Inter-Domain Routing: BGP II

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(drawn mostly from lecture notes

by Hari Balakrishnan and Nick Feamster, MIT)

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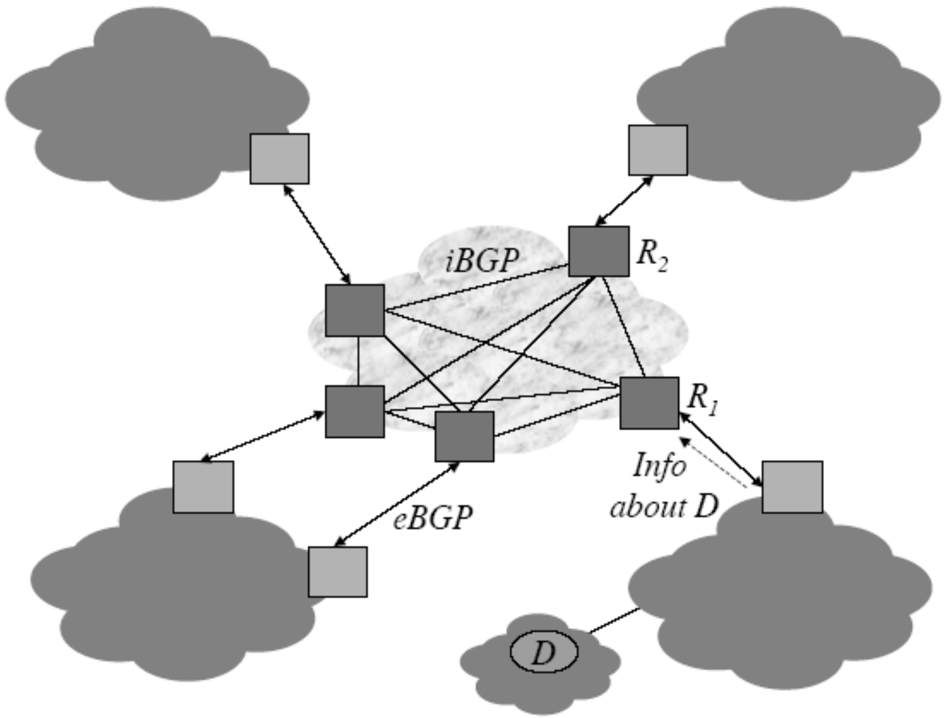
BGP Protocol (cont'd)

- BGP doesn't chiefly aim to compute shortest paths (or minimize other metric, as do DV, LS)
- Chief purpose of BGP is to announce reachability, and enable policy-based routing
- BGP announcement:
  - IP prefix: [Attribute 0] [Attribute1] […]

Outline

- Context: Inter-Domain Routing
- Relationships between ASes
- Enforcing Policy, not Optimality
- BGP Design Goals
- BGP Protocol
- eBGP and iBGP
- BGP Route Attributes
- Synthesis: Policy through Route Attributes
- War Story: Depeering

eBGP and iBGP



- eBGP: external BGP advertises routes between ASes
- iBGP: internal BGP propagates external routes throughout receiving AS

eBGP and iBGP (cont'd)

- Each eBGP participant hears different advertisements from neighboring ASes
- Must propagate routes learned via eBGP throughout AS
- Design goals:
  - Loop-free forwarding: forwarding paths over routes learned via eBGP should not loop
  - Complete visibility: all routers within AS must choose same, best route to destination learned via eBGP

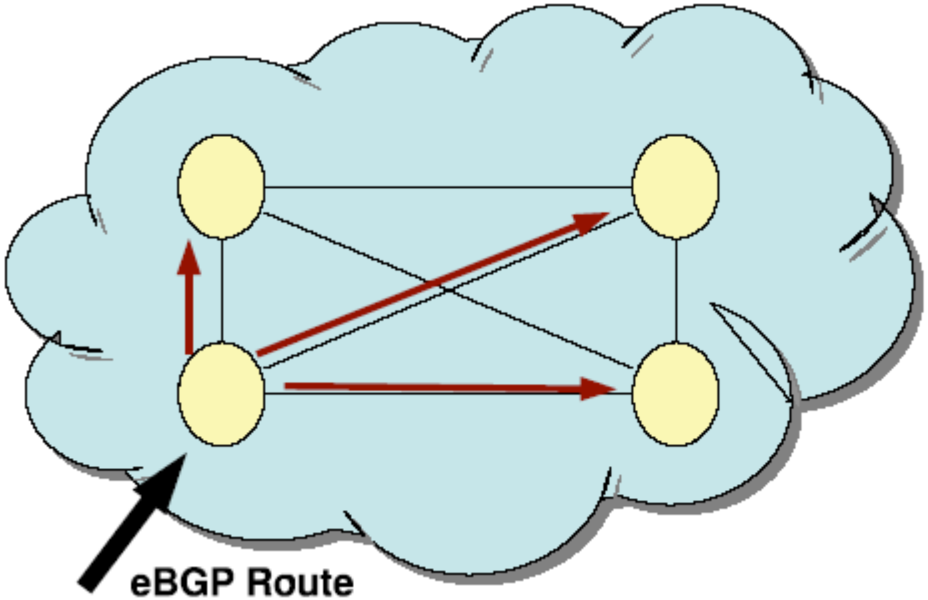
eBGP and iBGP (cont'd)

- Each eBGP participant hears different advertisements from neighboring ASes

Within AS1, choosing external route to destination in AS2 amounts to **choosing egress router within AS1**

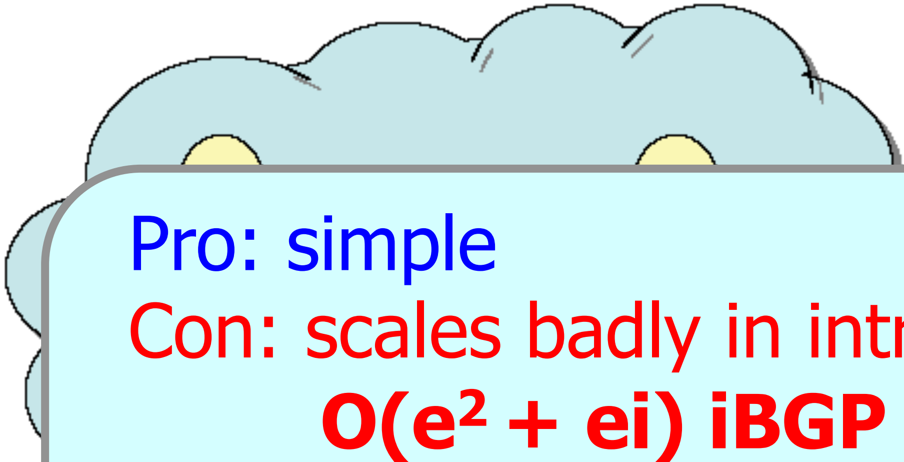
  - Loop-free forwarding: forwarding paths over routes learned via eBGP should not loop
  - Complete visibility: all routers within AS must choose same, best route to destination learned via eBGP

Simple iBGP: Full Mesh



- How to achieve complete visibility?
  - Push all routes learned via eBGP to all internal routers using iBGP
- Full Mesh: each eBGP router floods routes it learns to all other routers in AS
- Flooding done over TCP, using intra-AS routing provided by IGP (e.g., link state routing)

Simple iBGP: Full Mesh



- How to achieve complete visibility?
  - Push all routes learned via eBGP to all internal

Pro: simple

Con: scales badly in intra-AS router count:

$O(e^2 + ei)$ iBGP sessions

(where e eBGP routers, i iBGP routers)

More scalable iBGP uses route reflectors or confederations; details in lecture notes

IGP (e.g., link state routing)

Synthesis: Routing with IGP + iBGP

- Every router in AS now learns two routing tables
  - IGP (e.g., link state) table: routes to every router within AS, via interface
  - EGP (e.g., iBGP) table: routes to every prefix in global Internet, via egress router IP
- Produce one integrated forwarding table
  - All IGP entries kept as-is
  - For each EGP entry
    - find next-hop interface i for egress router IP in IGP table
    - add entry: <foreign prefix, i>
  - End result: O(prefixes) entries in all routers' tables

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Using Route Attributes

- Recall: BGP route advertisement is simply:
  - IP Prefix: [Attribute 0] [Attribute 1] […]
- Administrators enforce policy routing using attributes:
  - filter and rank routes based on attributes
  - modify "next hop" IP address attribute
  - tag a route with attribute to influence ranking and filtering of route at other routers

NEXT HOP Attribute

- Indicates IP address of next-hop router
- Modified as routes are announced
  - eBGP: when border router announces outside of AS, changes to own IP address
  - iBGP: when border router disseminates within AS, changes to own IP address
  - iBGP: any iBGP router that repeats route to other iBGP router leaves unchanged

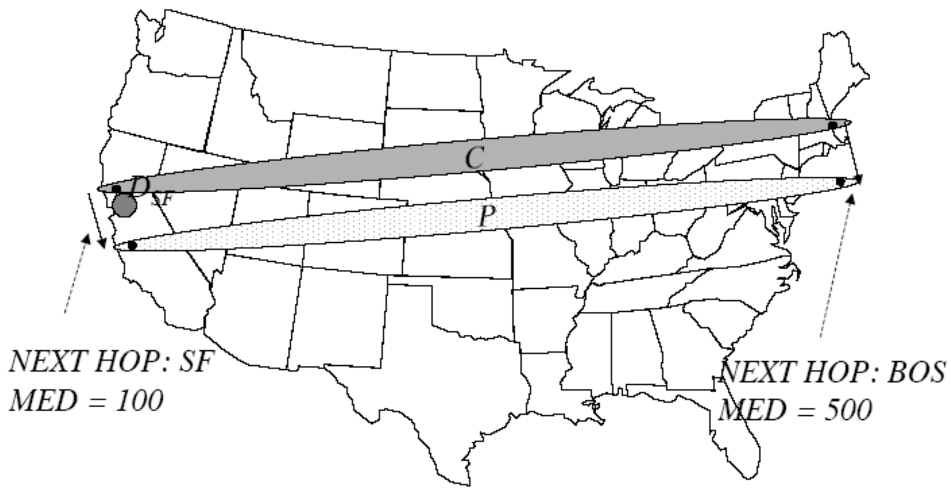
ASPATH Attribute: Path Vector Routing

- Contains full list of AS numbers along path to destination prefix
- Ingress router prepends own AS number to ASPATH of routes heard over eBGP
- Functions like distance vector routing, but with explicit enumeration of AS "hops"
- Barring local policy settings, shorter ASPATHs preferred to longer ones
- If reject routes that contain own AS number, cannot choose route that loops among ASes!

MED Attribute: Choosing Among Multiple Exit Points

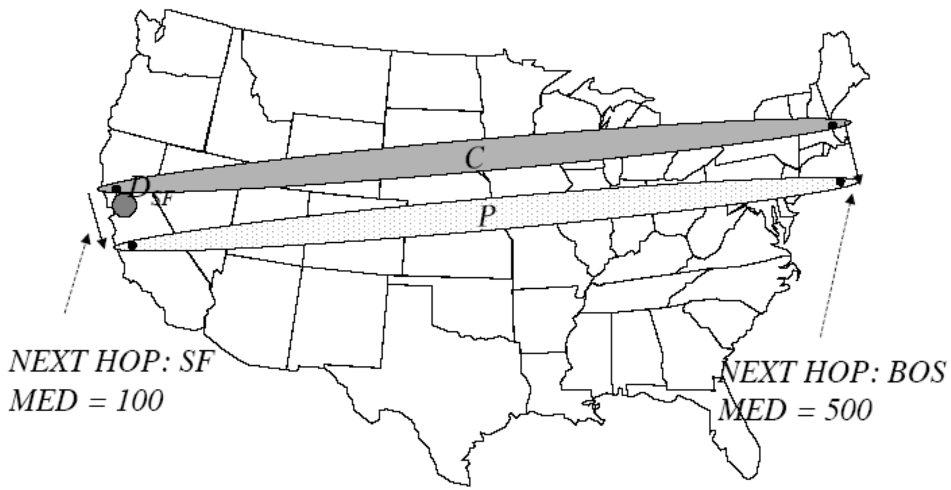
- ASes often connect at multiple points (e.g., global backbones)
- ASPATHs will be same length
- But AS' administrator may prefer a particular transit point
  - …often the one that saves him money!
- MED Attribute: Multi-Exit Discriminator, allows choosing transit point between two ASes

MED Attribute: Example



- Provider P, customer C
- Source: Boston on P, Destination: San Francisco on C
- Whose backbone for cross-country trip?
- C wants traffic to cross country on P

MED Attribute: Example (cont'd)



- C adds MED attribute to advertisements of routes to D_{SF}
  - Integer cost
- C's router in SF advertises MED 100; in BOS advertises 500
- P should choose MED with least cost for destination D_{SF}
- Result: traffic crosses country on P

MED Attribute: Example (cont'd)

- C adds MED attribute to advertisements of routes to D_{SF}

AS need not honor MEDs from neighbor

AS only motivated to honor MEDs from other AS with whom financial settlement in place; i.e., not done in peering arrangements

Most ISPs prefer **shortest-exit routing:** get packet onto someone else's backbone as quickly as possible

Result: **highly asymmetric routes!** (why?)

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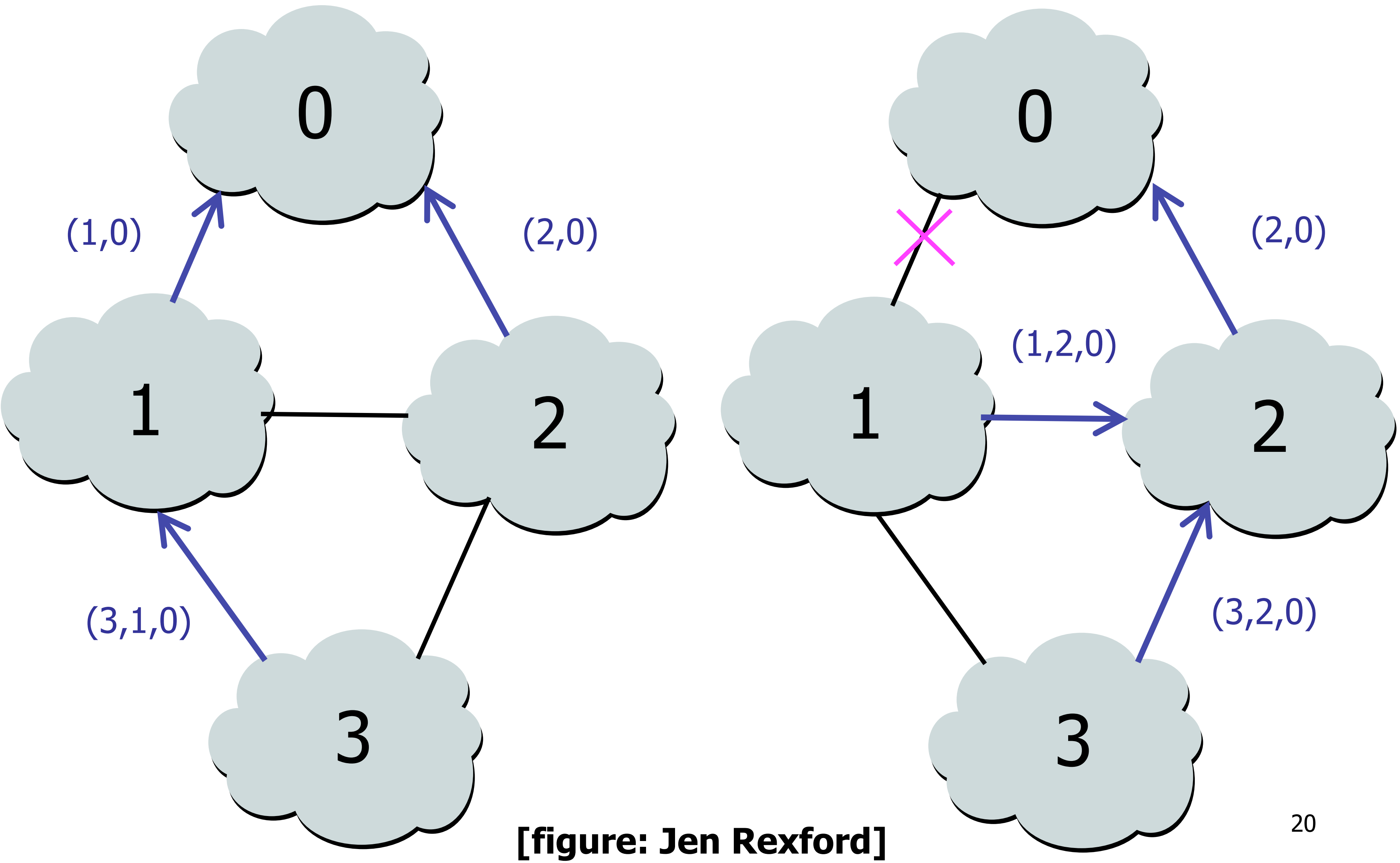
Synthesis: Multiple Attributes into Policy Routing

- How do attributes interact? Priority order:

Priority	Rule	Details
1	LOCAL PREF	**Highest LOCAL PREF (e.g., prefer transit customer routes over peer and provider routes)**
2	ASPATH	**Shortest ASPATH length**
3	MED	**Lowest MED**
4	eBGP > iBGP	**Prefer routes learned over eBGP vs. over iBGP**
5	IGP path	**"Nearest" egress router**
6	Router ID	**Smallest router IP address**

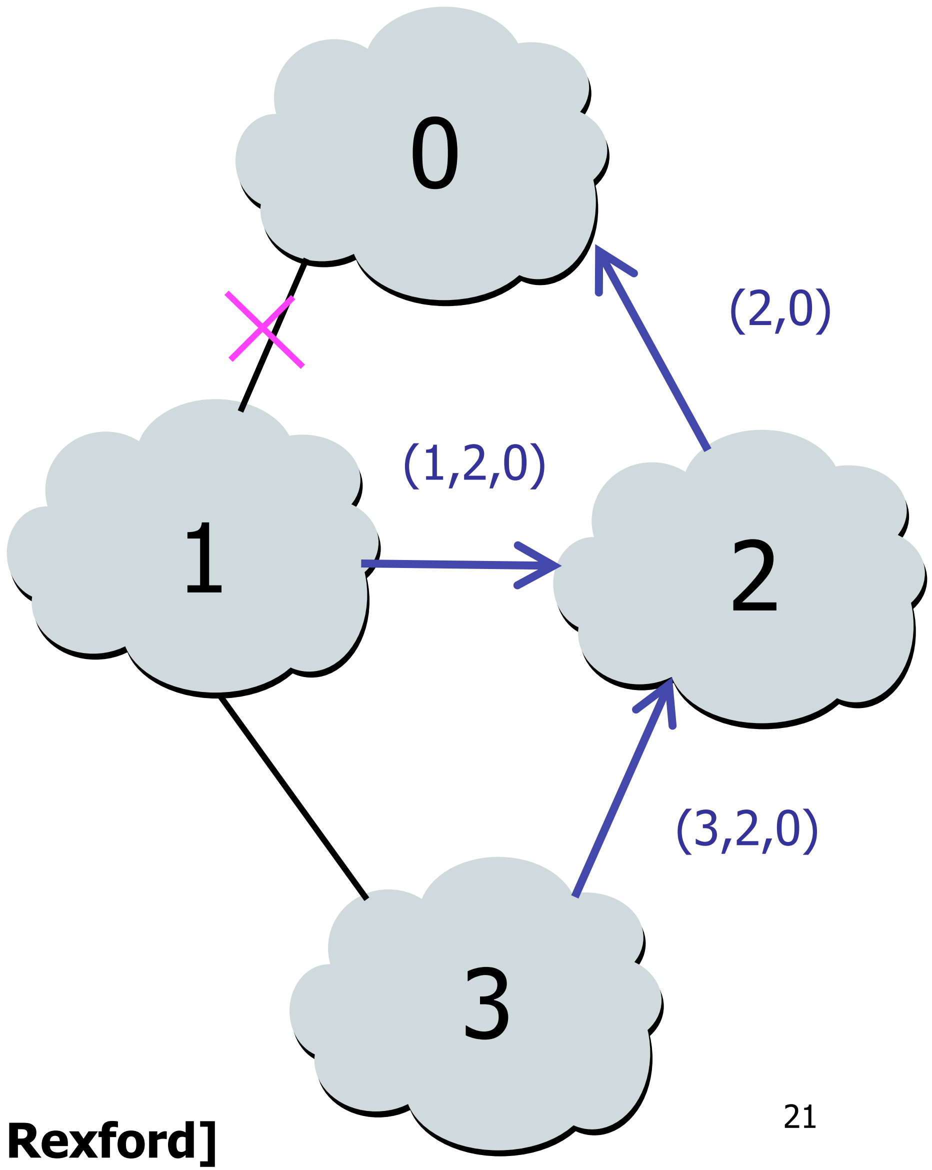
BGP Dynamics



[figure: Jen Rexford]

BGP Dynamics: Path Exploration

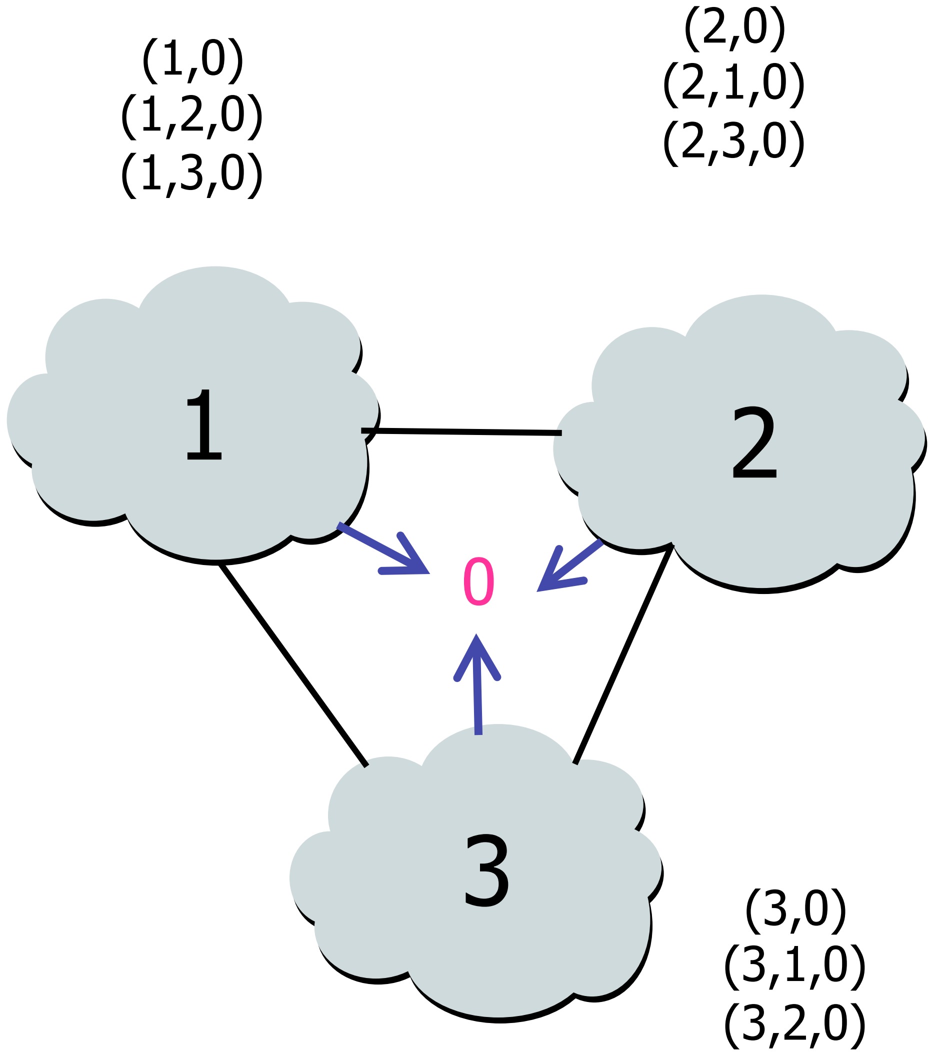
- AS 1
  - Delete the route (1,0)
  - Switch to next route (1,2,0)
  - Announce route (1,2,0) to AS 3
- AS 3
  - Sees (1,2,0) replace (1,0)
  - Compares to route (2,0)
  - Switches to using AS 2



[slide: Jen Rexford]

Path Exploration: Slower Example

- Initial situation
  - Destination 0 is alive
  - All ASes use direct path
- When destination dies
  - All ASes lose direct path
  - All repeatedly switch to longer paths
  - Eventually withdrawn
- e.g., AS 2
  - (2,0) → (2,1,0)
  - (2,1,0) → (2,3,0)
  - (2,3,0) → (2,1,3,0)
  - (2,1,3,0) → null



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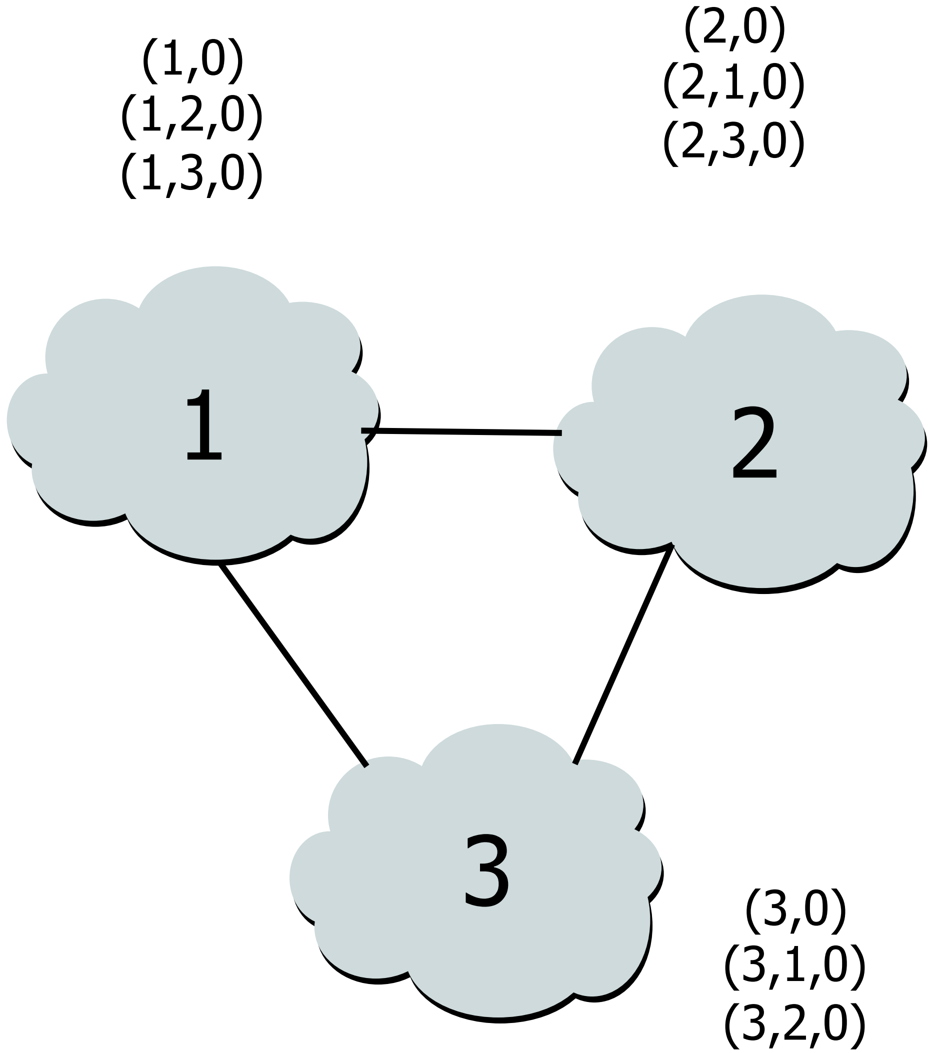

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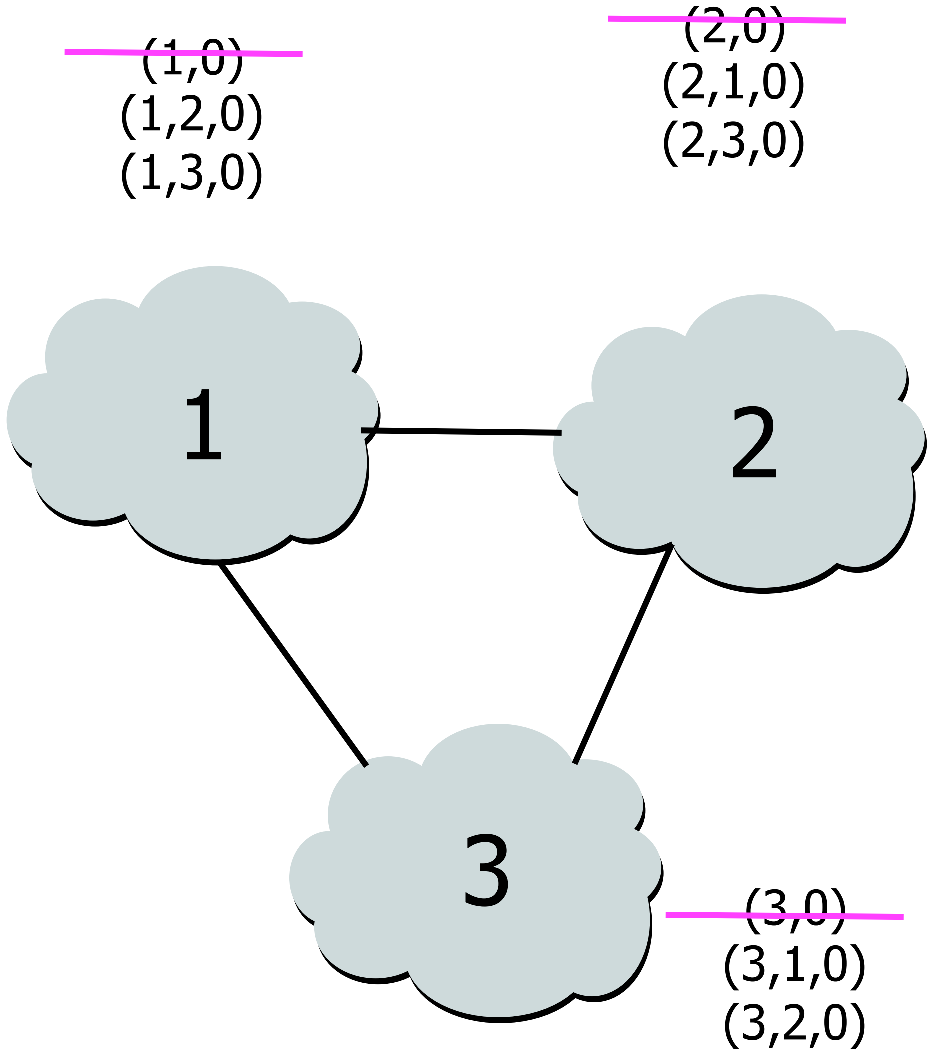


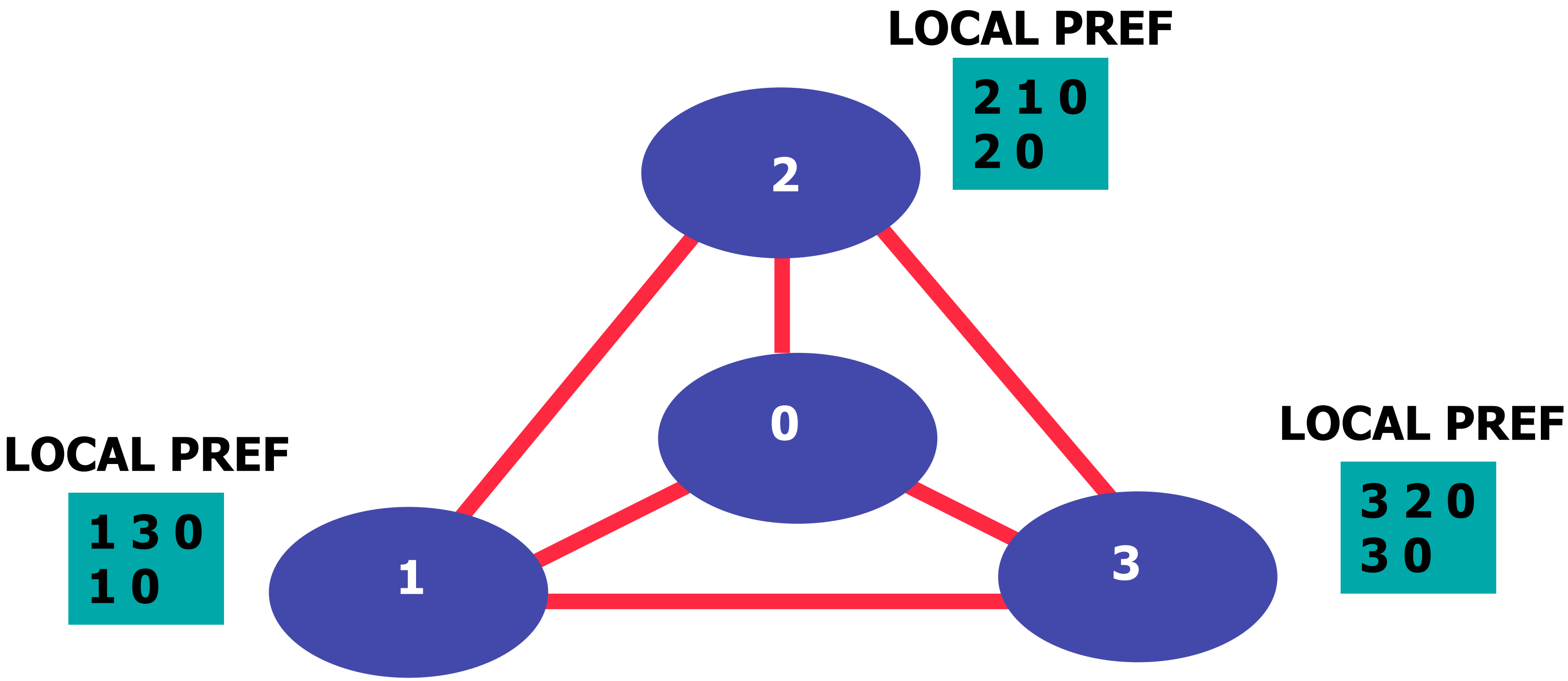
[slide: Jen Rexford]

Limiting Update Traffic

- Minimum route advertisement interval (MRAI)
  - Minimum spacing between announcements
  - For a particular (prefix, peer) pair
- Advantages
  - Provides a rate limit on BGP updates
  - Allows grouping of updates within interval
- Disadvantages
  - Adds delay to convergence process
  - e.g., 30 seconds for each step

[slide: Jen Rexford]

Policies May Cause Persistent Oscillations ("Dispute Wheels")



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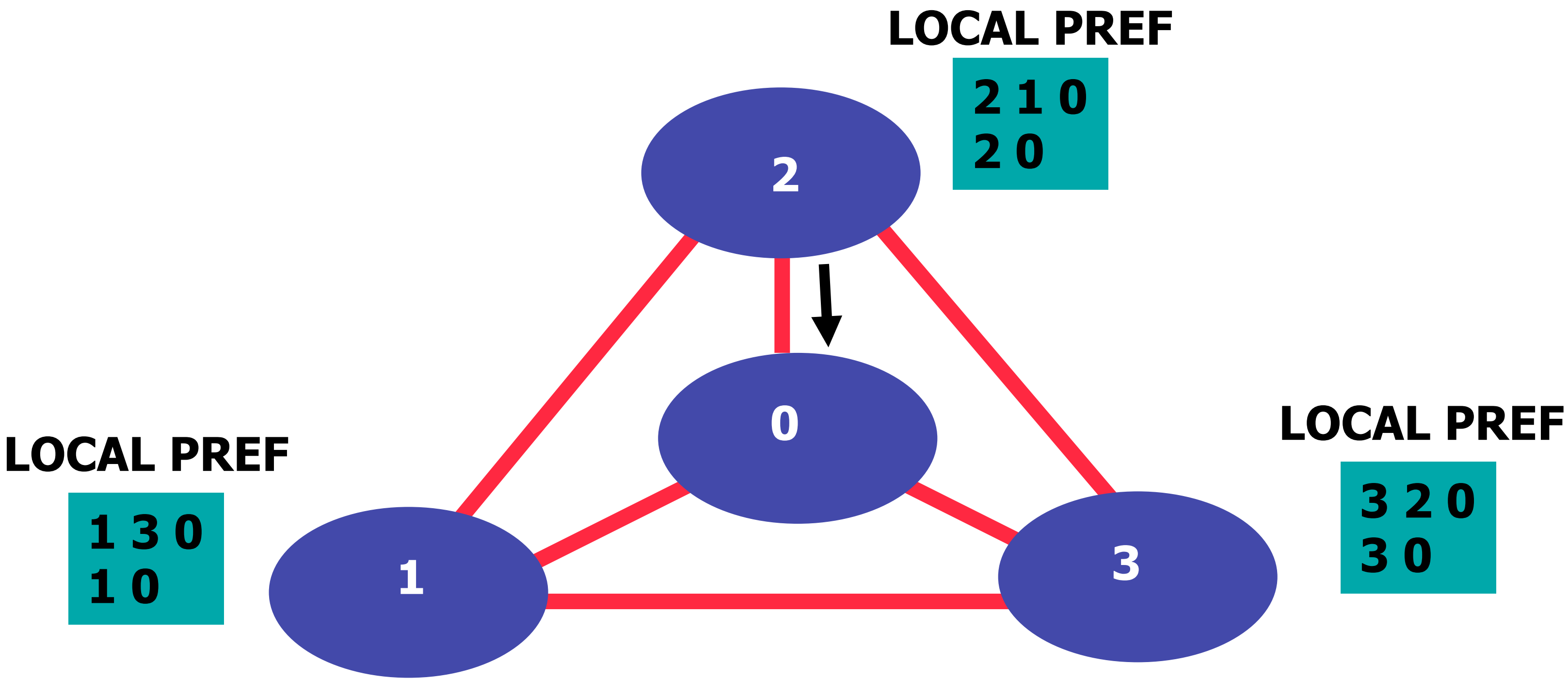

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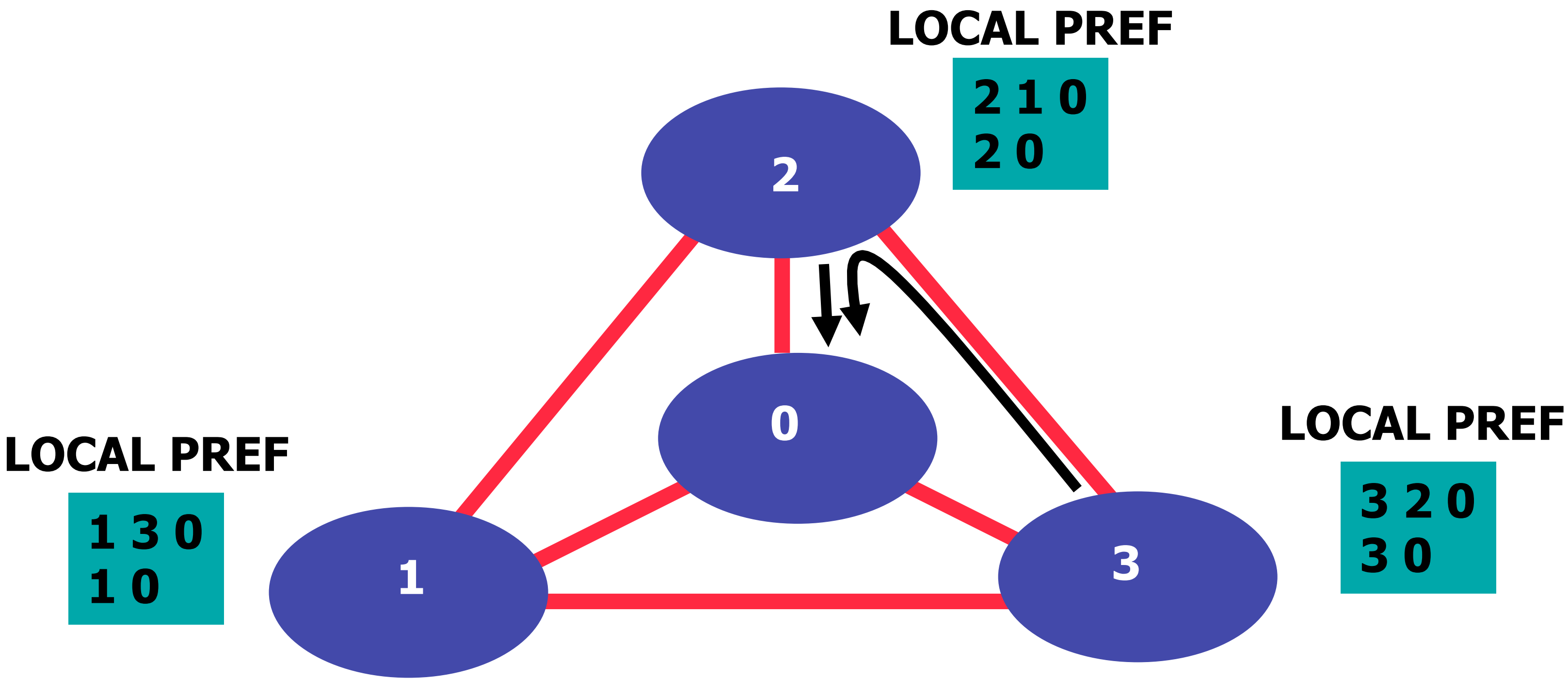

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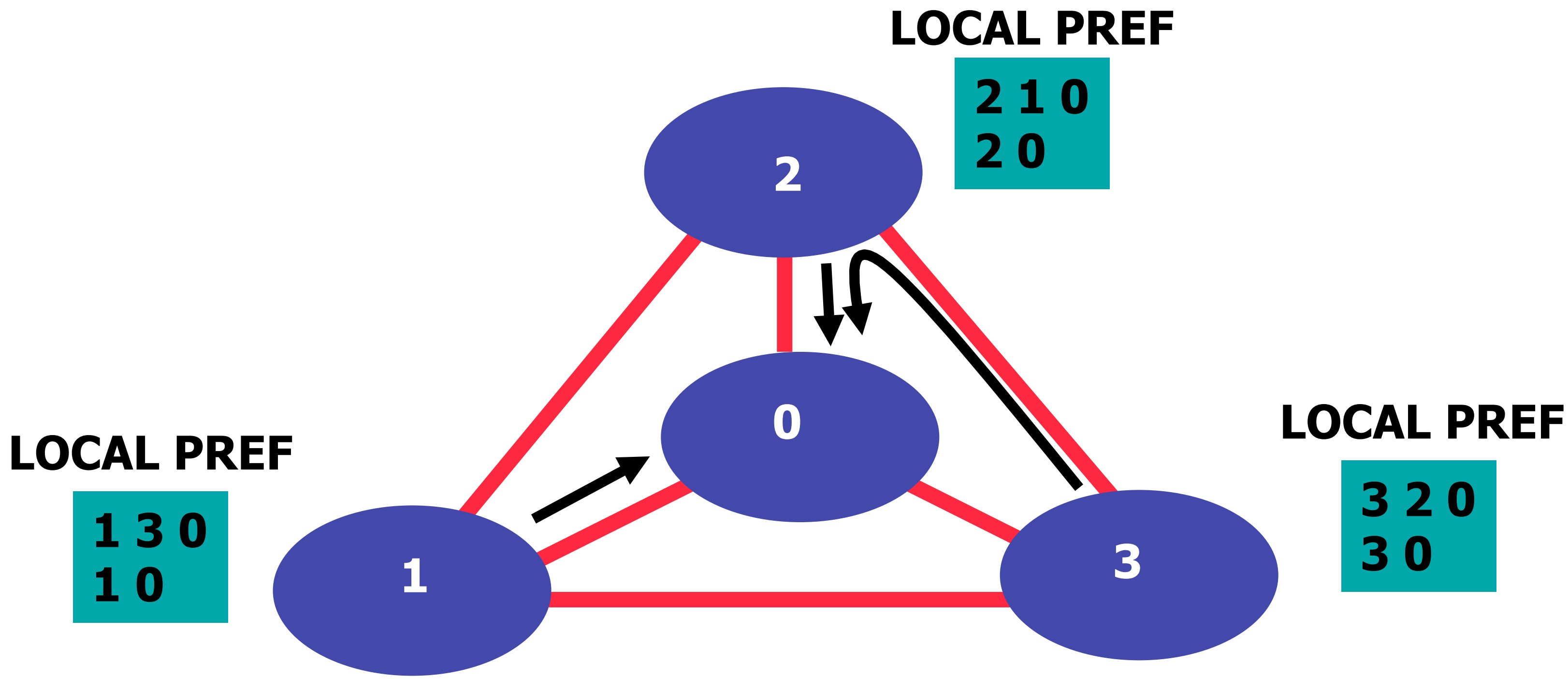

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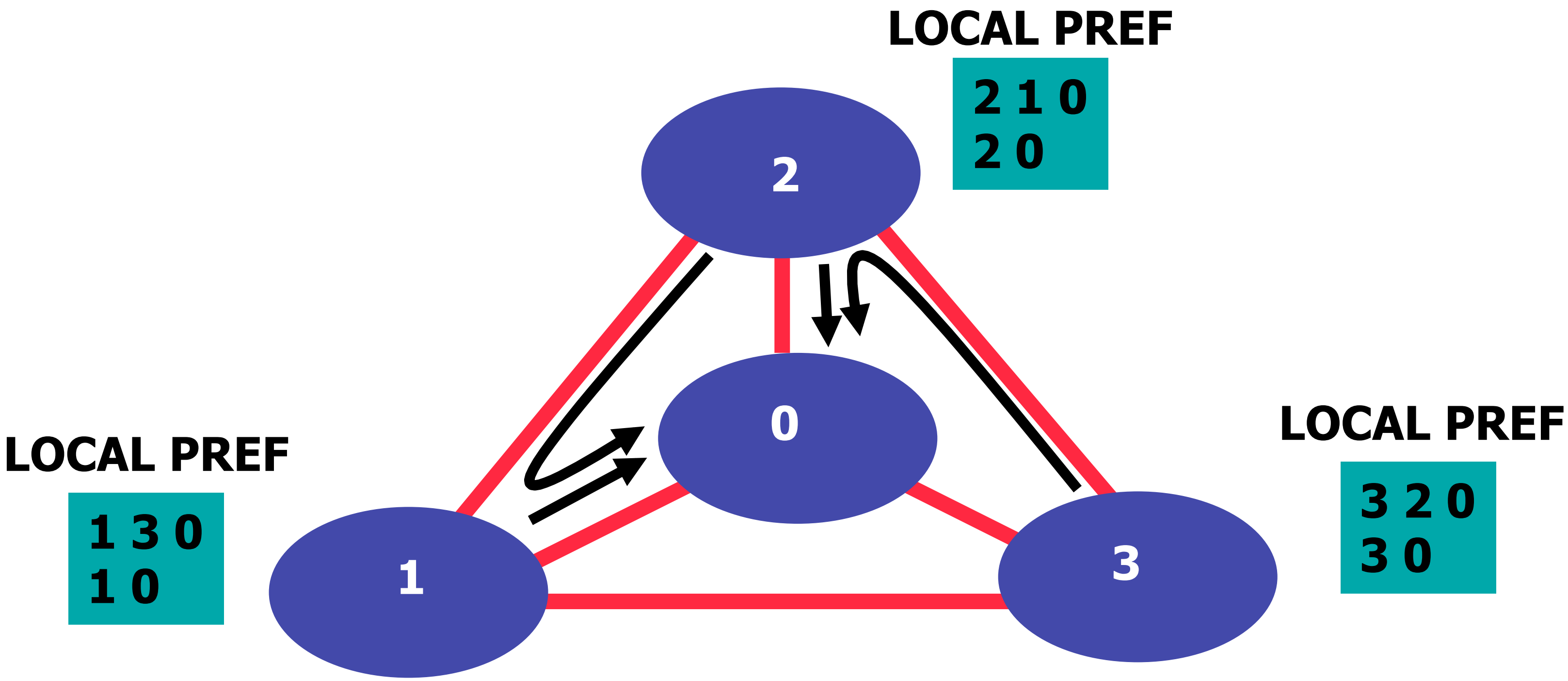

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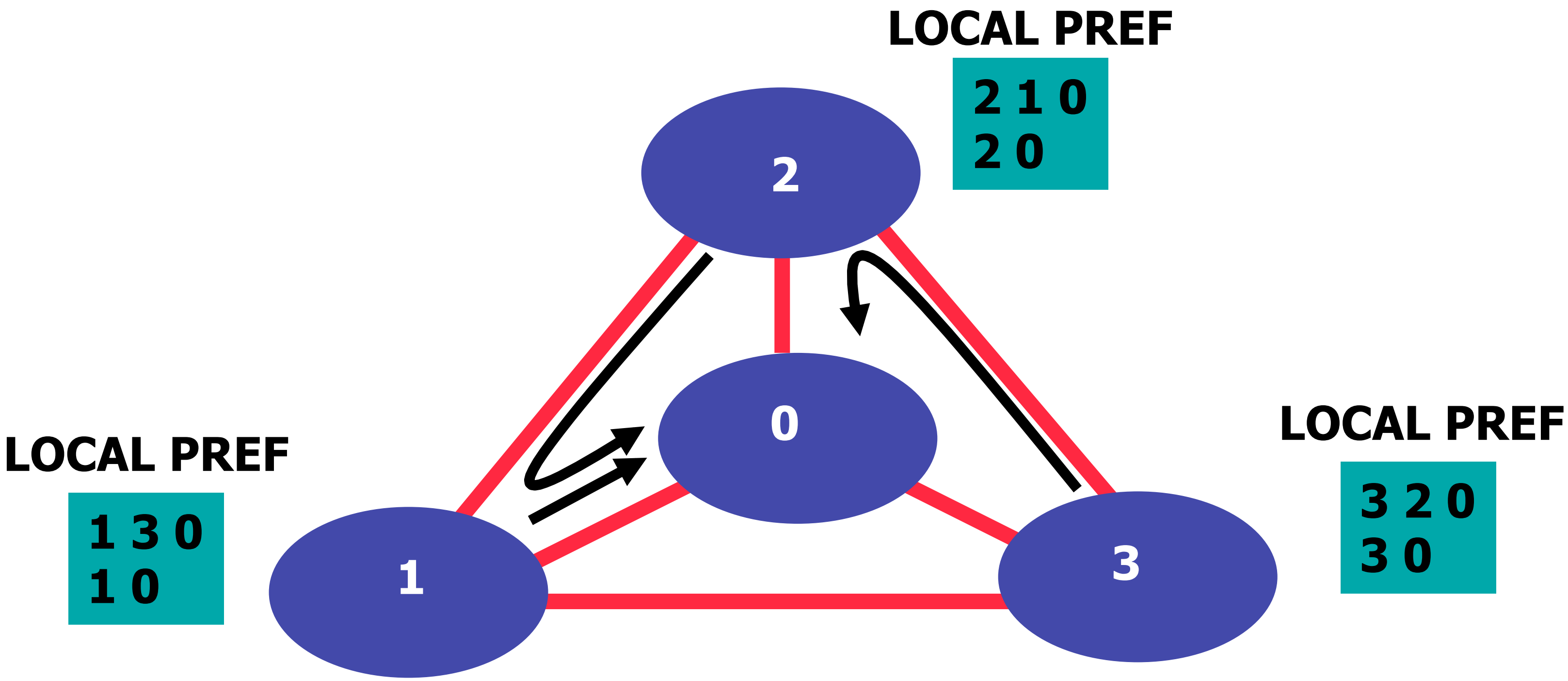

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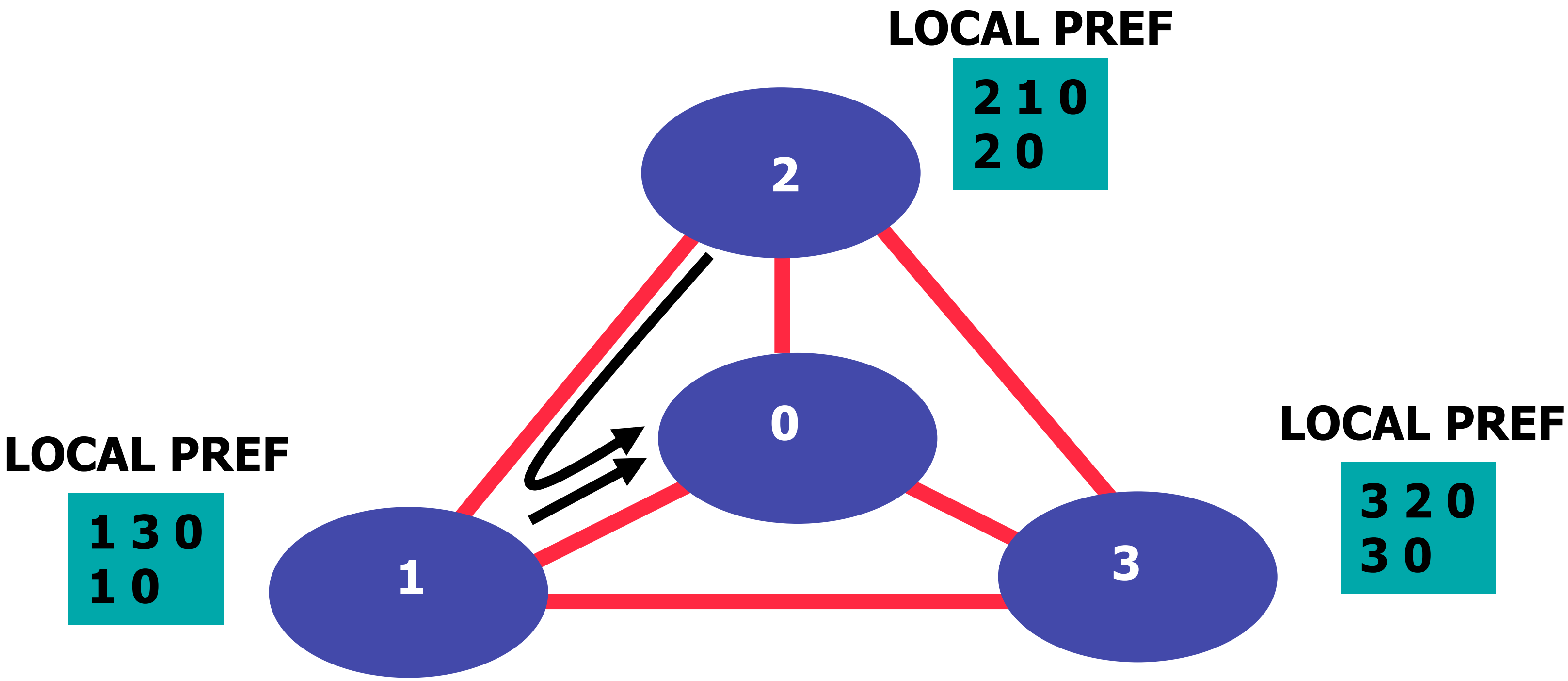

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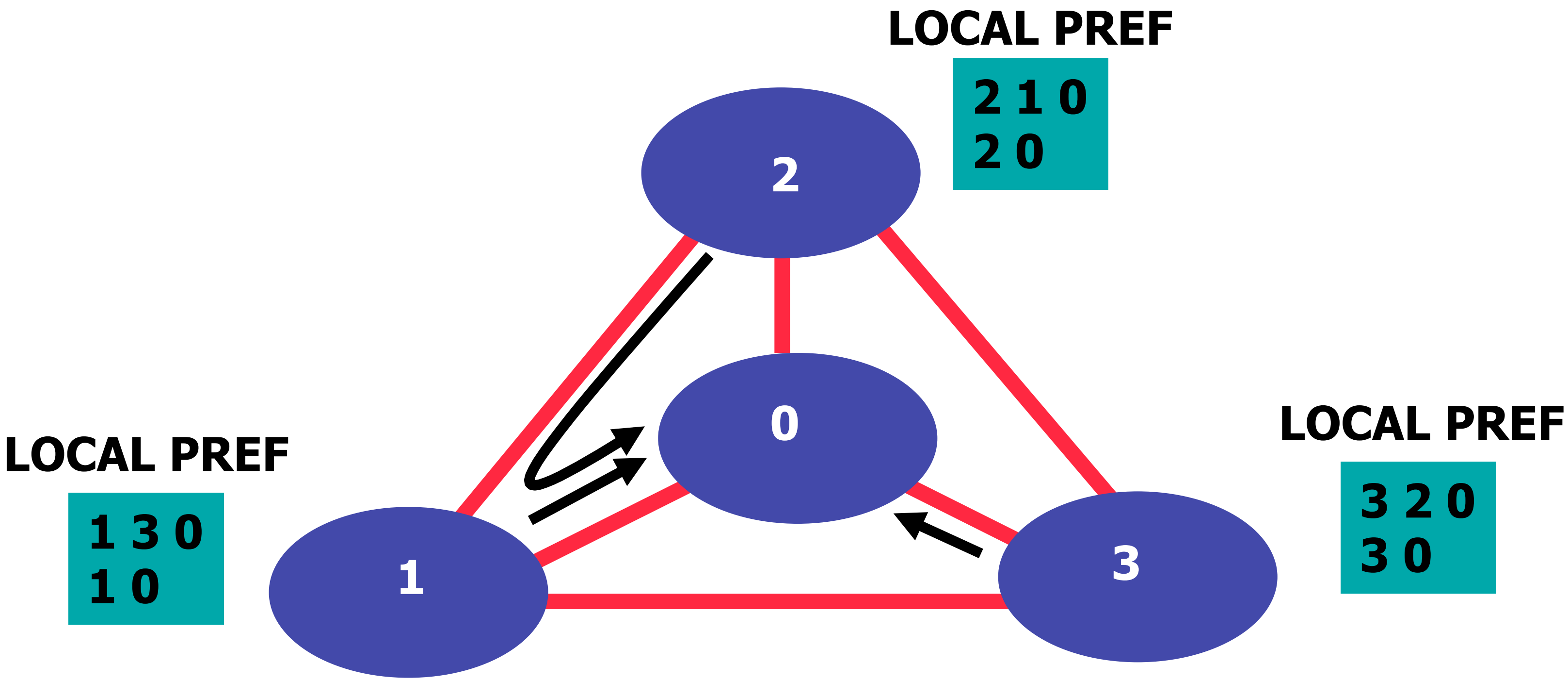

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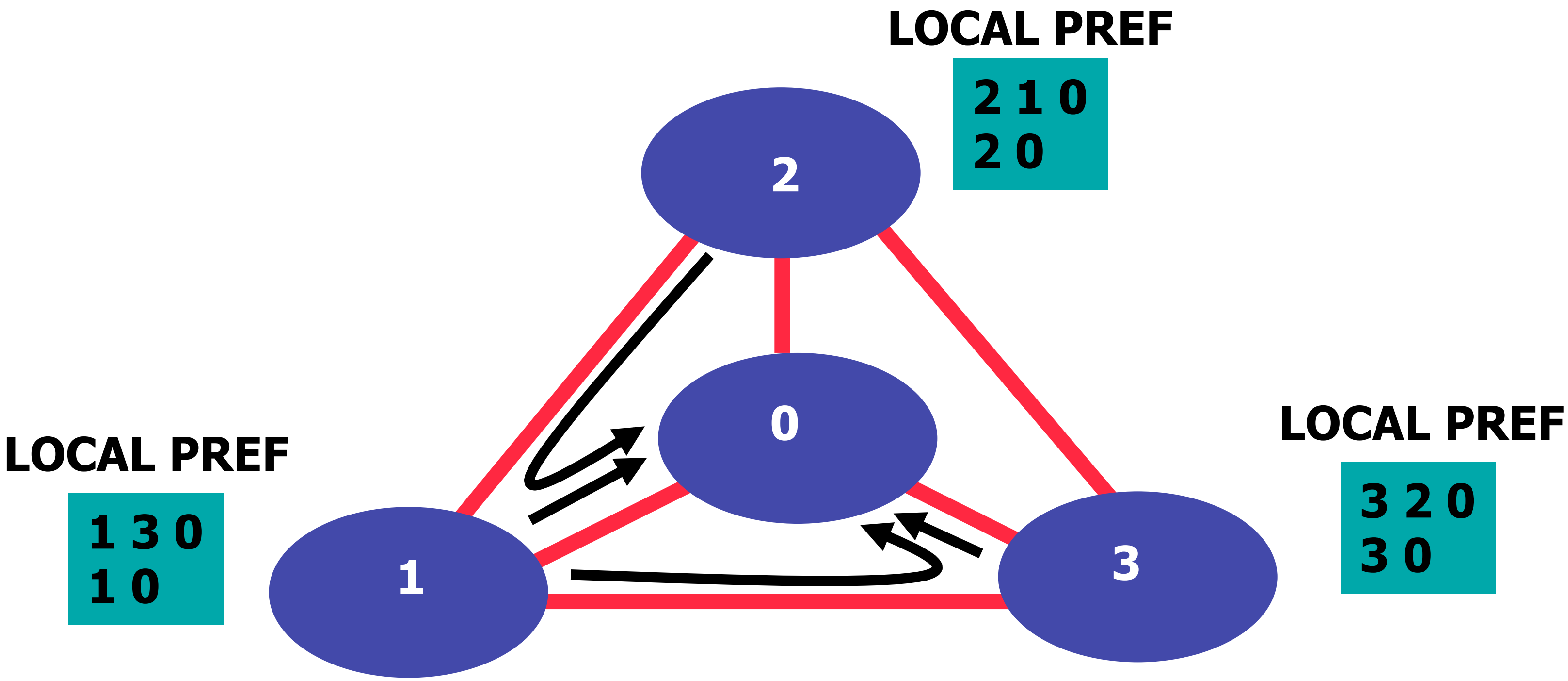

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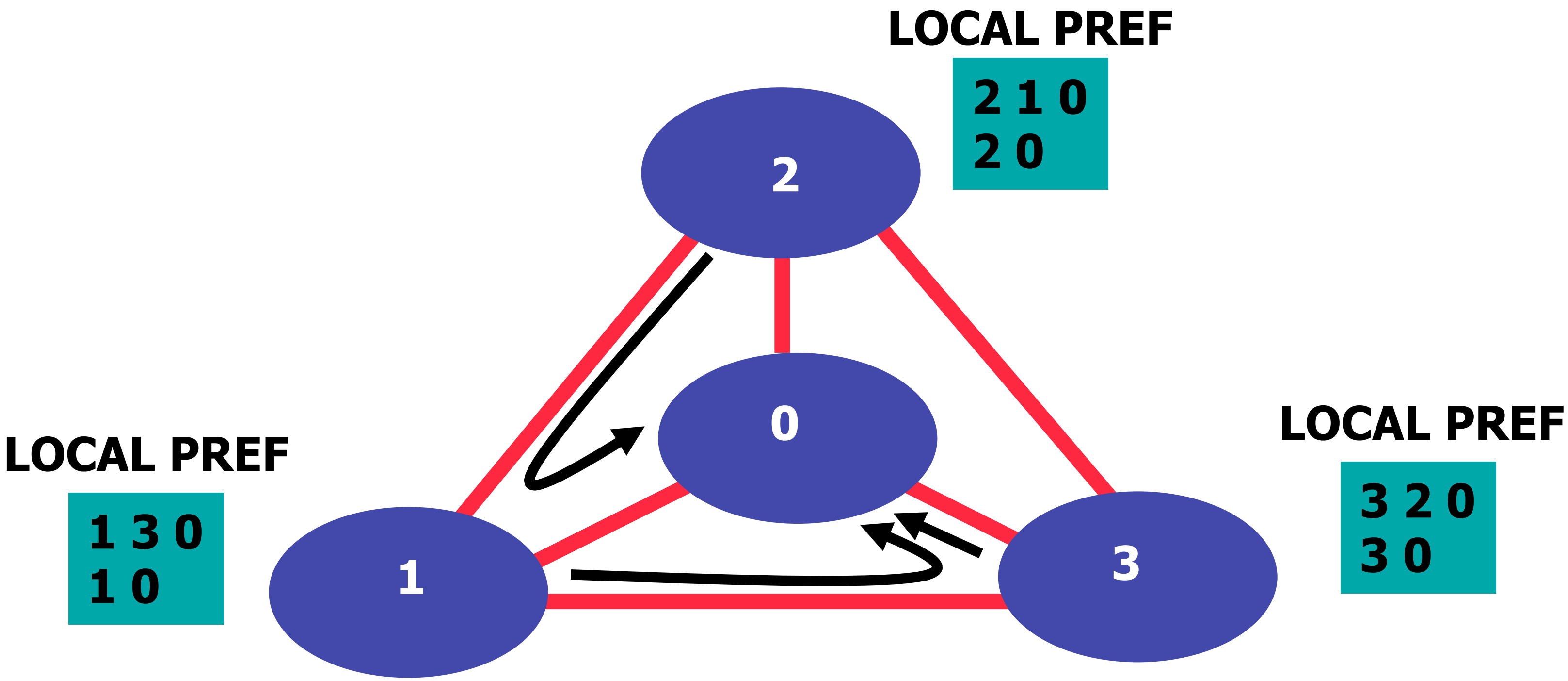

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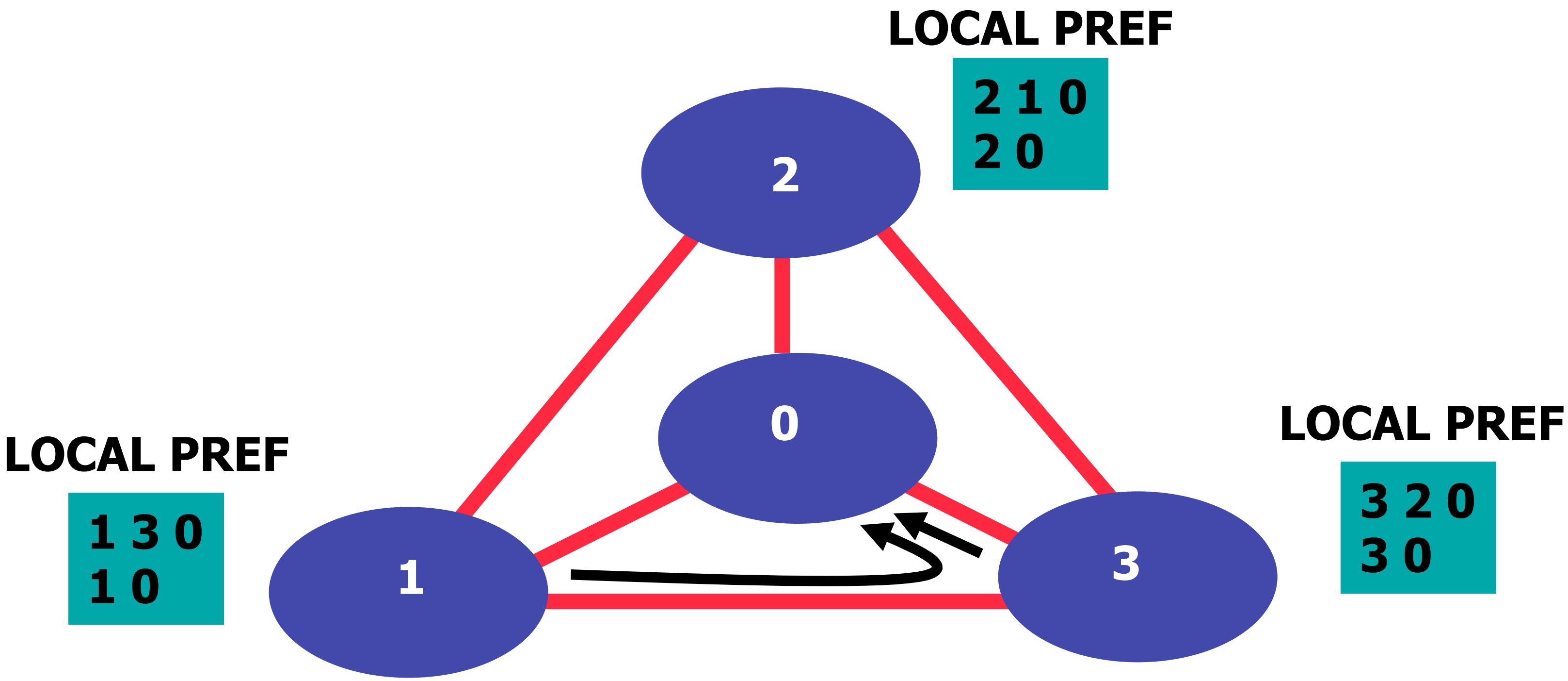

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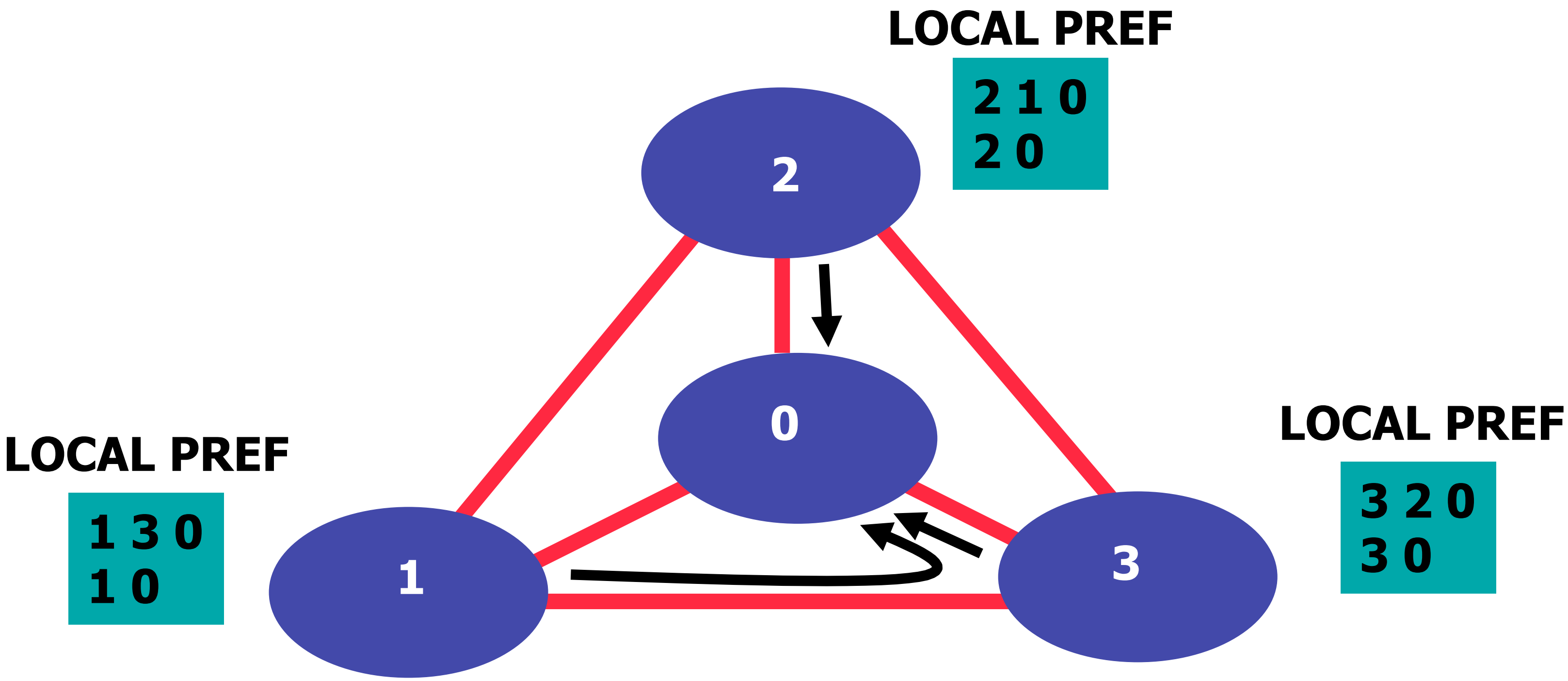

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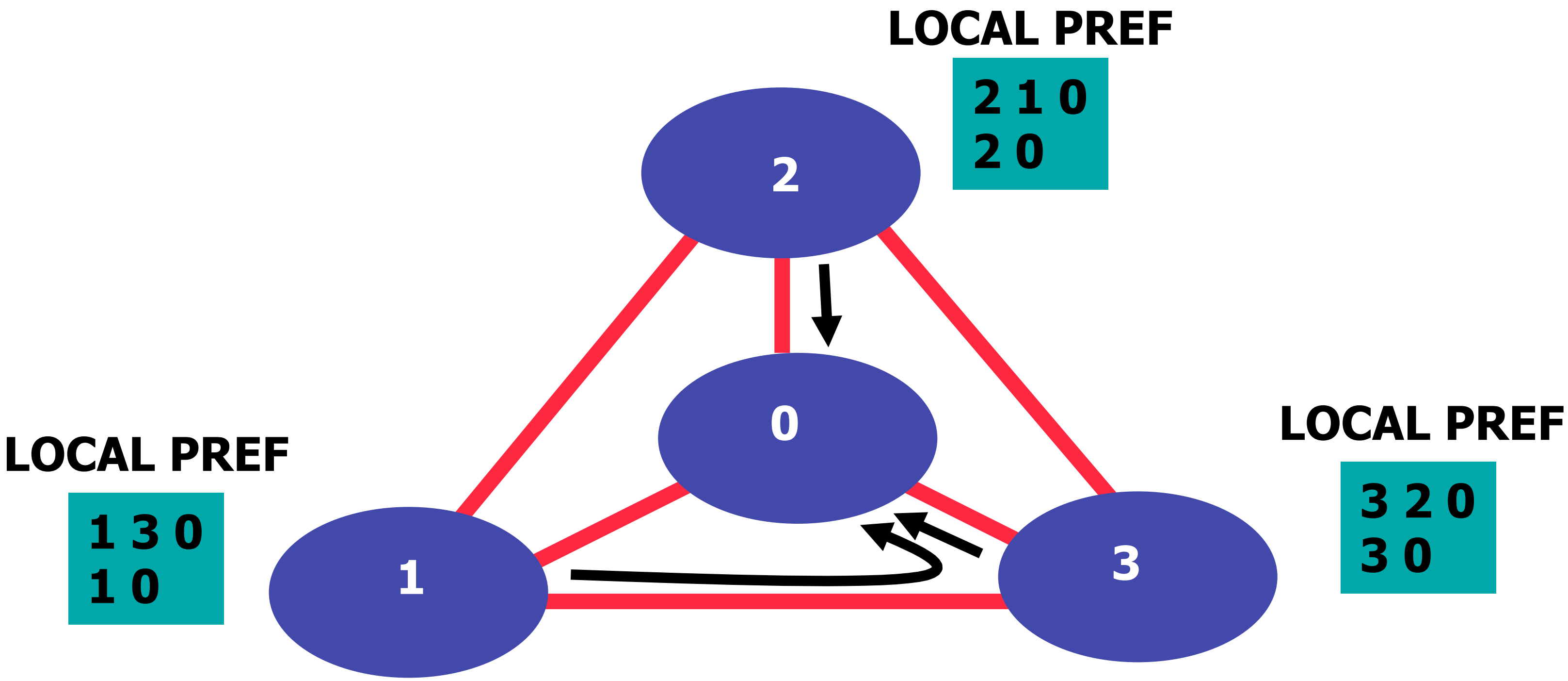


- Suppose each AS prefers two-hop path to direct one
- Repeats forever!

[figure: Jen Rexford]

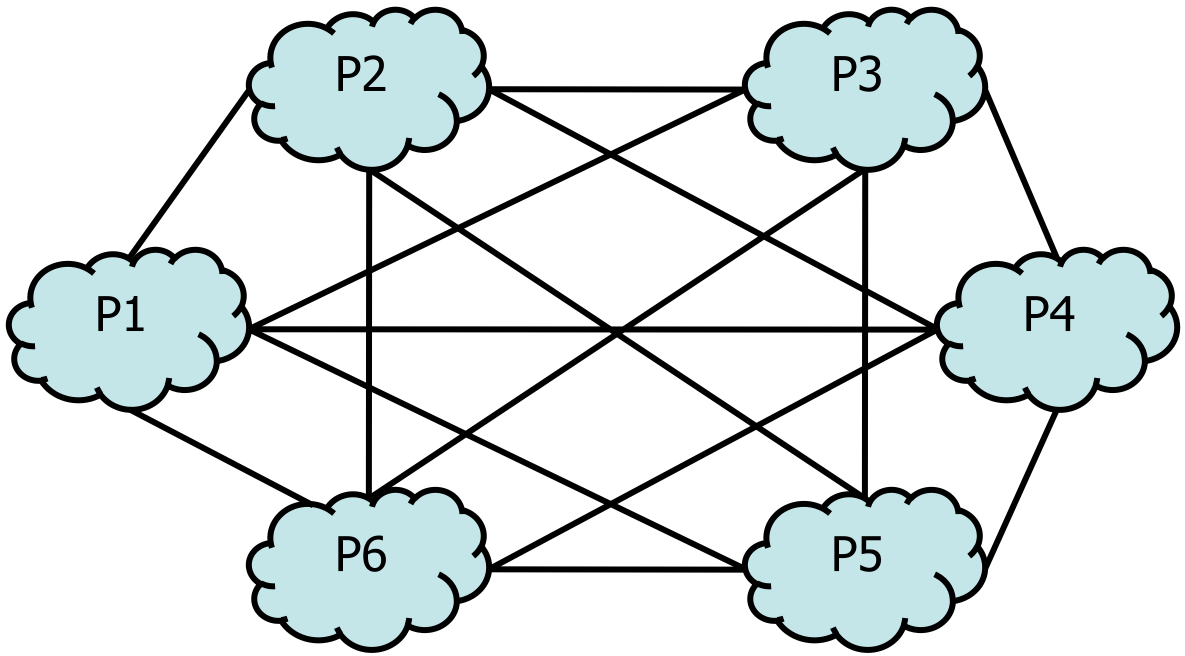
War Story: Depeering

- All tier-1 ISPs peer directly with one another in a full mesh
- True tier-1 ISPs do not pay for peering and buy transit from no one
- A few *other* large ISPs pay no transit provider:
  - they peer with all tier-1 ISPs…
  - …but pay settlements to one or more of them

ISPs with no Transit Provider (as of January 2009)

- Qwest (AS209)
- Verizon (AS701)
- Sprint (AS1239)
- Telia (AS1299)
- XO (AS2828)
- NTT (AS2914)
- Level 3 (AS3356)
- Global Crossing (AS3549)
- Savvis (AS3561)
- Teleglobe (AS6453)
- Abovenet (AS6461)
- AT&T (AS7018)

Full-Mesh Peering



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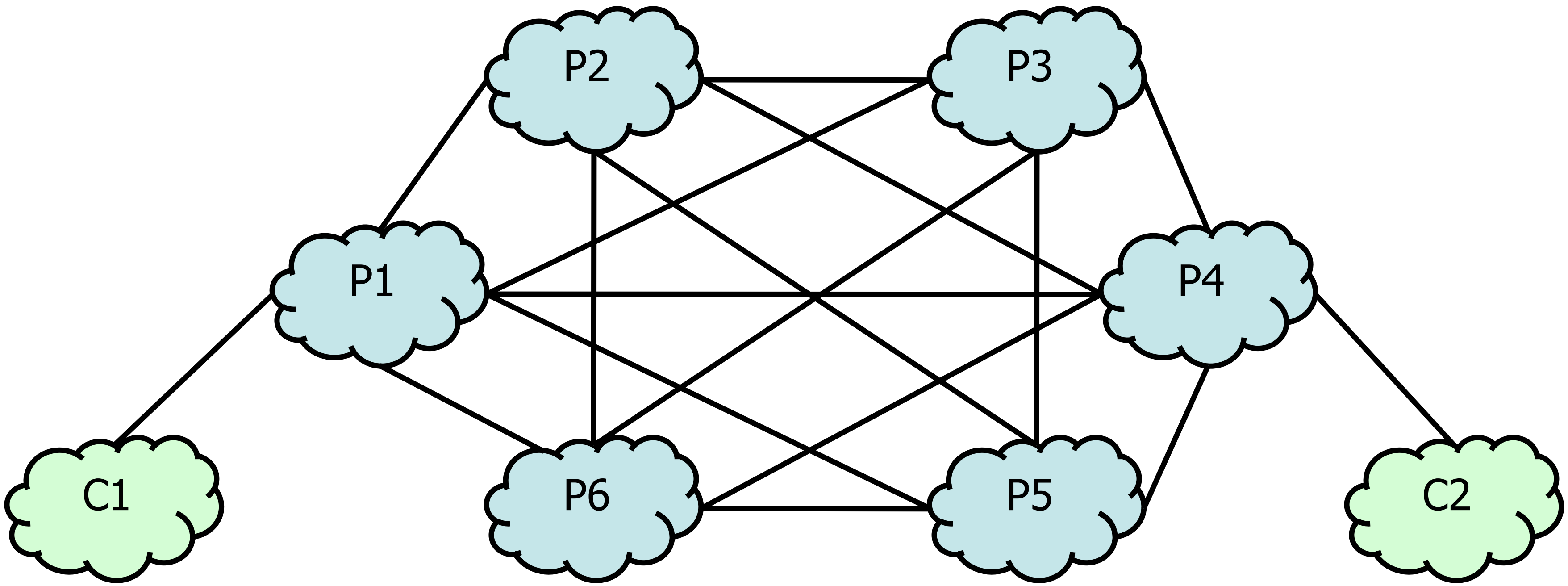

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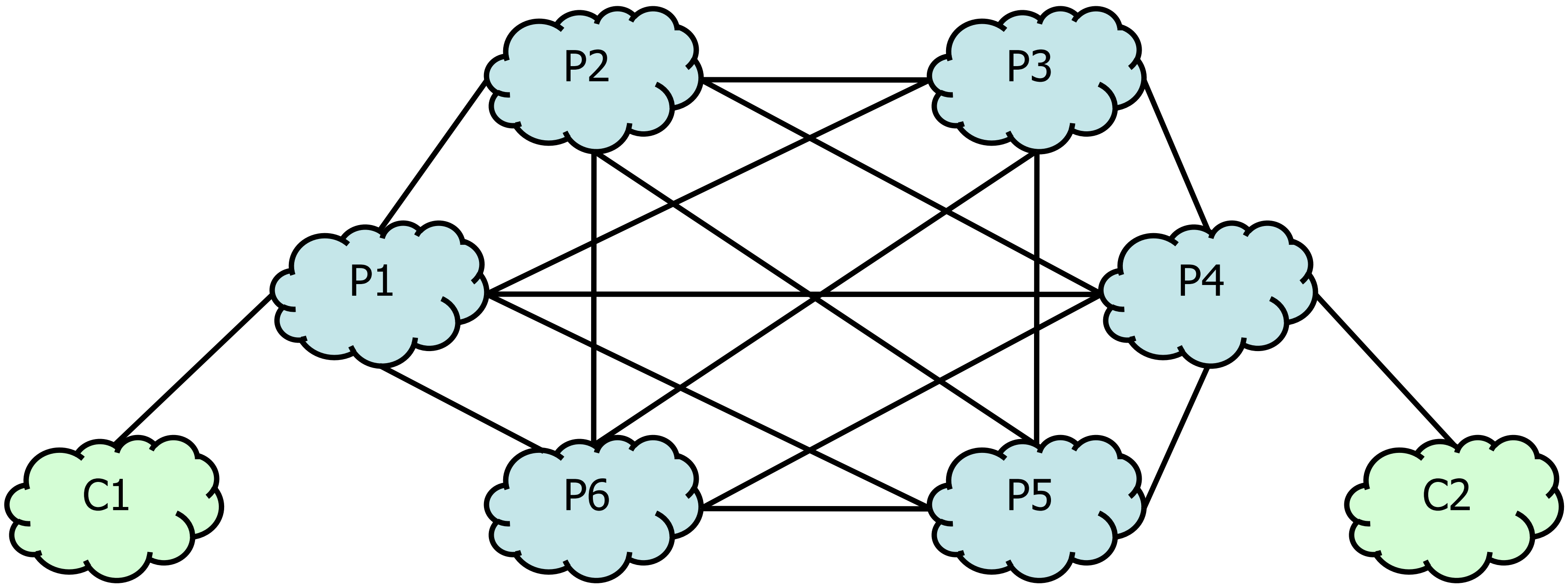
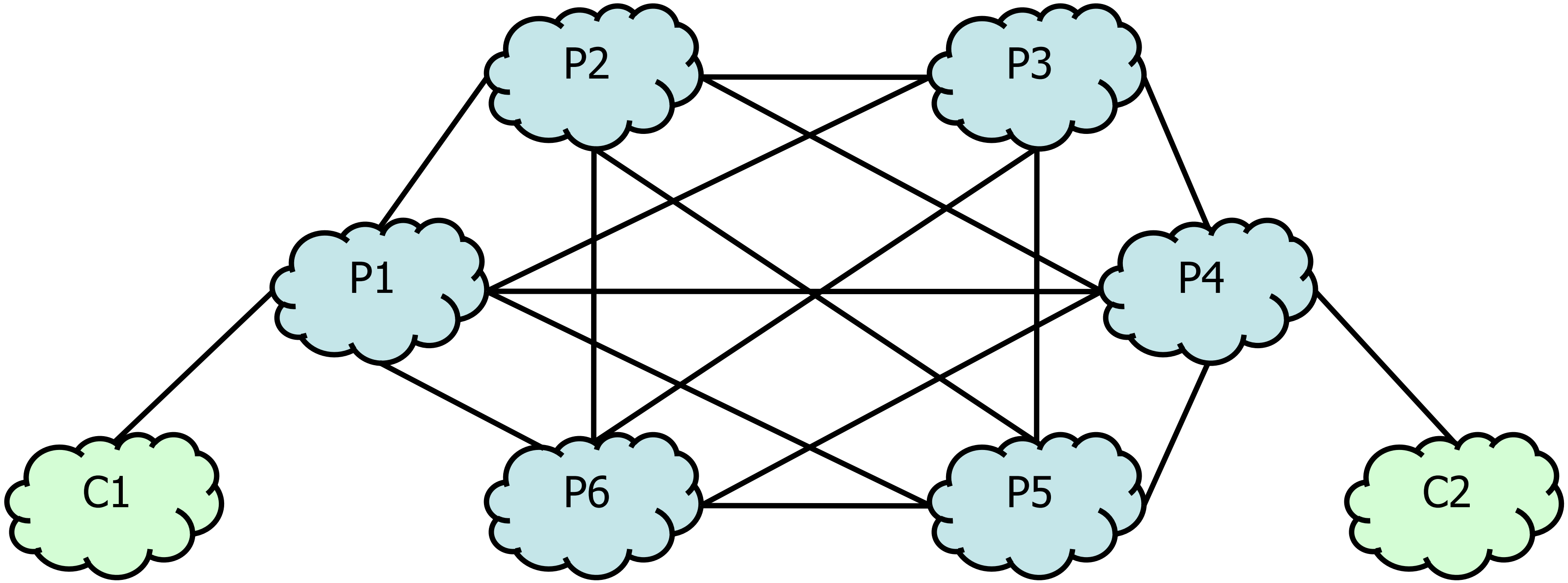


For Internet to be connected, **all** ISPs who do not buy transit service **must** be connected in full mesh!

A Peers' Quarrel: Depeering



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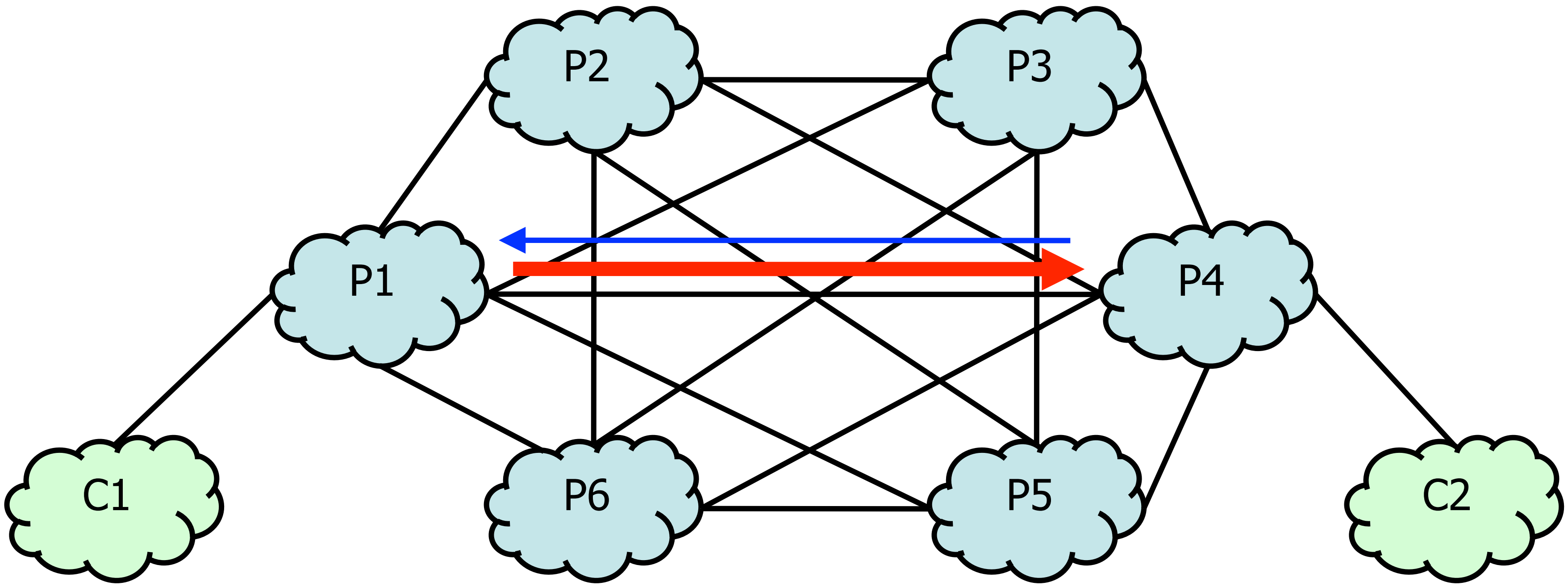

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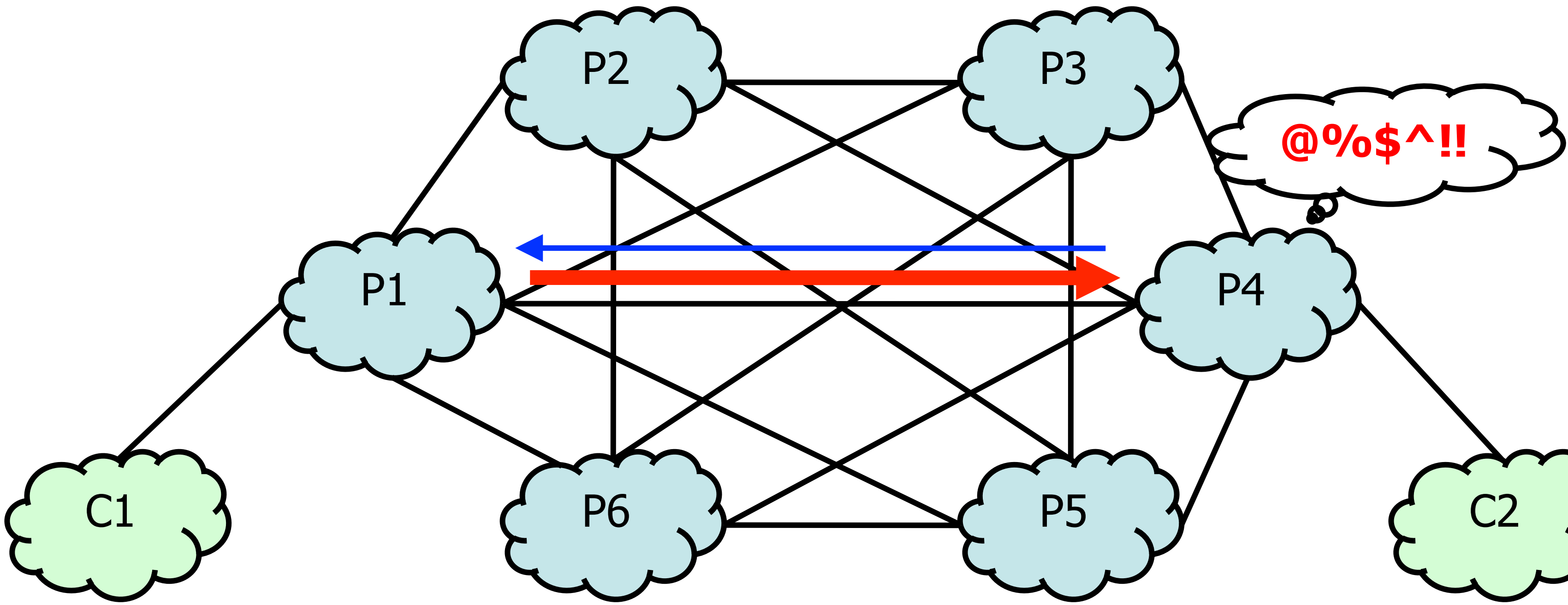

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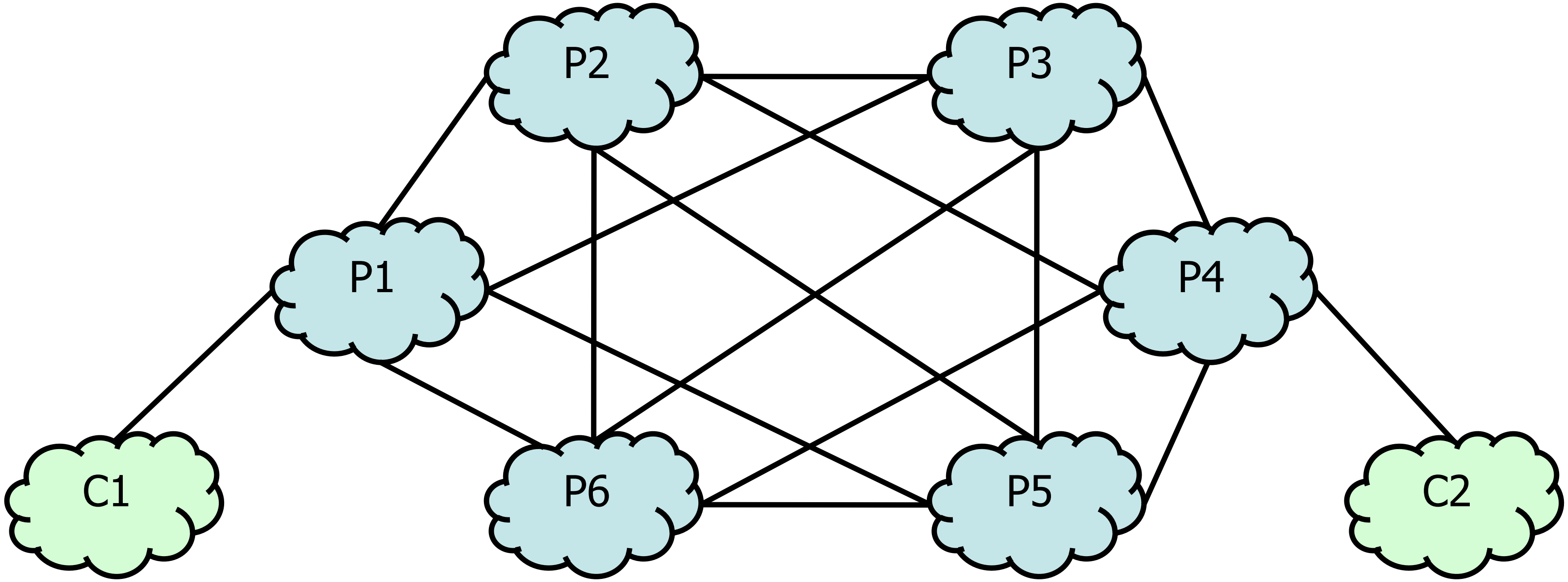

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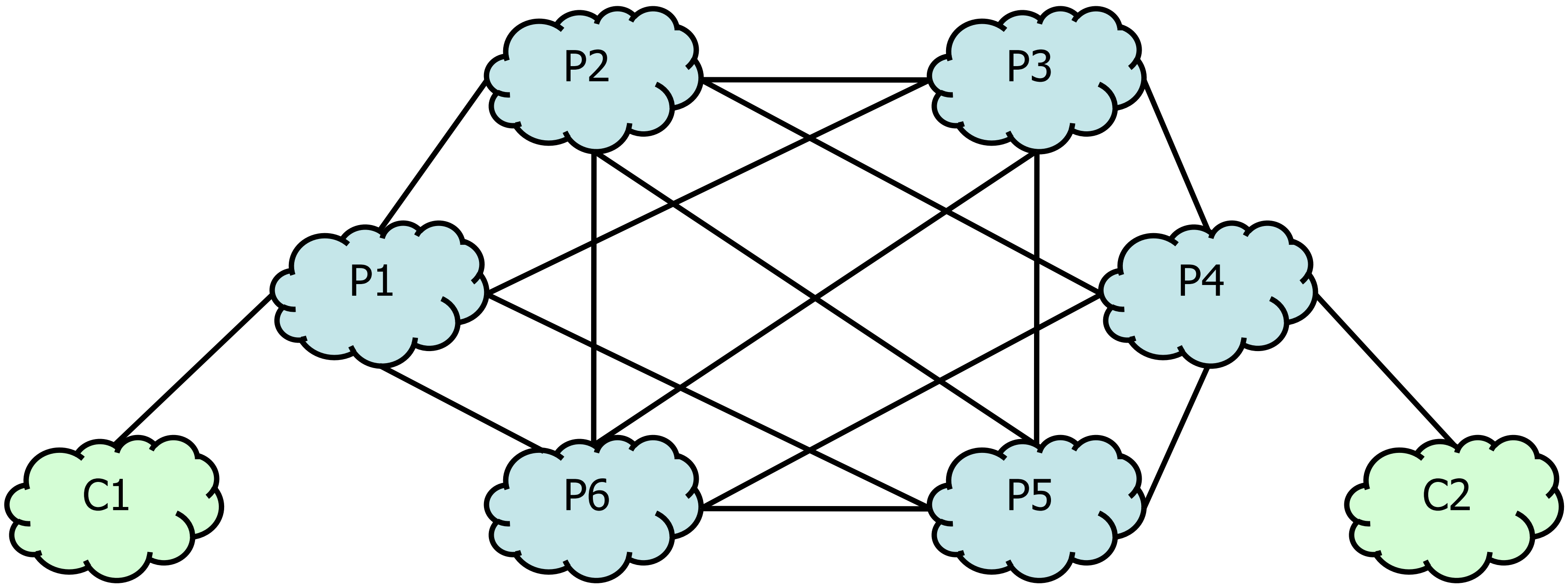

When P4 terminates BGP peering with P1, C1 and C2 can no longer reach one another, if they have no other transit path!

P4 has partitioned the Internet!

Depeering Happens

- 10/2005: Level 3 depeered Cogent
- 3/2008: Telia depeered Cogent
- 10/2008: Sprint depeered Cogent
  - lasted from 30th October – 2nd November, 2008
  - 3.3% of IP prefixes in global Internet behind one ISP partitioned from other, including NASA, Maryland Dept. of Trans., New York Court System, 128 educational institutions, Pfizer, Merck, Northup Grumman, ...

Summary: Inter-Domain Routing with BGP

- Inter-domain routing chiefly concerned with policy, not optimality
  - Economic motivation: cost of carrying traffic
  - Different relationships demand different routing: customer-provider vs. peering
- BGP: Path-Vector inter-domain routing protocol
  - Scalable in number of ASes
  - Route attributes support policy routing
  - Loop-free at AS granularity
  - Shortest ASPATHs achieved, after policy enforced
- Behavior and configuration of BGP very complex and poorly understood; open research problem!