Stable Paths Problem

Recall how BGP works

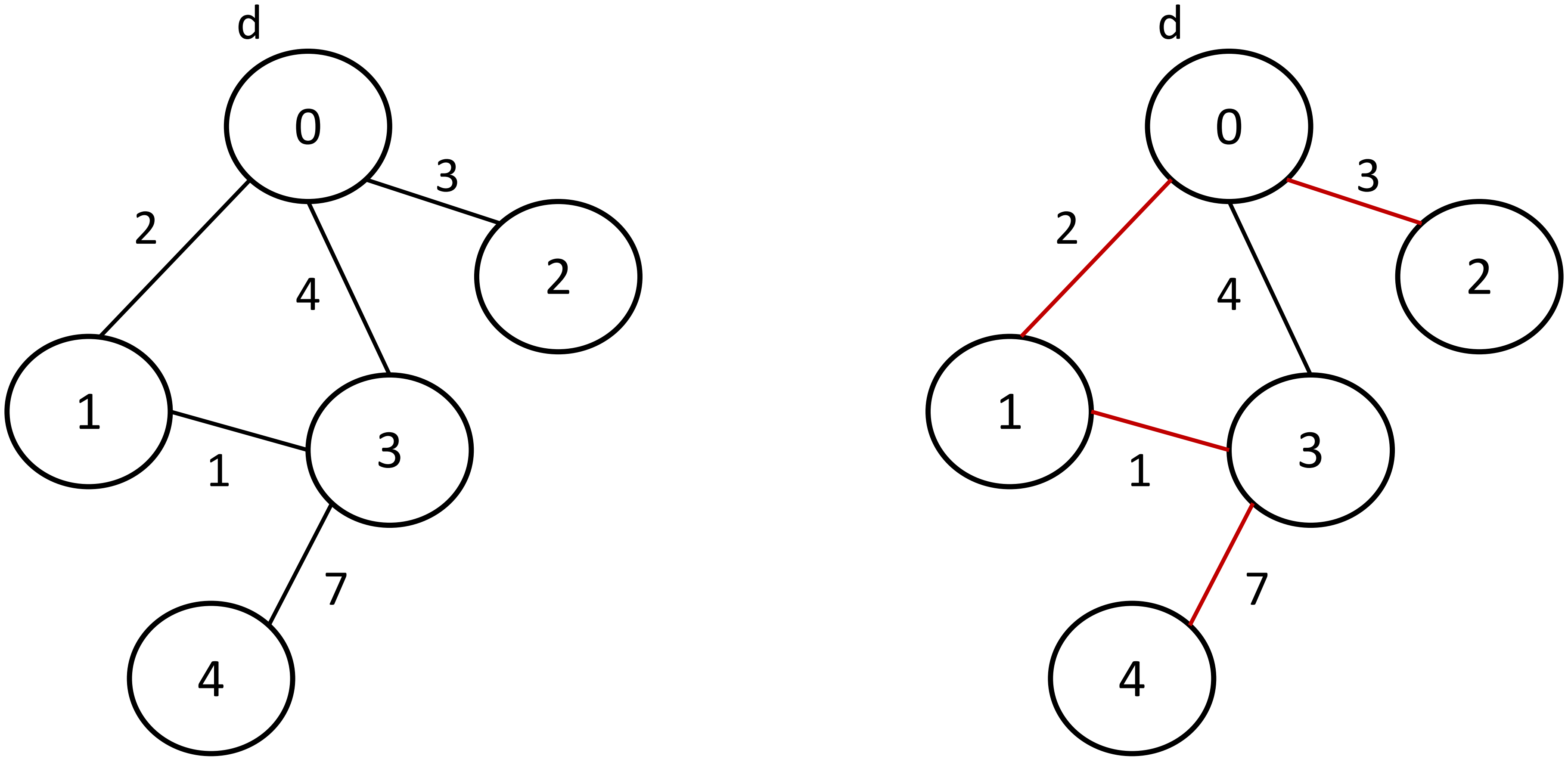
1. Path-vector routing protocol
   - Similar to distance vector, but routes carry the entire path
   - Each hop is an ASN (organization in internet, router in DC)

2. Independent organizations have different policy
   - Not necessarily shortest path
   - Could be least cost, cold-potato, avoid China, etc.

Policy in BGP

1. Export policy
   - Determines what to announce to whom
2. Import policy
   - Determine how to modify (or drop) incoming announcements
   - Can set the BGP local-preference field (highest priority in decision process)
3. Decision process
   - Determine “best” path among all those available

Distance Vector Routing (Shortest Paths)



Solution forms a shortest path tree

What problem is BGP solving?

RIP, OSPF, … → Shortest Paths Problem

BGP → ???

BGP created in 1989 to solve a pressing need.

Protocol dynamics not well understood at the time.

What problem is BGP solving?

RIP, OSPF, … → Shortest Paths Problem

BGP → Stable Paths Problem

“The Stable Paths Problem and Interdomain Routing”

Timothy G. Griffin and F. Bruce Shepherd and Gordon Wilfong (2002)

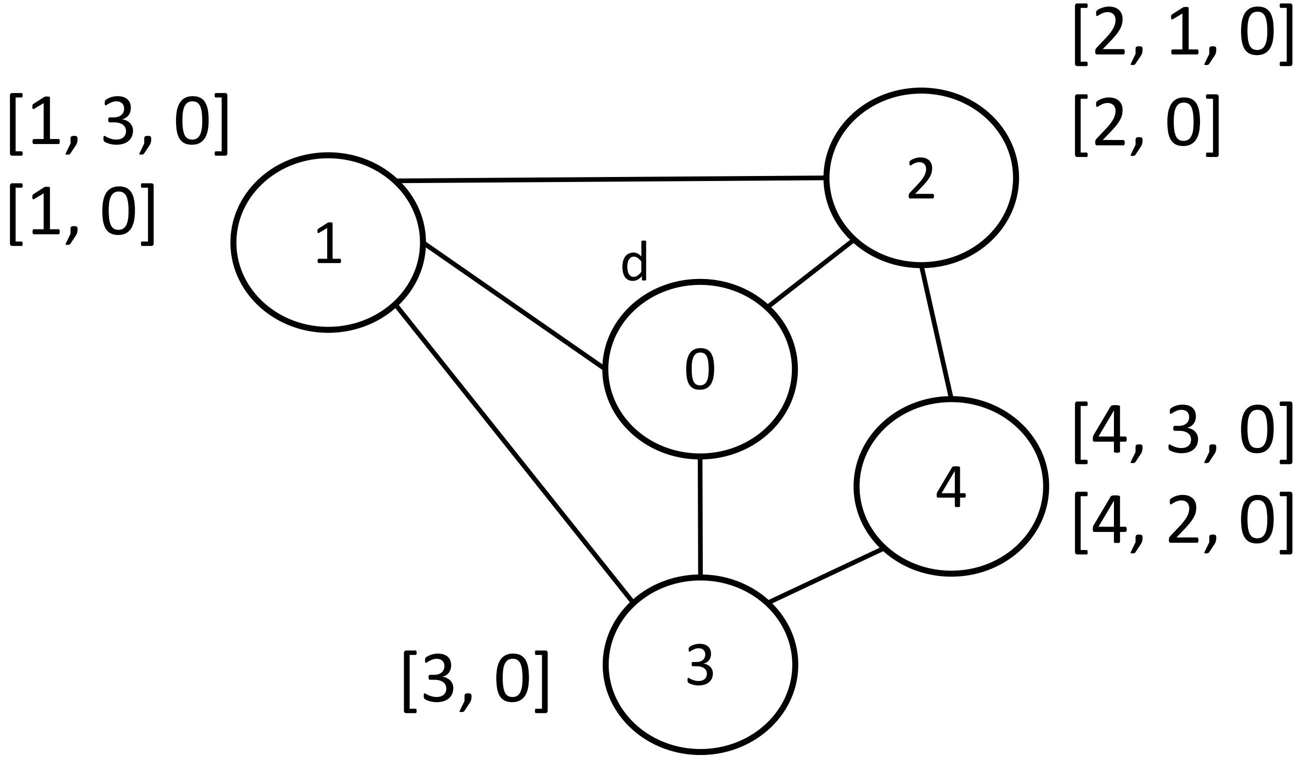
Insights from the paper

- BGP can (always, sometimes, never) converge.
- BGP will solve for a “stable tree”
  - A local equilibrium rather than a global optimum.
  - Stable tree: each node has no preference to change from its current path.
  - Related to Nash Equilibrium from game theory.
- Relationship as follows:
  - If no stable tree, then BGP will never converge.
  - If a unique stable tree, then BGP will converge optimally.
  - If multiple stable trees, then BGP may converge to any tree or may diverge.

Simple Model of BGP

- Network topology is an undirected graph
- Each node list paths that aren’t filtered
    - List of paths is sorted by preference at that node

BGP will always converge (“good gadget”)



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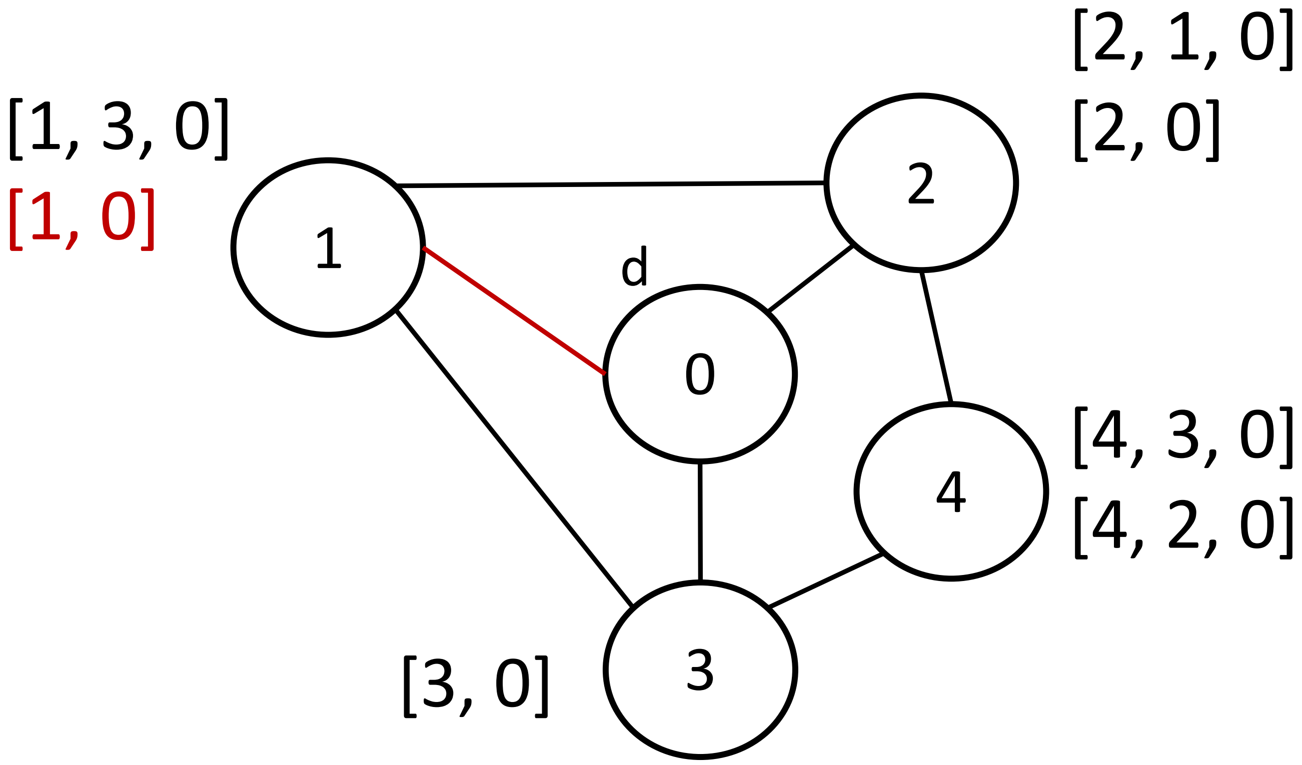

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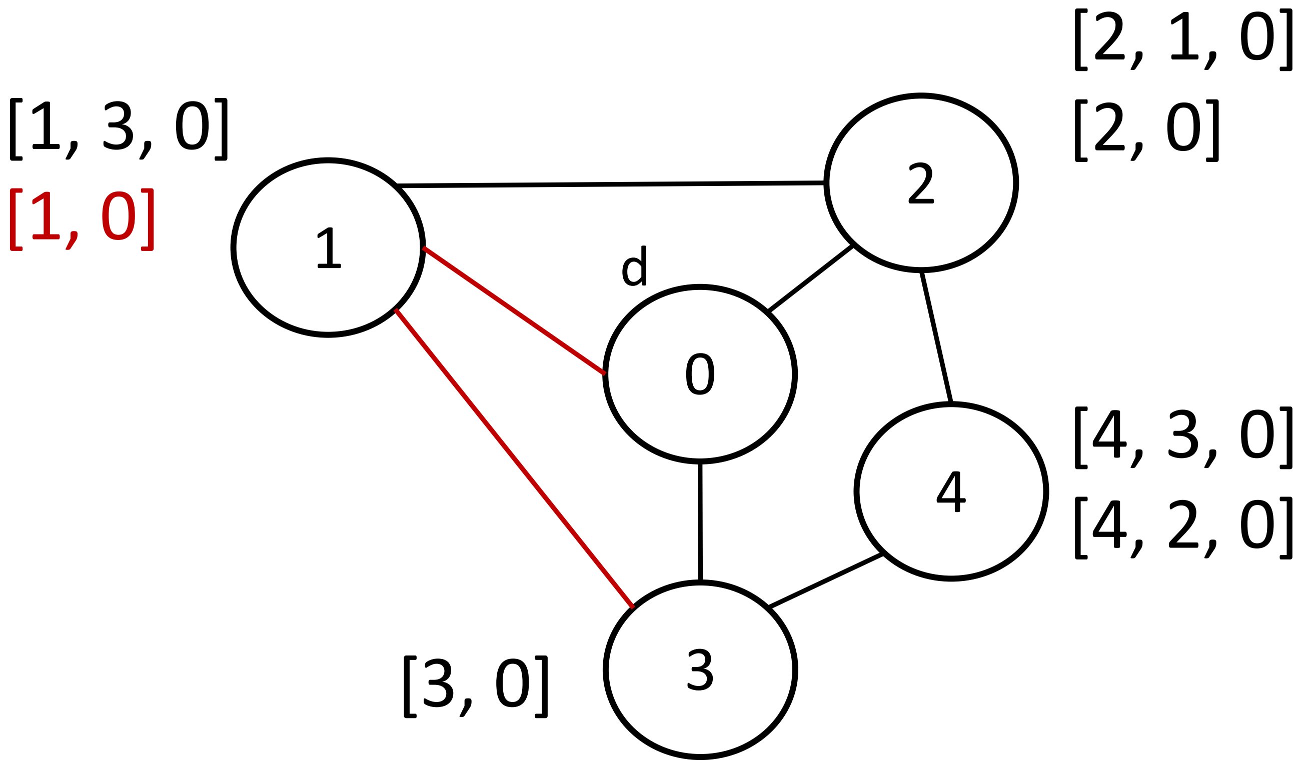

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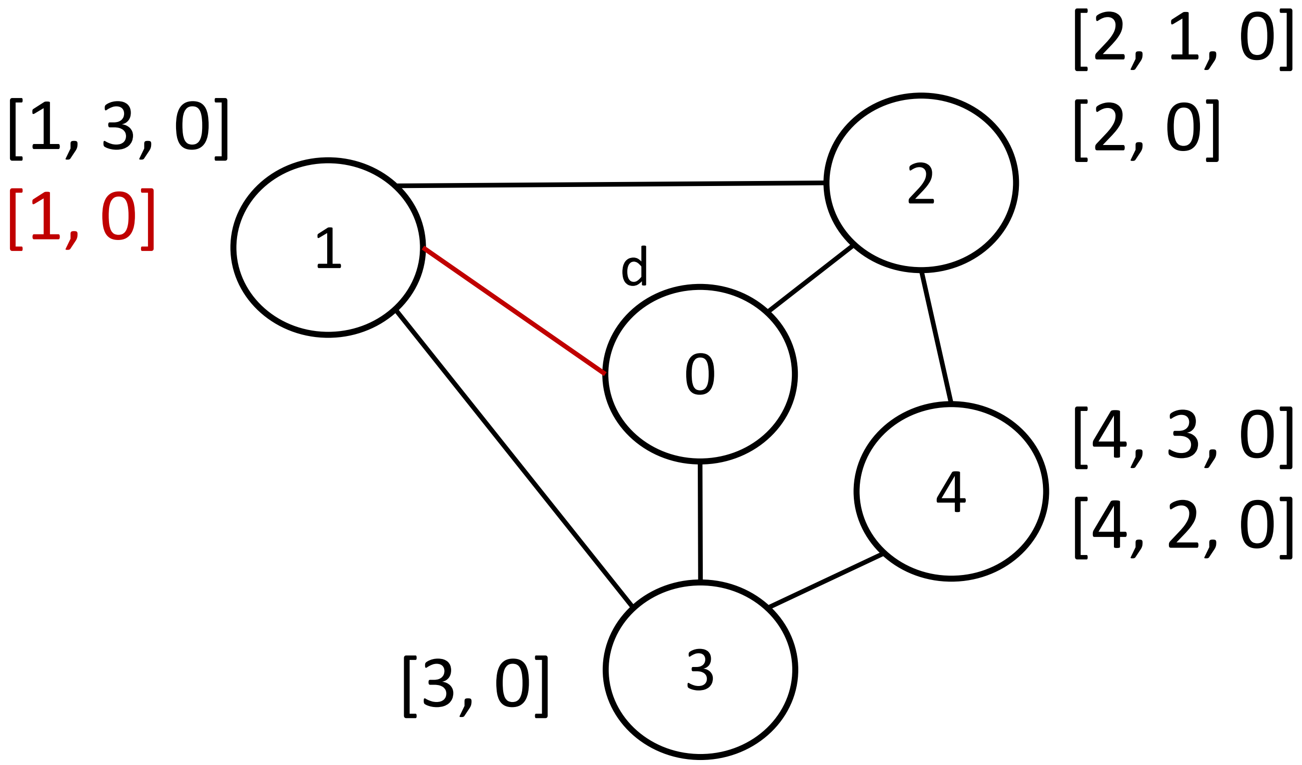

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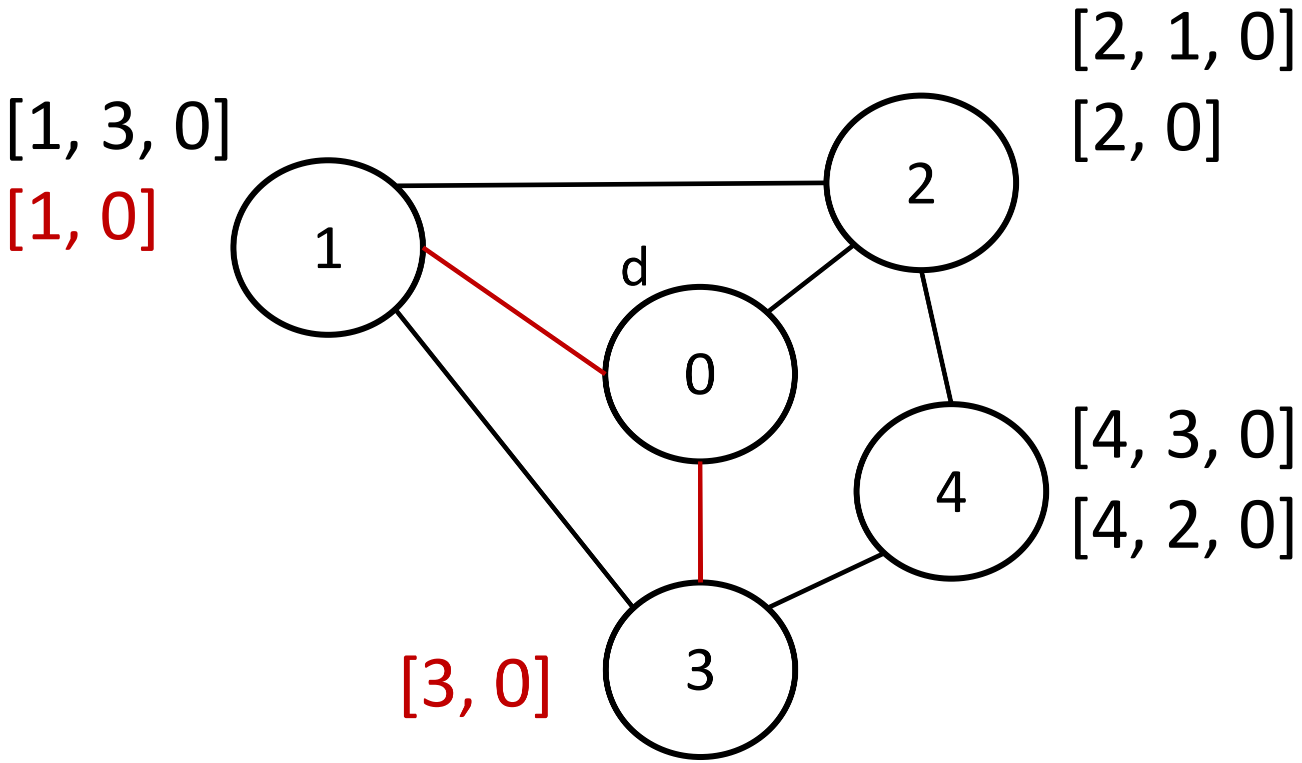

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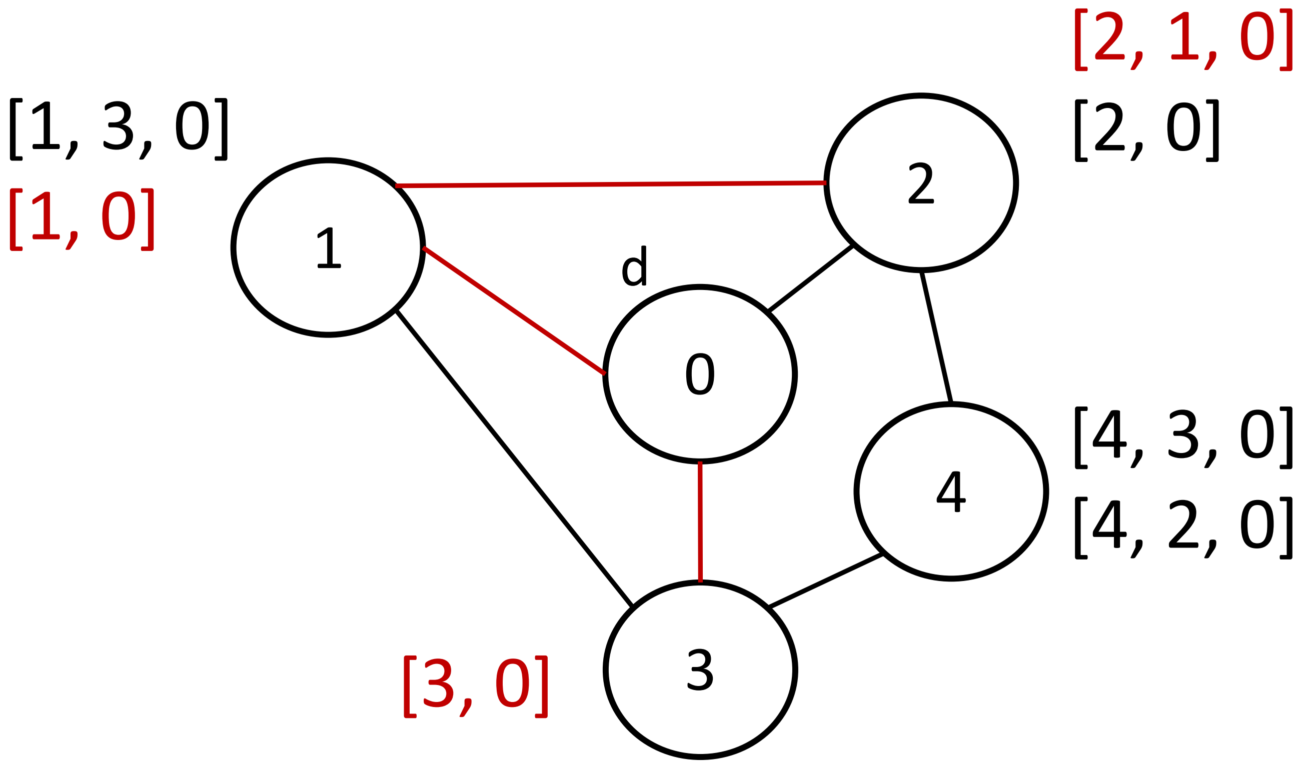

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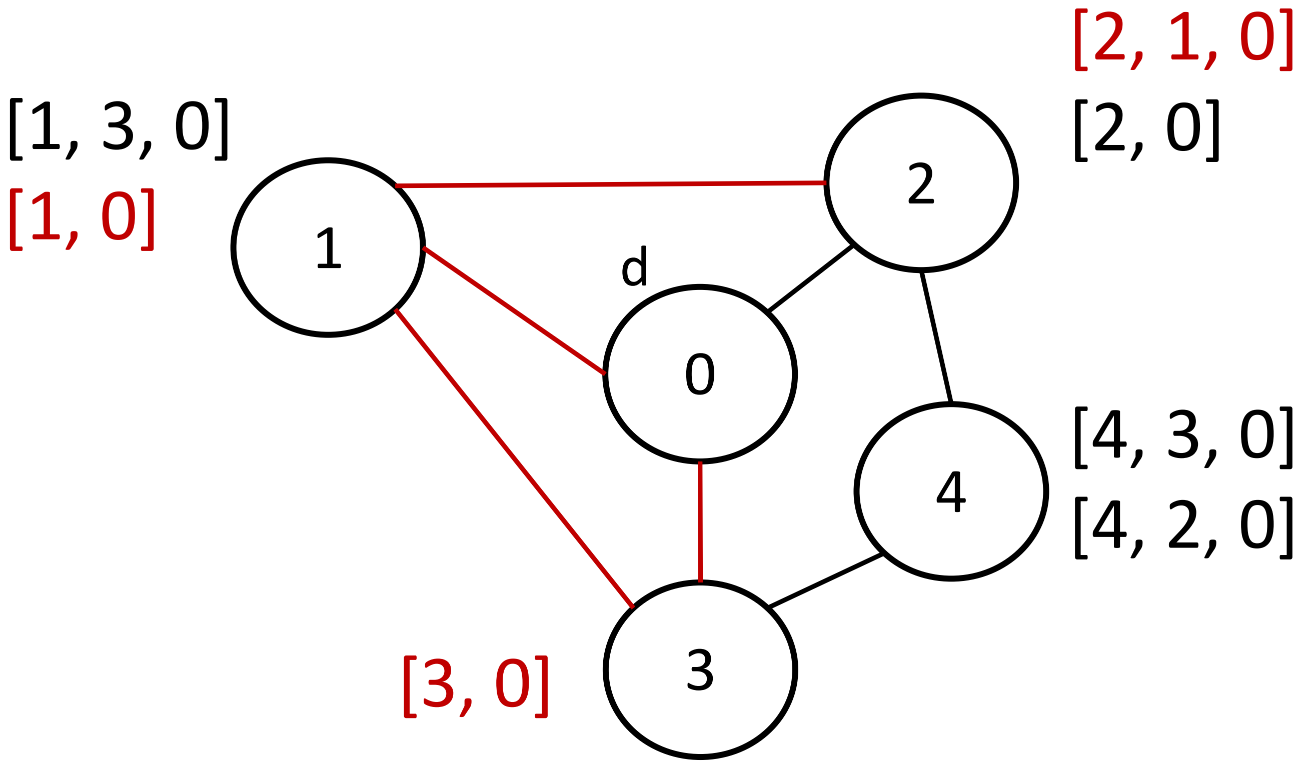

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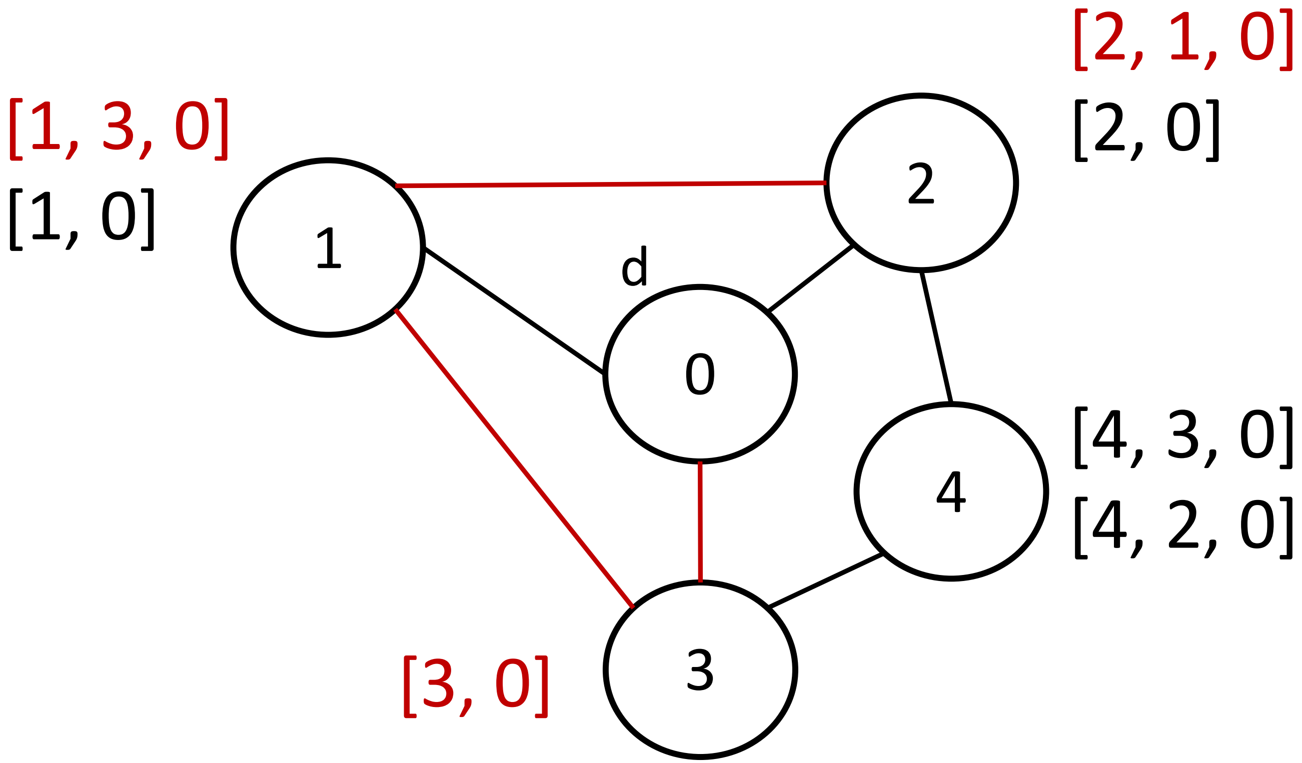

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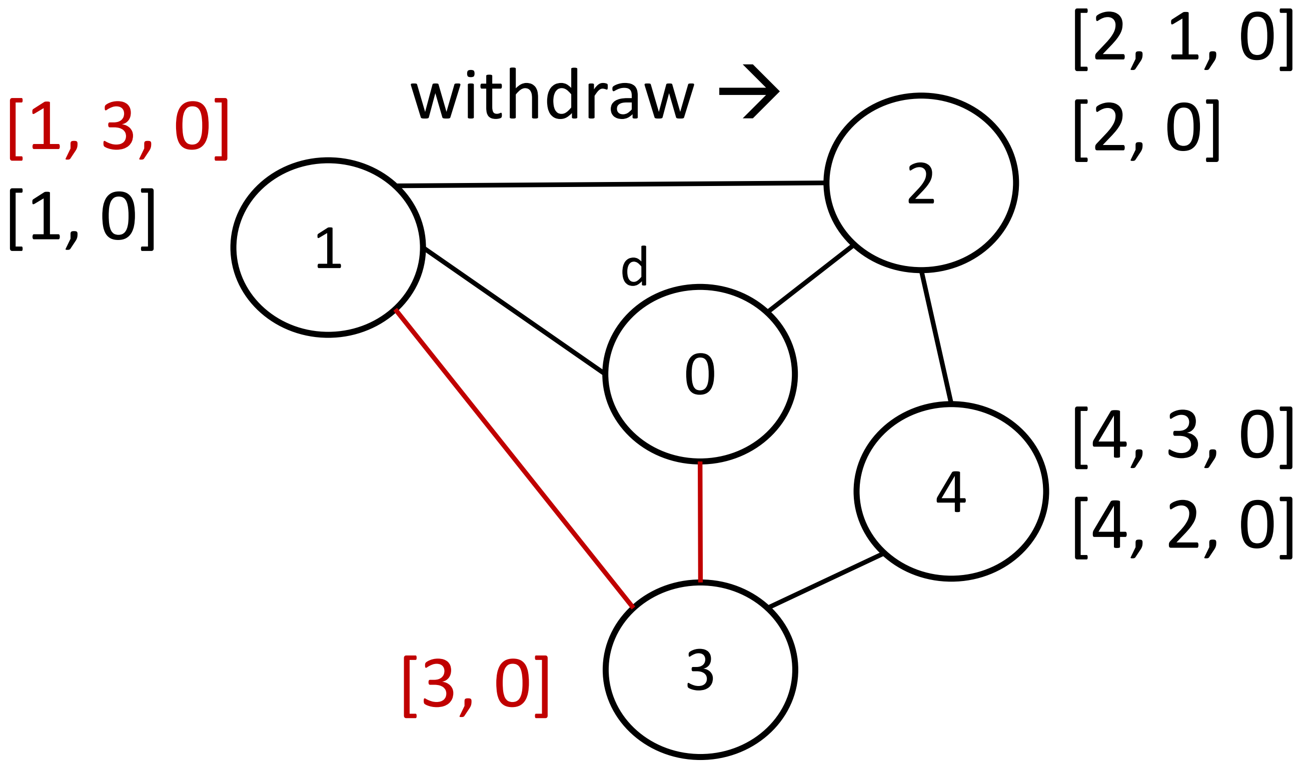

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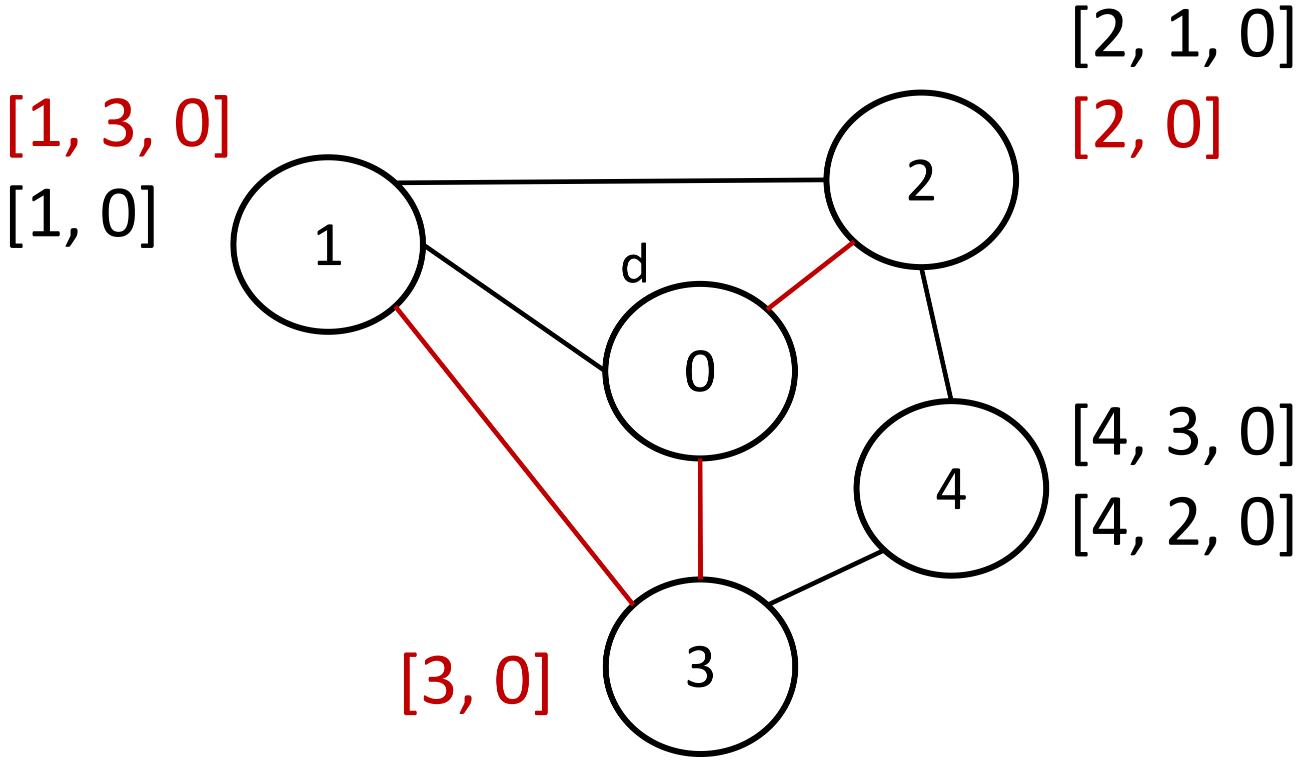

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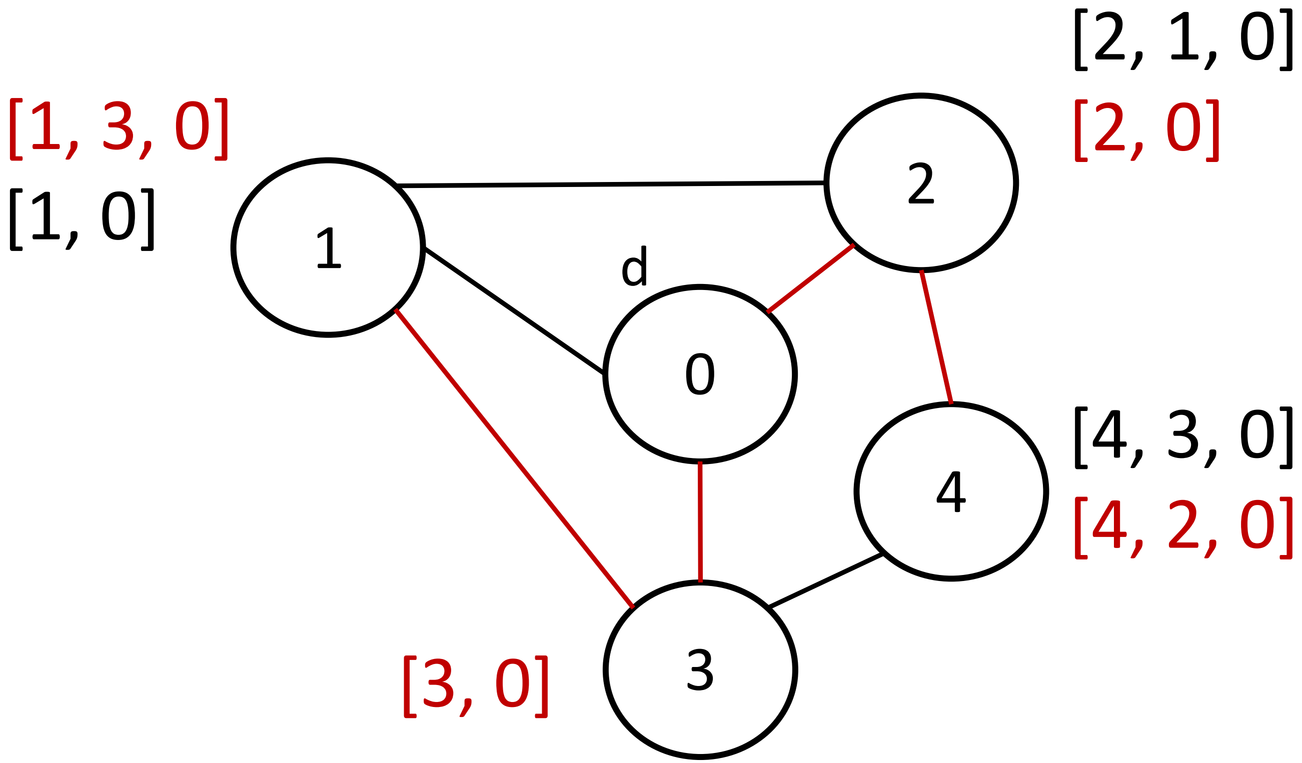

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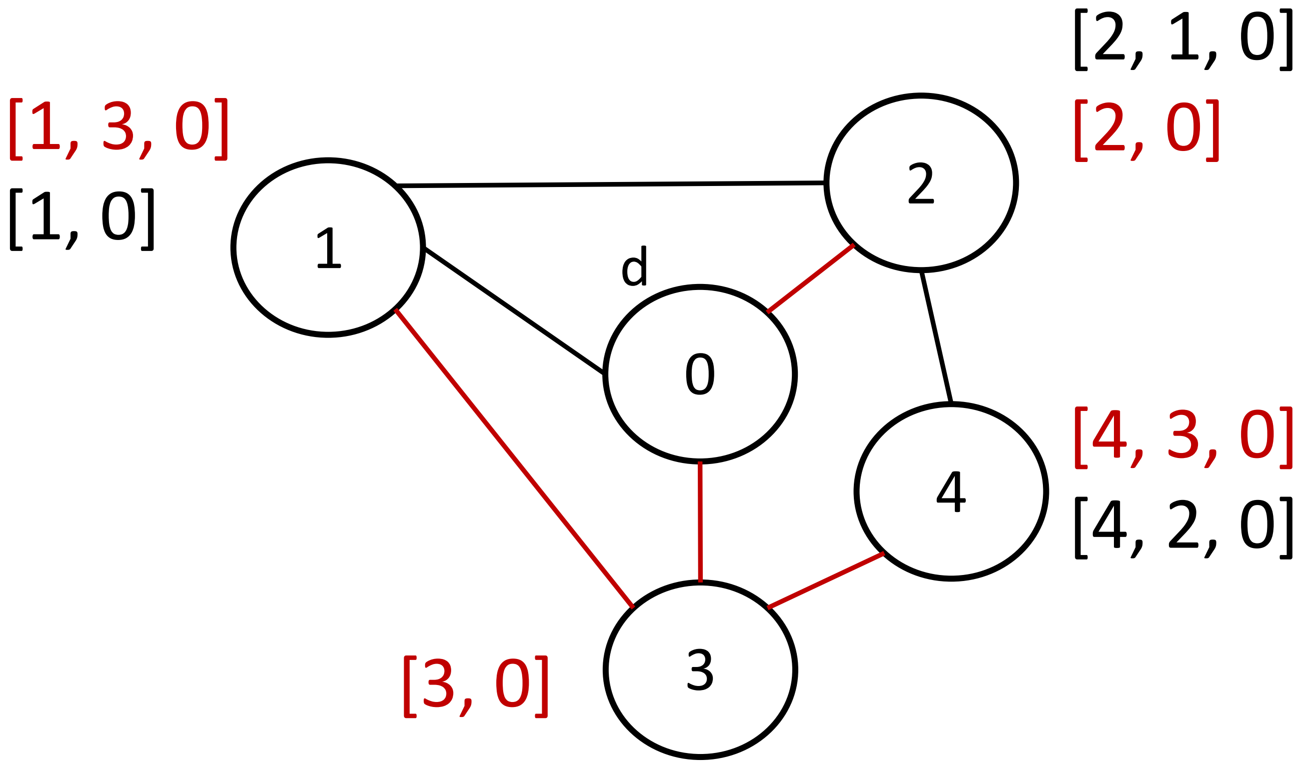

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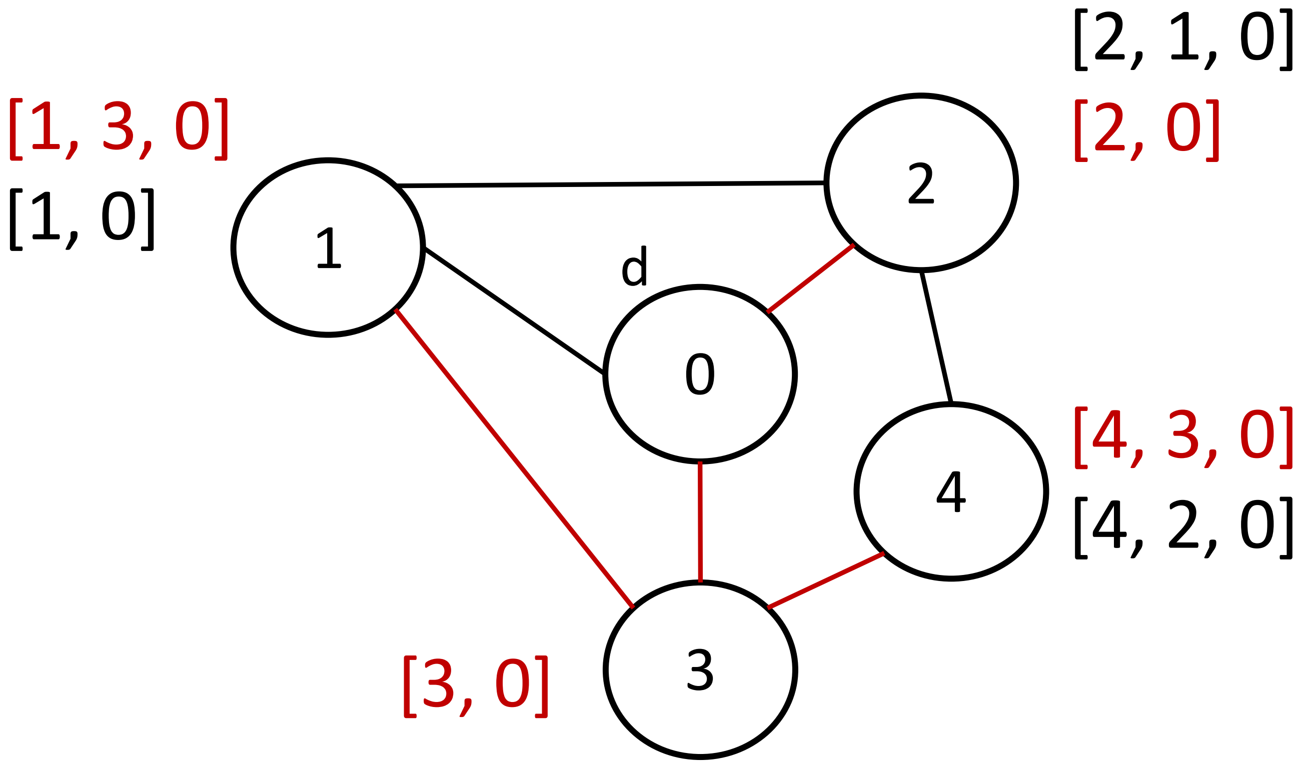
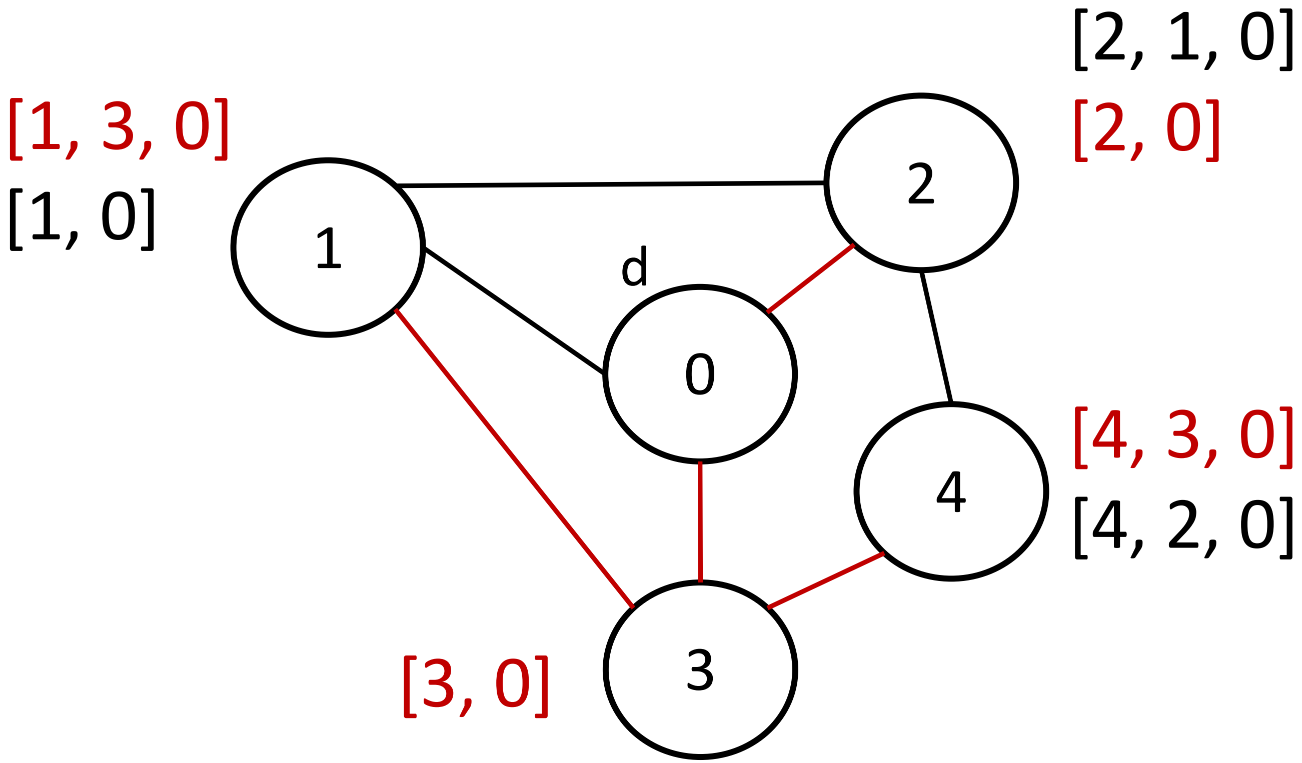


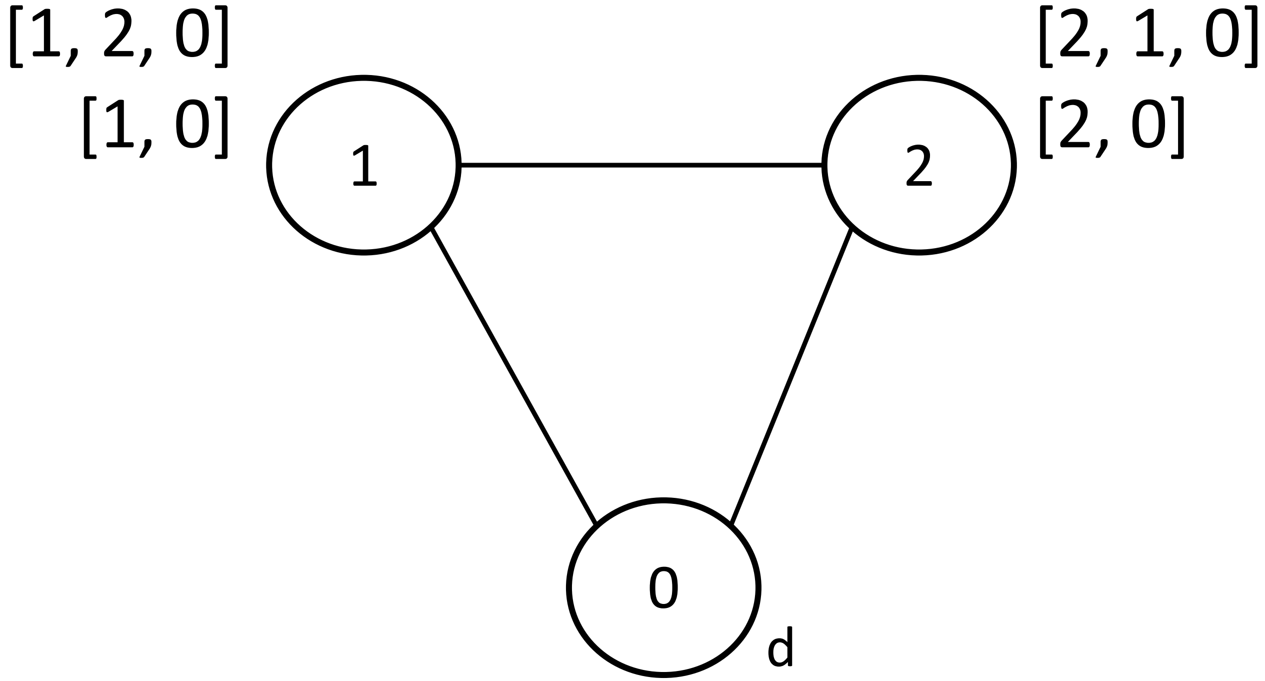
stable solution: each node is locally stable (no better option)

BGP will always converge (“good gadget”)



solution is *unique* (any asynchronous order would lead here)

BGP *may* converge (“diagree”)



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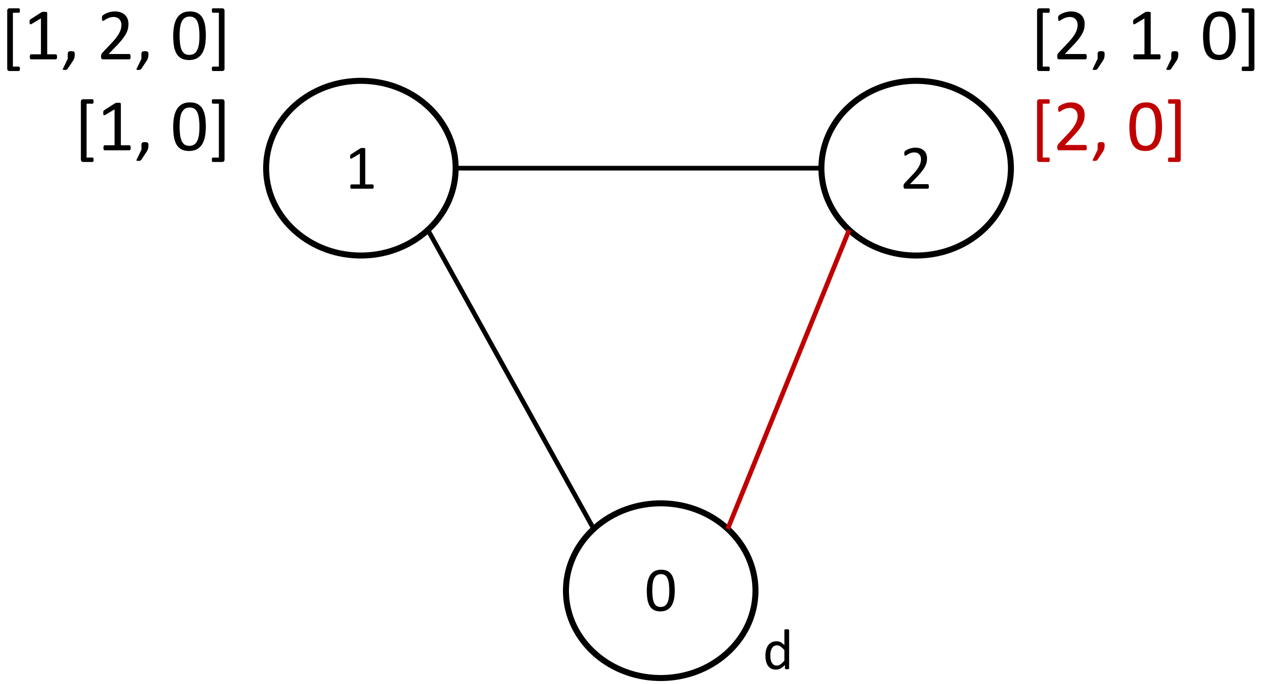

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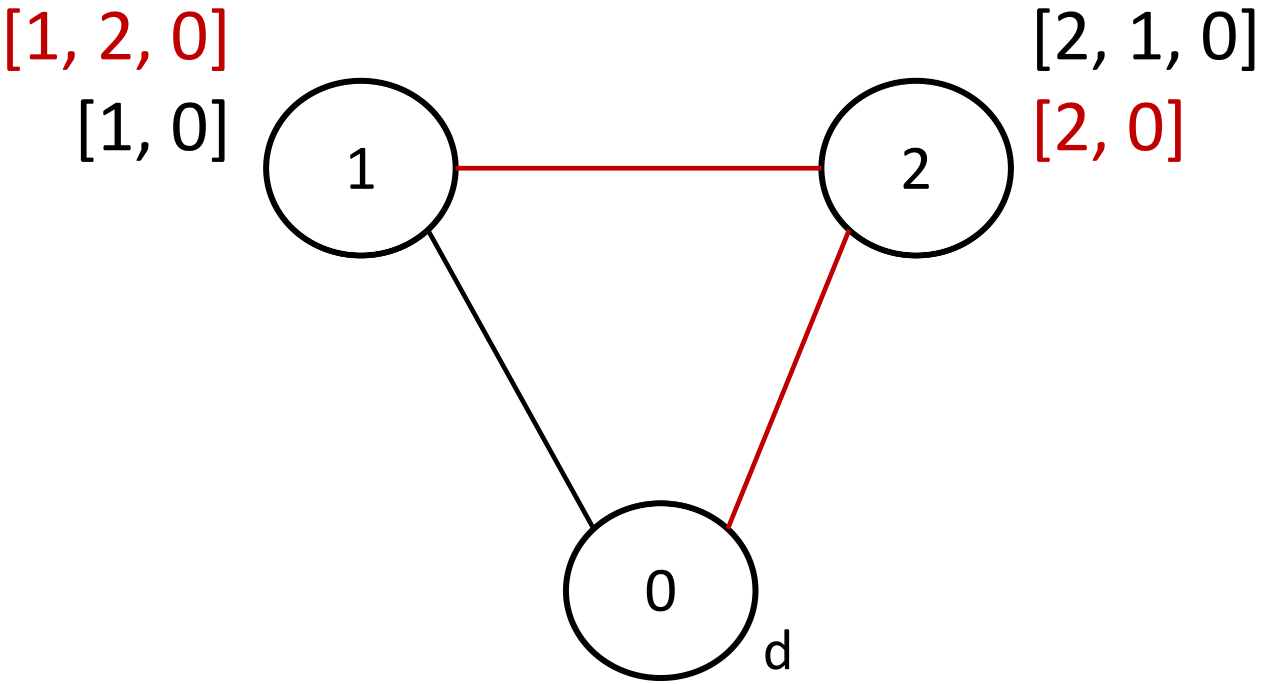

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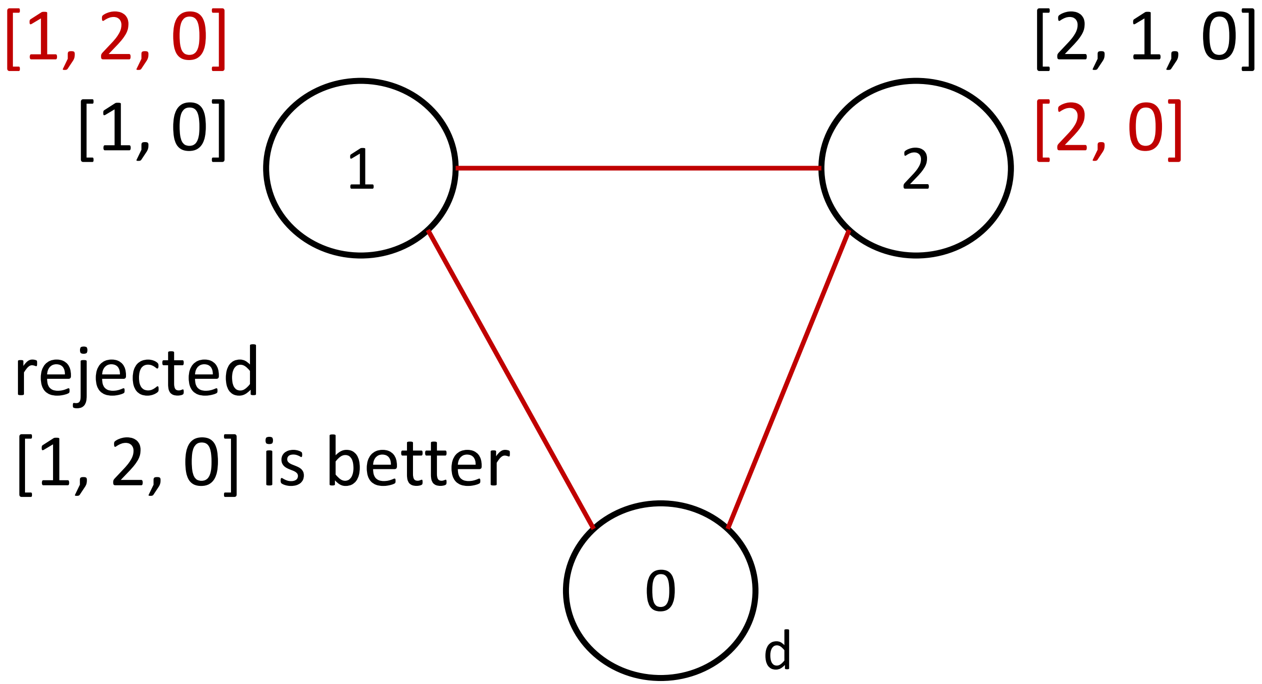

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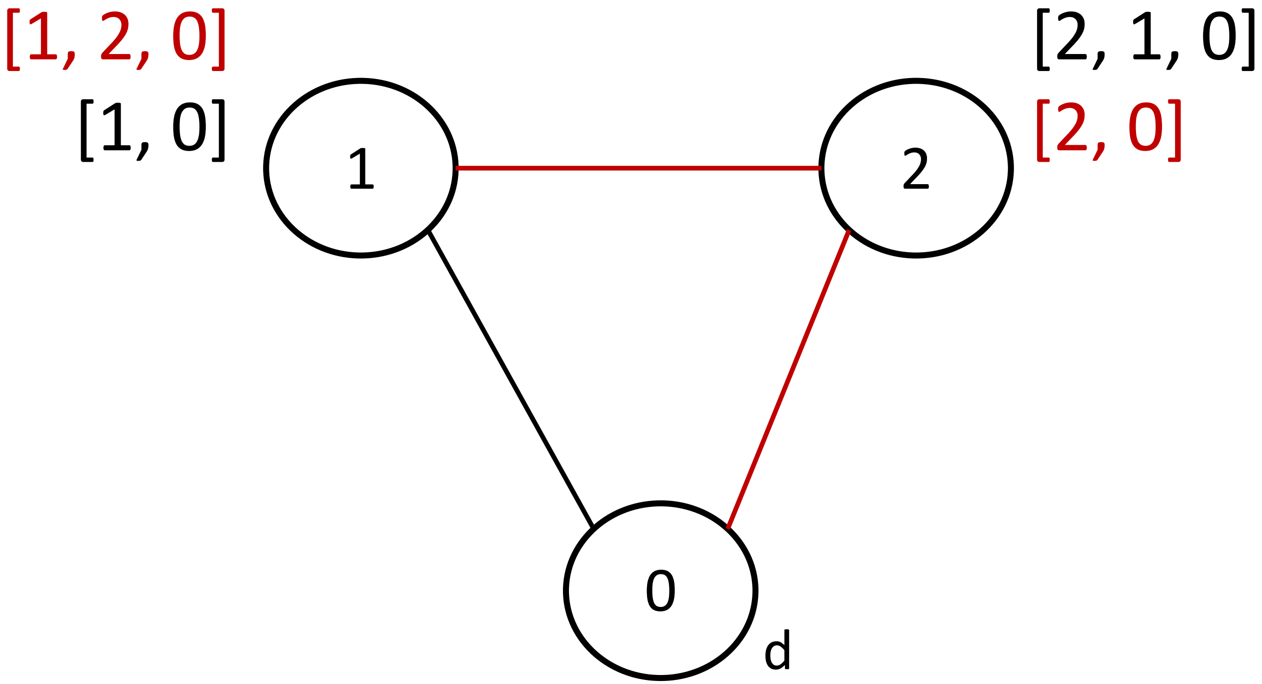
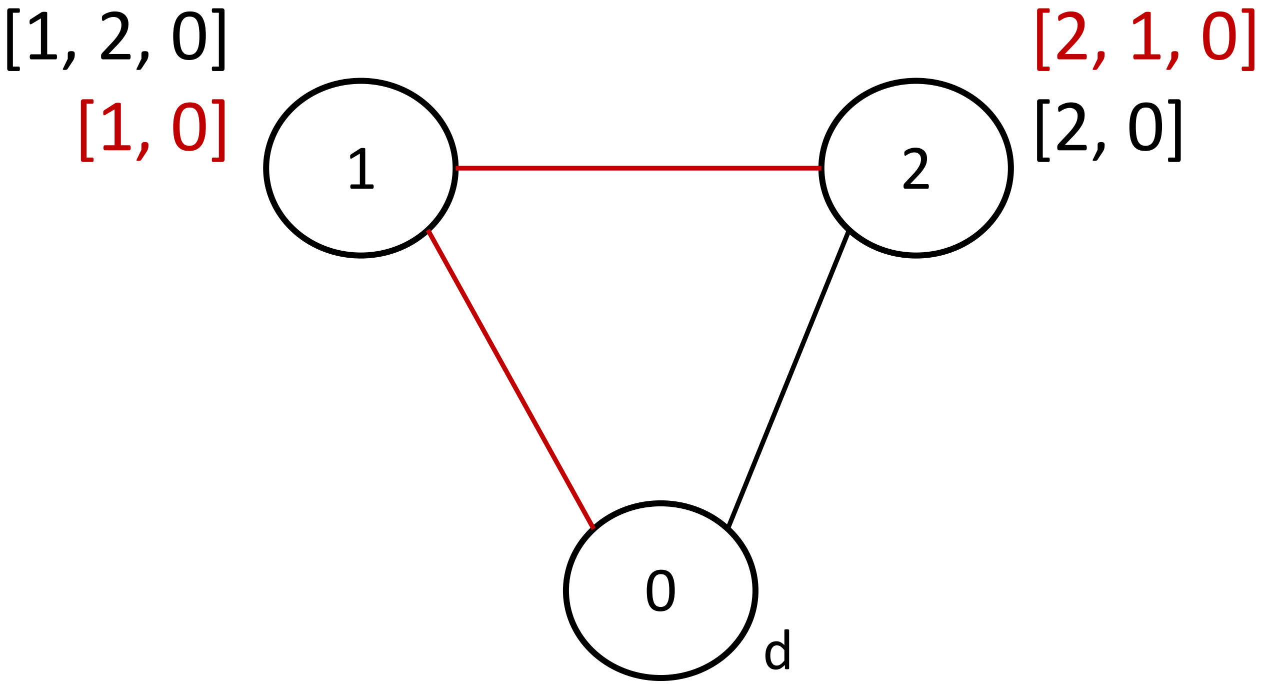


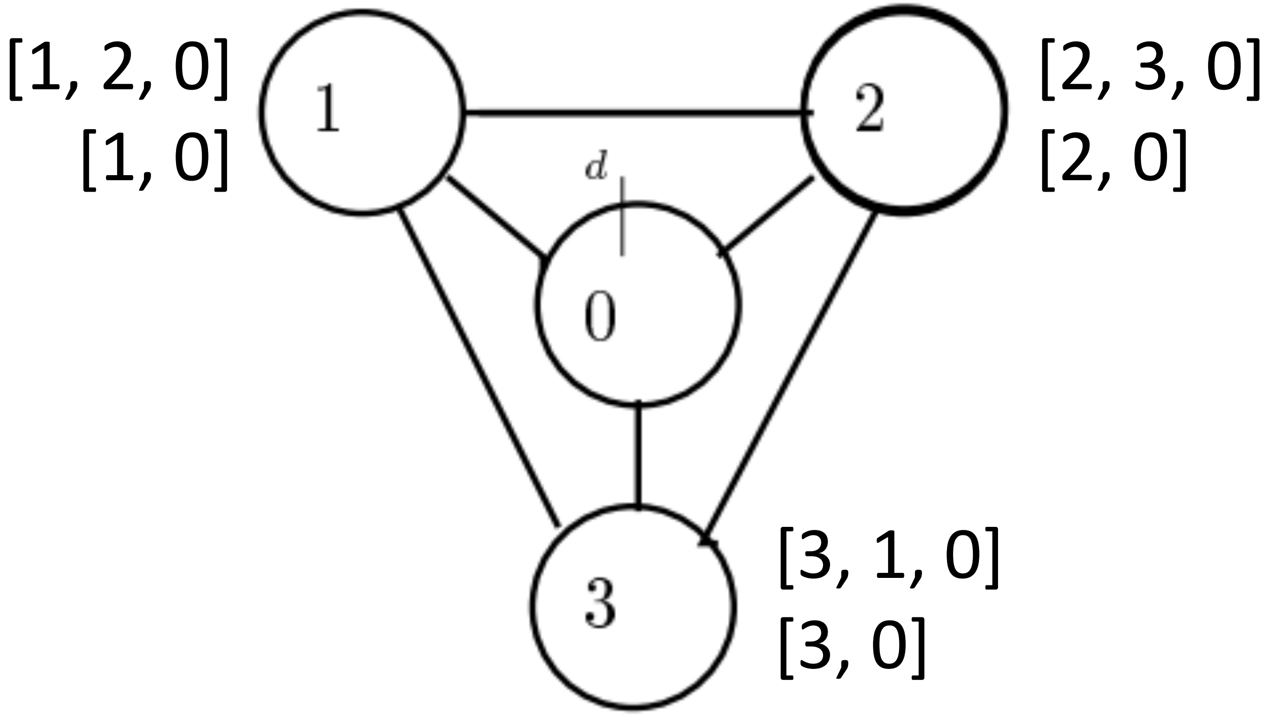
stable solution: each node is locally stable (2 never hears [2, 1, 0])

BGP *may* converge (“diagree”)



Another symmetric solution

BGP *never* converges (“bad gadget”)



[1, 2, 0]
[1, 0]

[2, 3, 0]
[2, 0]

[3, 1, 0]
[3, 0]

No stable tree for the bad gadget exists

Determining convergence is NP-Complete

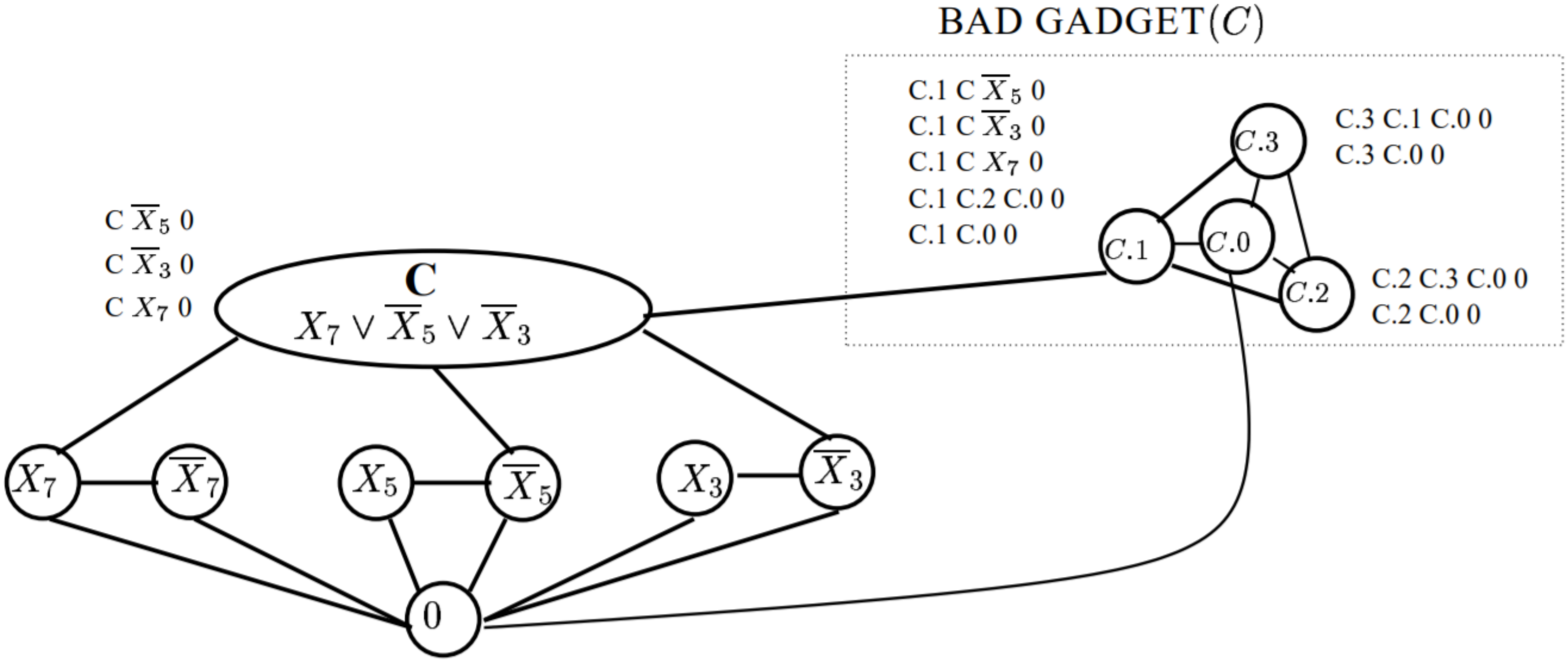


Fig. 7. Example of construction for clause $C = X_7 \vee \overline{X_5} \vee \overline{X_3}$

Paper for next week: Minesweeper

1. Stable paths is a tool for studying protocol convergence.
   - Simple mathematical model for routing solutions.
   - BGP converges iff a stable tree.

2. Paper insight: can we leverage this for verification?
   - Verifying all asynchronous executions of BGP → Hard!
   - Verifying all stable trees → Less Hard!
   - Can we use SMT since already NP-Complete?