Graph-based Testing

CS 3250
Software Testing

[Ammann and Offutt, "Introduction to Software Testing," Ch. 7]

Structures for Criteria-Based Testing

Four structures for modeling software

- Input space
- Graph
  - Applied to
    - Source
    - Design
    - Specs
    - Use cases
- Logic
  - Applied to
    - Source
    - Specs
    - FSMs
    - DNF
- Syntax
  - Applied to
    - Source
    - Models
    - Integration
    - Inputs

Input space	Graph	Logic	Syntax
---R	R--R	RI-R	RIPR

Today's Objectives

- Start investigating some of the most widely known test coverage criteria
- Understand basic theory of graph
  - Generic view of graph without regard to the graph's source
- Understand test paths, visiting and touring
- Mapping test case inputs and test paths

Overview

- Graphs are the most commonly used structure for testing
- Graphs can come from many sources
  - Control flow graphs from source
  - Design structures
  - Finite state machine (FSM)
  - Statecharts
  - Use cases
- The graph is not the same as the artifact under test, and usually omits certain details
- Tests must cover the graph in some way
  - Usually traversing specific portions of the graph

Graph: Nodes and Edges

- Node represents
  - Statement
  - State
  - Method
  - Basic block
- Edge represents
  - Branch
  - Transition
  - Method call

Basic Notion of a Graph

- Nodes:
  - N = a set of nodes, N must not be empty
- Initial nodes
  - N_0 = a set of initial nodes, must not be empty
  - Single entry vs. multiple entry
- Final nodes
  - N_f = a set of final nodes, must not be empty
  - Single exit vs. multiple exit

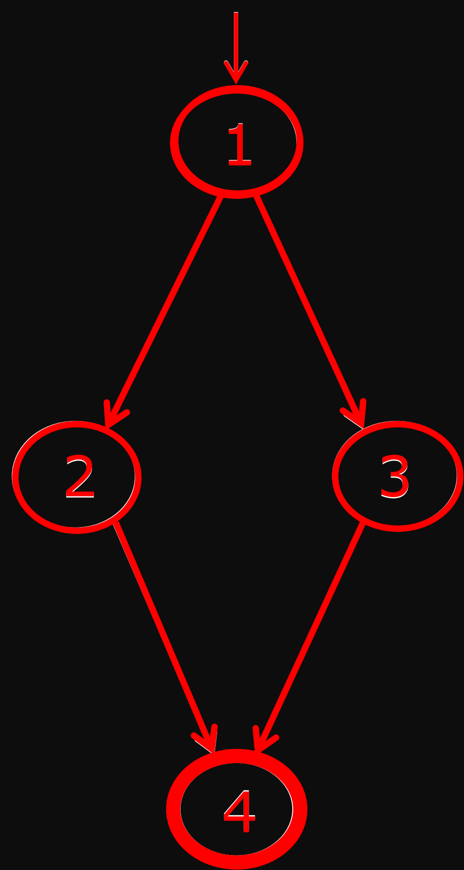
Every test must **start** in some initial node, and **end** in some final node

- Edges:
  - E = a set of edges, each edge from one node to another
  - An edge is written as (n_i, n_j)
    - n_i is predecessor, n_j is successor

Note on Graphs

- The concept of a final node depends on the kind of software artifact the graph represents
- Some test criteria require tests to end in a particular final node
- Some test criteria are satisfied with any node for a final node (i.e., the set N_f = the set N)

Example Graph



- Node

  $N = \{1, 2, 3, 4\}$

  $N_0 = \{1\}$

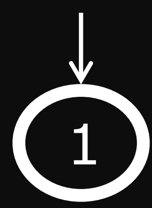
  $N_f = \{4\}$

- Edge

  $E = \{(1,2), (1,3), (2,4), (3,4)\}$

Single-Entry, Single-Exit (SESE)

Is this a graph?



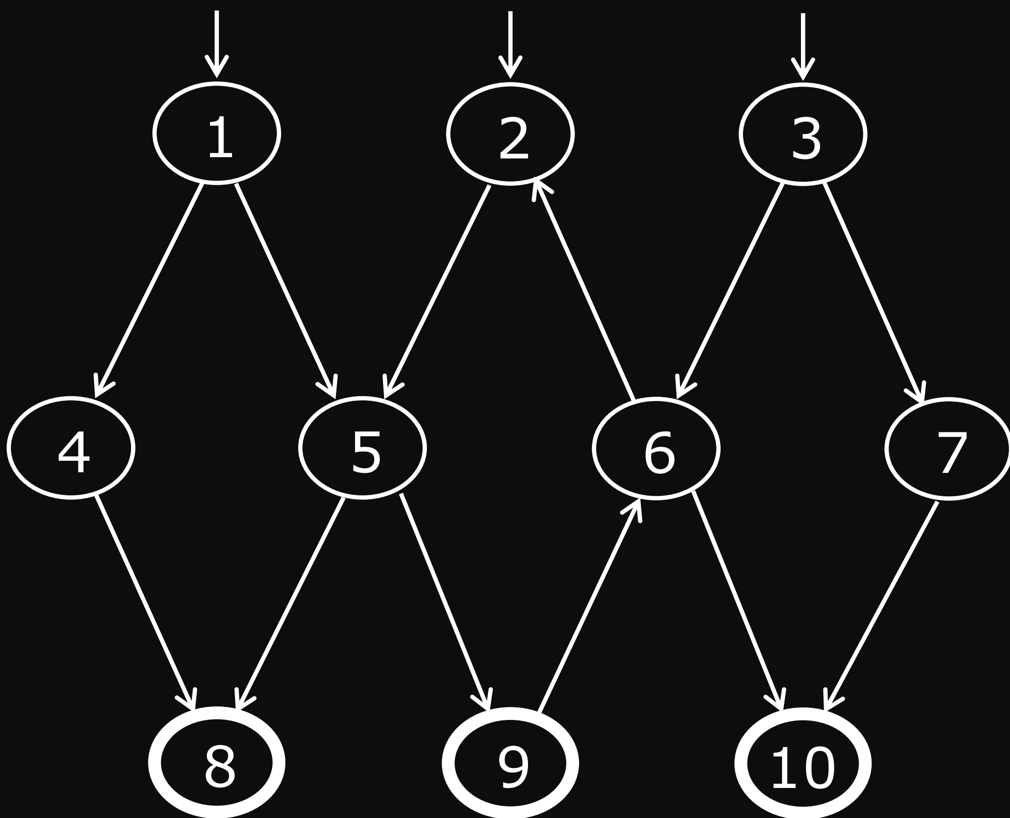
$N = \{1\}$

$N_0 = \{1\}$

$N_f = \{1\}$

$E = \{\ \}$

Example Graph



Multiple-entry, multiple-exit

- Node

  $N = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$

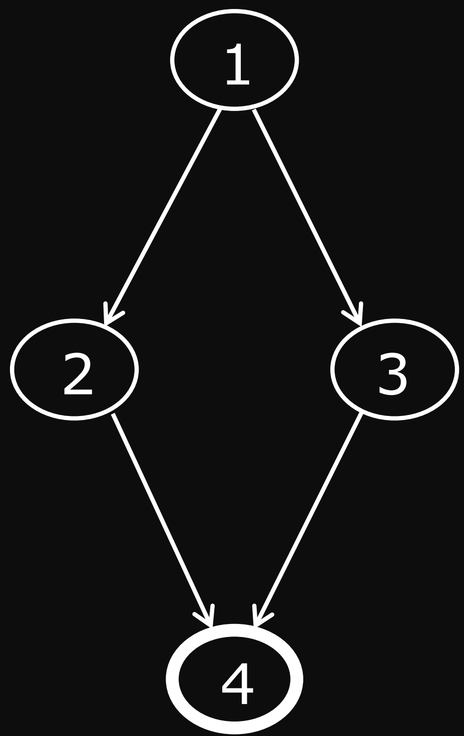
  $N_0 = \{1, 2, 3\}$

  $N_f = \{8, 9, 10\}$

- Edge

  $E = \{(1,4), (1,5), (2,5), (6,2), (3,6), (3,7), (4,8), (5,8), (5,9), (6,10), (7,10), (9,6)\}$

Example Graph



- Node

  $N = \{1, 2, 3, 4\}$

  $\boxed{N_0 = \{\}}$

  $N_f = \{4\}$

- Edge

  $E = \{(1,2), (1,3), (2,4), (3,4)\}$

Not valid graph – no initial nodes
Not useful for generating test cases

Let's Try (1)

Consider the graph defined by the following sets:

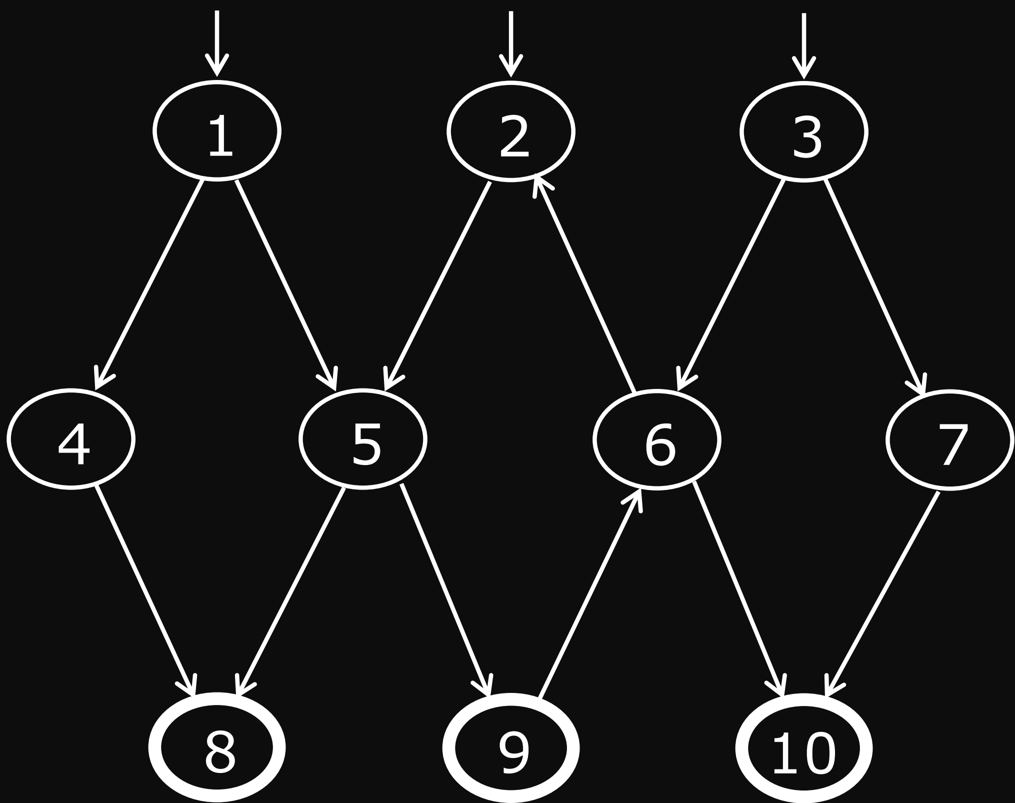
$$
\begin{aligned}
N &= \{1, 2, 3\} \\
N_0 &= \{1\} \\
N_f &= \{3\} \\
E &= \{ (1,2), (1,3), (2,1), (2,3), (3,1) \}
\end{aligned}
$$

- Draw the graph
- Is this a valid graph?

Paths in Graphs

- Path *p*
  - A sequence of nodes, $[n_1, n_2, \ldots, n_M]$
  - Each pair of adjacent nodes, (n_i, n_{i+1}), is an edge
- Length
  - The number of edges
  - A single node is a path of length 0
- Subpath
  - A subsequence of nodes in *p* (possibly *p* itself)

Example Paths

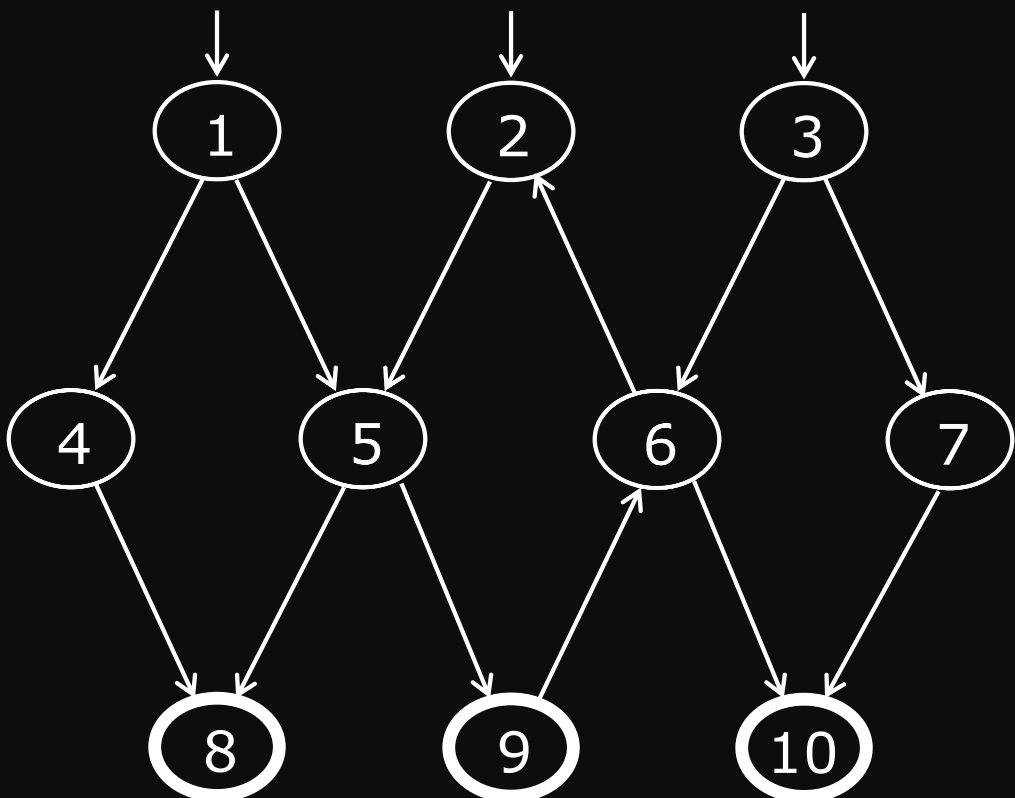


- Paths

  [1, 4, 8]
  [2, 5, 8]
  [2, 5, 9]
  [2, 5, 9, 6, 10]
  [3, 6, 10]
  [3, 7, 10]
  [3, 6, 2, 5, 9]
  …
  cycle
  [2, 5, 9, 6, 2]

Cycle – a path that begins and ends at the same node

Example Paths



- Invalid paths

  [1, 8]

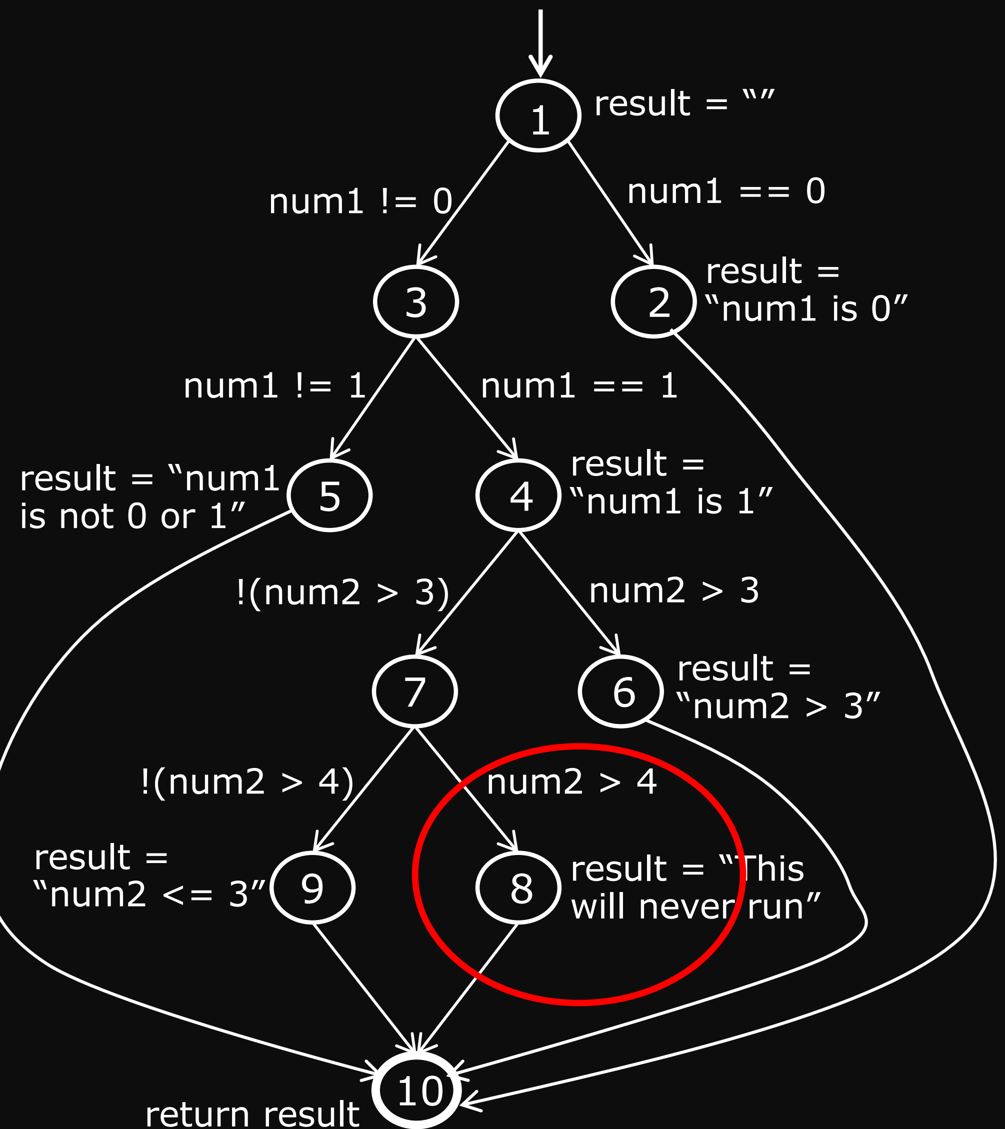
  [4, 5]

  [3, 7, 9]

Invalid path – a path where the two nodes are not connected by an edge

Example Invalid Path

```
def template(num1, num2):
    result = ""
    if num1 == 0:
        result = "num1 is 0"
    elif num1 == 1:
        result = "num1 is 1"
        if num2 > 3:
            result = " num2 > 3"
        elif num2 > 4:
            result = " This will never run"
        else:
            result = " num2 <= 3"
    else:
        result = "num1 is not 0 or 1"
    return result
```



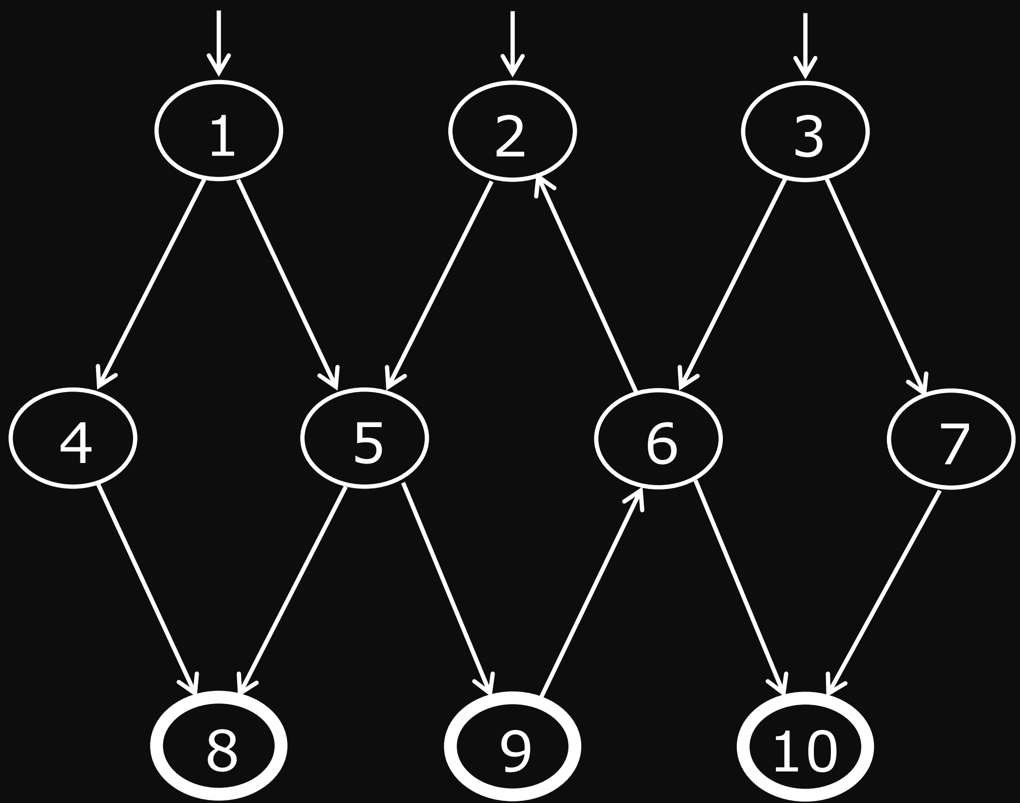
Invalid Paths

- Many test criteria require inputs that start at one node and end at another. – This is only possible if those nodes are connected by a path.
- When applying these criteria on specific graphs, we sometimes find that we have asked for a path that for some reason cannot be executed.
- Example: a path may demand that a loop be executed zero time, where the program always executed the loop at least once.
- This problem is based on the semantics of the software artifact that the graph represents.
- For now, let’s emphasize only the syntax of the graph

Graph and Reachability

- 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
- Syntactically reachable
  - There exists a subpath from node n_i to n (or to edge e)
- Semantically reachable
  - There exists a test that can execute that subpath

Example: Reachability



Some graphs (such as finite state machines) have explicit edges from a node to itself, that is (n_i, n_i)

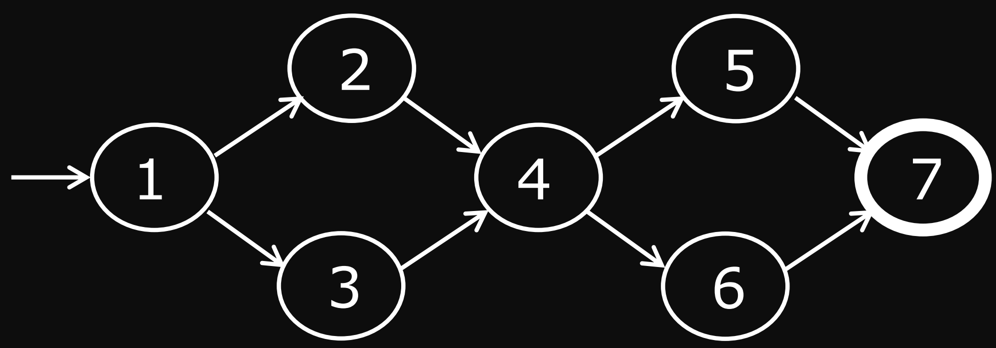
- From node 1
  - Possible to reach all nodes except nodes 3 and 7
- From node 5
  - Possible to reach all nodes except nodes 1, 3, 4, and 7
- From edge (7, 10)
  - Possible to reach nodes 7 and 10 and edge (7, 10)

Test Paths

- A path that starts at an initial node and end at a final node
- A test path represents the execution test cases
  - Some test paths can be executed by many test cases
  - Some test paths cannot be executed by any test cases
  - Some test paths cannot be executed because they are infeasible

SESE Graphs

- SESE (Single-Entry-Single-Exit) graphs
  - The set N_0 has exactly one node (n_0)
  - The set N_f has exactly one node (n_f), n_f may be the same as n_0
  - n_f must be syntactically reachable from every node in N
  - No node in N (except n_f) be syntactically reachable from n_f (unless n_0 and n_f are the same node)



"Double-diamonded graph"
(two if-then-else statements)

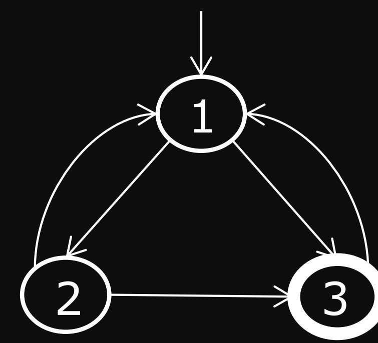
4 test paths

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

Let’s Try (2)

Consider the graph defined by the following sets:

$N = \{1, 2, 3\}$
$N_0 = \{1\}$
$N_f = \{3\}$
$E = \{ (1,2), (1,3), (2,1), (2,3), (3,1) \}$



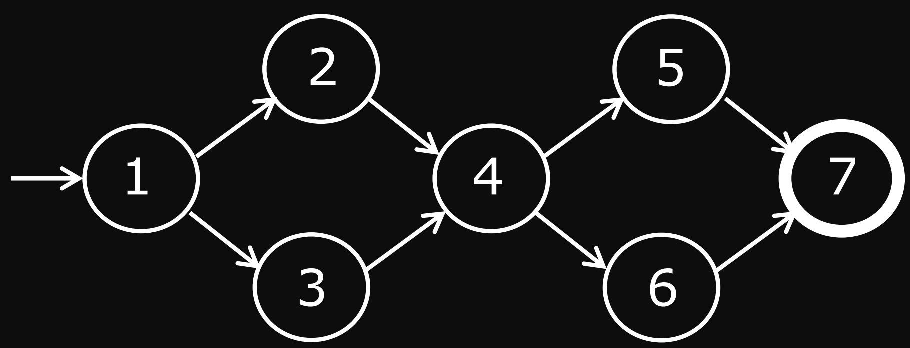
Also consider the following (candidate) paths:

$p_1 = [1, 2, 3, 1]$
$p_2 = [1, 3, 1, 2, 3]$
$p_3 = [1, 2, 3, 1, 2, 1, 3]$
$p_4 = [2, 3, 1, 3]$
$p_5 = [1, 2, 3, 2, 3]$

Which of these paths are test paths?
For any path that is not a test path, explain why not.

Visiting

- A test path *p* visits node *n* if *n* is in *p*
- A test path *p* visits edge *e* if *e* is in *p*



Node *N* = {1, 2, 3, 4, 5, 6, 7}

Edge *E* = {(1,2), (1,3), (2,4), (3,4), (4,5), (4,6), (5,7), (6,7)}

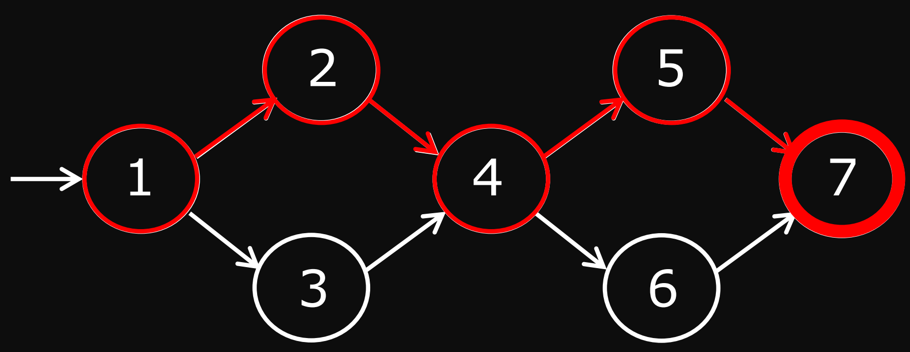
Consider path [1, 2, 4, 5, 7]

Visits node: 1, 2, 4, 5, 7

Visits edge: (1,2), (2,4), (4,5), (5,7)

Touring

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



Node N = {1, 2, 3, 4, 5, 6, 7}

Edge E = {(1,2), (1,3), (2,4), (3,4), (4,5), (4,6), (5,7), (6,7)}

(Each edge is technically a subpath)

Consider a test path [1, 2, 4, 5, 7]

Visit nodes: 1, 2, 4, 5, 7

Visit edges: (1,2), (2,4), (4,5), (5,7)

Tours subpaths: [1,2,4,5,7], [1,2,4,5], [2,4,5,7], [1,2,4], [2,4,5], [4,5,7], [1,2], [2,4], [4,5], [5,7]

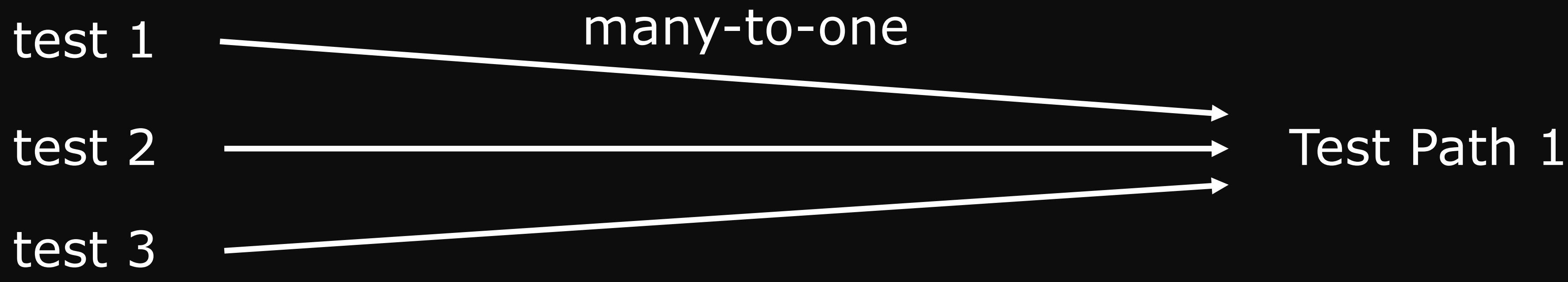
Any given path *p* always tours itself

Mapping: Test Cases – Test Paths

- path(*t*) = Test path executed by test case *t*
- path(*T*) = Set of test paths executed by set of tests *T*
- Test path is a complete execution from a start node to a final node
- Minimal set of test paths = the fewest test paths that will satisfy test requirements
  - Taking any test path out will no longer satisfy the criterion

Mapping: Test Cases – Test Paths

many-to-one

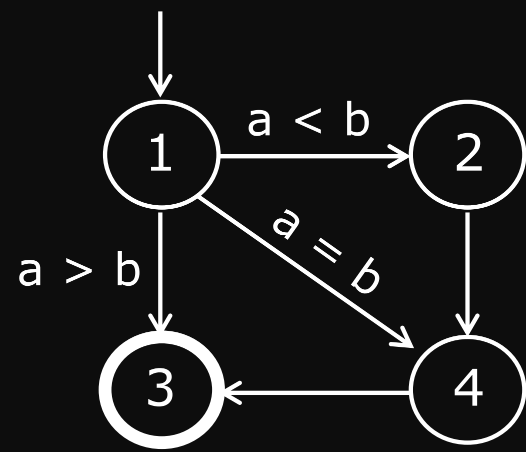


Deterministic software: test always executes the same test path

many-to-many

Non-deterministic software: the same test can execute different test paths

Example Mapping
Test Case inputs – Test Paths



Test case t1 inputs: (a=0, b=1) $\xrightarrow{\text{map to}}$ [Test path p1: 1, 2, 4, 3]

Test case t2 inputs: (a=1, b=1) $\longrightarrow$ [Test path p2: 1, 4, 3]

Test case t3 inputs: (a=2, b=1) $\longrightarrow$ [Test path p3: 1, 3]

[AO, page 111, Figure 7.5]