Lecture 12: Inter-Domain Routing (Part II)

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COS 461: Computer Networks

Slides adapted from H. Balakrishnan, N. Feamster, B. Karp, J. Rexford

BGP Protocol (cont'd)

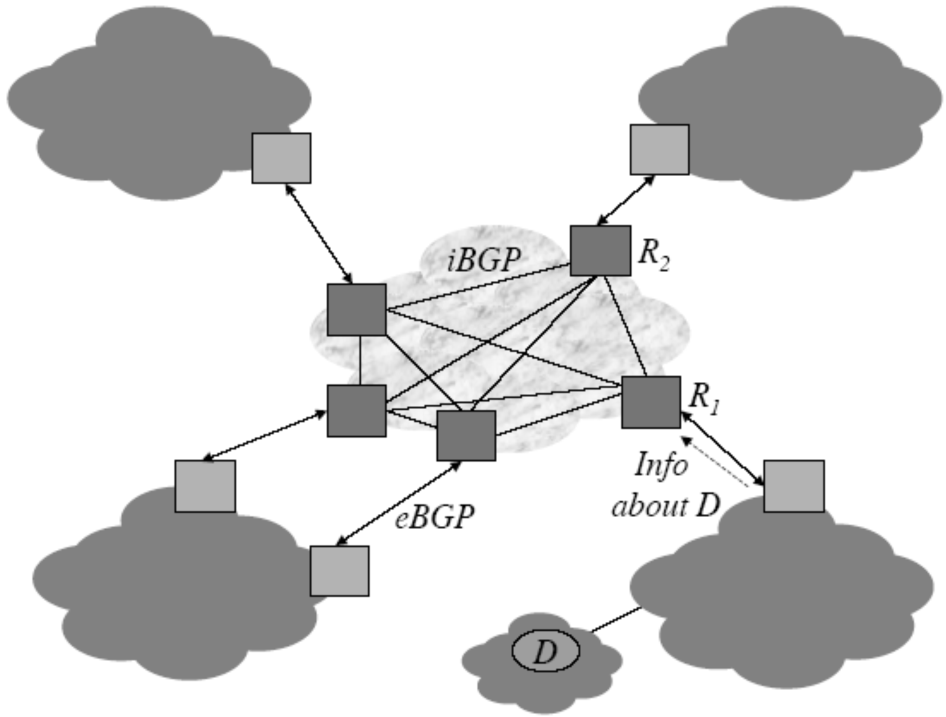
- BGP doesn't chiefly aim to compute shortest paths (or minimize other metric, as do DV, LS)
- Chief purpose of BGP is to announce reachability, and enable policy-based routing
- BGP announcement:
  - IP prefix: [Attribute 0] [Attribute1] […]

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



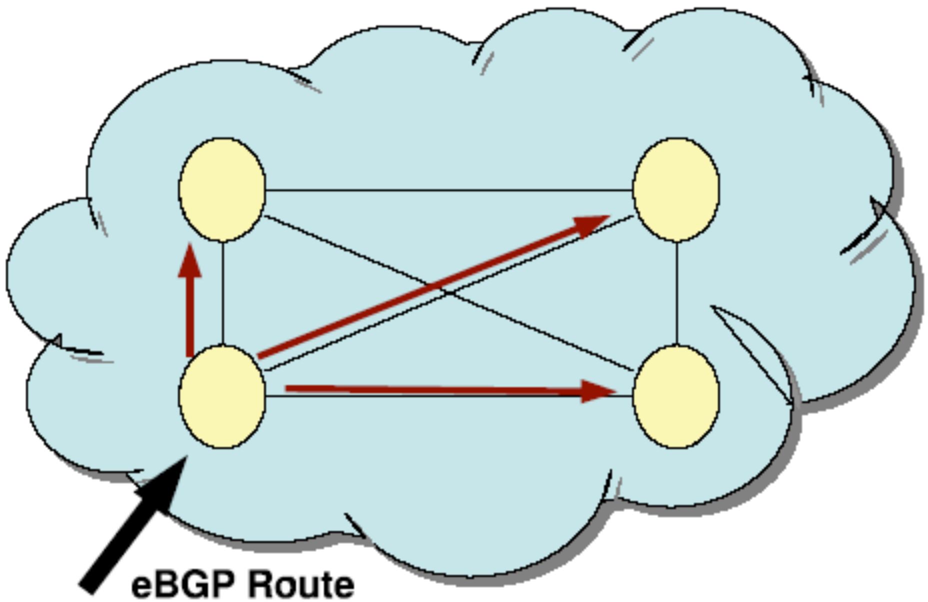
- Exterior BGP (eBGP): external BGP advertises routes between ASes
- Interior BGP (iBGP): internal BGP propagates external routes throughout receiving AS

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

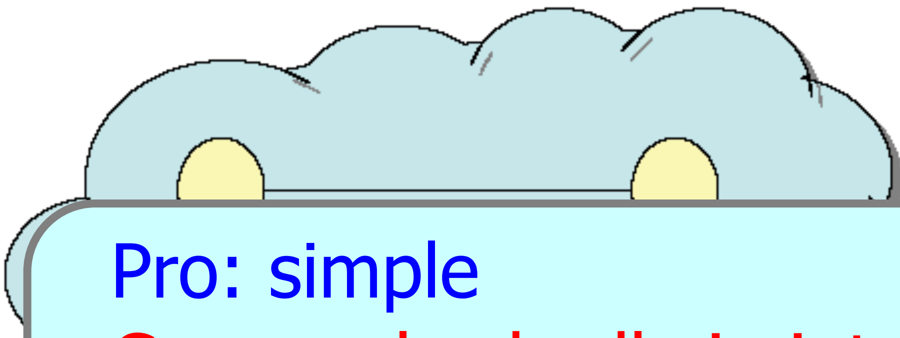
Within AS1, choosing external route to destination in AS2 amounts to **choosing egress router within AS1**

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 routers using iBGP

Pro: simple

Con: scales badly in intra-AS router count:

$O(e^2 + e*i)$ iBGP sessions

(where e eBGP routers, i iBGP routers)

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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Route Attributes Enforce Policy

- 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

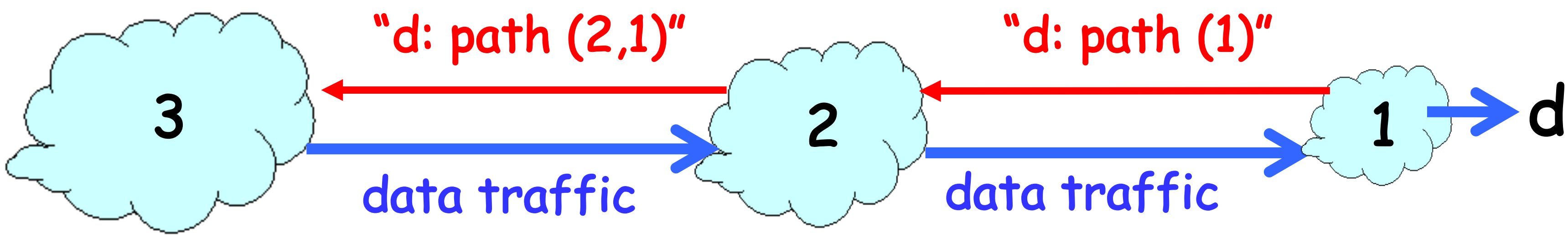
- Indicates IP address of next-hop router
- Modified as routes are announced
  - eBGP: when border router announces outside of AS, changes to own IP address
  - iBGP: when border router disseminates within AS, changes to own IP address
  - iBGP: any iBGP router that repeats route to other iBGP router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

Path-Vector Routing

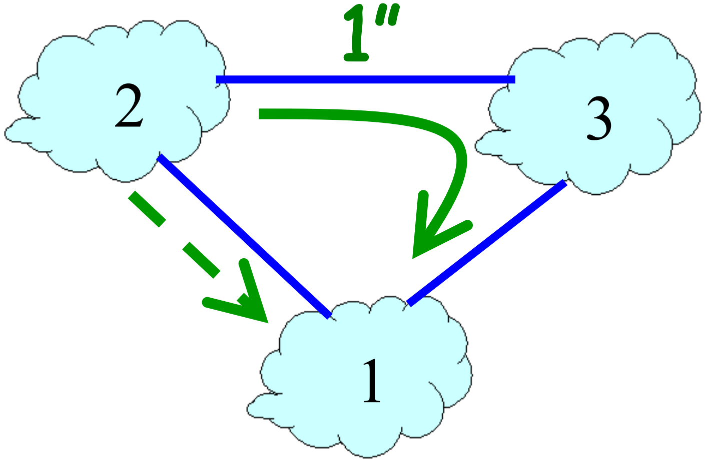
- Extension of distance-vector routing
- Key idea: advertise the entire path
  - Distance vector: send *distance metric* per dest d
  - Path vector: send the *entire path* for each dest d



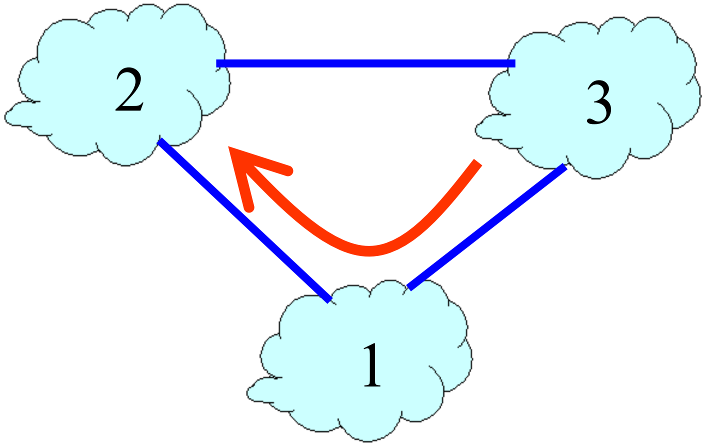
Path-Vector: Flexible Policies

- Each node can apply local policies
  - Path selection: Which path to use?
  - Path export: Which paths to advertise?

Node 2 prefers "2, 3, 1" over "2, 1"

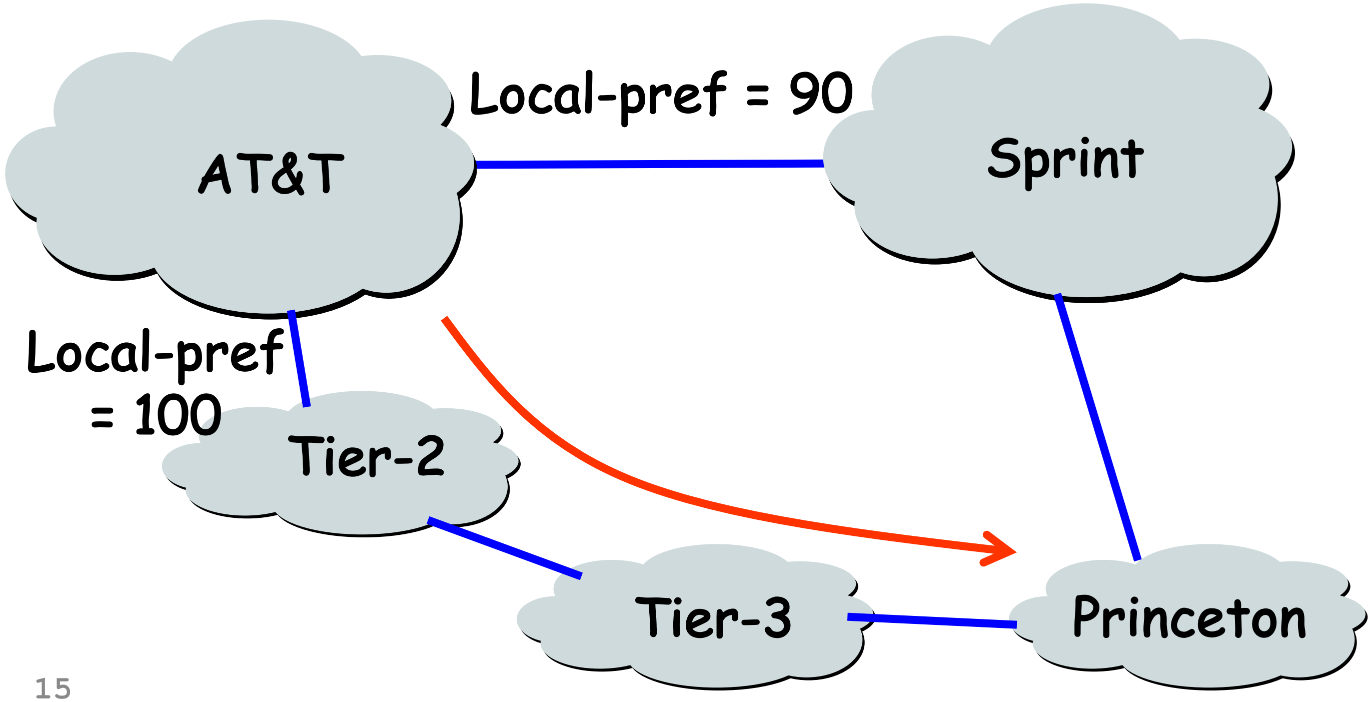


Node 1 doesn't let 3 hear the path "1, 2"



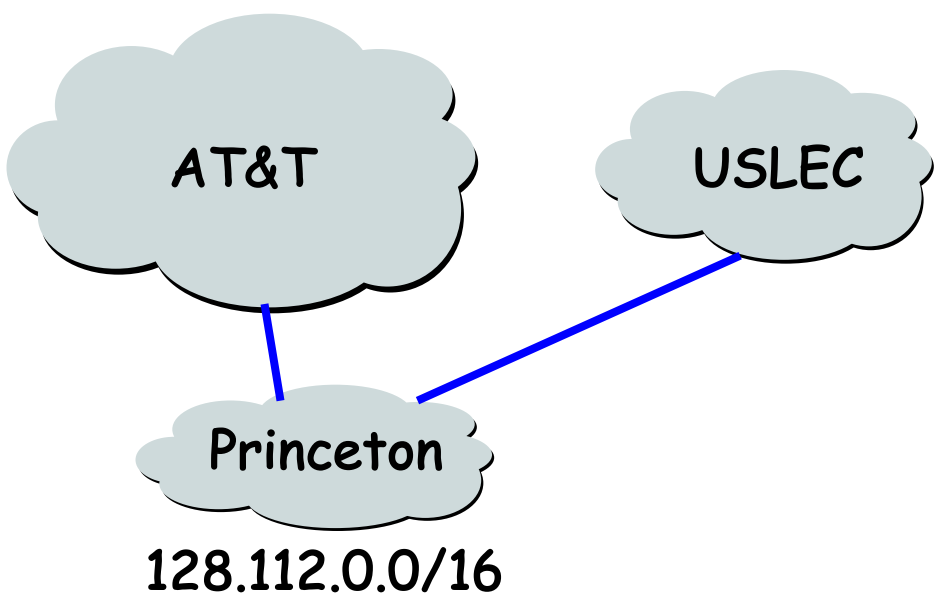
Import Policy: Local Preference

- Favor one path over another
  - Override the influence of AS path length
- Example: prefer customer over peer



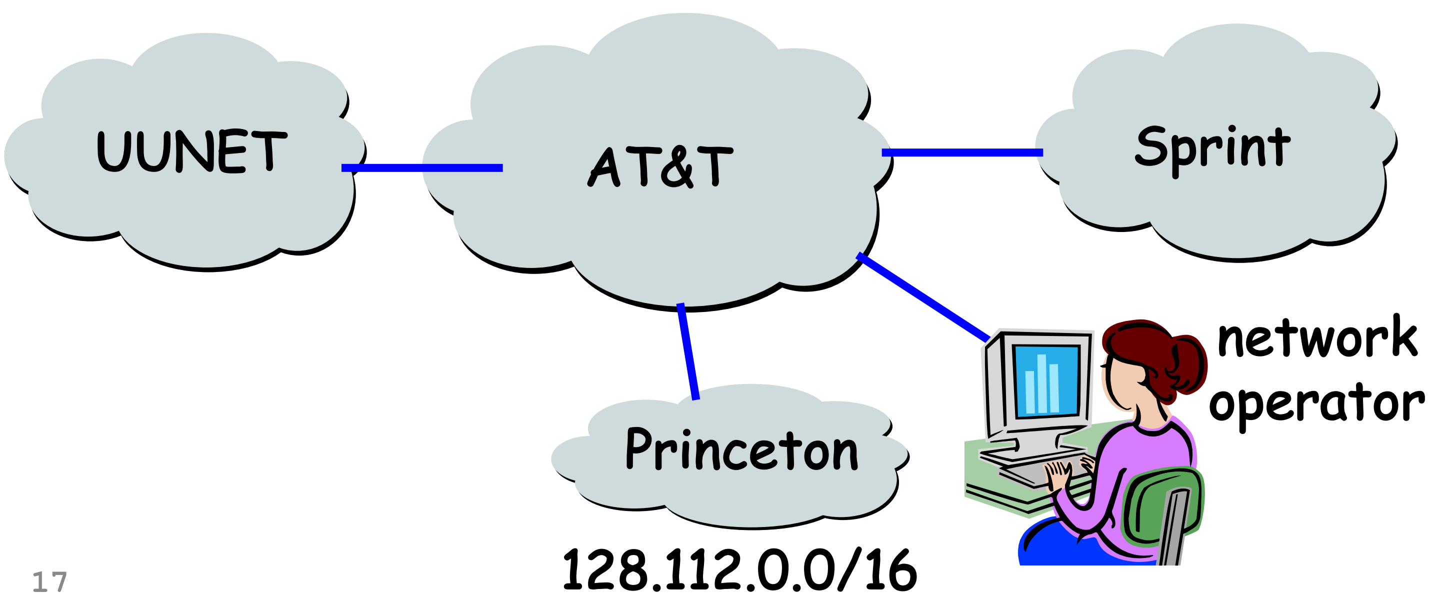
Import Policy: Filtering

- Discard some route announcements
  - Detect configuration mistakes and attacks
- Examples on session to a customer
  - Discard route if prefix not owned by the customer
  - Discard route with other large ISP in the AS path



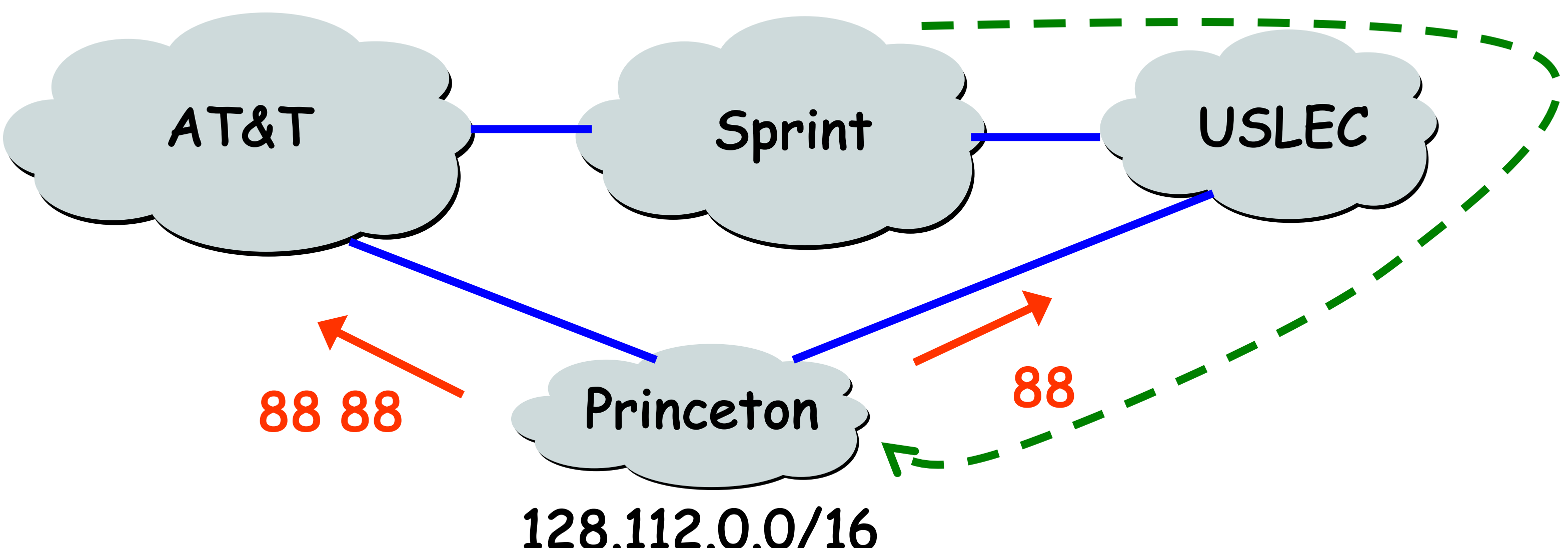
Export Policy: Filtering

- Discard some route announcements
  - Limit propagation of routing information
- Examples
  - Don't announce routes from one peer to another
  - Don't announce routes for management hosts



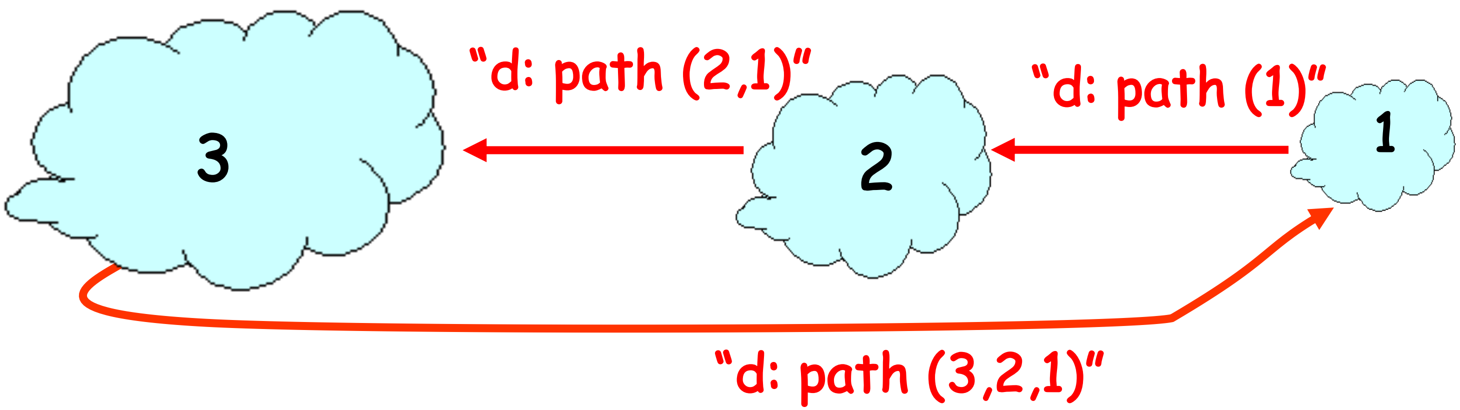
Export Policy: Attribute Manipulation

- Modify attributes of the active route
  - To influence the way other ASes behave
- Example: AS prepending
  - Artificially inflate AS path length seen by others
  - Convince some ASes to send traffic another way



Path Vector: Faster Loop Detection

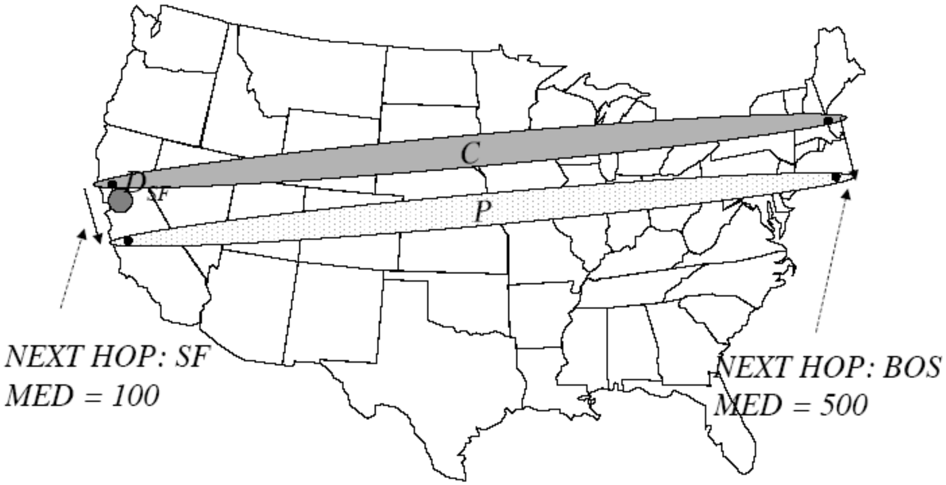
- Node can easily detect a loop
  - Look for its own node identifier in the path
  - E.g., node 1 sees itself in the path "3, 2, 1"
- Node can simply discard paths with loops
  - E.g., node 1 simply discards the advertisement



MED Attribute: Choosing Among Multiple Exit Points

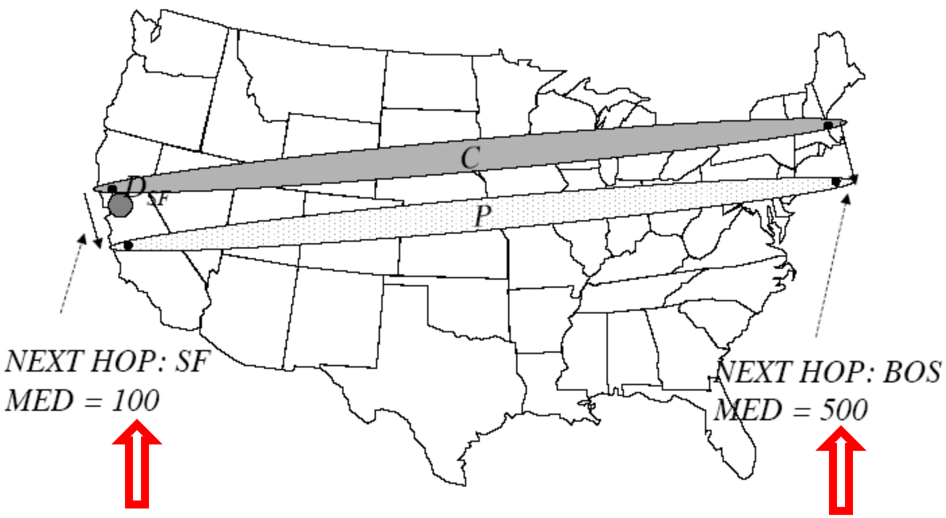
- ASes often connect at multiple points (e.g., global backbones)
- ASPATHs will be same length
- But AS' administrator may prefer a particular transit point…often the one that saves them money!
- MED Attribute: Multi-Exit Discriminator, allows choosing transit point between two ASes

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)

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!**

destination D_{SF}

- Result: traffic crosses country on P

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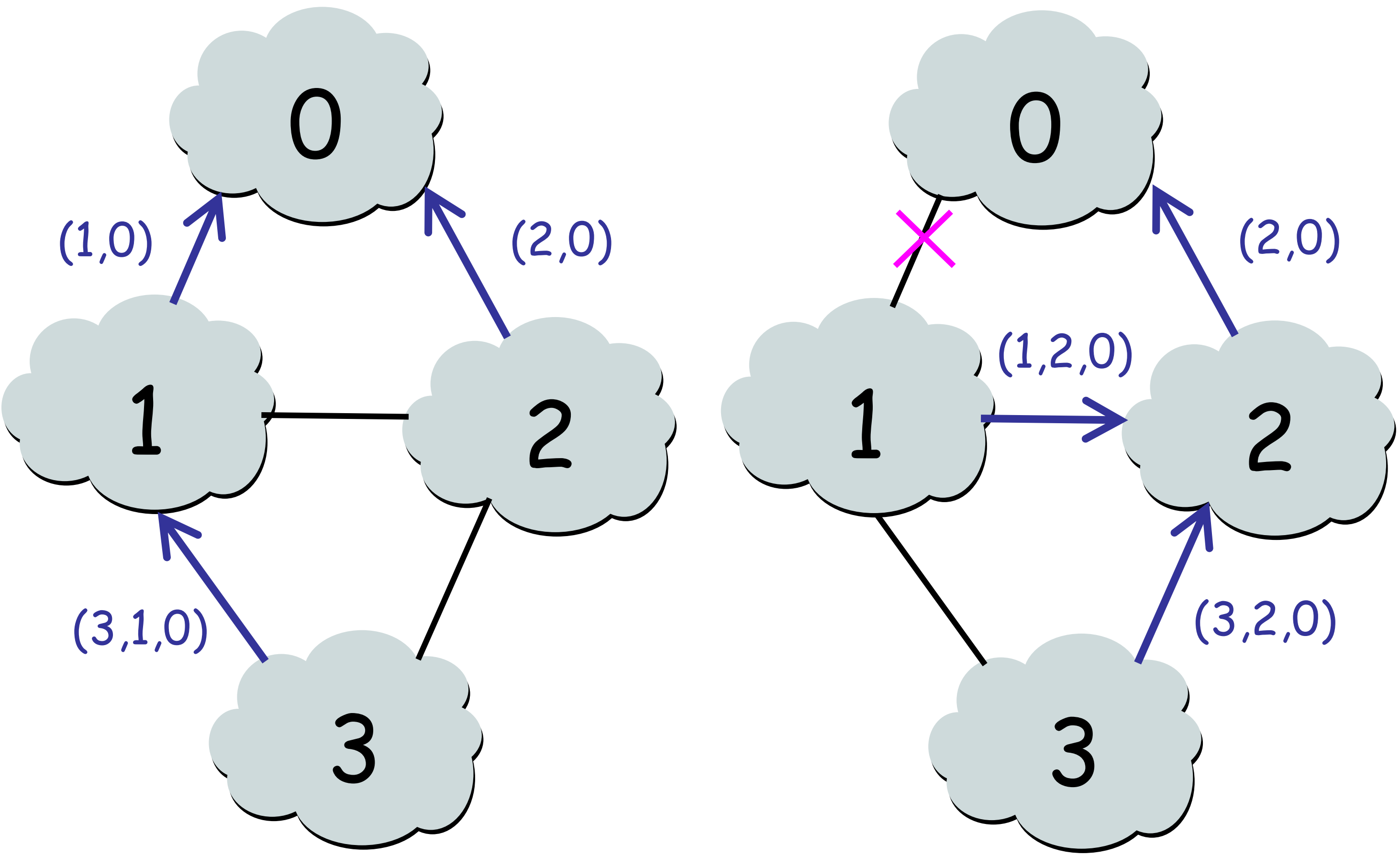
Synthesis: Multiple Attributes into Policy Routing

- 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

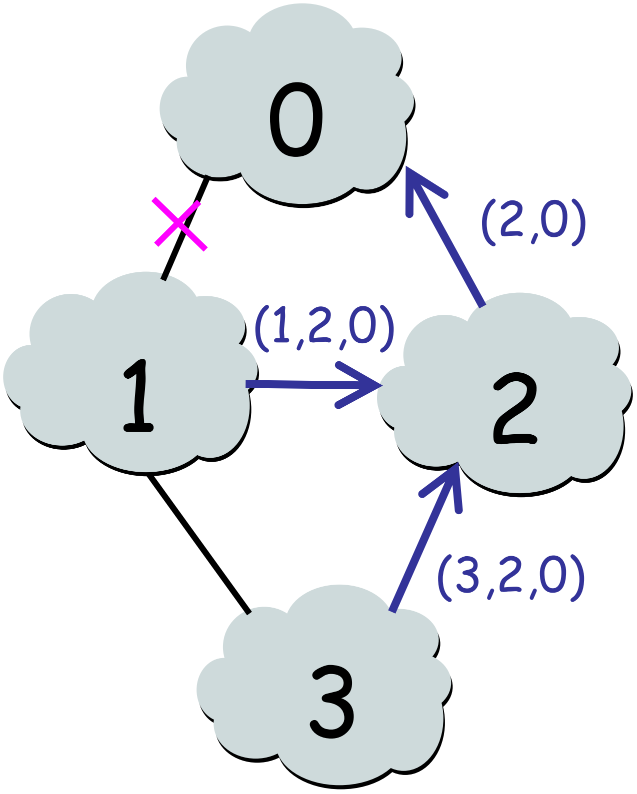
BGP Dynamics



BGP Dynamics: Path Exploration

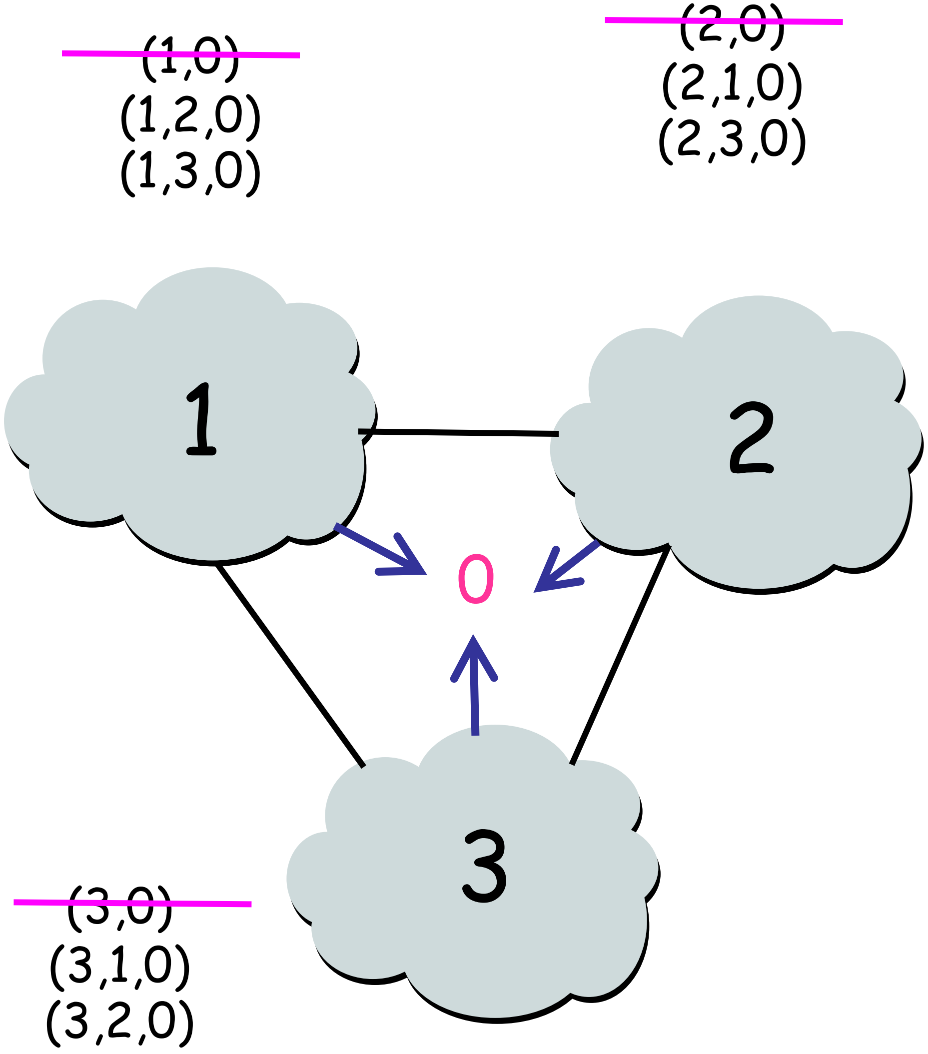
- AS 1
  - Delete the route (1,0)
  - Switch to next route (1,2,0)
  - Announce route (1,2,0) to AS 3

- AS 3
  - Sees (1,2,0) replace (1,0)
  - Compares to route (2,0)
  - Switches to using AS 2



Path Exploration: Slower Example

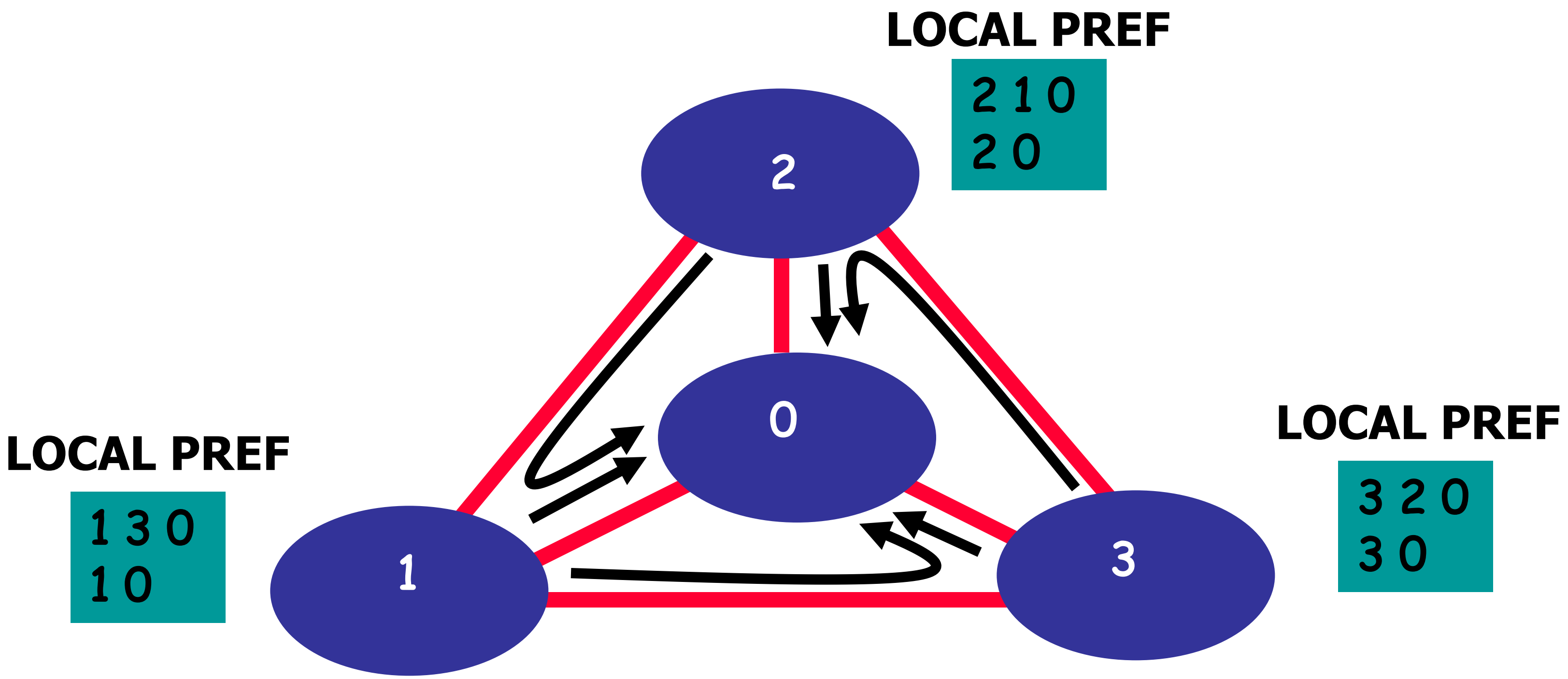
- Initial situation
  - Destination 0 is alive
  - All ASes use direct path
- When destination dies
  - All ASes lose direct path
  - All repeatedly switch to longer paths
  - Eventually withdrawn
- e.g., AS 2
  - (2,0) → (2,1,0)
  - (2,1,0) → (2,3,0)
  - (2,3,0) → (2,1,3,0)
  - (2,1,3,0) → no route



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

Policies May Cause Persistent Oscillations ("Dispute Wheels")

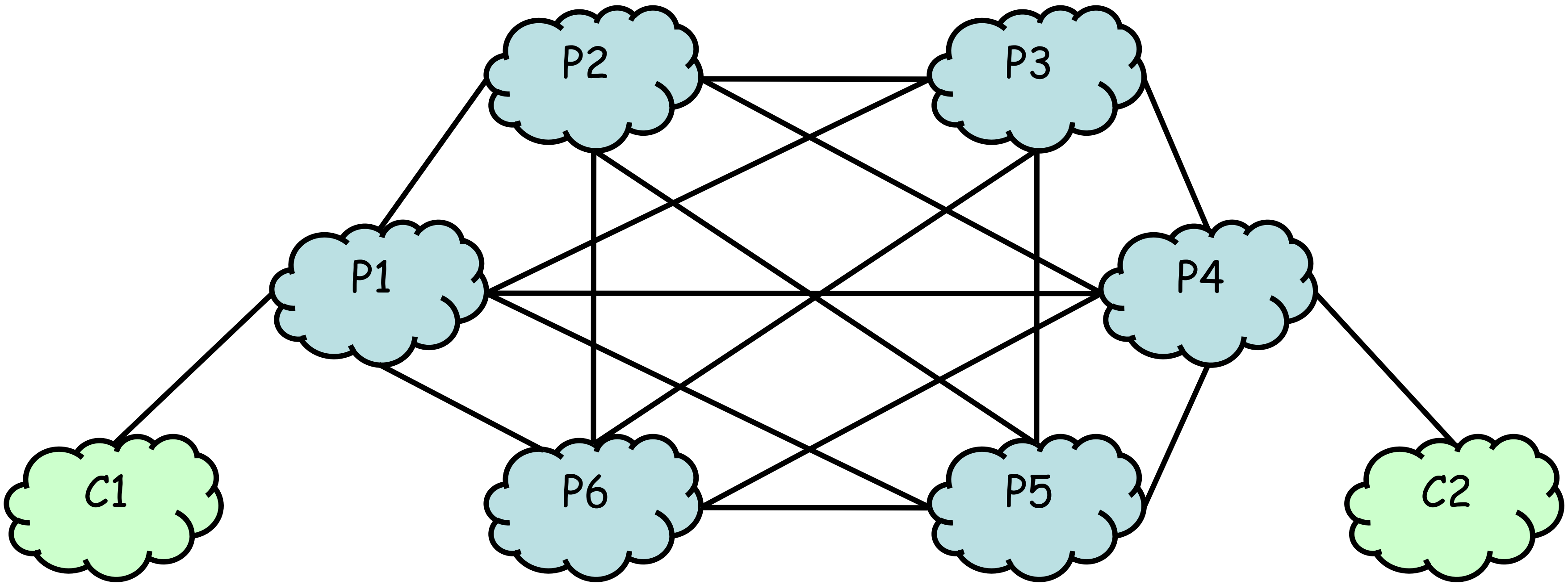


- Suppose each AS prefers two-hop path to direct one
- Repeats forever!

War Story: Depeering

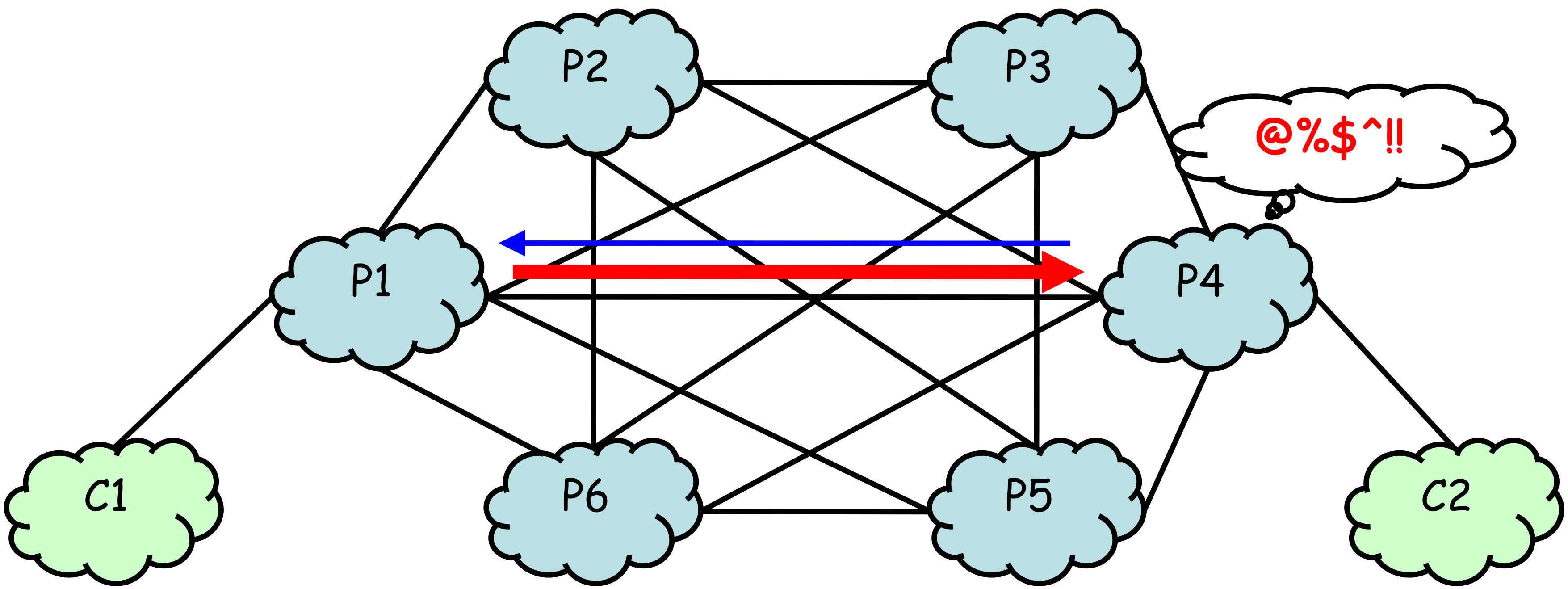
- All tier-1 ISPs peer directly with one another in a full mesh
- True tier-1 ISPs do not pay for peering and buy transit from no one
- A few *other* large ISPs pay no transit provider:
  - they peer with all tier-1 ISPs…
  - …but pay settlements to one or more of them

Full-Mesh Peering



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

A Peers' Quarrel: Depeering



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!