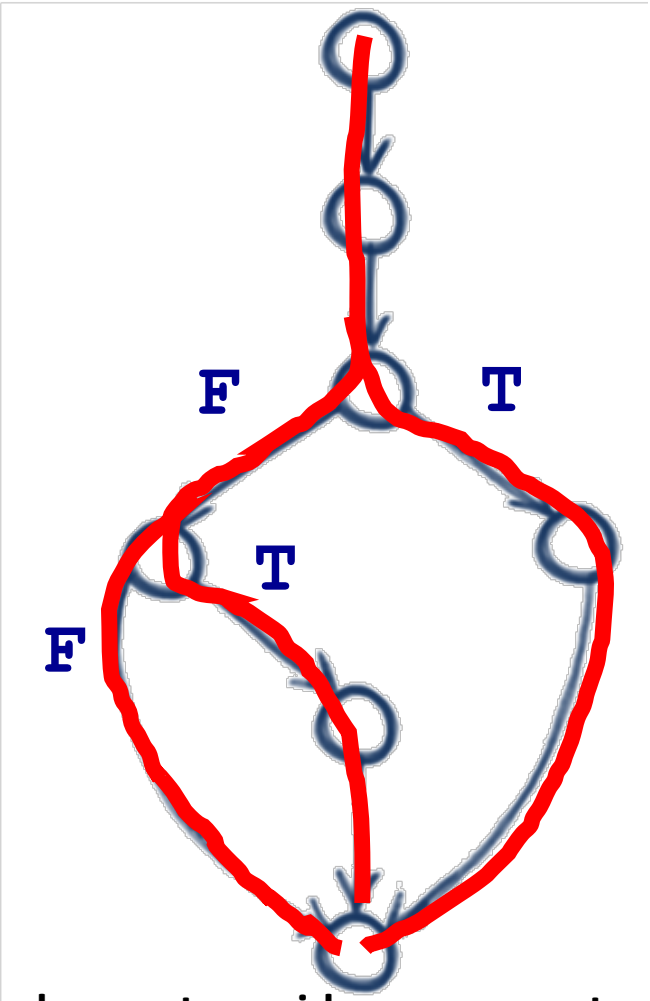


printSum: Branch coverage

TC #1	TC #2	TC #3
a == 5	a == 0	a == 0
b == -4	b == -1	b == 0

```
1.  printSum (int a, int b) {
2.      int result = a+b;
3.      if (result > 0)
4.          printcol("red", result);
5.      else if (result < 0)
6.          printcol("blue", result);
7.      [else DO NOTHING]
8.  }
```



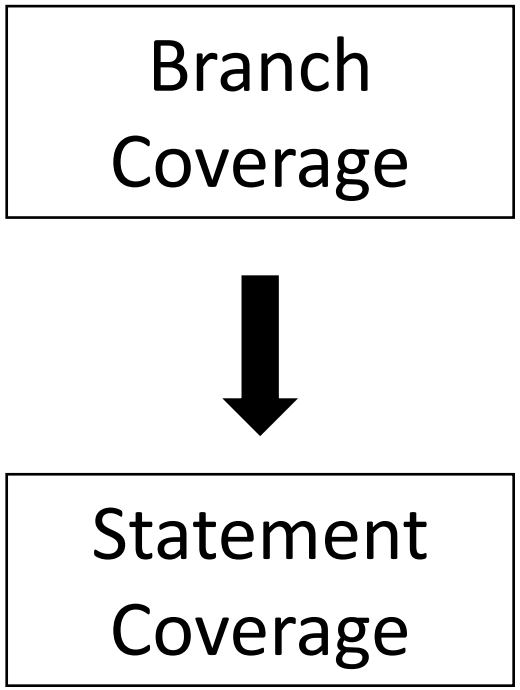


Coverage [100 %]

Note: 100% coverage does not provide any guarantee of finding the problems in the code.

Test Criteria Subsumption

One test criteria subsumes another criteria when all the test suites that satisfy that criteria will also satisfy the other one



Branch Coverage is a stronger criteria than Statement Coverage. There is no way of covering all branches but leaving out some statements.

Slide adapted from Alessandro Orso

Lets consider another example

```
1. void main () {
2.    float x, y;
3.    read (x);
4.    read (y);
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```

Lets consider another example

```
1. void main () {
2.    float x, y;
3.    read (x);
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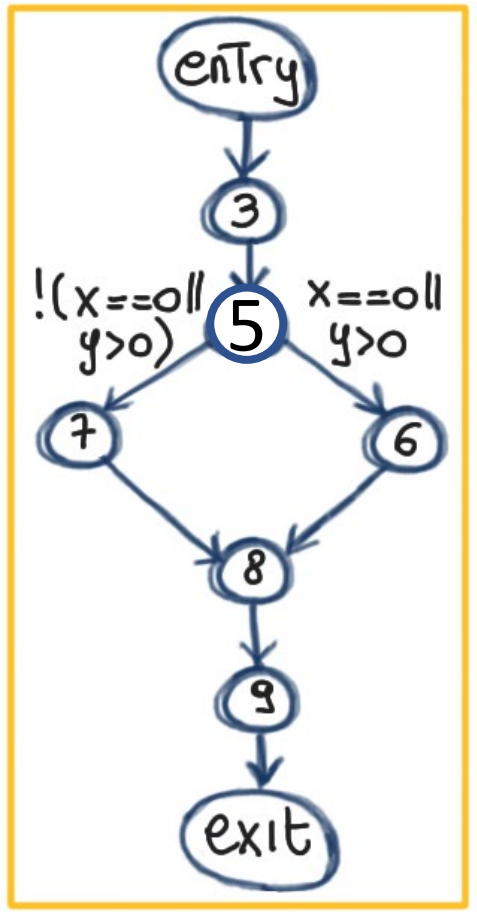
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```



Lets consider another example

```
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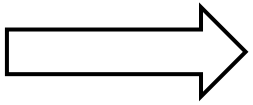
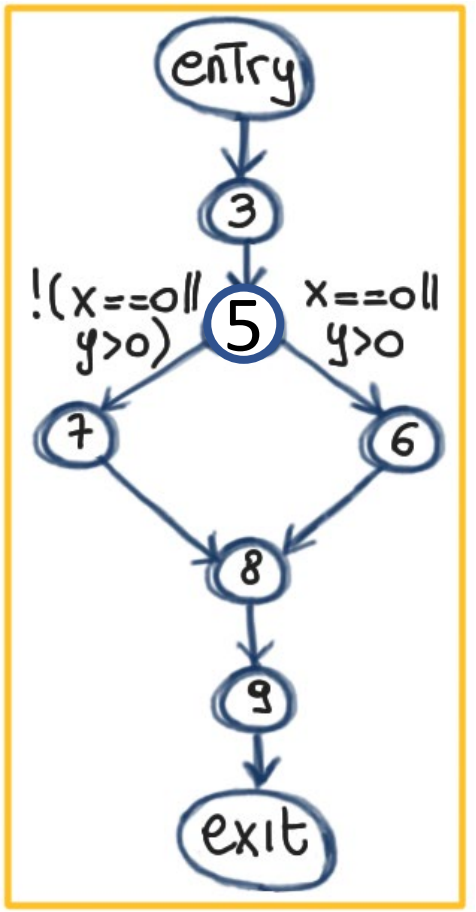
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```





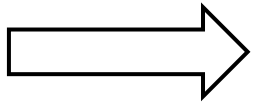
x = 5; y = 5;
x = 5; y = -5;

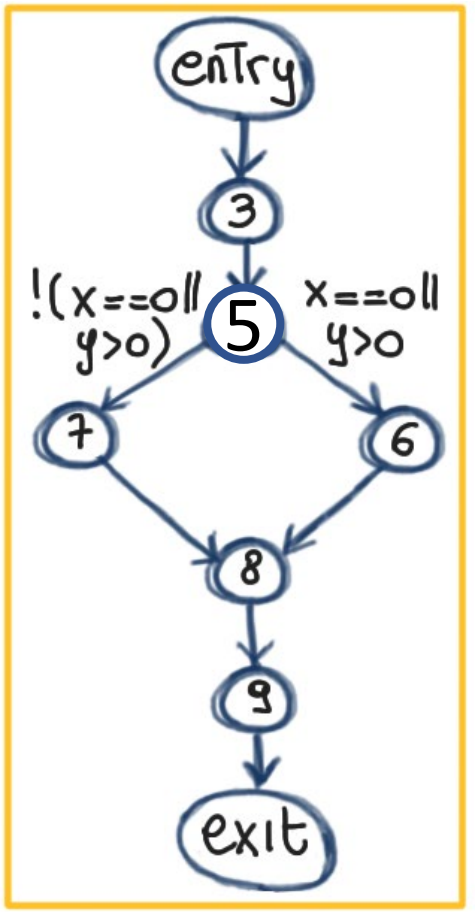
Branch Coverage: ?

100%

Lets consider another example

```
1. void main () {
2.    float x, y;
3.    read (x);
4.    read (y);
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```





x = 5; y = 5;
x = 5; y = -5;

Branch Coverage:

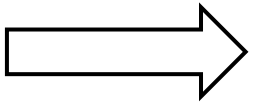
100%

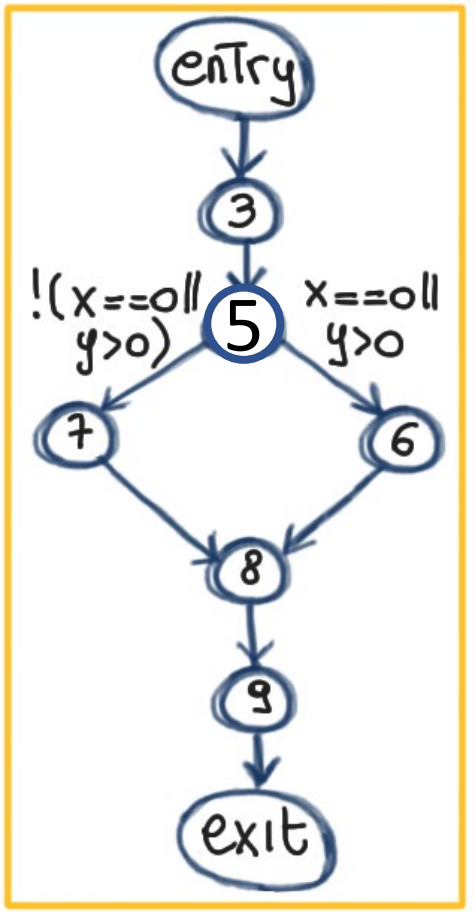
Identify a test case when code can fail:

x = 0, y can be anything

Lets consider another example

```
1. void main () {
2.    float x, y;
3.    read (x);
4.    read (y);
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```





x = 5; y = 5;
x = 5; y = -5;

Branch Coverage:

100%

Identify a test case when code can fail:

x = 0

How can we be more thorough?

Each condition T and F

Coverage Criteria: Condition Coverage

Test Requirements	Individual Conditions in the program
Coverage Measure	$\frac{\text{Number of conditions that are both T and F}}{\text{Total number of Conditions}}$

Has each condition evaluated to true and false?

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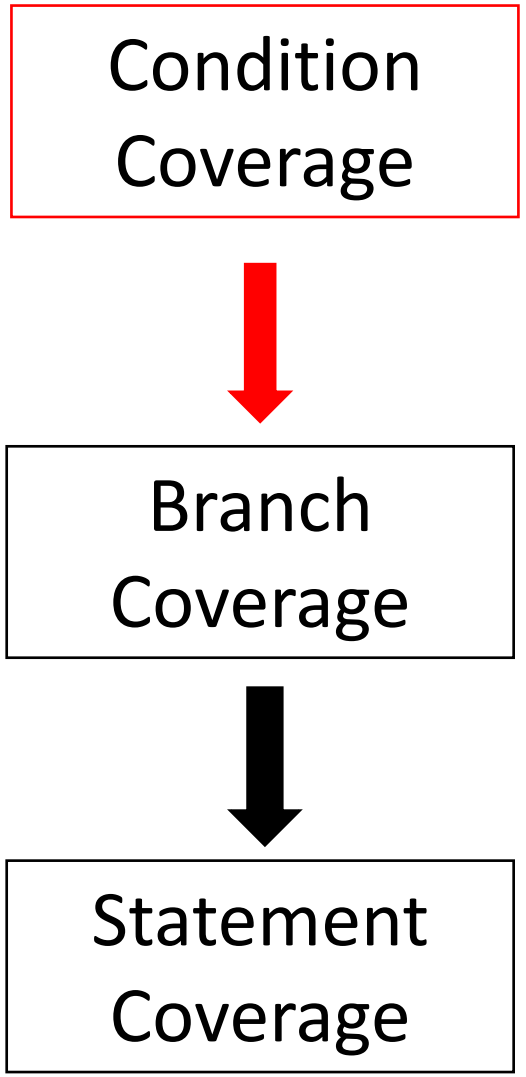
Subsumption

Does Condition Coverage imply branch coverage?

[ ] Yes
[✓] No



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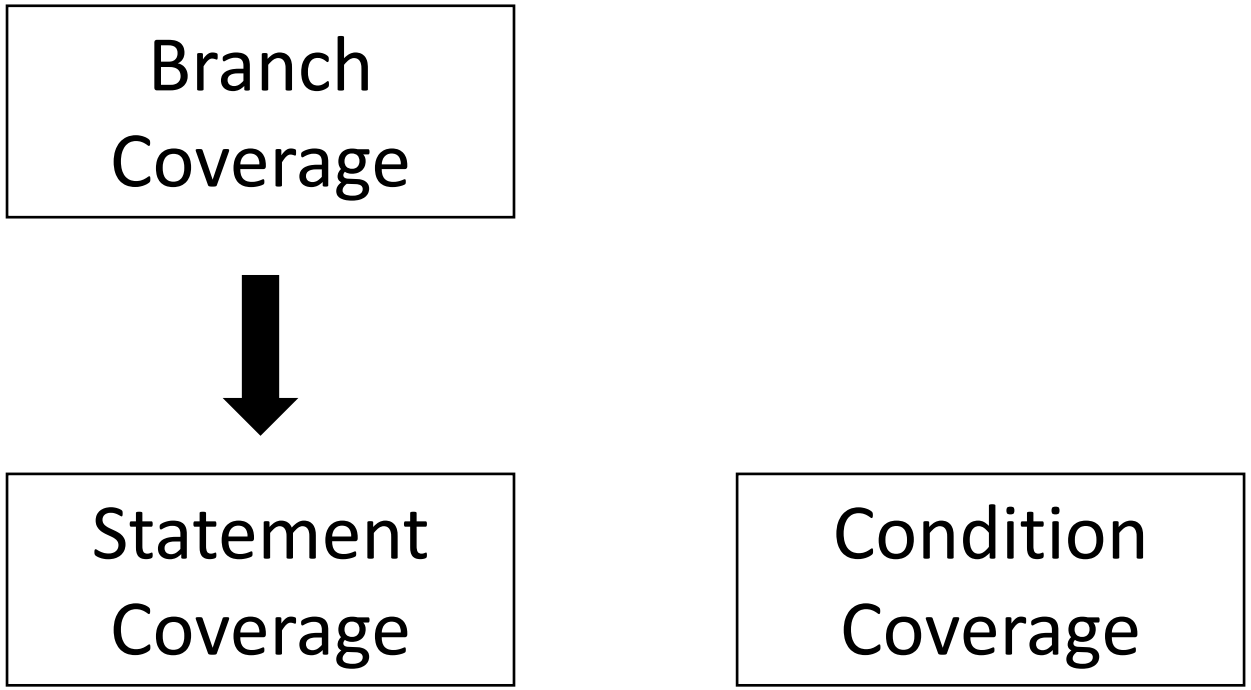
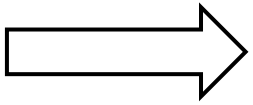
Test Criteria Subsumption

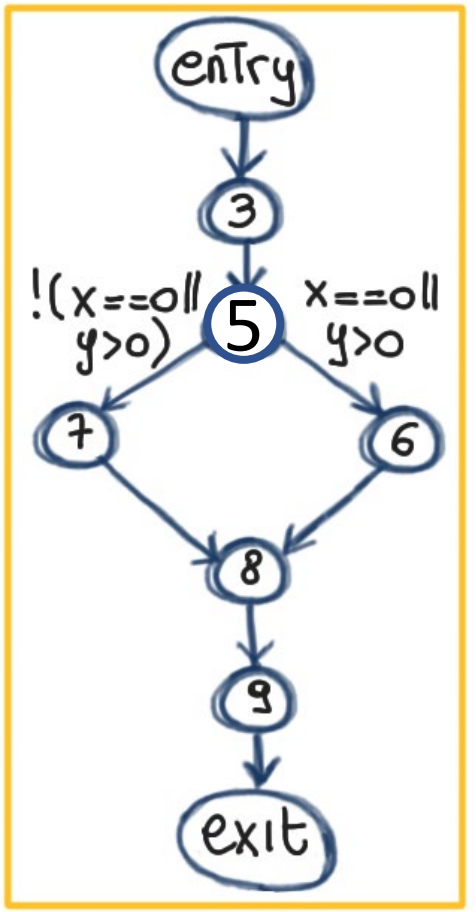


Slide adapted from Alessandro Orso

Lets consider the previous example

```
1. void main () {
2.    float x, y;
3.    read (x);
4.    read (y);
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```





x = 0; y = -5;
x = 5; y = 5;

Condition Coverage: ?

100%

Lets consider the previous example

```
1. void main () {
2.    float x, y;
3.    read (x);
4.    read (y);
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
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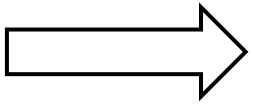
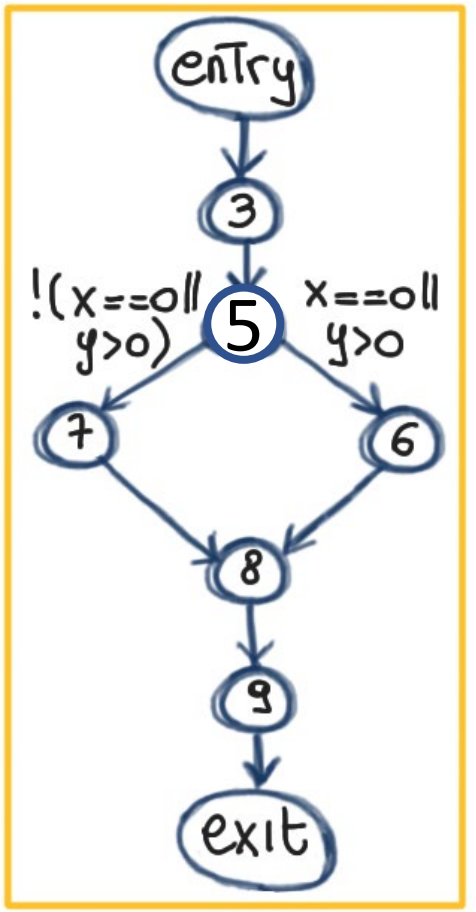




x = 0; y = -5;
x = 5; y = 5;

Condition Coverage: ?

100%

Branch Coverage:?

50 %

Coverage Criteria: Branch and Condition Coverage

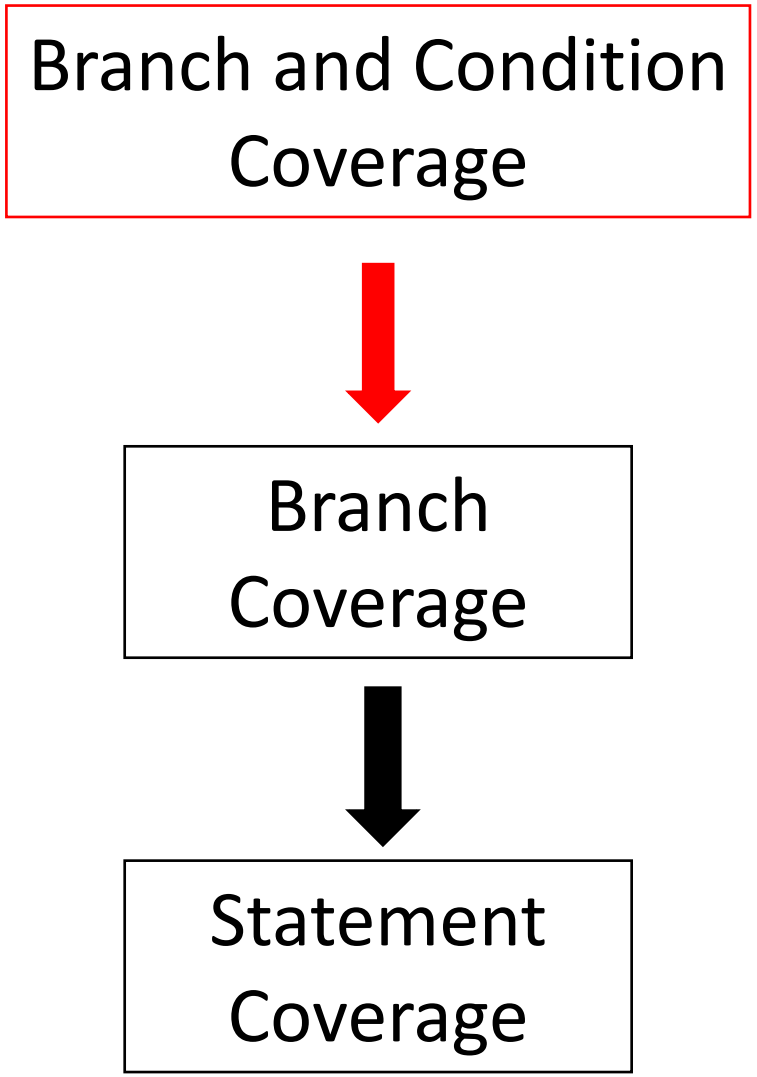
Test Requirements	Branches and Individual Conditions in the program
Coverage Measure	Computed using both coverage measures

Slide adapted from Alessandro Orso

Subsumption

Does Branch and Condition Coverage imply branch coverage?

[✓] Yes
[ ] No



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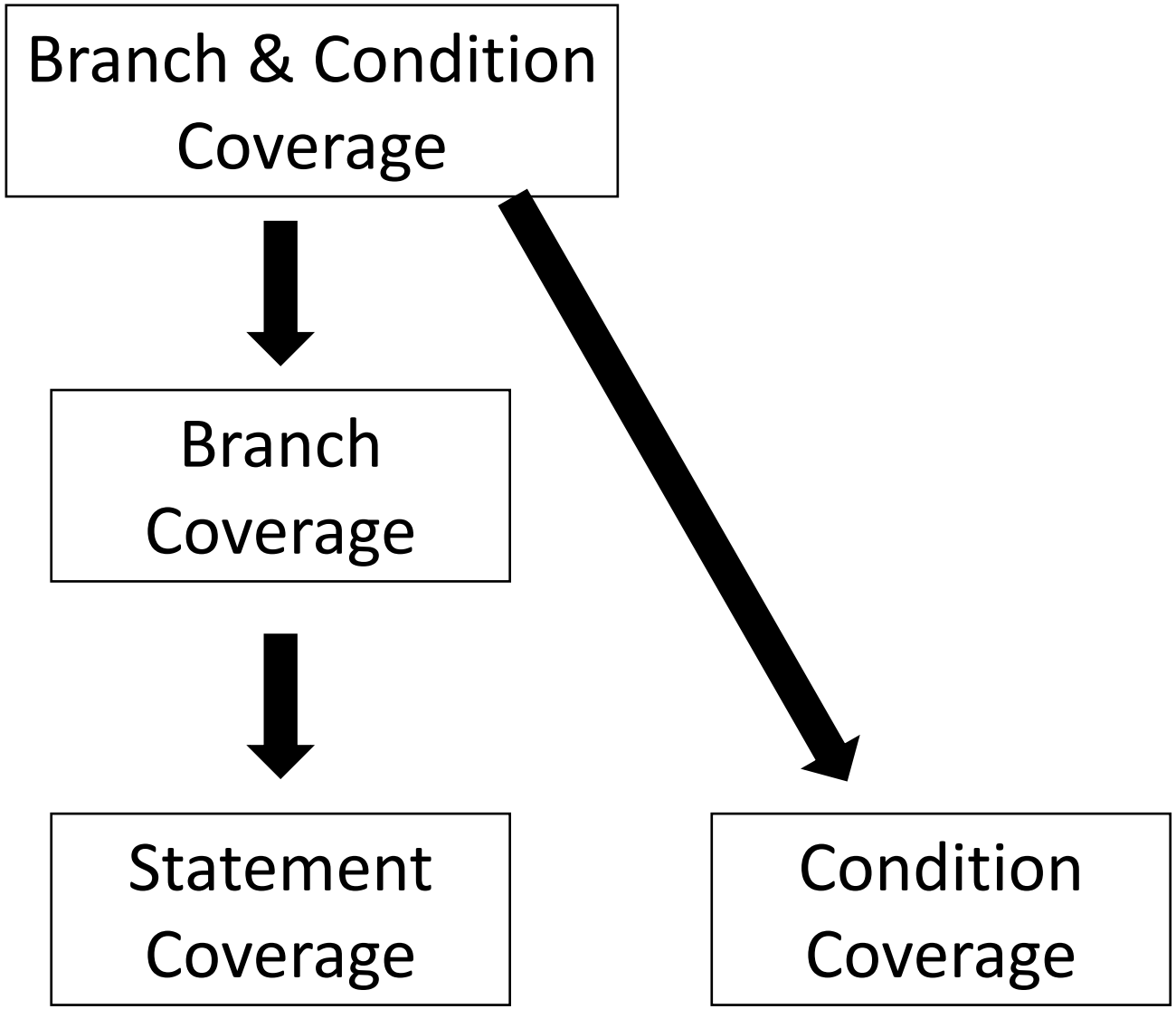
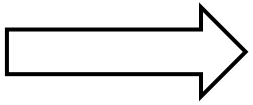
Test Criteria Subsumption

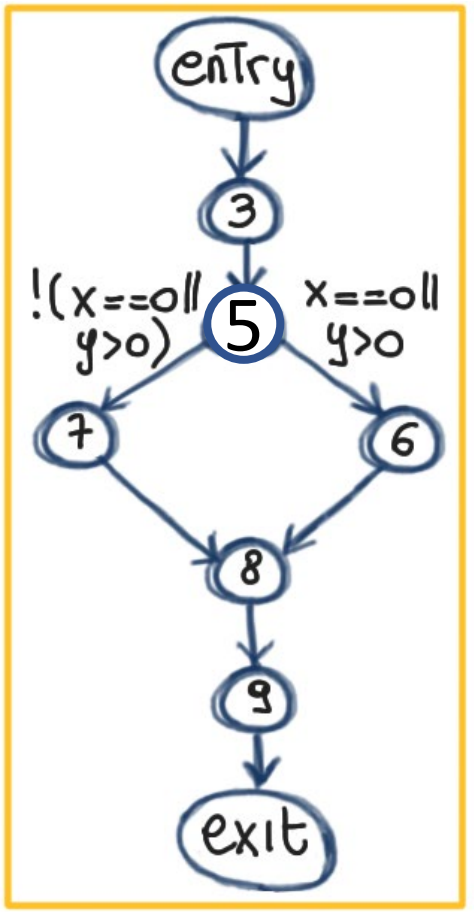


Slide adapted from Alessandro Orso

Achieving 100% B&C Coverage

```
1. void main () {
2.    float x, y;
3.    read (x);
4.    read (y);
5.    if ((x== 0) || (y > 0))
6.        y = y/x;
7.    else          x = y+2;
8.    write (x);
9.    write(y);
10.}
```





x = 0; y = -5;
x = 5; y = 5;

Add a test case to achieve 100% B&C Coverage

x = 3, y = -2

Multiple Condition Coverage – permutation-combination of conditions in a decision statement

Coverage Criteria: Modified Condition/Decision Coverage

Very Important Criteria; Often required for safety critical applications. For example: FAA requires SW that runs on commercial airplanes to be tested according to this criteria

Key Idea: Test important combinations of conditions and limited testing costs

Extend Branch and Decision Coverage with the requirement that each condition should affect the decision outcome independently

Slide adapted from Alessandro Orso

MC/DC Example

a && b && c

Test Case	A	B	C	Outcome
1	True	True	True	True
2	True	True	False	False
3	True	False	True	False
4	True	False	False	False
5	False	True	True	False
6	False	True	False	False
7	False	False	True	False
8	False	False	False	False

1	True	True	True	True
5	False	True	True	False

MC/DC Example

a && b && c

Test Case	A	B	C	Outcome
1	True	True	True	True
2	True	True	False	False
3	True	False	True	False
4	True	False	False	False
5	False	True	True	False
6	False	True	False	False
7	False	False	True	False
8	False	False	False	False

1	True	True	True	True
5	False	True	True	False
3	True	False	True	False

MC/DC Example

a && b && c

Test Case	A	B	C	Outcome
1	True	True	True	True
2	True	True	False	False
3	True	False	True	False
4	True	False	False	False
5	False	True	True	False
6	False	True	False	False
7	False	False	True	False
8	False	False	False	False

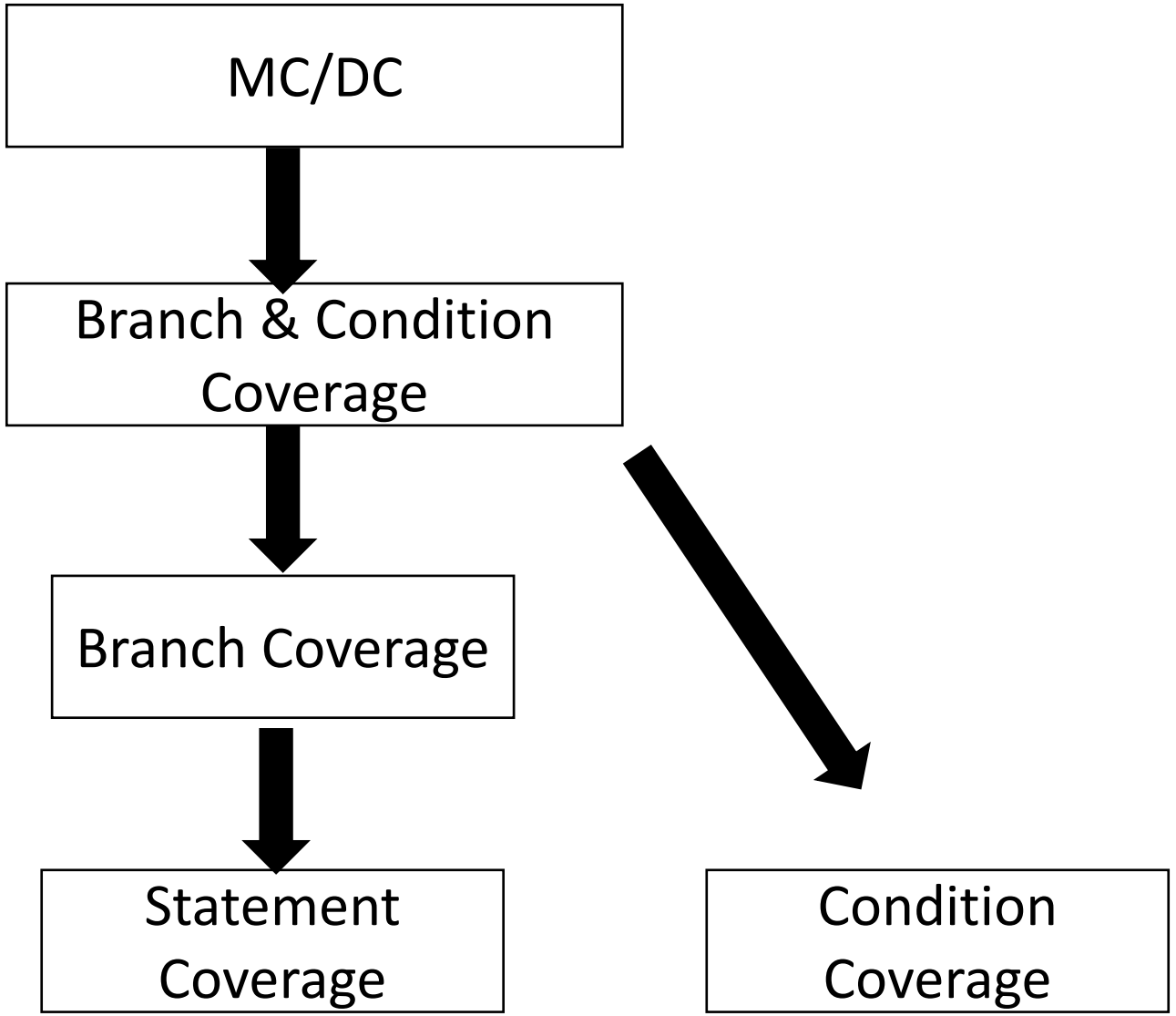
8 TC

To

1	True	True	True	True
5	False	True	True	False
3	True	False	True	False
2	True	True	False	False

4 TC

Test Criteria Subsumption



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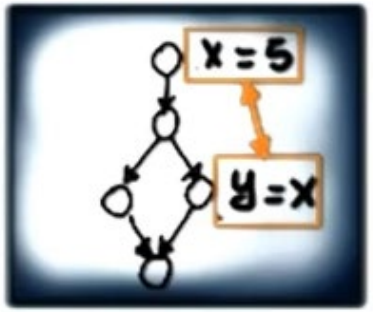
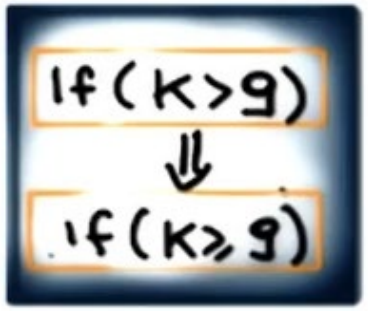
Other Criteria

Path Coverage (all paths are covered- incredibly expensive)

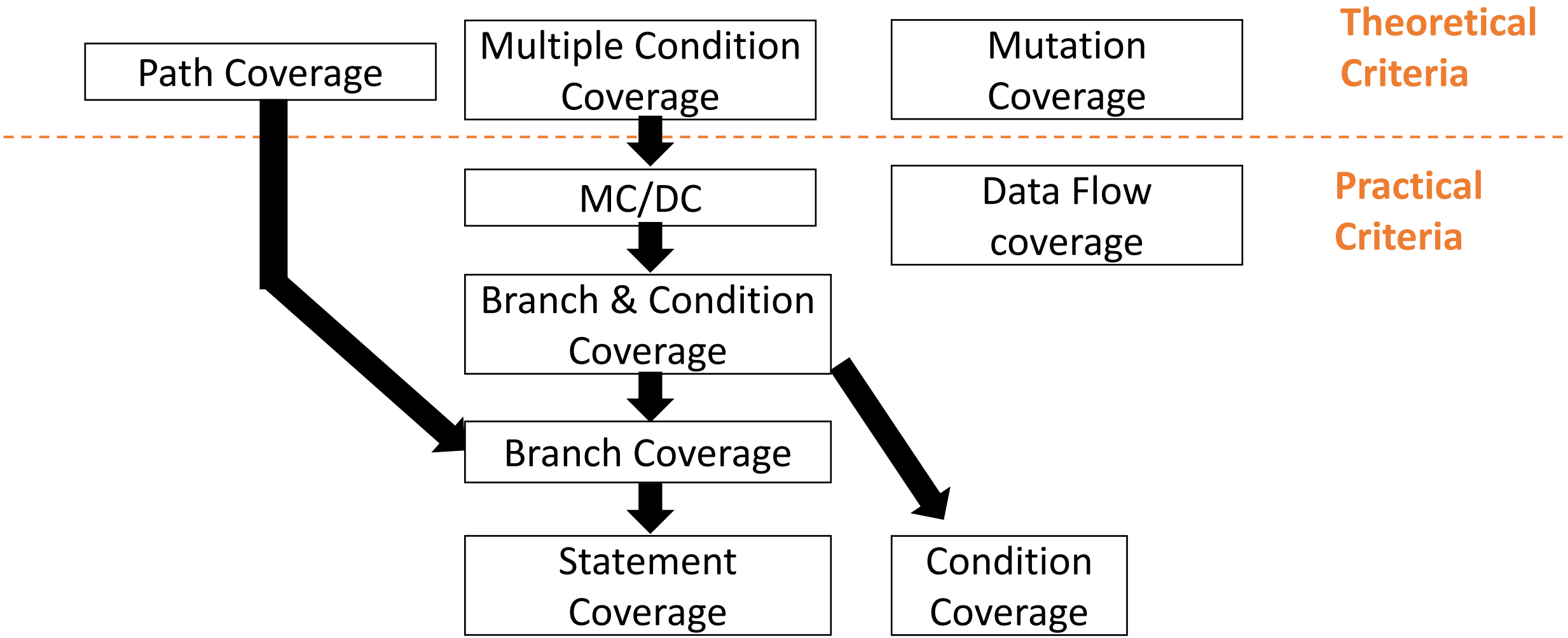


Data-Flow Coverage (coverage of pairs of elements; coverage of Statements, in which the content of some memory locations are modified, and statements in which the content of the same memory location is used). If a variable x is defined at one point and later used, data-flow coverage will ensure that the path between its definition and its use is tested. This helps catch errors like uninitialized variables or unintended variable overwrites.



Mutation Coverage (evaluate goodness of test by modifying the code; The more mutants identified by test, the better they are at identifying real faults)

Test Criteria Subsumption



Slide adapted from Alessandro Orso

White box testing Quiz

```
1. int i;
2. read (i);
3. print (10/(i-3))
```

Test Suite: (1, -5), (-1, 2.5), (0, -3.3)

Does it achieve path coverage?

Yes

Does it reveal the fault at line 3?

No

Even path coverage couldn't detect the fault. Exhaustive testing is the only way to ensure all possible test cases.

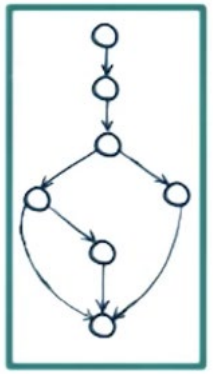
White box testing Quiz

```
1. int i = 0;
2. int j;
3. read (j);
4. if ((j > 5) && (i > 0))
5.    print (i)
```

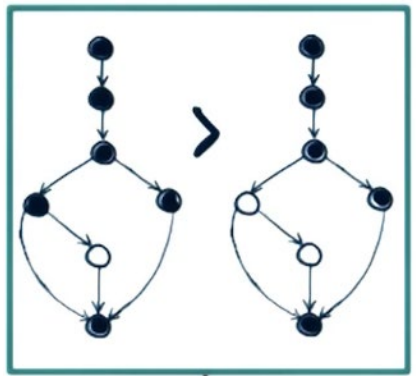
Can you create a test suite to adhere statement coverage?

No; Dead/ Unreachable Code.
infeasible paths, inexecutable statements, conditions that can never be true all are present in codes. Hence industry targets ~80% coverage

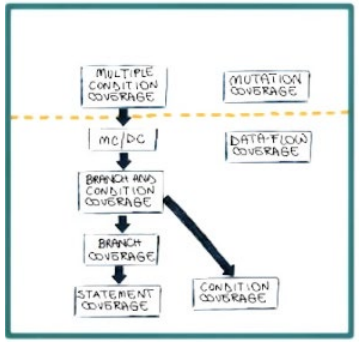
White-box testing Summary



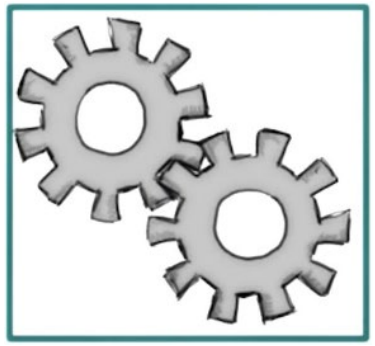
Works on a formal Model - No subjective decisions on level of abstraction needed



Comparable- coverage percentage as objective measure



2 broad classes: Practical and Theoretical



Fully Automatable

Industry Standard Today

- Junit
  - unit testing framework that supports test automation in Java Programming Language, provides the Test coverage report as well; licensed under Eclipse Public License
- Nunit
  - open source unit testing framework that supports all .NET languages
- Fiddler
  - Popular framework for web applications; logs and scrutinizes all HTTP(s) traffic between your system and the Internet.
- Bugzilla
  - popular defect tracking system; records the steps that lead up to reproduce the bug, so developers have all the information they need to fix it.
- Parasoft Jtest
  - Used to test and improve Java codebase on both development and production systems.maintain Junit tests
- Security vulnerabilities - Wireshark (network protocol analyzer), ZAP, Nmap

Industry Standard Today

Code Coverage Measurement in IDEs: IDEs like IntelliJ IDEA, Eclipse, and Visual Studio, are equipped with tools like JaCoCo (for Java) or Coverage.py (for Python) to measure code coverage by identifying which parts of the code have been executed through the test cases. Coverage types generally include:

- **Statement Coverage**: Determines if each line of code has been executed.
- **Branch Coverage**: Checks if all branches (like if/else conditions) are covered.
- **Condition/Decision Coverage**: Ensures each logical condition has been evaluated.

Assignment Today

Given code base. Write test cases manually vs using AI. Measure coverage in VS Code and discuss results

Quizizz