University of Sheffield

COM3529 Software Testing and Analysis

White-Box Coverage Criteria based on Control Flow Analysis

Dr José Miguel Rojas
slides by Prof Phil McMinn

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,
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        for (int j = i + 1; j < s.length(); j++) {
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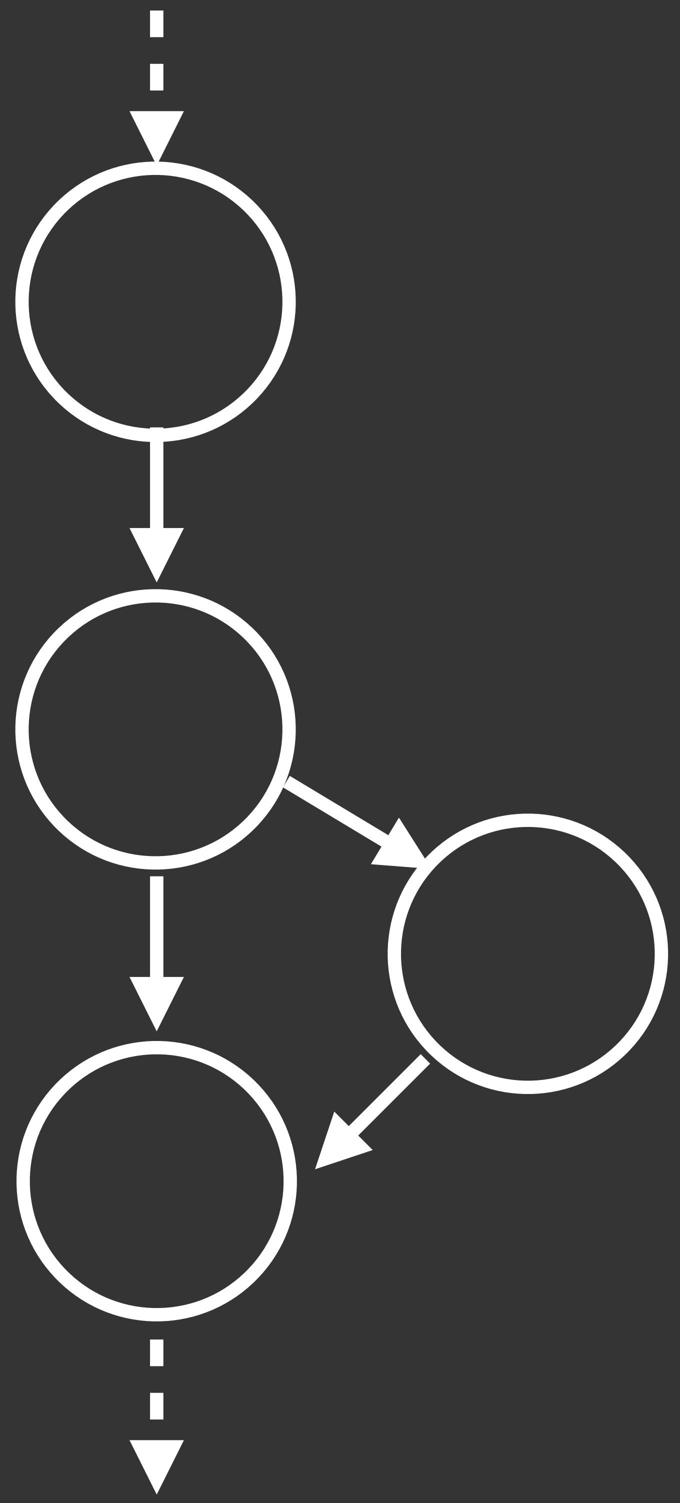
Control Flow Graph

(CFG)



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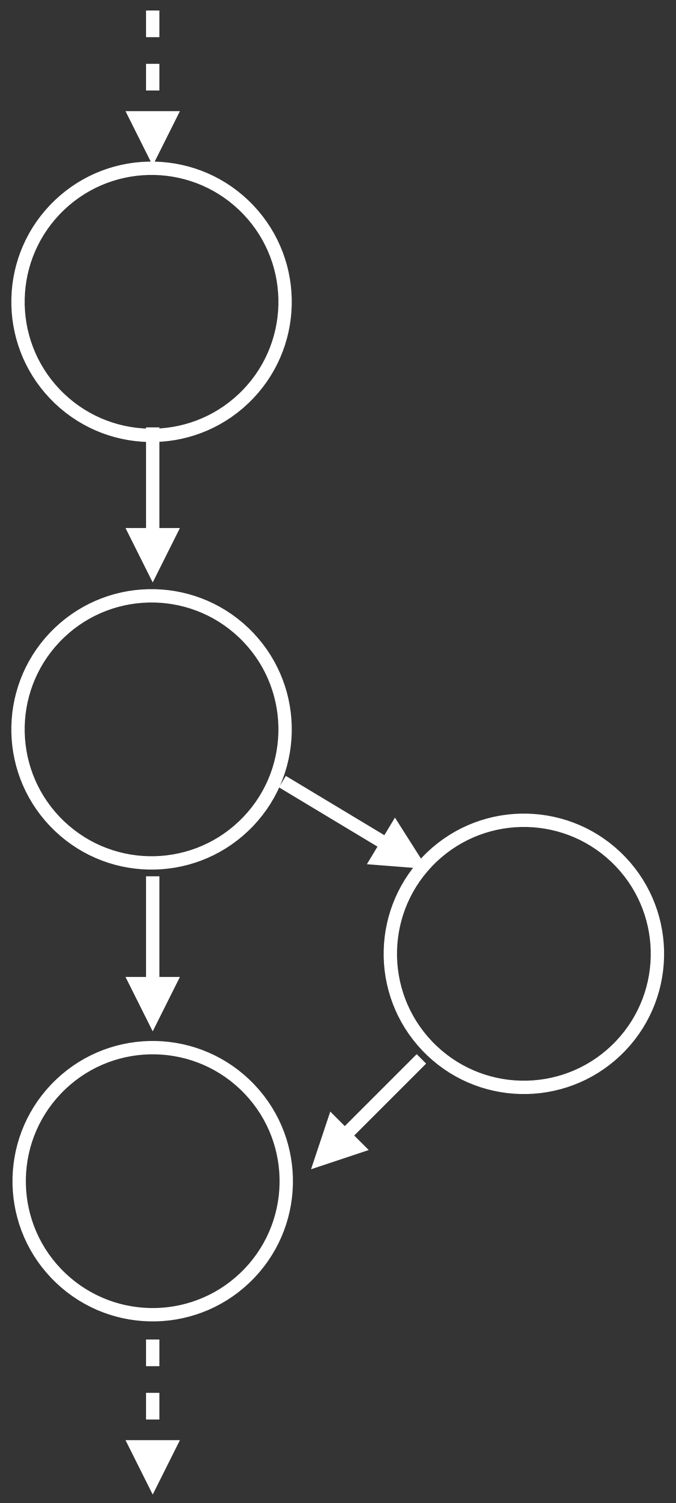

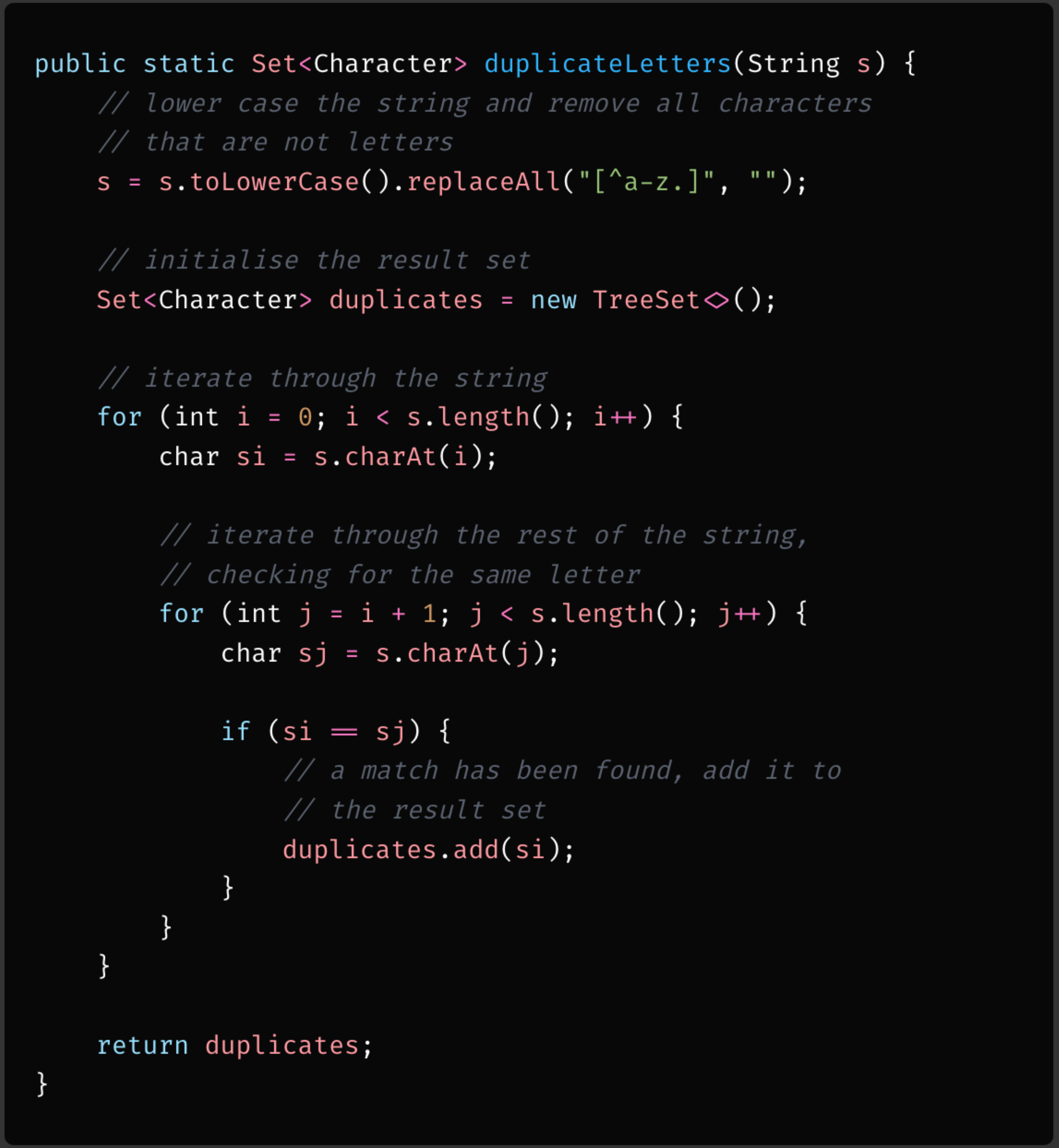

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Linear Sequences of Statements

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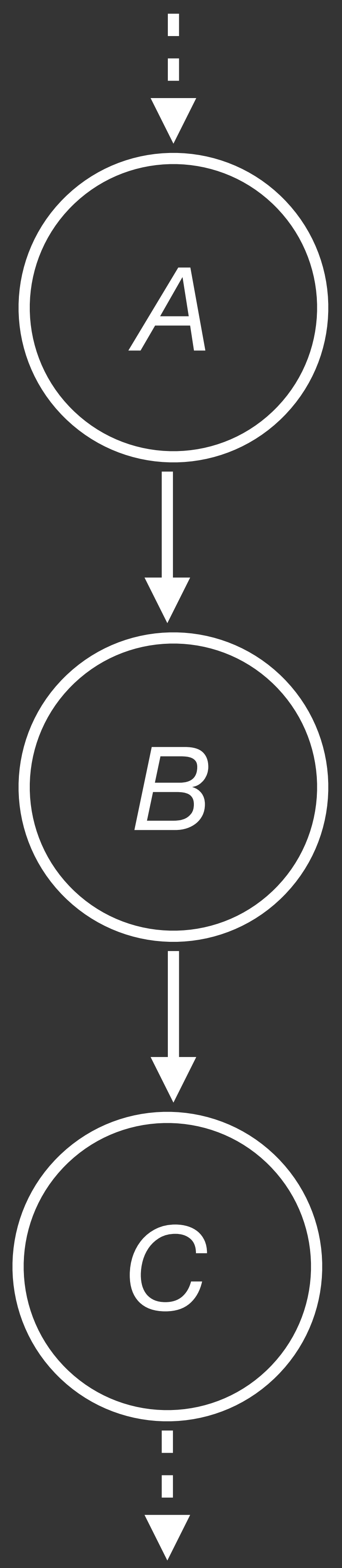

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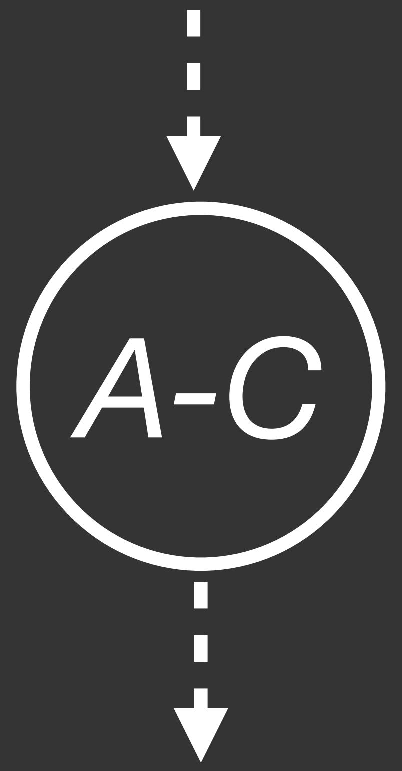
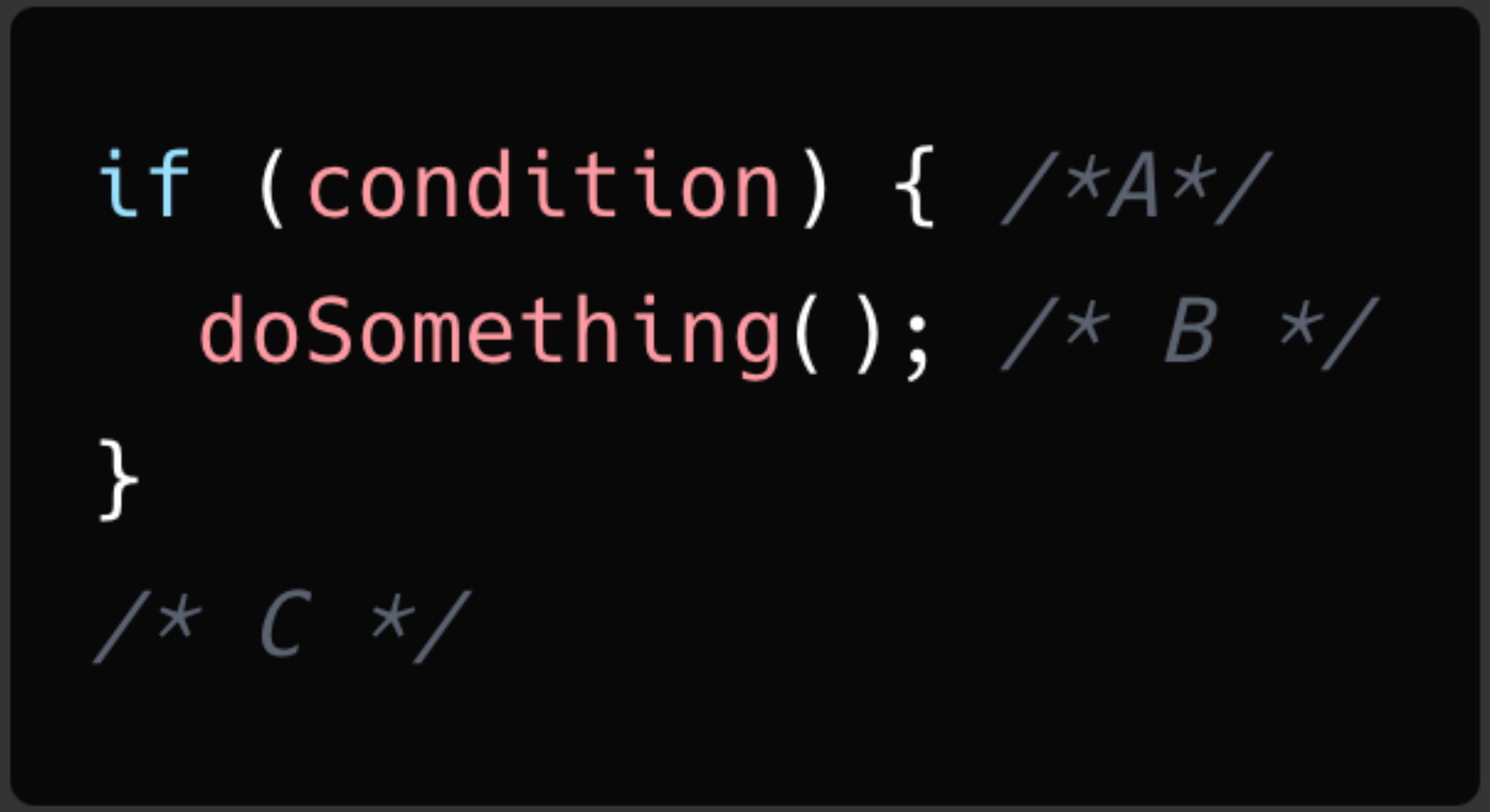
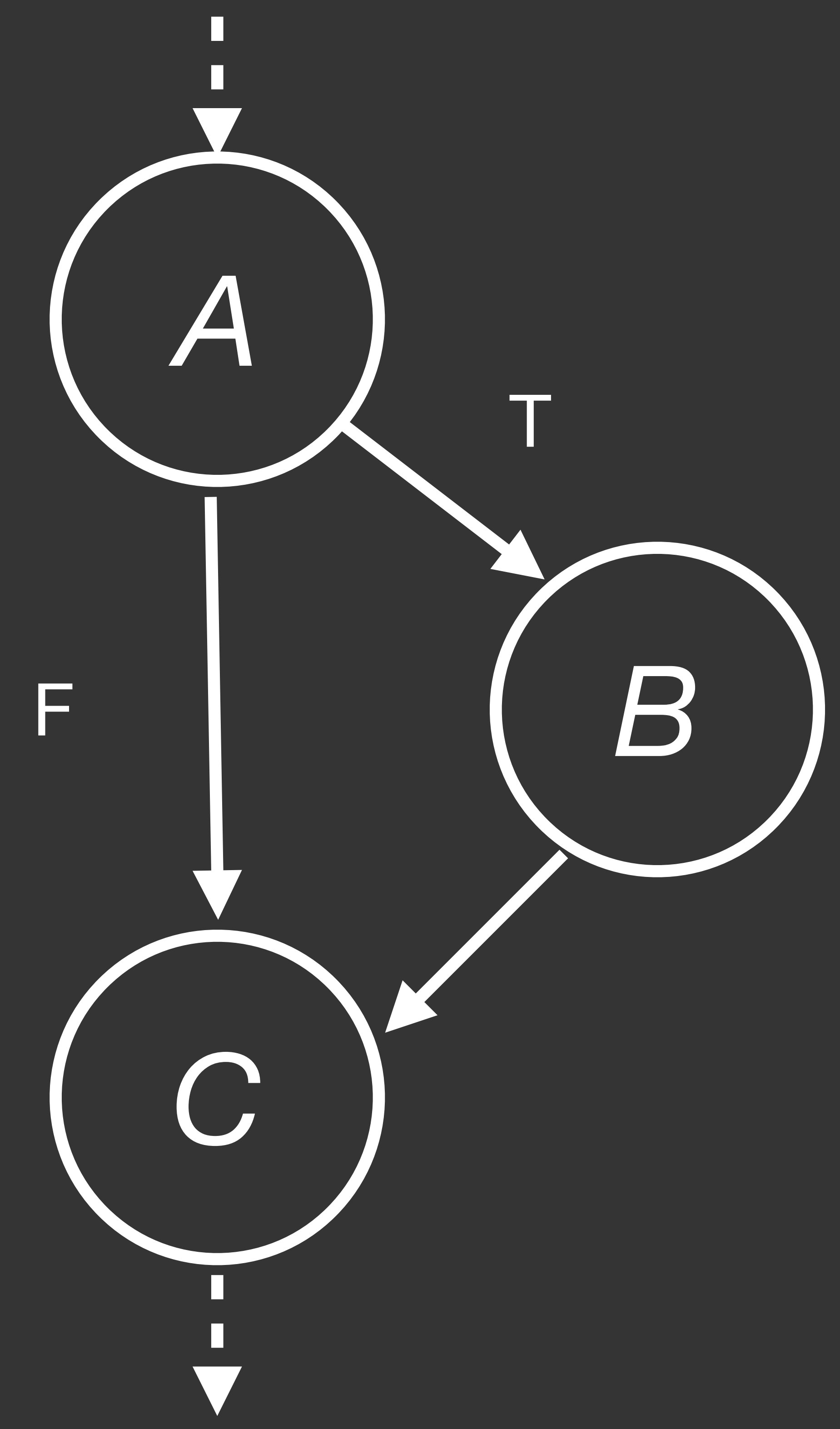


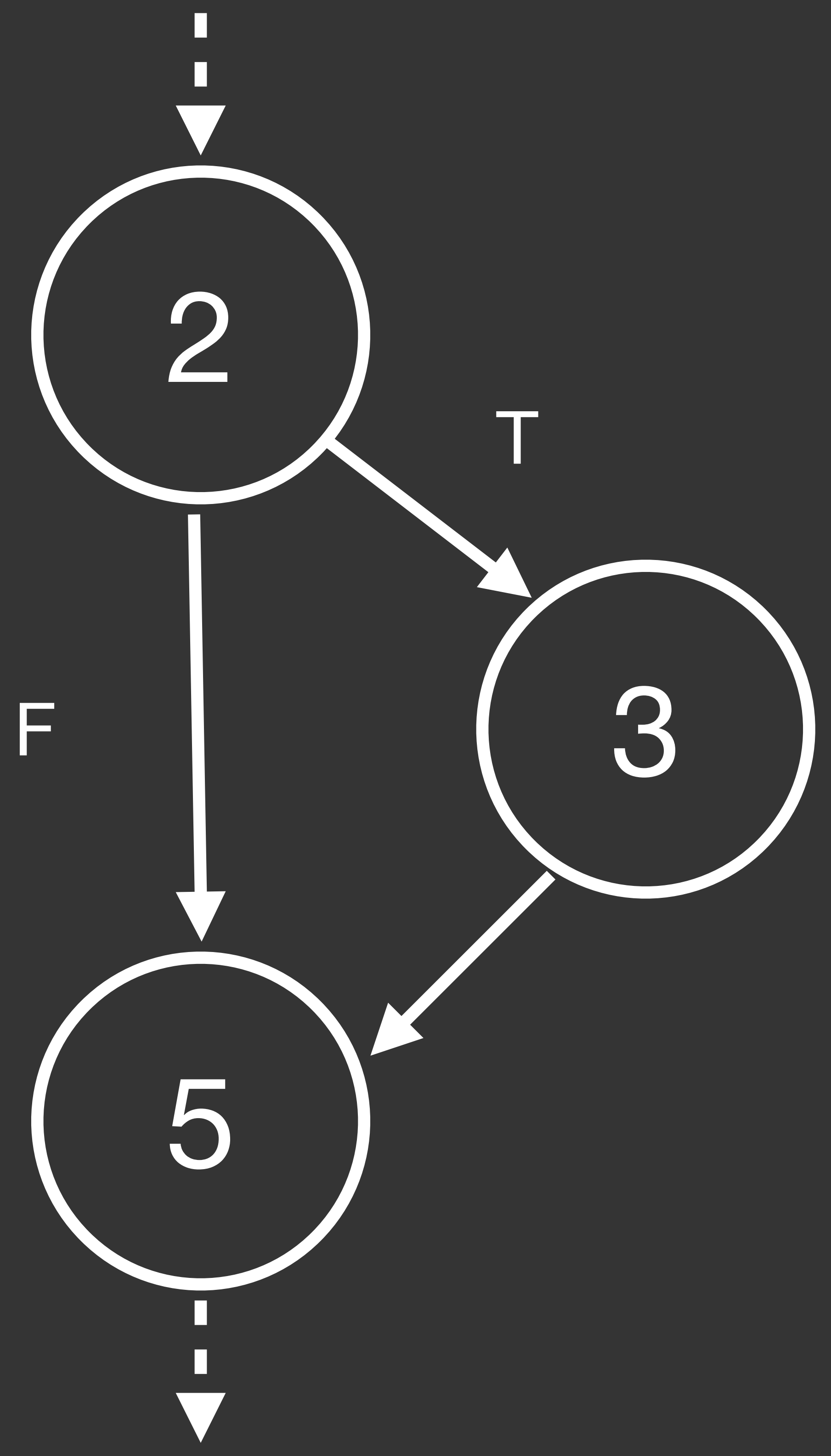
“If” Constructs


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



Methods

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



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1 public void printGreeting() {
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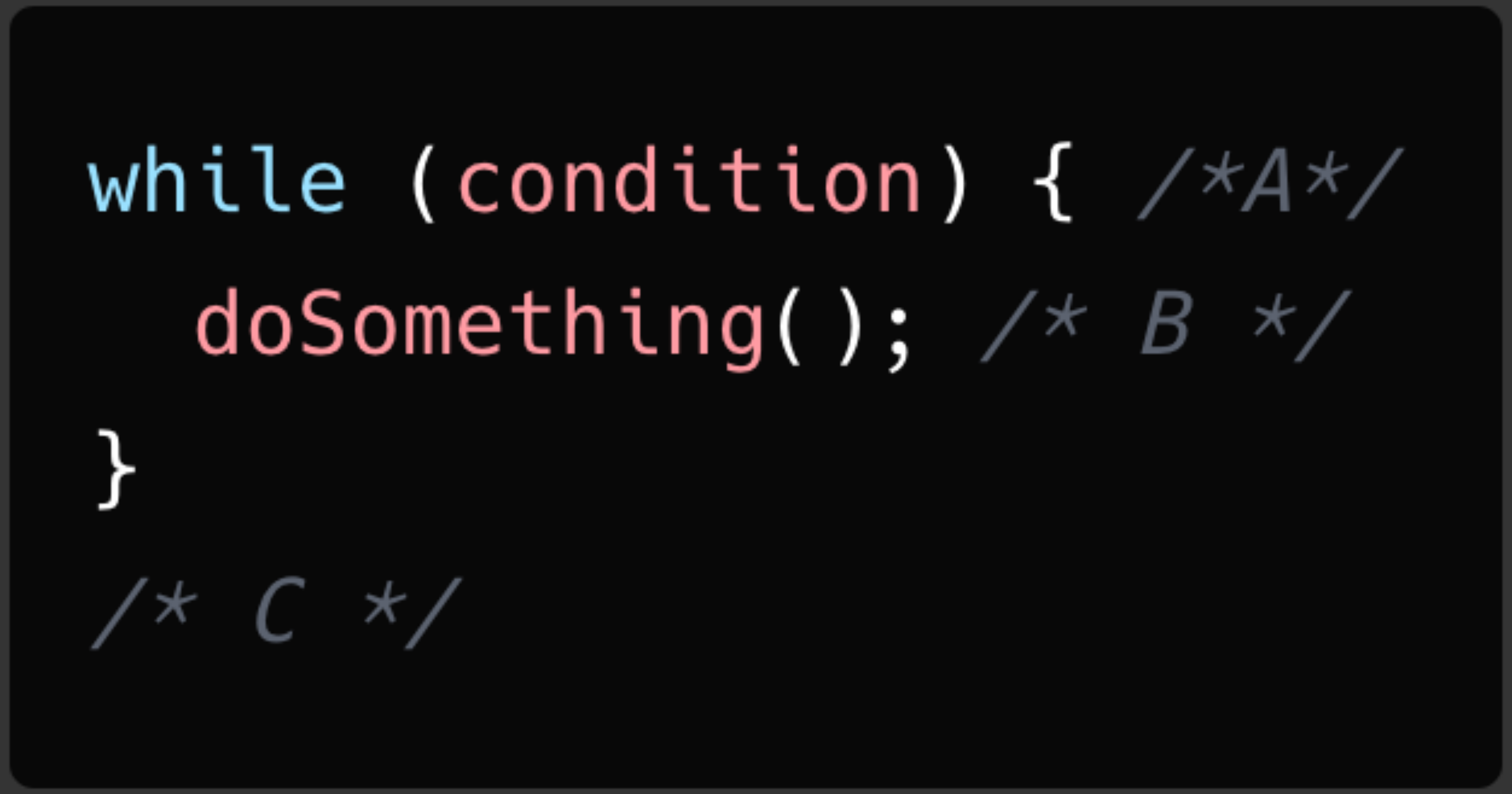
$$\begin{tikzcd}
s \arrow[d] & \\
2 \arrow[dd, "F"'] \arrow[dr, "T"] & \\
 & 3 \arrow[dl] \\
e &
\end{tikzcd}$$

Nesting

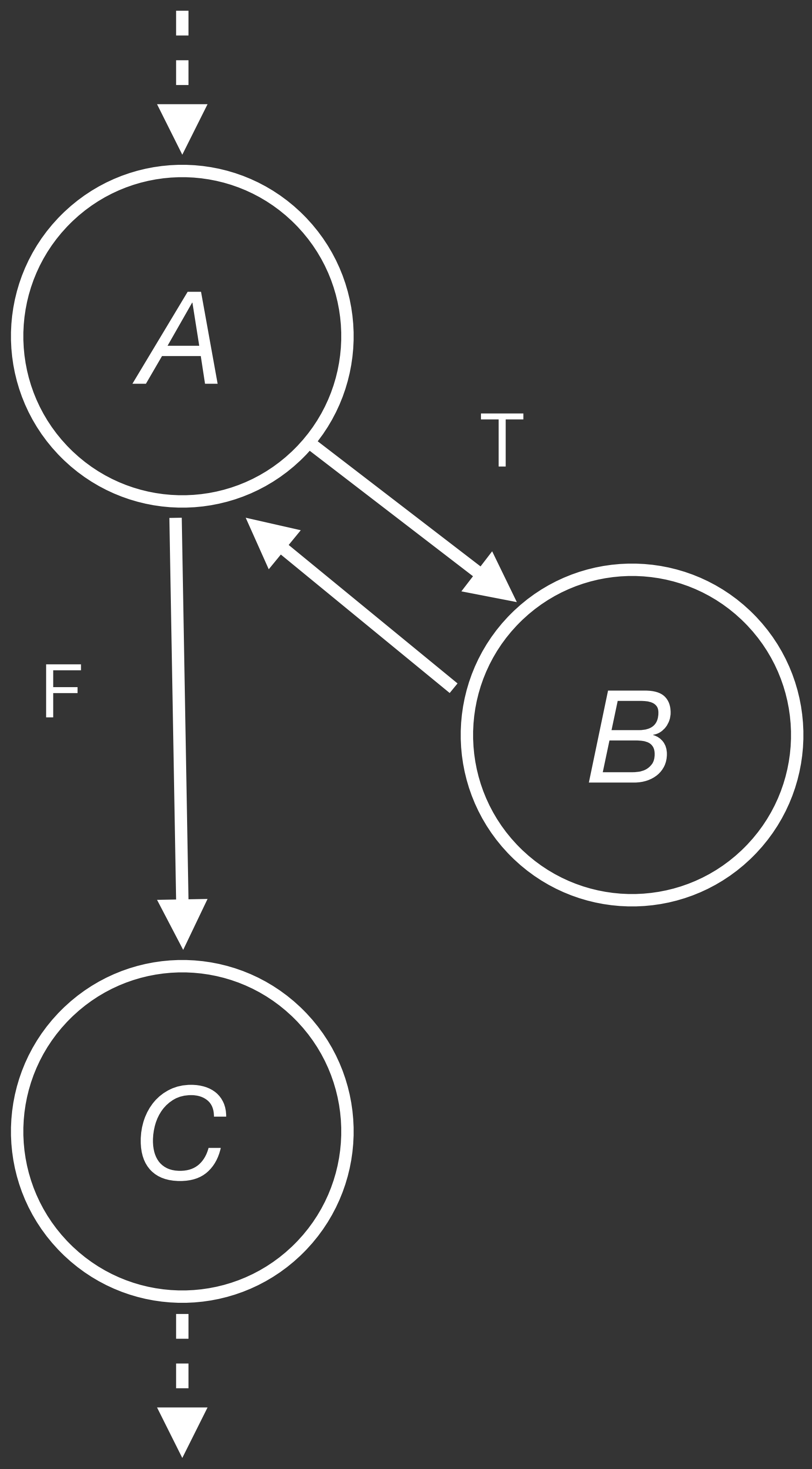
```
1 public void printGreeting() {
2   if (isMorning()) {
3     System.out.println("Good Morning!");
4   } else if (isAfternoon()) {
5     System.out.println("Good Afternoon!");
6     System.out.println("Lovely day for a stroll!");
7   } else if (isEvening()) {
8     System.out.println("Good Evening!");
9   }
10 }
```

$$\begin{tikzcd}
s \arrow[d] & & \\
2 \arrow[d, "F"'] \arrow[r, "T"] & 3 \arrow[dddl, bend left=60] & \\
4 \arrow[d, "F"'] \arrow[drr, "T"] & & \\
7 \arrow[d, "F"'] \arrow[r, "T"] & 8 \arrow[dl] & \text{5-6} \arrow[dll, bend left] \\
e & &
\end{tikzcd}$$

“While” Constructs

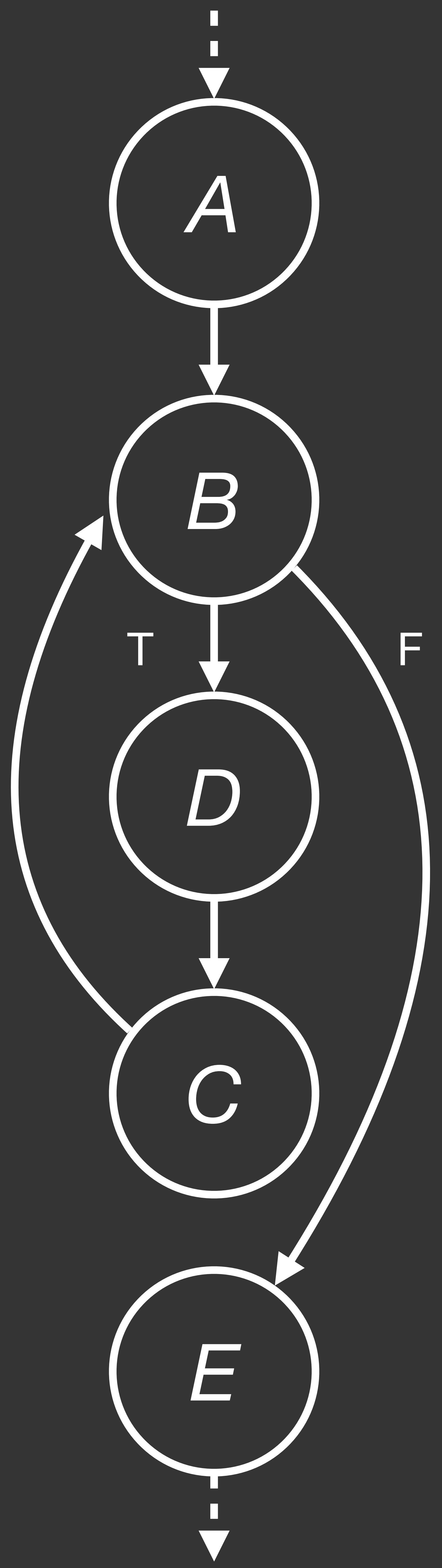


```
while (condition) { /*A*/
  doSomething(); /* B */
}
/* C */
```


$$\begin{tikzcd}
{} \arrow[d, dashed] & \\
A \arrow[r, bend left, "T"] \arrow[d, "F"'] & B \arrow[l, bend left] \\
C \arrow[d, dashed] & \\
{} &
\end{tikzcd}$$

“For” Constructs

```
for (/*A*/ int i = 0; /*B*/ i < 10; /*C*/ i ++) {
  doSomething(); /* D */
}
// E
```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{}
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1 public int countZeros(int[] x) {
2   int count = 0;
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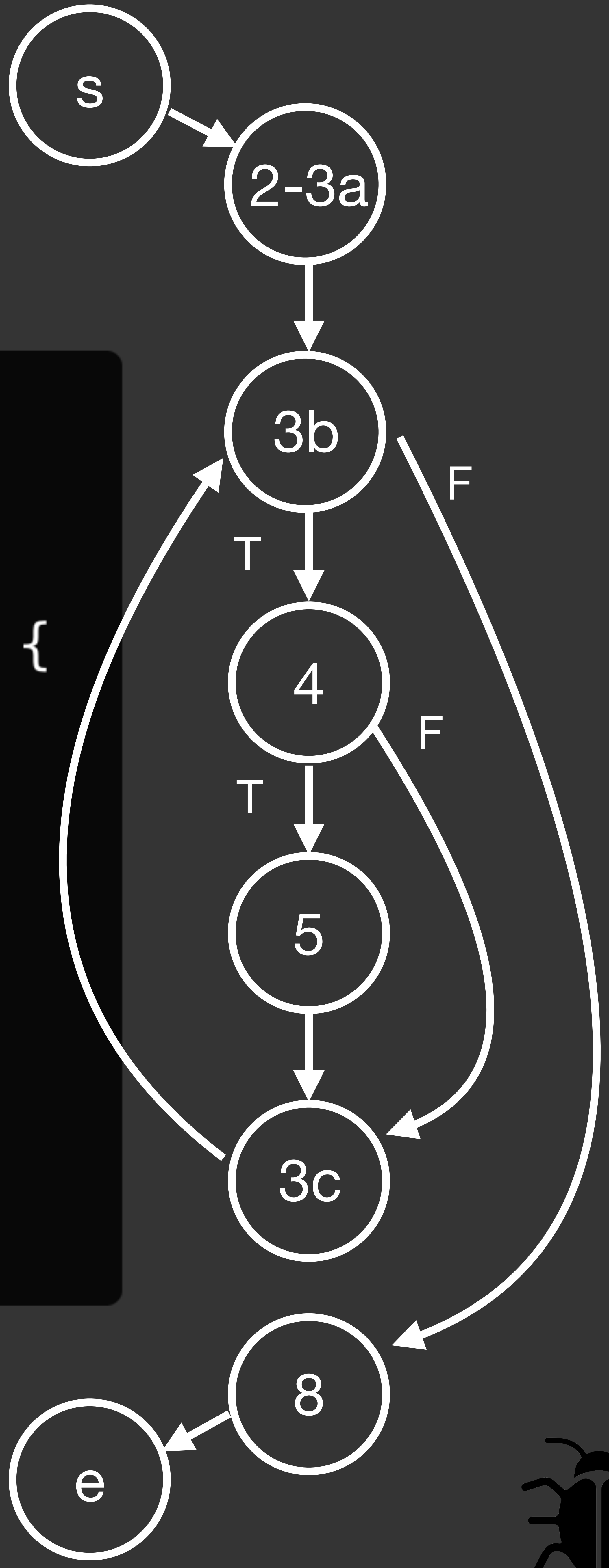

Statement Coverage

The test suite should execute all nodes of the CFG

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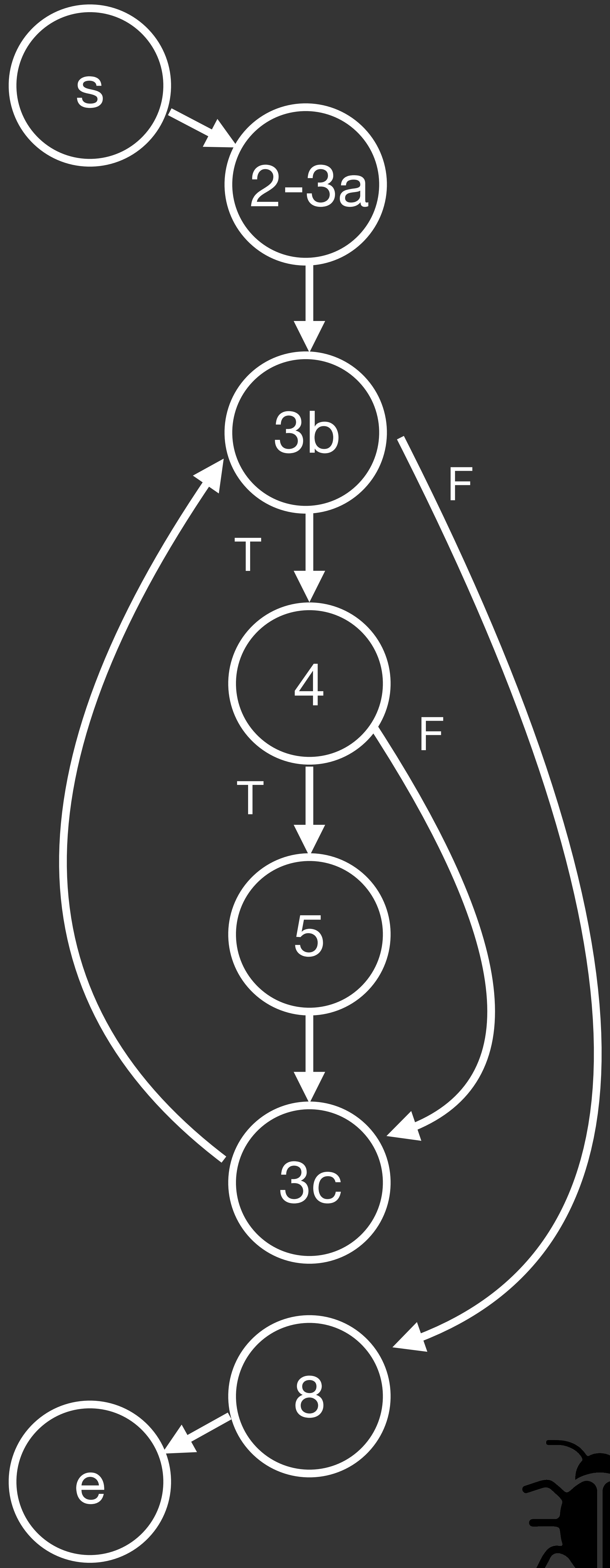

Statement Coverage

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

It takes the path s → 2-3a → 3b → 4 → 5 → 3c → 3b → e

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

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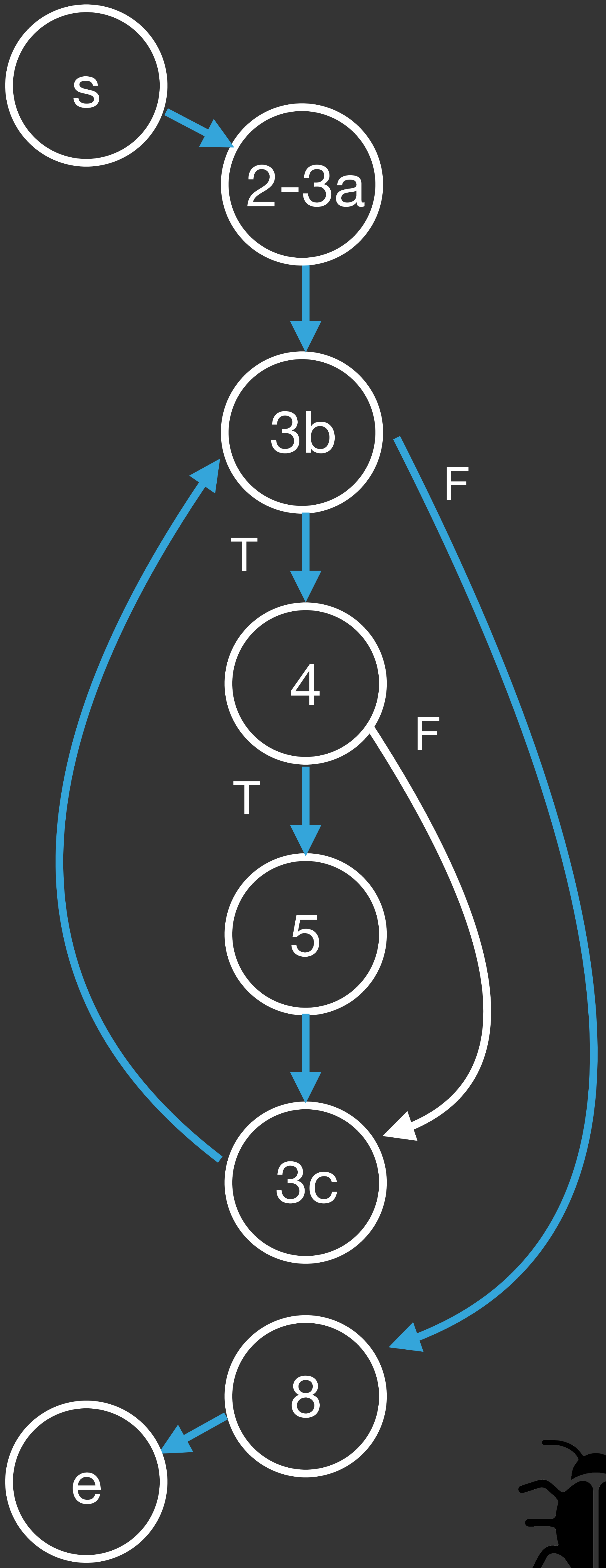
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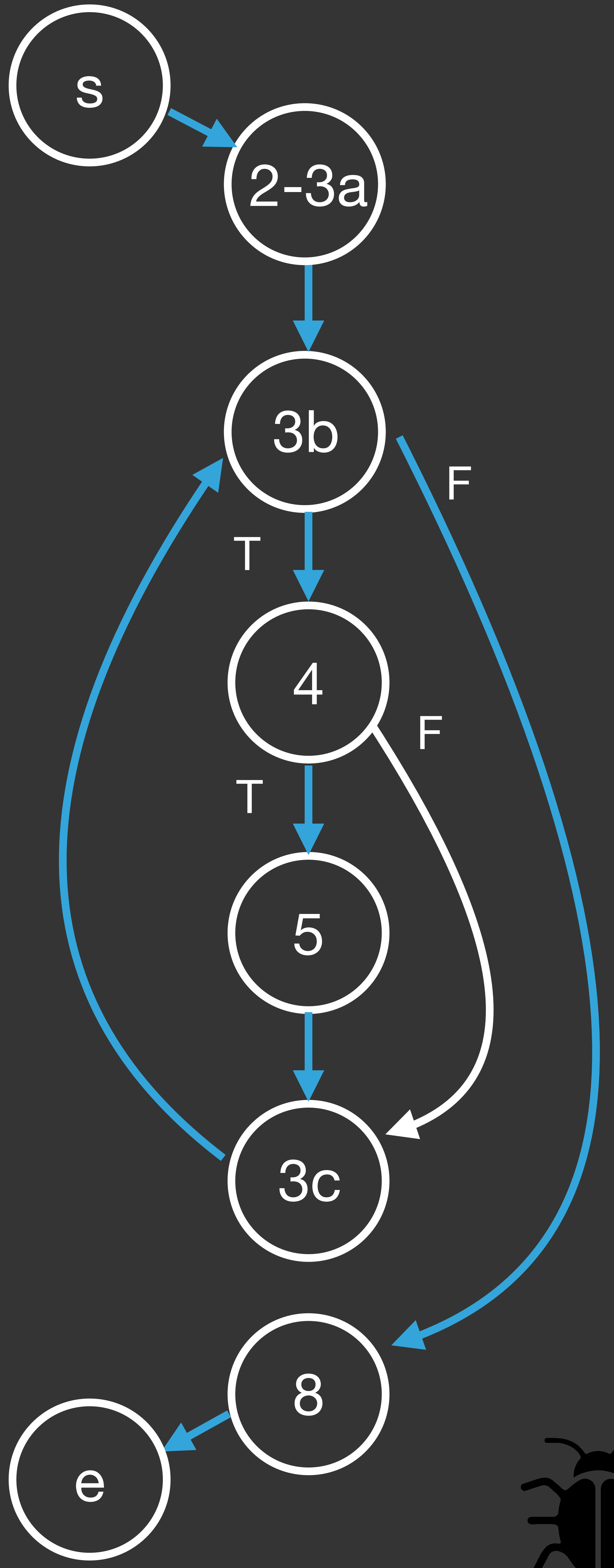

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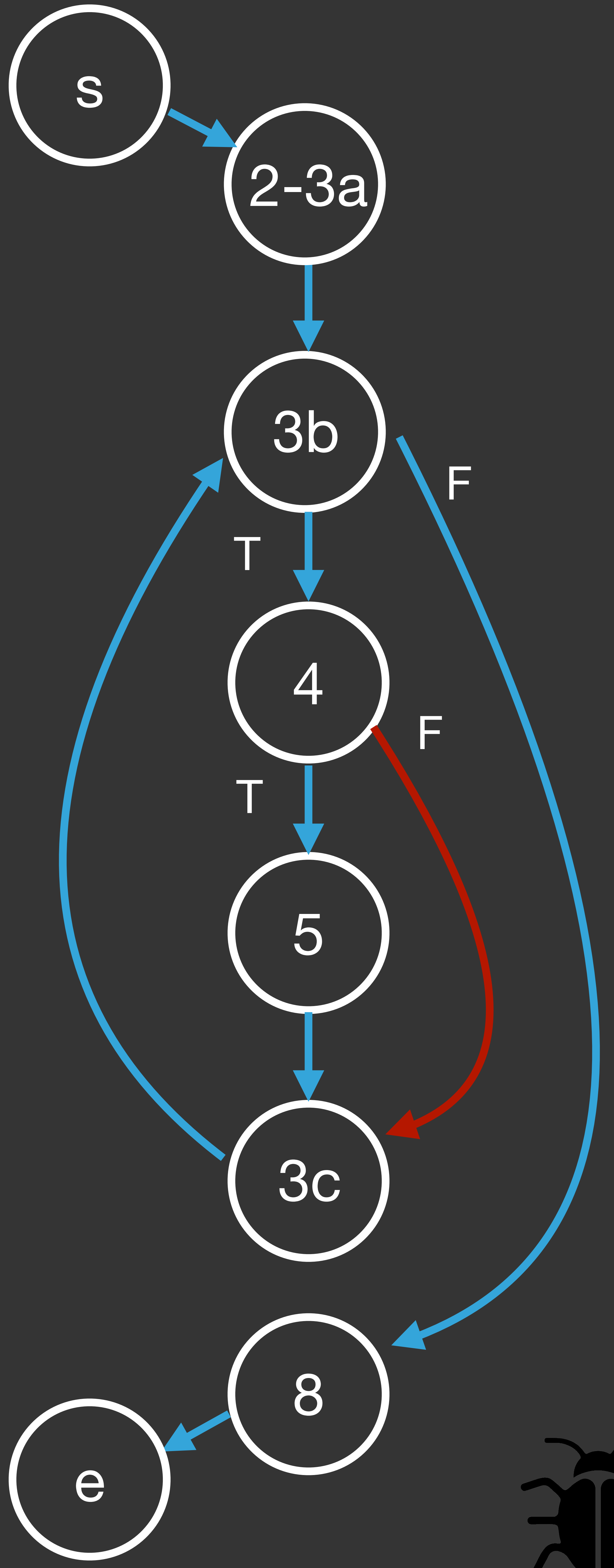

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The test case x = [0] and x = [1] would execute all true/false branches

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])

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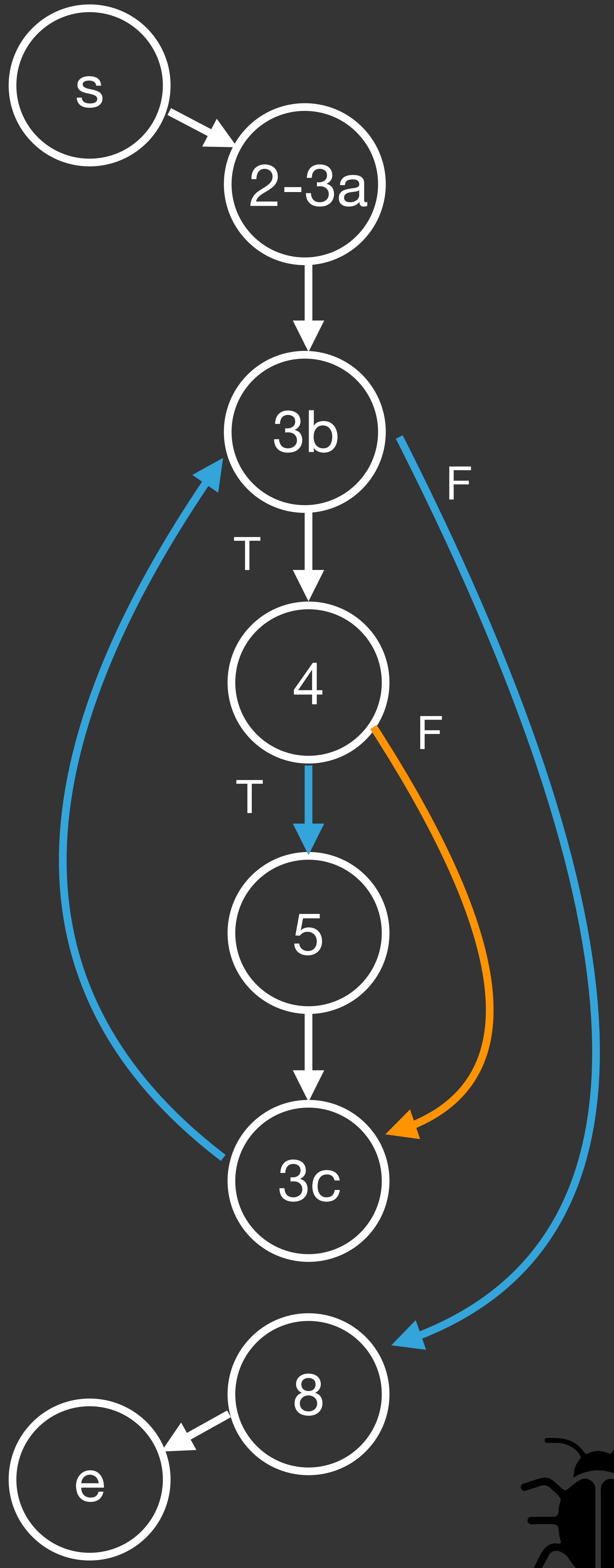

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Path Coverage

The test suite should execute all paths through the CFG

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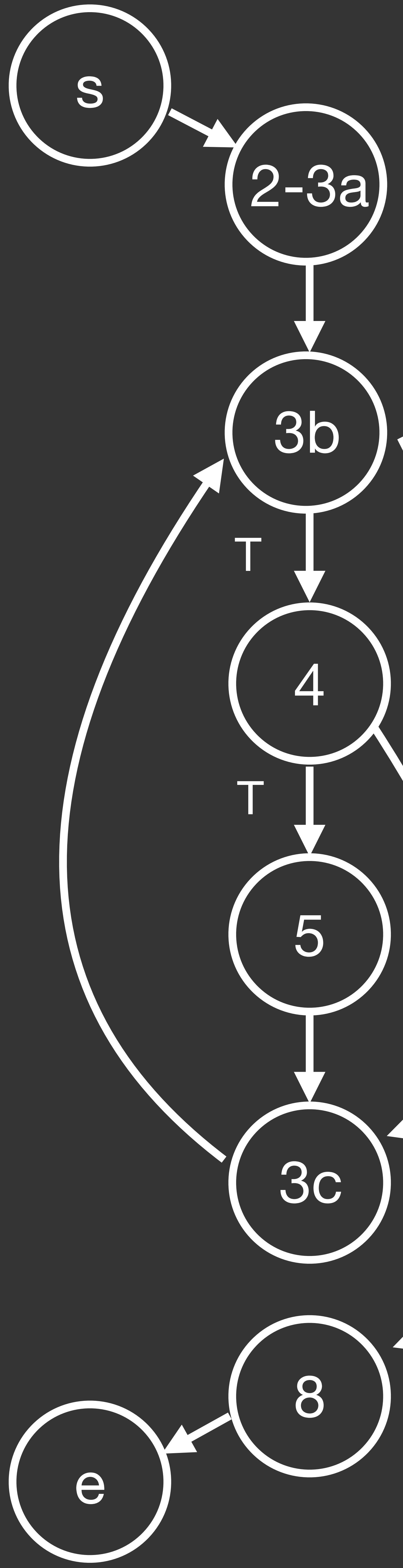

Path Coverage

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

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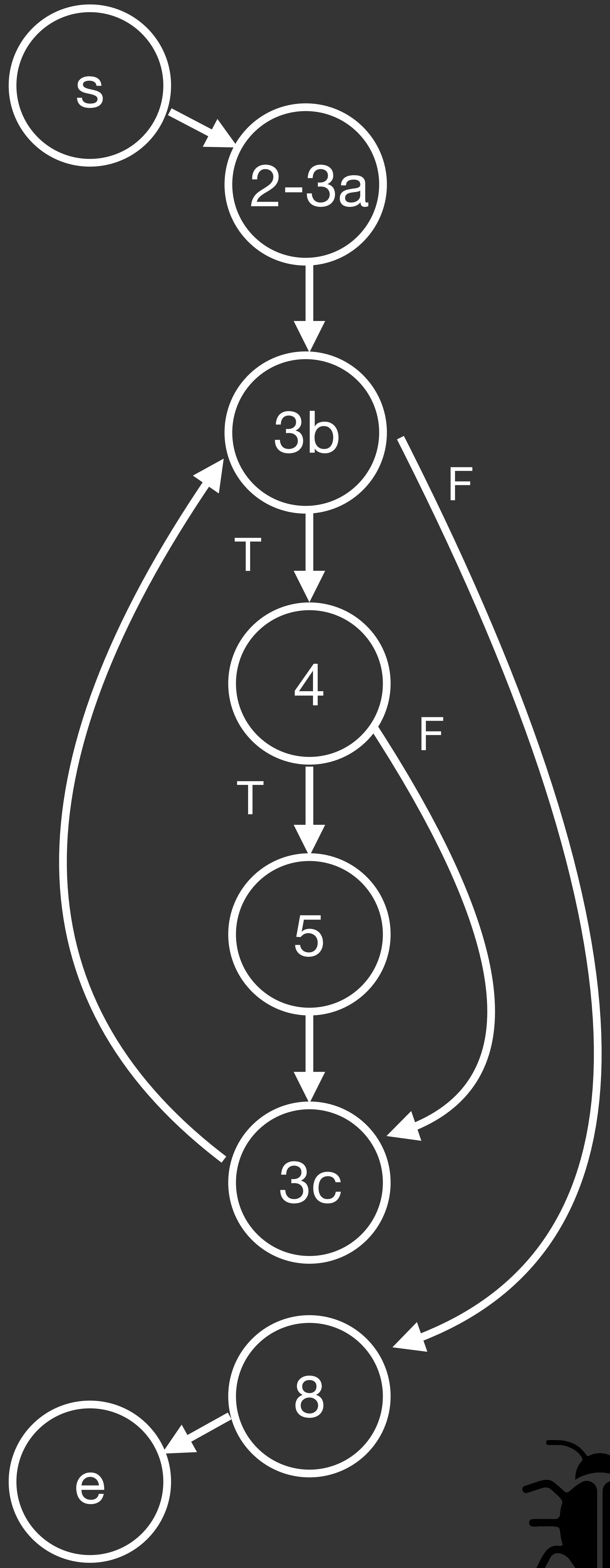

There is a problem lurking here for Branch Coverage. What is it?

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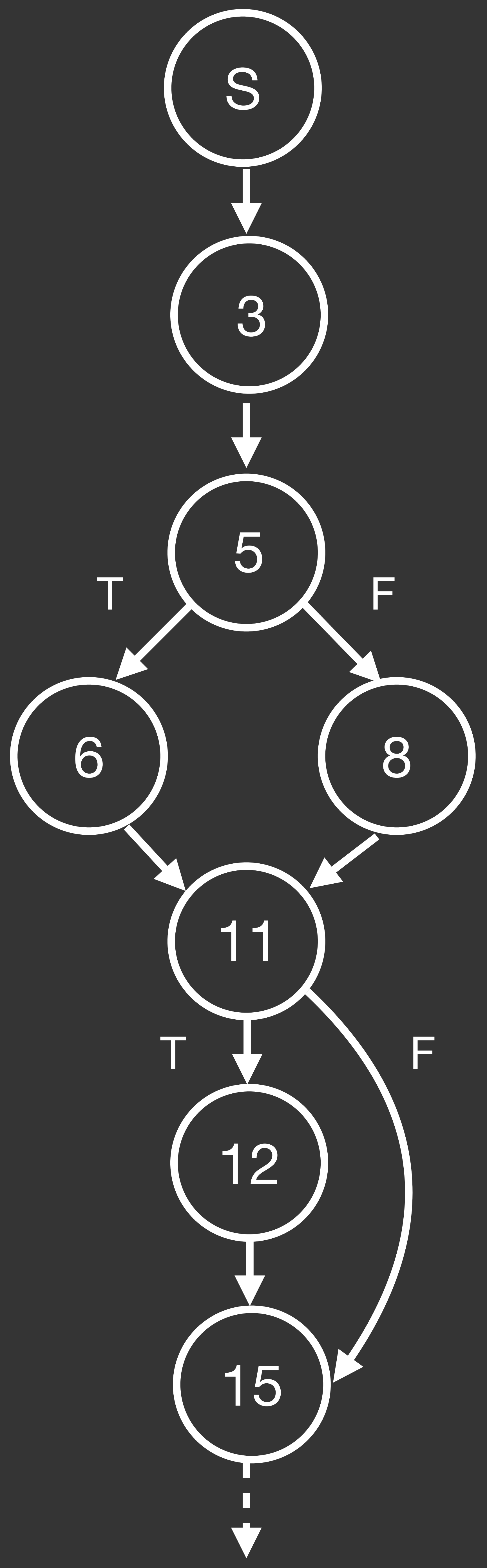
 5   if (x > 0) {
 6       y = y + 1;
 7   } else {
 8       y = y + 2;
 9   }
10
11   if (y > 0) {
12       y = y + 1;
13   }
14
15   // ...
```



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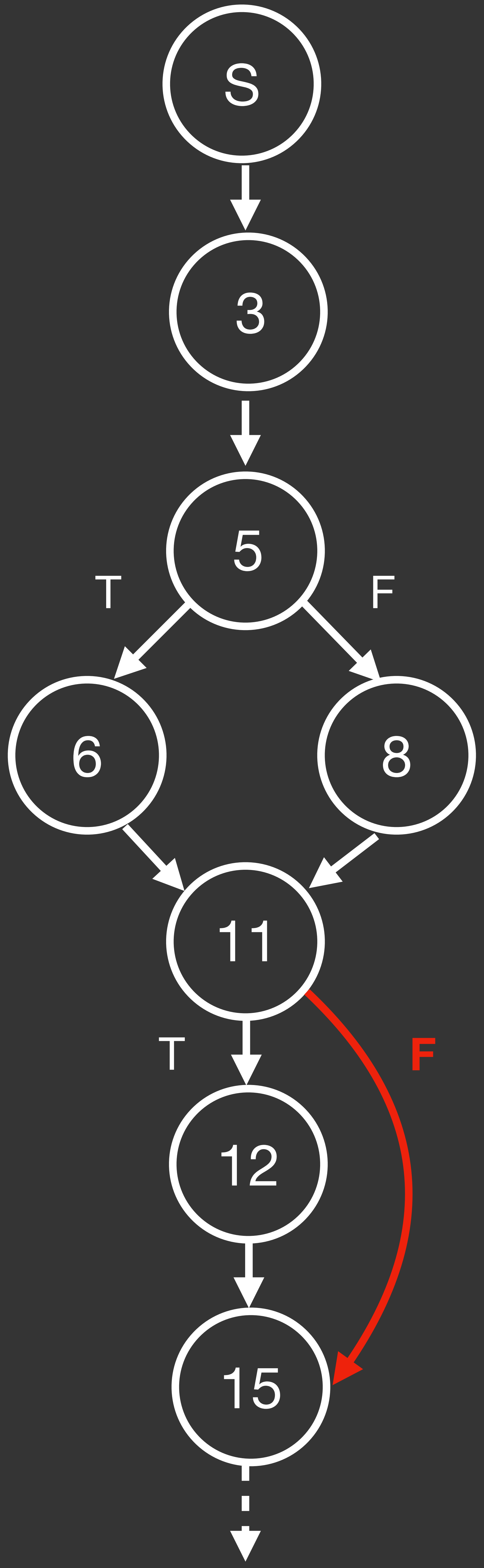

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- This *can* also happen with Statement Coverage
    - Infeasible statements point to dead code
- It is *more likely* to happen with Branch Coverage
    - Infeasible branches point to redundant decisions in the code
- It is *very likely* with Path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

Subsumption of Structural Coverage Criteria

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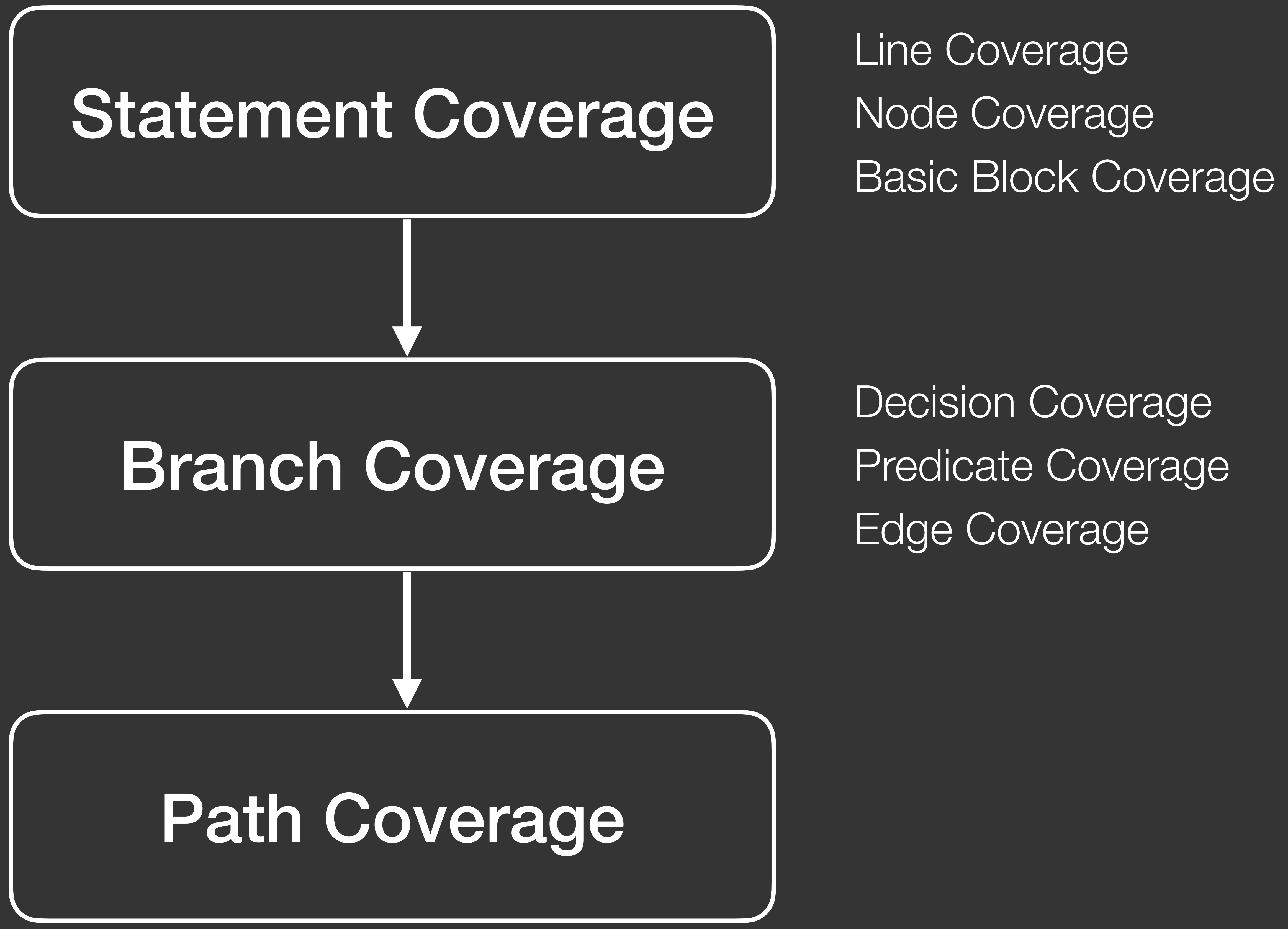

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    - As such Statement/Line Coverage is a commonly used metric
    - But Branch Coverage is stronger, and obtainable without much more additional effort
    - Path Coverage is less common and often intractable