COM 3529
Software Testing & Analysis

Professor Phil McMinn

2.2 White-Box Coverage Criteria Based on
Control Flow Analysis

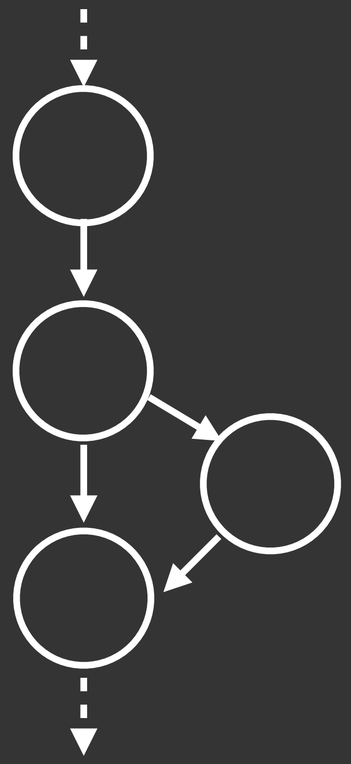
Control Flow

```java
public static Set<Character> duplicateLetters(String s) {
    // lower case the string and remove all characters
    // that are not letters
    s = s.toLowerCase().replaceAll("[^a-z.]", "");

    // initialise the result set
    Set<Character> duplicates = new TreeSet<>();

    // iterate through the string
    for (int i = 0; i < s.length(); i++) {
        char si = s.charAt(i);

        // iterate through the rest of the string,
        // checking for the same letter
        for (int j = i + 1; j < s.length(); j++) {
            char sj = s.charAt(j);

            if (si == sj) {
                // a match has been found, add it to
                // the result set
                duplicates.add(si);
            }
        }
    }

    return duplicates;
}
```

Control Flow Graph

```java
public static Set<Character> duplicateLetters(String s) {
    // lower case the string and remove all characters
    // that are not letters
    s = s.toLowerCase().replaceAll("[^a-z.]", "");

    // initialise the result set
    Set<Character> duplicates = new TreeSet<>();

    // iterate through the string
    for (int i = 0; i < s.length(); i++) {
        char si = s.charAt(i);

        // iterate through the rest of the string,
        // checking for the same letter
        for (int j = i + 1; j < s.length(); j++) {
            char sj = s.charAt(j);

            if (si == sj) {
                // a match has been found, add it to
                // the result set
                duplicates.add(si);
            }
        }
    }

    return duplicates;
}
```

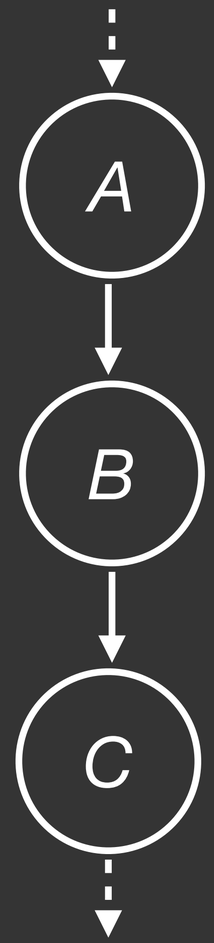
Control Flow Graph (CFG)




```java
public static Set<Character> duplicateLetters(String s) {
    // lower case the string and remove all characters
    // that are not letters
    s = s.toLowerCase().replaceAll("[^a-z.]", "");

    // initialise the result set
    Set<Character> duplicates = new TreeSet<>();

    // iterate through the string
    for (int i = 0; i < s.length(); i++) {
        char si = s.charAt(i);

        // iterate through the rest of the string,
        // checking for the same letter
        for (int j = i + 1; j < s.length(); j++) {
            char sj = s.charAt(j);

            if (si == sj) {
                // a match has been found, add it to
                // the result set
                duplicates.add(si);
            }
        }
    }

    return duplicates;
}
```

Linear Sequences of Statements

```
doSomething(); /* A */
doSomethingElse(); /* B */
doSomethingDifferent(); /* C */
```

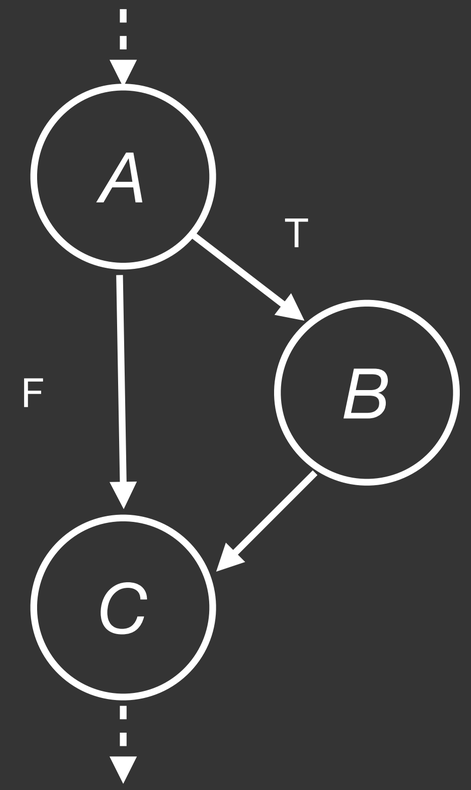


Linear Sequences of Statements

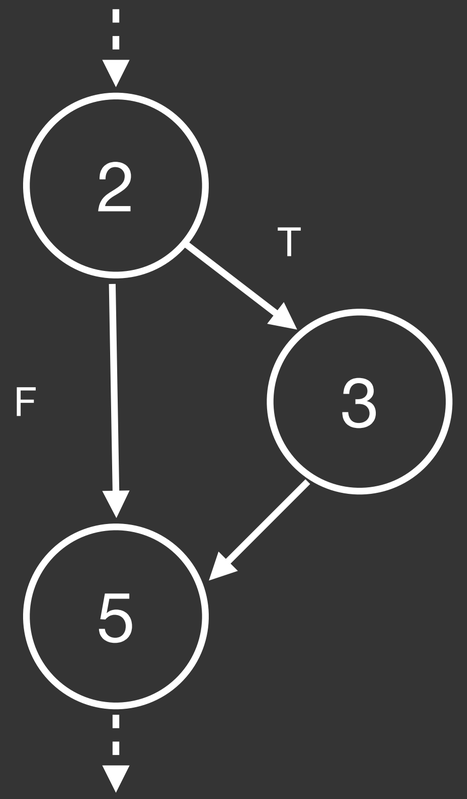
```
doSomething(); /* A */
doSomethingElse(); /* B */
doSomethingDifferent(); /* C */
```

“If” Constructs

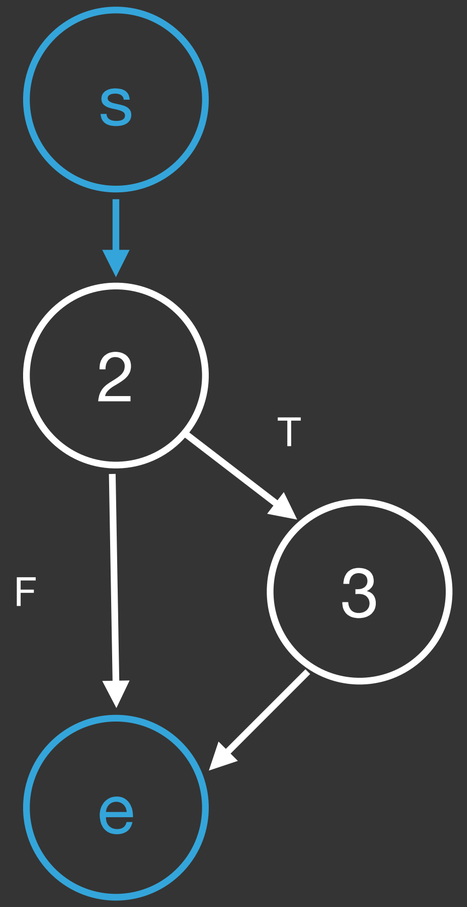
```
if (condition) { /*A*/
  doSomething(); /* B */
}
/* C */
```



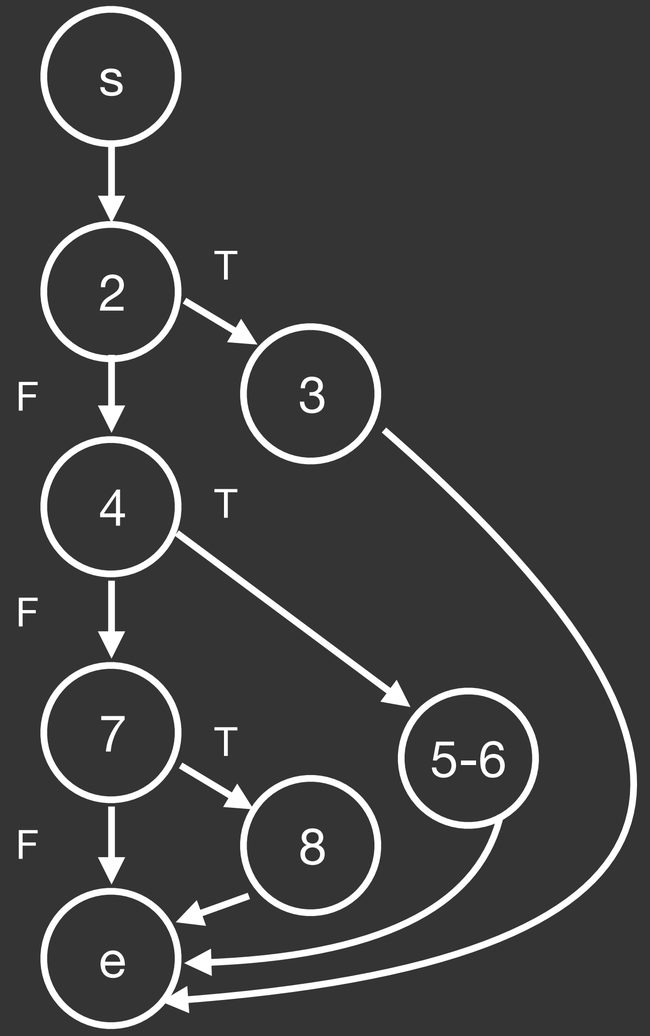
```java
1 public void printGreeting() {
2   if (isMorning()) {
3     System.out.println("Good Morning!");
4   }
5 }
```



```java
public void printGreeting() {
  if (isMorning()) {
    System.out.println("Good Morning!");
  }
}
```

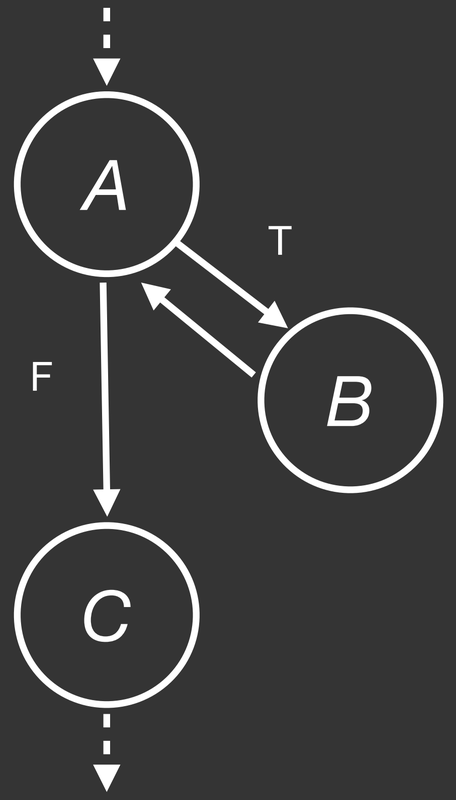


```java
public void printGreeting() {
  if (isMorning()) {
    System.out.println("Good Morning!");
  } else if (isAfternoon()) {
    System.out.println("Good Afternoon!");
    System.out.println("Lovely day for a stroll!");
  } else if (isEvening()) {
    System.out.println("Good Evening!");
  }
}
```



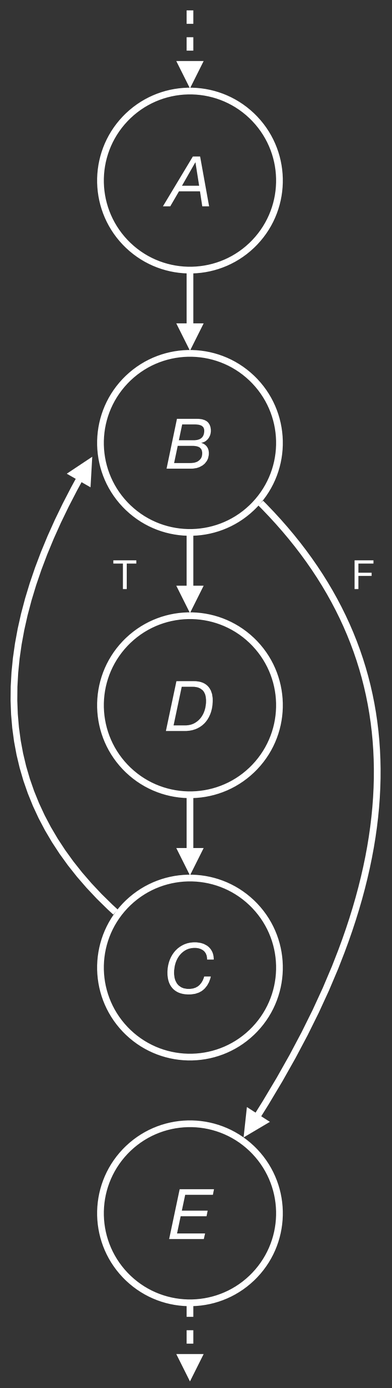
“While” Constructs

```
while (condition) { /*A*/
  doSomething(); /* B */
}
/* C */
```

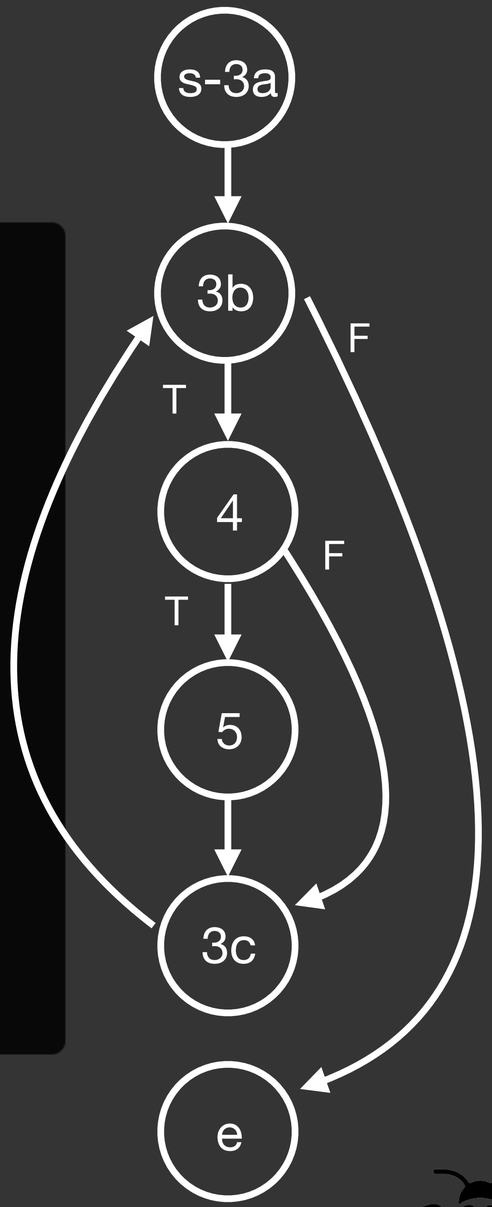


“For” Constructs

```
for (/*A*/ int i = 0; /*B*/ i < 10; /*C*/ i ++) {
  doSomething(); /* D */
}
// E
```



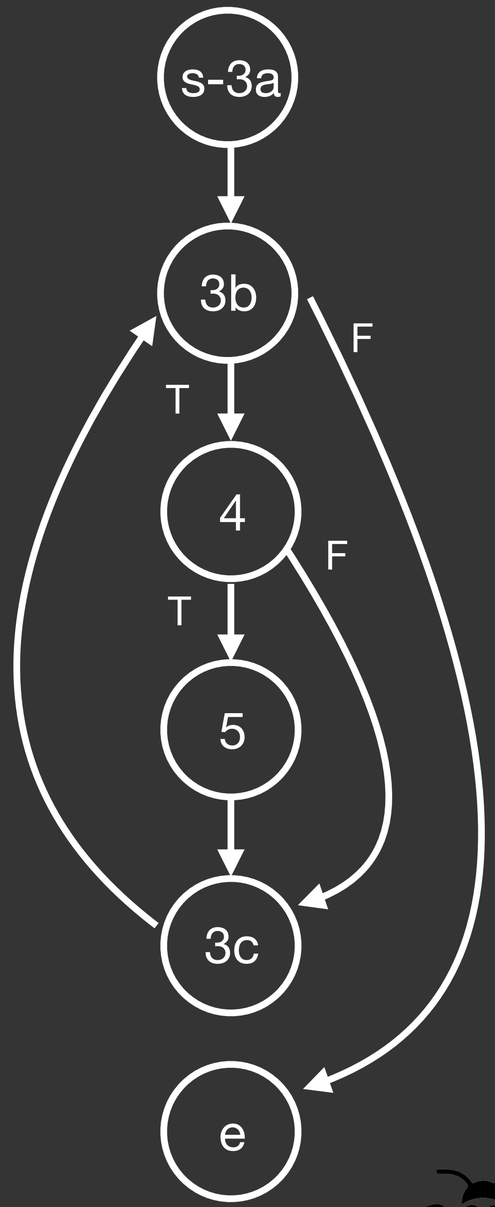
```java
public int countZeros(int[] x) {
  int count = 0;
  for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
    if (x[i] == 0) {
        count ++;
    }
  }
  return count;
}
```



Statement Coverage

The test suite should execute all nodes of the CFG

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



Statement Coverage

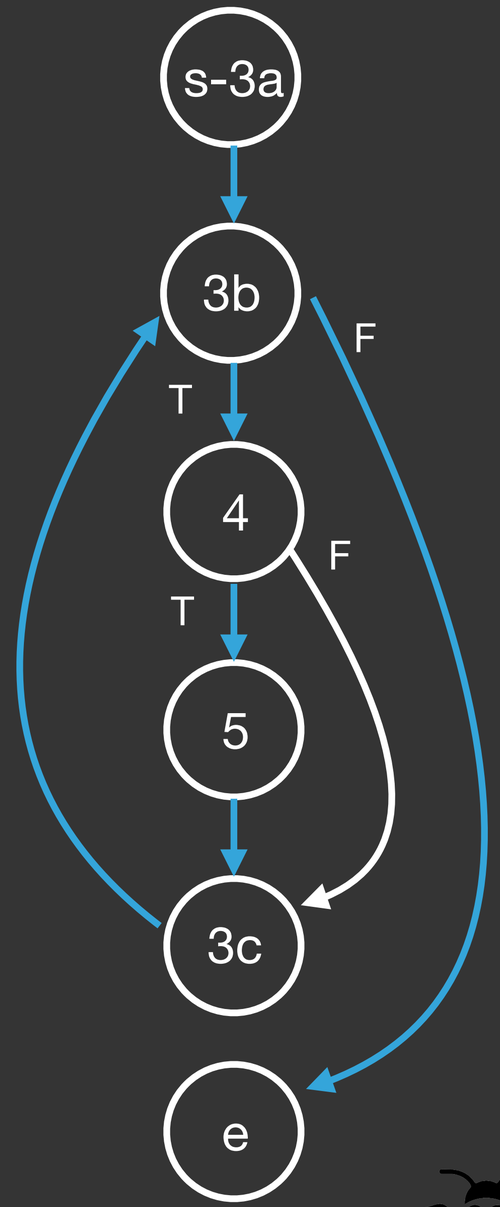
The test suite should execute all nodes of the CFG

The test case x = [0] would execute all nodes

It takes the path s-3a → 3b → 4 → 5 → 3c → 3b → e

(In practice covering all nodes may need several test cases)

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



Statement Coverage

The test suite should execute all nodes of the CFG

Also known as:

- Line Coverage
- Node Coverage
- Basic Block Coverage

Statement Coverage

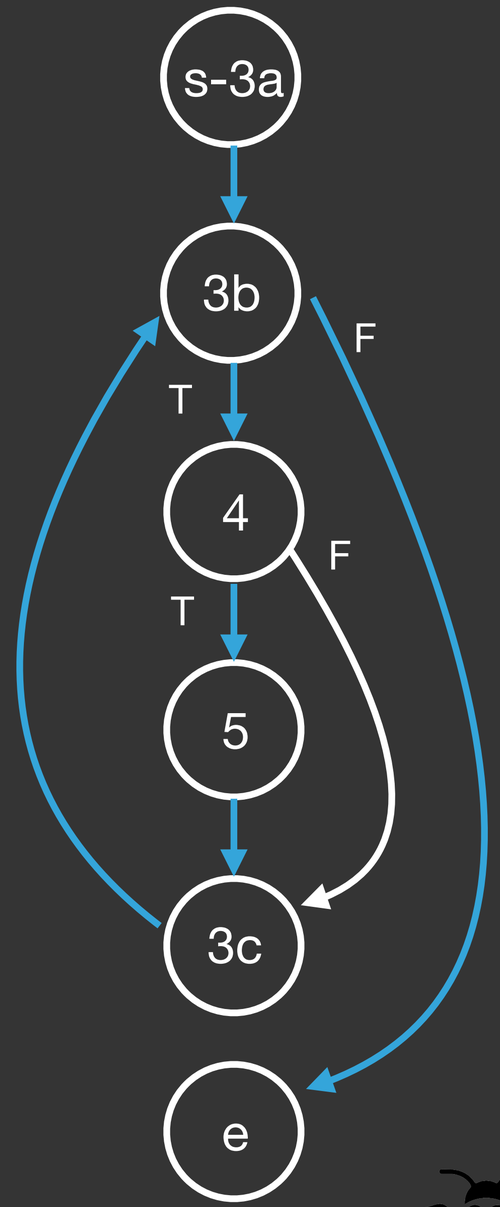
The test suite should execute all nodes of the CFG

The test case x = [0] would execute all nodes

It takes the path s-3a → 3b → 4 → 5 → 3c → 3b → e

(In practice covering all nodes may need several test cases)

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



Statement Coverage

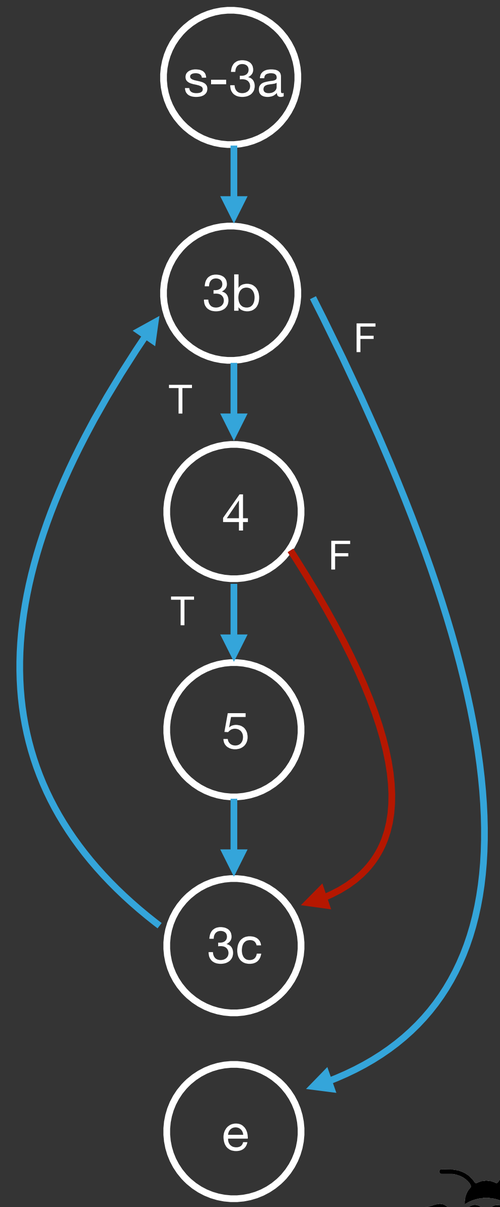
The test suite should execute all nodes of the CFG

The test case x = [0] would execute all nodes

It takes the path s-3a → 3b → 4 → 5 → 3c → 3b → e

(In practice covering all nodes may need several test cases)

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



Branch Coverage

The test suite should execute all true/false edges of the CFG

Branch Coverage

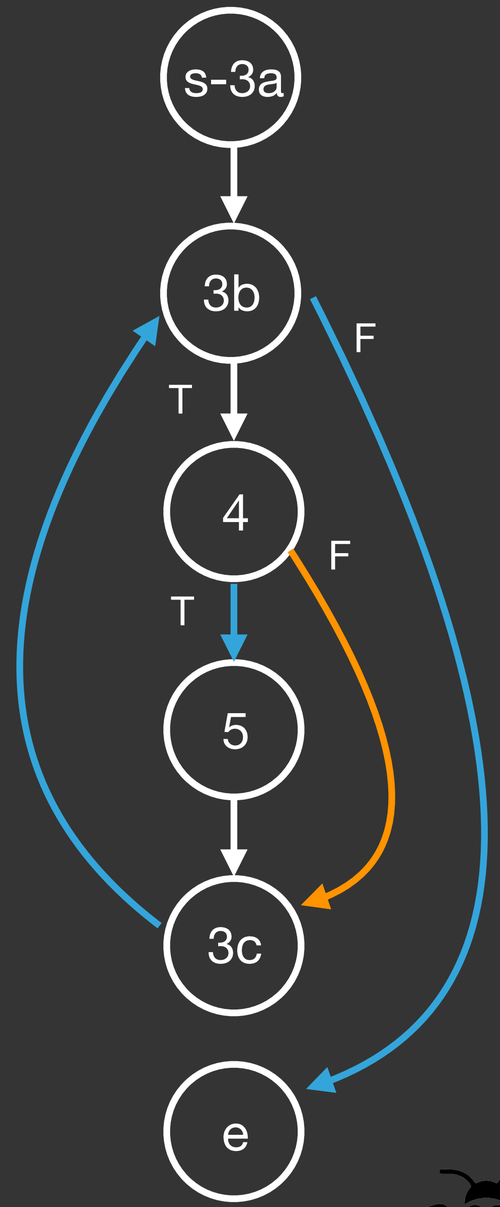
The test suite should execute all true/false edges of the CFG

The test case x = [0] and x = [1] would execute all true/false branches

x = [0] takes the true branch from node 4, x = [1] takes the false branch

(Note: the test cases could be merged into one: x = [0, 1])

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



Branch Coverage

The test suite should execute all true/false edges of the CFG

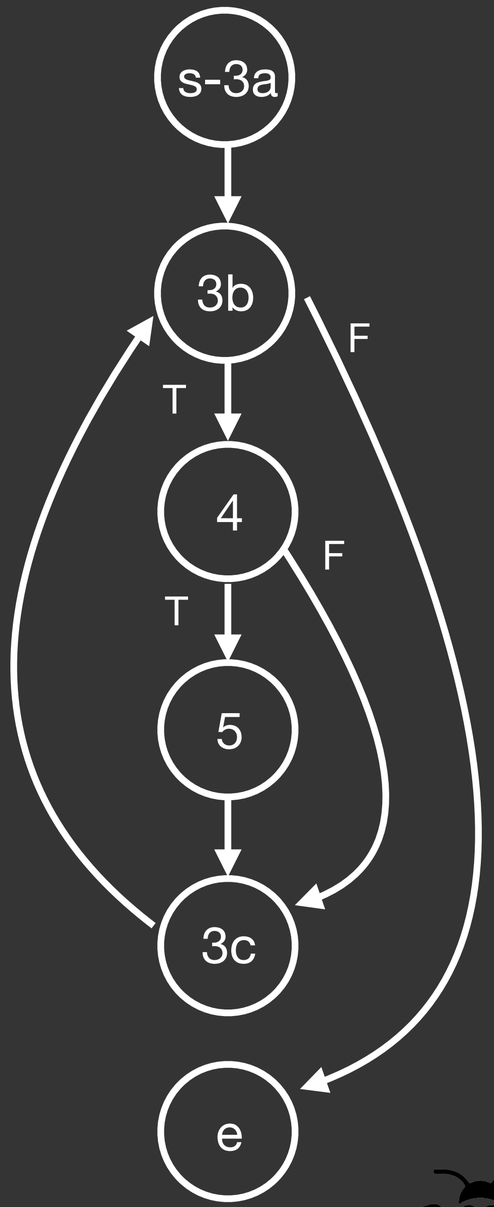
Also known as:

- Decision Coverage
- Predicate Coverage
- Edge Coverage

Path Coverage

The test suite should execute all paths through the CFG

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



Path Coverage

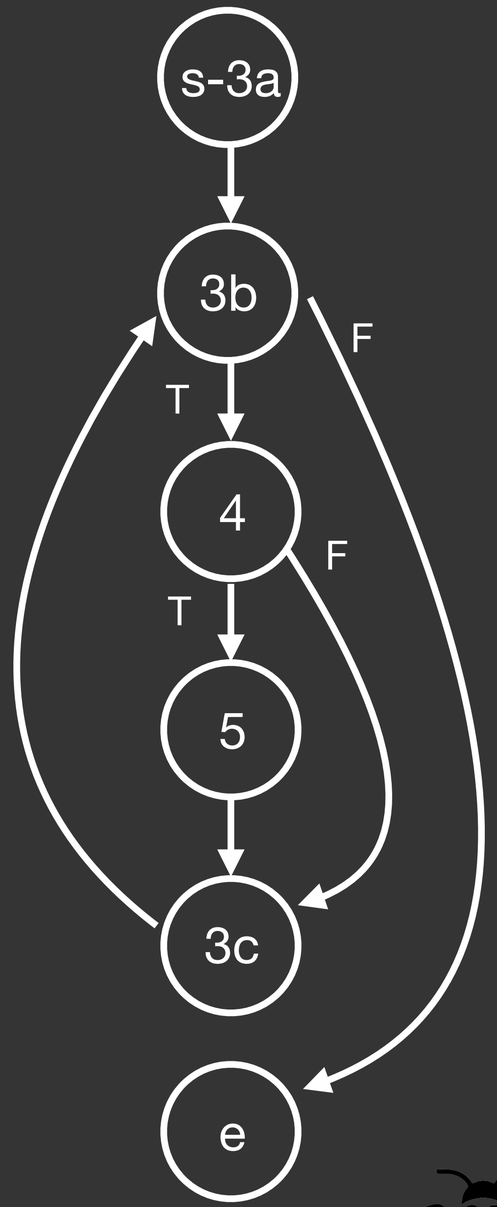
The test suite should execute all paths through the CFG

Usually not possible in practice

The number of paths through `countZeros` is dependent on the length of x

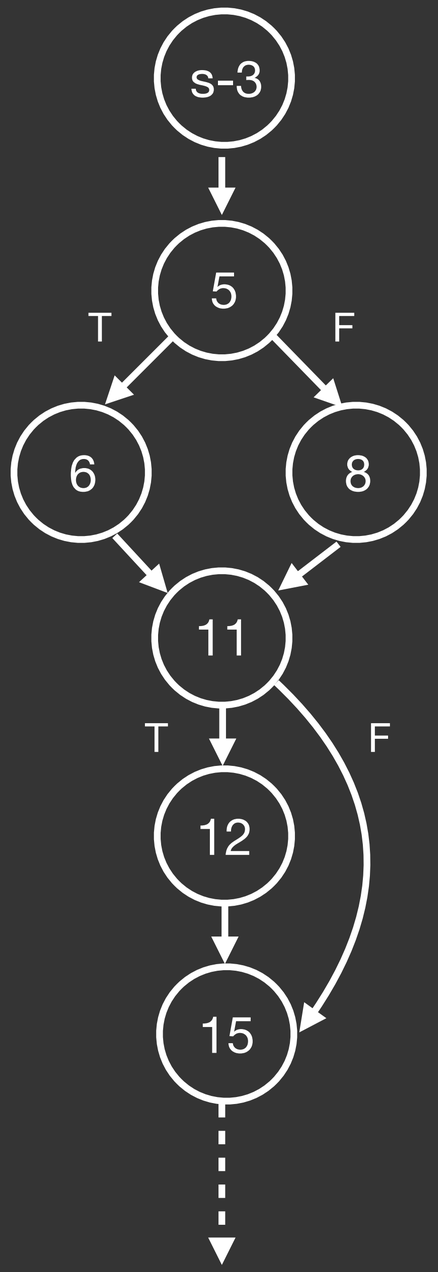
Some versions of Path Coverage concentrate on 0, 1 or more executions of every loop to mitigate potentially infinite numbers of paths

```
1 public int countZeros(int[] x) {
2   int count = 0;
3   for (int i=0 /* 3a */; i < x.length /* 3b */; i++ /* 3c */) {
4     if (x[i] == 0) {
5         count ++;
6     }
7   }
8   return count;
9 }
```



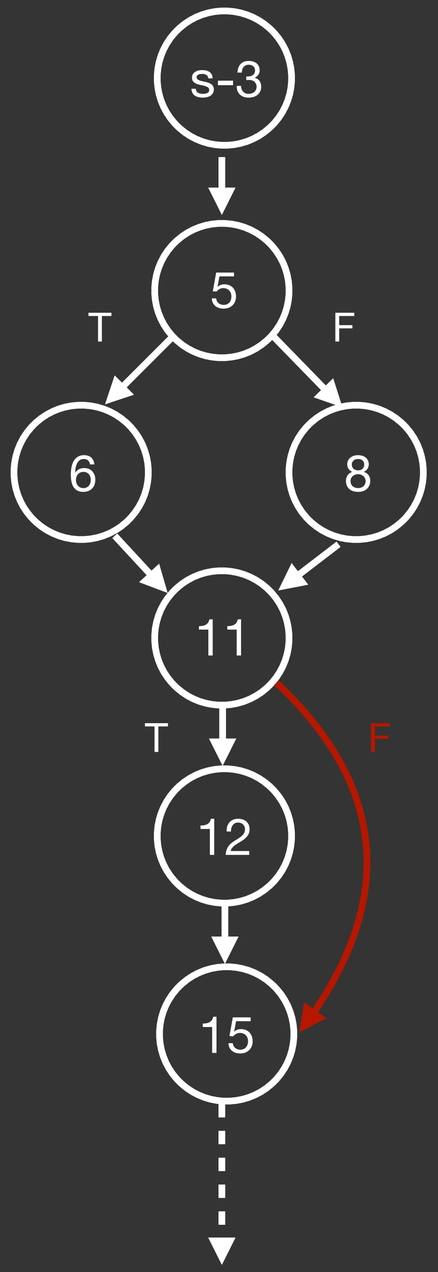
There is a problem lurking here for Branch Coverage. What is it?

```
1  public void testMe(int x) {
2
3    int y = 0;
4
5    if (x > 0) {
6        y = y + 1;
7    } else {
8        y = y + 2;
9    }
10
11   if (y > 0) {
12       y = y + 1;
13   }
14
15   // ...
```



There is a problem lurking here for Branch Coverage. What is it?

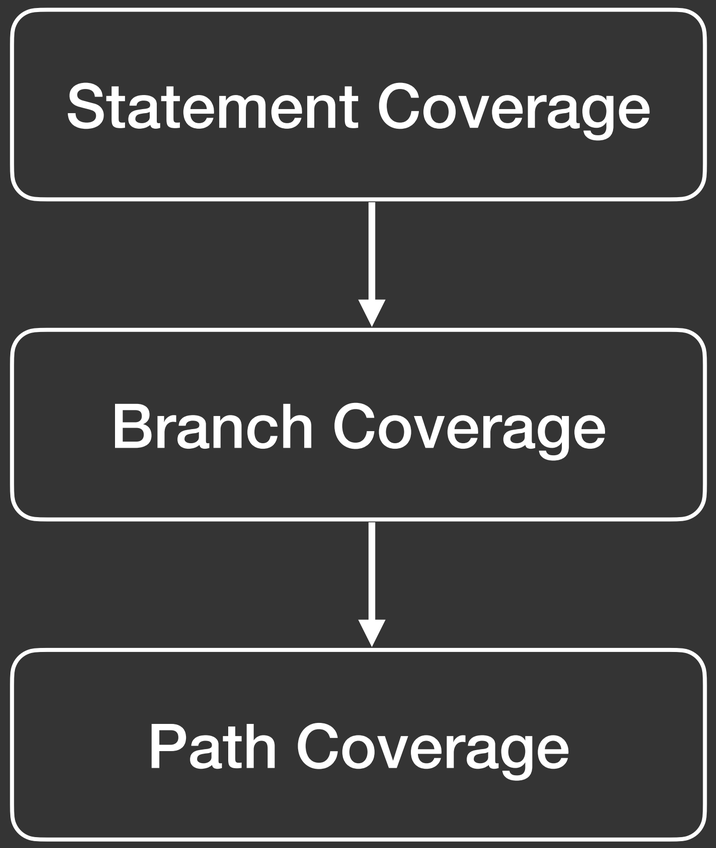
```
1  public void testMe(int x) {
2
3    int y = 0;
4
5    if (x > 0) {
6        y = y + 1;
7    } else {
8        y = y + 2;
9    }
10
11   if (y > 0) {
12       y = y + 1;
13   }
14
15   // ...
```



Coverage Criteria are Subject To Infeasible Test Requirements

- This *can* also happen with Statement Coverage
    - Infeasible statements correspond to dead code
- It is *more likely* to happen with Branch Coverage
    - Infeasible branches point to redundant decisions in the code
- It is *very likely* with Path Coverage
    - Infeasible paths are not necessarily the result of redundancy
    - Not all the paths through the CFG are legitmately possible in the actual code

Subsumption of Structural Coverage Criteria



Line Coverage
Node Coverage
Basic Block Coverage

Decision Coverage
Predicate Coverage
Edge Coverage

When to Use Structural Coverage

- Structural coverage level is a useful metric to understand how much of your code is executed by your test suite.
- Common Rationale: you wouldn't want to release parts of your code that weren't exercised at least once by at least one test
  - As such Statement/Line Coverage is a commonly used metric
  - But Branch Coverage is stronger, and obtainable without much more additional effort
  - Path Coverage is less common and often intractable