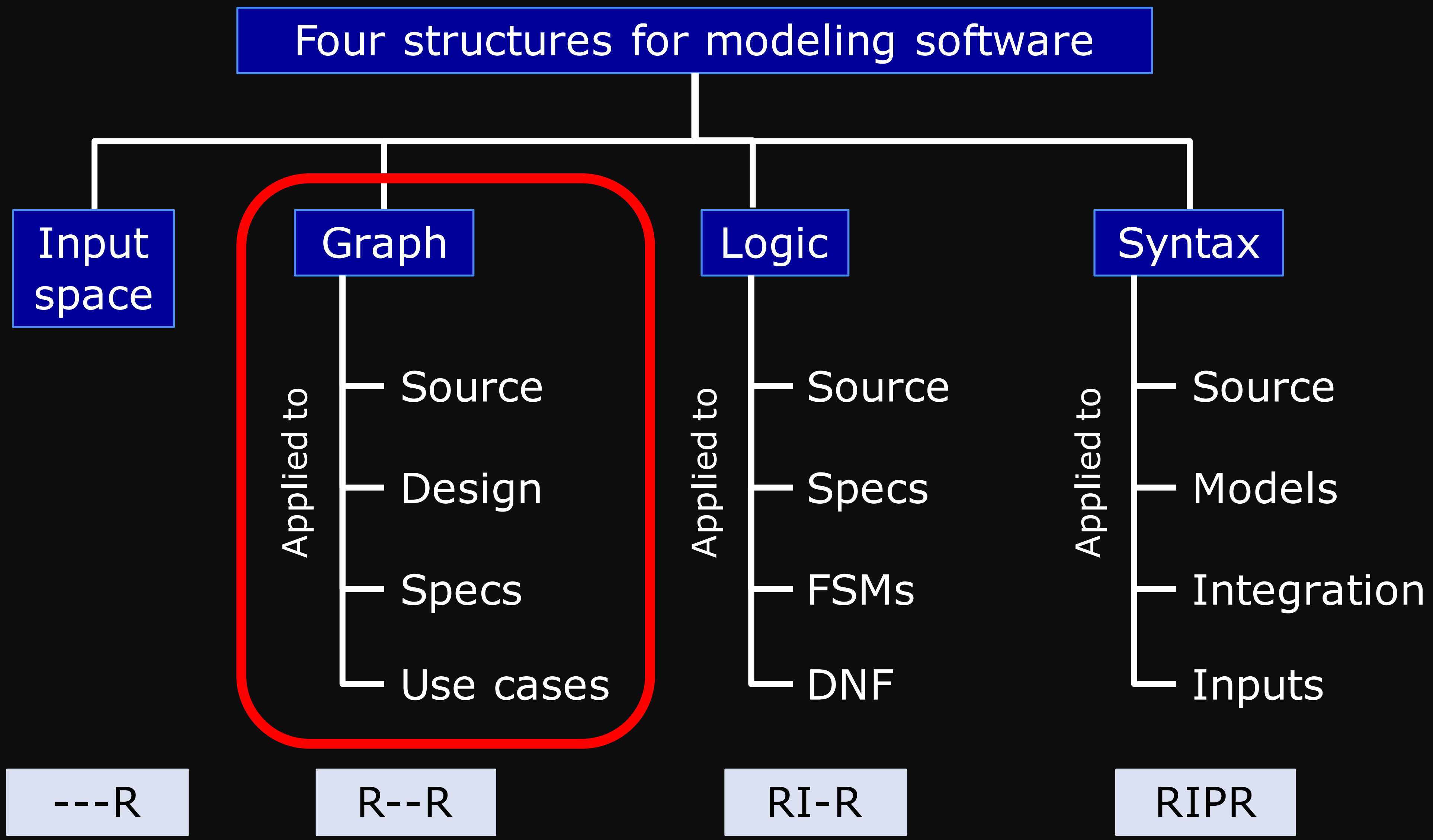
Graph: Data Flow Coverage Criteria

CS 3250
Software Testing

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

Structures for Criteria-Based Testing



revisit

Graph Coverage Criteria

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*

Two types

1. Structural coverage criteria
   - Define a graph just in terms of nodes and edges

2. Data flow coverage criteria
   - Requires a graph to be annotated with references to variables

Today’s Objectives

- Analyze data flow of software artifacts
- Understand how to integrate data flow into a graph model of the program under test
- Focusing on the flow of data, understand how to define criteria and design tests
  - All-Defs Coverage (ADC)
  - All-Uses Coverage (AUC)
  - All-DU-Paths Coverage (ADUPC)

Data Flow Criteria

- Goal: Ensure that the values are created and used correctly
- How: Focus on definitions and uses of values
- Definition (def): A location where a value for a variable is stored in a memory
- Use: A location where a variable's value is accessed

Values are carried from defs to uses, refer to as "***du-pairs***"

- Also known *definition-use*, *def-use*, *du associations*

Data Flow Criteria

Data flow coverage criteria define test requirements TR in terms of the flows of data values in a graph G

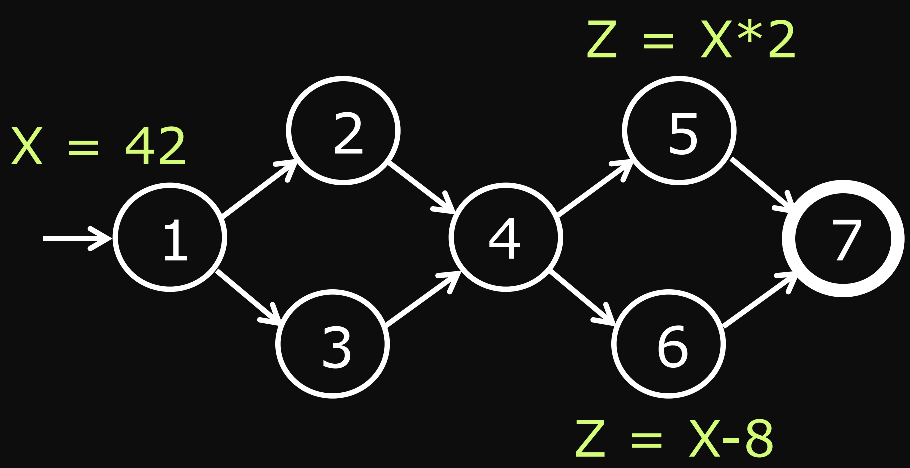
Steps:

1. Develop a model of the software as a graph
2. Integrate data flow into the graph
3. A test requirement is met by visiting a particular node or edge or by touring a particular path

Def, Use, and DU Pairs

- def(n) or def(e): The set of variables defined by node n or edge e
- use(n) or use(e): The set of variables 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

Example: Defs, Uses, DU-Pairs



defs:

- def(1) = { X }
- def(5) = { Z }
- def(6) = { Z }

uses:

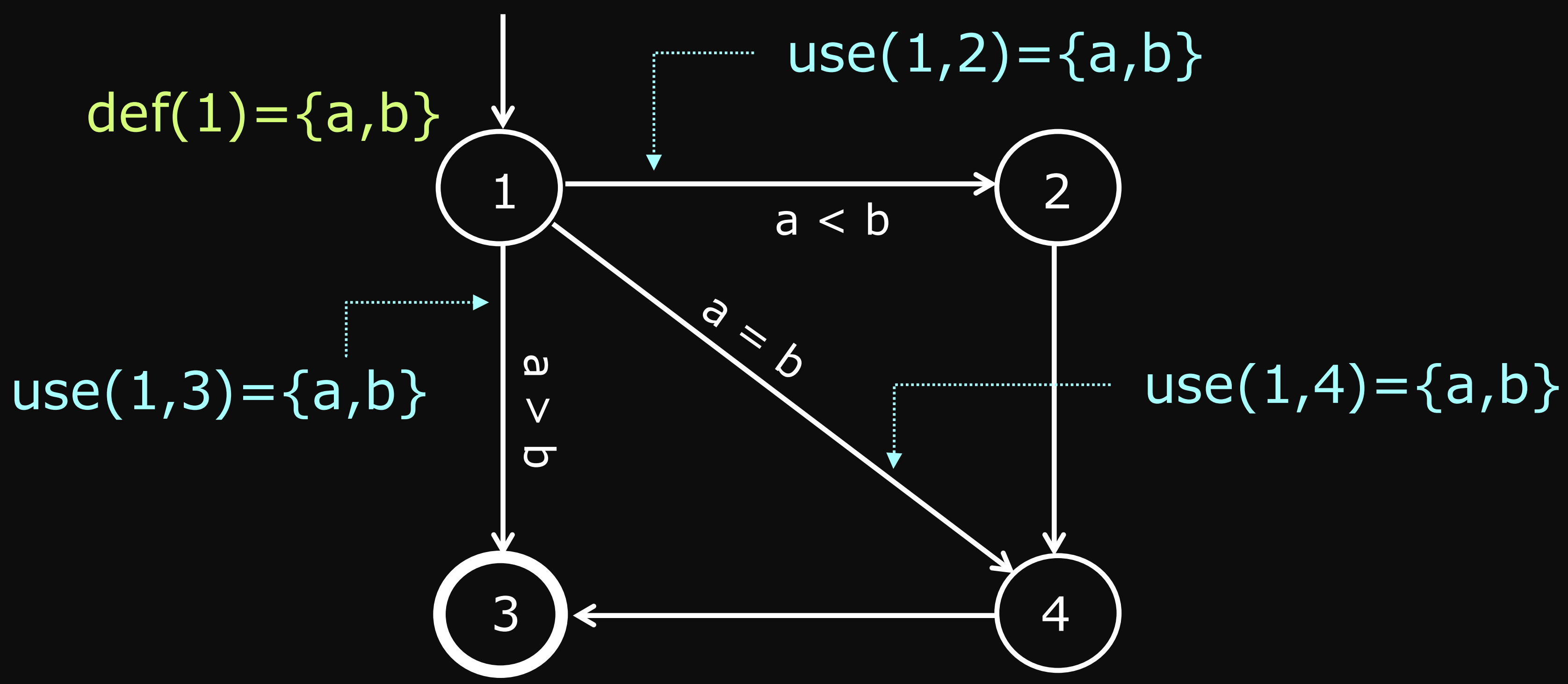
- use(5) = { X }
- use(6) = { X }

du-pairs: for variable X

- (1, 5)
- (1, 6)

Example (2)

All variables involved in a decision are assumed to be used on the associated edges



Your Turn: POTD 5 (1)

```
N   = { 1, 2, 3, 4, 5, 6 }
N0  = { 1 }
Nf  = { 6 }
E   = { (1,2), (2,3), (2,6), (3,4), (3,5), (4,5), (5,2) }
def(1) = def(3) = use(3) = use(6) = { x }
// Assume the use of x in node 3 precedes the def
```

1. Draw the graph. Be sure to annotate all information

Def-clear and Reach

- 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

- The values given in defs should reach at least one, some, or all possible uses. However, a def of a variable may or may not reach a particular use

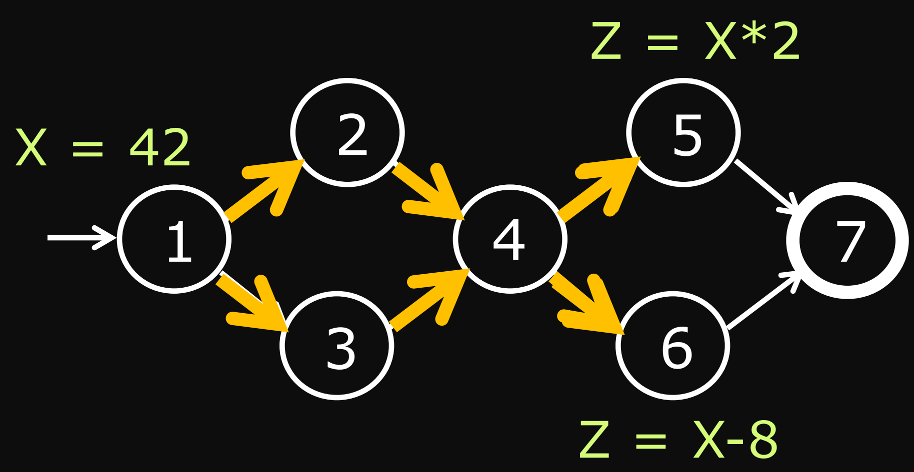
- Why?
  - No path goes from a location where a variable is defined to a location where the variable is used
  - A variable's value may be changed by another def before it reaches the use

- 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-Paths

- du-path: A simple subpath that is def-clear with respect to a variable *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
- Keep the path simple to ensure a reasonably small number of paths

Example: DU-Paths



defs:

- def(1) = { X }
- def(5) = { Z }
- def(6) = { Z }

uses:

- use(5) = { X }
- use(6) = { X }

du-pairs: for variable X

- (1, 5)
- (1, 6)

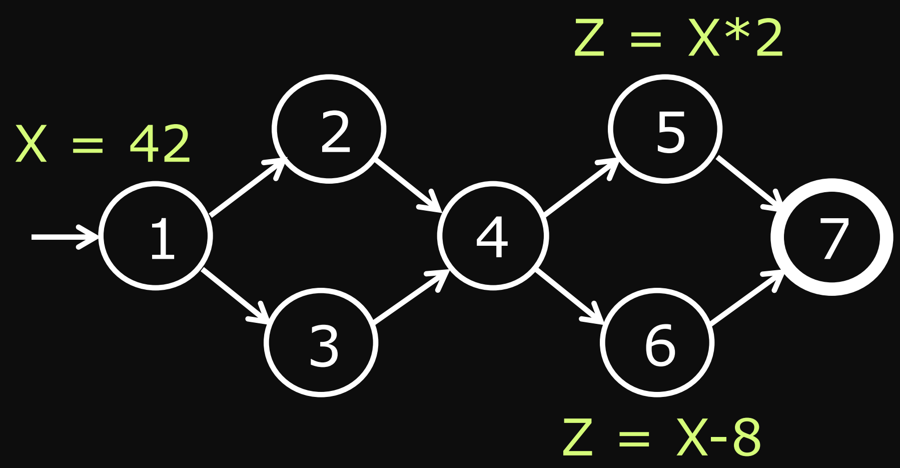
du-paths: for variable X

- du(1, 5, X) = {[1,2,4,5],
  [1,3,4,5]}
- du(1, 6, X) = {[1,2,4,6]
  [1,3,4,6]}

Categorizing DU-Paths

- The core of data flow testing – allowing definitions to flow to uses
- The test criteria for data flow will be defined as sets of du-paths. Thus, we first categorize the du-paths according to:
- def-path set
  - du(n_i, v): All simple paths w.r.t. a given variable v defined in a given node
- def-pair set
  - du(n_i, n_j, v): All simple paths w.r.t. a given variable v from a given definition (n_i) to a given use (n_j)

Example: Def-Path and Def-Pair



du-path sets

- du(1, X) = {[1,2,4,5],
  [1,3,4,5],
  [1,2,4,6],
  [1,3,4,6]}

du-pair sets

- du(1, 5, X) = {[1,2,4,5],
  [1,3,4,5]}
- du(1, 6, X) = {[1,2,4,6],
  [1,3,4,6]}

Your Turn: POTD 5 (2)

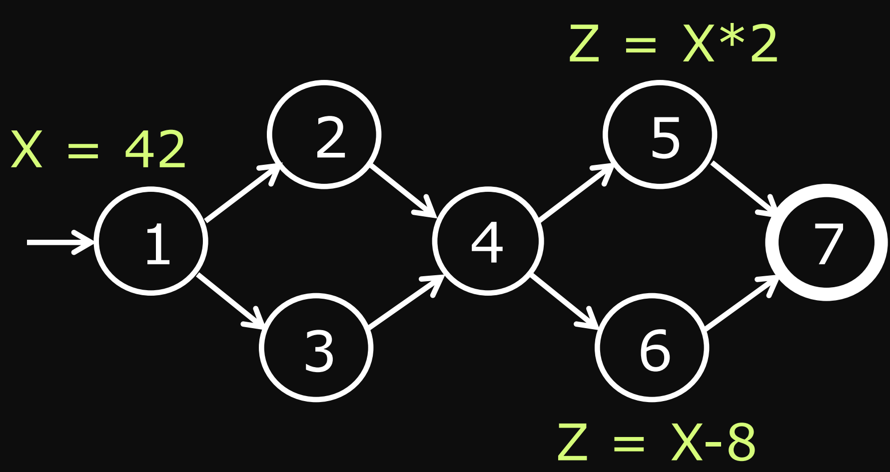
```
N   = { 1, 2, 3, 4, 5, 6 }
N0  = { 1 }
Nf  = { 6 }
E   = { (1,2), (2,3), (2,6), (3,4), (3,5), (4,5), (5,2) }
def(1) = def(3) = use(3) = use(6) = { x }
// Assume the use of x in node 3 precedes the def
```

2. List all of the du-paths with respect to x

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



Test path [1,2,4,5,7] du-tours du-path [1,2,4,5]

du-path sets

- du(1, X) = {[1,2,4,5], [1,3,4,5], [1,2,4,6], [1,3,4,6]}

du-pair sets

- du(1, 5, X) = {[1,2,4,5], [1,3,4,5]}
- du(1, 6, X) = {[1,2,4,6], [1,3,4,6]}

Your Turn: POTD 5 (3)

```
N  = { 1, 2, 3, 4, 5, 6 }
N0 = { 1 }
Nf = { 6 }
E  = { (1,2), (2,3), (2,6), (3,4), (3,5), (4,5), (5,2) }
def(1) = def(3) = use(3) = use(6) = { x }
// Assume the use of x in node 3 precedes the def

Test paths
t1 = [1, 2, 6]
t2 = [1, 2, 3, 4, 5, 2, 3, 5, 2, 6]
t3 = [1, 2, 3, 5, 2, 3, 4, 5, 2, 6]
t4 = [1, 2, 3, 5, 2, 6]
```

3. Determine which du-paths each test path tours.

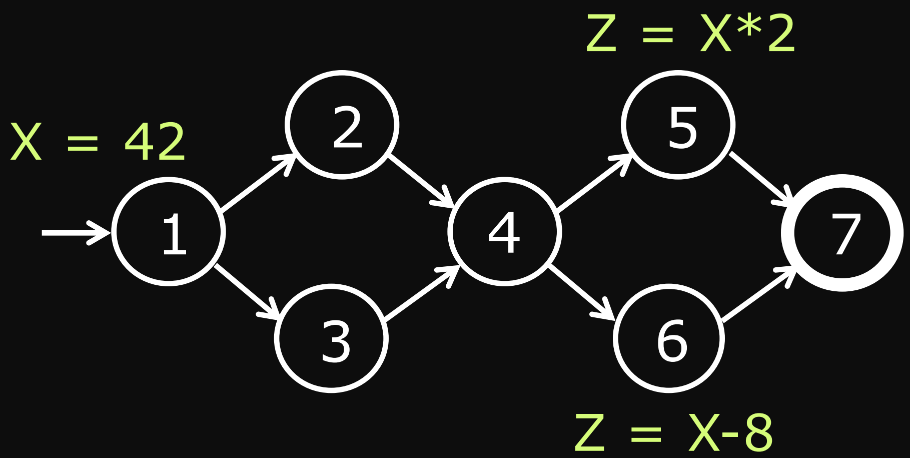
Data Flow Coverage Criteria

- All-Defs Coverage (ADC)
  - Use every def
- All-Uses Coverage (AUC)
  - Get to every use
- All-du-Paths Coverage (ADUPC)
  - Follow all du-paths

All-Defs Coverage (ADC)

For each set of du-paths S = du(n,v), TR contains at least one path d in S

- For each def, at least one use must be reached



du-path sets

- du(1, X) = {[1,2,4,5],
  [1,3,4,5],
  [1,2,4,6],
  [1,3,4,6]}

TR for X = {[1,2,4,5]}

Test paths = {[1,2,4,5,7]}

Your Turn: POTD 5 (4)

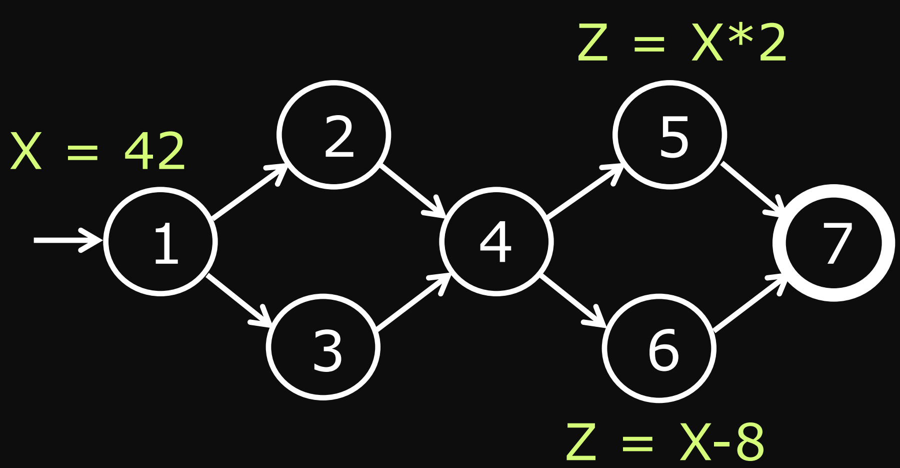
```
N   = { 1, 2, 3, 4, 5, 6 }
N0  = { 1 }
Nf  = { 6 }
E   = { (1,2), (2,3), (2,6), (3,4), (3,5), (4,5), (5,2) }
def(1) = def(3) = use(3) = use(6) = { x }
// Assume the use of x in node 3 precedes the def

Test paths
t1 = [1, 2, 6]
t2 = [1, 2, 3, 4, 5, 2, 3, 5, 2, 6]
t3 = [1, 2, 3, 5, 2, 3, 4, 5, 2, 6]
t4 = [1, 2, 3, 5, 2, 6]
```

4. List a minimal test set that satisfies **all defs** coverage with respect to x (direct tours only).

All-Uses Coverage (AUC)

For each set of du-paths $S = du(n_i, n_j, v)$, TR contains at least one path d in S

- For each def, all uses must be reached



du-pair sets

- du(1, 5, X) = {[1,2,4,5], [1,3,4,5]}
- du(1, 6, X) = {[1,2,4,6], [1,3,4,6]}

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

Test paths = {[1,2,4,5,7], [1,2,4,6,7]}

Your Turn: POTD 5 (5)

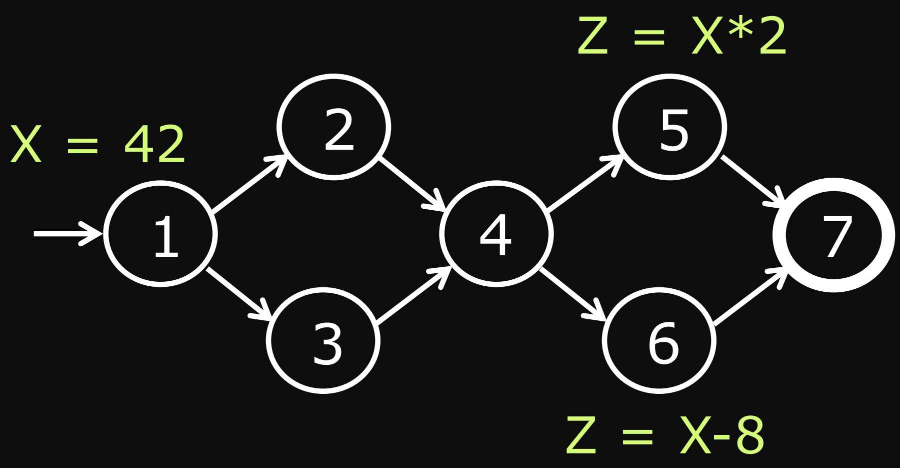
```
N   = { 1, 2, 3, 4, 5, 6 }
N0  = { 1 }
Nf  = { 6 }
E   = { (1,2), (2,3), (2,6), (3,4), (3,5), (4,5), (5,2) }
def(1) = def(3) = use(3) = use(6) = { x }
// Assume the use of x in node 3 precedes the def

Test paths
t1 = [1, 2, 6]
t2 = [1, 2, 3, 4, 5, 2, 3, 5, 2, 6]
t3 = [1, 2, 3, 5, 2, 3, 4, 5, 2, 6]
t4 = [1, 2, 3, 5, 2, 6]
```

5. List a minimal test set that satisfies **all uses** coverage with respect to x (direct tours only).

All-DU-Paths Coverage (ADUPC)

For each set of du-paths S = du(n_i, n_j, v), TR contains every path d in S

- For each def-use pair, all paths between defs and uses must be covered



du-pair sets

- du(1, 5, X) = {[1,2,4,5], [1,3,4,5]}
- du(1, 6, X) = {[1,2,4,6], [1,3,4,6]}

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

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

Your Turn: POTD 5 (6)

```
N   = { 1, 2, 3, 4, 5, 6 }
N0  = { 1 }
Nf  = { 6 }
E   = { (1,2), (2,3), (2,6), (3,4), (3,5), (4,5), (5,2) }
def(1) = def(3) = use(3) = use(6) = { x }
// Assume the use of x in node 3 precedes the def

Test paths
t1 = [1, 2, 6]
t2 = [1, 2, 3, 4, 5, 2, 3, 5, 2, 6]
t3 = [1, 2, 3, 5, 2, 3, 4, 5, 2, 6]
t4 = [1, 2, 3, 5, 2, 6]
```

6. List a minimal test set that satisfies **all du-paths** coverage with respect to x (direct tours only).

Summary

- Graphs are very powerful abstraction for designing tests
- Graphs appear in many situations in software
- Each criterion has its own cost/benefit tradeoffs
  - No silver bullet
  - When possible, choose the criterion that yields the smallest number of test requirements while maintaining fault detection capability

Graph Coverage Criteria Subsumption