Introduction to Software Testing
(2nd edition)
Chapter 7.1, 7.2

Overview Graph Coverage Criteria
(*active class version*)

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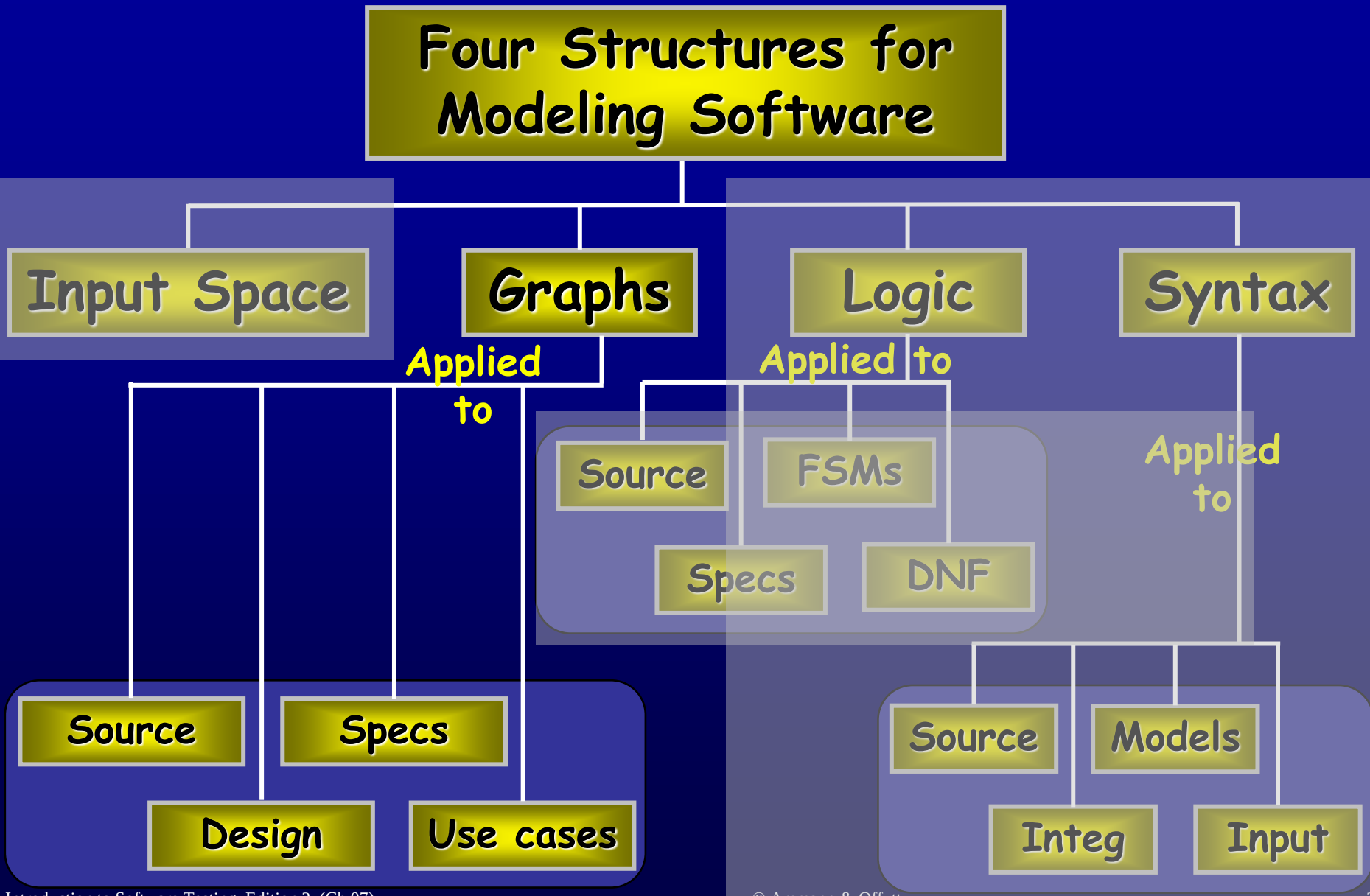
Ch. 7 : Graph Coverage



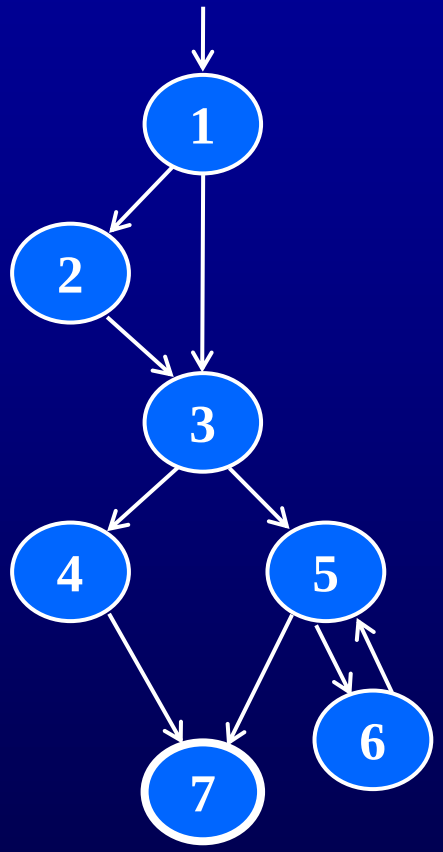
Covering Multiple Edges

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

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

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

Structural Coverage Example



Write down the TRs and Test Paths for these criteria

Node Coverage

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

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

Edge Coverage

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]

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

Complete Path Coverage

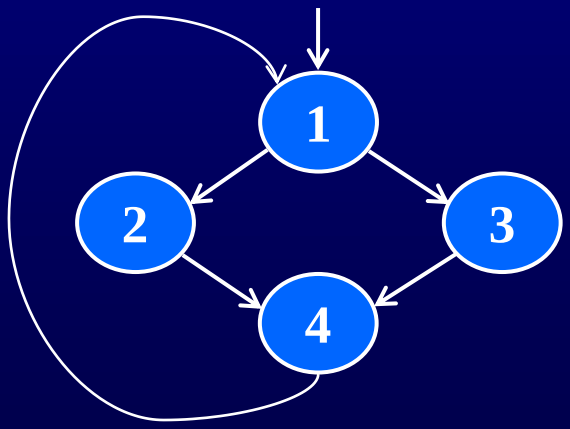
Test Paths: [1, 2, 3, 4, 7] [1, 2, 3, 5, 7] [1, 2, 3, 5, 6, 5, 7] [1, 2, 3, 5, 6, 5, 6, 5, 7] [1, 2, 3, 5, 6, 5, 6, 5, 6, 5, 7] …

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 ([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 (touring, sidetrips, and detours)

Simple Paths and Prime Paths

- Simple Path : *A path from node ni to nj 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 : [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], [4,1,3], [2,4], [3,4], [4,1], [1], [2], [3], [4]

Write down the simple and prime paths for this graph

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

Prime Path Coverage

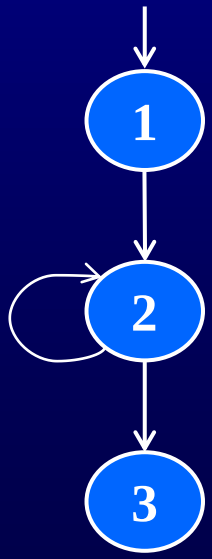
- A simple, elegant and finite criterion that requires loops to be executed as well as skipped

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 …

PPC Does Not Subsume EPC

- If a node *n* 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 : ?

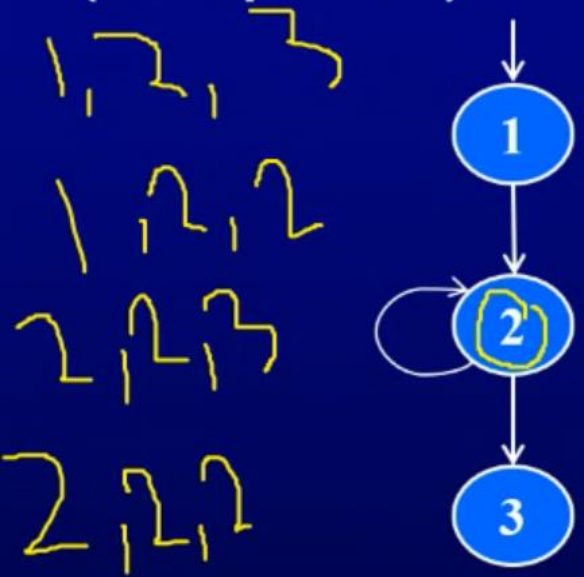
TR = { [1,2,3], [1,2,2], [2,2,3], [2,2,2] }

PPC Requirements : ?

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

PPC Does Not Subsume EPC

- If a node *n* 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)



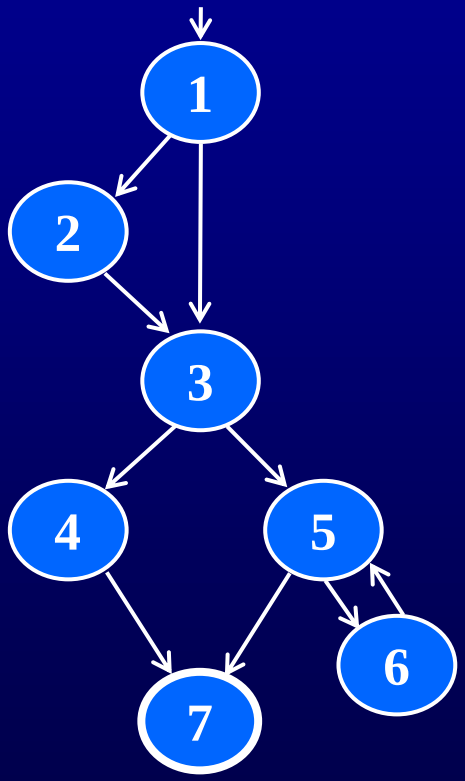
EPC Requirements : ?

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

PPC Requirements : ?

Prime Path Example

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



Write down all 9 prime paths

Prime Paths

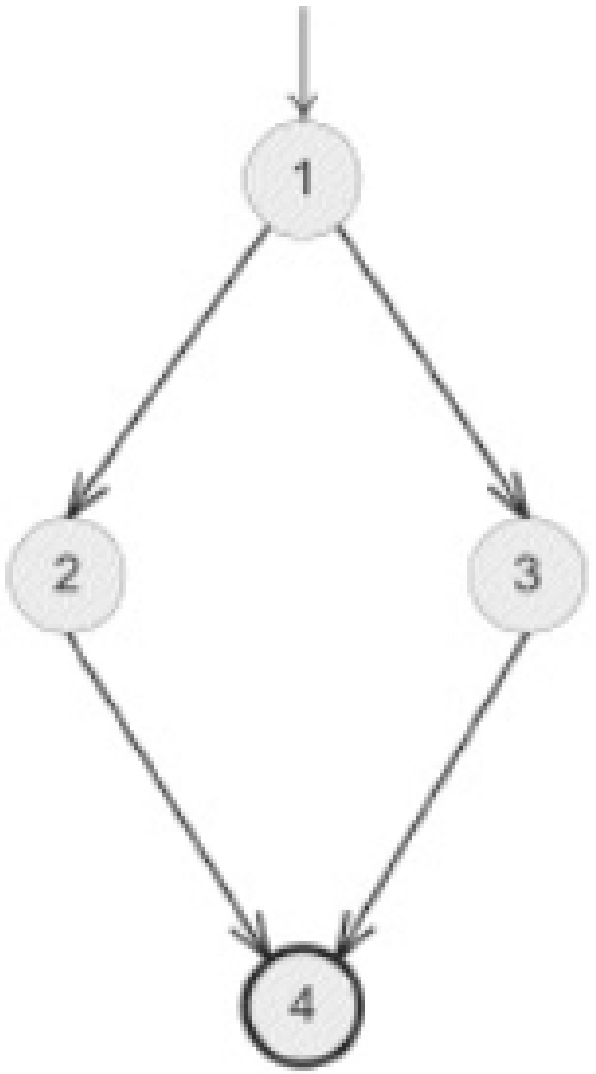
[1, 2, 3, 4, 7]
[1, 2, 3, 5, 7]
[1, 2, 3, 5, 6]
[1, 3, 4, 7]
[1, 3, 5, 7]
[1, 3, 5, 6]
[6, 5, 7]
[6, 5, 6]
[5, 6, 5]

Execute loop 0 times

Execute loop once

Execute loop more than once

Prime Path Coverage vs Complete Path Coverage



Prime Paths = { [1, 2, 4], [1, 3, 4] }

path (t_1) = [1, 2, 4]

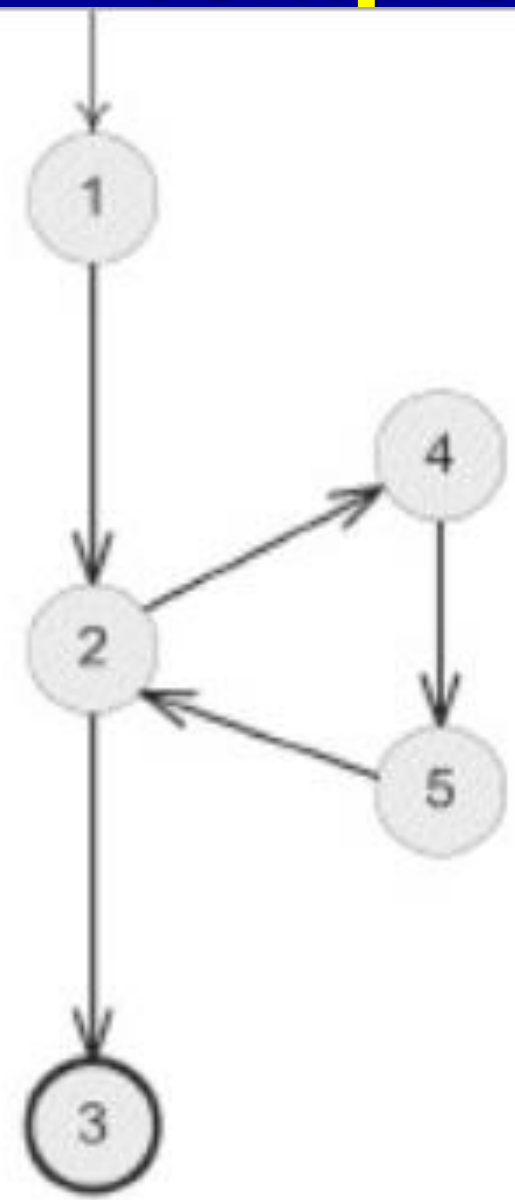
path (t_2) = [1, 3, 4]

$T_1 = \{t_1, t_2\}$

T_1 satisfies prime path coverage on the graph

(a) Prime Path Coverage on a Graph With No Loops

Prime Path Coverage vs Complete Path Coverage



Prime Paths = { [1, 2, 3], [1, 2, 4, 5], [2, 4, 5, 2], [4, 5, 2, 4], [5, 2, 4, 5], [4, 5, 2, 3] }

path (t_3) = [1, 2, 3]

path (t_4) = [1, 2, 4, 5, 2, 4, 5, 2, 3]

$T_2 = \{t_3, t_4\}$

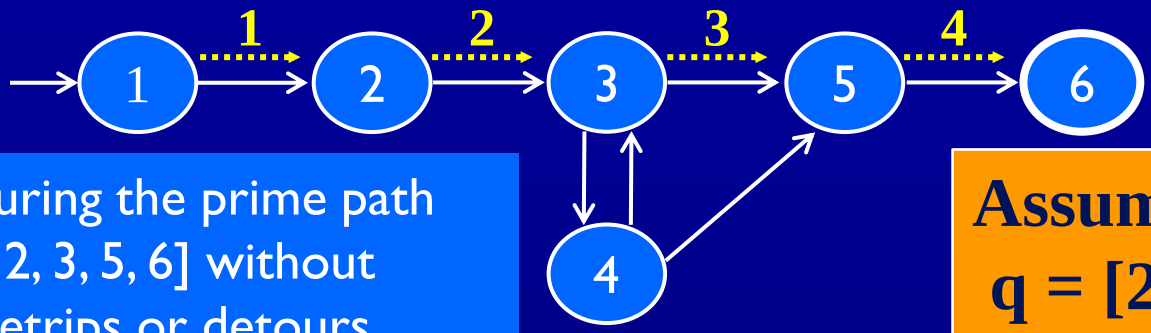
T_2 satisfies prime path coverage on the graph

(b) Prime Path Coverage on a Graph With Loops

Touring, Sidetrips, and Detours

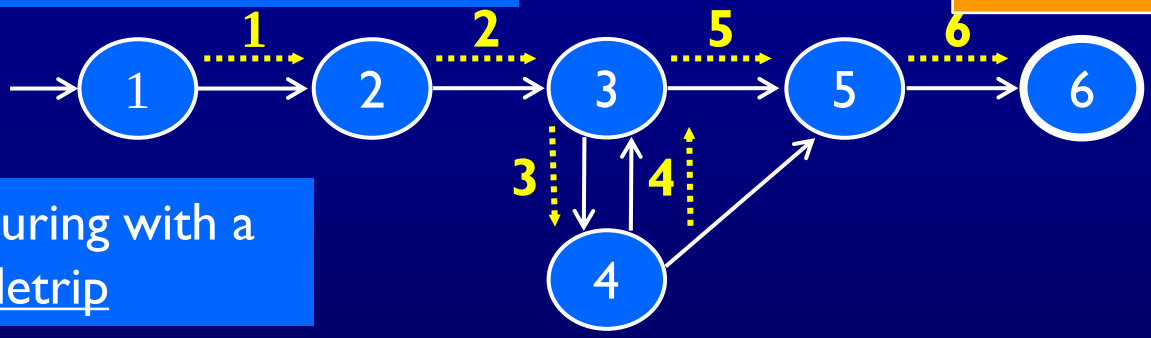
- Prime paths do not have internal loops
- Assume that q is a simple path. Test paths might
- Tour (directly) : *A test path p tours subpath q if q is a subpath of p*
- Tour With Sidetrips : *A test path p tours subpath q with sidetrips iff every* ***edge*** *in q is also in p in the same order*
- Tour With Detours : *A test path p tours subpath q with detours iff every* ***node*** *in q is also in p in the same order*

Sidetrips and Detours Example

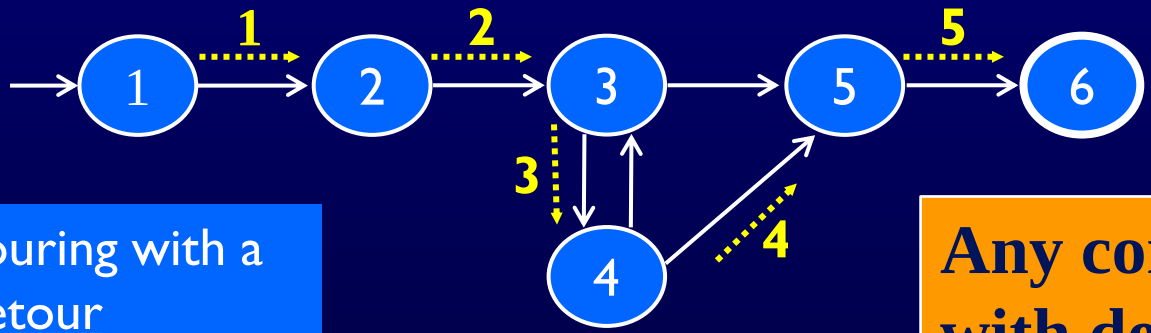


Touring the prime path [1, 2, 3, 5, 6] without sidetrips or detours

Assume
q = [2, 3, 5]



Touring with a sidetrip



Touring with a detour

Any concern with detours?

Prime Path coverage : 0 or more iterations

```
print(  Say hello!  );
for (i=0i;5;i++)
    print Hii;

print Bye
```

```
print (Say Hello)
int = 0
do{
   print Hi
} while (i< 5)
   print Bye
```

Infeasible Test Requirements

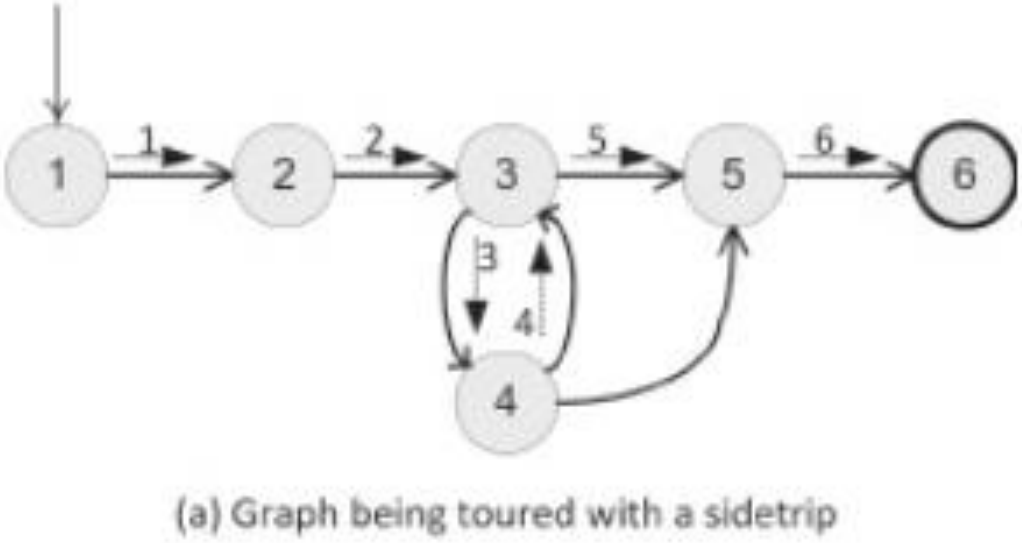
- An infeasible test requirement cannot be satisfied
  - Unreachable statement (dead code)
  - Subpath that can only be executed with a contradiction (*X* > *0* and *X* < *0*)
- Most test criteria have some infeasible test requirements

```
If (false)
    unreachableCall();
```

```
If (x>0)
    if(x < 0)
        unreachableCall();
```

Infeasible Test Requirements

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



(a) Graph being toured with a sidetrip

- **When do you need to tour this graph with side trips?**
- **When would side trips be a bad idea?**

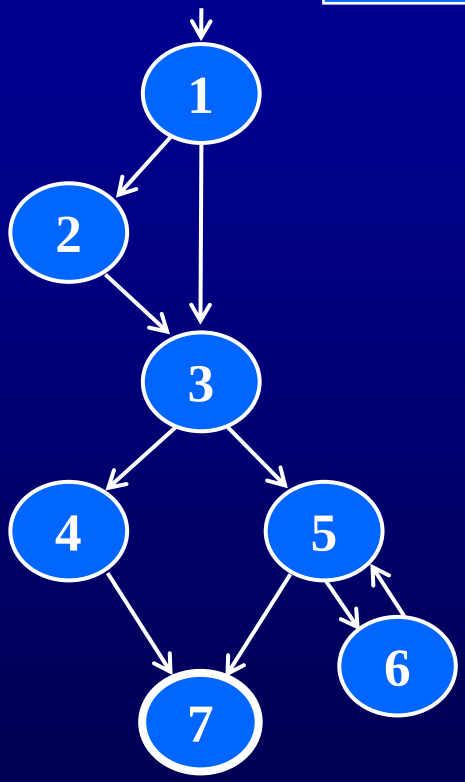
Refining Coverage Criteria

- We could define each graph coverage criterion and explicitly include the kinds of tours allowed, e.g.
  - prime paths, with direct tours;
  - prime paths, side-trips allowed;
  - prime paths, detours allowed.
- Detours seem less practical, so we do not include detours further.
- 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 remaining test requirements**

Finding Prime Test Paths



Simple paths

Len 0
[1]
[5]
[6]
[7] !

Write paths of length 0

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

Write paths of length 1

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

Write paths of length 2

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

Write paths of length 3

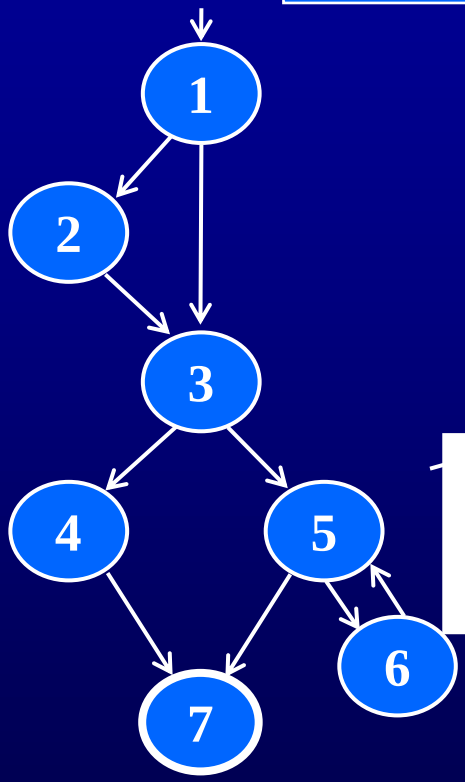
Len 4

Write paths of length 4

Prime Paths ?

Test paths?
Test paths need not be prime!

Finding Prime Test Paths



Simple paths

Len 0
[1]
[2]
[3]
[4]
[5]
[6]
[7] !

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] !

'!' means path terminates

'*' means path cycles

Prime Paths ?

Test paths?
Test paths need not be prime!

Required Reading

- Sections 7.1 and 7.2 from the text book: An Introduction to Software Testing, 2nd edition.