Introduction to Software Testing

Graph Coverage Criteria(Ch. 7.2)

Software Testing & Maintenance

SWE 437

http://go.gmu.edu/swe437

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(Dr. B for short)

Testing & Covering Graphs (7.2)

We use graphs in testing as follows:

-Develop a model of the software as a graph

-Require tests to visit or tour specific sets of nodes, edges, or subpaths

Test requirements (TR): Describe properties of test paths

Test Criterion: Rules that define test requirements

Satisfaction: Given a set *TR* of test requirements for a criterion *C*, a set of tests *T* satisfies *C* on a graph if and only if for every test requirement in *TR*, there is a test path in *path(T)* that meets the test requirement *tr*.

Structural Coverage Criteria: Defined on a graph just in terms of nodes and edges

Node and Edge Coverage

The first (and simplest) two criteria require that each node and edge in a graph be executed.

<u>Node Coverage (NC)</u> : Test set *T* satisfies node coverage on graph *G* iff for every syntactically reachable node *n* in *N*, there is some path *p* in *path(T)* such that *p* visits *n*.

This statement is a bit cumbersome, so we abbreviate it in terms of the set of test requirements.

<u>Node Coverage (NC)</u> : TR contains each reachable node in G.

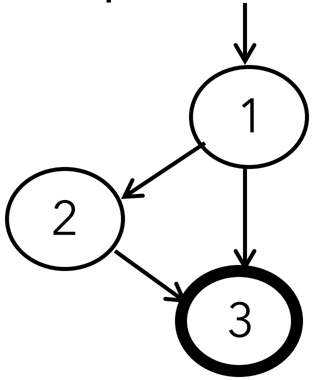
Node and Edge Coverage

Edge coverage is slightly stronger than node coverage

<u>Edge Coverage (EC)</u> : TR contains each reachable path of length up to 1, inclusive, in G

The phrase "*length up to 1*" allows for graphs with one node and no edges

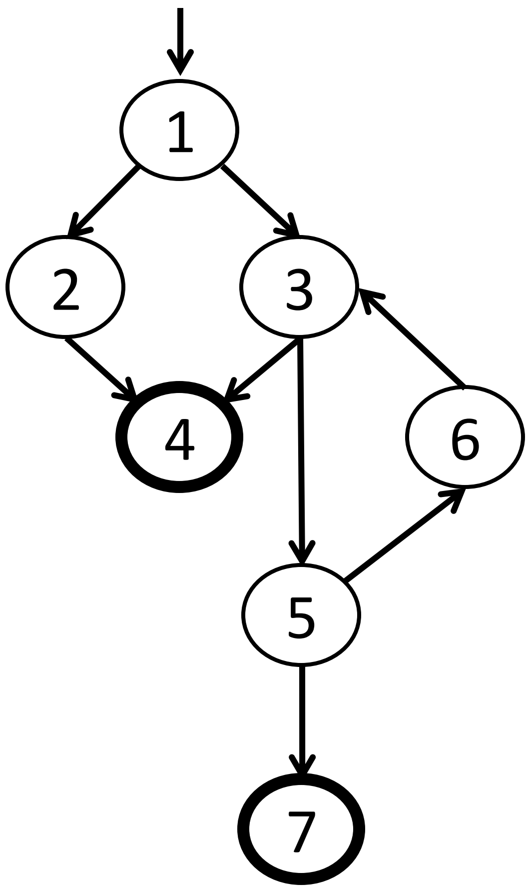
NC and EC are only different when there is an edge and another subpath between a pair of nodes (as in an "if-else" statement)



<u>Node Coverage</u> : TR = { 1, 2, 3 }
Test Path = [1, 2, 3]

<u>Edge Coverage</u> : TR = { (1, 2), (1, 3), (2, 3) }
Test Paths = [1, 2, 3]
[1, 3]

In-class Exercise

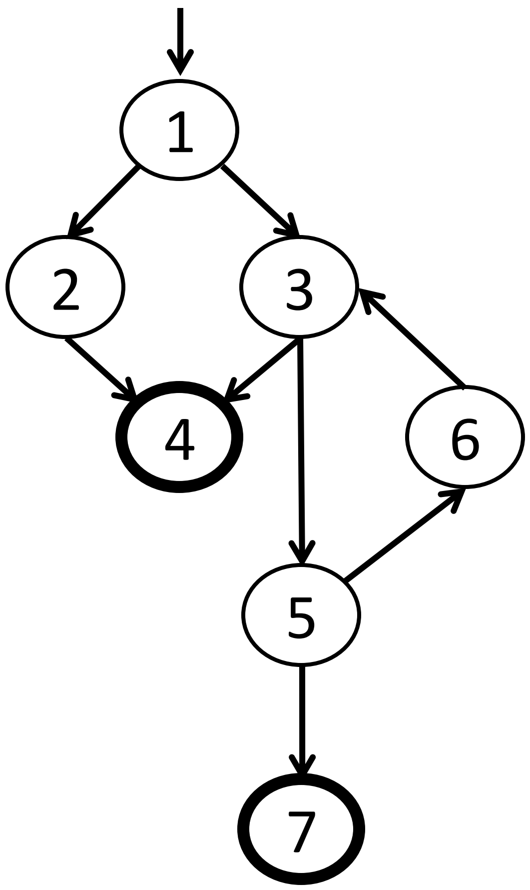


Graph Criteria EC

Answer the following questions for the graph on the left

1. List test paths that satisfy edge coverage.
2. Write the set of test requirements for edge-pair coverage.
3. List test paths that satisfy edge-pair coverage.
4. Write the set of test requirements for prime path coverage.
5. List test paths that satisfy prime path

In-class Exercise



Graph Criteria EC

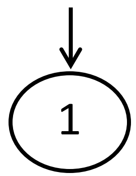
Answer the following questions for the graph on the left

1. List test paths that satisfy edge coverage.

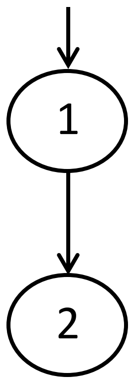
[1, 2, 4]
[1, 3, 5, 6, 3, 4]
[1, 3, 5, 7]

Node and Edge Coverage

A graph with **only one node** will not have any edges



It may seem trivial, but formally, Edge Coverage needs to require Node Coverage on this graph



Otherwise, Edge Coverage will not subsume Node Coverage

-So we define "**length up to 1**" instead of simply "length 1"

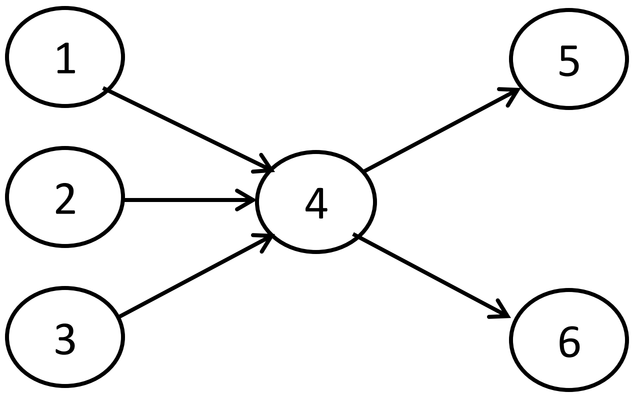
We have the same issue with graphs that have only **one edge** – for Edge-Pair Coverage…

Covering Multiple Edges

Edge-pair coverage requires **pairs of edges**, or subpaths of length 2

Edge-Pair Coverage (EPC) : TR contains each reachable path of length up to 2, inclusive, in G

The phrase "**length up to 2**" is used to include graphs that have less than 2 edges

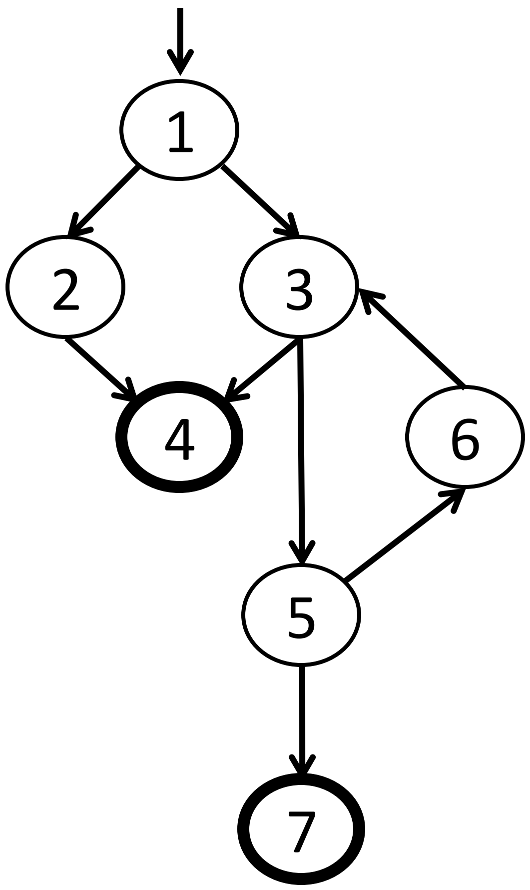


Edge-Pair Coverage : ?

TR = { [1,4,5], [1,4,6], [2,4,5], [2,4,6], [3,4,5], [3,4,6] }

The logical extension is to require **all paths**…

In-class Exercise



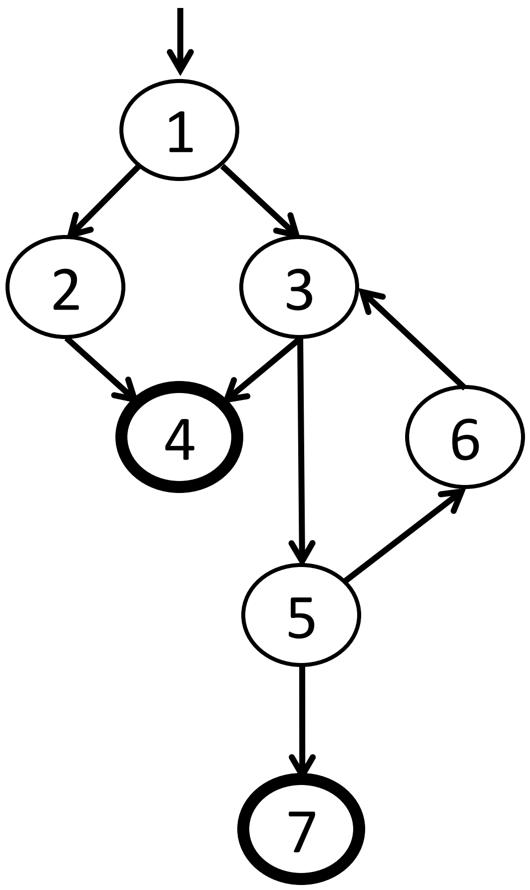
Graph Criteria EPC

Answer the following questions for the graph on the left

1. List test paths that satisfy edge coverage.
2. Write the set of test requirements for edge-pair coverage.
3. List test paths that satisfy edge-pair coverage.
4. Write the set of test requirements for prime path coverage.
5. List test paths that satisfy prime path

In-class Exercise

Graph Criteria EPC



Answer the following questions for the graph on the left

1. List test paths that satisfy edge coverage.
2. Write the set of test requirements for edge-pair coverage.
3. List test paths that satisfy edge-pair coverage.

TR = {[1, 2, 4], [1, 3, 4], [1, 3, 5], [3, 5, 6], [5, 6, 3], [6, 3, 4], [6, 3, 5], [3, 5, 7]}

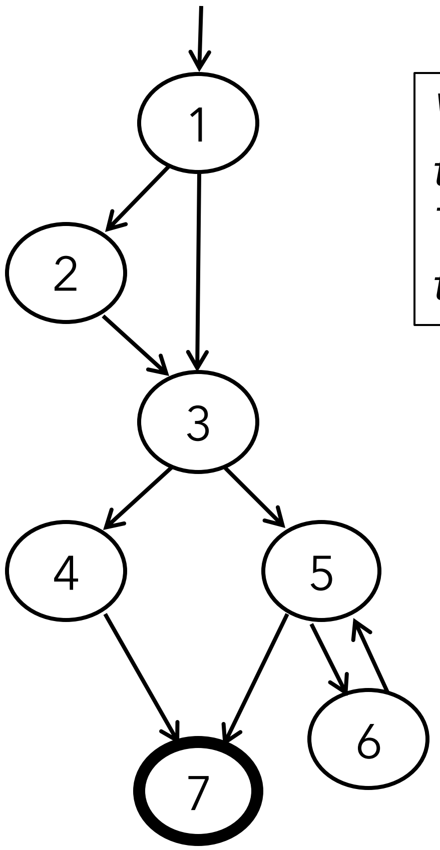
Covering Multiple Edges

Complete Path Coverage (CPC): TR contains all paths in G.

Unfortunately, this is **impossible** if the graph has a loop, so a weak compromise make the tester decide which paths:

Specified Path Coverage (SPC): TR contains a set *S* of test paths, where *S* is supplied as a parameter.

Covering Multiple Edges



Write down the TRs and Test Paths for these criteria

<u>Node Coverage</u>

TR = { 1, 2, 3, 4, 5, 6, 7 }
Test Paths: [1, 2, 3, 4, 7] [1, 2, 3, 5, 6, 5, 7]

<u>Edge Coverage</u>

TR = { (1,2), (1, 3), (2, 3), (3, 4), (3, 5), (4, 7), (5, 6), (5, 7), (6, 5) }
Test Paths: [1, 2, 3, 4, 7] [1, 3, 5, 6, 5, 7]

<u>Edge-Pair Coverage</u>

TR = { [1,2,3], [1,3,4], [1,3,5], [2,3,4], [2,3,5], [3,4,7], [3,5,6], [3,5,7], [5,6,5], [6,5,6], [6,5,7] }
Test Paths: [1, 2, 3, 4, 7] [1, 2, 3, 5, 7] [1, 3, 4, 7] [1, 3, 5, 6, 5, 6, 5, 7]

<u>Complete Path Coverage</u>

Test Paths: [1, 2, 3, 4, 7] [1, 2, 3, 5, 7] [1, 2, 3, 5, 6, 5, 7] [1, 2, 3, 5, 6, 5, 6, 5, 7] [1, 2, 3, 5, 6, 5, 6, 5, 6, 5, 7] …

Handling Loops in Graphs

If a graph contains a loop, it has an **infinite** number of paths.

Thus CPC is **not feasible**.

SPC is not satisfactory because the results are **subjective** and vary with the tester.

Attempts to “deal with” **loops**:

- -**1970s**: Execute cycles once
- -**1980s**: Execute each loop, exactly once
- -**1990s**: Execute loops 0 times, once, more than once
- -**2000s**: Prime paths (touring, sidetrips, detours)

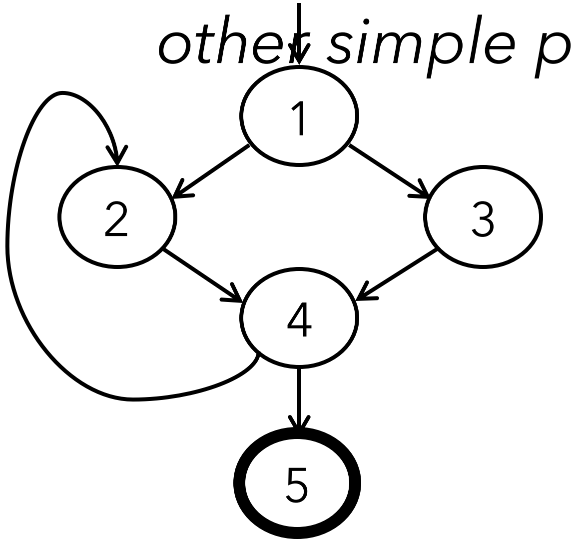
Simple Paths & Prime Paths

Simple path: *A path from node ni to nj is simple if no node appears more than once, except possible the first and last nodes are the same*

-No internal loops

-A loop is a simple path

Prime path: *A simple path that does not appear as a proper subpath of any other simple path*



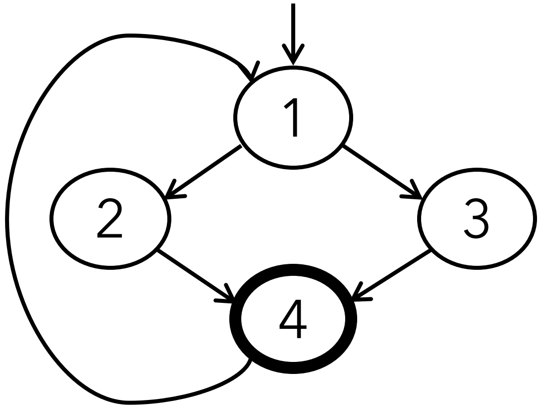
Write down the simple and prime paths for this graph

Simple Paths : [1,2,4,5], [1,3,4,2], [1,3,4,5], [1,2,4], [1,3,4], [2,4,2], [2,4,5], [3,4,2], [3,4,5], [4,2,4], [1,2], [1,3], [2,4], [3,4], [4,2], [4,5], [1], [2], [3], [4], [5]

Prime Paths : [1,2,4,5], [1,3,4,2], [1,3,4,5], [2,4,2], [4,2,4]

Simple Paths & Prime Paths

What if we change the graph?



Write down the simple and prime paths for this graph

Simple Paths : [1,2,4,1], [1,3,4,1], [2,4,1,2], [2,4,1,3], [3,4,1,2], [3,4,1,3], [4,1,2,4], [4,1,3,4], [1,2,4], [1,3,4], [2,4,1], [3,4,1], [4,1,2], [4,1,3], [1,2], [1,3], [2,4], [3,4], [4,1], [1], [2], [3], [4]

Prime Paths : [1,2,4,1], [1,3,4,1], [2,4,1,2], [2,4,1,3], [3,4,1,2], [3,4,1,3], [4,1,2,4], [4,1,3,4]

Prime Path Coverage

A simple, elegant and finite criterion that requires **loops** to be executed as well as skipped

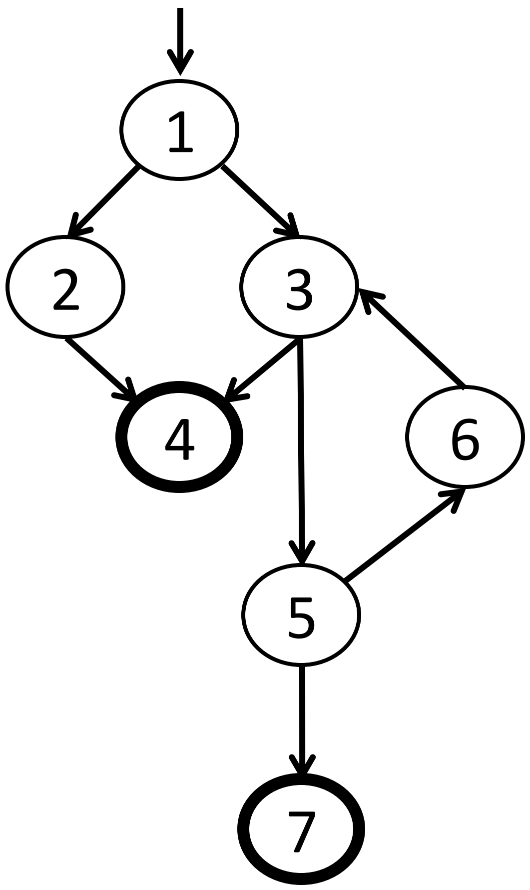
Prime Path Coverage (PPC): TR contains each prime path in G.

Will tour all paths of length 0, 1,…

That is, it **subsumes** node and edge coverage

PPC almost, but **not quite**, subsumes **EPC**…

In-class Exercise



Graph Criteria PPC

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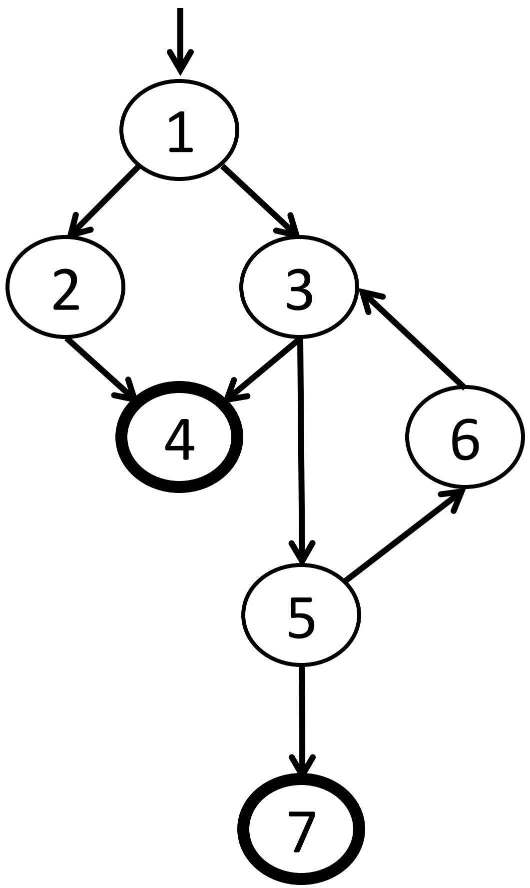

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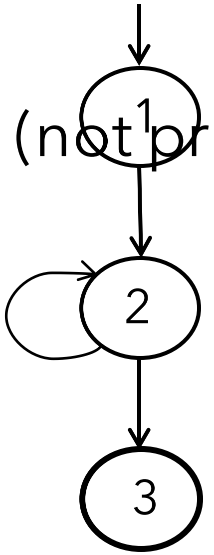
PPC does not subsume EPC

If a node has an edge to itself (*self edge*), **EPC** requires **[n, n, m]** and **[m, n, n]**

[n, n, m] is not prime

Neither **[n, n, m]** nor **[m, n, n]** are simple paths (not prime)



EPC Requirements : ?

TR = { [1,2,3], [1,2,2], [2,2,3], [2,2,2] }

PPC Requirements : ?

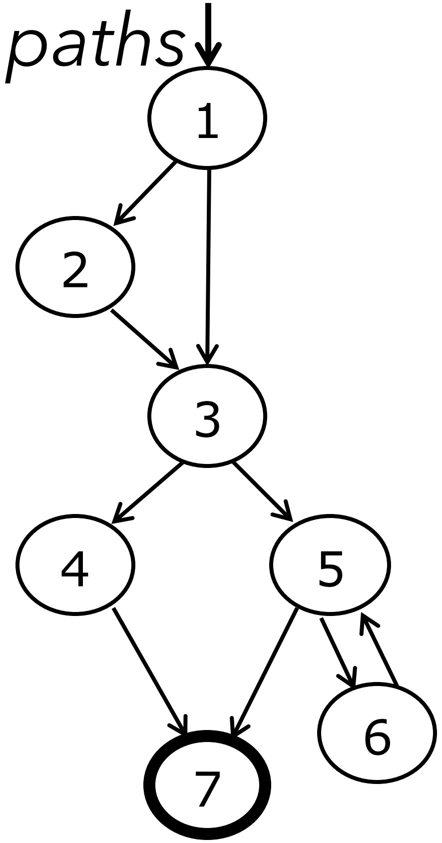
TR = { [1,2,3], [2,2] }

Prime Path Example

The previous example has 38 **simple** paths

Only **nine** *prime paths*

Write down all 9 prime paths



Prime Paths

[1, 2, 3, 4, 7]
[1, 2, 3, 5, 7]
[1, 2, 3, 5, 6]
[1, 3, 4, 7]
[1, 3, 5, 7]
[1, 3, 5, 6]
[6, 5, 7]
[6, 5, 6]
[5, 6, 5]

Execute loop 0 times

Execute loop once

Execute loop more than once

Touring, Sidetrips, and Detours

Prime paths do not have **internal loops** … test paths <u>might</u>

Tour: *A test path p tours subpath q if q is a subpath of p*

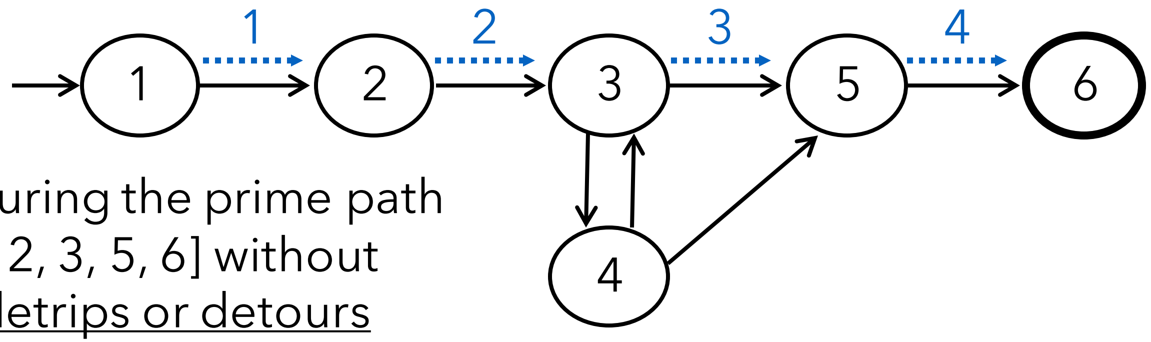
Tour with sidetrips: *A test path p tours subpath q with sidetrips iff every edge in q is also in p in the same order*

-The tour can include a sidetrip, as long as it comes back to the same node

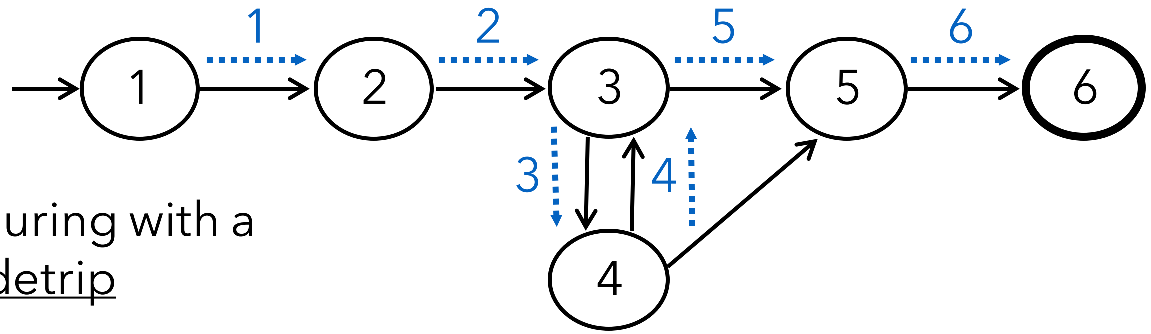
Tour with detours: *A test path p tours subpath q with detours iff every node in q is also in p in the same order*

-The tour can include a detour from node *ni*, as long as it comes back to the prime path at a successor of *ni*

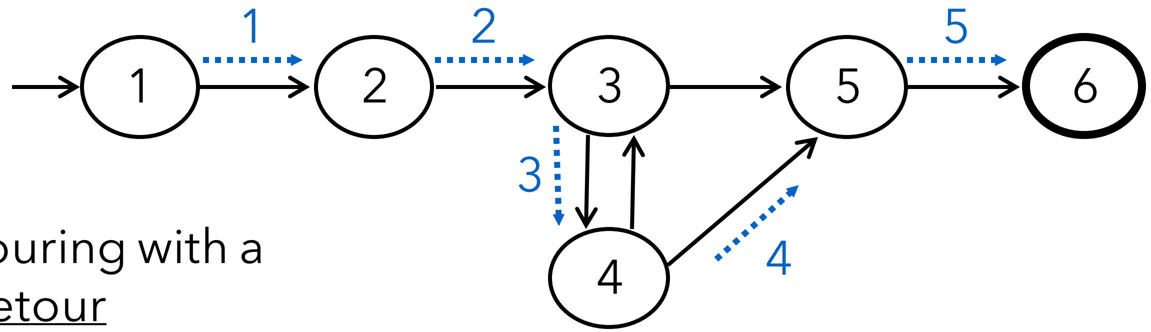
Sidetrips and Detours Example



Touring the prime path [1, 2, 3, 5, 6] without <u>sidetrips or detours</u>



Touring with a <u>sidetrip</u>



Touring with a <u>detour</u>

Infeasible Test Requirements

An **infeasible** test requirement <u>cannot be satisfied</u>.

- -Unreachable statement (dead code)
- -Subpath that can only be executed with a contradiction ($x > 0$ *and* $x < 0$)

Most test **criteria** have some infeasible test requirements

It is usually **undecidable** whether all test requirements are feasible

When sidetrips are not allowed, many structural criteria have **more infeasible test requirements**

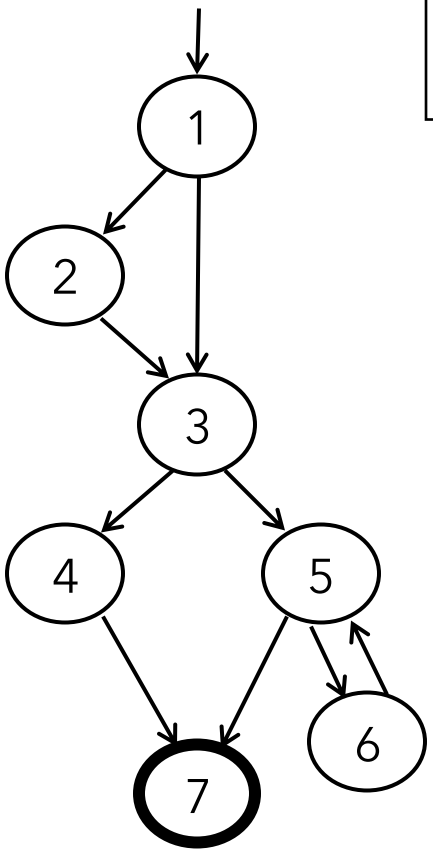
However, always allowing **sidetrips weakens** the test criteria

<u>Practical recommendation—Best Effort Touring</u>

– Satisfy as many test requirements as possible without sidetrips

– Allow sidetrips to try to satisfy remaining test requirements

Simple & Prime Path Example



Simple paths

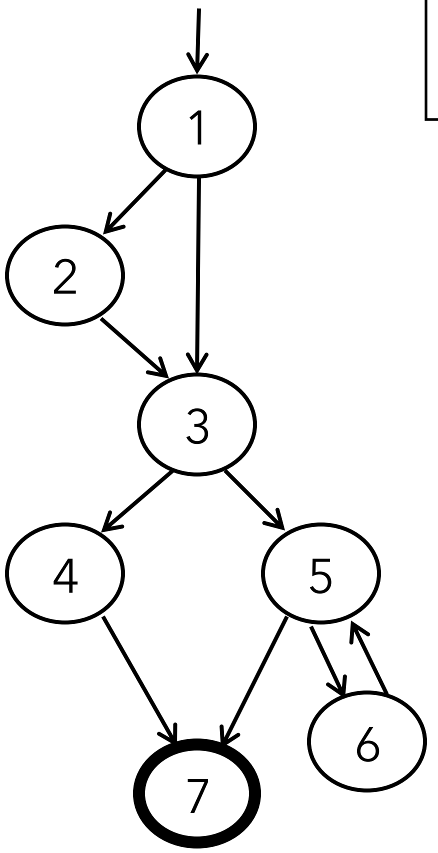
Write paths of length 0

Len 0

[1]
[2]
[3]
[4]
[5]
[6]
[7] !

'!' means path terminates

Simple & Prime Path Example

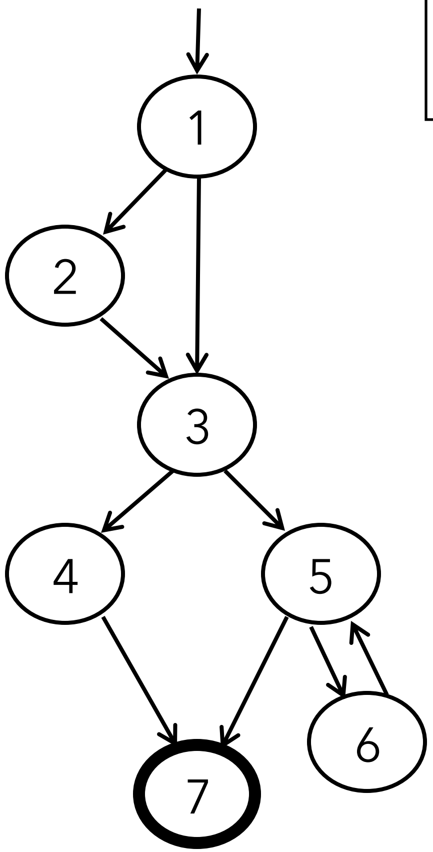


Simpl
e
paths

Write paths of length 1

<u>Len 1</u>
[1, 2]
[1, 3]
[2, 3]
[3, 4]
[3, 5]
[4, 7] !
[5, 7] !
[5, 6]
[6, 5]

Simple & Prime Path Example



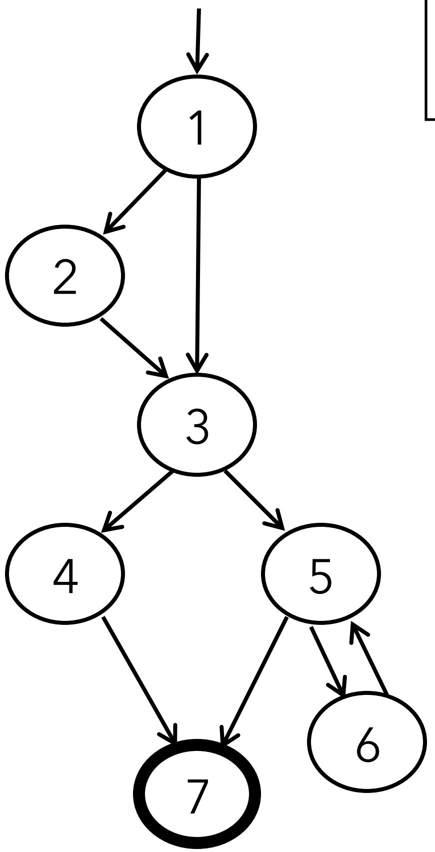
Simpl
e
paths

Write paths of length 2

<u>Len 2</u>
[1, 2, 3]
[1, 3, 4]
[1, 3, 5]
[2, 3, 4]
[2, 3, 5]
[3, 4, 7] !
[3, 5, 7] !
[3, 5, 6] !
[5, 6, 5] *
[6, 5, 7] !
[6, 5, 6] *

'*' means path cycles

Simple & Prime Path Example



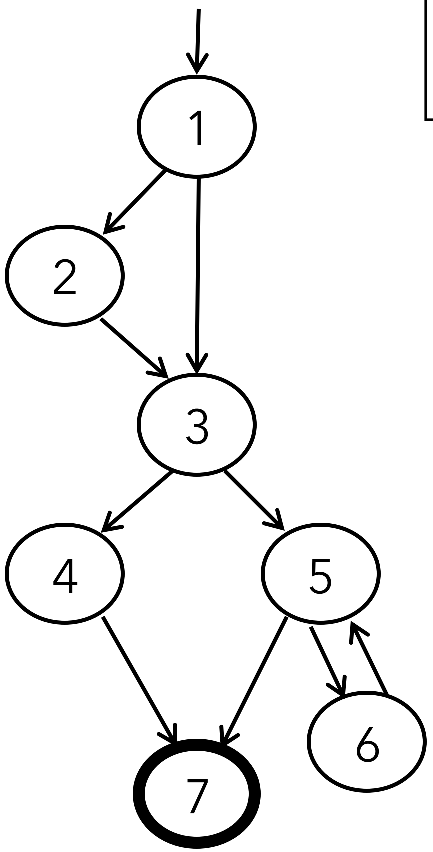
Simpl
e
paths

Write paths of length 3

<u>Len 3</u>

[1, 2, 3, 4]
[1, 2, 3, 5]
[1, 3, 4, 7] !
[1, 3, 5, 7] !
[1, 3, 5, 6] !
[2, 3, 4, 7] !
[2, 3, 5, 6] !
[2, 3, 5, 7] !

Simple & Prime Path Example



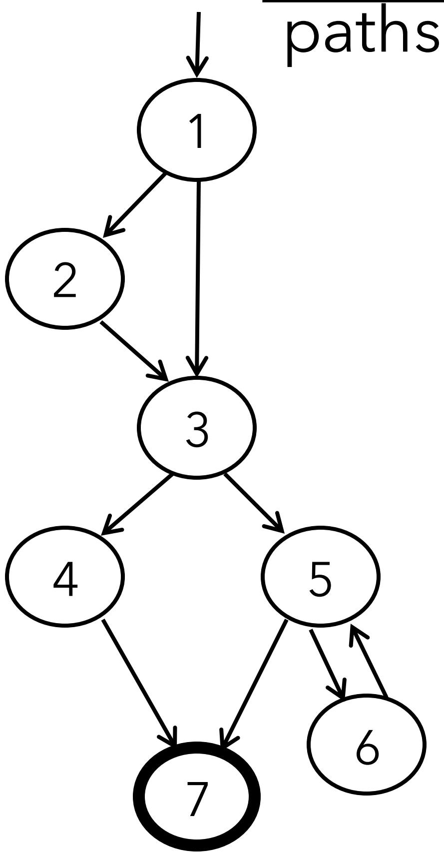
Simpl
e
paths

Write paths of length 4

<u>Len 4</u>

[1, 2, 3, 4, 7] !
[1, 2, 3, 5, 7] !
[1, 2, 3, 5, 6] !

Simple & Prime Path Example



Simple paths

Len 1
[1, 2]
[1, 3]
[2, 3]
[3, 4]
[3, 5]
[4, 7] !
[5, 7] !
[5, 6]
[6, 5]

Len 2
[1, 2, 3]
[1, 3, 4]
[1, 3, 5]
[2, 3, 4]
[2, 3, 5]
[3, 4, 7] !
[3, 5, 7] !
[3, 5, 6] !
[5, 6, 5] *
[6, 5, 7] !
[6, 5, 6] *

Len 3
[1, 2, 3, 4]
[1, 2, 3, 5]
[1, 3, 4, 7] !
[1, 3, 5, 7] !
[1, 3, 5, 6] !
[2, 3, 4, 7] !
[2, 3, 5, 6] !
[2, 3, 5, 7] !

Len 4
[1, 2, 3, 4, 7] !
[1, 2, 3, 5, 7] !
[1, 2, 3, 5, 6] !

Prime Paths ?

Round Trips

Round-Trip Path: *A prime path that starts and ends at the same node*

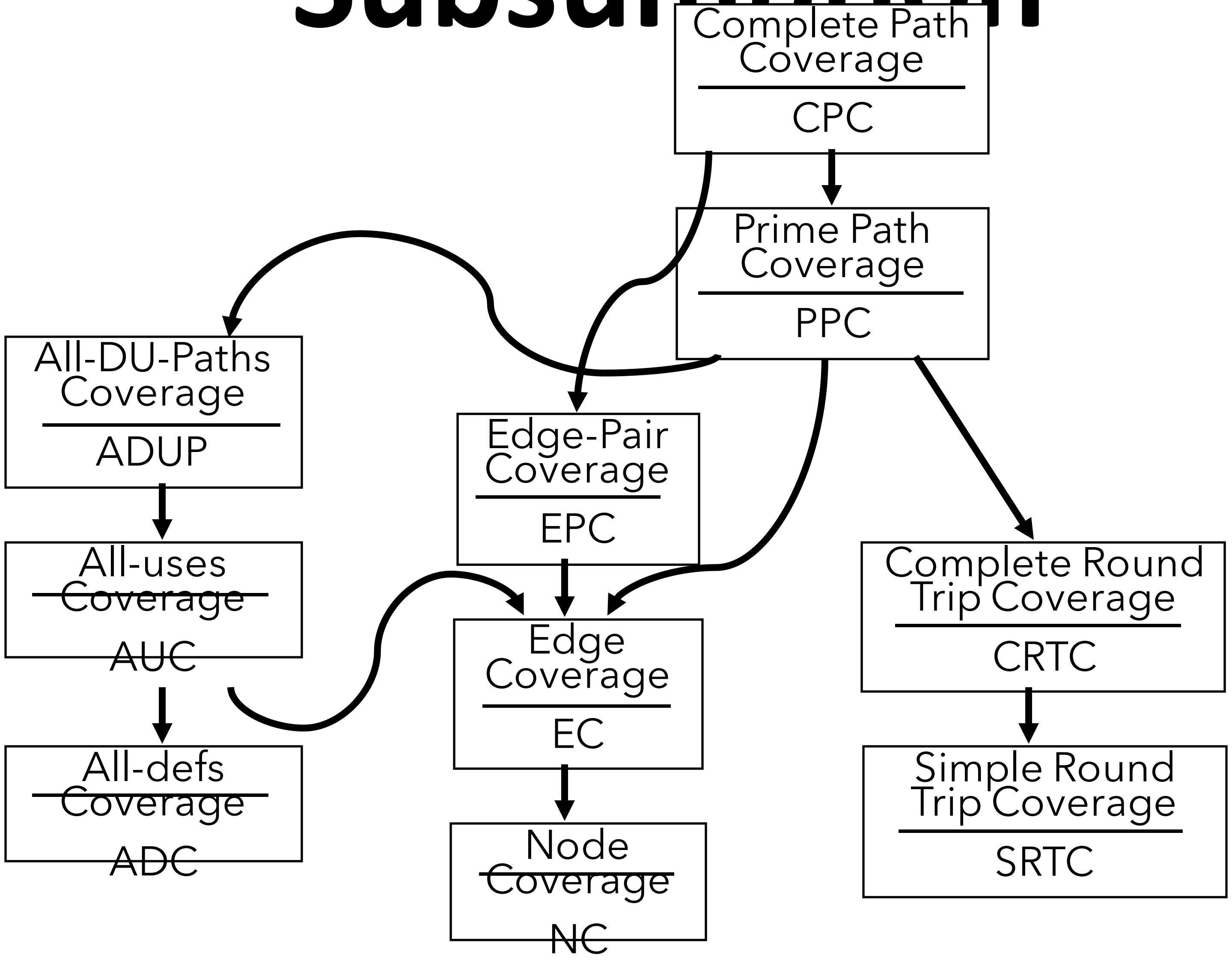
Simple Round Trip Coverage (SRTC): TR contains at least one round-trip path for each reachable node in G that begins and ends a round-trip path.

Complete Round Trip Coverage (SRTC): TR contains all round-trip paths for each reachable node in G.

These criteria **omit nodes and edges** that are not in round trips

Thus they do **not subsume** edge-pair, edge, or node coverage

Graph Coverage Criteria Subsumption



Graph Coverage Summary (7.1-7.2)

Graphs are a very **powerful abstraction** for designing tests

The various criteria allow lots of **cost/benefit** tradeoffs

These two sections are entirely at the "**design abstraction level**" from chapter 2

Graphs appear in **many situations** in software

-As discussed in the rest of chapter 7