CMPT 473
Software Testing, Reliability and Security

Graph Coverage

Nick Sumner

Recall: Coverage/Adequacy

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- Need to determine if a test suite covers/is adequate for our quality objectives.
- So far: Input & Requirements based

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How might we do better?

White Box / Black Blox

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  - Treats the program like an opaque box
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- Considering only the requirements or input is a ***black box*** approach
  - Treats the program like an opaque box
  - No deep knowledge of the program's structure
- Techniques that use artifacts of the program structure are ***white box*** approaches
  - They can 'see into' the program's implementation

White Box Testing

- What is a simple approach that solves our problem here?

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- Statement Coverage
  - How many of the statements did the suite test? (%)

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White Box Testing

- What is a simple approach that solves our problem here?
- Statement Coverage
  - How many of the statements did the suite test? (%)
- Branch Coverage
  - How many of the condition outcomes were tested? (%)

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So a bit of review…

Graphs

- What is a *graph* G?

Graphs

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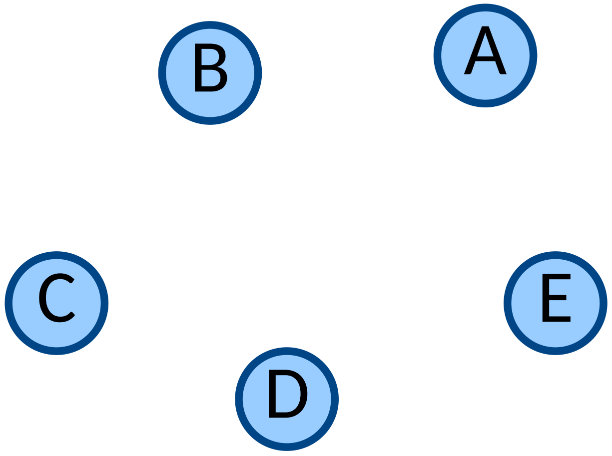
  - A set N of nodes



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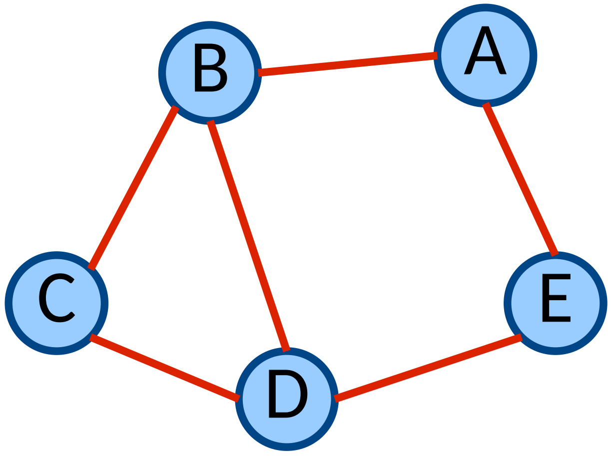

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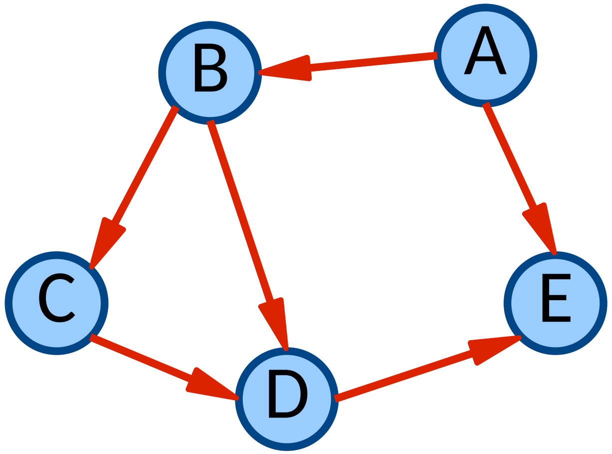
- When edges are directed from one node to another, the graph is a *directed graph*



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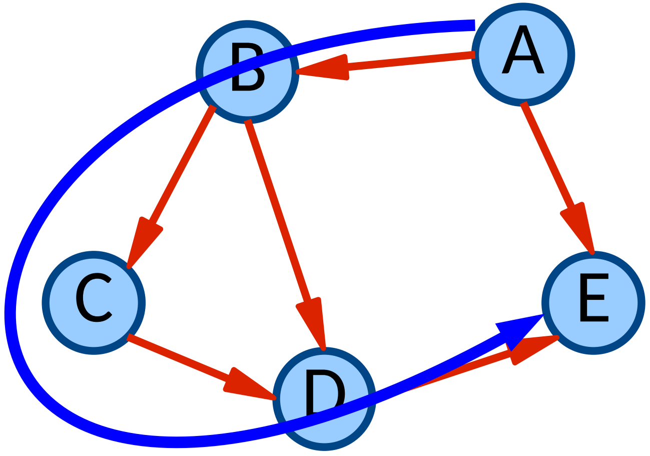

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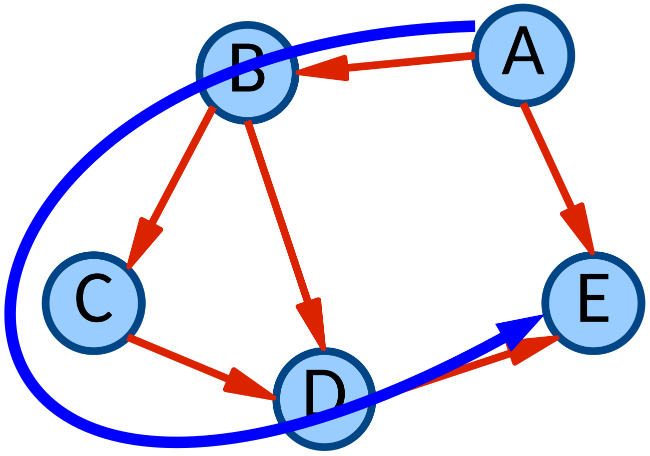
ABCDE



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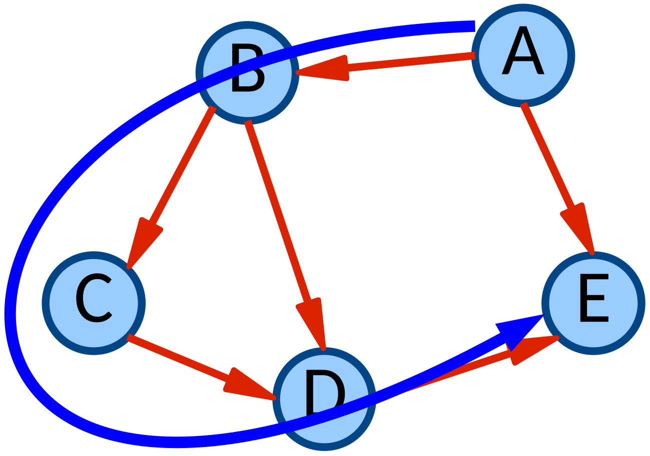

ABCDE
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AE
BCDE
BD

Control Flow Graphs (CFGs)

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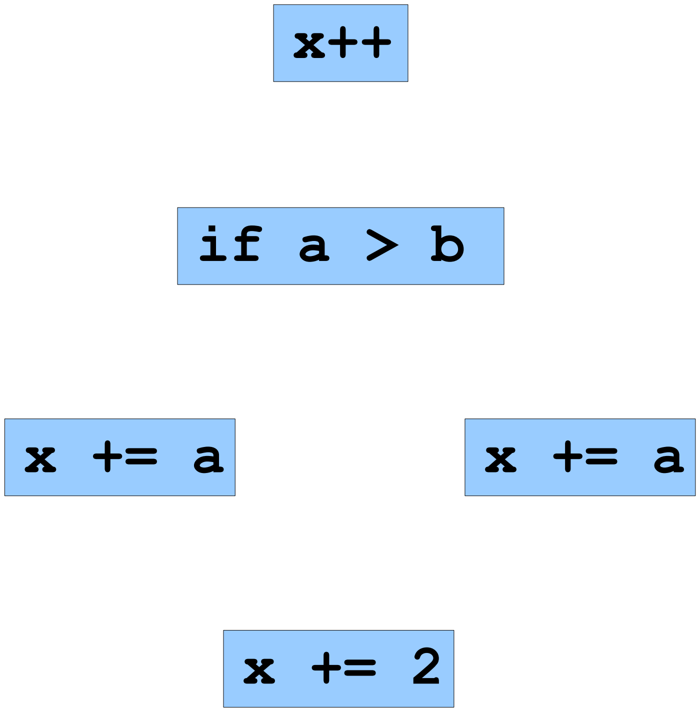
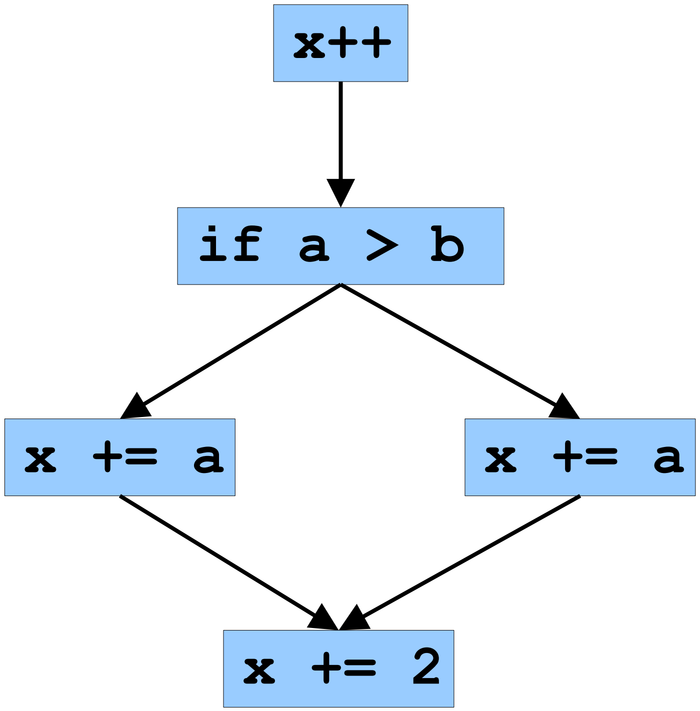


Control Flow Graphs (CFGs)

- Programs can be modeled as graphs
  - Used extensively in compilers
  - Also used in testing!
- *Control Flow Graphs*
  - Nodes comprise the code of a program
  - Edges show the paths that an execution may take through a program



Control Flow Graphs

Example:

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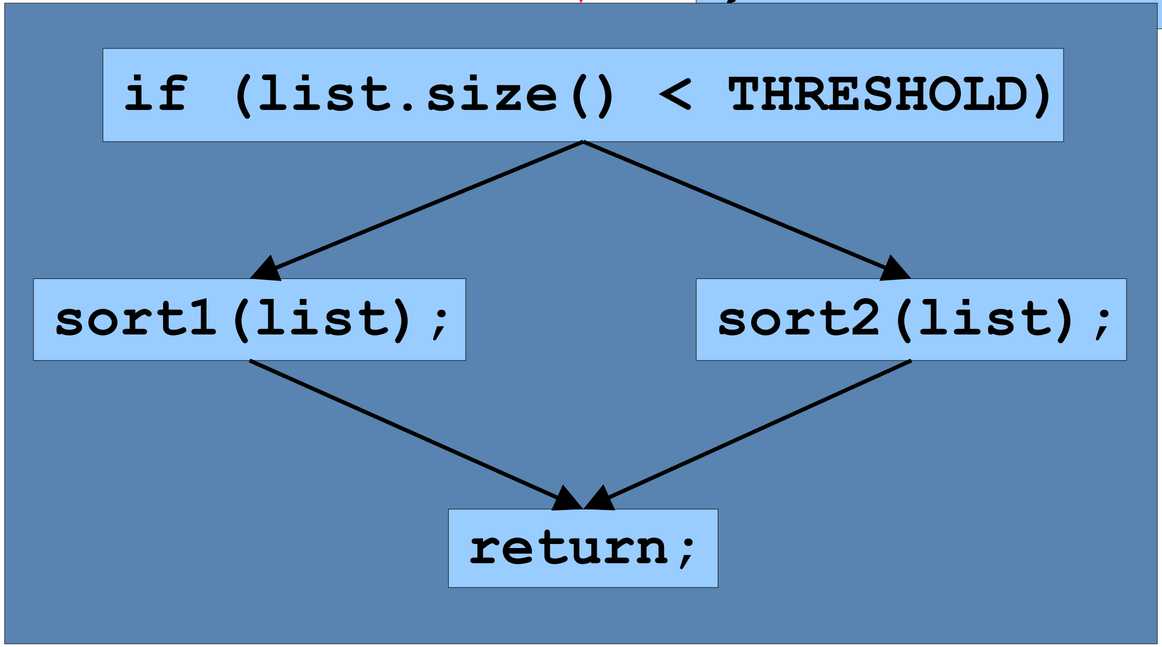

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```
if (list.size() < THRESHOLD)
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```
sort1(list);
```

```
sort2(list);
```

```
return;
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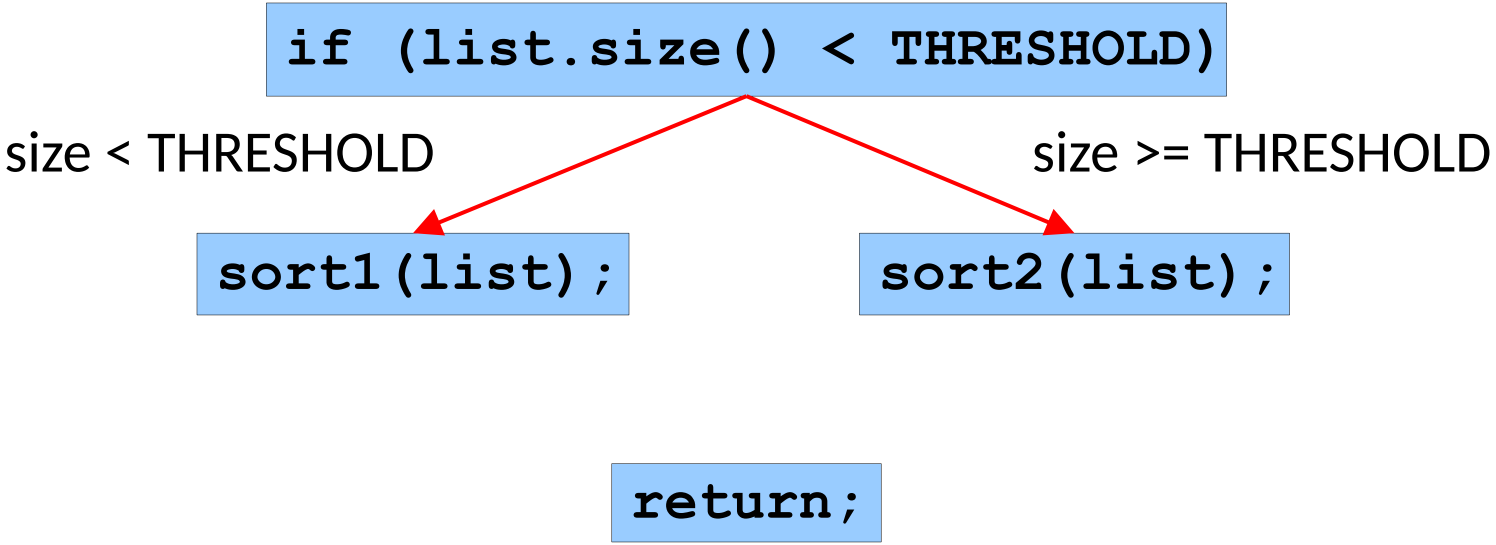

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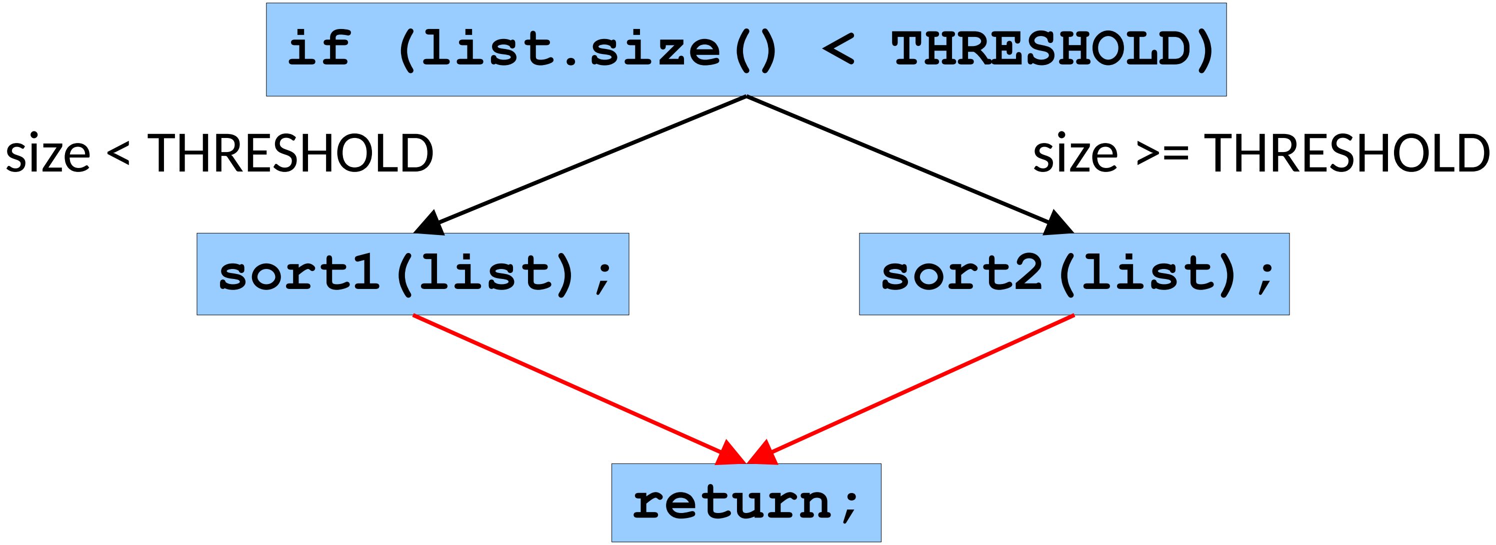
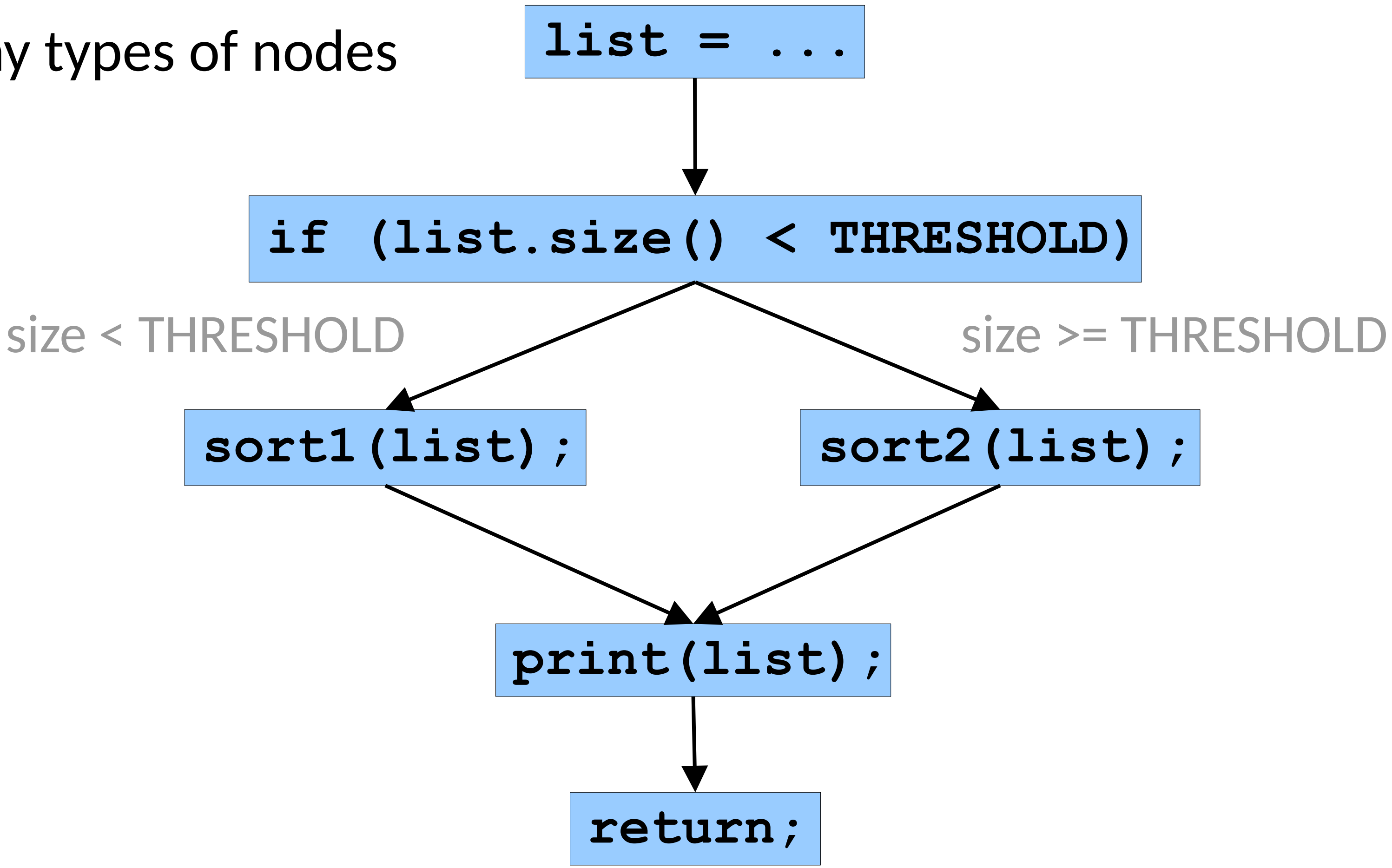


Control Flow Graphs

- Many types of nodes



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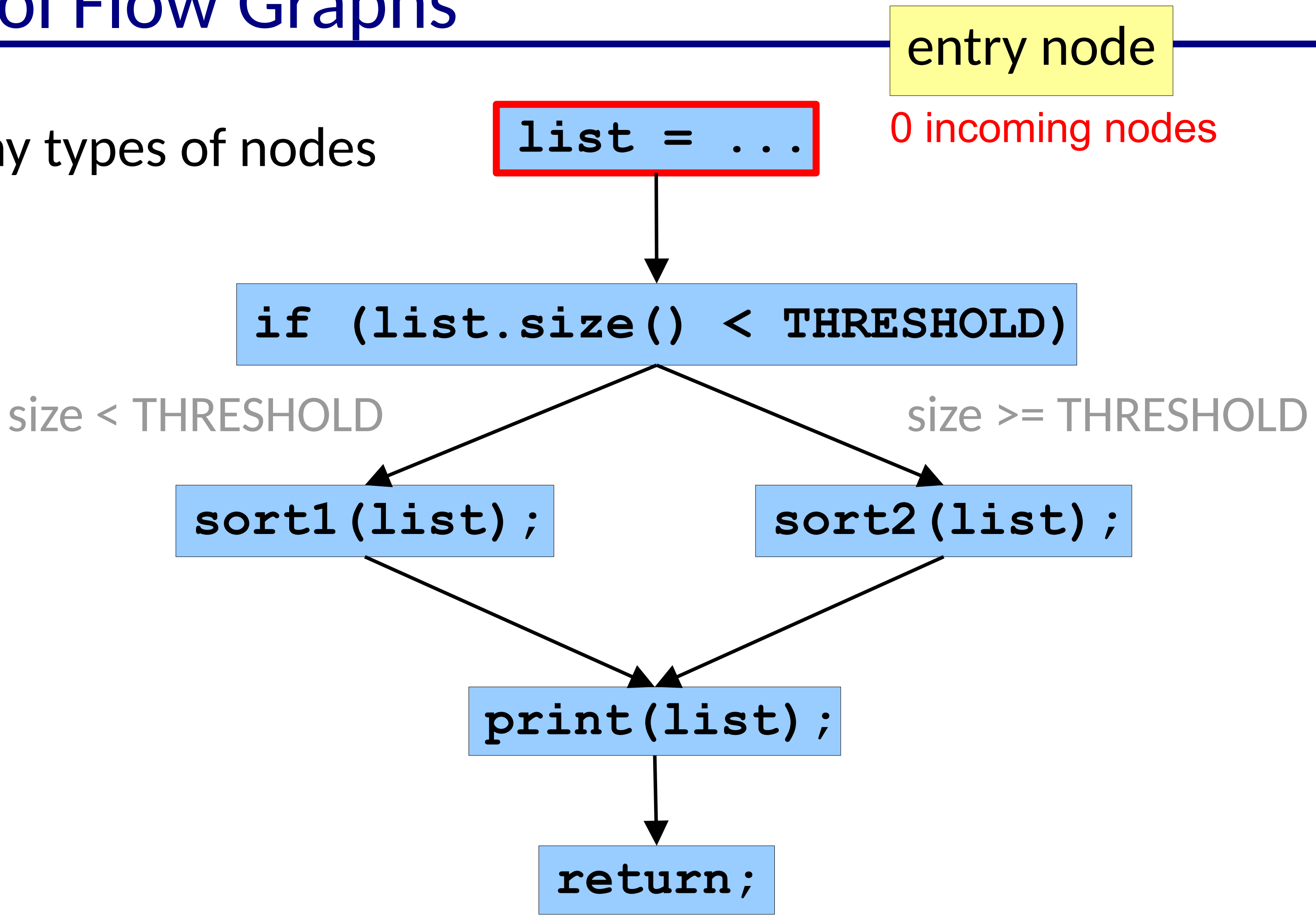

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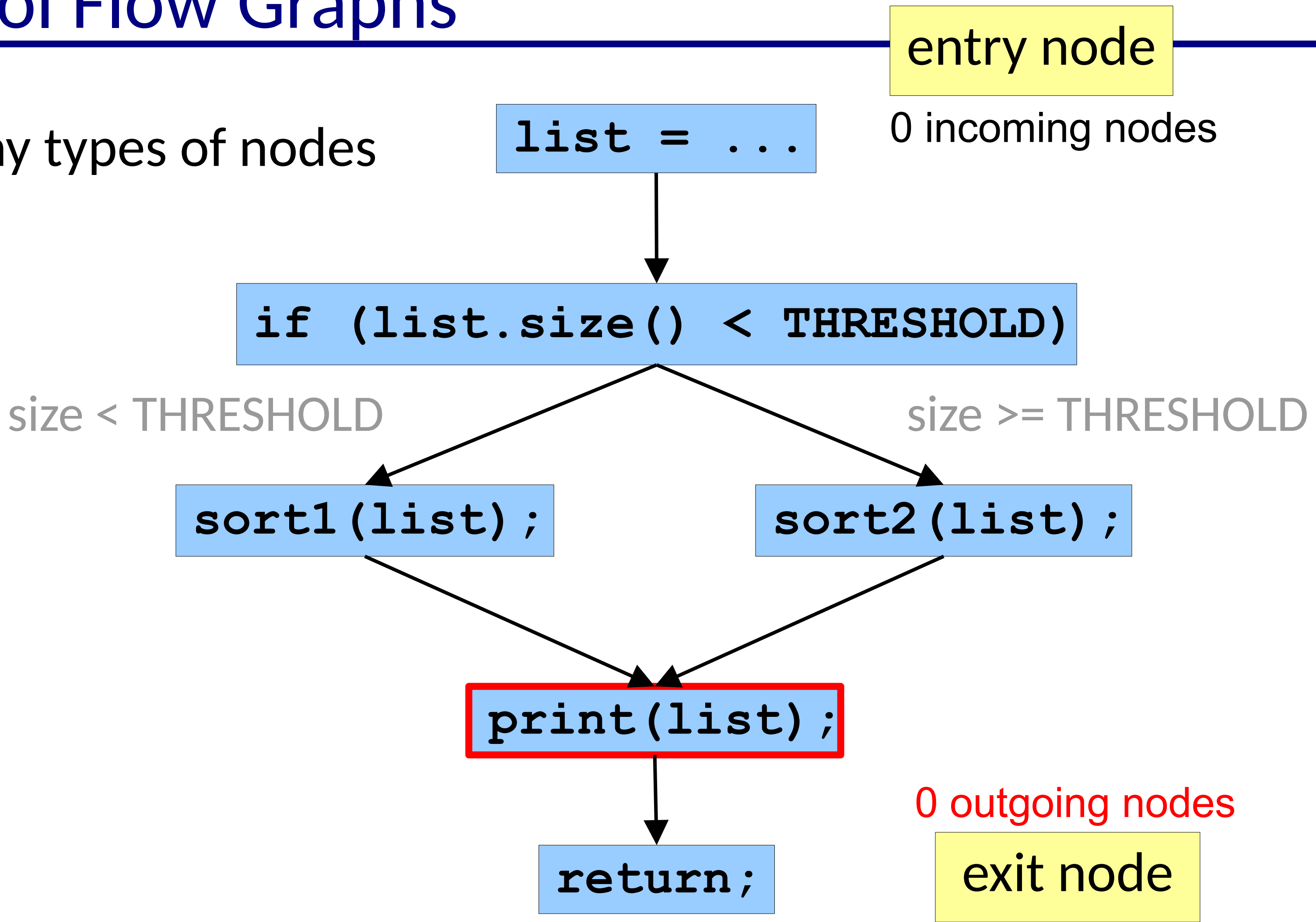

Control Flow Graphs

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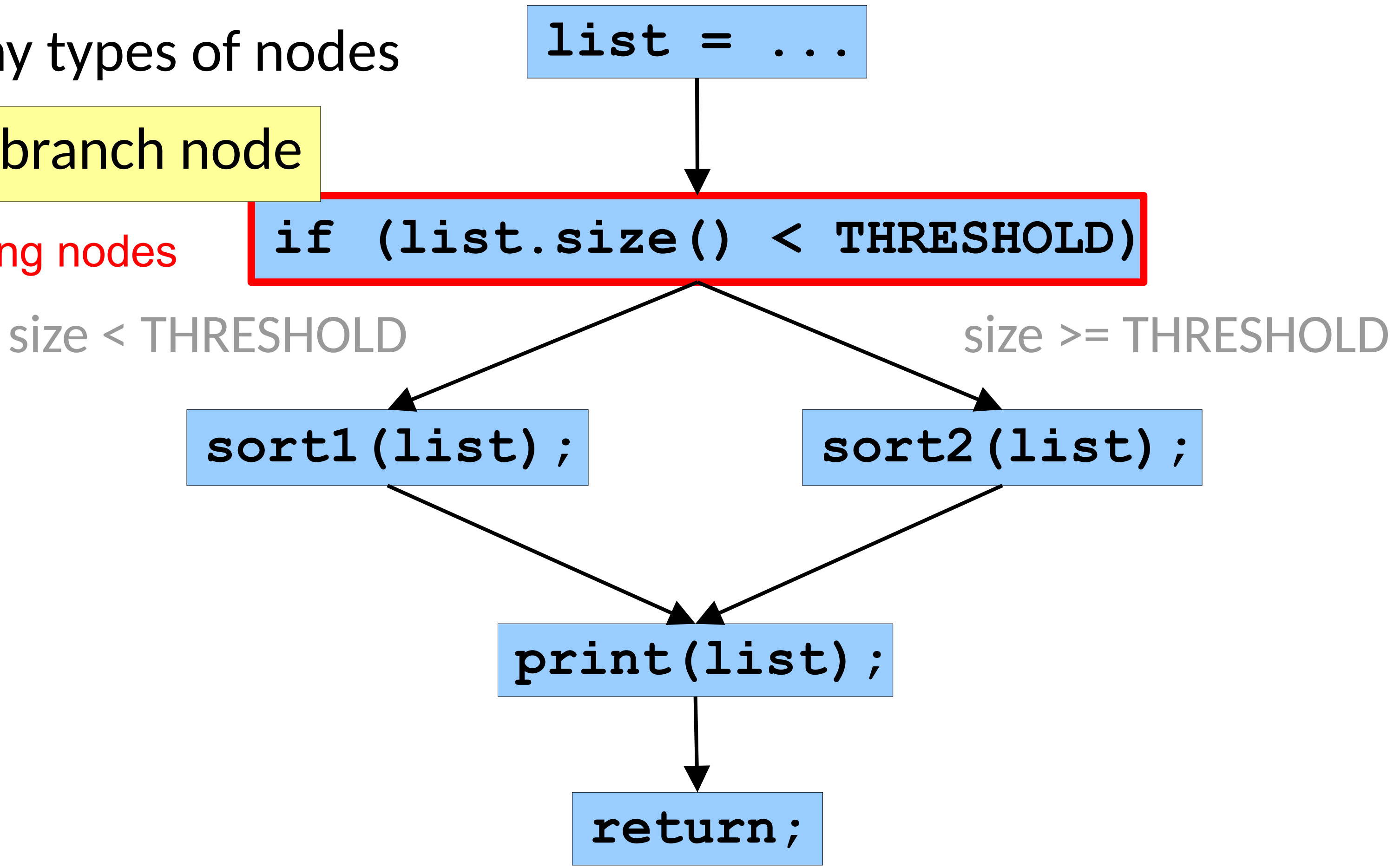
decision / branch node

>1 outgoing nodes



Control Flow Graphs

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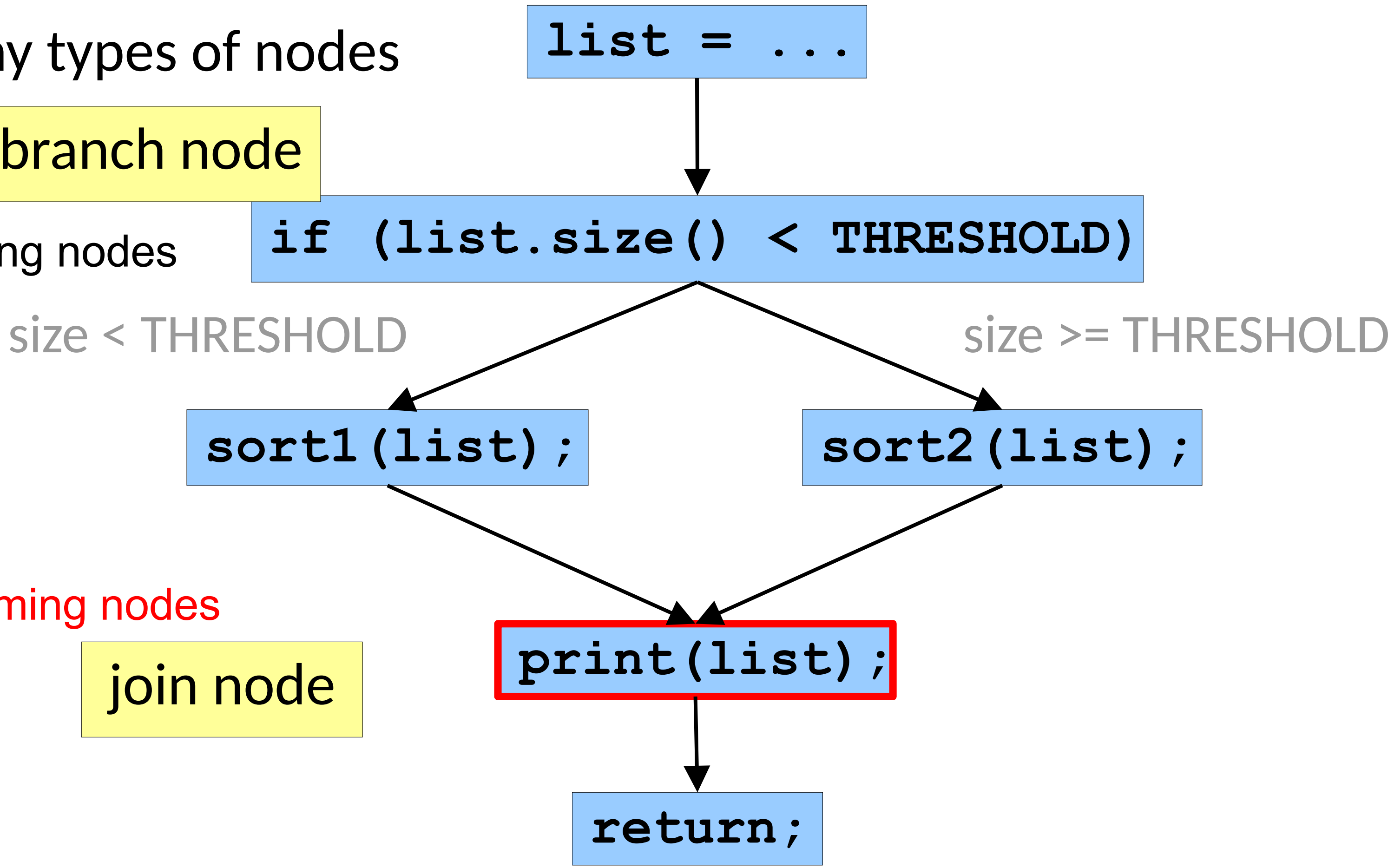
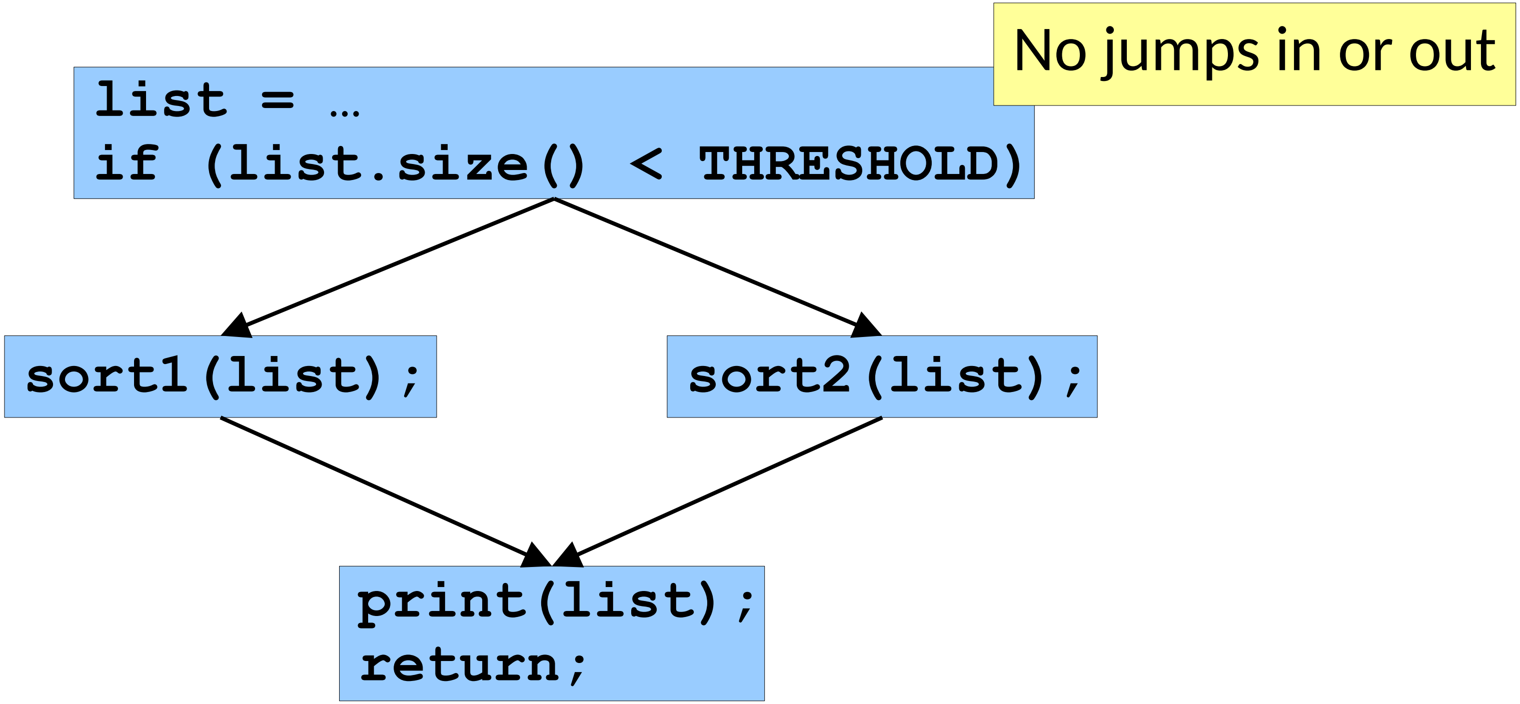
join node



Control Flow Graphs

- Straight line code is grouped into ***basic blocks***



Control Flow Graphs

- Many patterns arise from common constructs

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q = 0;
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while r >= y {
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```
if (x == 0 || y/x > 1) {
    foo(x, y);
}
```

Control Flow Graphs

```
x = 0;
while (x < y) {
    y = f (x, y);
    if (y == 0) {
        break;
    } else if (y < 0) {
        y = y*2;
        continue;
    }
    x = x + 1;
}
print (y);
```


From: Ammann & Offutt

Control Flow Graphs

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            break;
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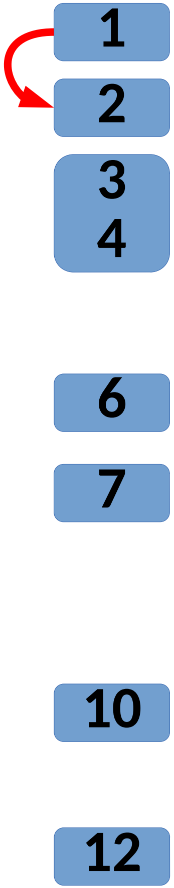


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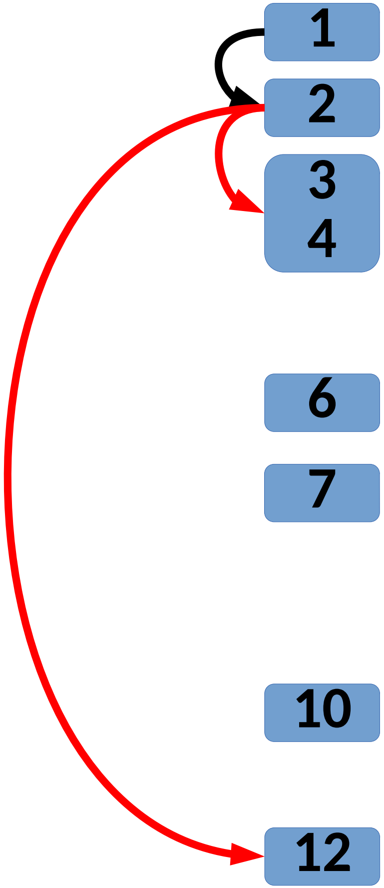


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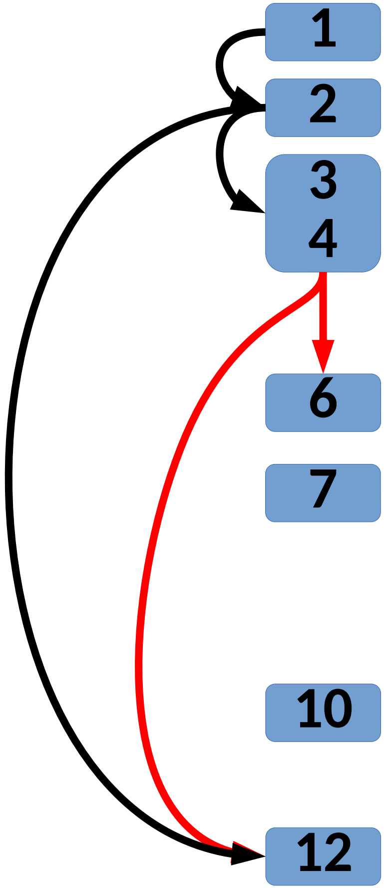


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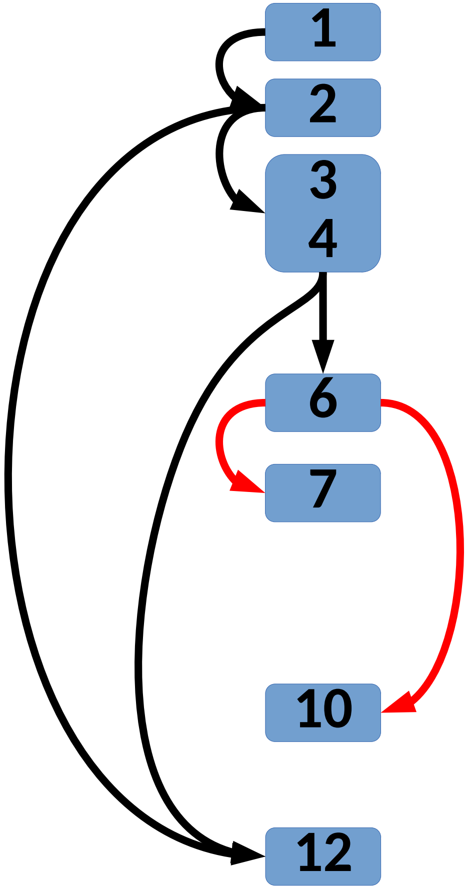


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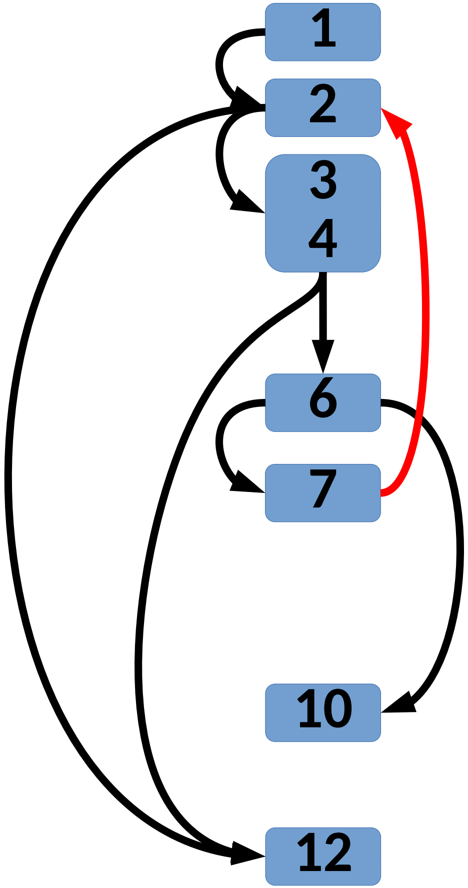


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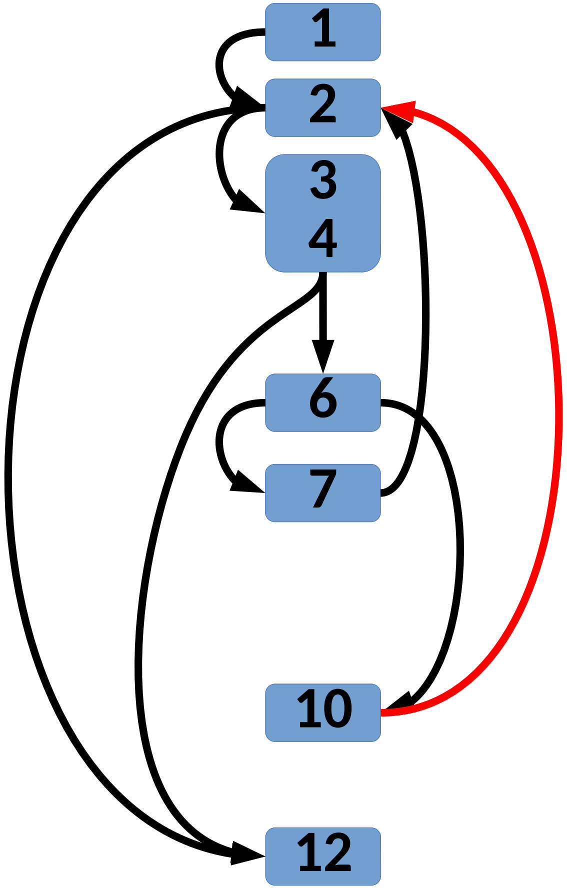


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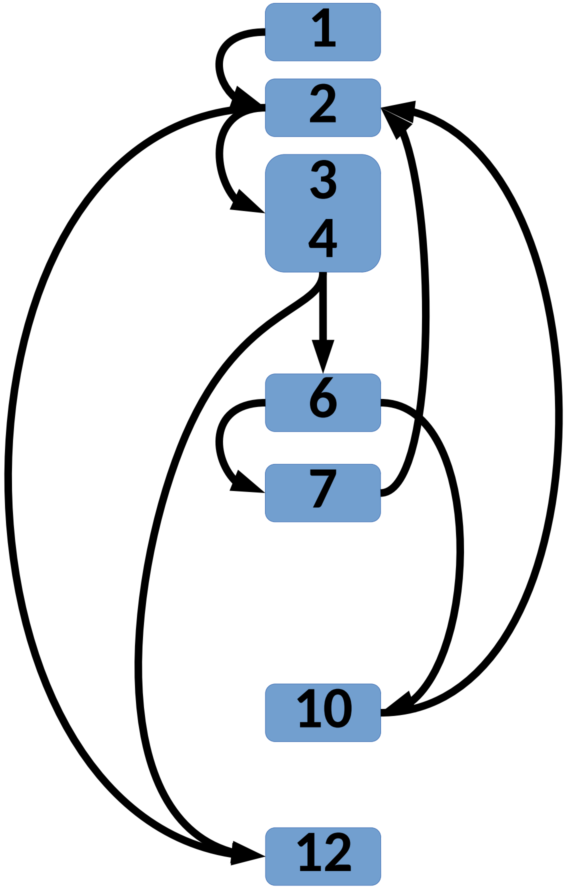


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- Statement Coverage → Node Coverage
  - Try to cover all *reachable* basic blocks

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Thinking in terms of node coverage can be more efficient. **Why**?

CFG Coverage

- Statement Coverage → Node Coverage
  - Try to cover all reachable basic blocks
- Branch Coverage → Edge Coverage
  - Try to cover all *reachable* paths of length ≤ 1

CFG Coverage

- Statement Coverage → Node Coverage
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  - Try to cover all reachable paths of length ≤ 1

How do node & edge coverage compare? **Why**?

Pragmatic Concerns

- The *goal* is full coverage (of whatever criteria)

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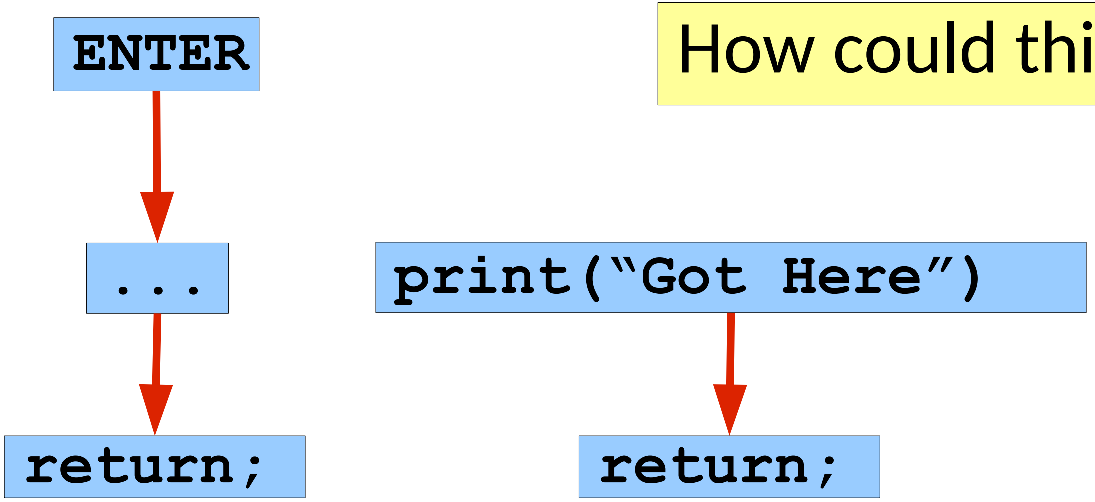

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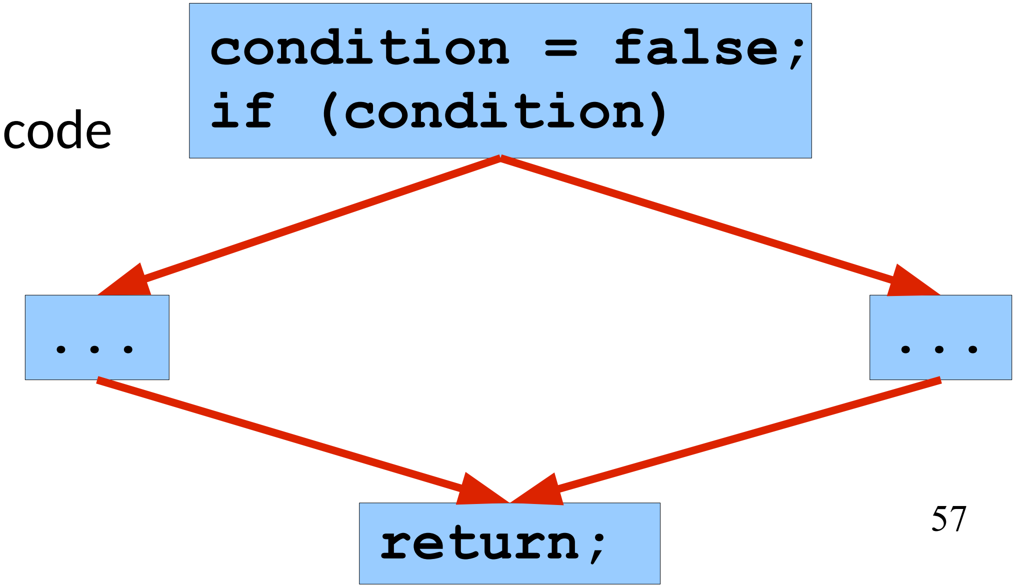

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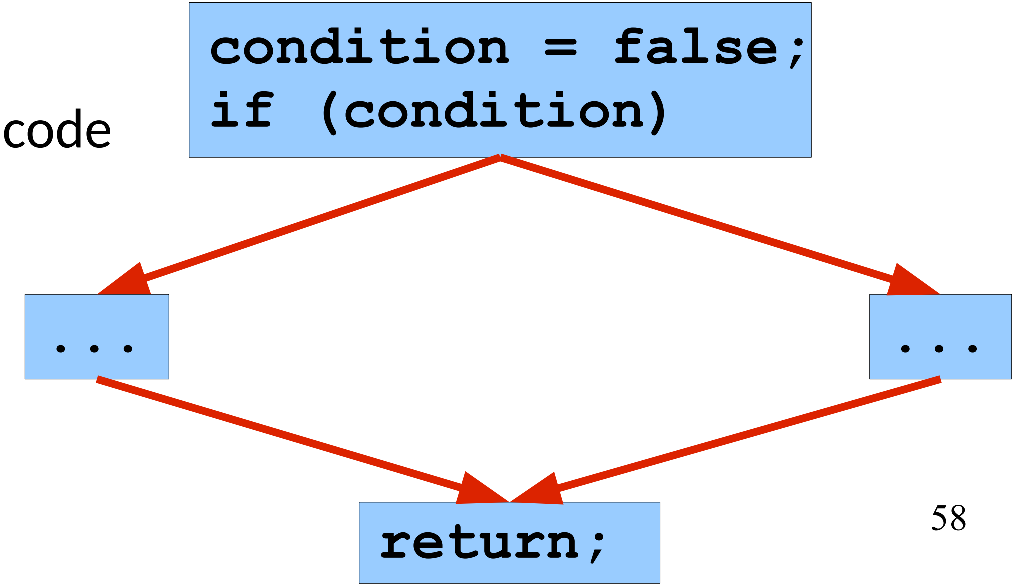
This can be *undecidable*!



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- So what do you do in practice?
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  - Relative degrees of coverage matter (40%? 80%?)

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```
def misleading(x: int, y: int) -> bool:
  if x > 0 or y > 0:
      return x + y >
  return x * y < 20
```

```
def test_misleading():
    assert not misleading(0,0)
    assert misleading(1,0)
```

pytest-cov → 100% branch coverage

Pragmatic Concerns

- Many branch coverage tools work only at **`if`** granularity

```
def misleading(x: int, y: int) -> bool:
```

```
ding():
isleading(0,0)
```

```
function misleading(x, y) {
  if (x > 0 || y > 0) {
    return x + y > 0;
  }
  return x * y < 20;
}
```

```
test('misleading branch coverage', () => {
  expect(misleading(0, 0)).toBe(true);
  expect(misleading(1, 0)).toBe(true);
});
```

jest → 100% branch coverage

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  - "*Condition coverage*" can complement this but is also misleading (more later)

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- Many branch coverage tools work only at `if` granularity
  - "Condition coverage" can complement this but is also misleading
- Other tools consider short-circuits to be branches
  - Common in native languages, Java, …
  - Recommended practice by the FAA….

Pragmatic Concerns

- Many branch coverage tools work only at `if` granularity
  - “Condition coverage” can complement this but is also misleading
- Stronger graph coverage criteria can help

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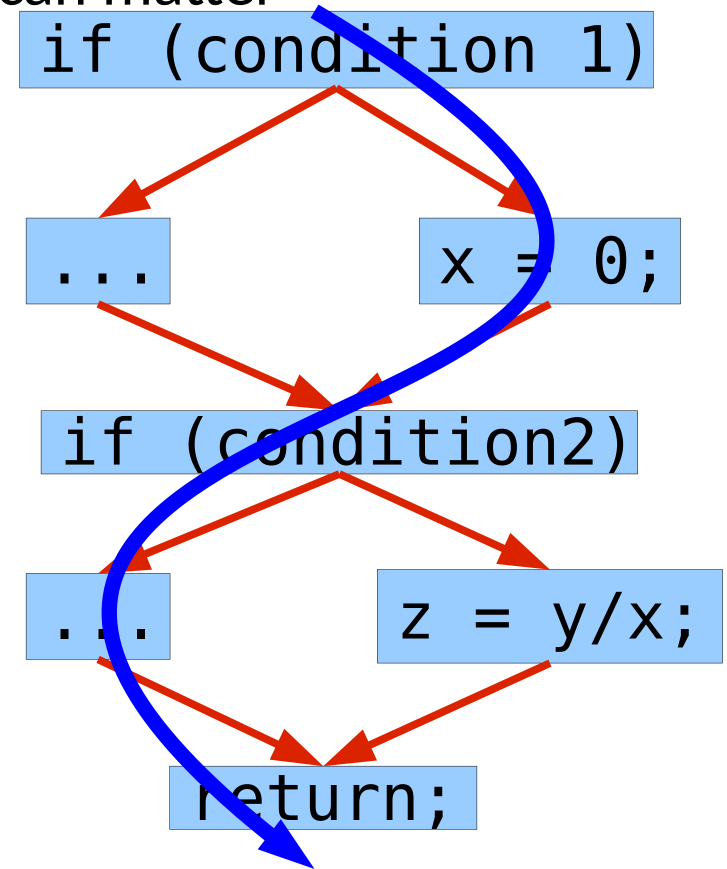

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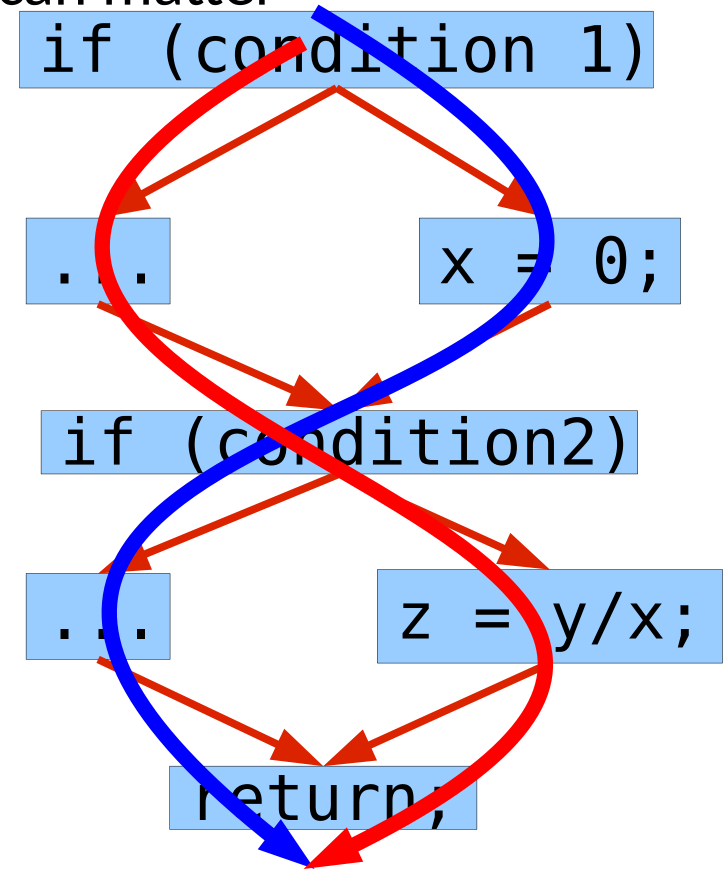

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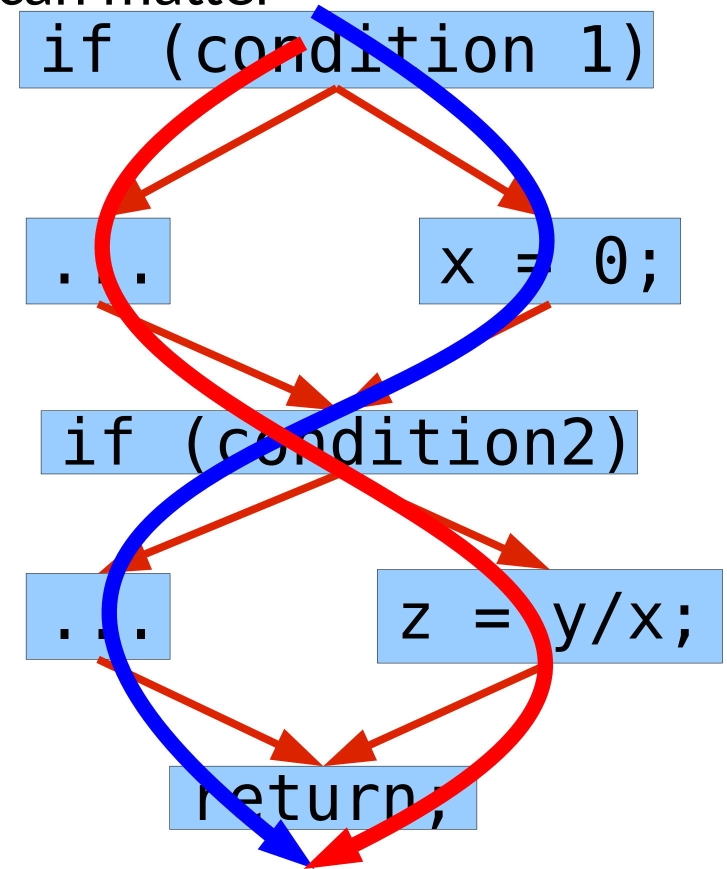
Full edge coverage & no bugs found



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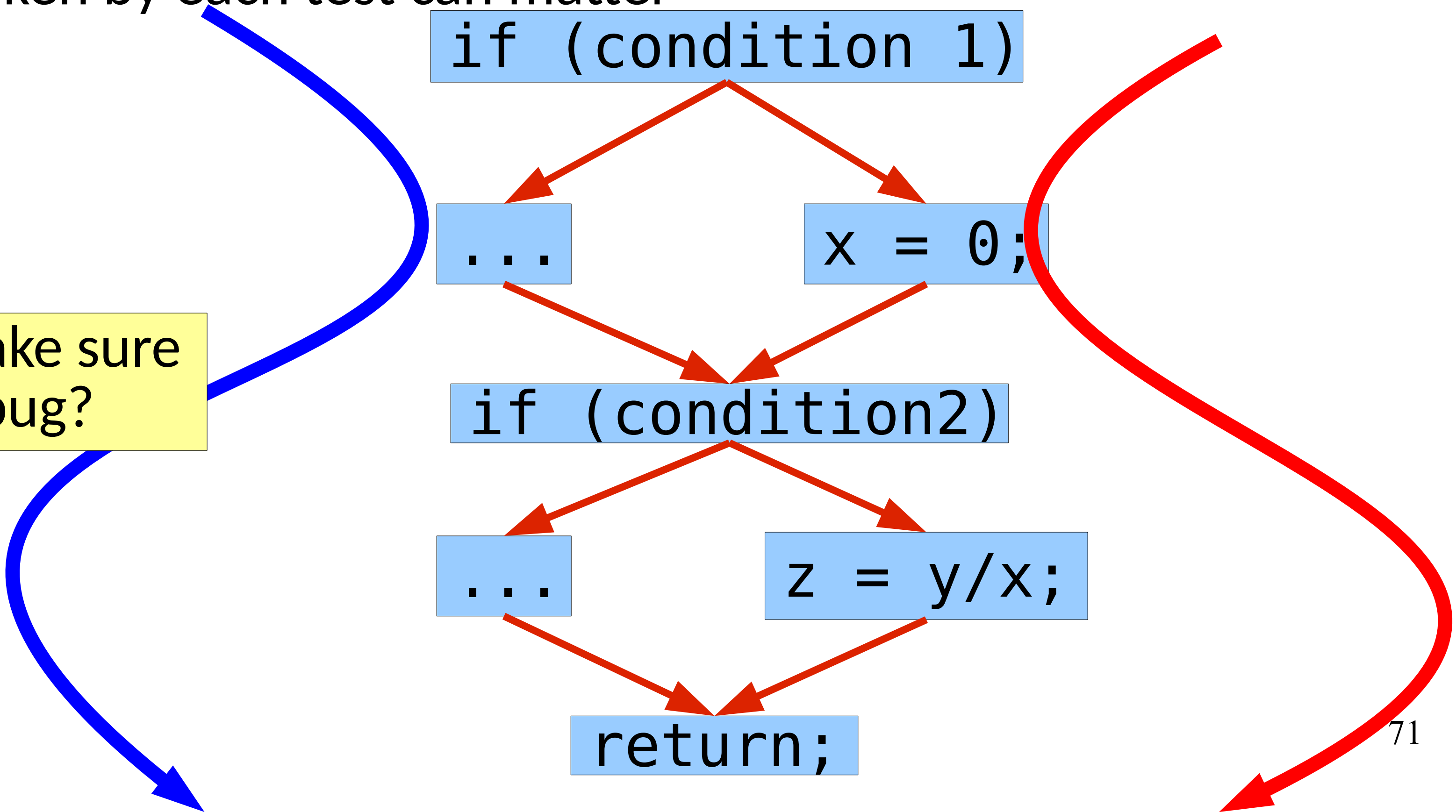

How can we make sure to find the bug?

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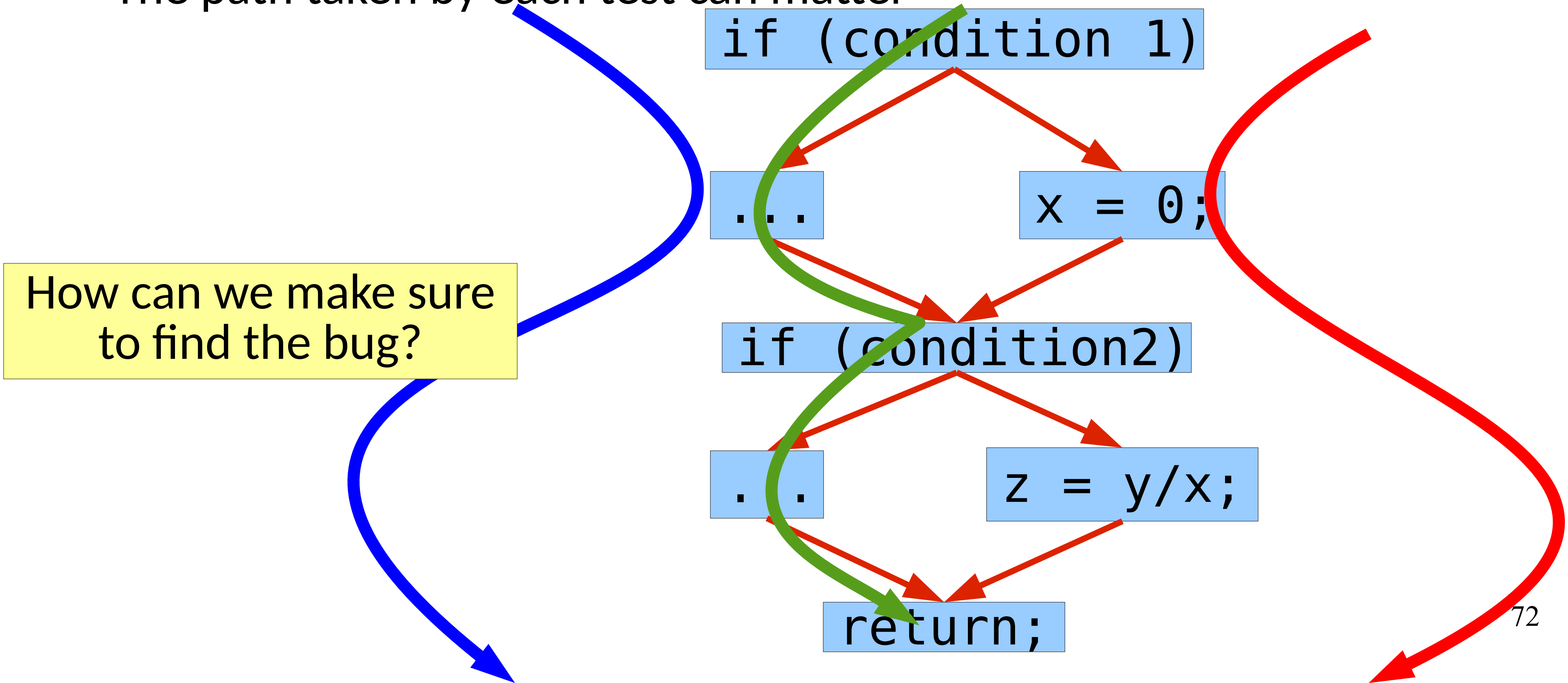

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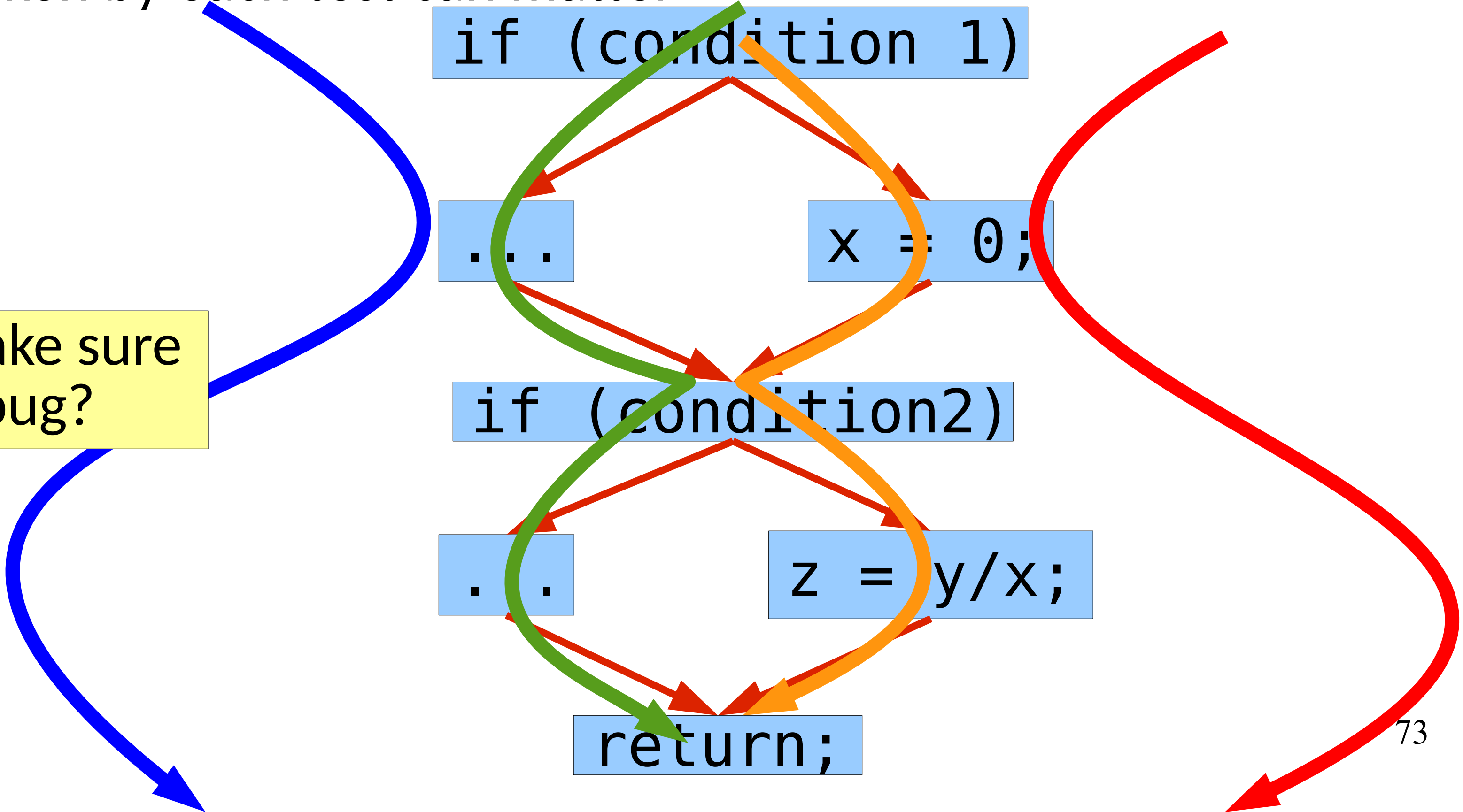

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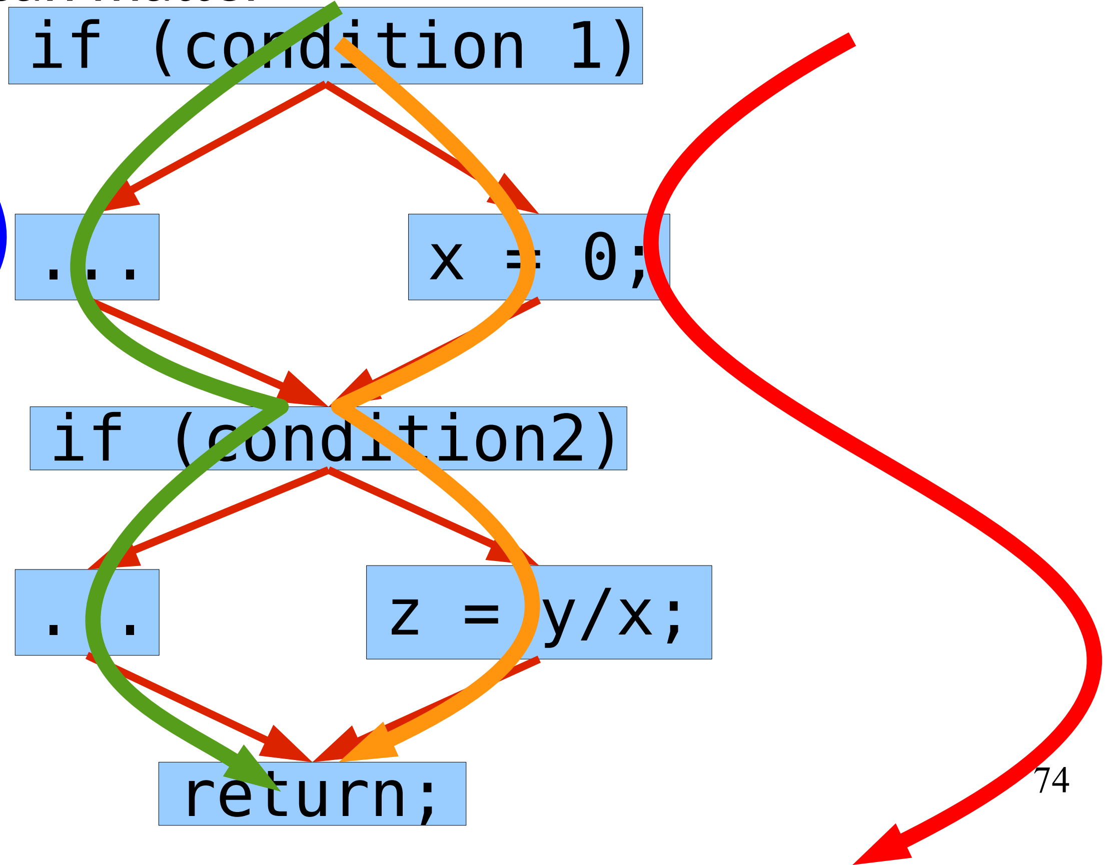

How can we make sure to find the bug?

Testing *all paths* exposes the bug.

Path Coverage

- Complete Path Coverage
  - Test all paths through the graph

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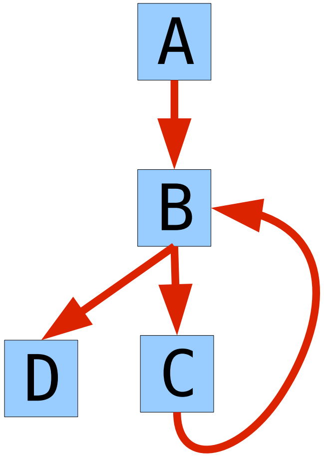

Infeasibility

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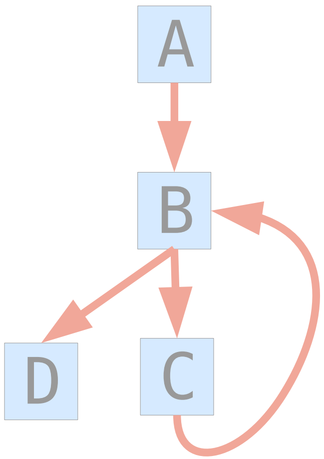

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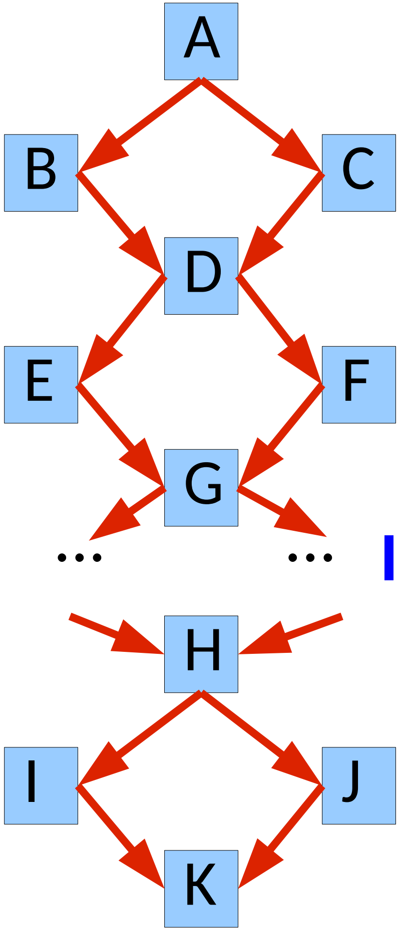

Intractability

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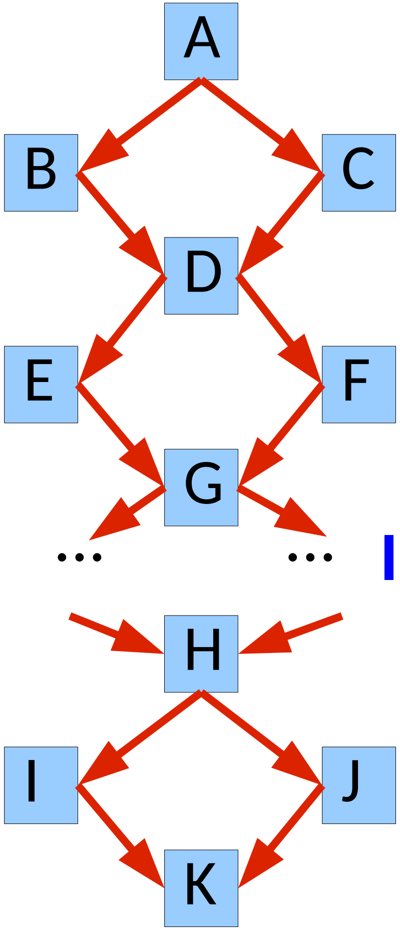
Why?

How many paths?

How does this relate to input based approaches?

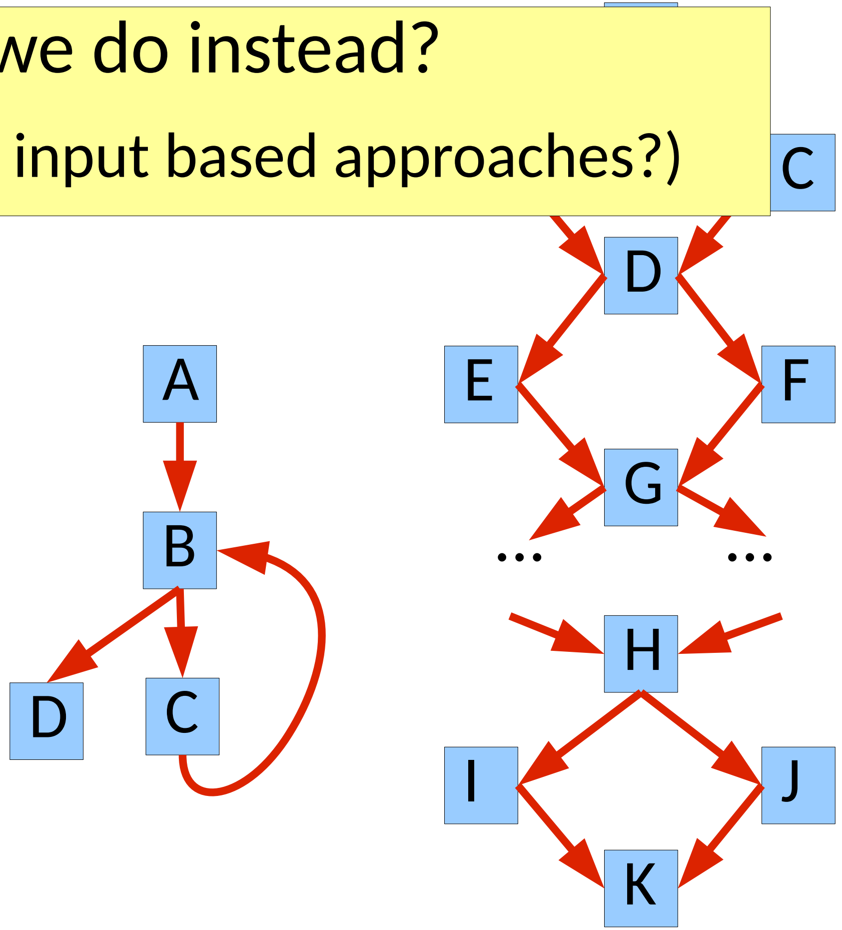


Intractability

Compromises?

What could we do instead?

(How did we handle the input based approaches?)



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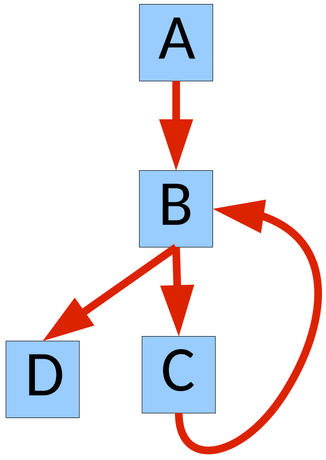

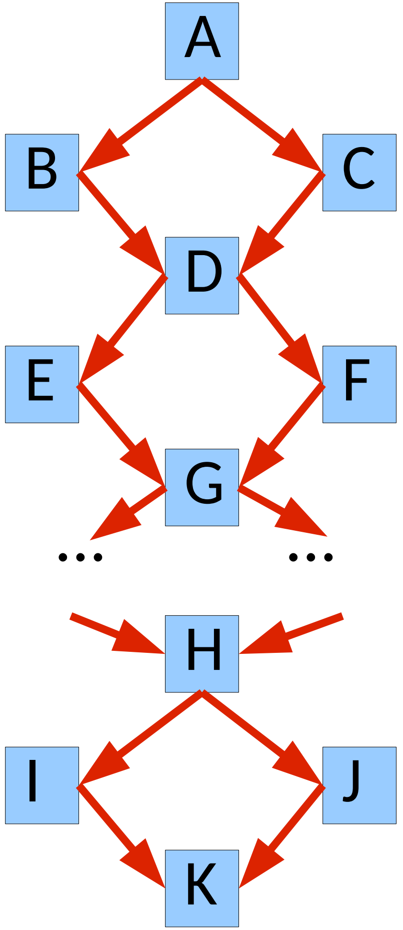

Compromises?

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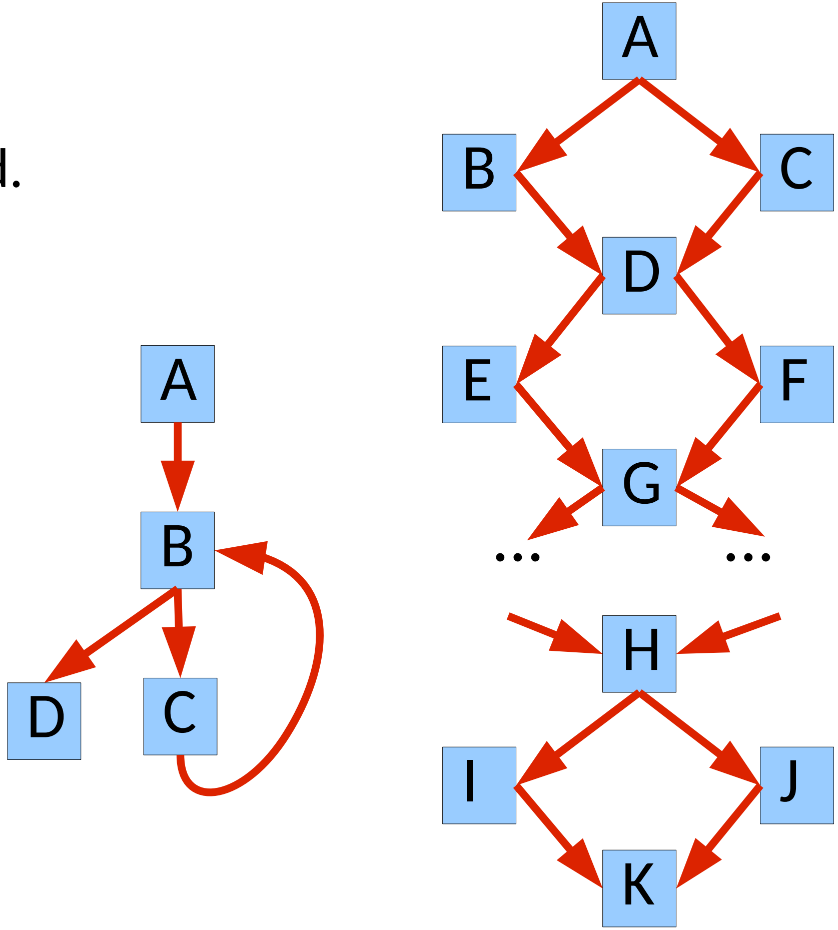
  - Each path of length <= 2 is tested.



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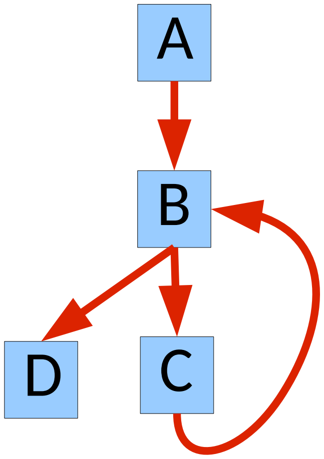

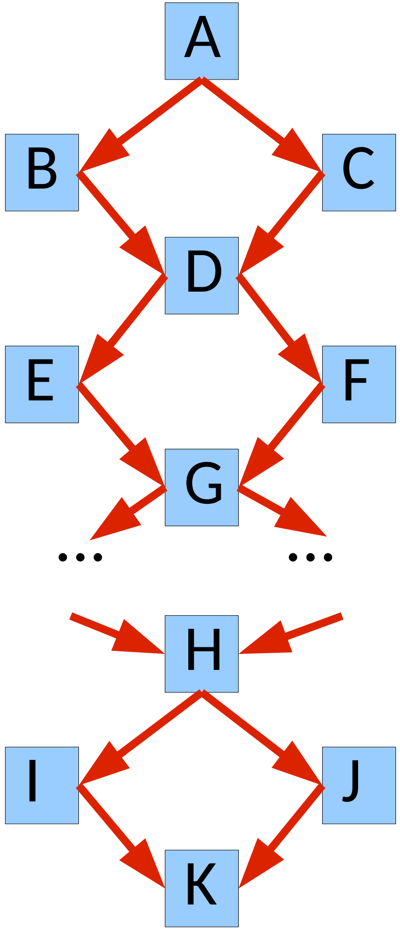

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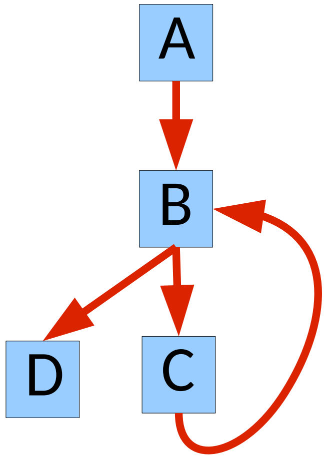
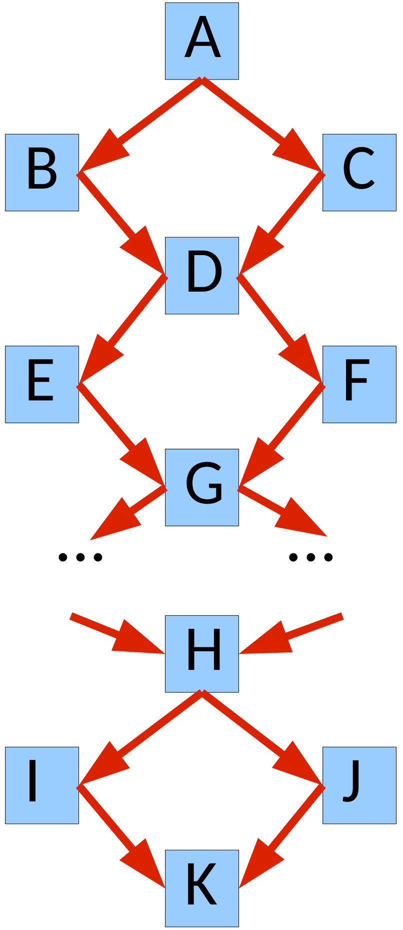
What do these look like?

Are they good?





Coping With Loops

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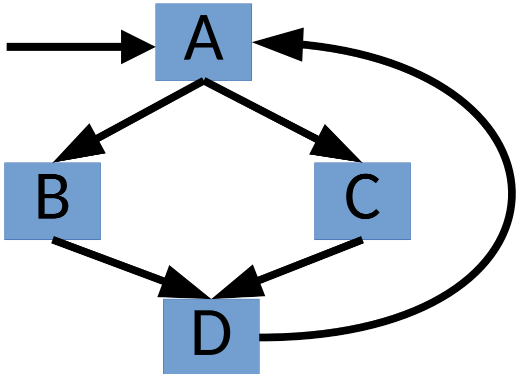

AB
CD
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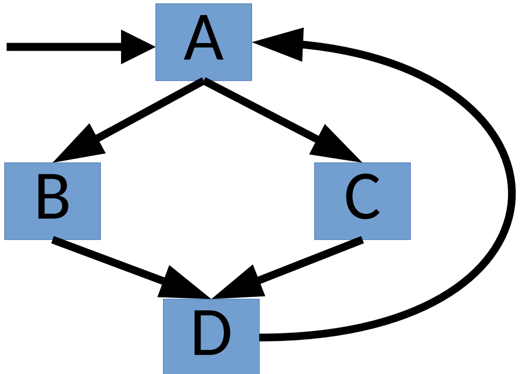

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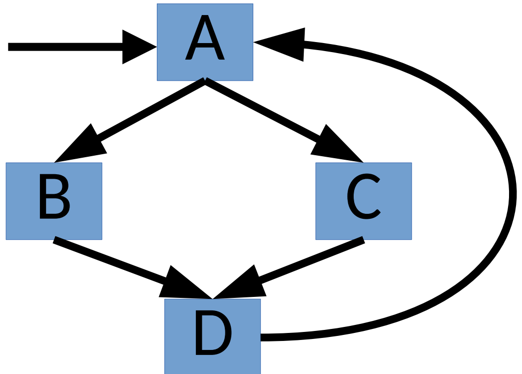

How many may there be?

Coping With Loops

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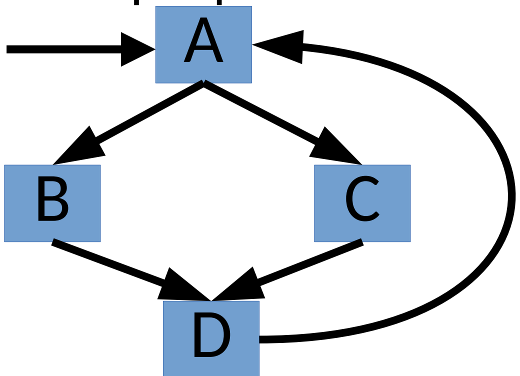

What does this provide?
What do they look like?

Coping With Loops

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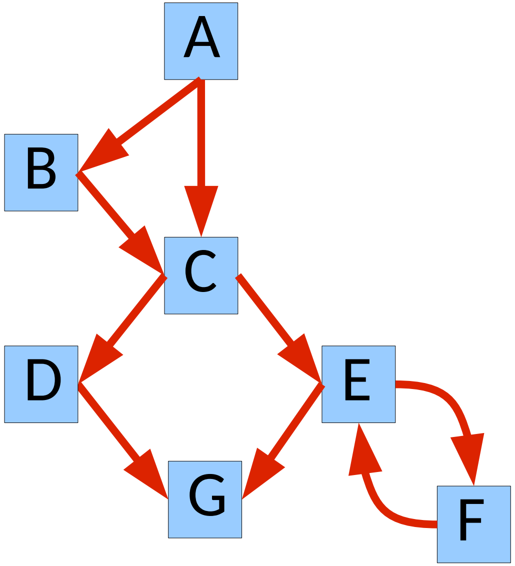

Example from Ammann & Offutt

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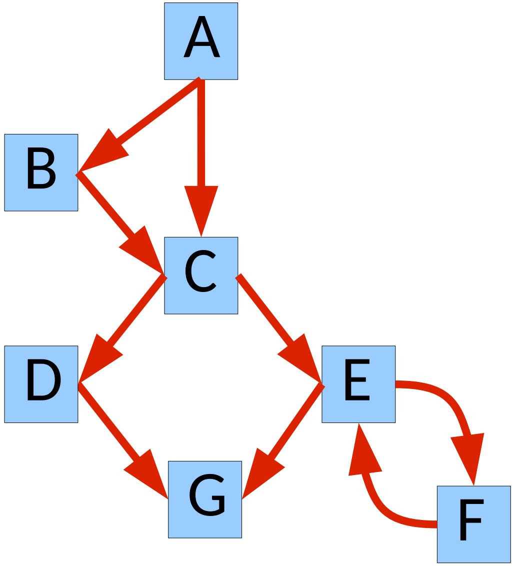

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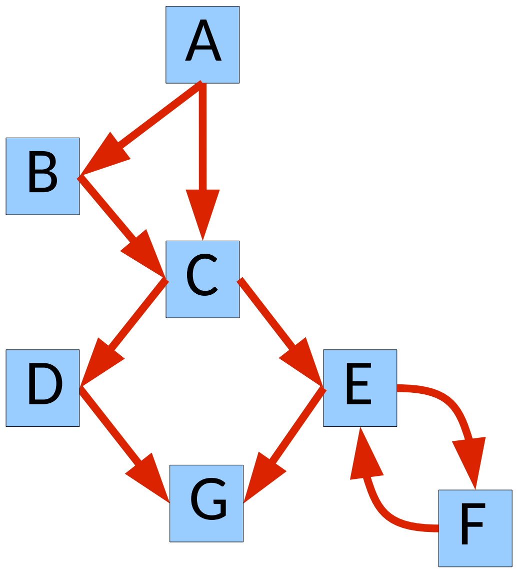

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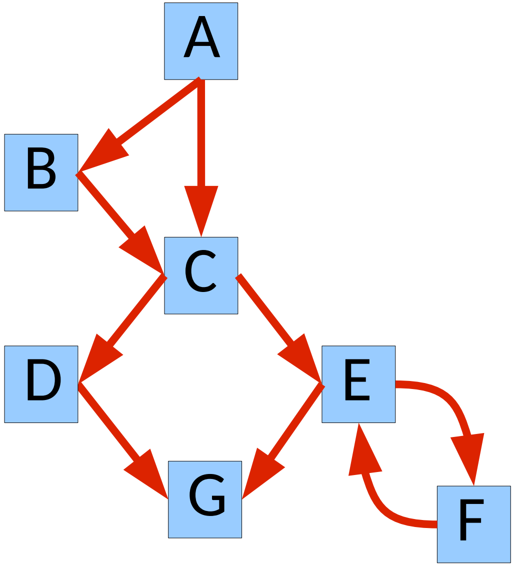

Example from Ammann & Offutt

What are the prime paths?

How many simple paths?

Can you intuitively explain what prime paths capture?

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Do they address all of the problems with path coverage?

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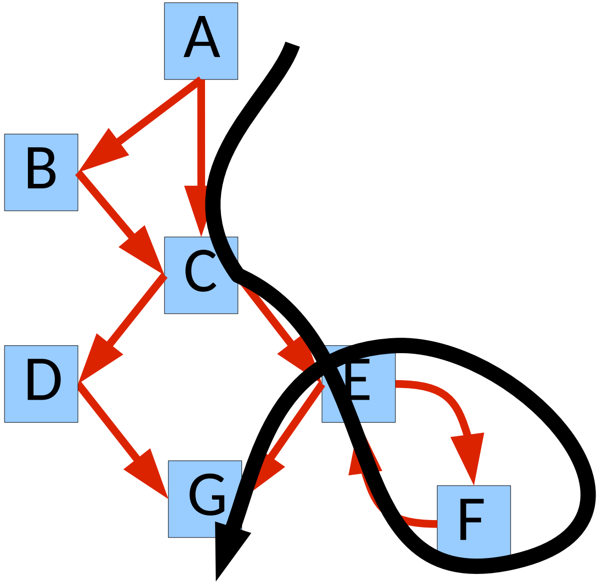
Can you think of things they miss?

Turning Them Into Tests

- Reconsider



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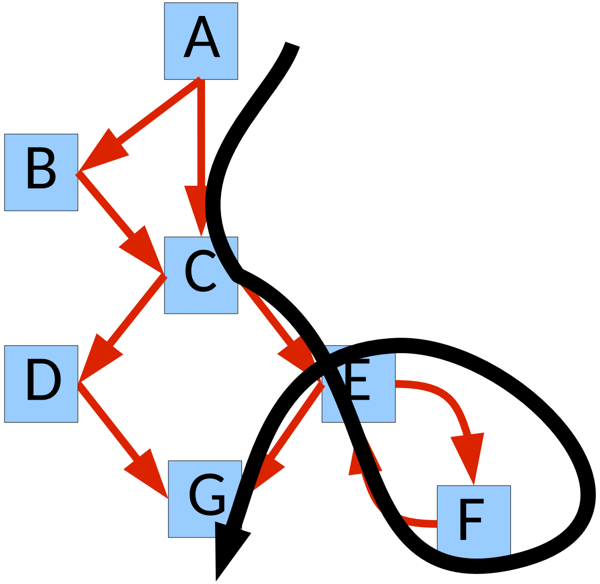

Is this path prime?

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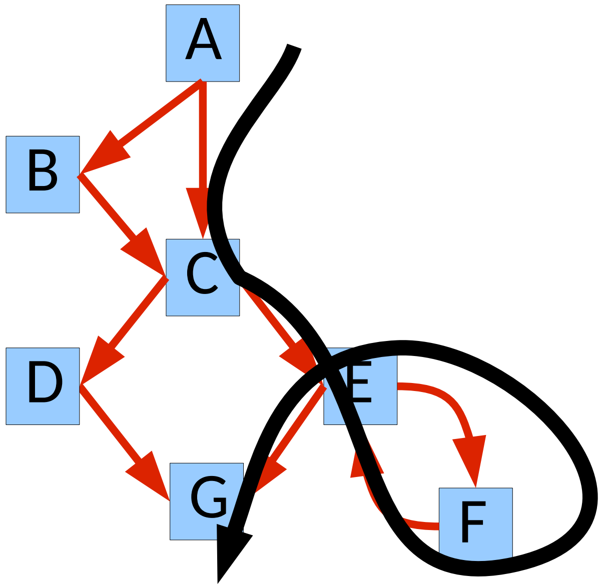

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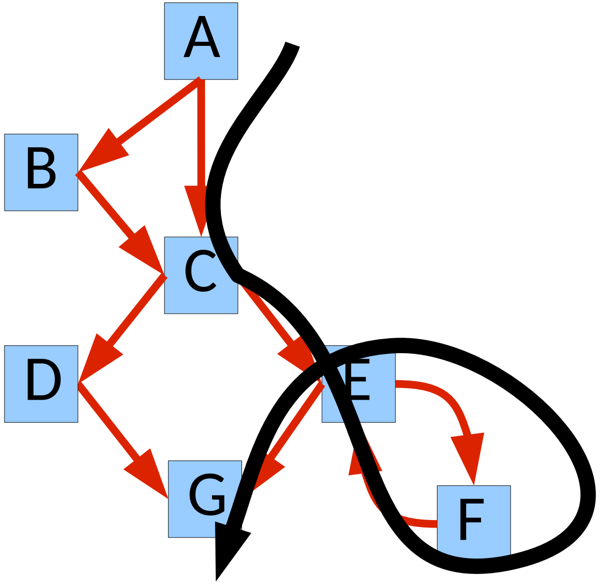

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Is it still useful?

One test may cover multiple prime paths!
Requirements ≠ Tests

Remember that graphs are everywhere

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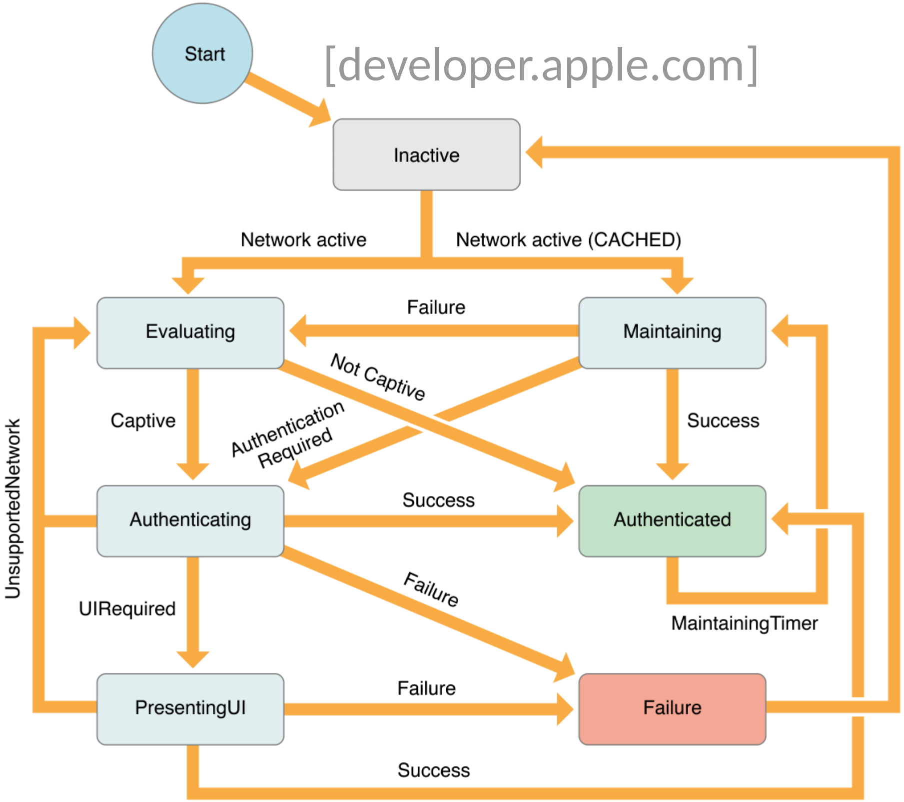
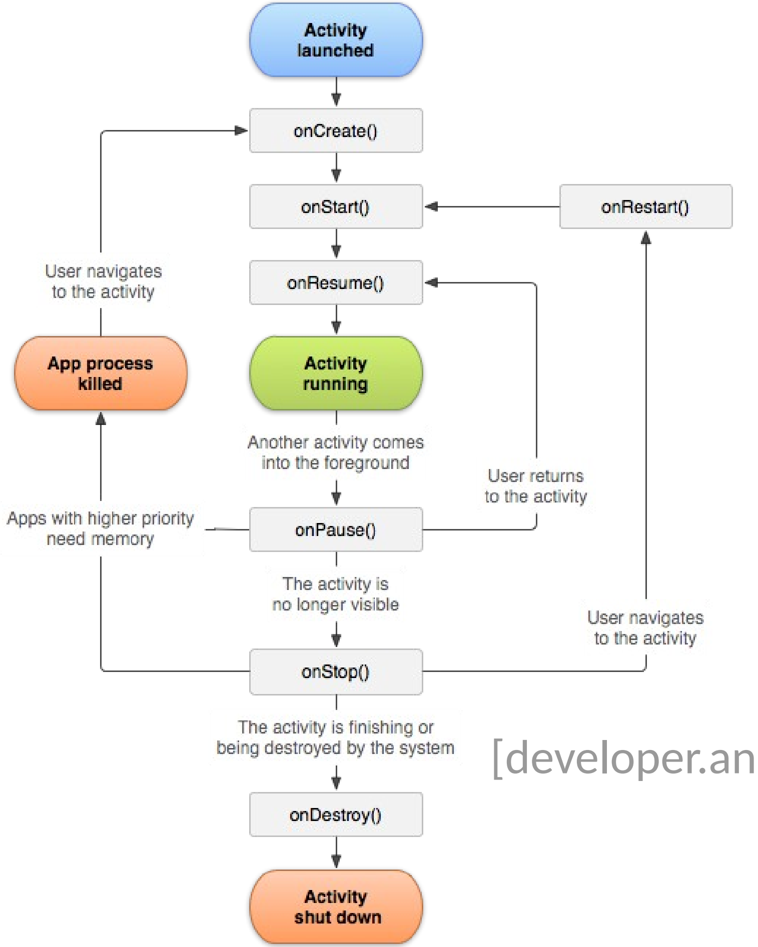
- Protocols and lifecycles



[developer.apple.com]



[developer.android.com]

Remember that graphs are everywhere

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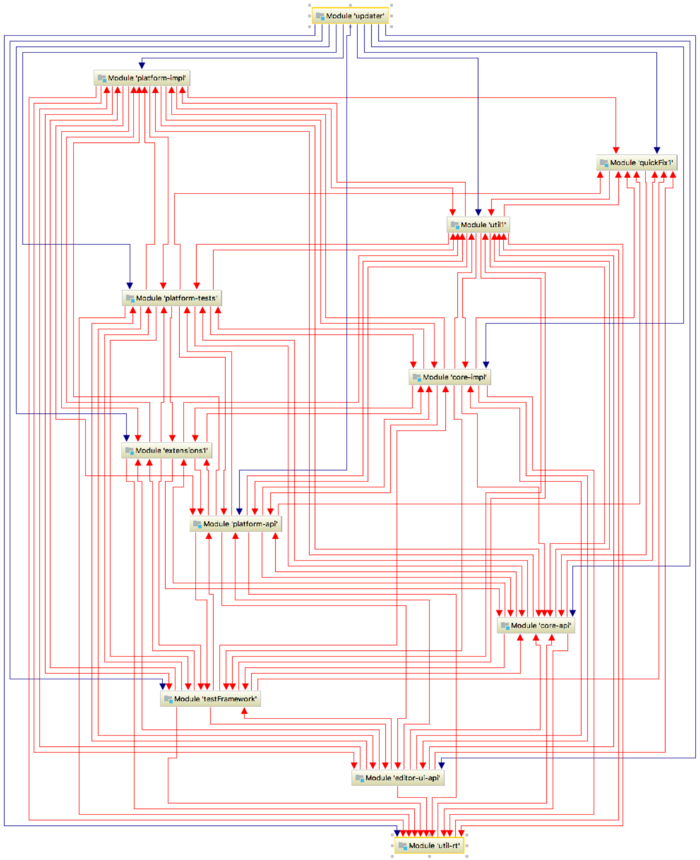

[www.jetbrains.com]

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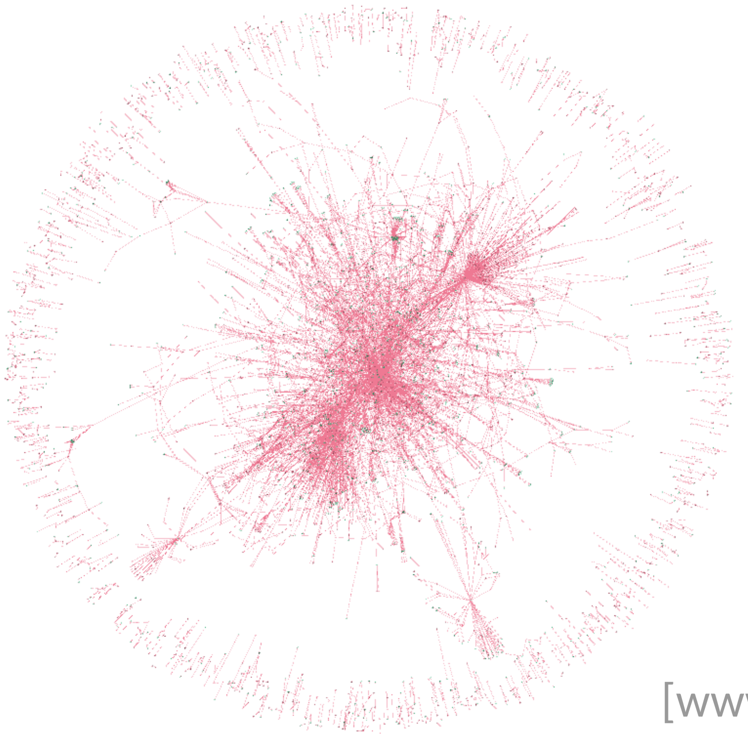
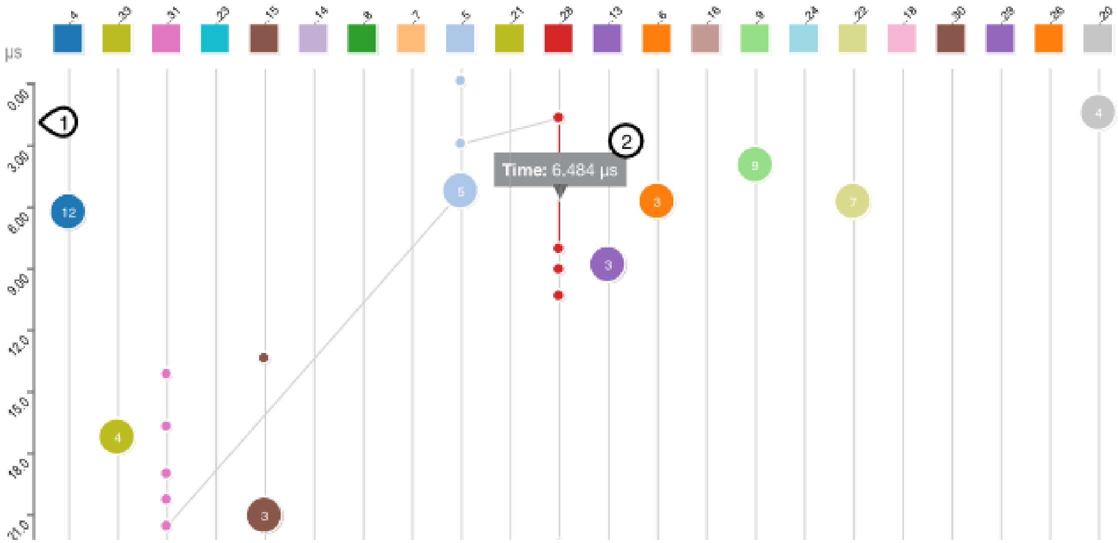


[www.androguard.com]

Remember that graphs are everywhere

- Protocols and lifecycles
- Dependencies between components
- Callgraphs
- (Micro)Services and distributed systems



[Beschastnikh et al.]

Summary

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