CMPT 473
Software Quality Assurance

Graph Coverage

Nick Sumner

Recall: Coverage/Adequacy

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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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void sortEfficiently(List list) {
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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?

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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…

White Box Testing

- In this course, we'll mostly look at graph coverage based techniques
  - Most commonly used metrics in the real world
  - Most concepts can be modeled through graphs
    e.g. programs, protocols, use patterns, designs, …

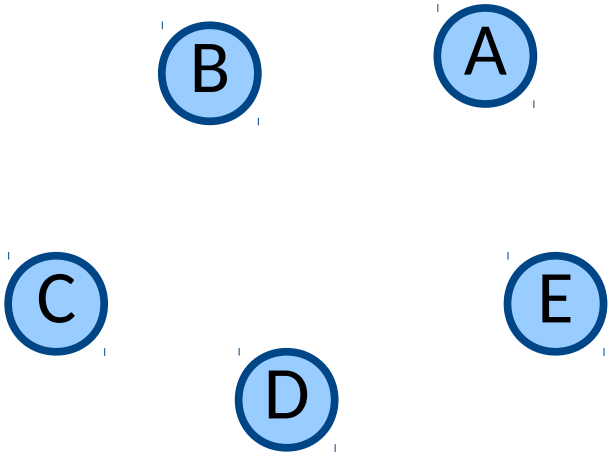
So a bit of review…

Graphs

- What is a *graph* G?

Graphs

- What is a *graph* G?
  - A set N of nodes



Graphs

- What is a *graph* G?
  - A set N of nodes
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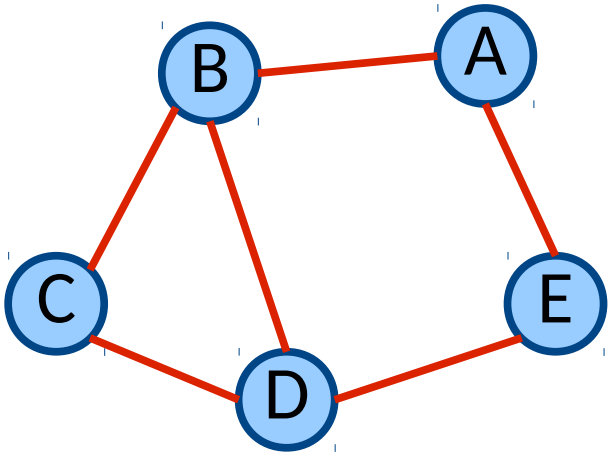

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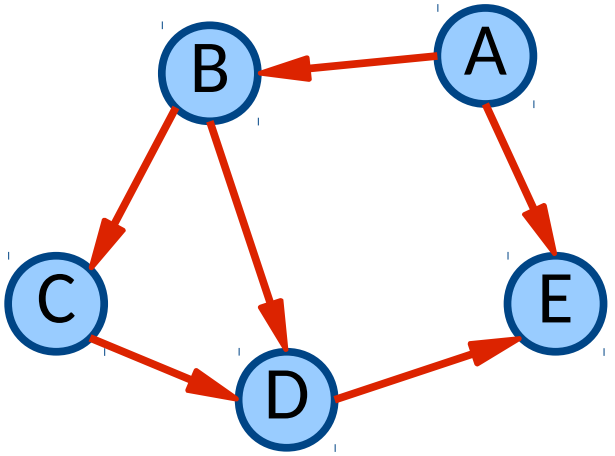
- When edges are directed from one node to another, the graph is a *directed graph*



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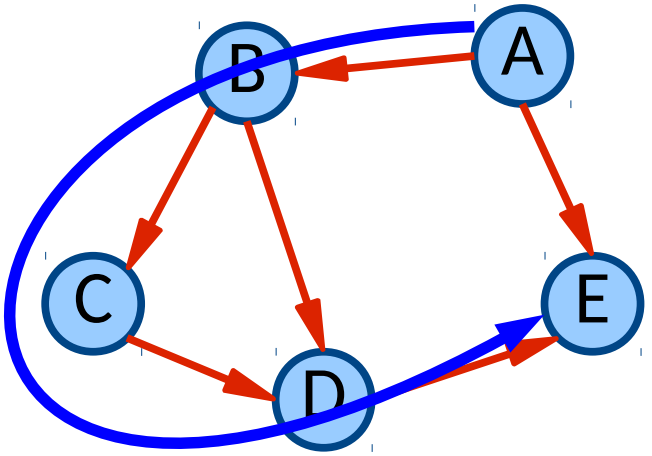

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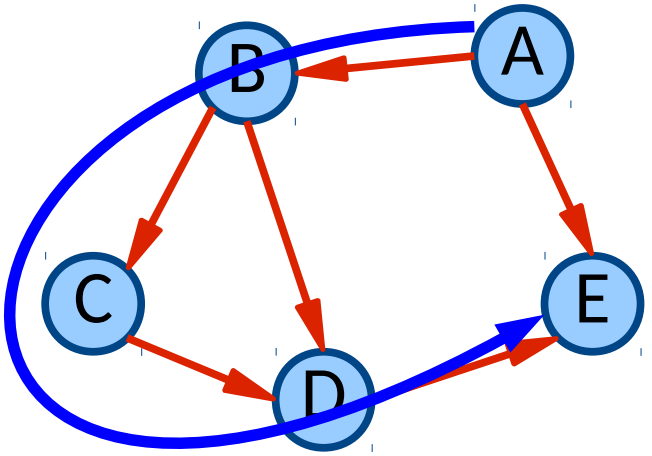
ABCDE



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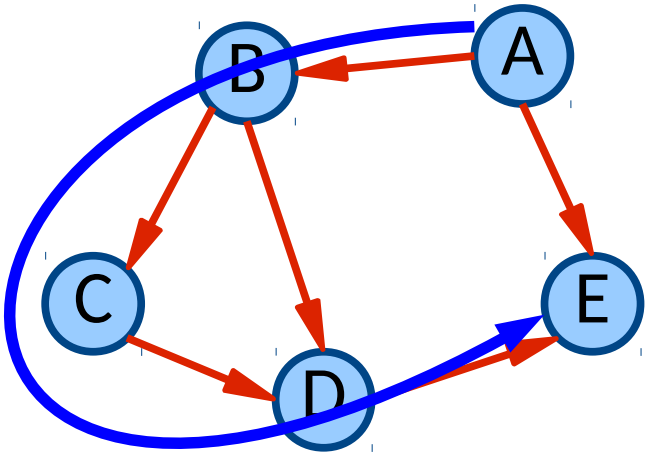
AE
BCDE
BD



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- Programs can be modeled as graphs
  - Used extensively in compilers
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- 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:

```
void sortEfficiently(List list) {
  if (list.size() < THRESHOLD) {
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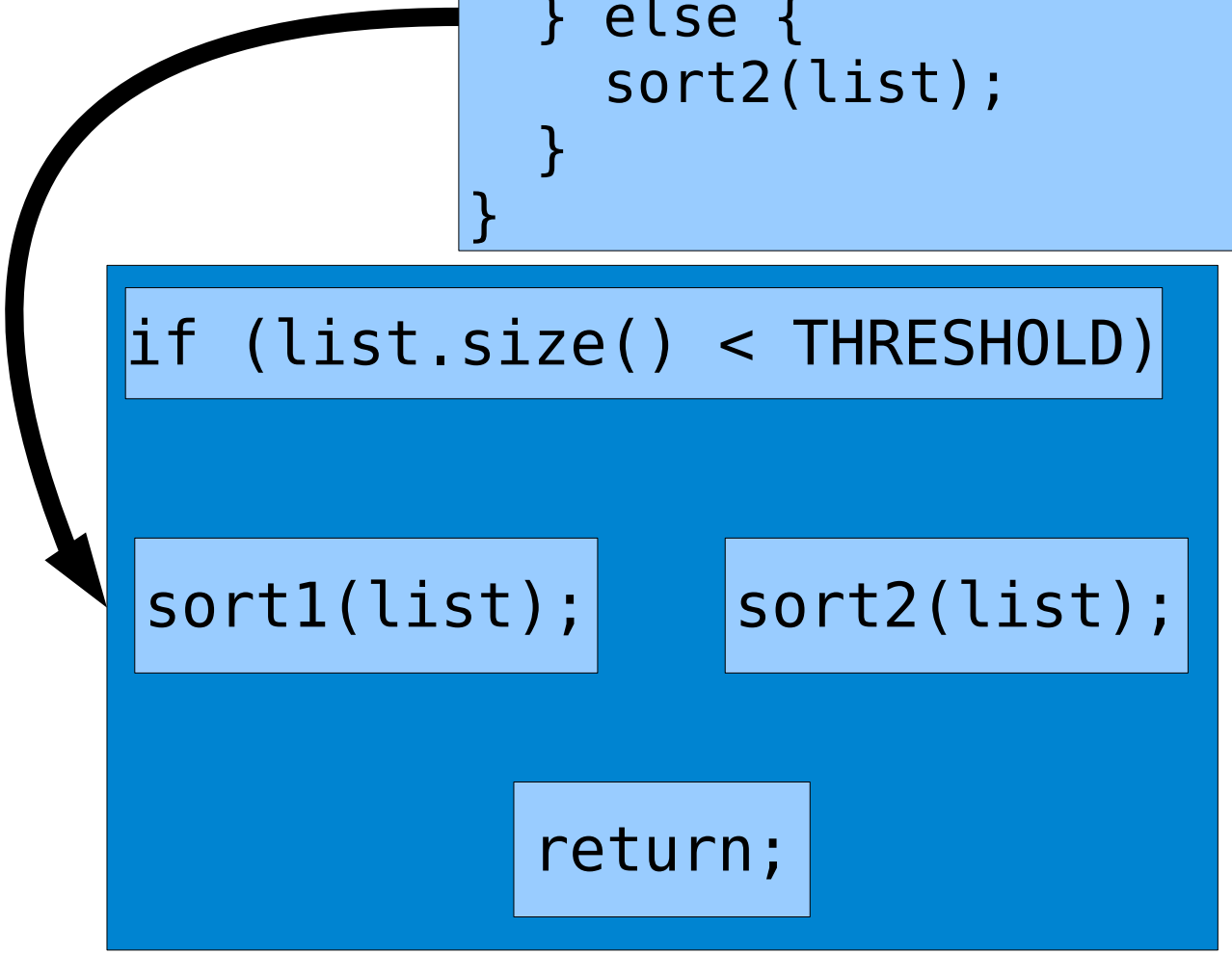

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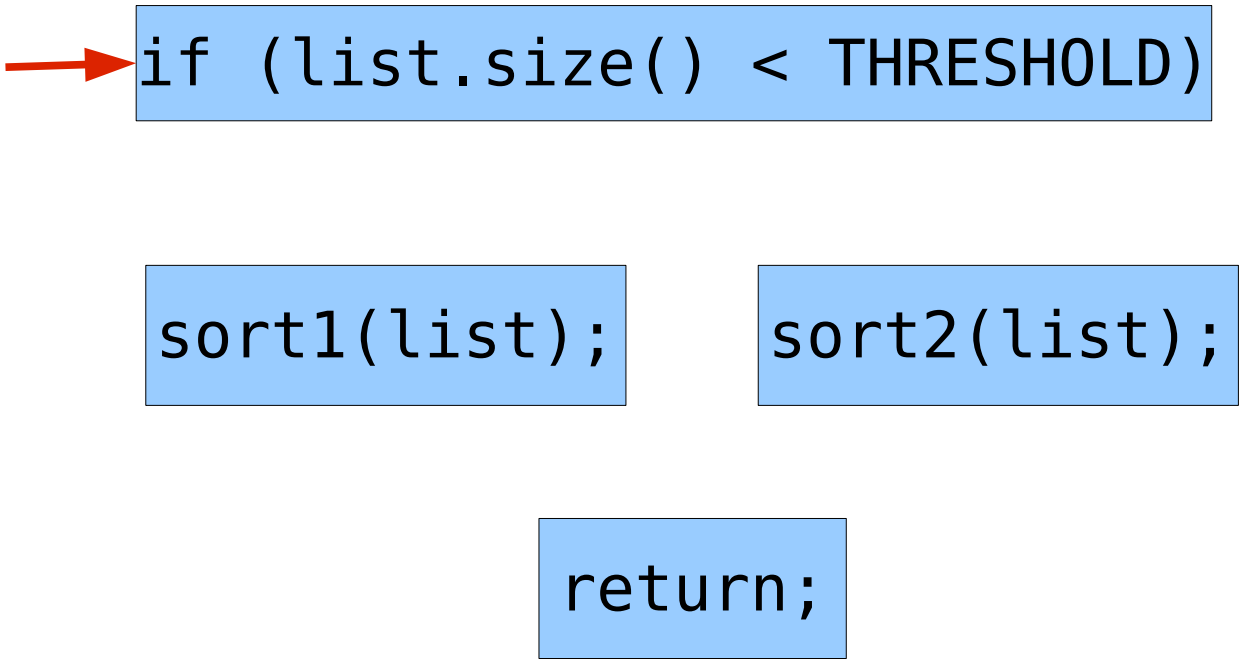

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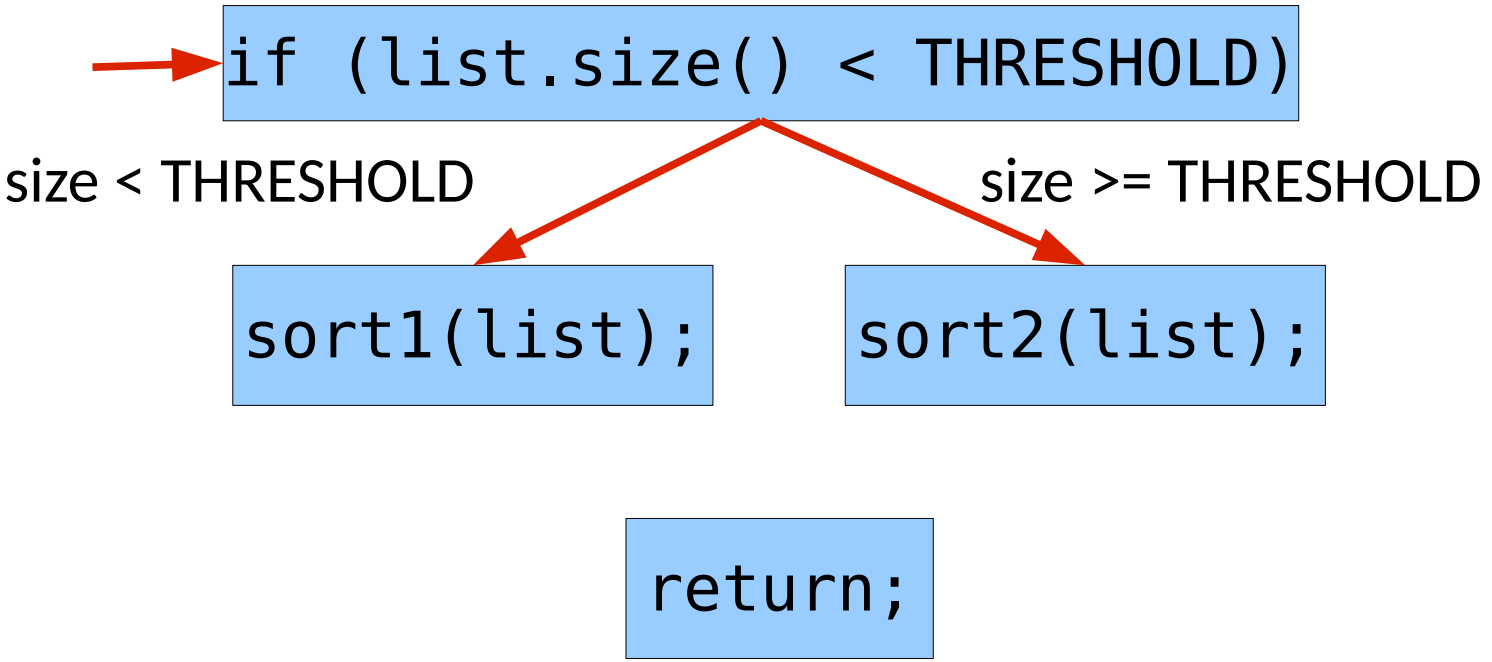

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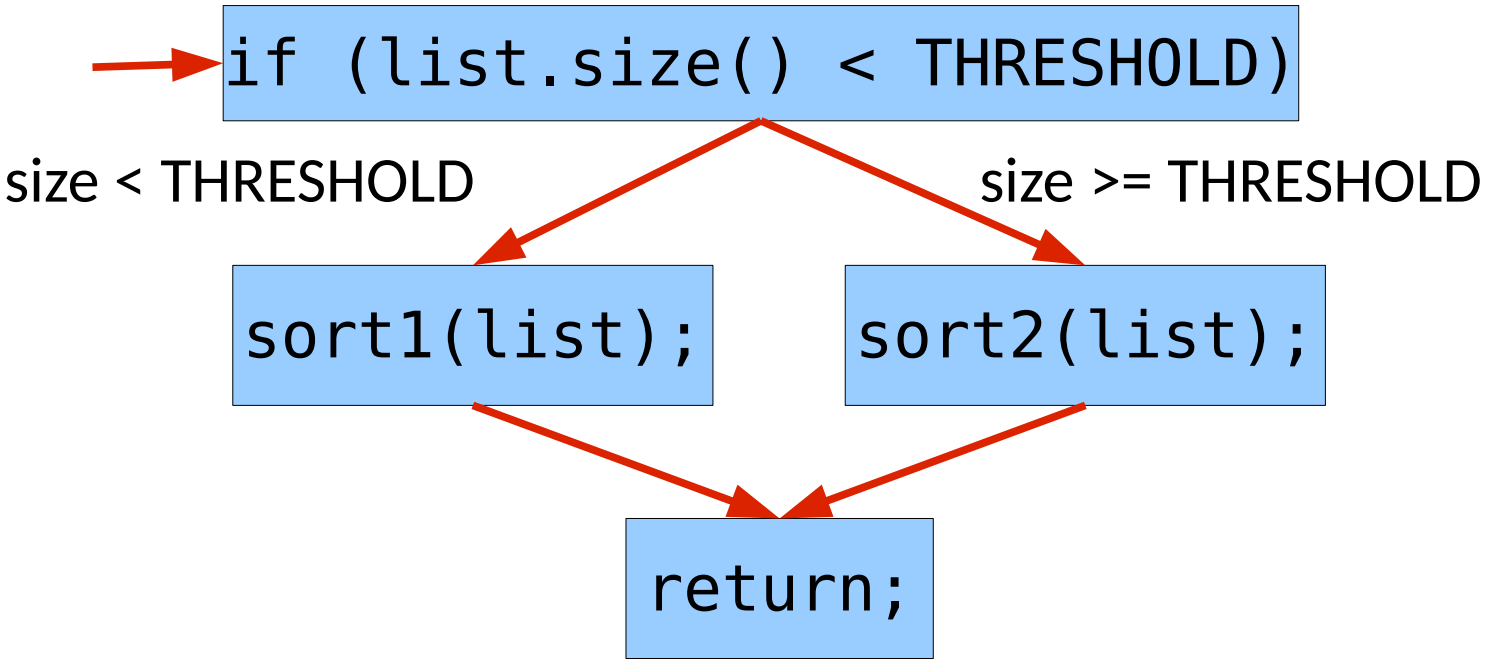

Control Flow Graphs

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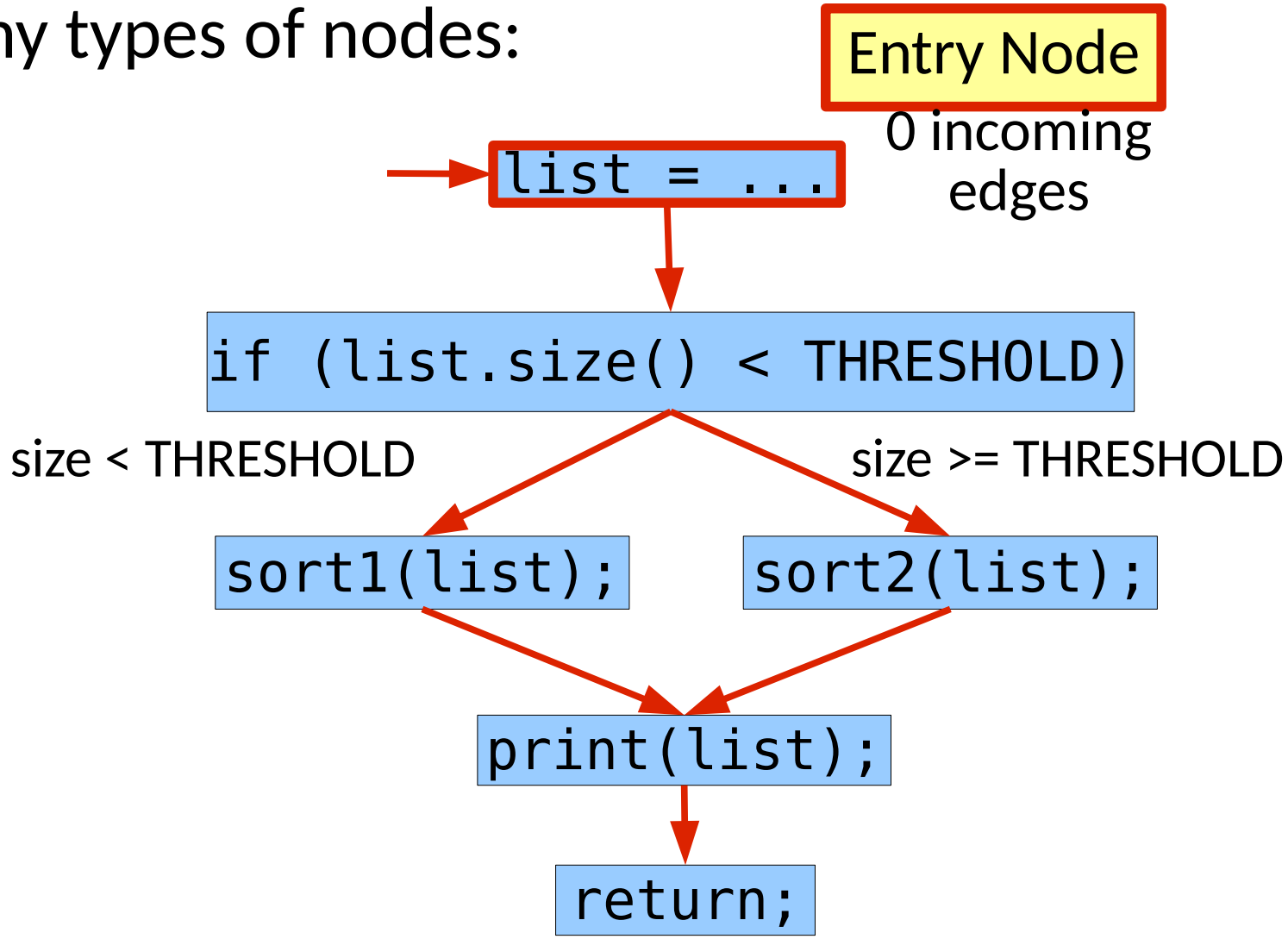

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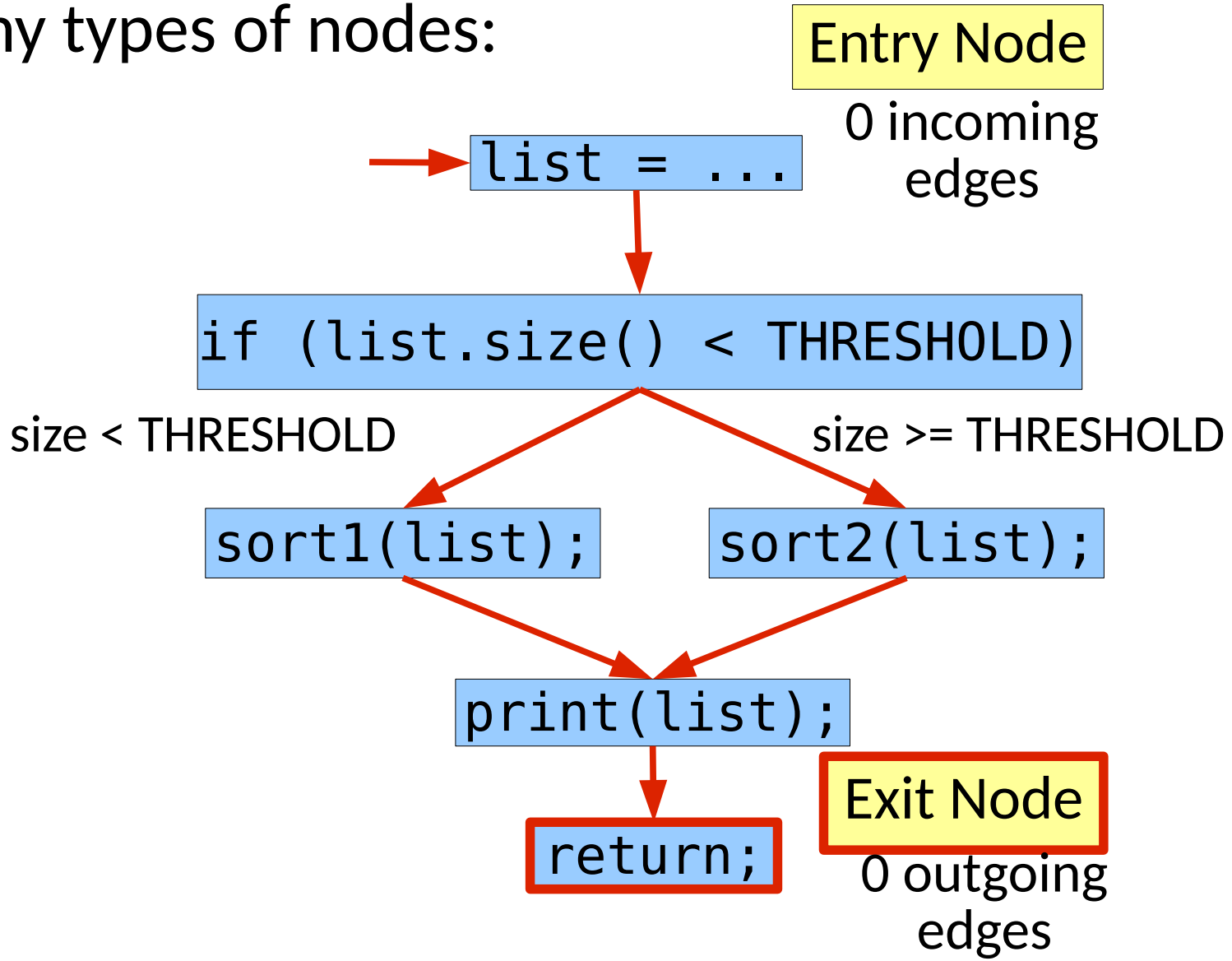

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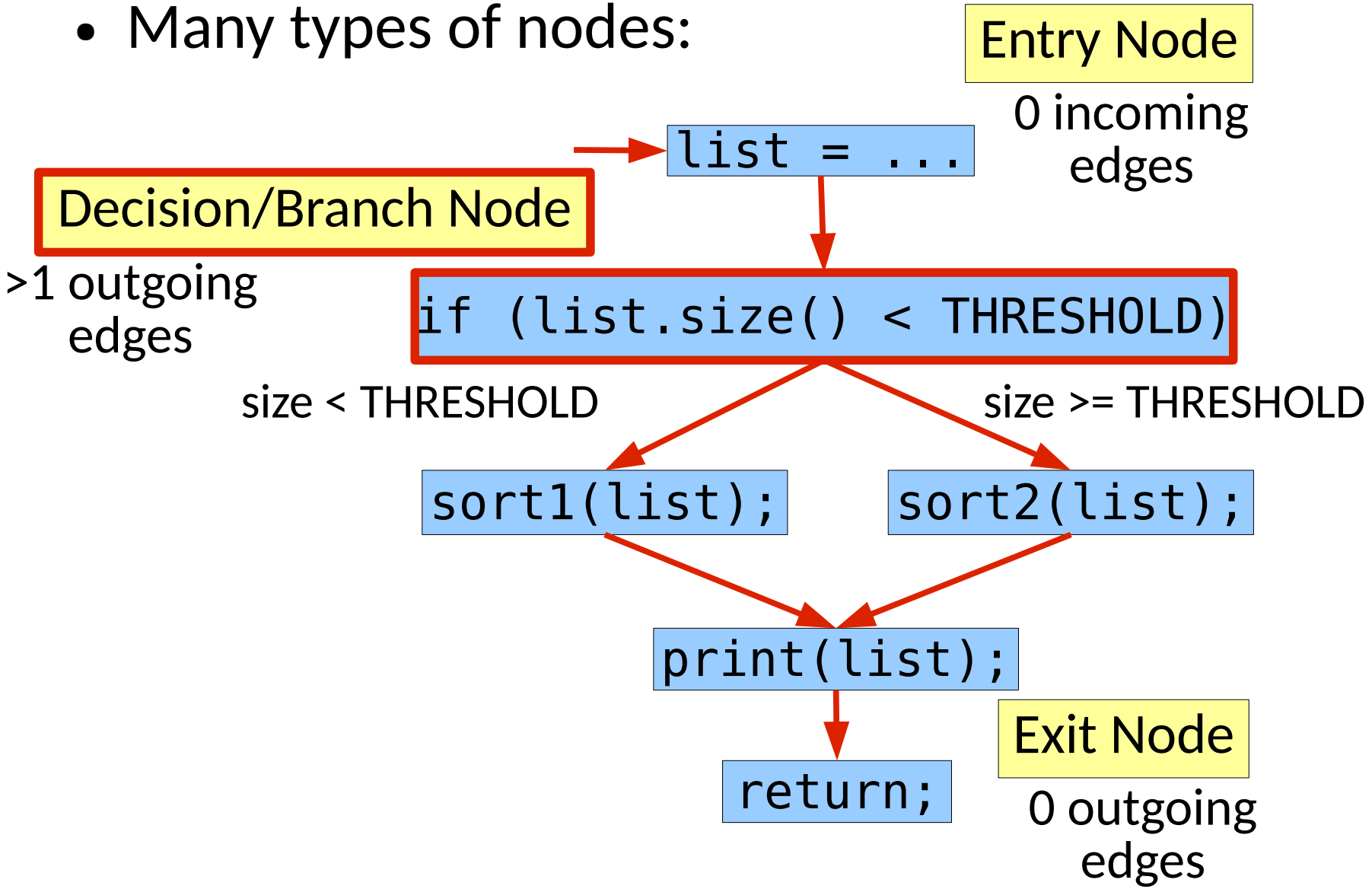

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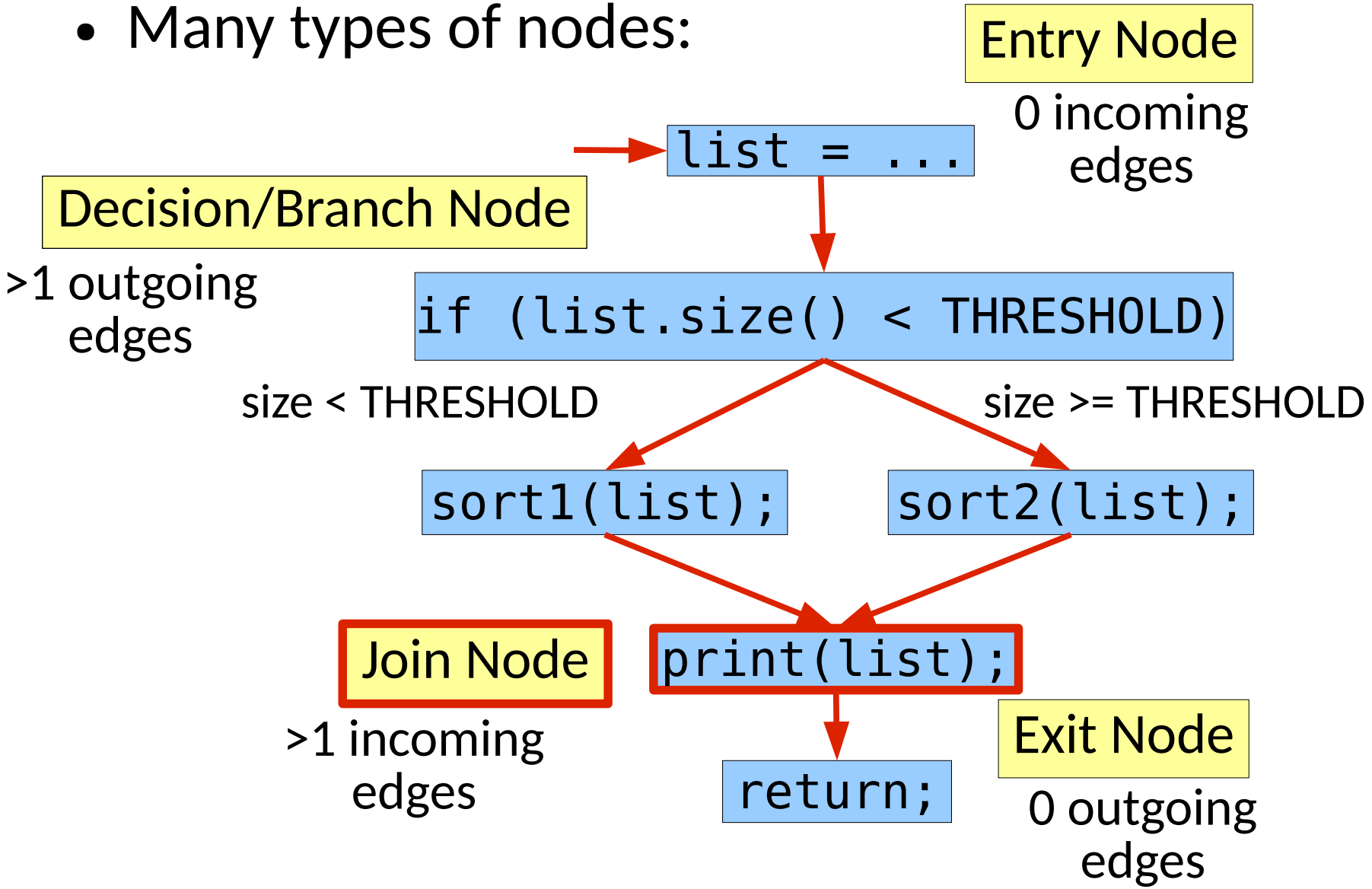

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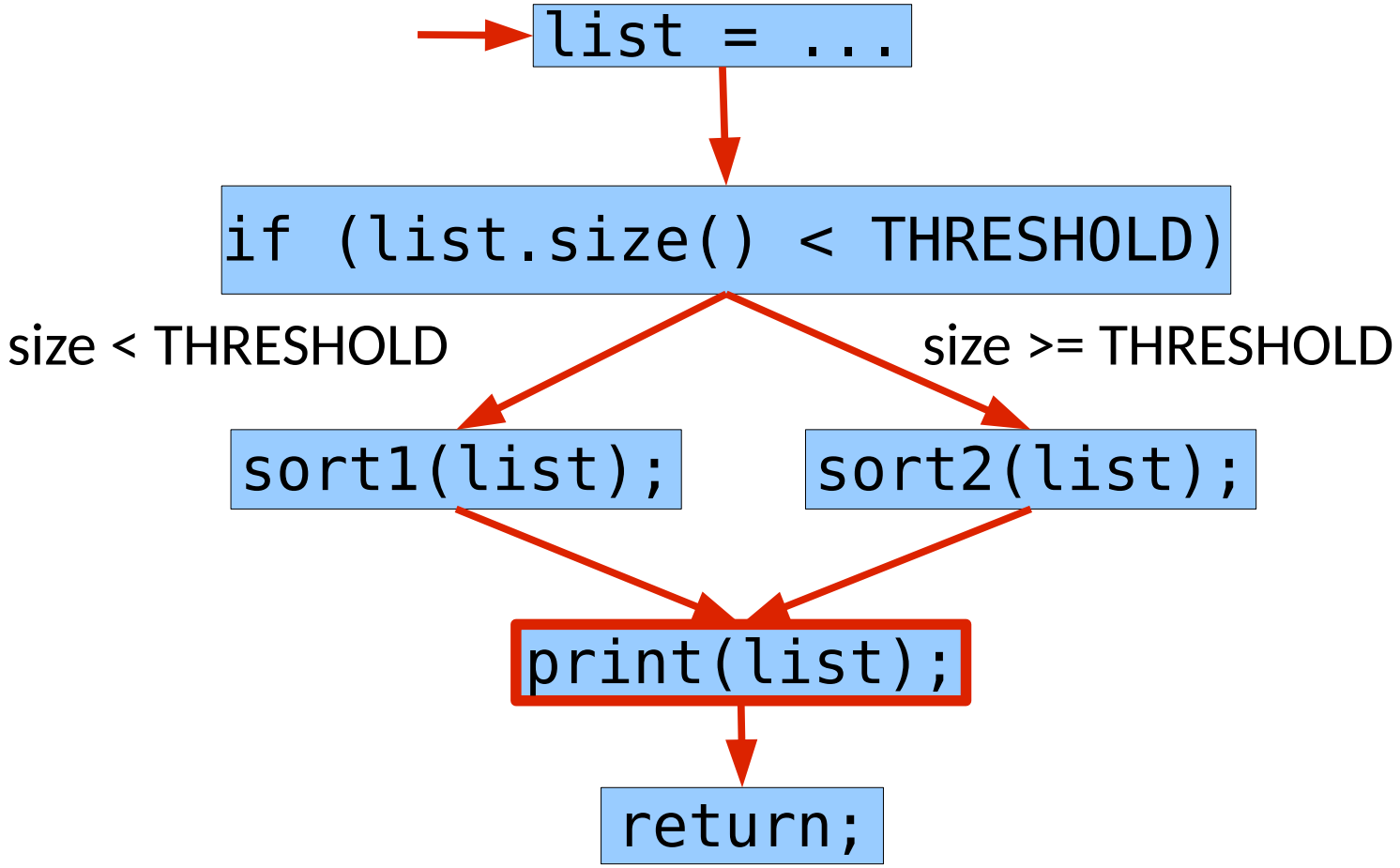
- Straight-line sequences of code are grouped into basic blocks:



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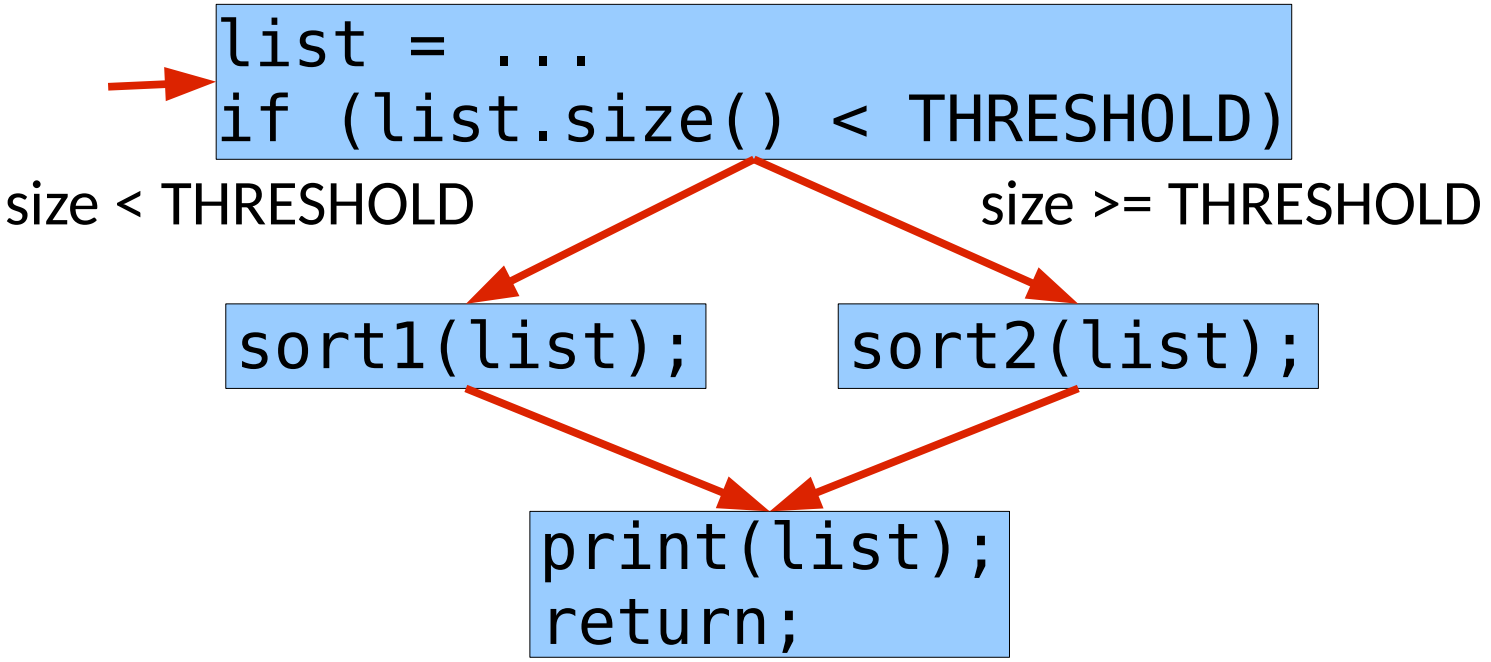

Control Flow Graphs

- Many patterns arise from common constructs

Control Flow Graphs

- Many patterns arise from common constructs
- What is the CFG for this program?

```
q = 0;
r = x;
while r >= y {
  r = r - y;
  q = q + 1;
}
```

Control Flow Graphs

- What is the CFG?

```
for (i = 0; i < n; i++) {
   foo(i);
}
```

Control Flow Graphs

- What is the CFG?
  - Don't forget implicit behavior like `default`!

```
switch  (x) {
   case a: foo(x); break;
   case b: bar(x);
   case c: baz(x); break;
}
```

Control Flow Graphs

- What is the CFG?
  - Short circuit operators can lead to subtle behavior!

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

Control Flow Graphs

- What is the CFG?
  - Control flow can become complex!
    From Ammann & Offutt:

```
x = 0;
while (x < y) {
   y = f (x, y);
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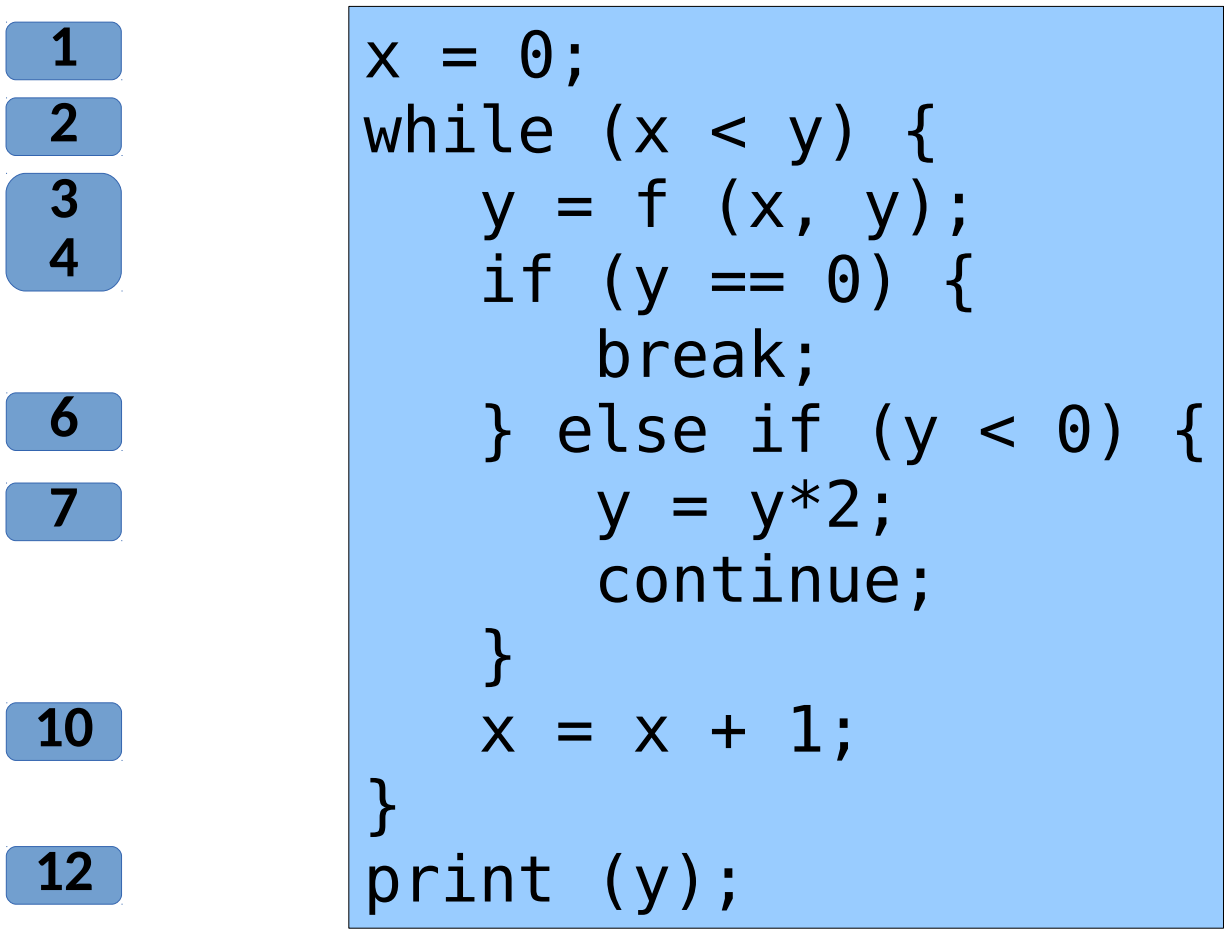

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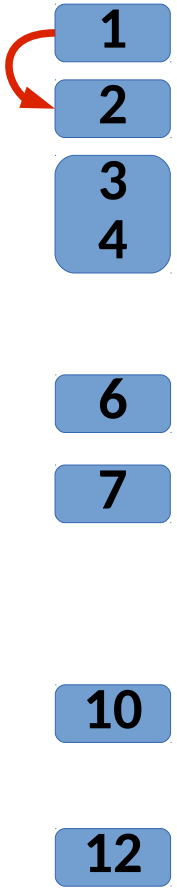


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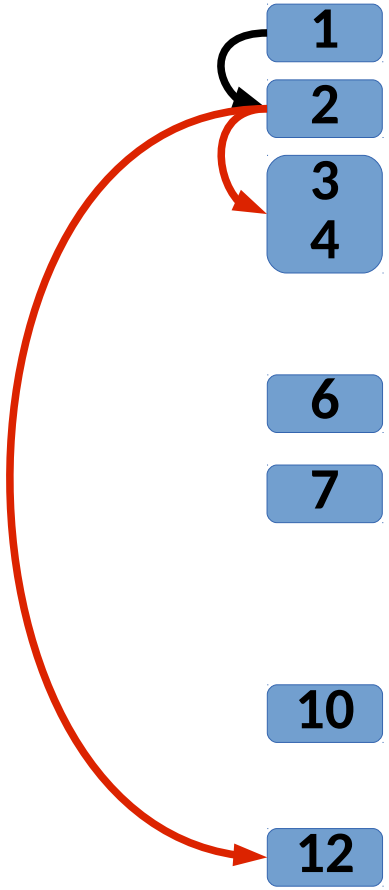


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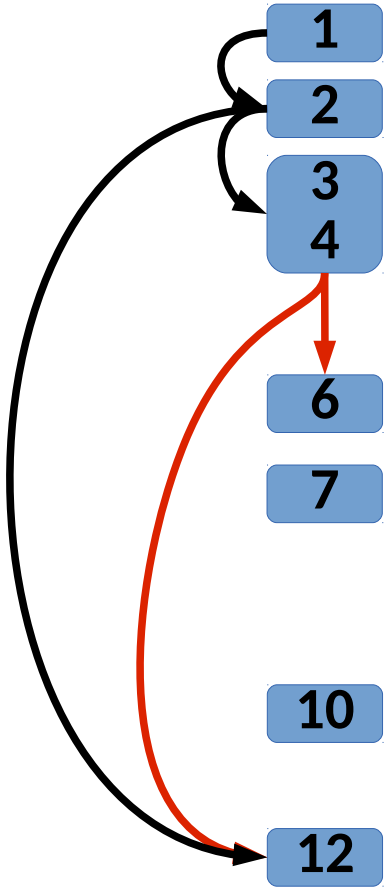


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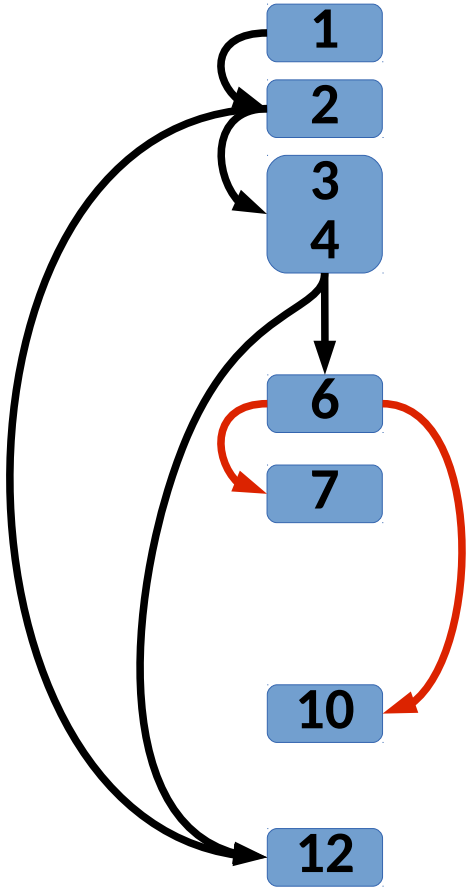


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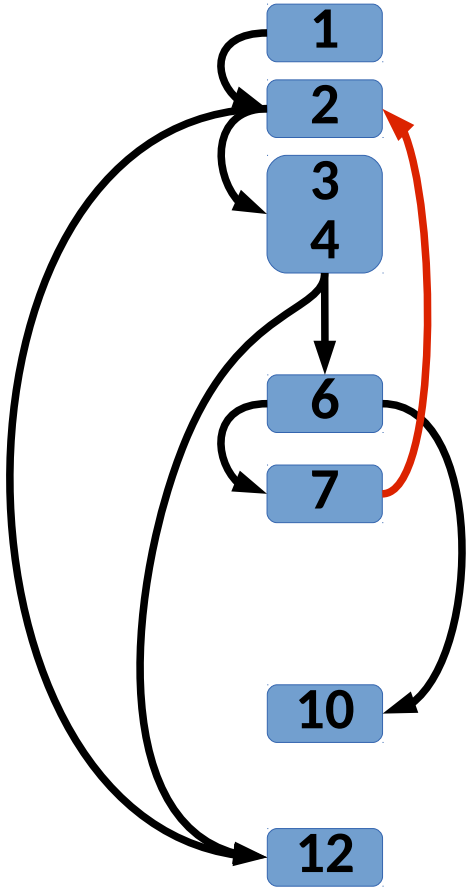


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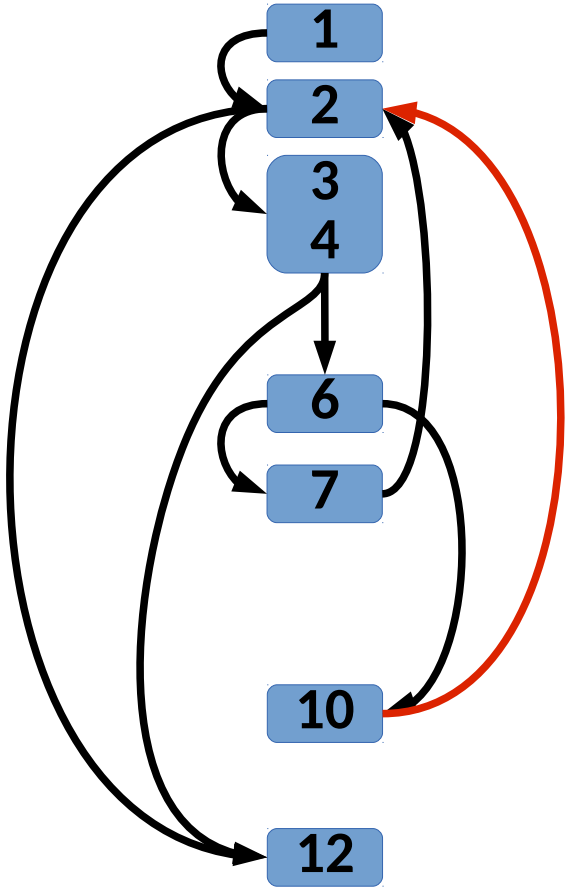


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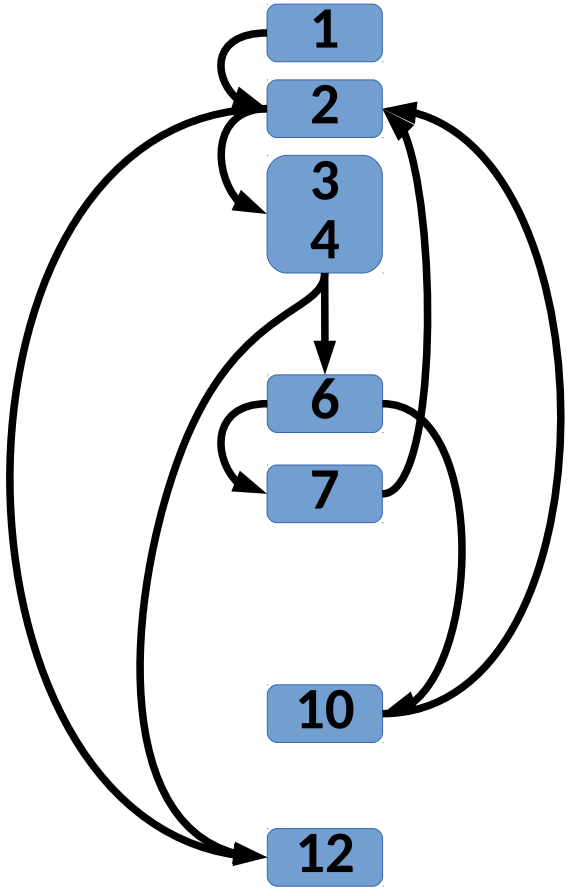


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CFG Coverage

- Statement Coverage → Node Coverage

Try to cover all reachable basic blocks.

CFG Coverage

- Statement Coverage → Node Coverage

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

CFG Coverage

- Statement Coverage → Node Coverage
- Branch Coverage → Edge Coverage

Try to cover all reachable paths of length ≤ 1.

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

CFG Coverage

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

Are these notions of coverage enough? **Why**?

Pragmatic Concerns

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Is that reasonable in practice?
Why?

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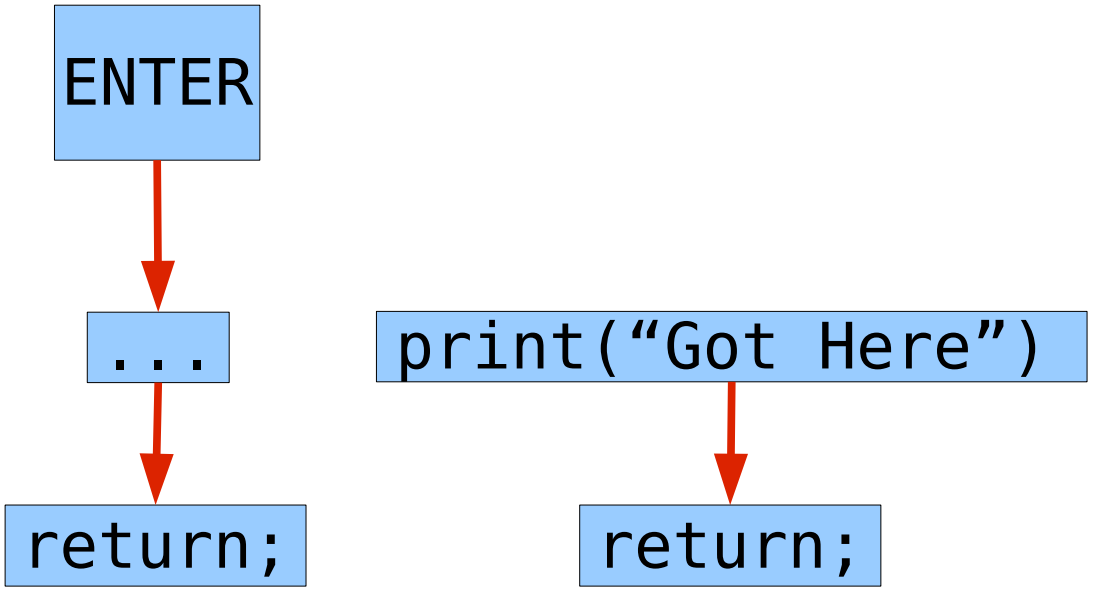

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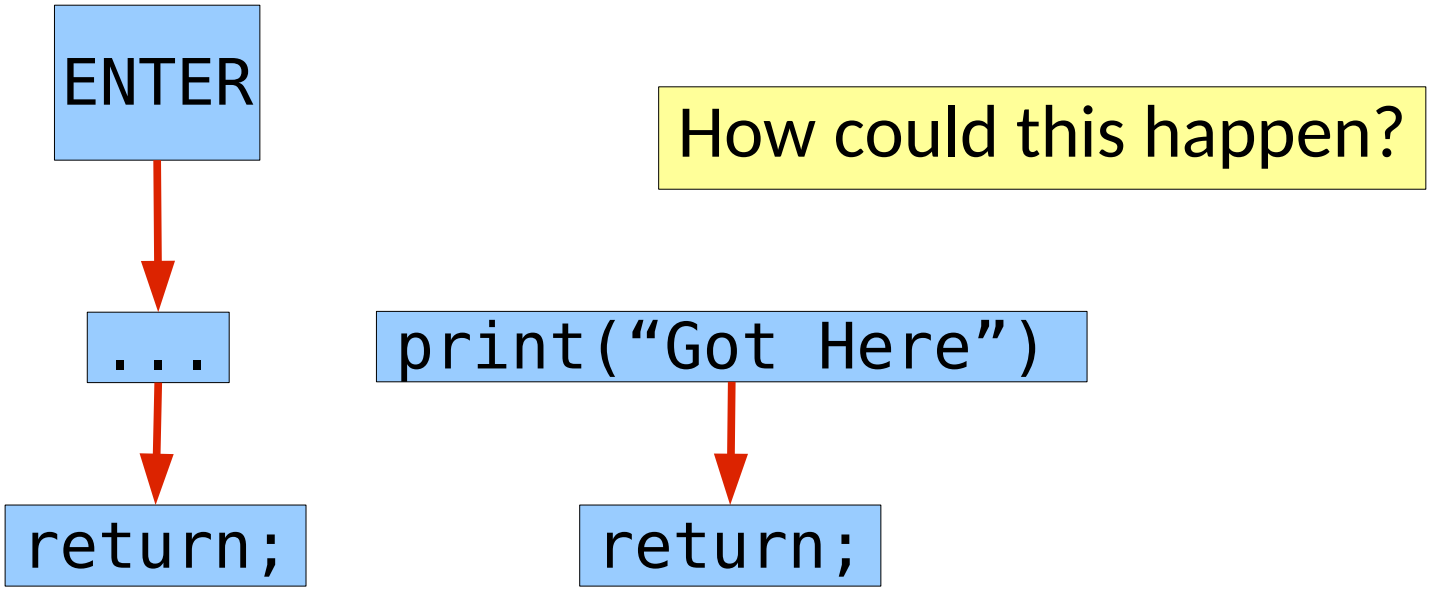

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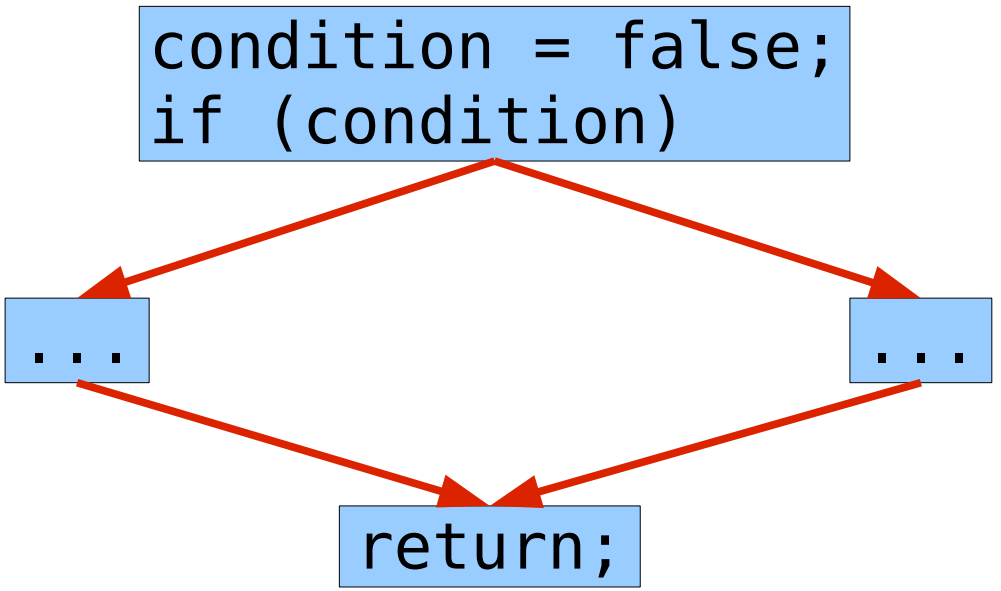

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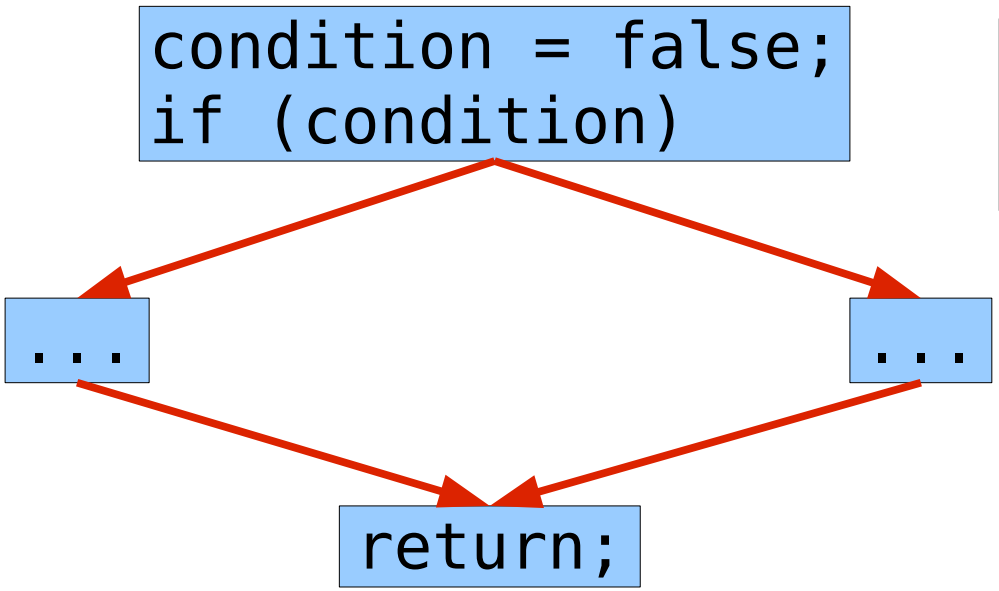

This can be ***undecidable***!

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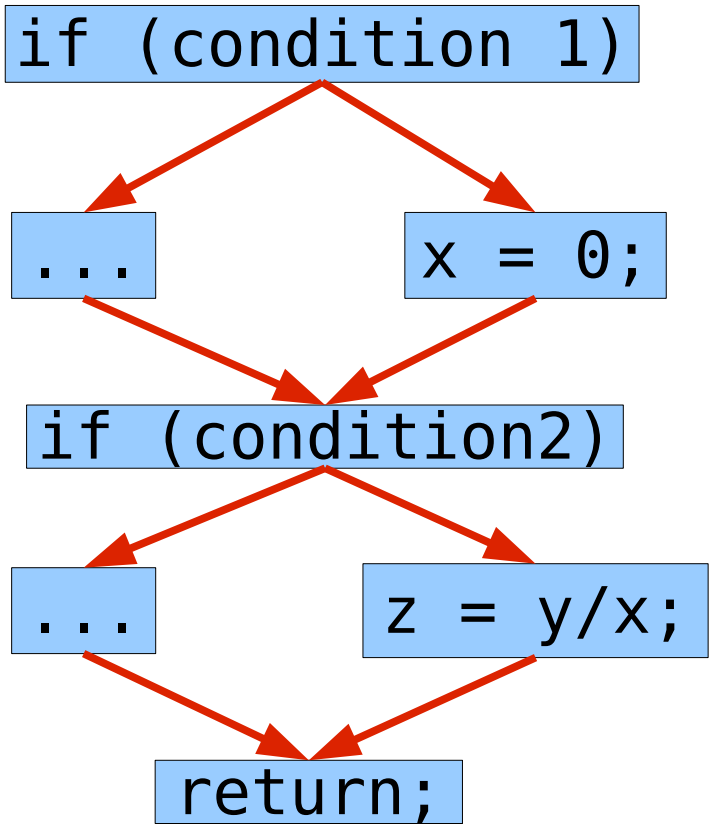
- So what do you do in practice?
  - No, really. What have *you* done in practice?
  - *Relative* degrees of coverage matter (40%? 80%?)

CFG Coverage

- The path taken by each test can matter



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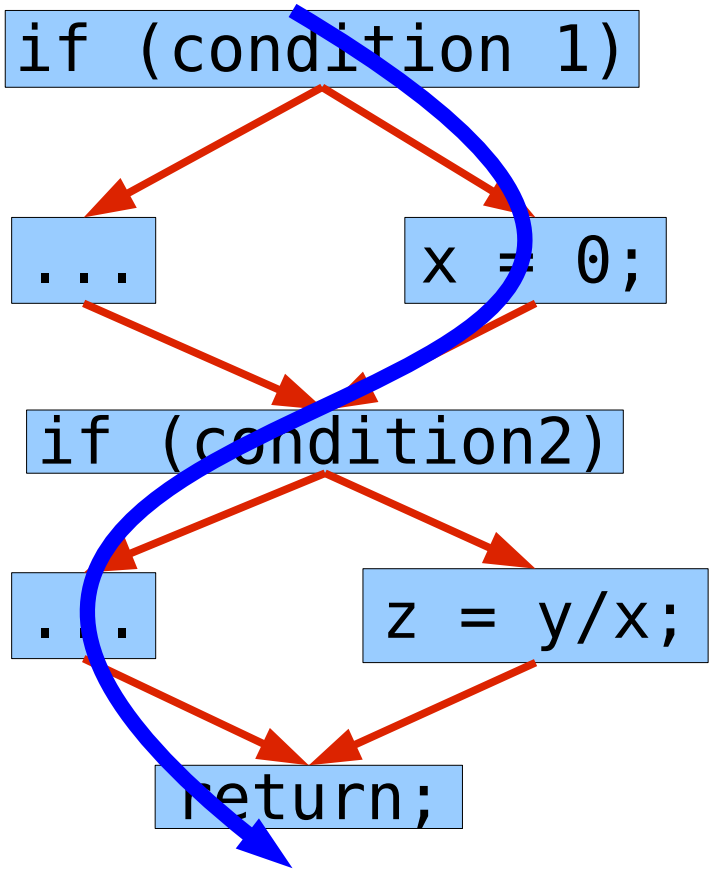

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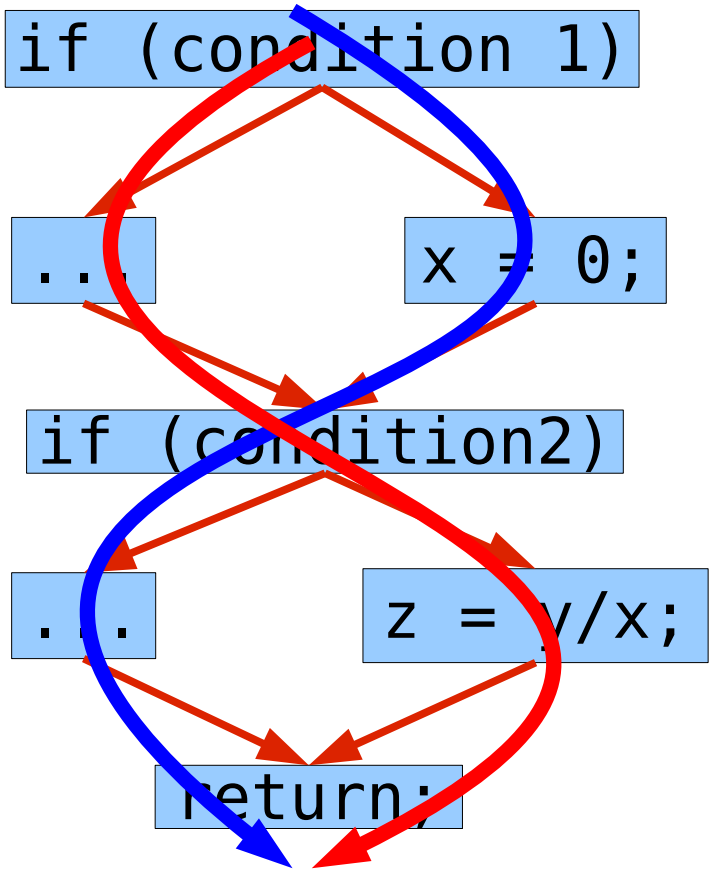
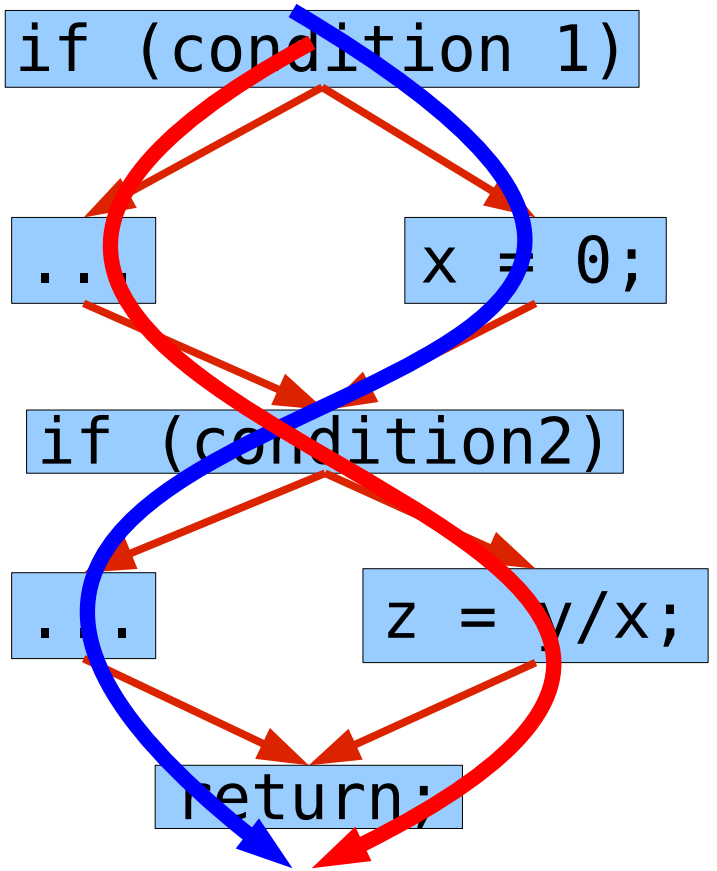


CFG Coverage

- The path taken by each test can matter

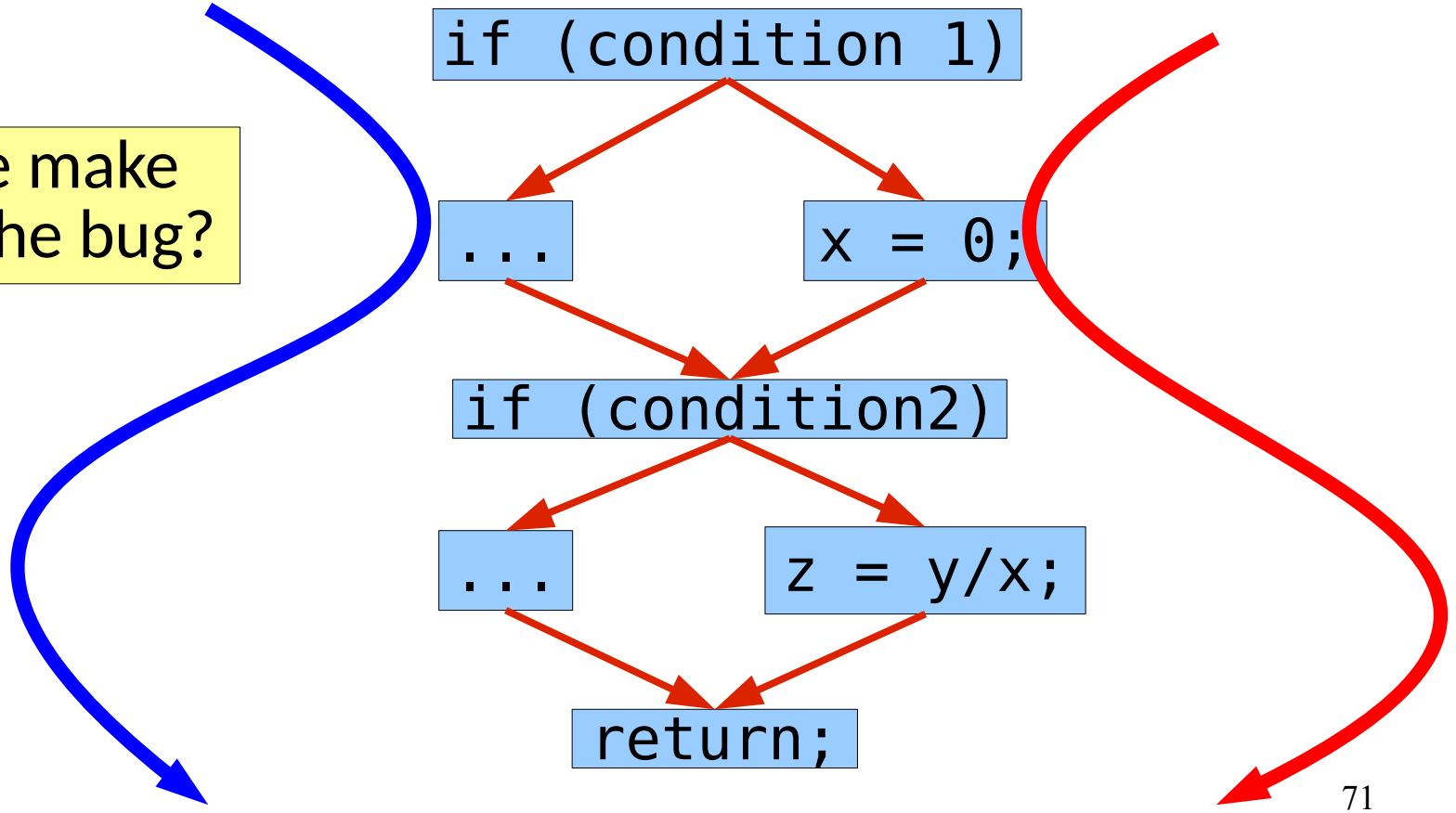
Full edge coverage
& no bugs found



CFG Coverage

- The path taken by each test can matter

How can we make sure to find the bug?



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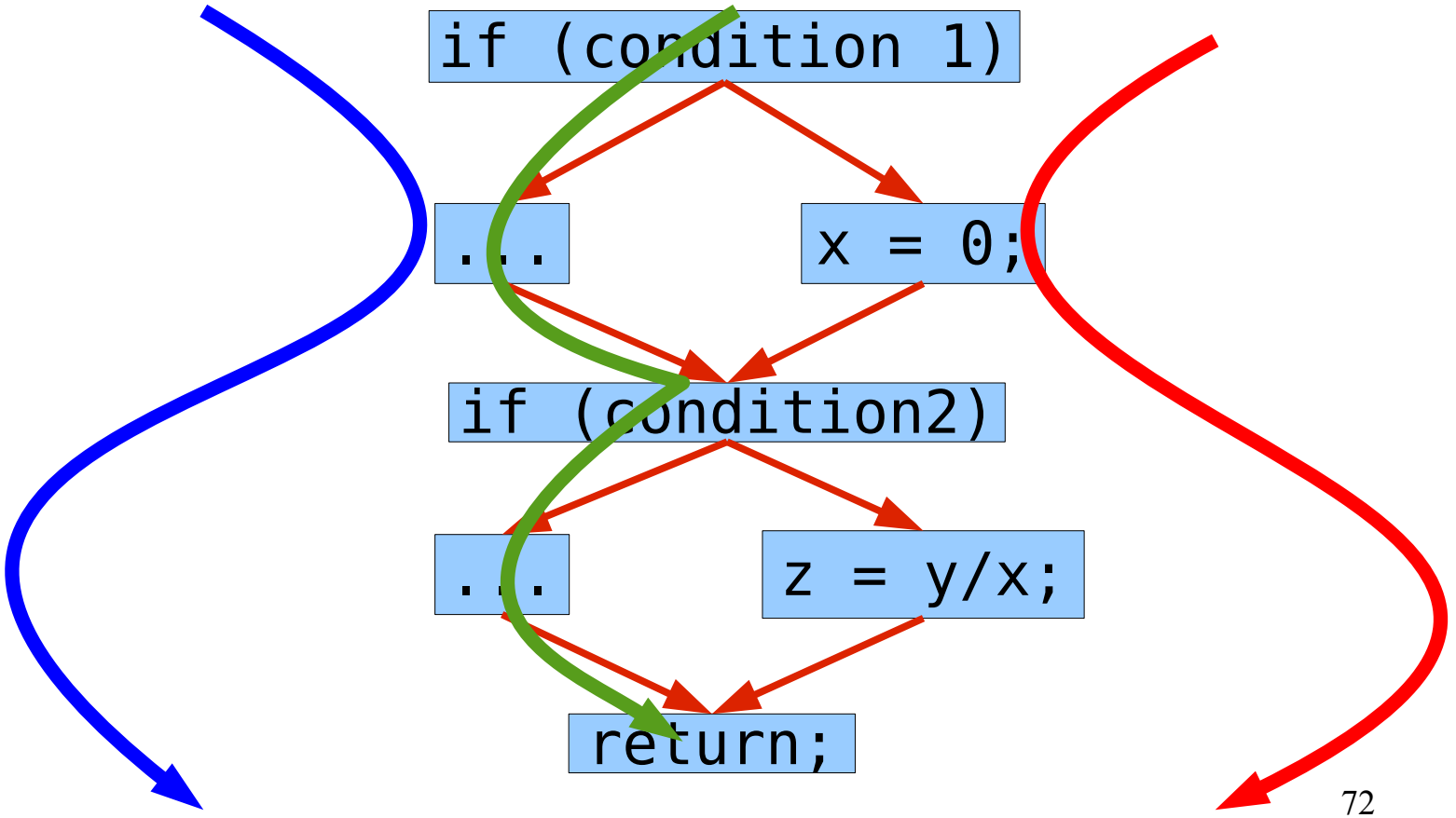

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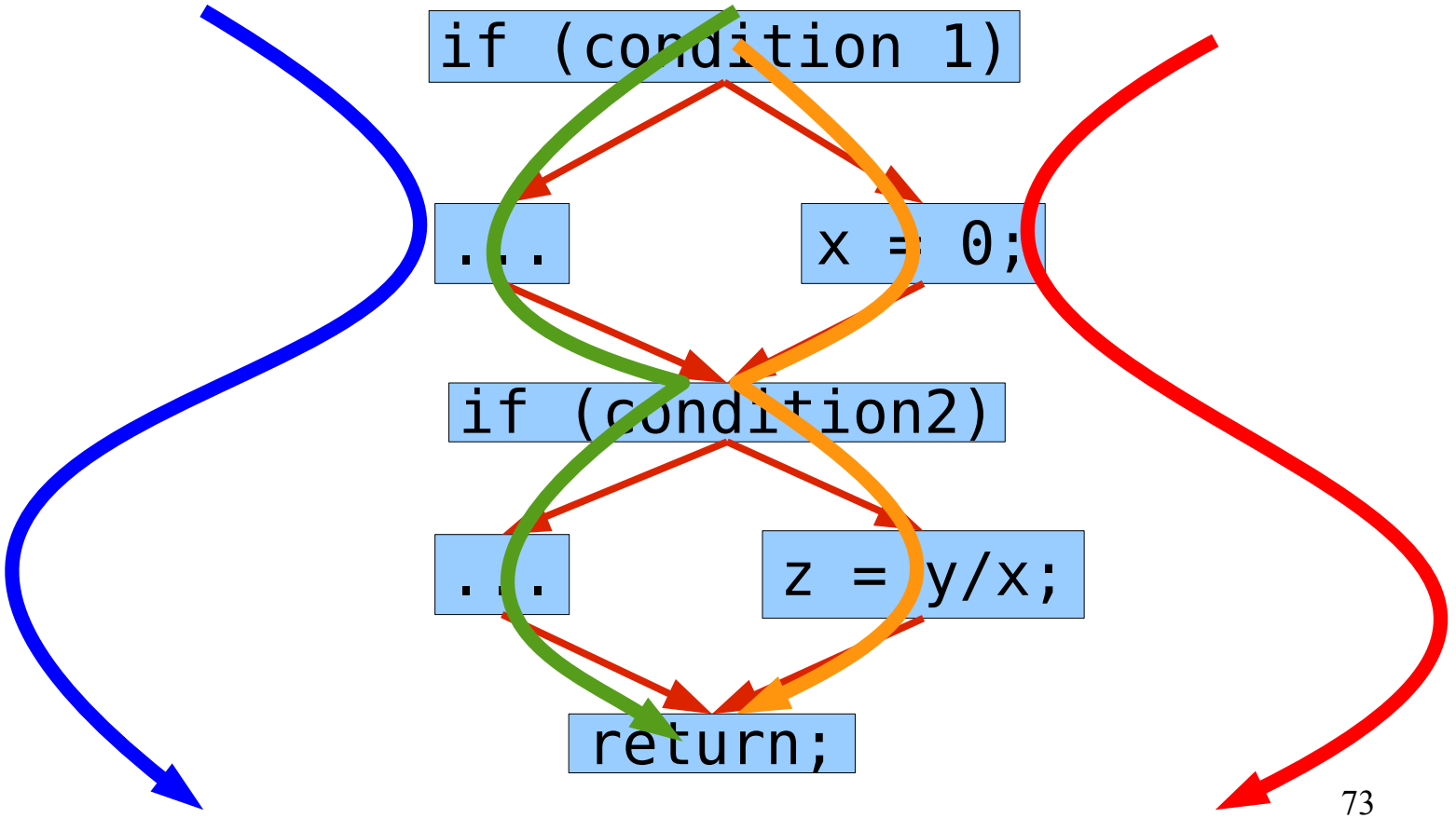
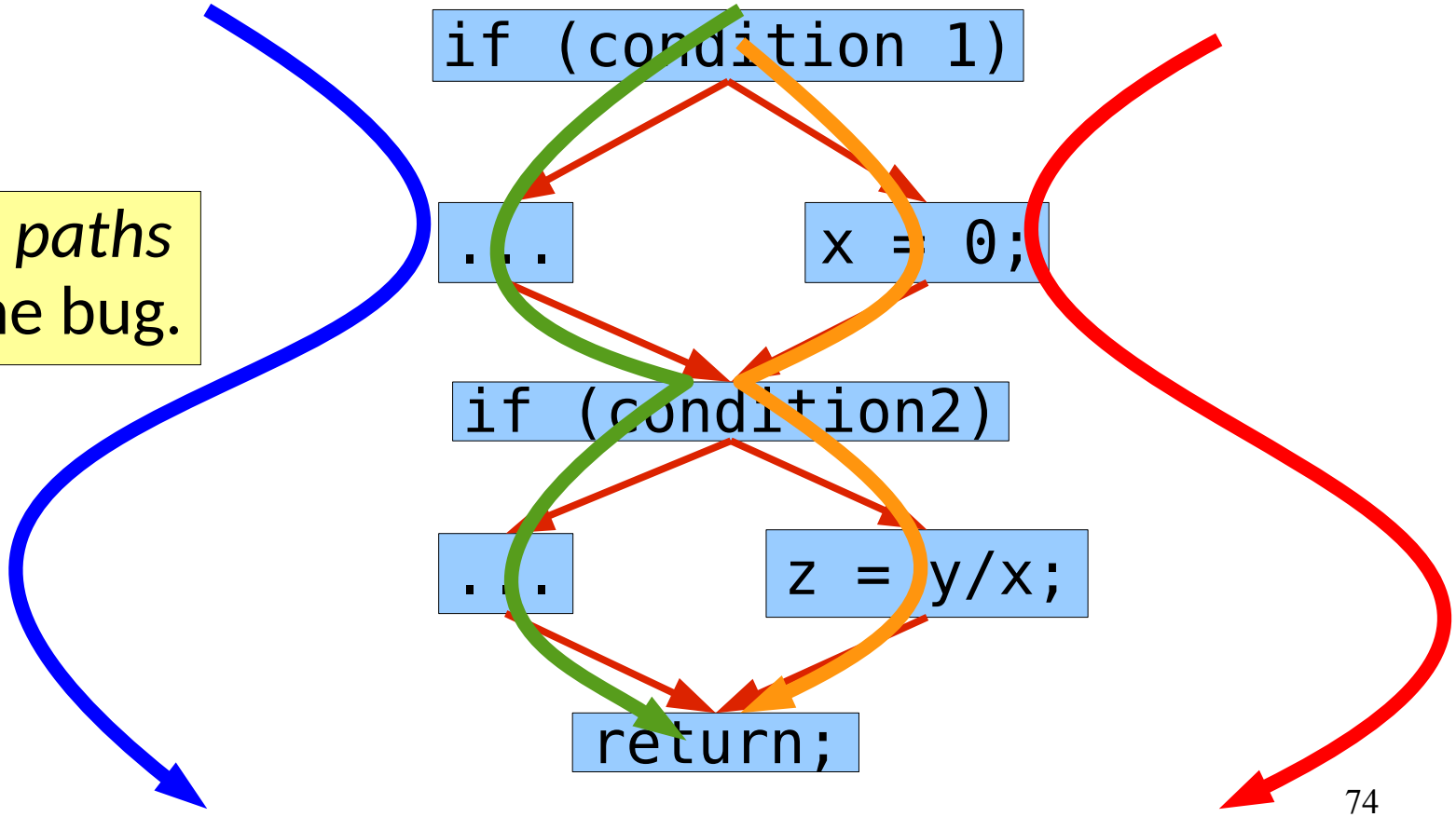


CFG Coverage

- The path taken by each test can matter

Testing *all paths* exposes the bug.



Path Coverage

- Complete Path Coverage
  - Test all paths through the graph

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Is this reasonable?
Why?

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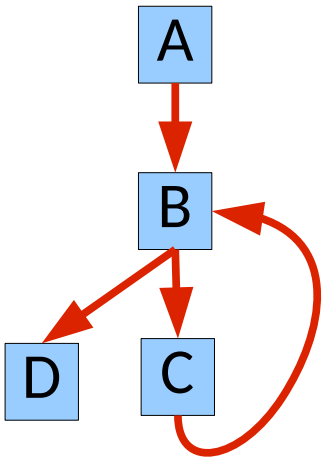

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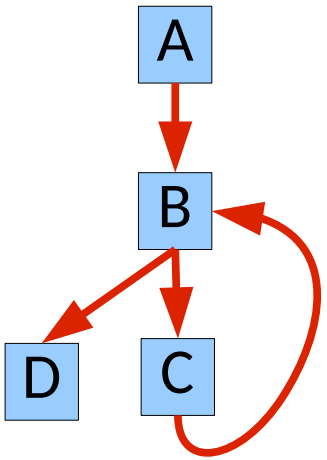

Infeasibility

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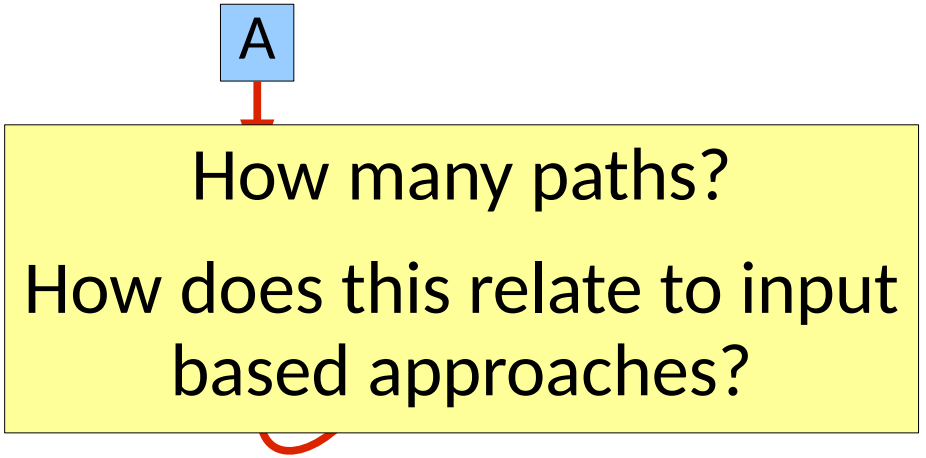

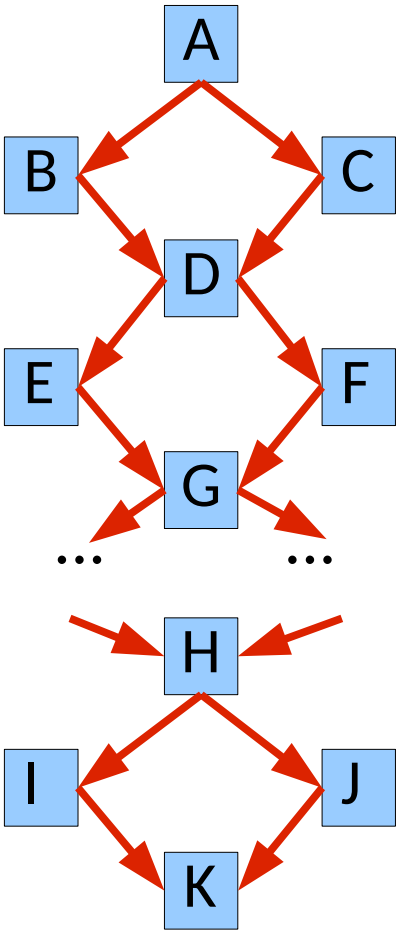

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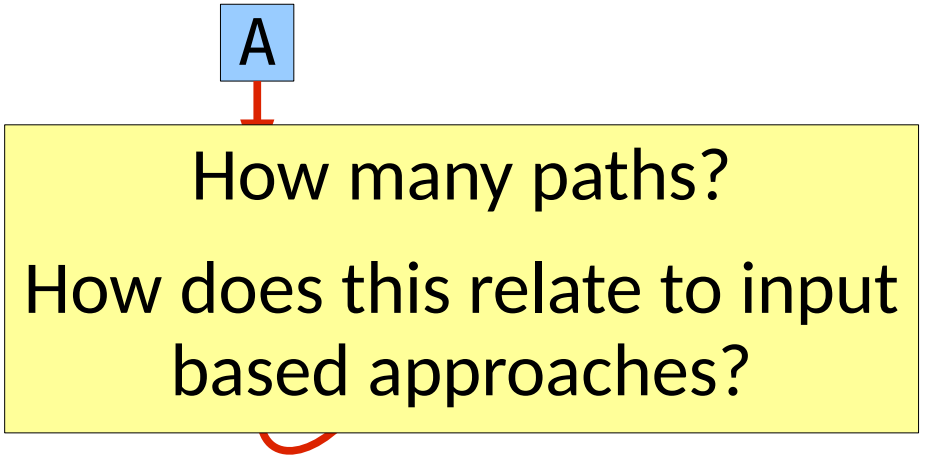

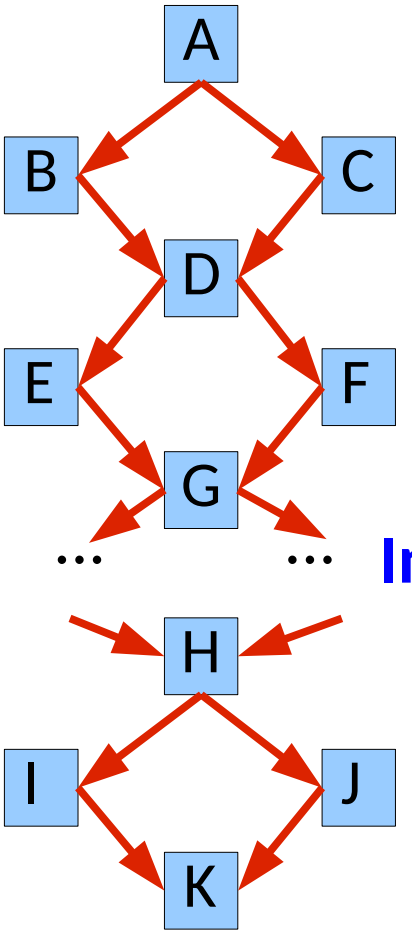

Intractability

Compromises?

- What could we do instead?

  (How did we handle the input based approaches?)

Compromises?

- Edge Pair Coverage
  - Each path of length <= 2 is tested.
- Specified Path Coverage
  - Given a number k, test k paths

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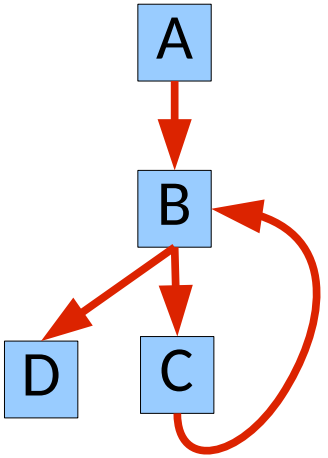

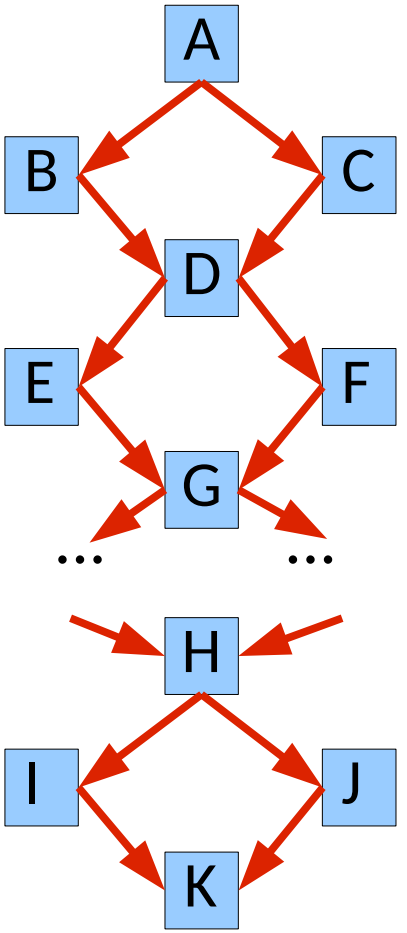

Compromises?

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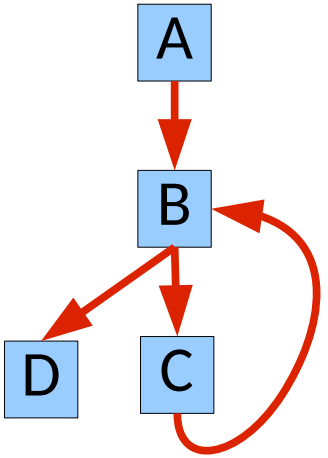
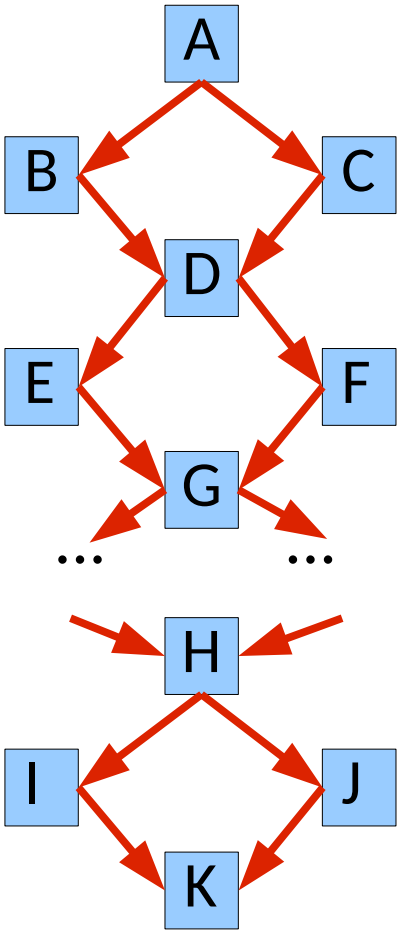
What do these look like?

Are they good?





Coping With Loops

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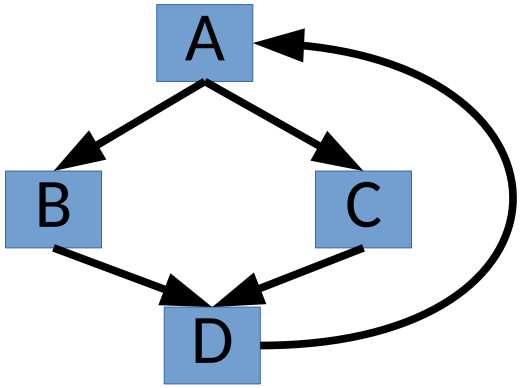
How many may there be?



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What does this provide?
What do they look like?

Coping With Loops

- Prime Path Coverage
  - Cover all prime paths

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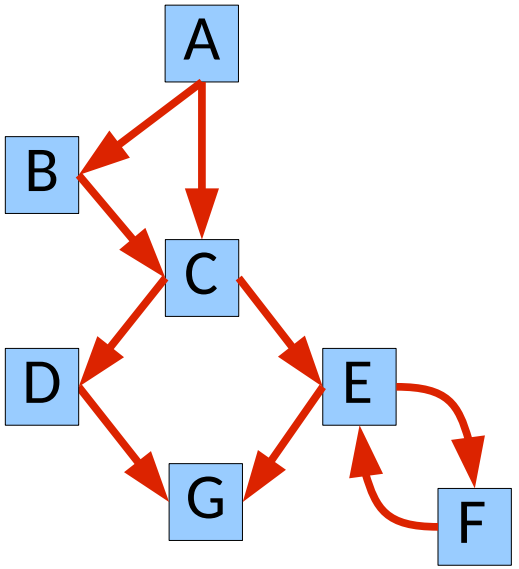

Example from Ammann & Offutt

Coping With Loops

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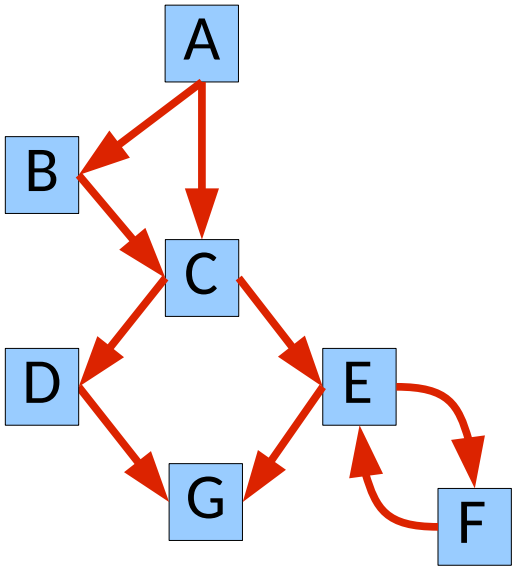

What are the prime paths?

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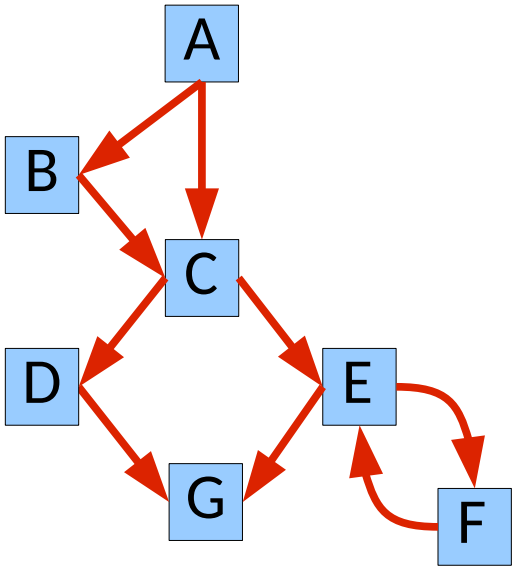

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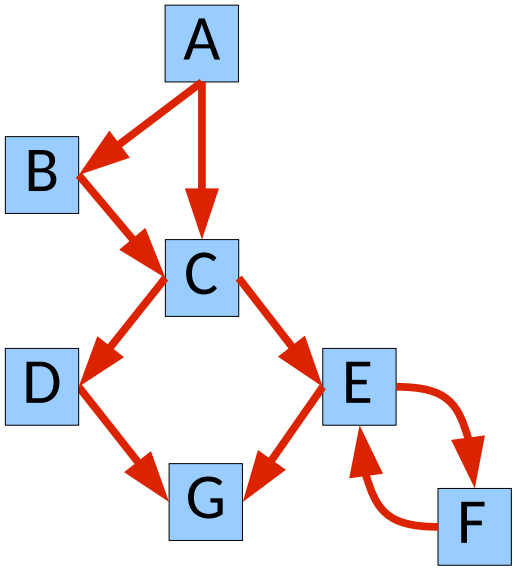

What are the prime paths?

How many simple paths?

Can you intuitively explain what prime paths capture?

Example from Ammann & Offutt

Coping With Loops

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Are these tests good or bad?

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Coping With Loops

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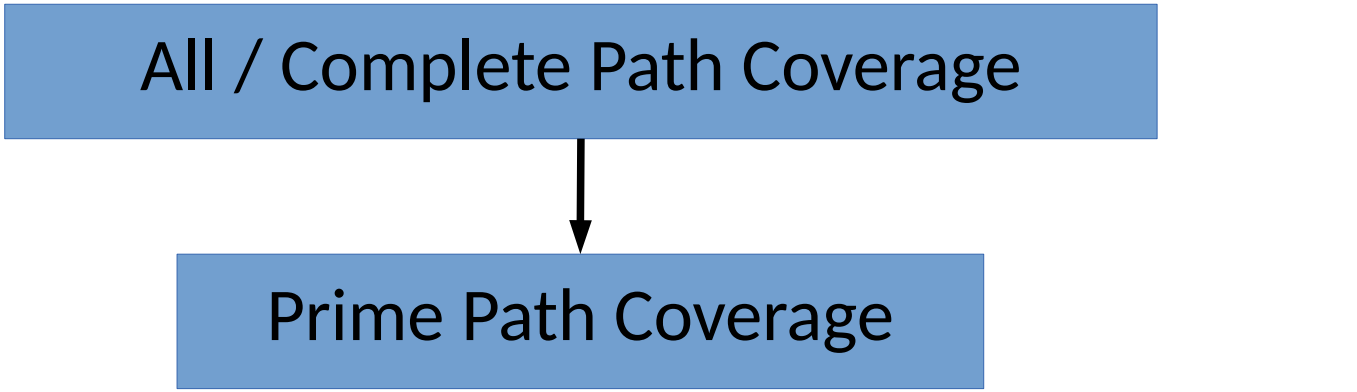
Are these tests good or bad?

Do they address all of the problems with path coverage?

Can you think of things they miss?

How Do They Relate?



How do they compare w/ edge coverage?

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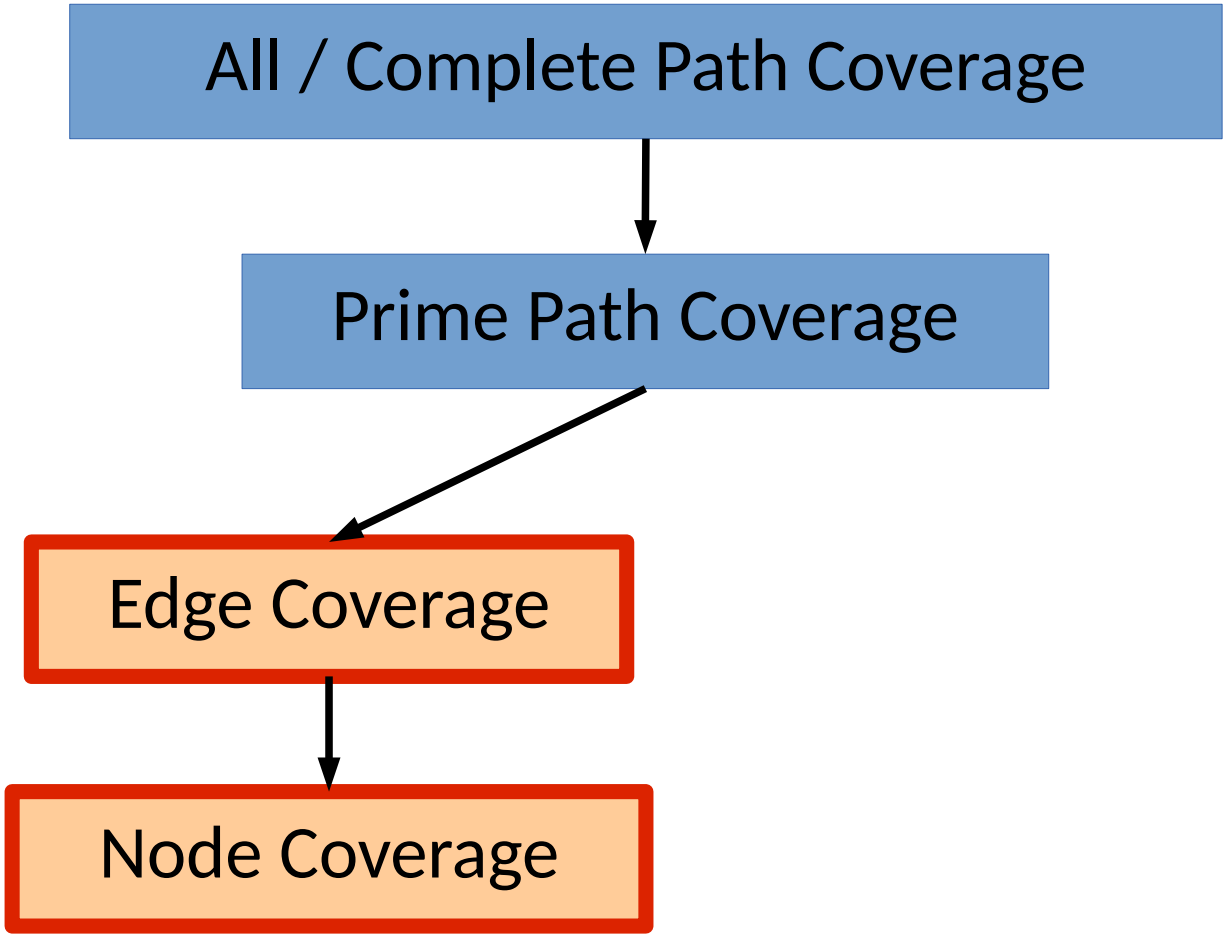

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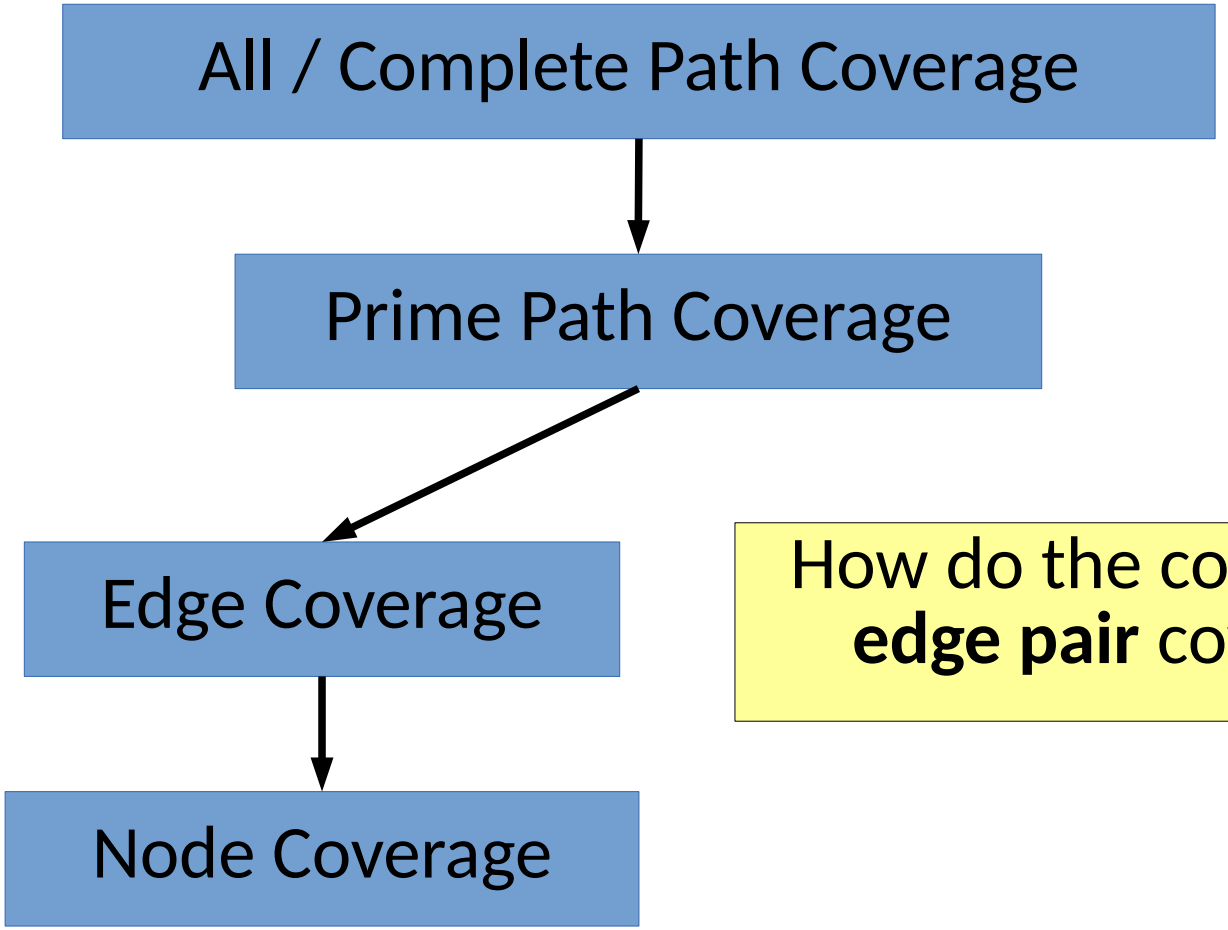

How do the compare w/ **edge pair** coverage?

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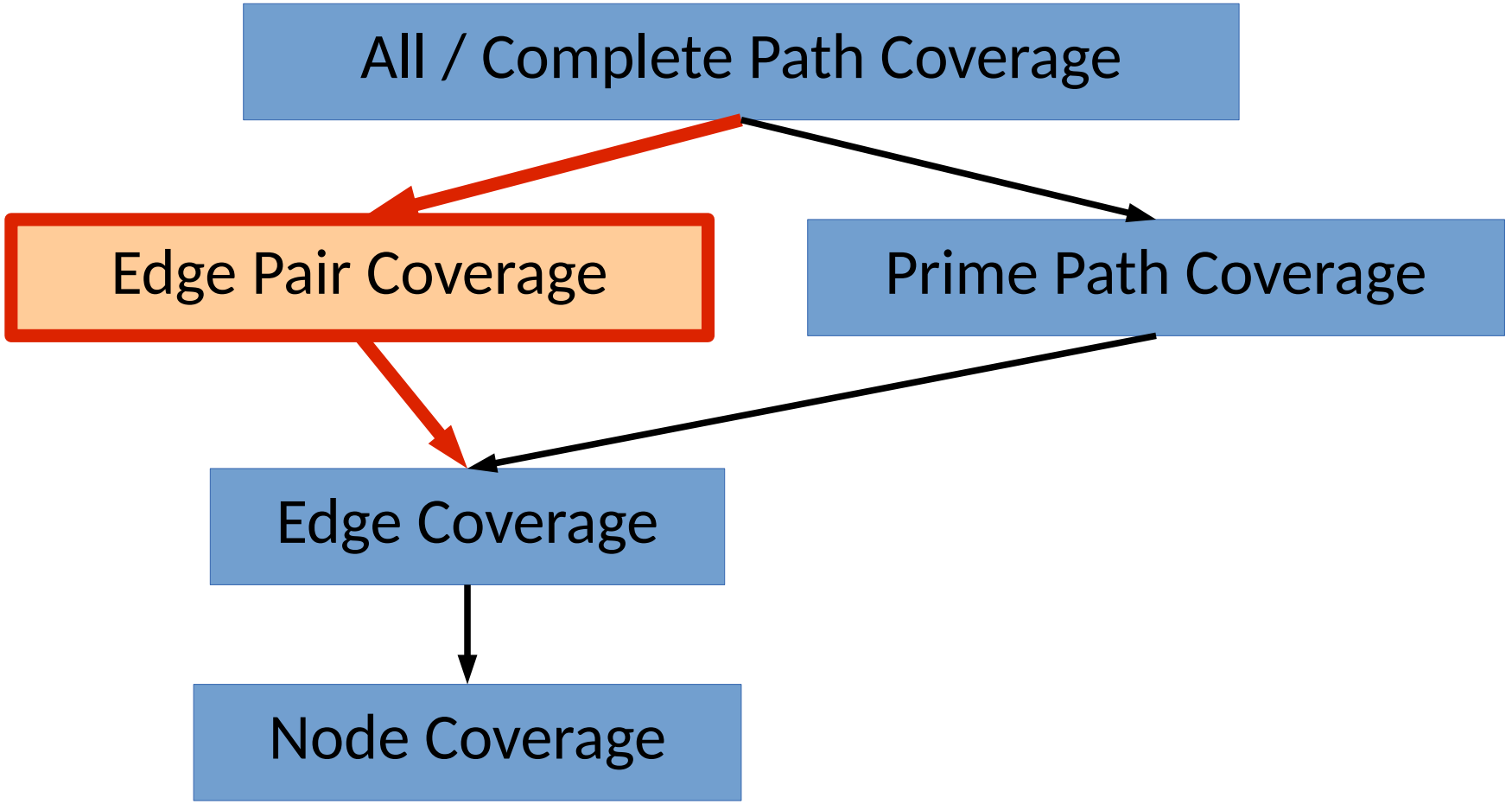

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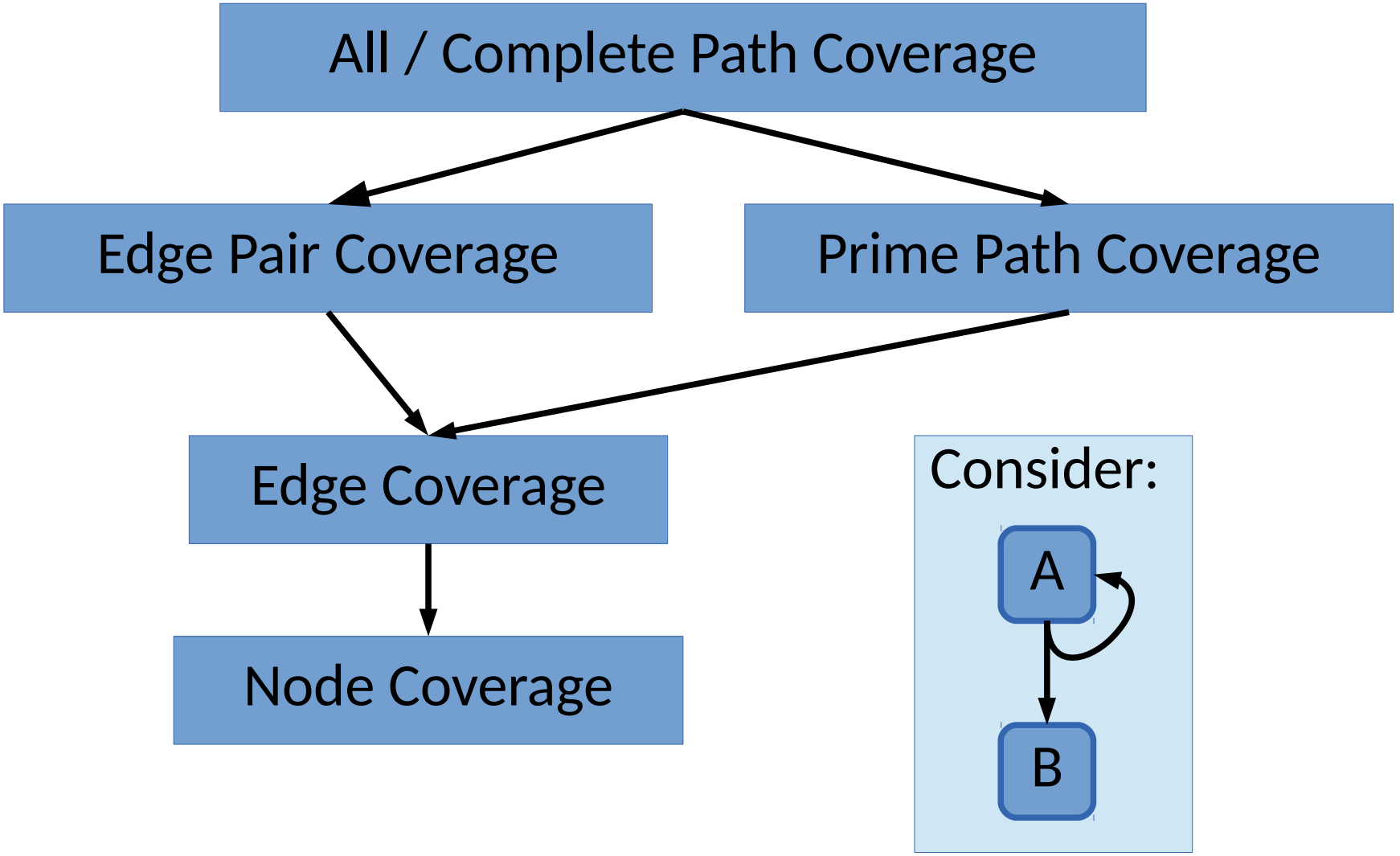

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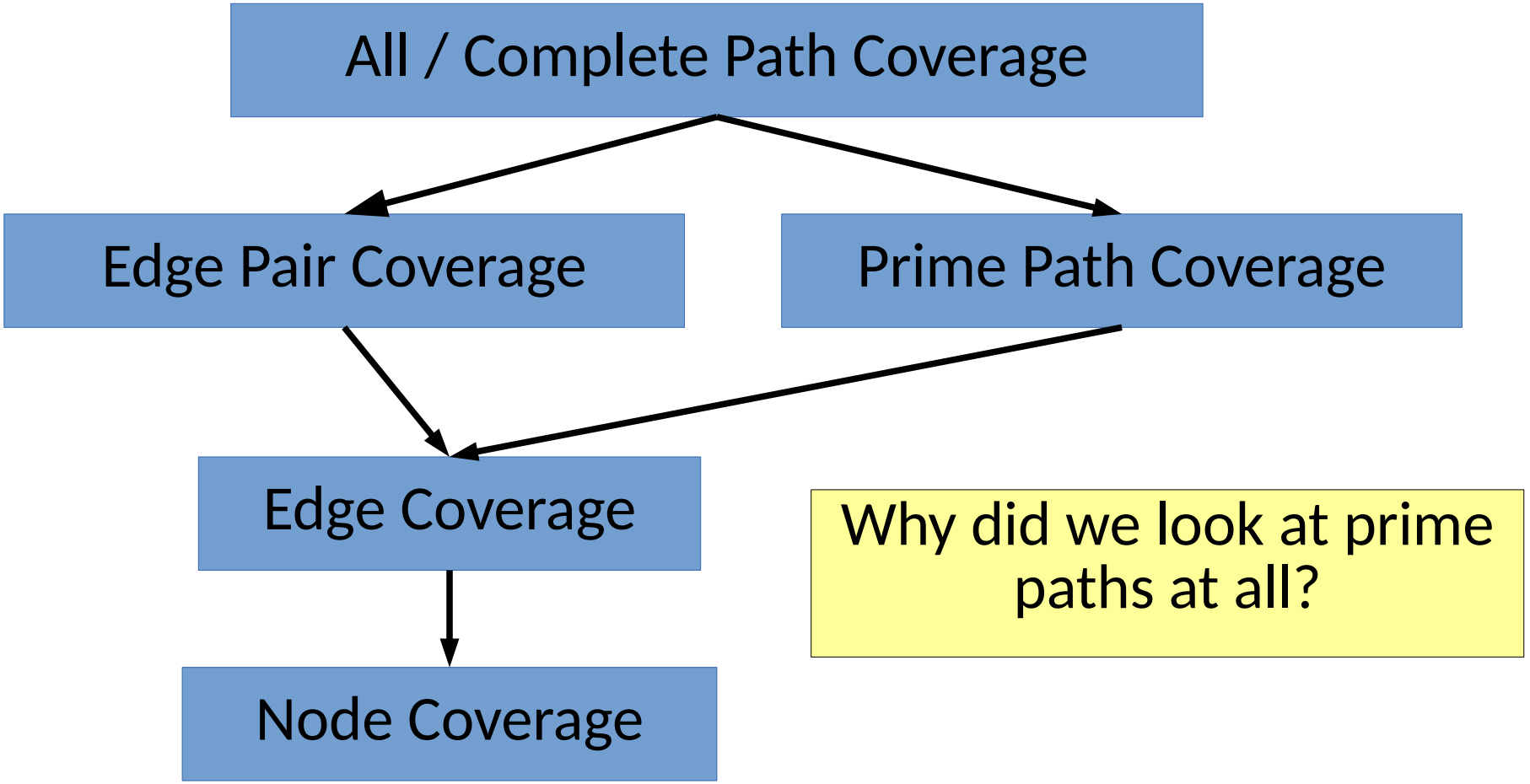

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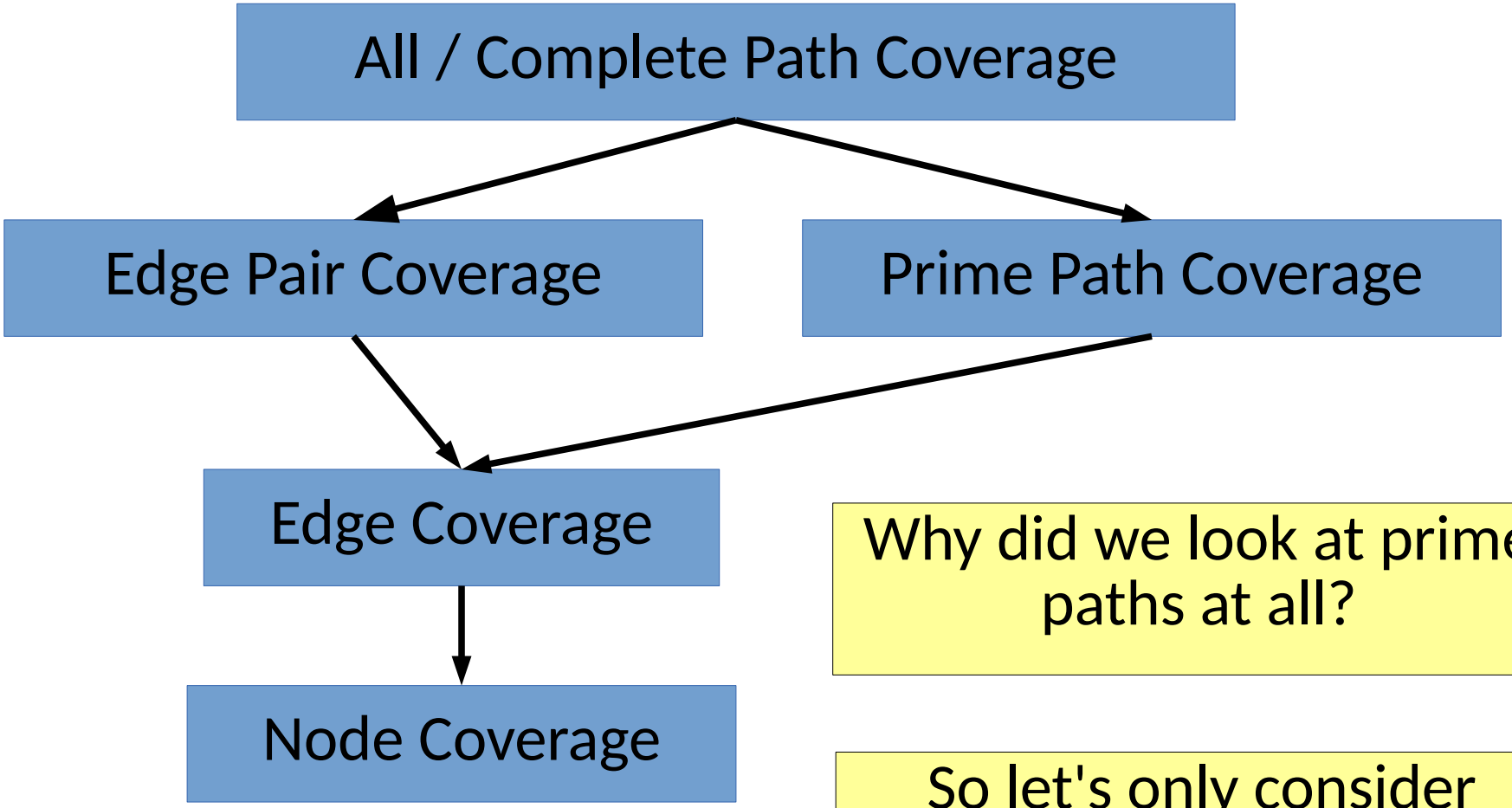


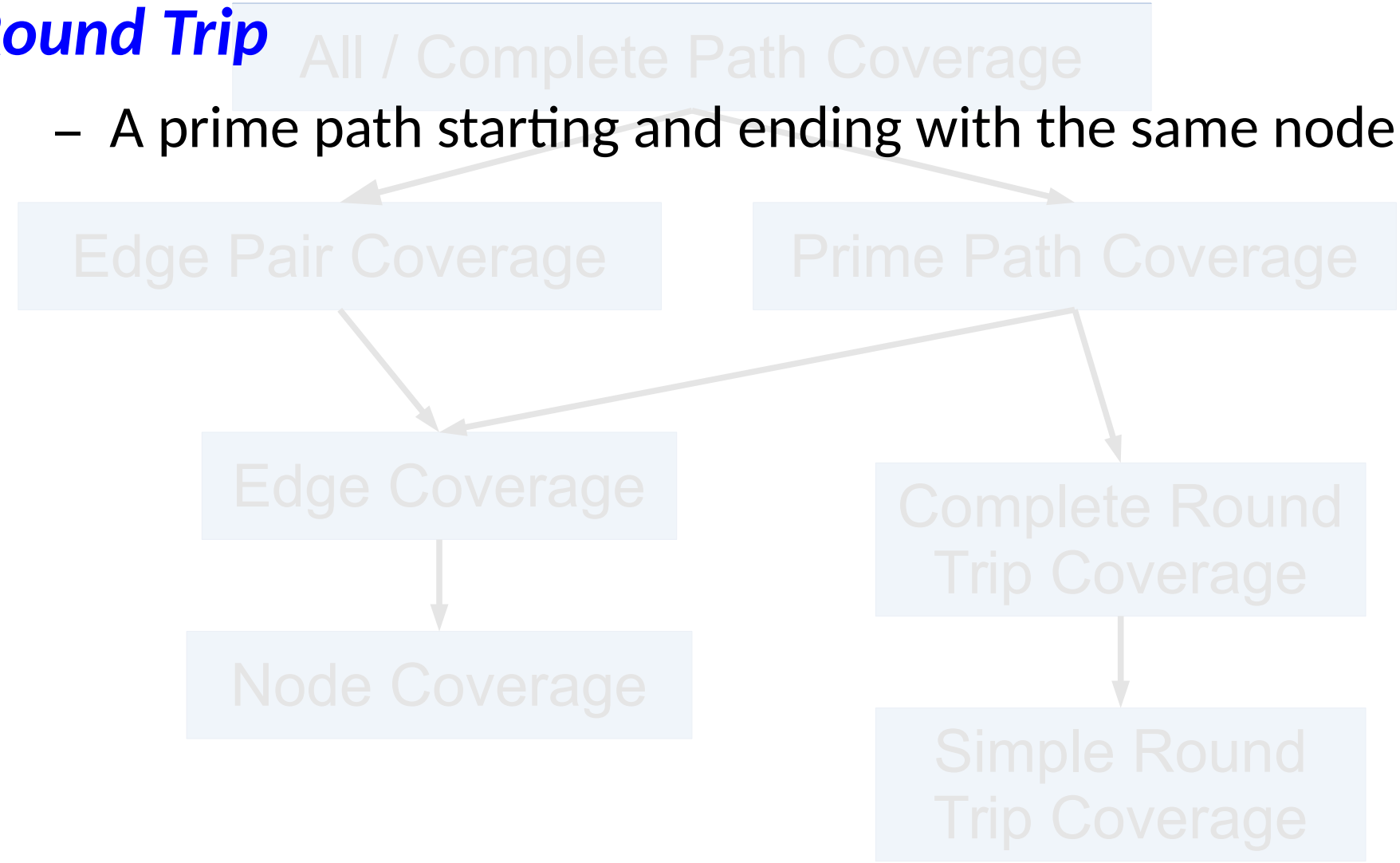
Why did we look at prime paths at all?

So let's only consider loops....

How Do They Relate?

Round Trip

– A prime path starting and ending with the same node



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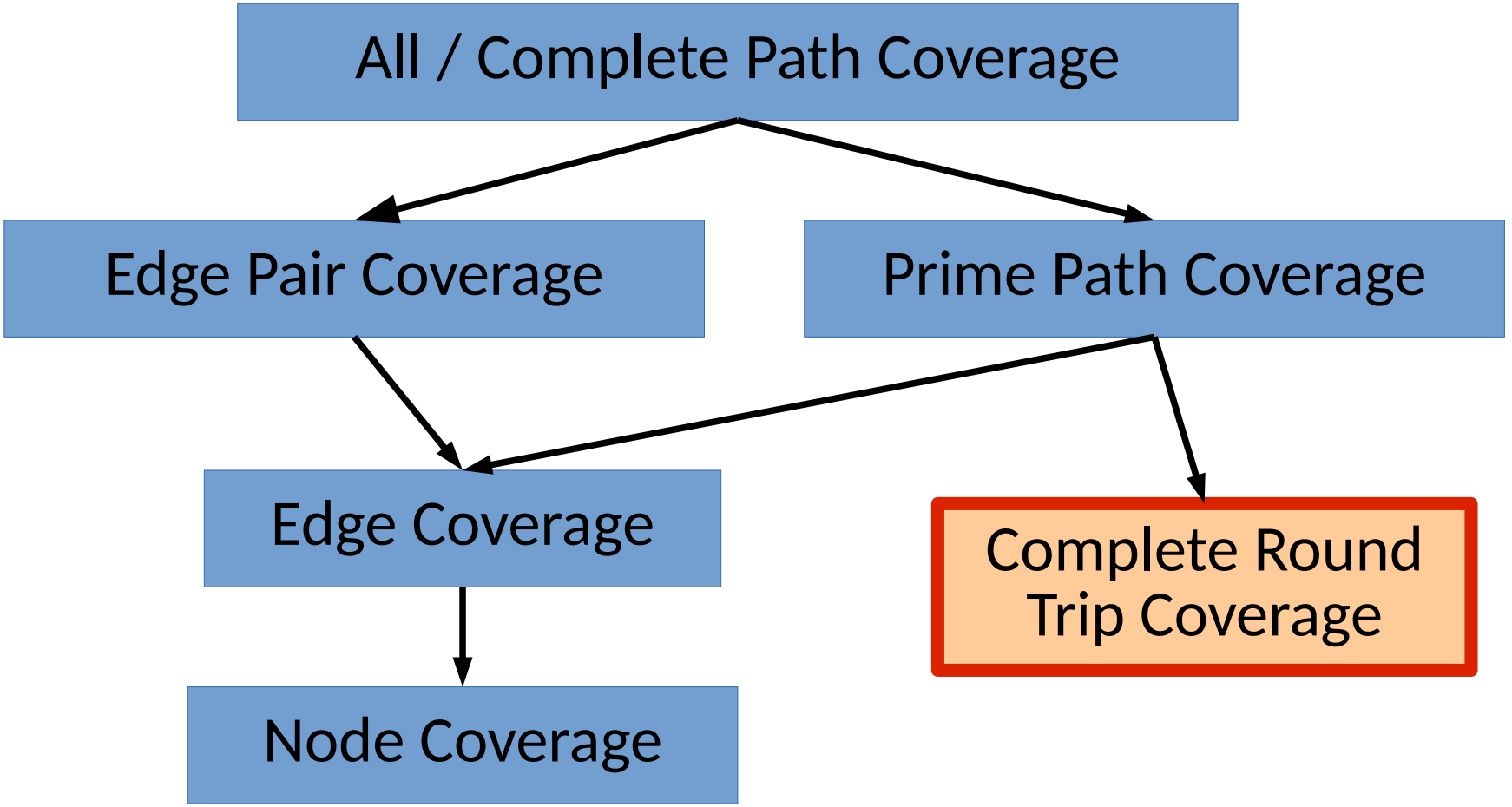
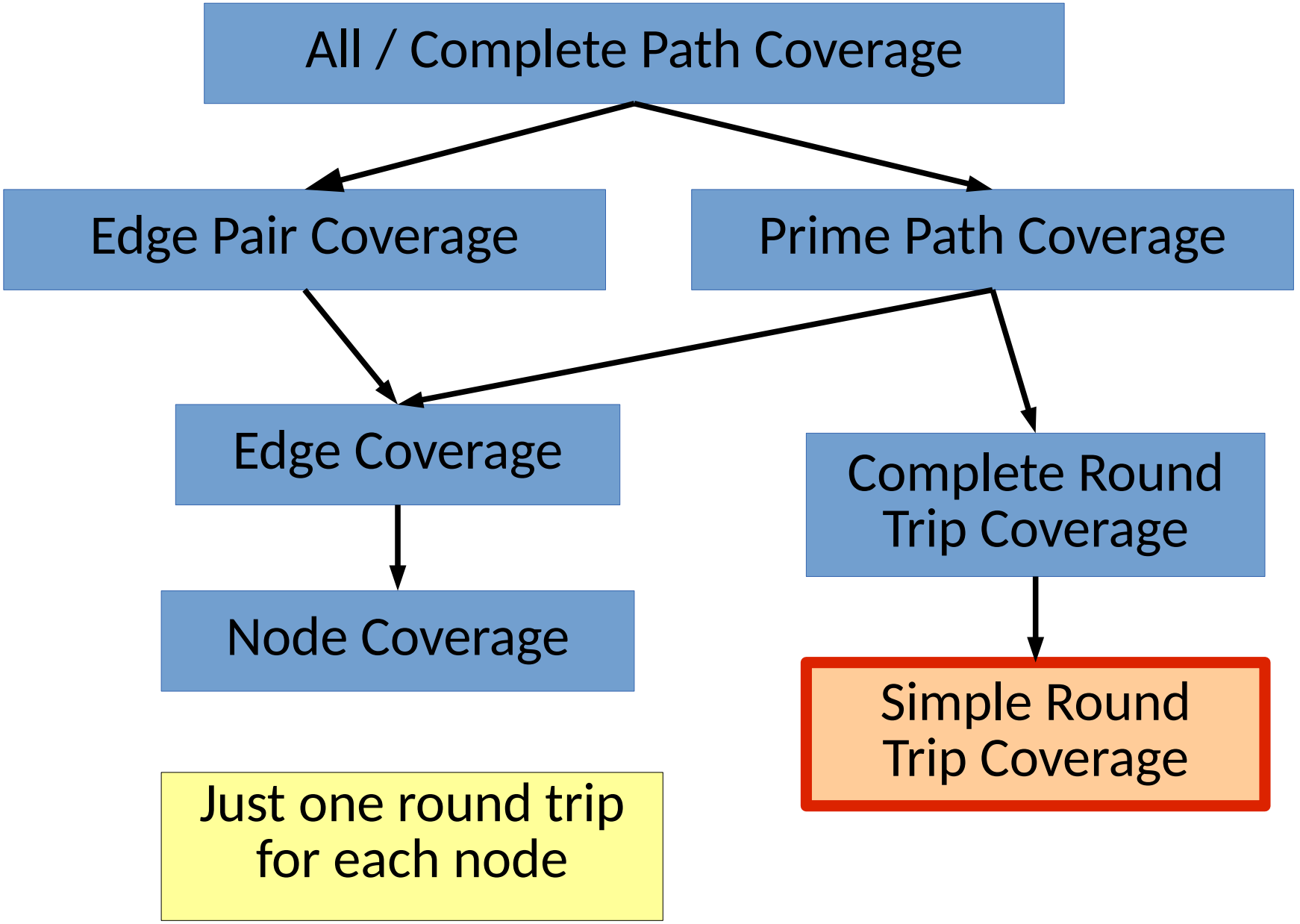


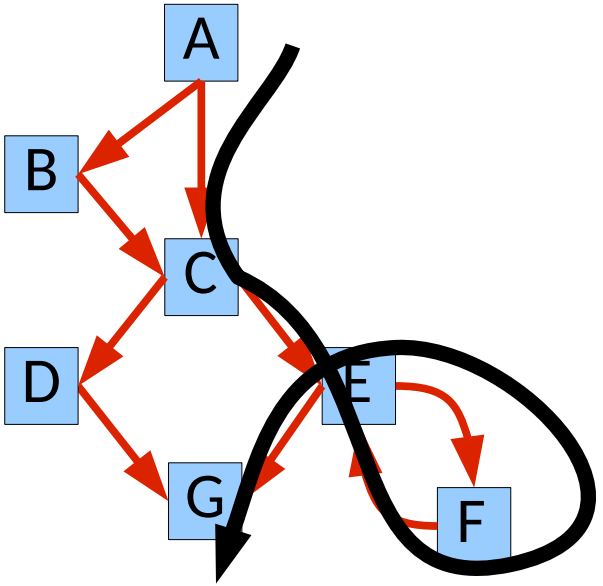
All round trips for each node

How Do They Relate?



Turning Them Into Tests

- Reconsider:



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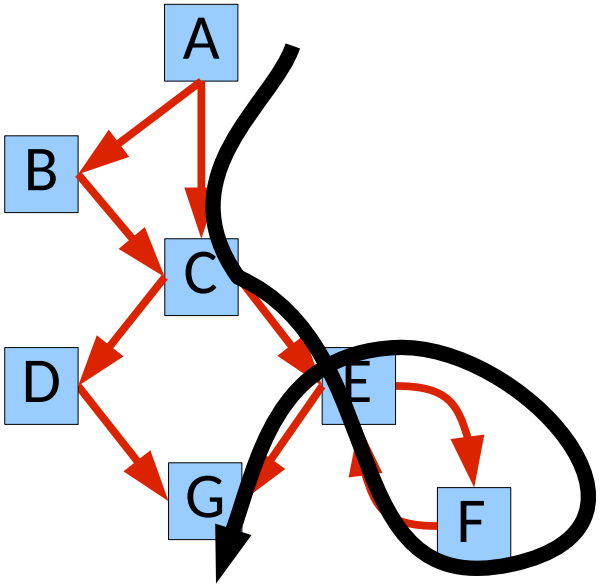

Is this path prime?

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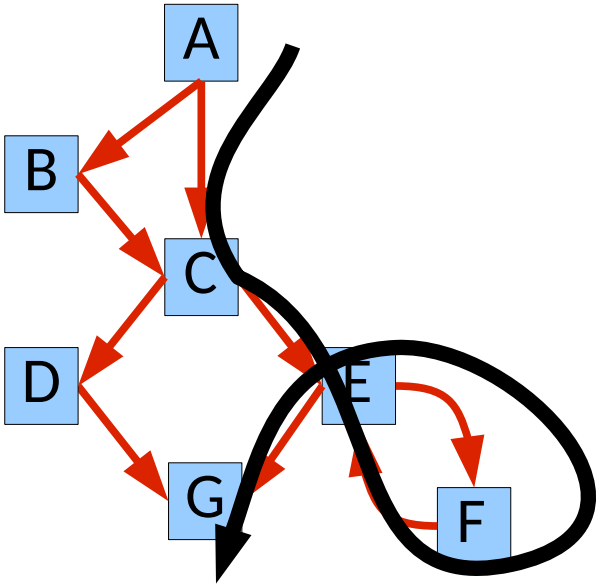

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Is it still useful?

Turning Them Into Tests

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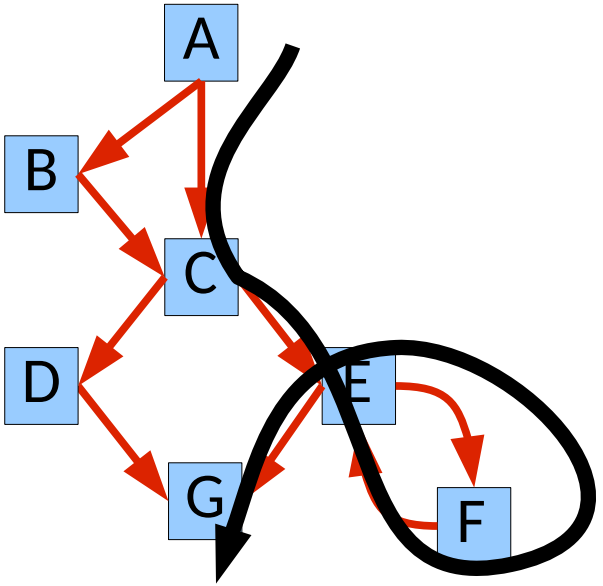

Is this path prime?

Is it still useful?

One test may cover multiple prime paths!

Requirements ≠ Tests

Turning Them Into Tests

- Relaxing our path requirements can help, too

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- Tour
  - A path *p* tours path *q* if *q* is a subpath of *p*
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This is strict!
Can we relax it?

Turning Them Into Tests

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  - Iff every ***edge*** of *q* appears in the same order in *p*
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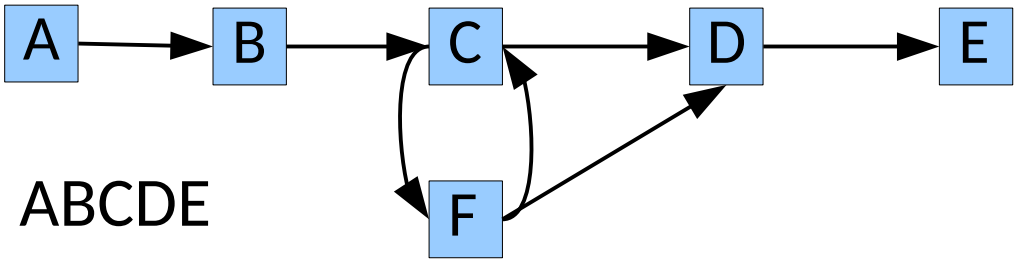
- Tour with sidetrips
  - Iff every ***edge*** of *q* appears in the same order in *p*
  - "Return to where you left"
- Tour with detours
  - Iff every ***node*** of *q* appears in the same order in *p*

Turning Them Into Tests



Strict Tour: ABCDE

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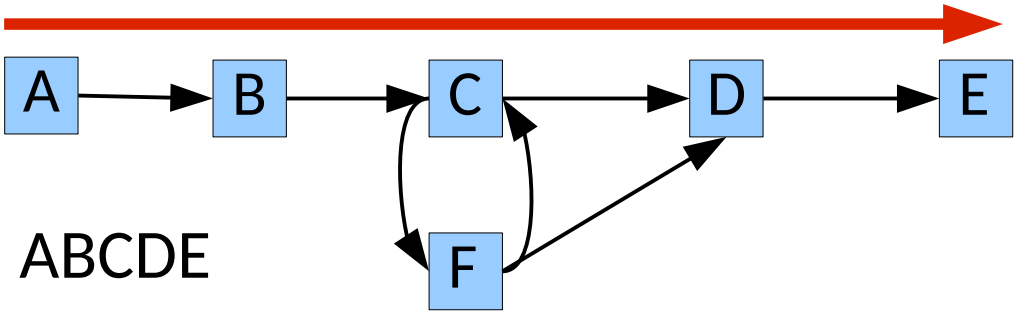

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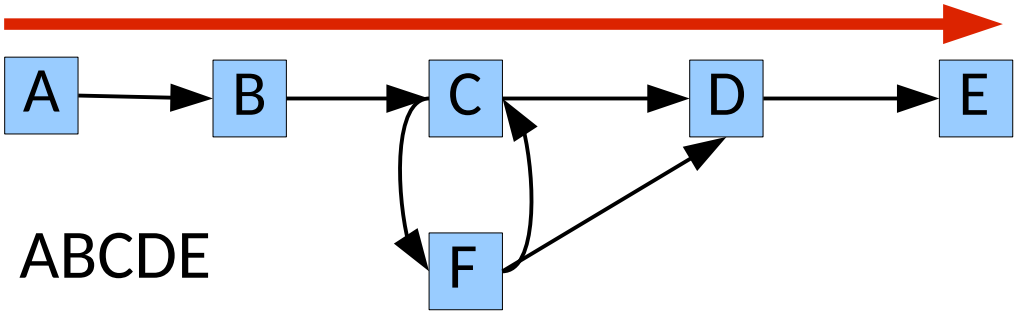

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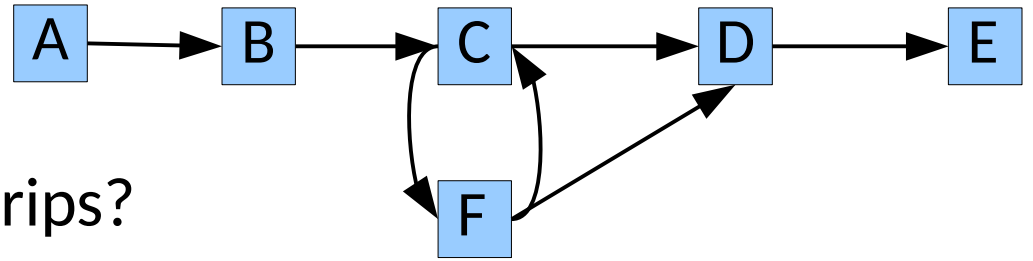
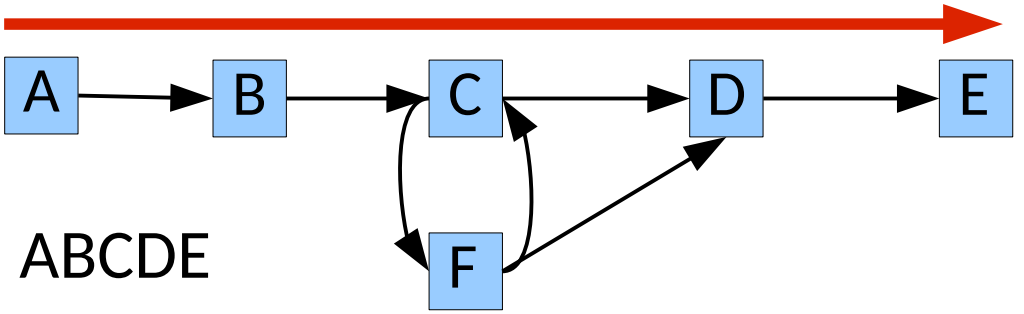


With Sidetrips?

Turning Them Into Tests



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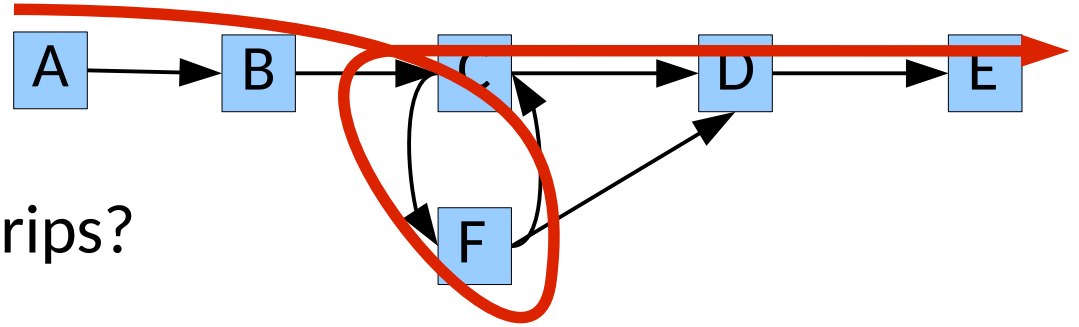

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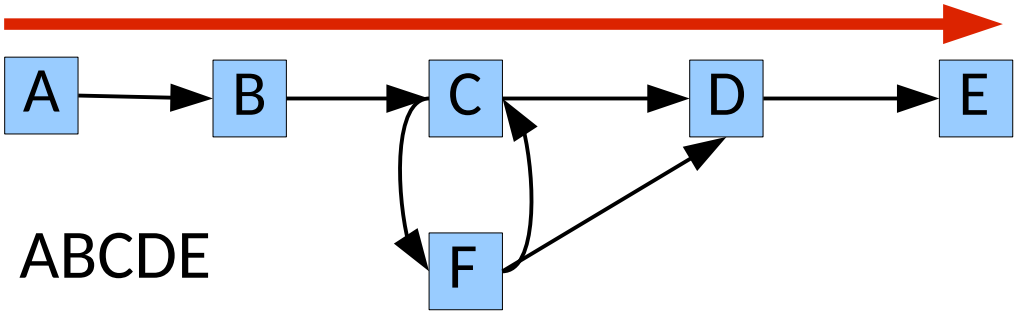

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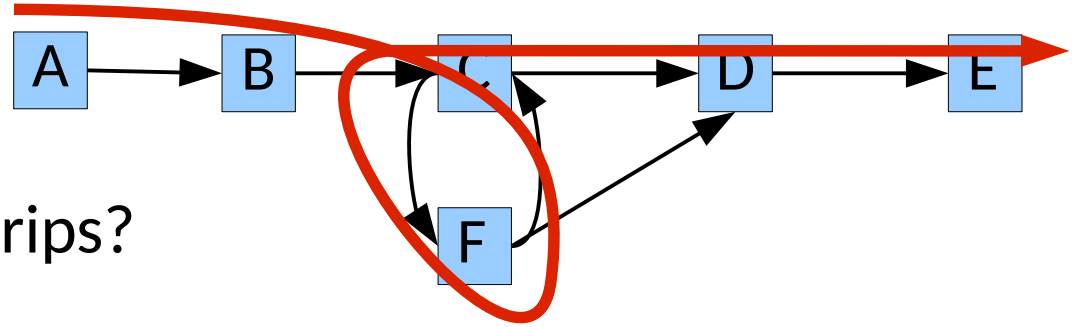

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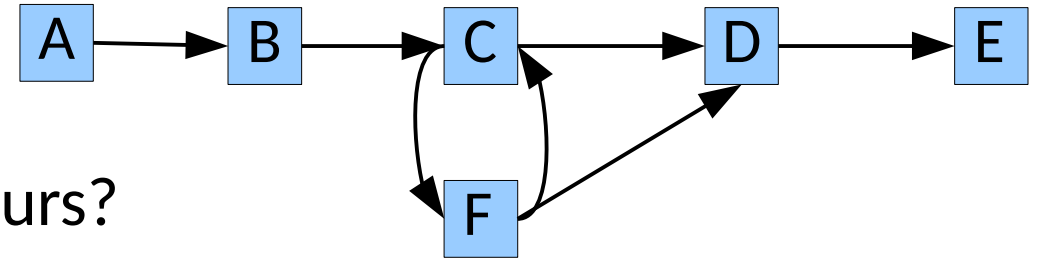

With Detours?

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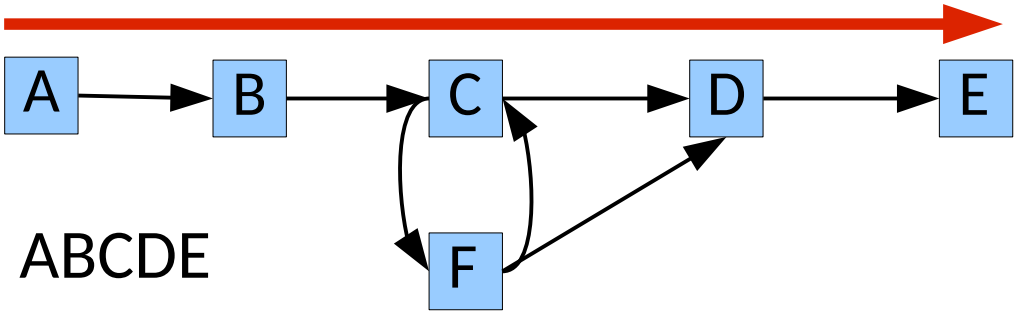
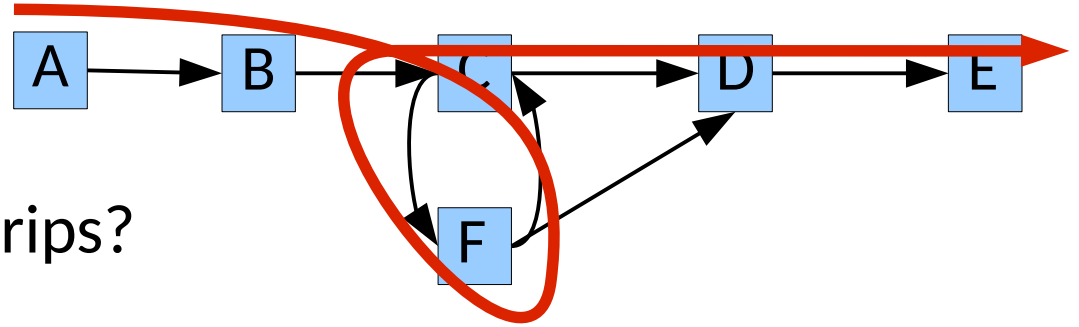
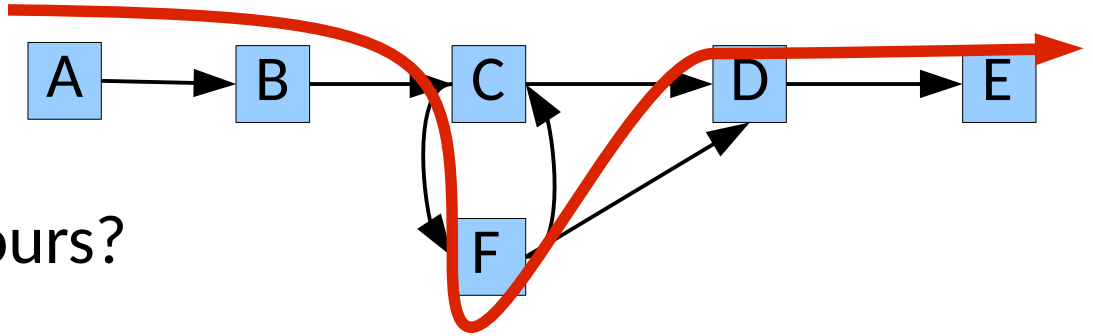


Strict Tour: ABCDE



With Sidetrips?



With Detours?

Turning Them Into Tests

- Do these relaxations help us with problems we have seen?

Turning Them Into Tests

- Do these relaxations help us with problems we have seen?
- Can you see any problems they may introduce?

Turning Them Into Tests

- Do these relaxations help us with problems we have seen?
- Can you see any problems they may introduce?
- How might this affect how you use them?

Onward

- But sometimes the structure of the CFG is not enough…