Games Engineering II

Paths, Prime paths, and coverage

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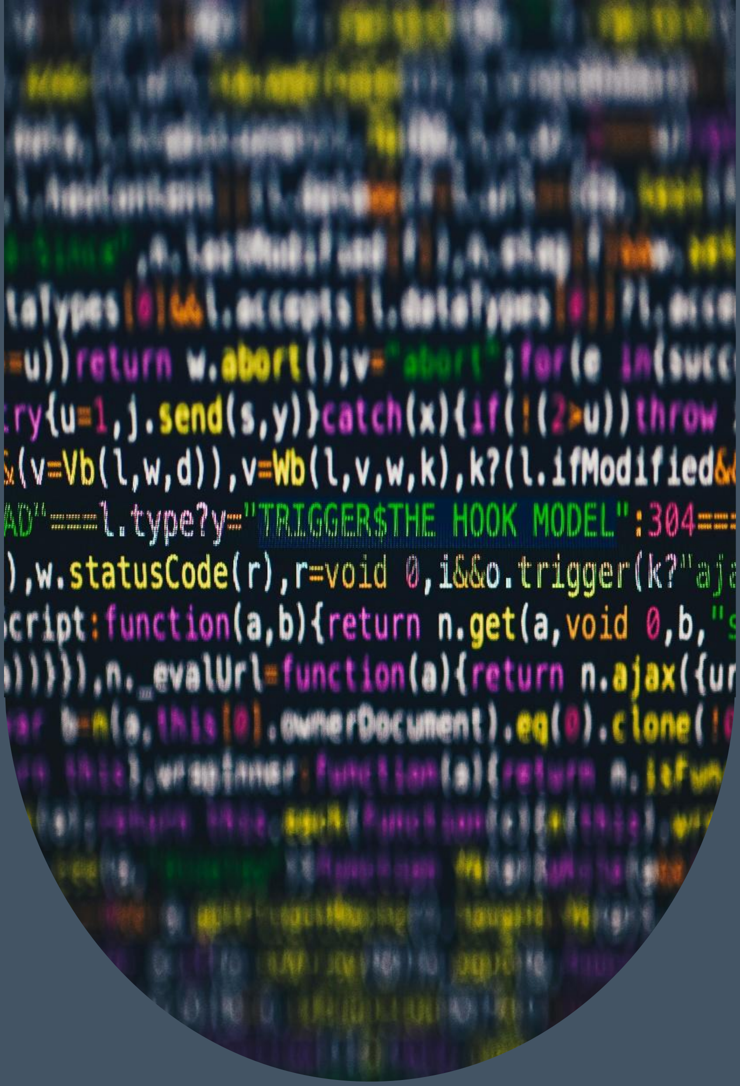

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INSPIRING FUTURES

Lec 02 - Recap

Covering Graphs

- Graphs are the most commonly used structure for testing

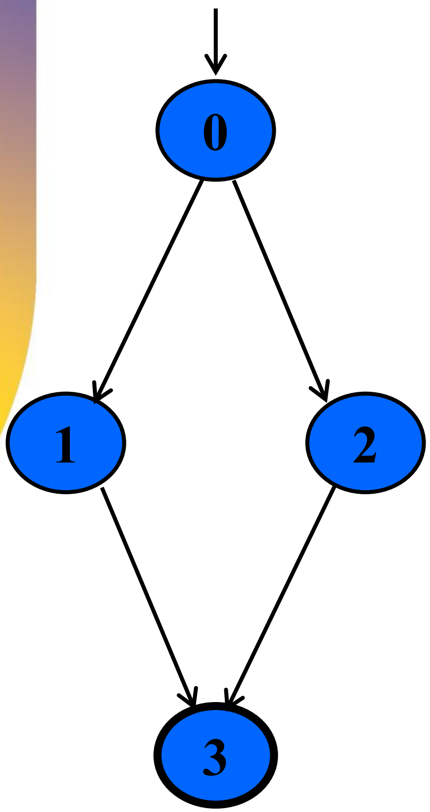
- Graphs can come from many sources
- Control flow graphs
- Design structure
- FSMs and statecharts
- Use cases

- Tests usually are intended to “**cover**” the graph in some way

Definition of a Graph

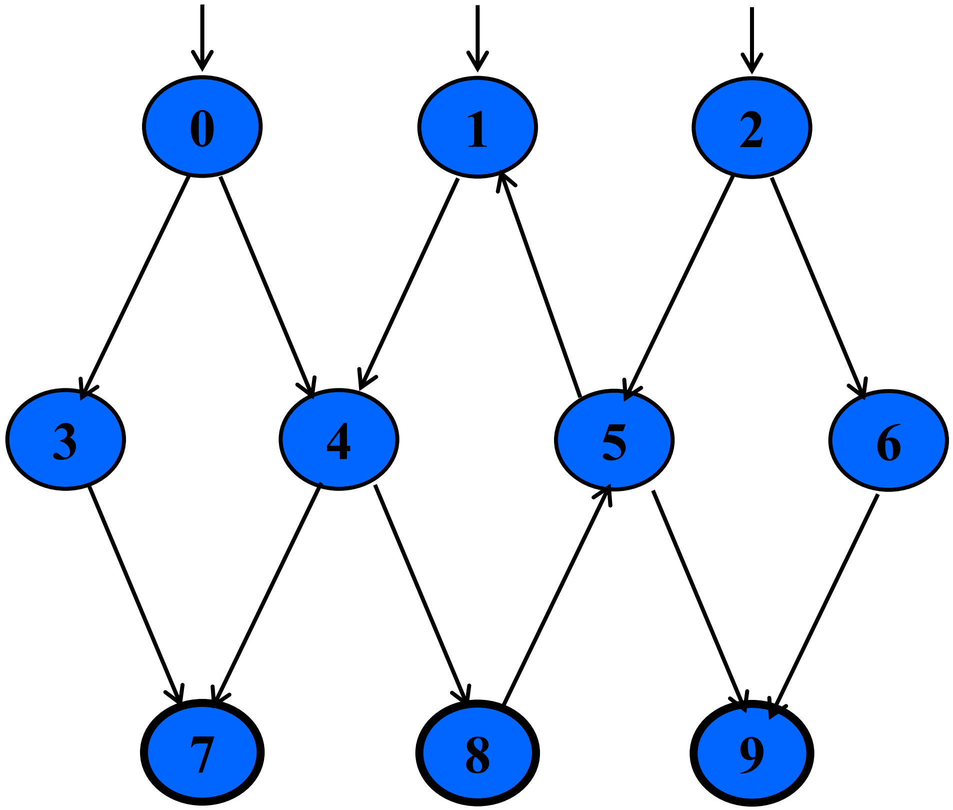
- A set N of nodes, N is not empty
- A set N_0 of initial nodes, N_0 is not empty
- A set N_f of final nodes, N_f is not empty
- A set E of edges, each edge from one node to another
- (n_i , n_j), i is predecessor, j is successor

Three Example Graphs



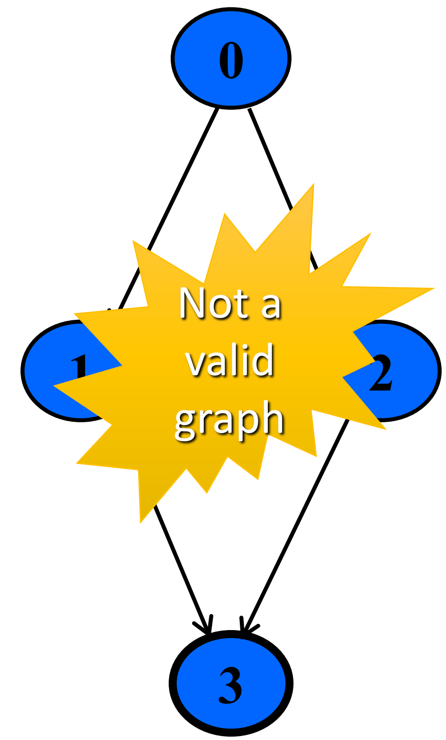
$N_0 = \{ 0 \}$

$N_f = \{ 3 \}$



$N_0 = \{ 0, 1, 2 \}$

$N_f = \{ 7, 8, 9 \}$

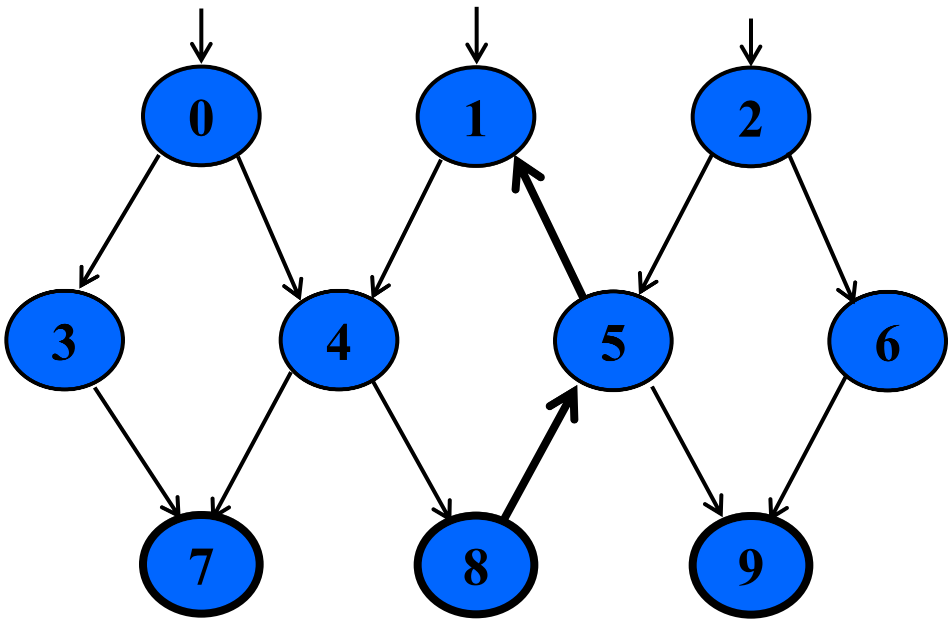


$N_0 = \{ \}$

$N_f = \{ 3 \}$

Paths in Graphs

- Path : A sequence of nodes – [n_1, n_2, …, n_M]
- Each pair of nodes is an edge
- Length : The number of edges
- A single node is a path of length 0
- Subpath : A subsequence of nodes in *p* is a subpath of *p*
- Reach (*n*) : Subgraph that can be reached from *n*



A Few Paths

[0, 3, 7]

[1, 4, 8, 5, 1]

[2, 6, 9]

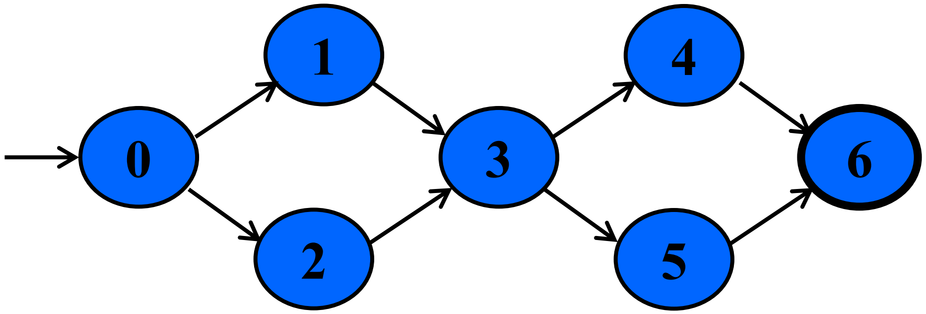
Reach (0) = { 0, 3, 4, 7, 8, 5, 1, 9 }

Reach([2,6]) = {2, 6, 9}

Test Paths and SESEs

- Test Path : A path that starts at an initial node and ends at a final node
- Test paths represent execution of test cases
- Some test paths can be executed by many tests
- Some test paths cannot be executed by any tests

- SESE graphs : All test paths start at a single node and end at another node
- Single-entry, single-exit
- N*0* and N*f* have exactly one node



Double-diamond graph

Four test paths

[0, 1, 3, 4, 6]

[0, 1, 3, 5, 6]

[0, 2, 3, 4, 6]

[0, 2, 3, 5, 6]

Visiting and Touring

- Visit : A test path *p* *visits* node *n* if *n* is in *p*

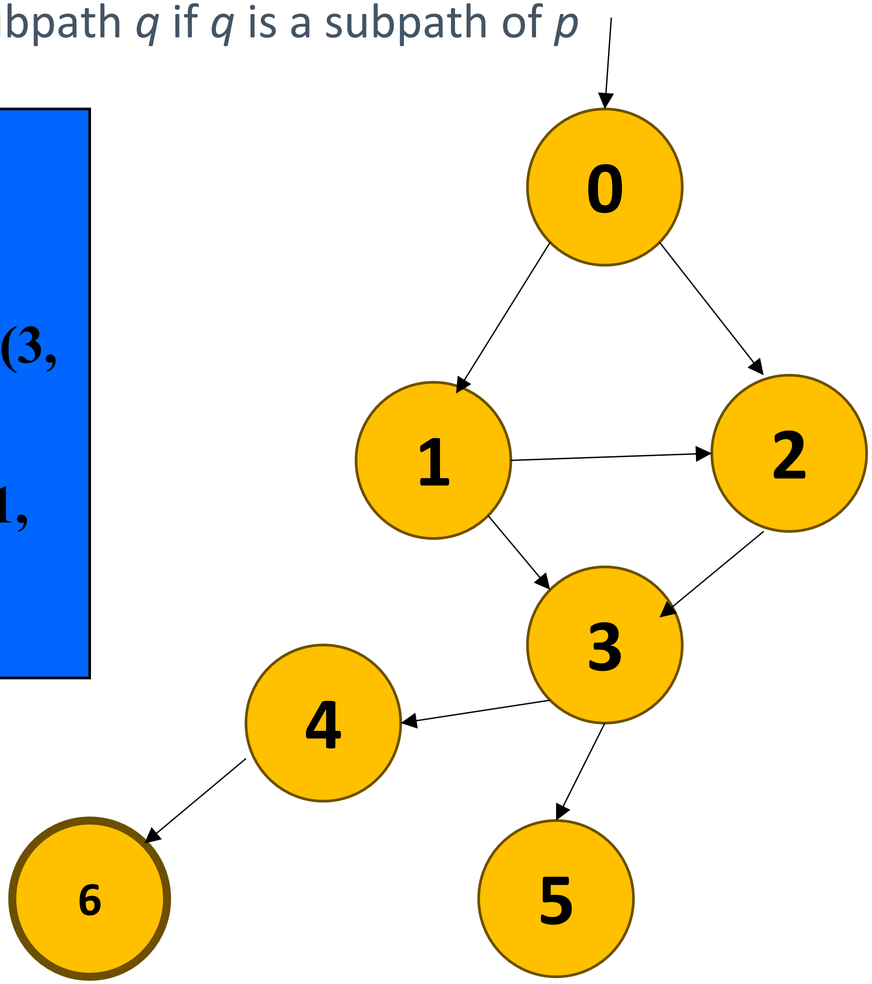
  A test path *p* *visits* edge *e* if *e* is in *p*
- Tour : A test path *p* *tours* subpath *q* if *q* is a subpath of *p*

Path [0, 1, 3, 4, 6]

Visits nodes 0, 1, 3, 4, 6

Visits edges (0, 1), (1, 3), (3, 4), (4, 6)

Tours subpaths [0, 1, 3], [1, 3, 4], [3, 4, 6], [0, 1, 3, 4], [1, 3, 4, 6]



Tests and Test Paths

- path (t) : The test path executed by test t
- path (T) : The set of test paths executed by the set of tests T
- Each test executes one and only one test path
- A location in a graph (node or edge) can be reached from another location if there is a sequence of edges from the first location to the second.

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

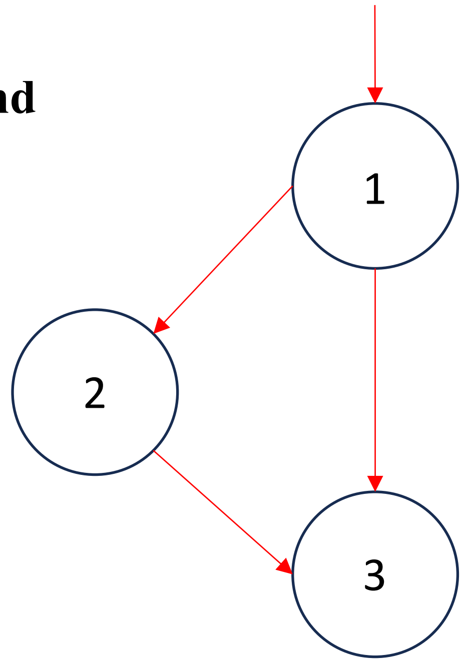
<u>Edge Coverage (EC)</u> : TR contains each reachable path of length up to 1, inclusive, in G.

- **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)**

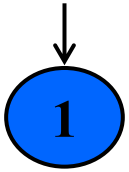
Node Coverage
TR = {1,2,3}
Test Path = [1,2,3]

Edge Coverage
TR = {(1,2),(2,3),(1,3)}
Test Path = [1,2,3] , [1,3]

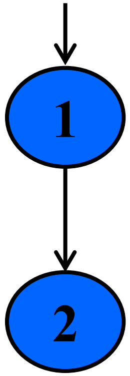


Paths of Length 1 and 0

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



- **It may be 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 only have one edge – for Edge Pair Coverage …**



Covering Multiple Edges

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

<u>Edge-Pair Coverage (EPC)</u> : 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**
- **The logical extension is to require all paths …**

<u>Complete Path Coverage (CPC)</u> : TR contains all paths in G.

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

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

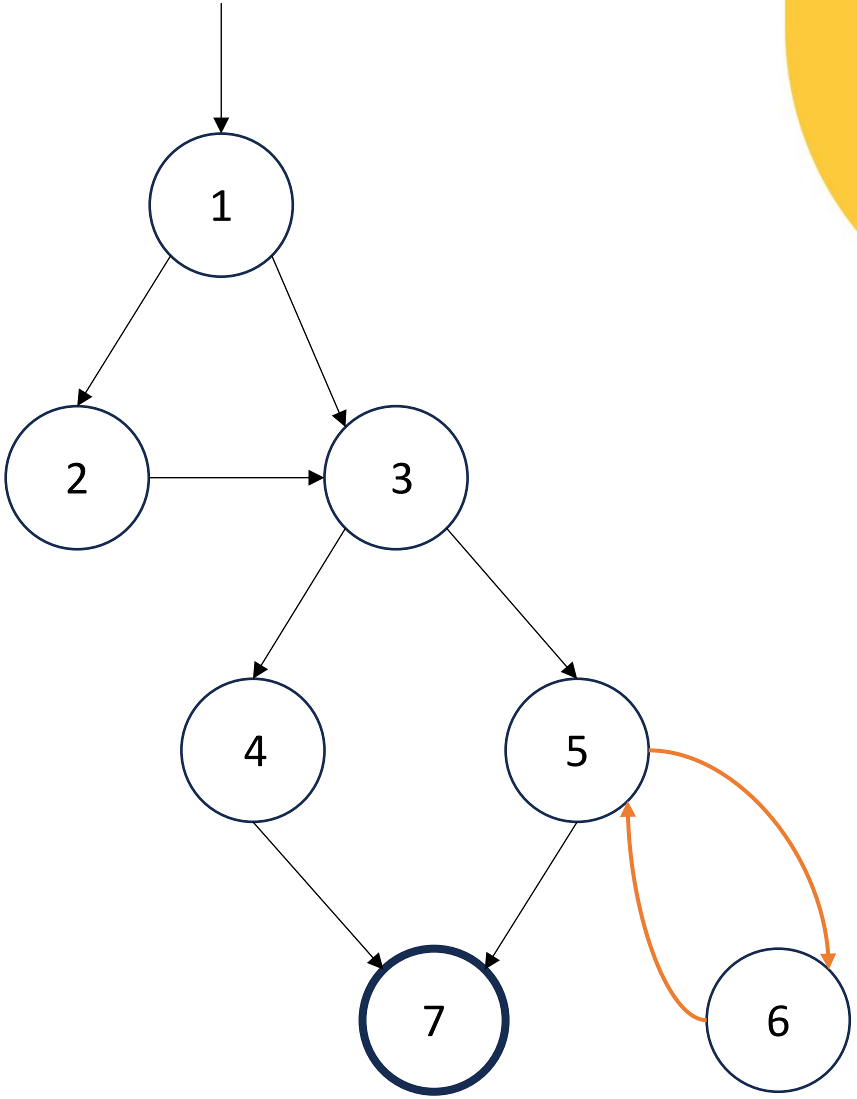
Structural Coverage Example

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

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

Edge-Pair Coverage
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]
[1,3,5,6,5,6,5,7]

Complete Path Coverage
TR: {[1,2,3,4,7] [1,2,3,5,7]}
Test Paths: [1,2,3,4,7] [1,2,3,5,7]
[1,2,3,5,6,5,7] [1,3,5,6,5,7][1,3,5,6,5,6,5,7]
[1,2,3,5,6,5,6,5,6,5,7]
[1,2,3,5,6,5,6,5,6,5,6,5,6,5,6 .....]



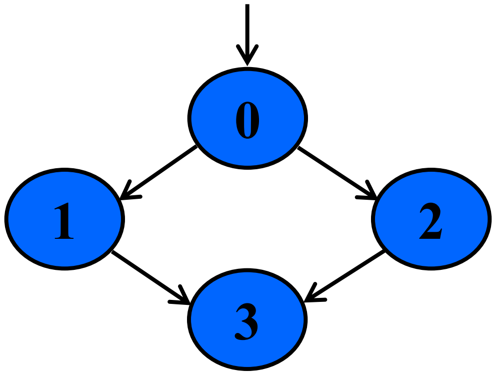
Loops in a Graph

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 ([4, 5, 4] in previous example, informal)
- 1980s : Execute each loop, exactly once (formalized)
- 1990s : Execute loops 0 times, once, more than once (informal description)
- 2000s : **Prime paths**
- **[Frances E Allen]**

Simple Paths and Prime Paths

- Simple Path : *A path from node n_i to n_j is simple if no node appears more than once, except possibly 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*



Simple Paths : [0, 1, 3, 0], [0, 2, 3, 0], [1, 3, 0, 1], [2, 3, 0, 2], [3, 0, 1, 3], [3, 0, 2, 3], [1, 3, 0, 2], [2, 3, 0, 1], [0, 1, 3], [0, 2, 3], [1, 3, 0], [2, 3, 0], [3, 0, 1], [3, 0, 2], [0, 1], [0, 2], [1, 3], [2, 3], [3, 0], [0], [1], [2], [3]

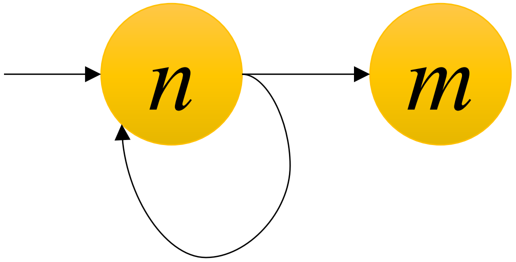
Prime Paths : [0, 1, 3, 0], [0, 2, 3, 0], [1, 3, 0, 1], [2, 3, 0, 2], [3, 0, 1, 3], [3, 0, 2, 3], [1, 3, 0, 2], [2, 3, 0, 1]

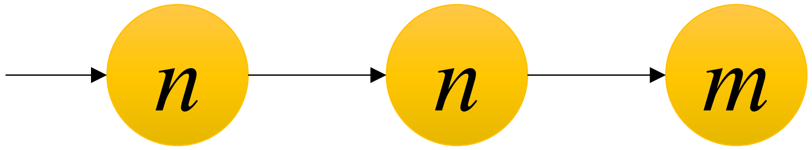
Prime Path Coverage

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

<u>Prime Path Coverage (PPC)</u> : TR contains each prime path in G.

- **Will tour all paths of length 0, 1, …**
- **That is, it *subsumes* *node* and *edge* coverage**
- **PPC does NOT subsume EPC**
  - **If a node *n* has an edge to itself, EPC will require [*n*, *n*, *m*]**
  - **[*n*, *n*, *m*] is not prime**





Round Trips

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

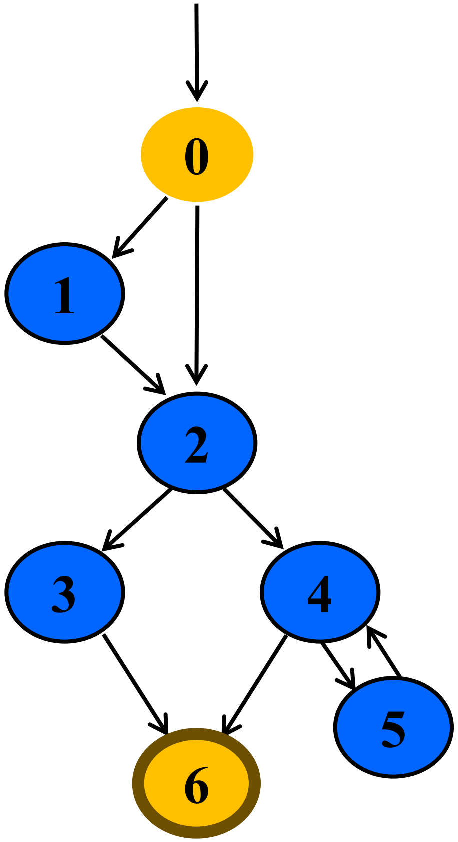
Simple Round Trip Coverage (SRTC) : TR contains at least one round-trip path for each reachable node in G that begins and ends a round-trip path.

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

- **These criteria omit nodes and edges that are not in round trips**
- **That is, they do not subsume edge-pair, edge, or node coverage**

Prime Path Example

- The previous example has ***38*** simple paths
- Only ***nine*** *prime paths*



Prime Paths

[0, 1, 2, 3, 6]
[0, 1, 2, 4, 5]
[0, 1, 2, 4, 6]
[0, 2, 3, 6]
[0, 2, 4, 5]
[0, 2, 4, 6]
[5, 4, 6]
[4, 5, 4]
[5, 4, 5]

Execute loop 0 times

Execute loop once

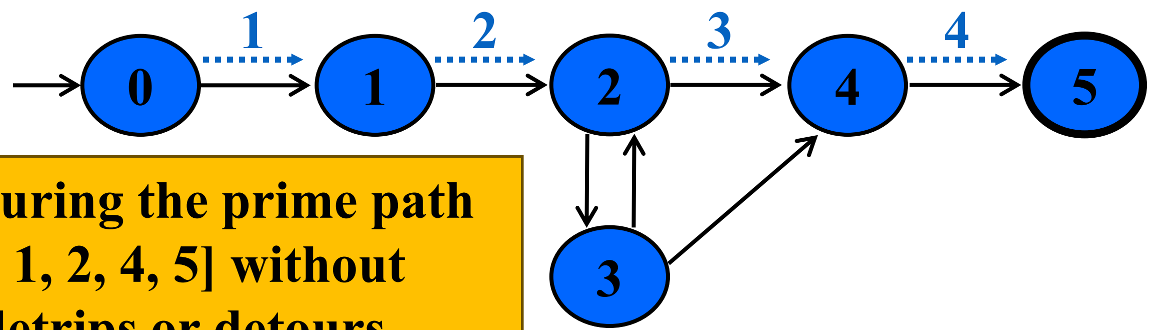
Execute loop more than once

Touring, Sidetrips and Detours

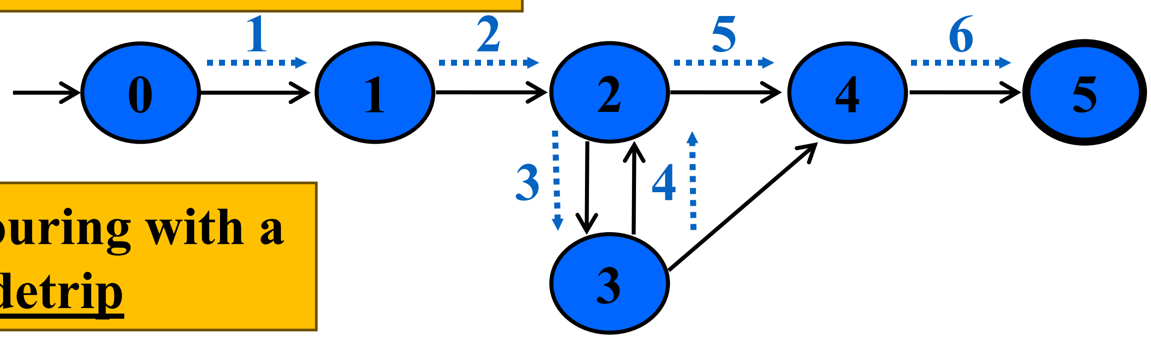
– Prime paths do not have internal loops … test paths might

- 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***

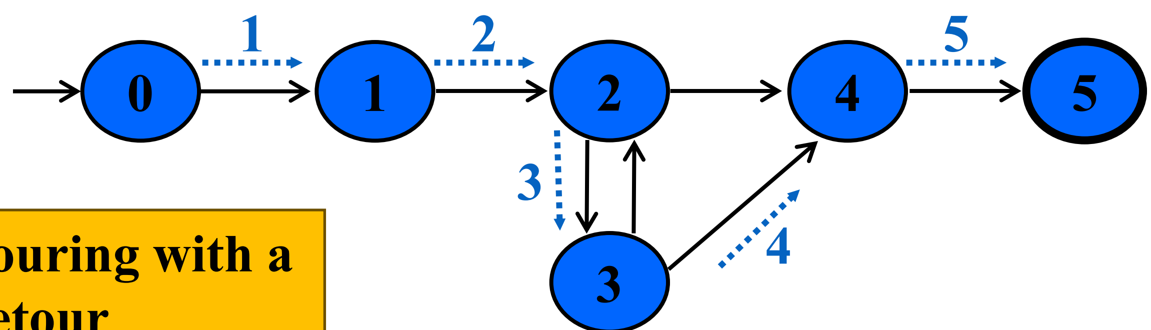
Sidetrips and Detours Example



Touring the prime path [0, 1, 2, 4, 5] without **sidetrips or detours**



Touring with a **sidetrip**



Touring with a **detour**

Infeasible Test Requirements

- An infeasible test requirement cannot be satisfied
- Unreachable statement (dead code)
- A subpath that can ***only be executed*** if a contradiction occurs ($X > 0$ 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**

Practical recommendation – Best Effort Touring

– Satisfy as many test requirements as possible without sidetrips

– Allow sidetrips to try to satisfy unsatisfied test requirements

Questions & Feedback?

Please feel free to email for your queries.

Course materials will be uploaded to Blackboard after every lecture.