Graph Coverage Overview Part 2

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Inspiration

“All software is a graph” – Anonymous

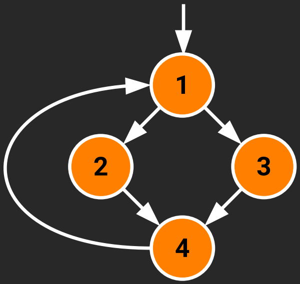
Outcomes

After today's lecture you will be able to:

- Understand the basic concepts of graph coverage
- Understand def, use, and du pairs
- Evaluate a given graph for graph coverage criteria

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*



Write down the simple and prime paths for this graph

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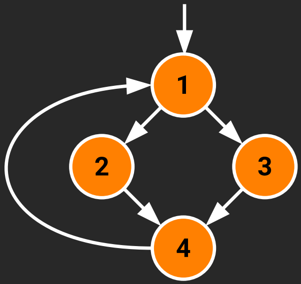


Write down the simple and prime paths for this graph

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:

[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*

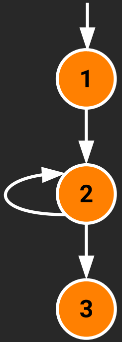
- Will tour all paths of length 0, 1, …

- 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 = ?

- **PPC Requirements:**

  TR =

PPC Does Not Subsume EPC

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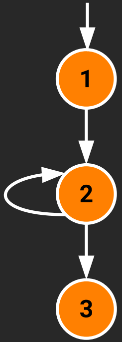

- **EPC Requirements:**

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

- **PPC Requirements:**

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

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Prime Path Example

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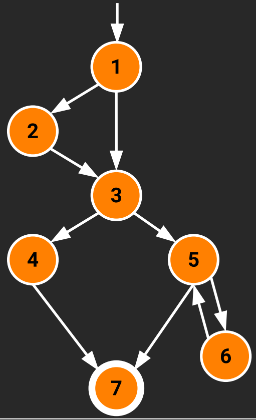
- The previous example has 38 **simple** paths
- Only **nine** prime paths



Prime Paths

Write down all 9 prime paths

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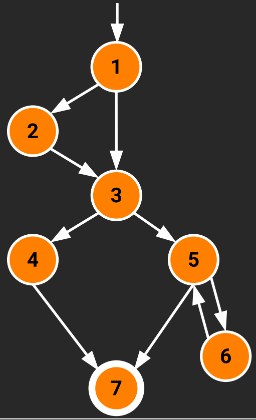
Prime Path Example

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



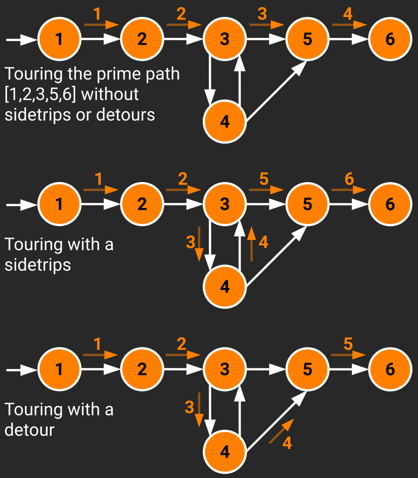
Prime Paths

[1, 2, 3, 4, 7]
[1, 2, 3, 5, 7]
[1, 2, 3, 5, 6]
[1, 3, 4, 7]
[1, 3, 5, 7] -> Execute Loop 0 times
[1, 3, 5, 6] -> Execute loop once
[6, 5, 7]
[6, 5, 6] -> Execute loop more than once
[5, 6, 5]

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 n_i, as long as it comes back to the prime path at a successor of n_i

Sidetrips and Detours Example



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
- 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 remaining test requirements

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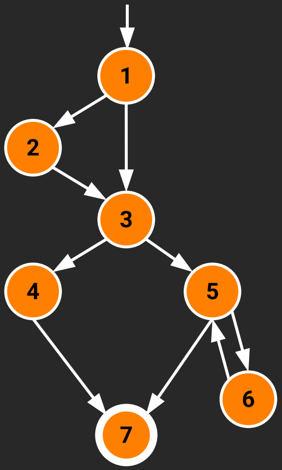
Simple & Prime Path Example



Simple Paths

Write all paths of length 0
Write Paths of length 1
Write paths of length 2
Write paths of length 3
Write paths of length 4

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Simple & Prime Path Example

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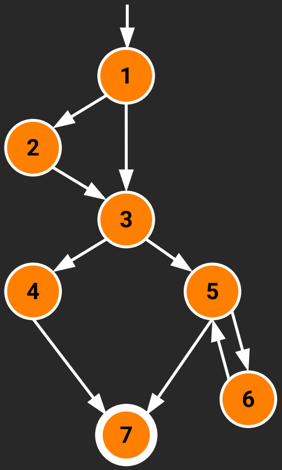

Simple Paths

Length 0: [1] [2] [3] [4] [5] [6] [7]!

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

Length 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]*

Length 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]!

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

Prime Paths?

! means path terminates
 means path is cyclic

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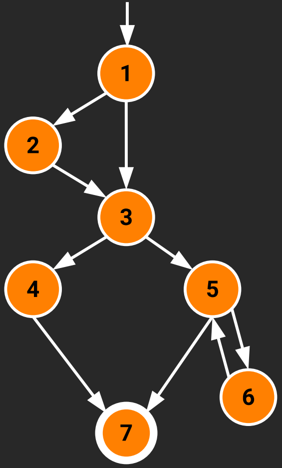
Simple & Prime Path Example



Simple Paths

Length 0: [1] [2] [3] [4] [5] [6] [7]!

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

Length 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]***

Length 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]!

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

! means path terminates
* means path is cyclic
Bold means prime path

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Round Trips

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- **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

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

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Data Flow Criteria

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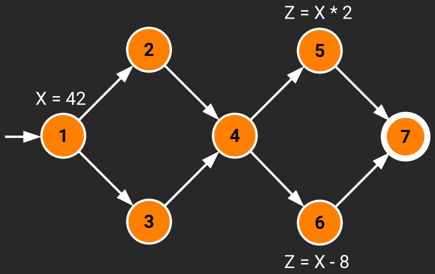
Goal: Ensure that values are computed and used correctly

- **Definition (def)**: A location where a value for a variable is stored into memory.
- **Use**: A location where a variable's value is accessed



Fill in the Sets

```
Defs: { }

Uses: { }
```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Data Flow Criteria

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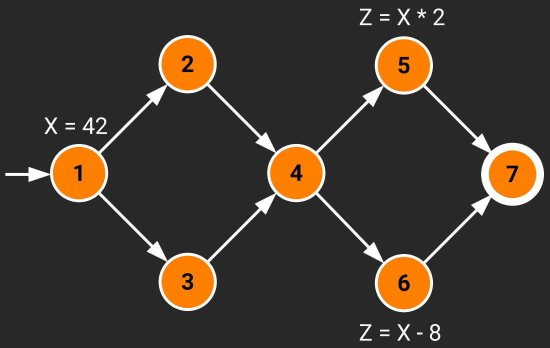

Fill in the Sets

```
Defs: {
  def (1) = { X }
  def (5) = { Z }
  def (6) = { Z }
}

Uses: {
  use (5) = { X }
  use (6) = { X }
}
```

The values given in **defs** should **reach** at least one, some, or all possible **uses**

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DU Pairs and DU Paths

- **def(n) or def (e)**: The set of variables that are defined by node *n* or edge *e*
- **use (n) or use (e)**: The set of variables that are used by node *n* or edge *e*
- **DU pair**: A pair of locations (l_i, l_j) such that a variable *v* is defined at l_i and used at l_j
- **Def-clear**: A path from l_i to l_j is *def-clear* with respect to variable *v* if *v* is not given another value on any of the nodes or edges in the path

DU Pairs and DU Paths

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- **Reach**: If there is a def-clear path from l_i to l_j with respect to v, the def of v at l_i reaches the use at l_j
- **du-path**: A simple subpath that is def-clear with respect to v from a def of v to a use of v
- **du**(n_i, n_j, v) - the set of du-paths from n_i to n_j
- **du**(n_i, v) - the set of du-paths that start at n_i

Touring DU-Paths

- A test path p **du-tours** subpath *d* with respect to *v* if *p* tours *d* and the subpath taken is def-clear with respect to *v*

- **Sidetrips** can be used, just as with previous touring

- Three criteria
  - Use every def
  - Get to every use
  - Follow all du-paths

Data Flow Test Criteria

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- First, we make sure **every def** reaches **a use**

  All-defs coverage (ADC): For each set of du-paths $S = du(n, v)$, TR contains at least one path $d \in S$.

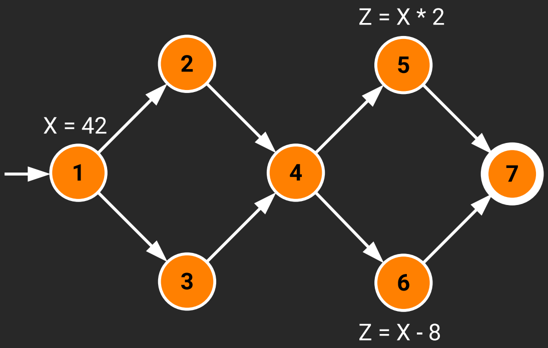
- Then we make sure that **every def** reaches **all** possible **uses**

  All-uses coverage (AUC): For each set of du-paths to uses $S = du(n_i, n_j, v)$, TR contains at least one path $d \in S$

- Finally, we cover **all the paths** between defs and uses

  All-du-paths coverage (ADUPC): For each set $S = du(n_i, n_j, v)$, TR contains every path $d \in S$.

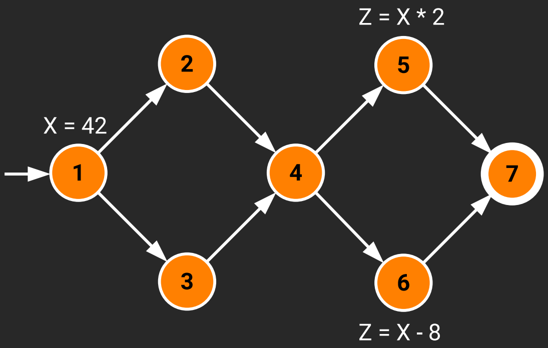
Data Flow Example



Exercise

- Write down paths to satisfy ADC for X.
- Write down paths to satisfy AUC for X.
- Write down paths to satisfy ADUPC for X.

Data Flow Example



Exercise

- Write down paths to satisfy ADC for X.

  All-defs for X: [1, 2, 4, 5]

- Write down paths to satisfy AUC for X.

  All-uses for X: [1, 2, 4, 5] [1, 2, 4, 6]

- Write down paths to satisfy ADUPC for X.

  All-du-paths for X: [1, 2, 4, 5], [1, 3, 4, 5], [1, 2, 4, 6], [1, 3, 4, 6]

Graph Coverage Criteria Subsumption

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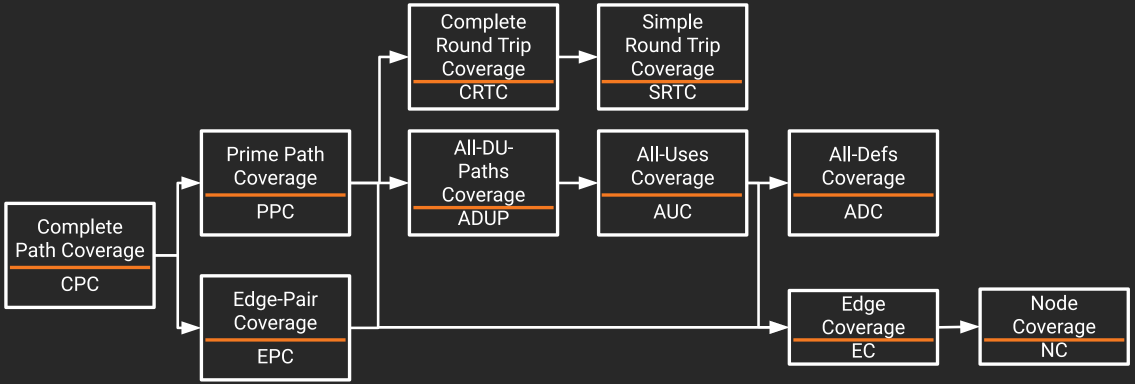

Summary

- 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 remainder of chapter 7

For Next Time

- Review the Reading
- Review this Lecture
- Come to Class

Are there any questions?