

EECS 489

Computer Networks

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Material with thanks to Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.

Agenda

- BGP policies and how they are implemented
- BGP protocol details
- BGP issues in practice

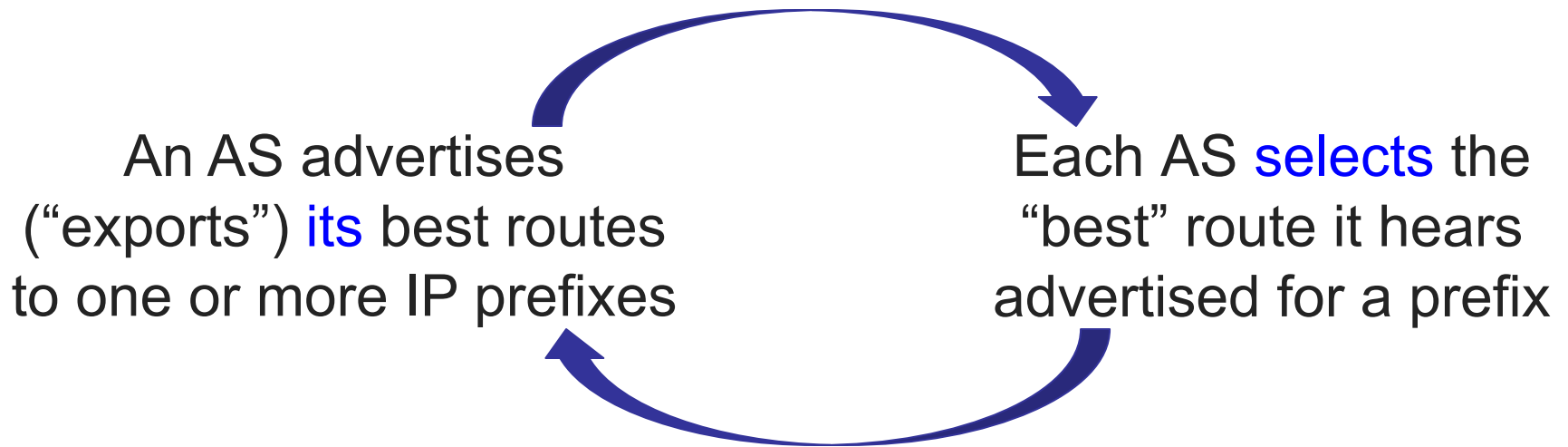
Topology & policy shaped by inter-AS business relationship

- Three basic kinds of relationships between ASes
 - AS A can be AS B's customer
 - AS A can be AS B's provider
 - AS A can be AS B's peer
- Business implications
 - Customer pays provider
 - Peers don't pay each other
 - » Exchange roughly equal traffic

Inter-domain routing: Setup

- Destinations are IP prefixes (12.0.0.0/8)
- Nodes are Autonomous Systems (ASes)
 - Internals of each AS are hidden
- Links represent both physical links and business relationships
- BGP (Border Gateway Protocol) is the Inter-domain routing protocol
 - Implemented by AS border routers

BGP: Basic idea

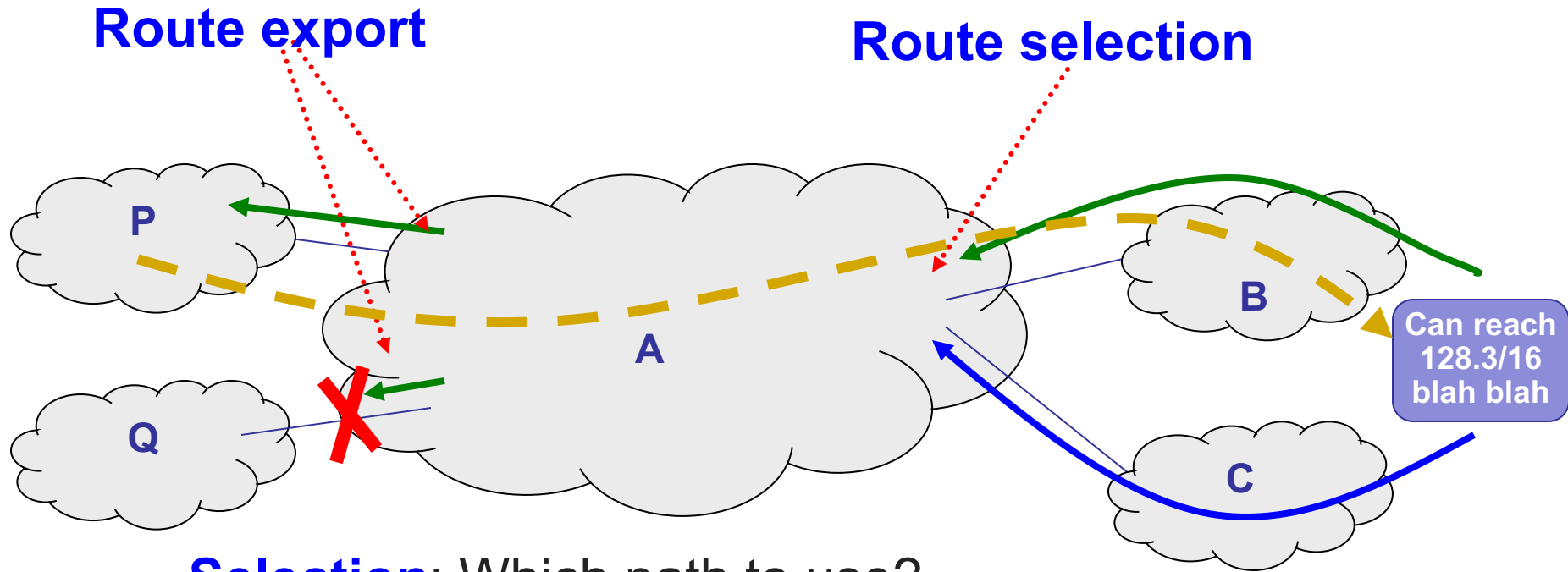


BGP inspired by Distance-Vector with four differences

- Shortest-path routes may not be picked to enforce policy
- Path-Vector routing to avoid loops
- Selective route advertisement may affect reachability
- Routes may be aggregated for scalability

BGP POLICIES

Policy dictates how routes are “selected” and “exported”



- **Selection:** Which path to use?
 - Controls whether/how traffic leaves the network
- **Export:** Which path to advertise?
 - Controls whether/how traffic enters the network

Typical selection policies

- In decreasing order of priority
 - Make/save money (send to customer > peer > provider)
 - Maximize performance (smallest AS path length)
 - Minimize use of my network bandwidth (“hot potato”)
 - ...

Typical export policy

Destination prefix advertised by...	Export route to...
Customer	Everyone (providers, peers, other customers)
Peer	Customers
Provider	Customers

We'll refer to these as the “Gao-Rexford” rules
(capture common – **but not required!** – practice)



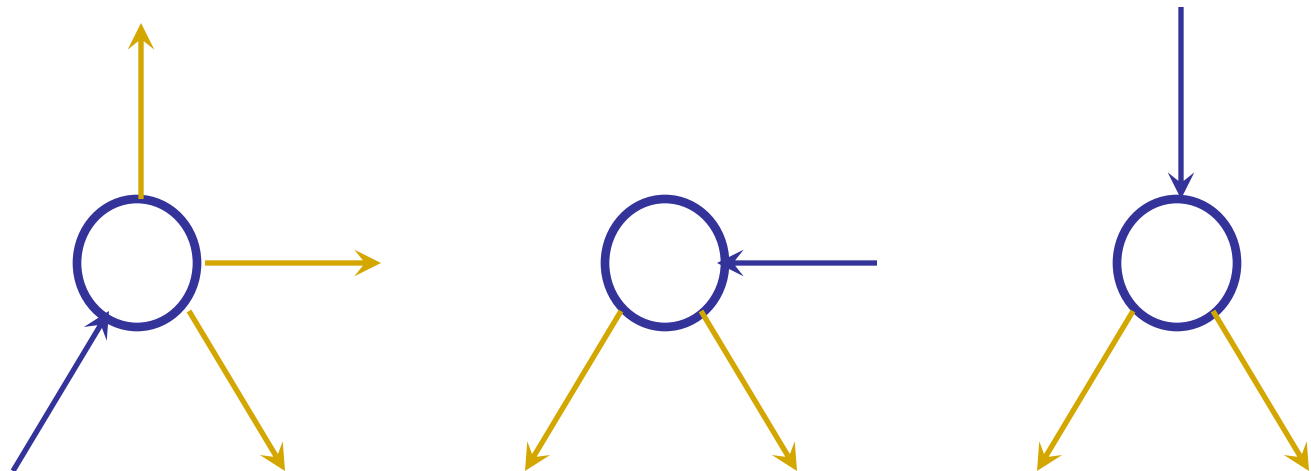
Gao-Rexford



Providers

Peers

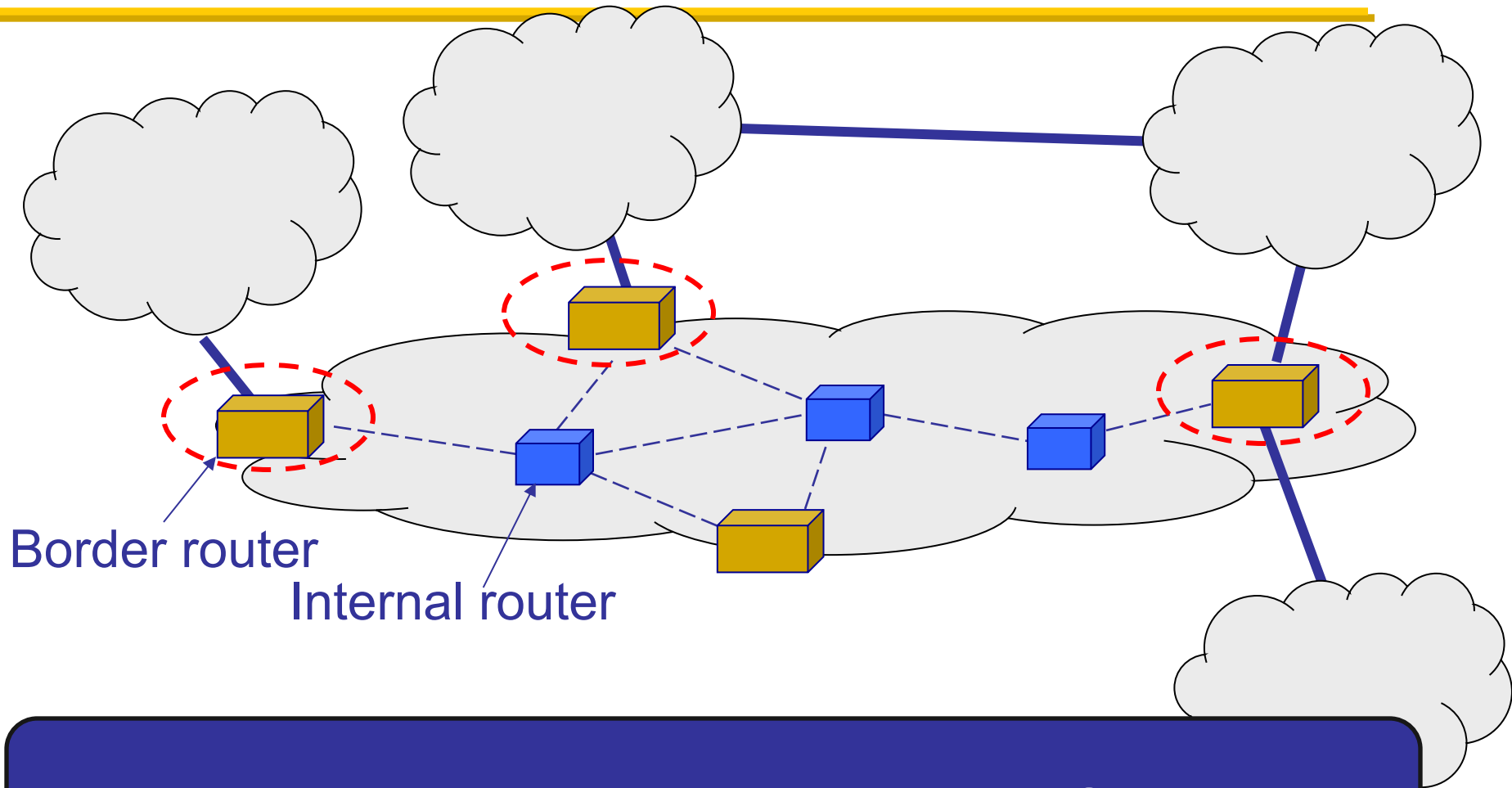
Customers



With Gao-Rexford, the AS policy graph is a DAG (directed acyclic graph) and routes are “valley free”

BGP PROTOCOL DETAILS

Who speaks BGP?

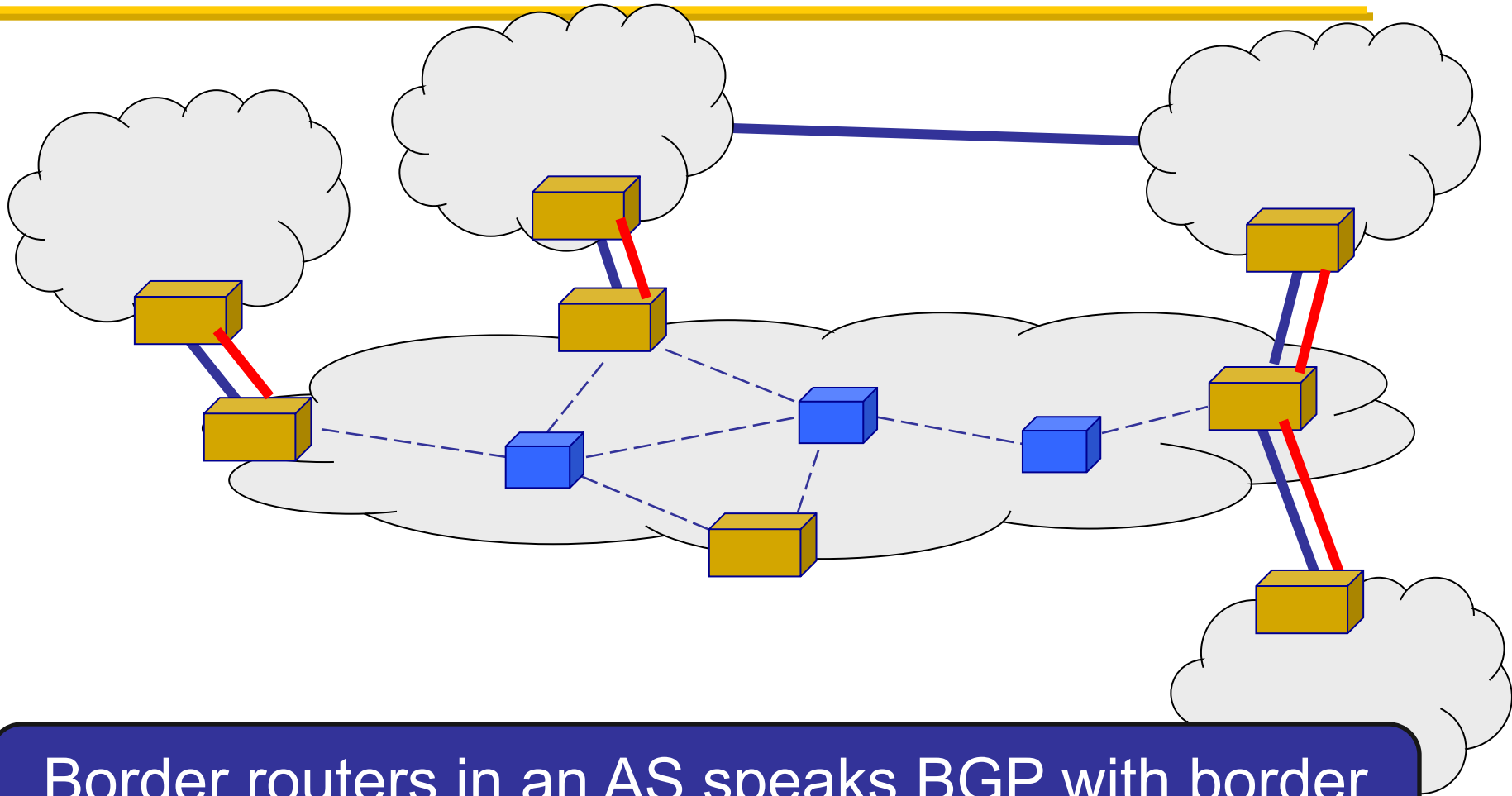


Border routers in an Autonomous System

What does “speak BGP” mean?

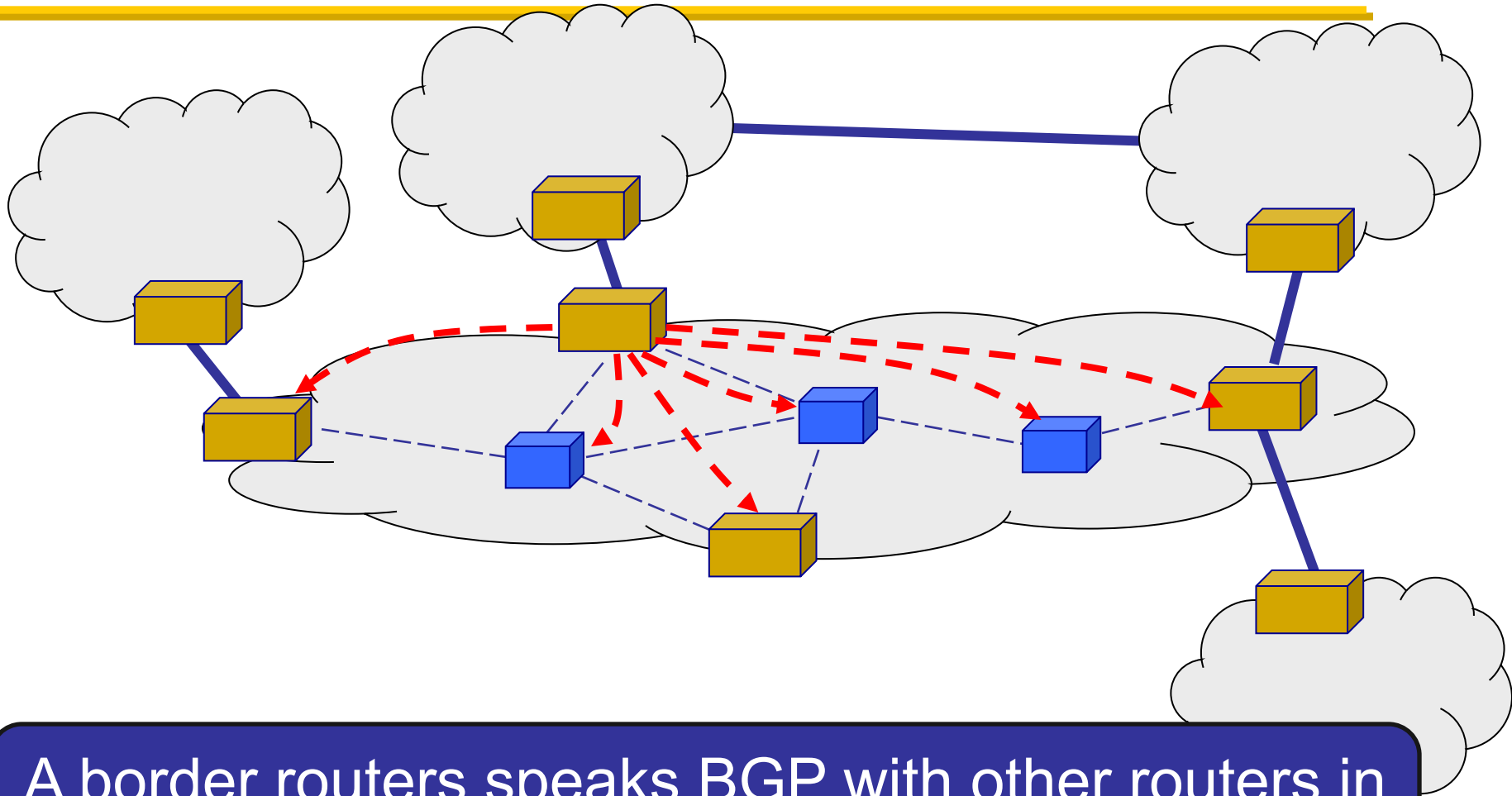
- Implement the BGP protocol standard
 - Read more here: <http://tools.ietf.org/html/rfc4271>
- Specifies what messages to exchange with other BGP “speakers”
 - Message types (e.g., route advertisements, updates)
 - Message syntax
- How to process these messages
 - E.g., “when you receive a BGP update, do....”
 - Follows BGP state machine in the protocol spec + policy decisions, etc.

BGP sessions: External



Border routers in an AS speak BGP with border routers in other ASes using **eBGP sessions**

BGP sessions: Internal



A border routers speaks BGP with other routers in the same AS using **iBGP sessions**

eBGP, iBGP, and IGP

- **eBGP**: BGP sessions between border routers in different ASes
 - Learn routes to external destinations
- **iBGP**: BGP sessions between border routers and other routers within the same AS
 - Distribute externally learned routes internally
- **IGP**: “Interior Gateway Protocol” = Intra-domain routing protocol
 - Provide internal reachability
 - E.g., OSPF, RIP

eBGP, iBGP, and IGP together

- Learn routes to external destination using eBGP
- Distribute externally learned routes internally using iBGP
- Travel shortest path to egress using IGP

Basic messages in BGP

- Open
 - Establishes BGP session (BGP uses TCP)
- Notification
 - Report unusual conditions
- Update
 - Inform neighbor of new routes
 - Inform neighbor of old routes that become inactive
- Keep-alive
 - Inform neighbor that connection is still viable

Route updates

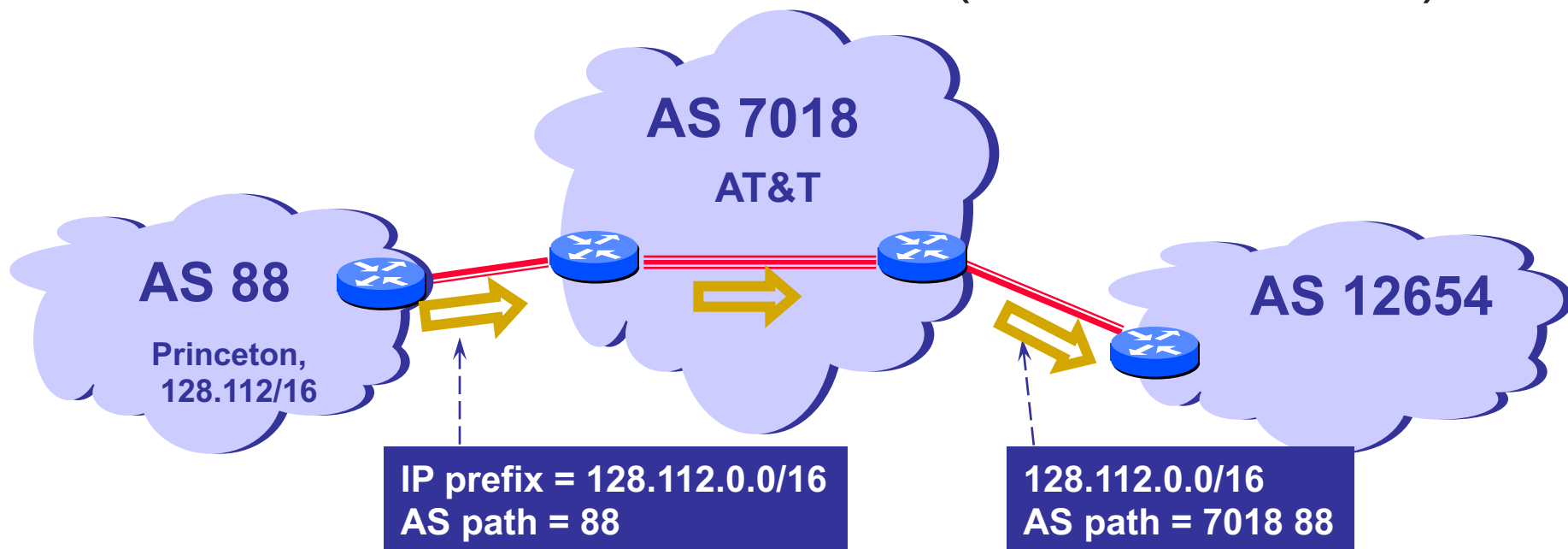
- Format <IP prefix: route attributes>
 - Attributes describe properties of the route
- Two kinds of updates
 - **Announcements**: new routes or changes to existing routes
 - **Withdrawal**: remove routes that no longer exist

Route attributes

- Routes are described using attributes
 - Used in route selection/export decisions
- Some attributes are local
 - I.e., private within an AS, not included in announcements
- Some attributes are propagated with eBGP route announcements
- There are many standardized attributes in BGP
 - We will discuss a few

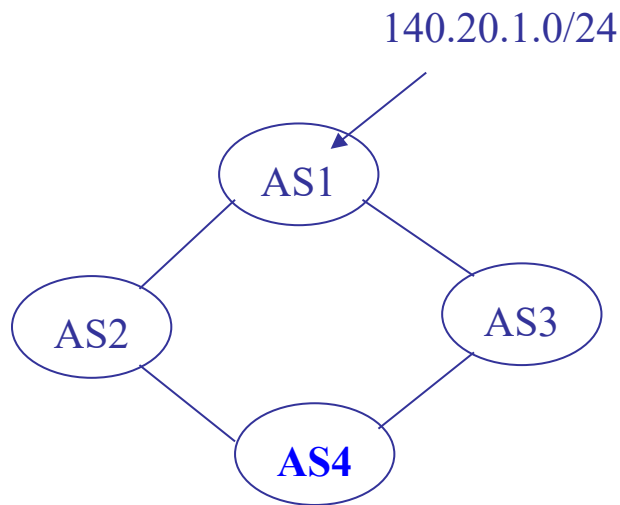
Attributes: (1) ASPATH

- Carried in route announcements
- Vector that lists all the ASes a route advertisement has traversed (in reverse order)



Attributes: (2) LOCAL PREF

- Local preference in choosing between different AS paths
 - Local to an AS; carried only in iBGP messages
- The higher the value the more preferred

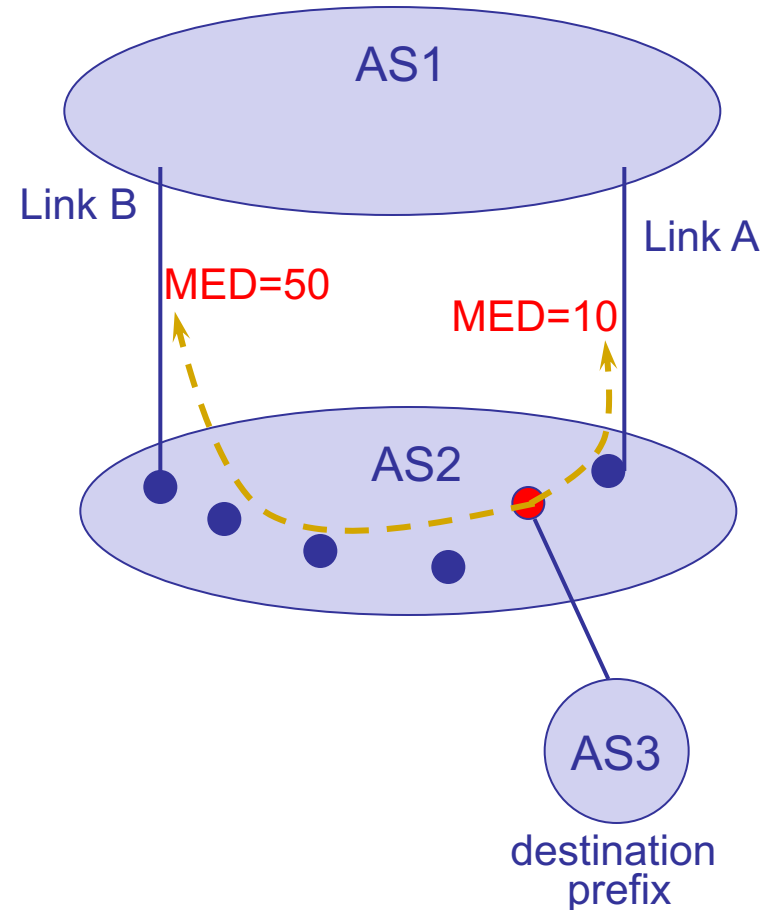


BGP table at AS4:

Destination	AS Path	Local Pref
140.20.1.0/24	AS3 AS1	300
140.20.1.0/24	AS2 AS1	100

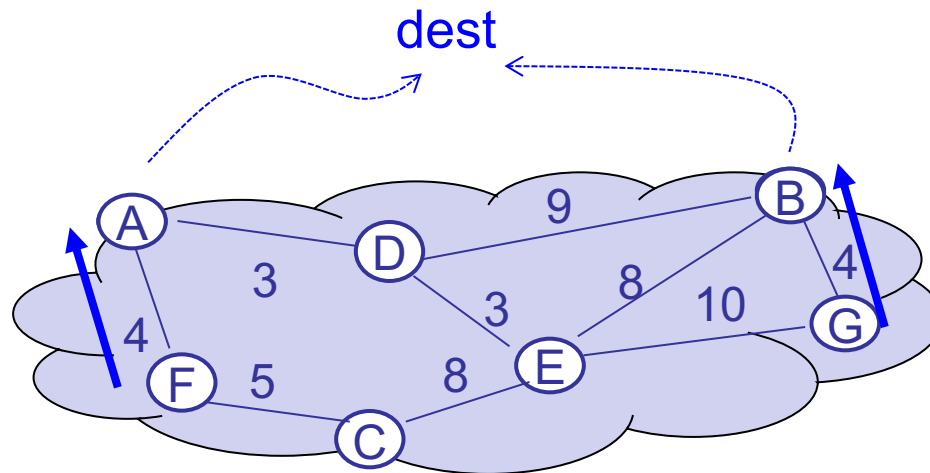
Attributes: (3) MED

- **Multi-exit discriminator** is used when ASes are interconnected via 2 or more links; it specifies how close a prefix is to the link it is announced on
- **Lower is better**
- AS that announces a prefix sets MED
- AS receiving the prefix (optionally!) uses MED to select link



Attributes: (4) IGP cost

- Used for hot-potato routing
 - Each router selects the closest egress point based on the path cost in intra-domain protocol

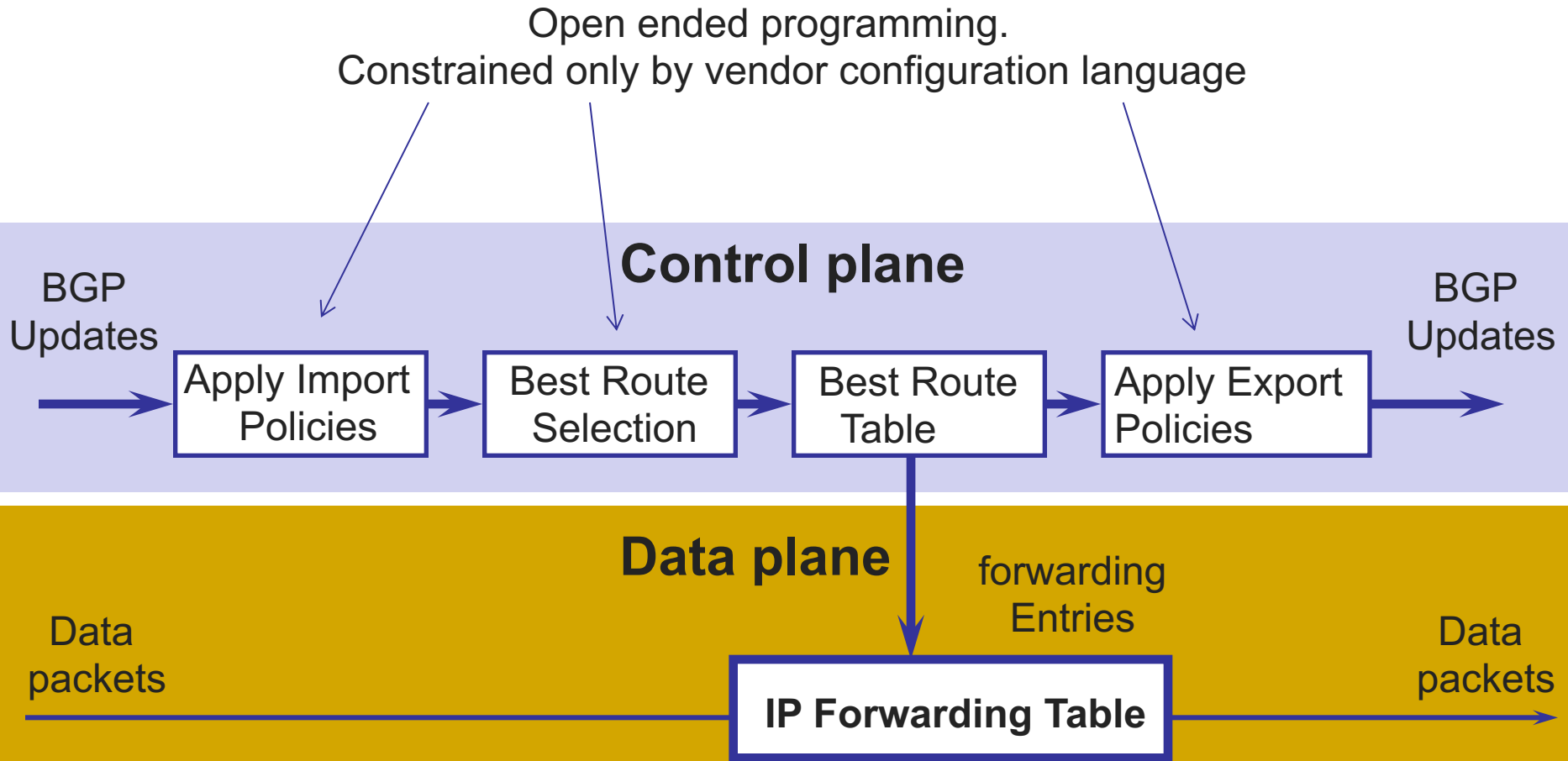


Using attributes

- Rules for route selection in priority order

Priority	Rule	Remarks
1	LOCAL PREF	Pick highest LOCAL PREF
2	ASPATH	Pick shortest ASPATH length
3	MED	Lowest MED preferred
4	eBGP > iBGP	Did AS learn route via eBGP (preferred) or iBGP?
5	iBGP path	Lowest IGP cost to next hop (egress router)
6	Router ID	Smallest next-hop router's IP address as tie-breaker

BGP UPDATE processing



5-MINUTE BREAK!

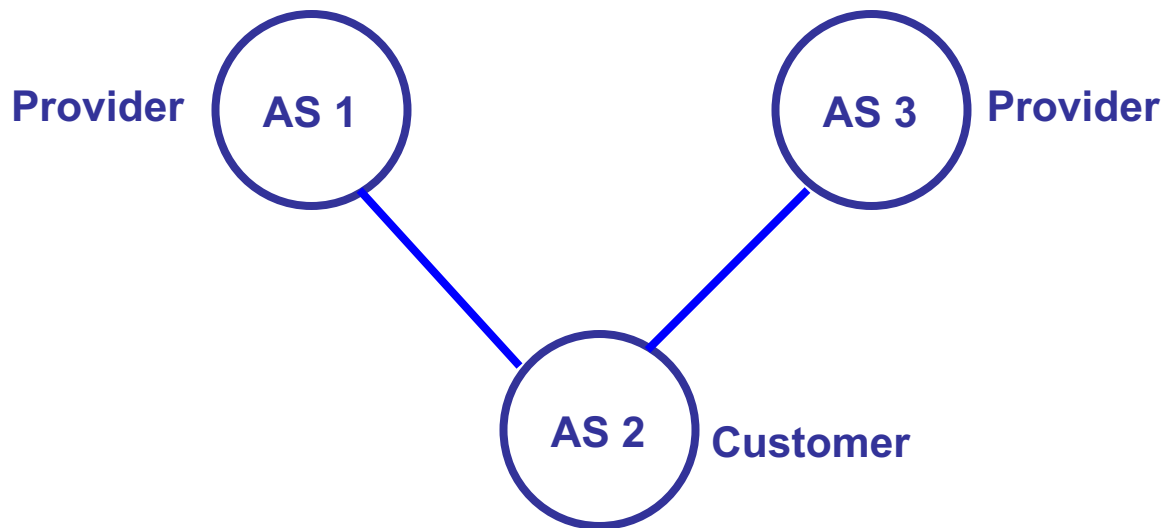
BGP ISSUES IN PRACTICE

Issues with BGP

- Reachability
- Security
- Convergence
- Performance
- Anomalies

Reachability

- In normal routing, if graph is connected then reachability is assured
- With policy routing, this does not always hold



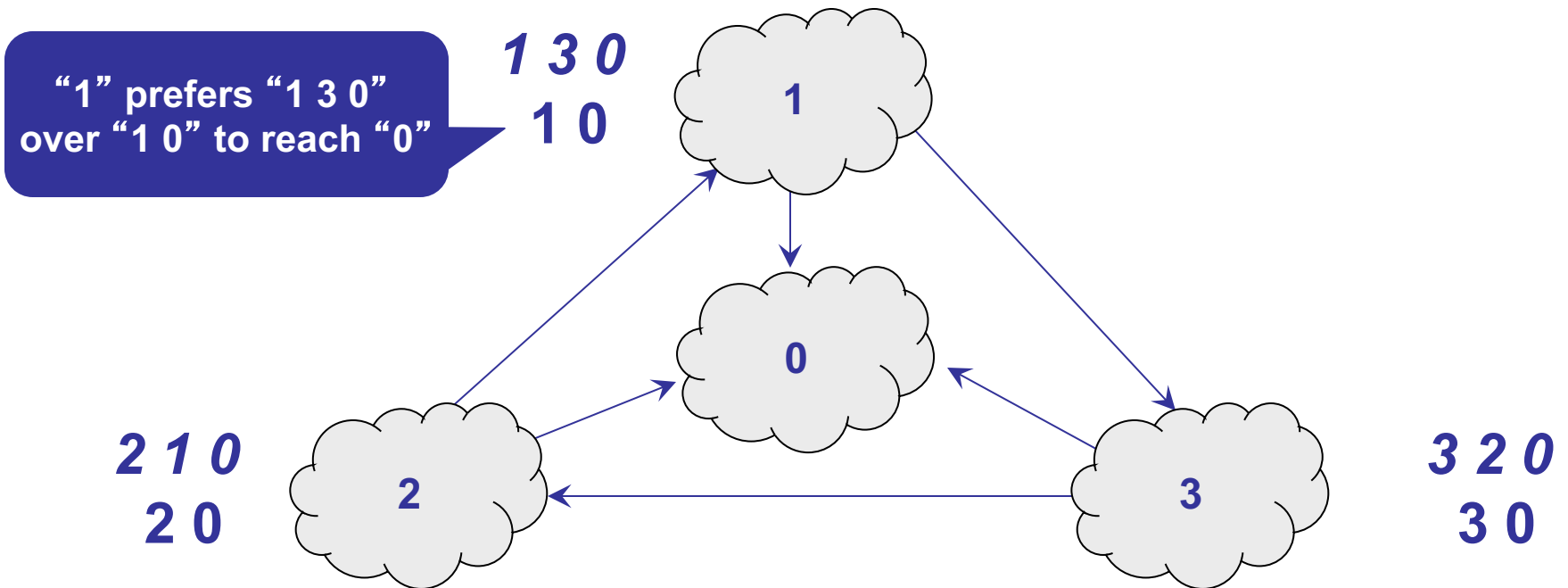
Security

- An AS can claim to serve a prefix that they do not have a route to (**blackholing**)
 - Problem not specific to policy or path vector
 - Important because of AS autonomy
 - Fixable: make ASes “prove” they have a path
- AS may forward packets along a route different from what is advertised
 - Tell customers about fictitious short path...
 - Much harder to fix!
 - More: <http://queue.acm.org/detail.cfm?id=2668966>

Convergence

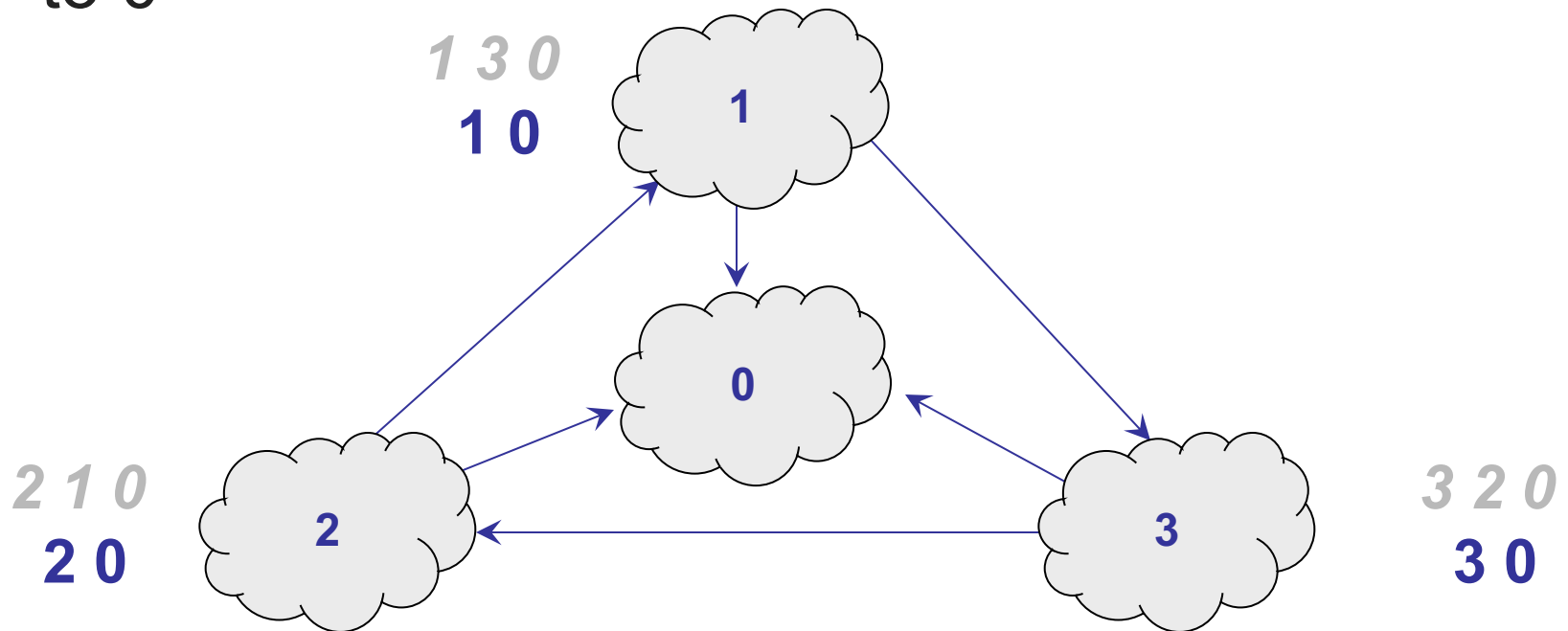
- If all AS policies follow “Gao-Rexford” rules, BGP is guaranteed to converge
- For arbitrary policies, BGP may fail to converge!

Example of policy oscillation



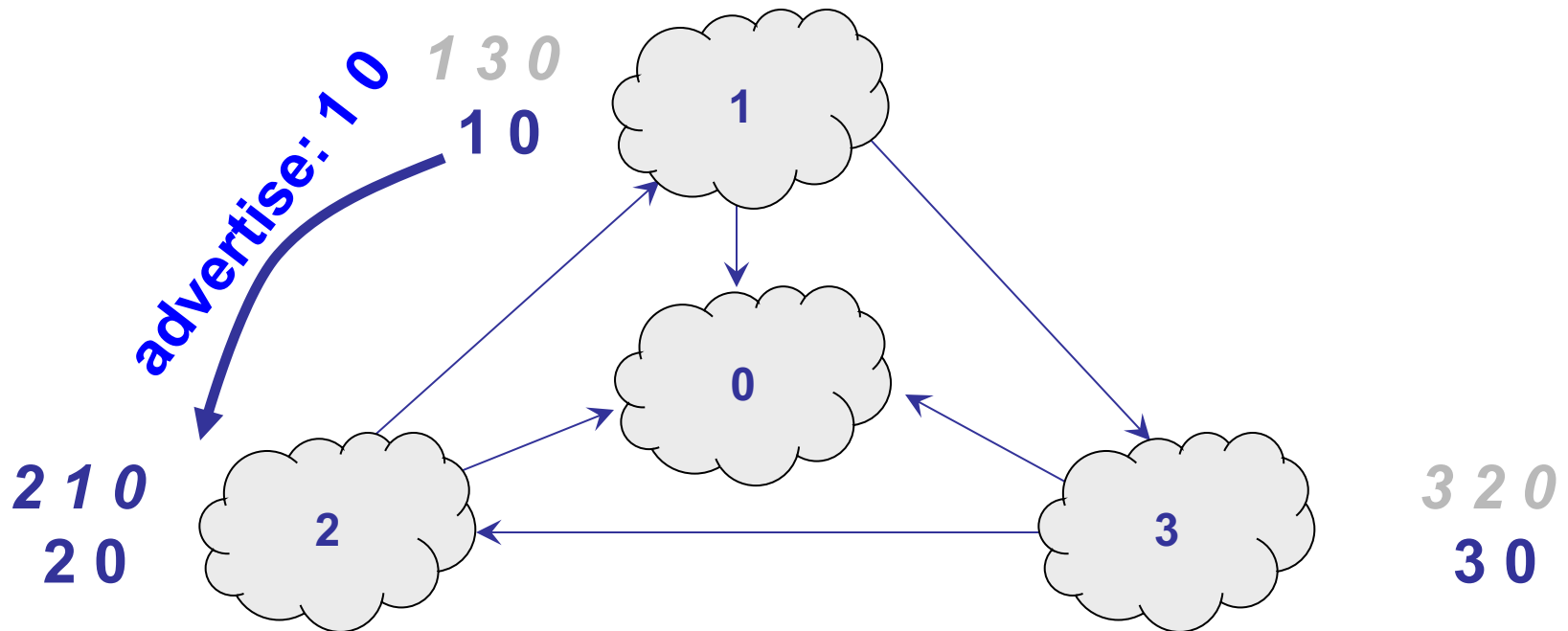
Step-by-step of policy oscillation

- Initially: nodes 1, 2, 3 know only shortest path to 0

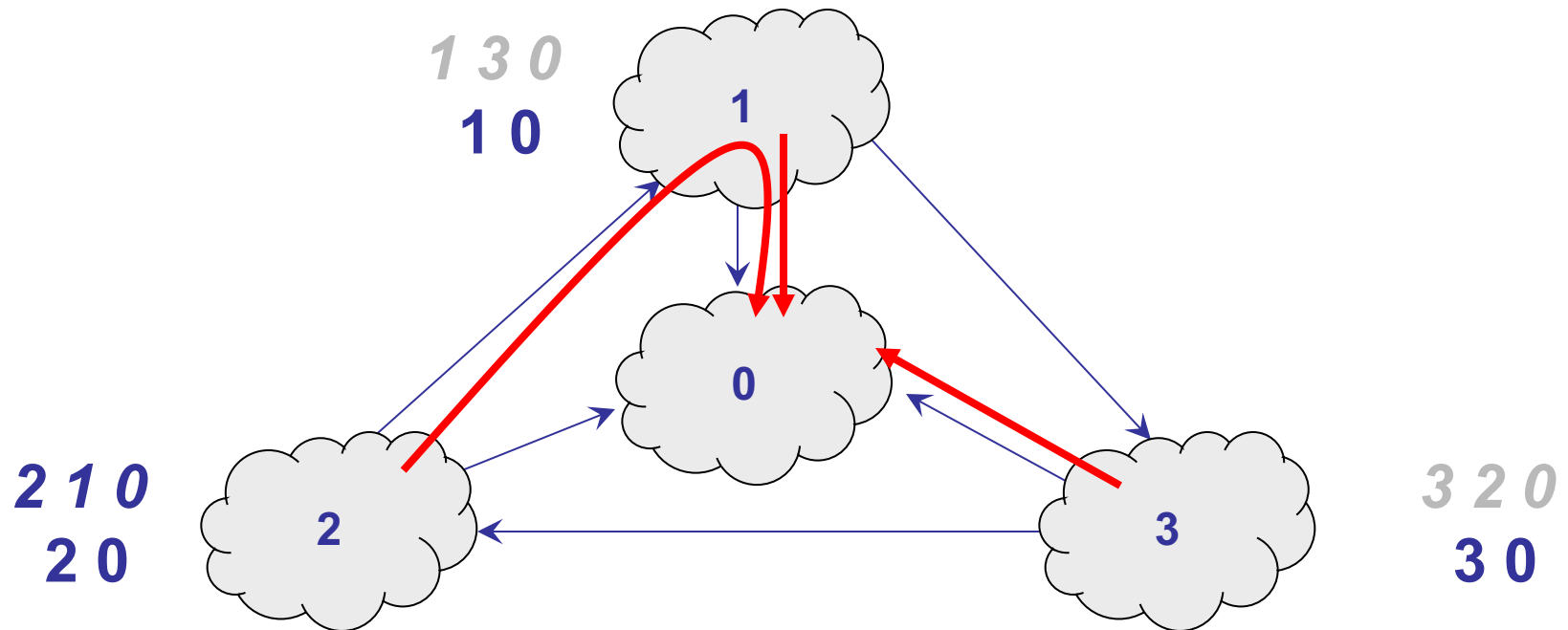


Step-by-step of policy oscillation

- 1 advertises its path 1 0 to 2

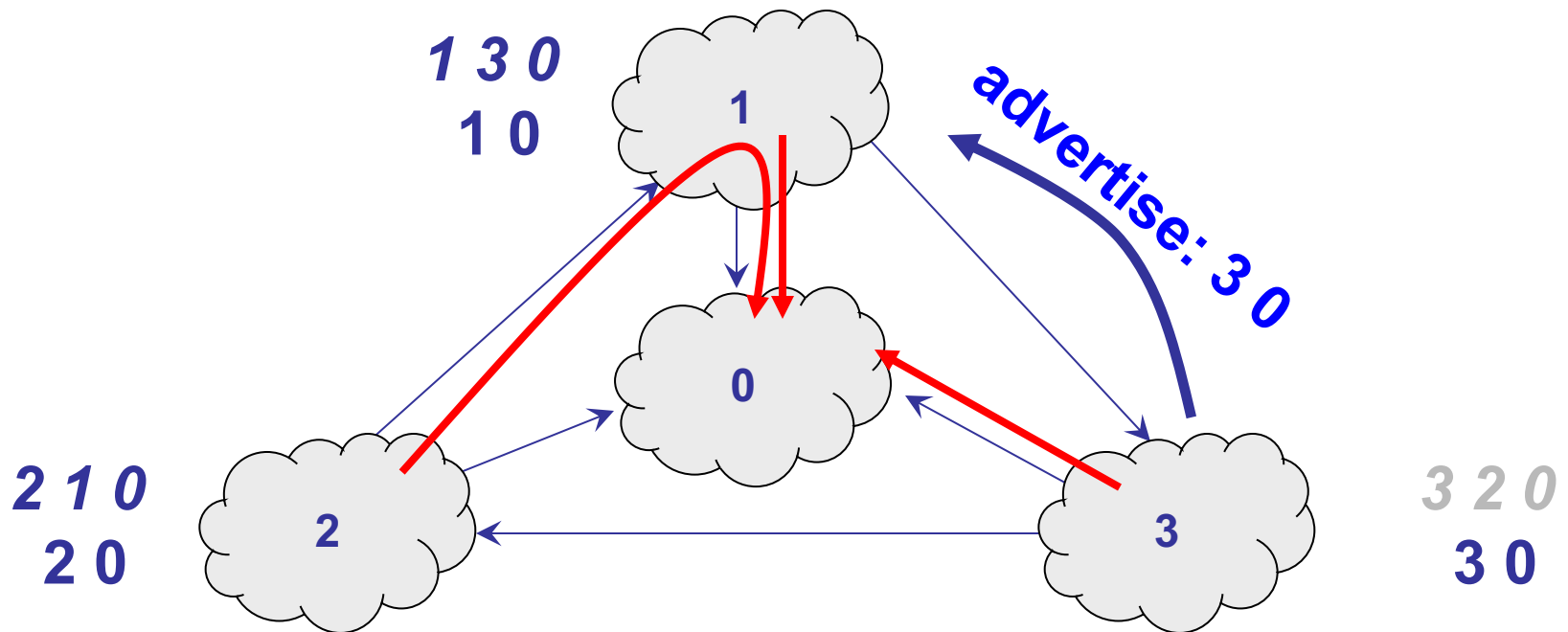


Step-by-step of policy oscillation

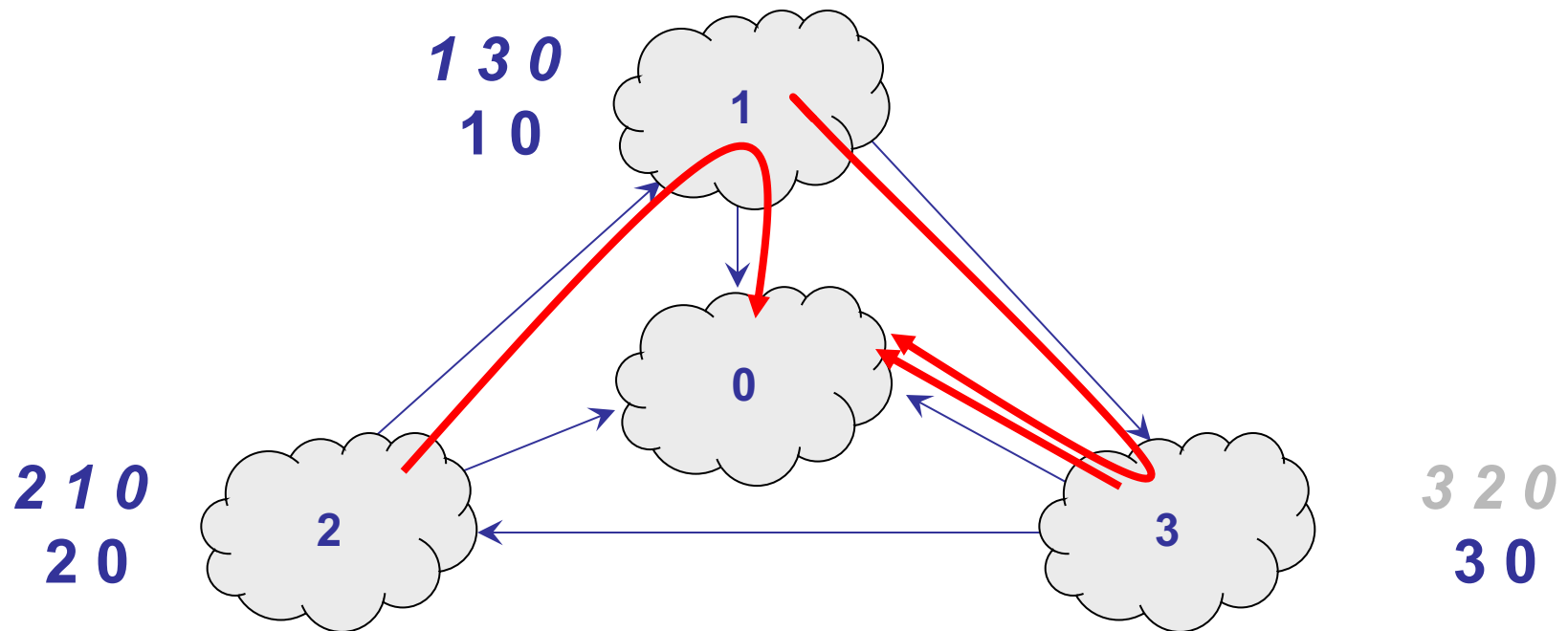


Step-by-step of policy oscillation

- 3 advertises its path 3 0 to 1

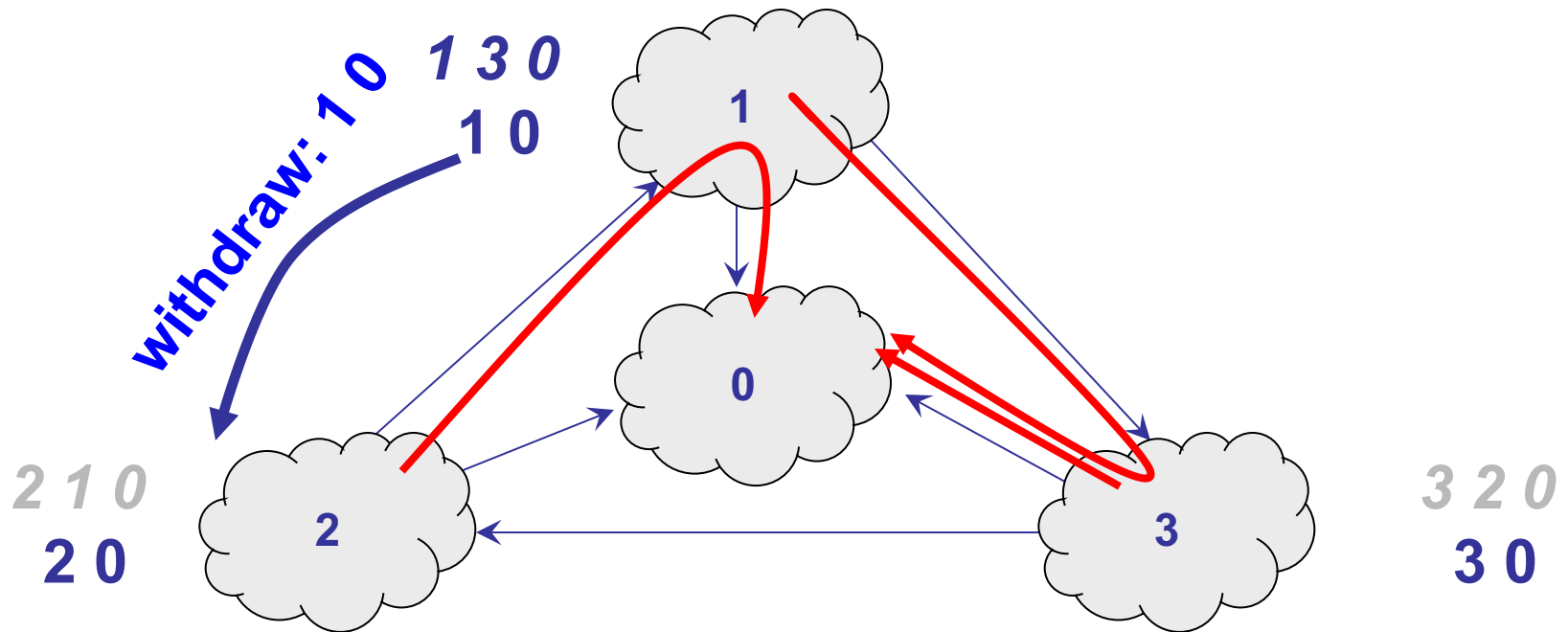


Step-by-step of policy oscillation

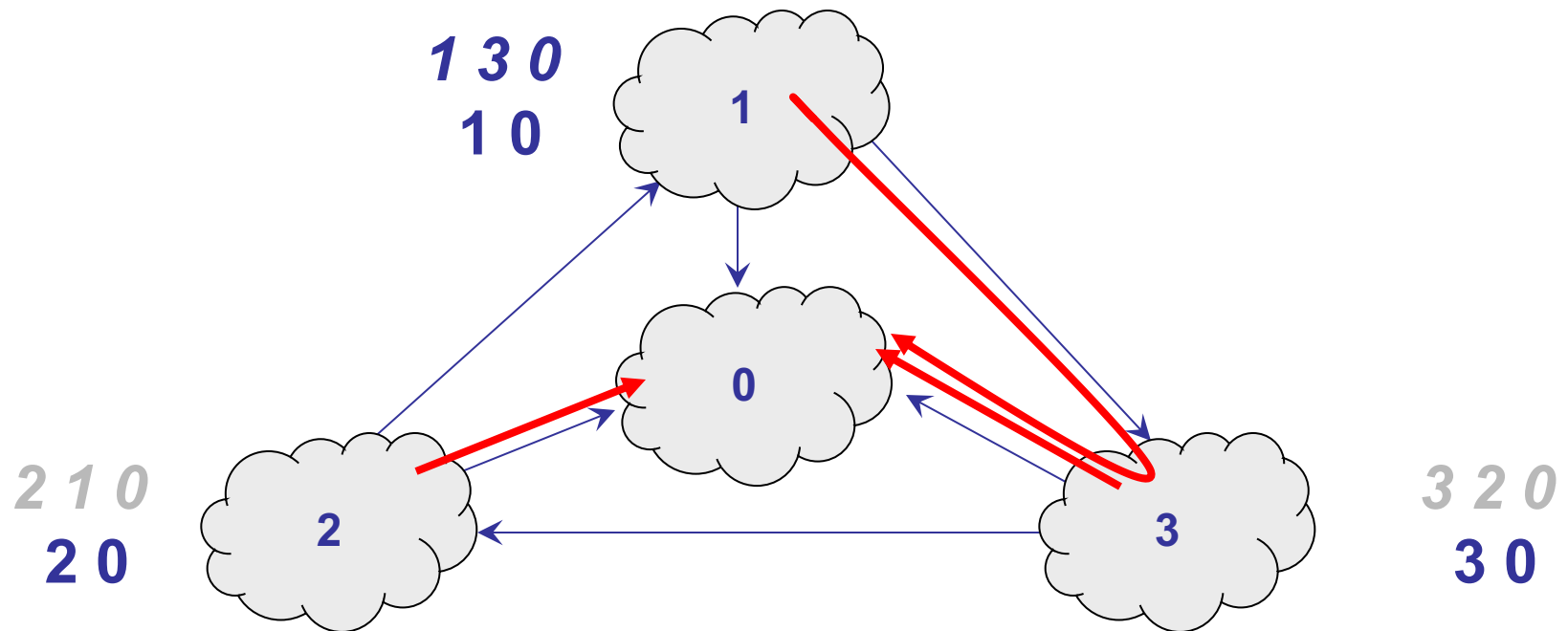


Step-by-step of policy oscillation

- 1 withdraws its path 1 0 from 2

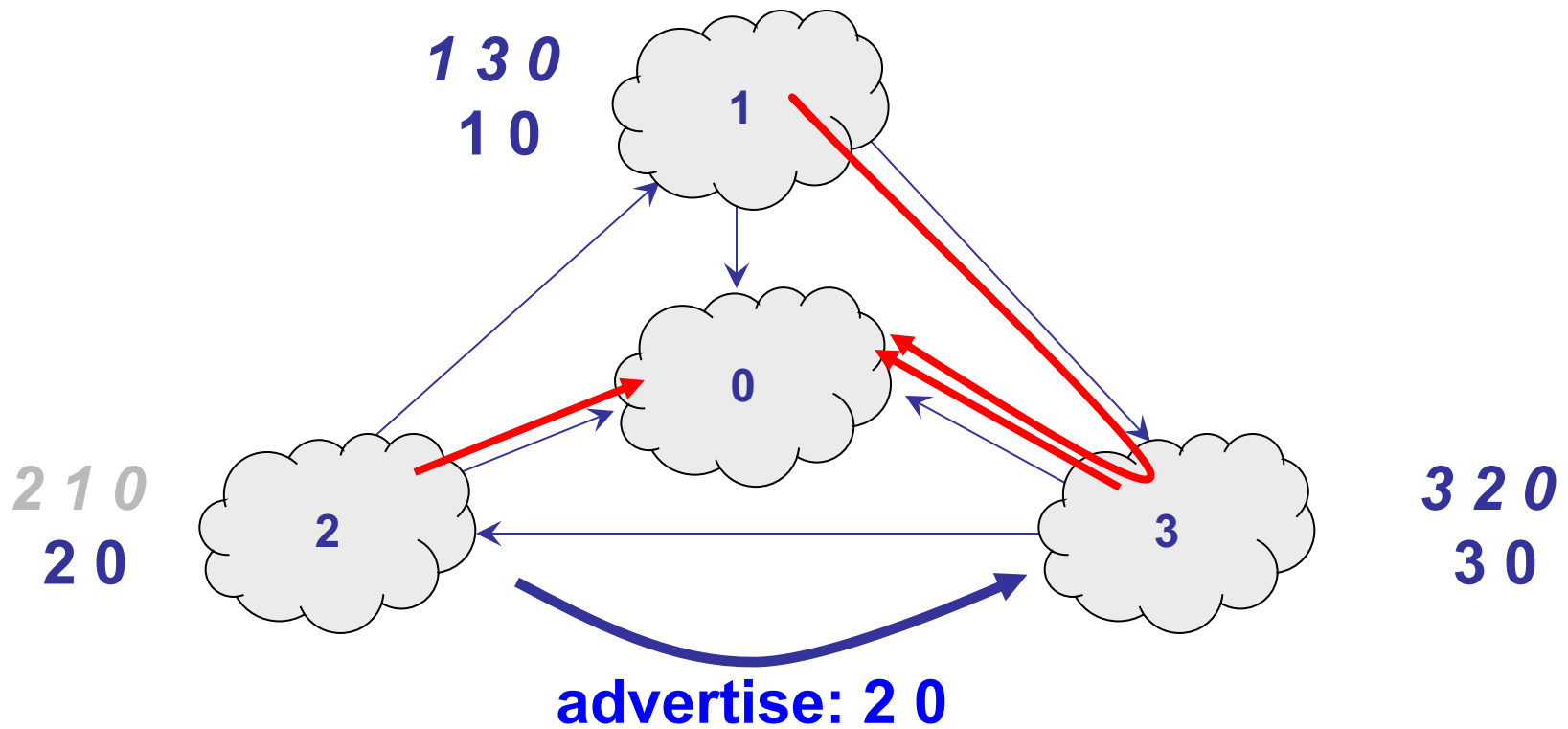


Step-by-step of policy oscillation

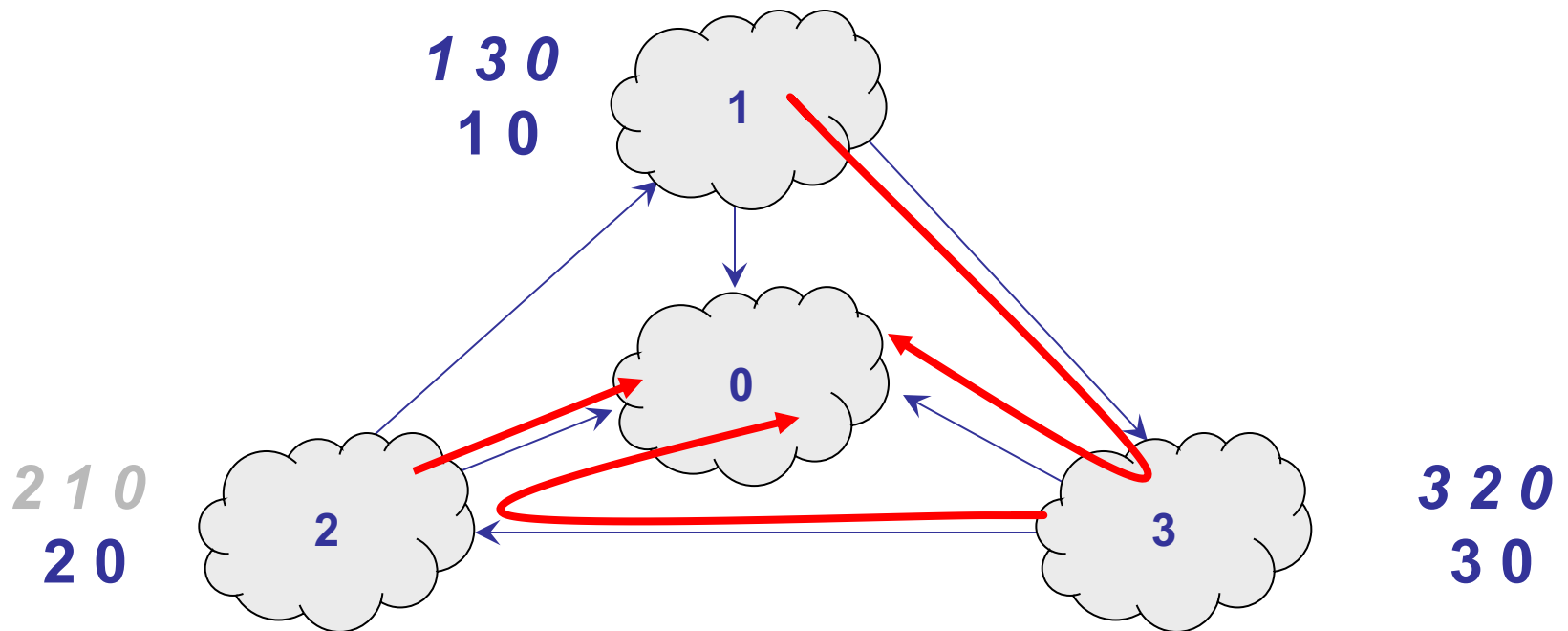


Step-by-step of policy oscillation

- 2 advertises its path 2 0 to 3

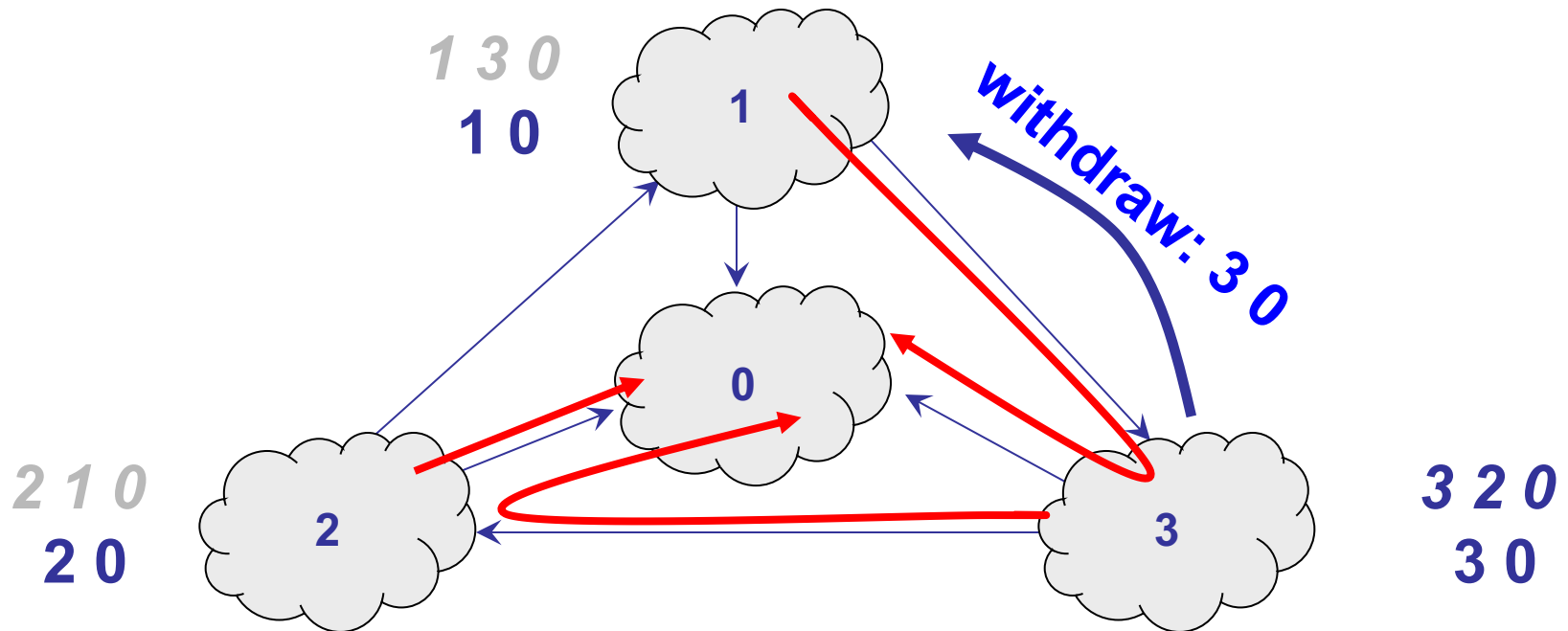


Step-by-step of policy oscillation

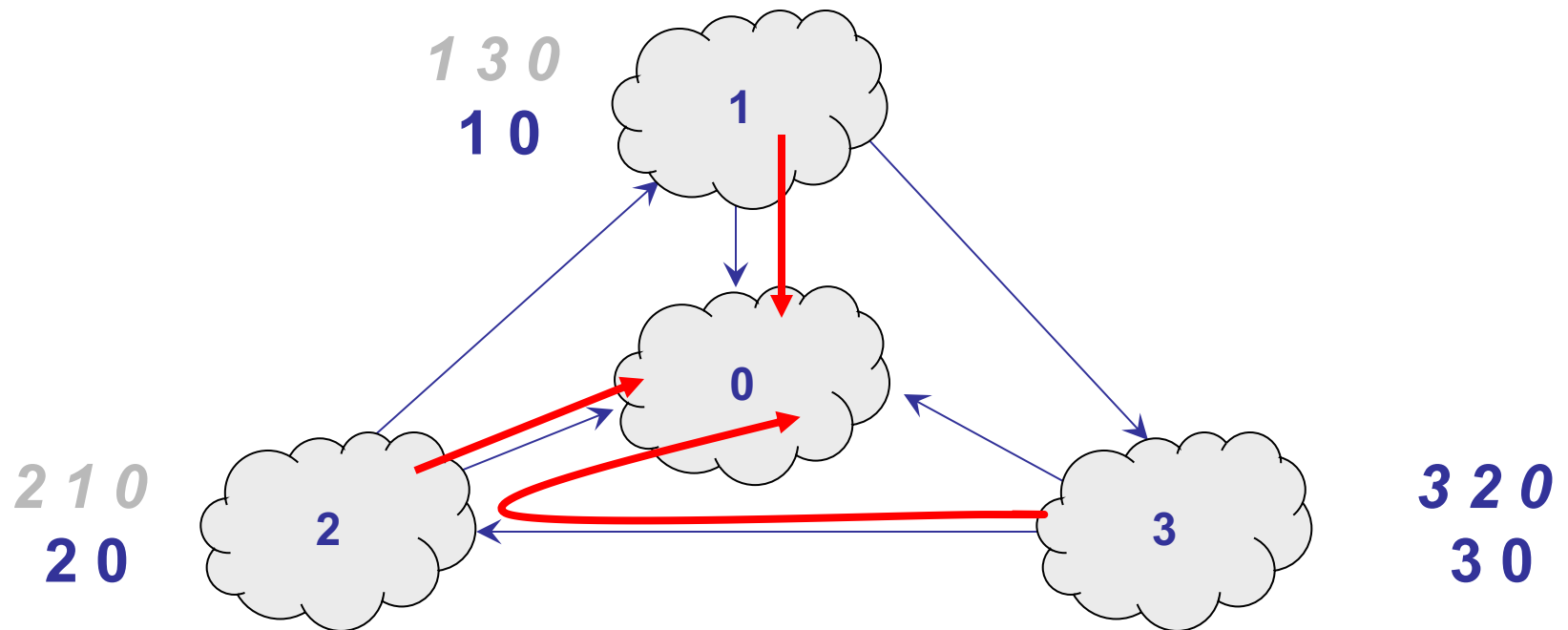


Step-by-step of policy oscillation

- 3 withdraws its path 3 0 from 1

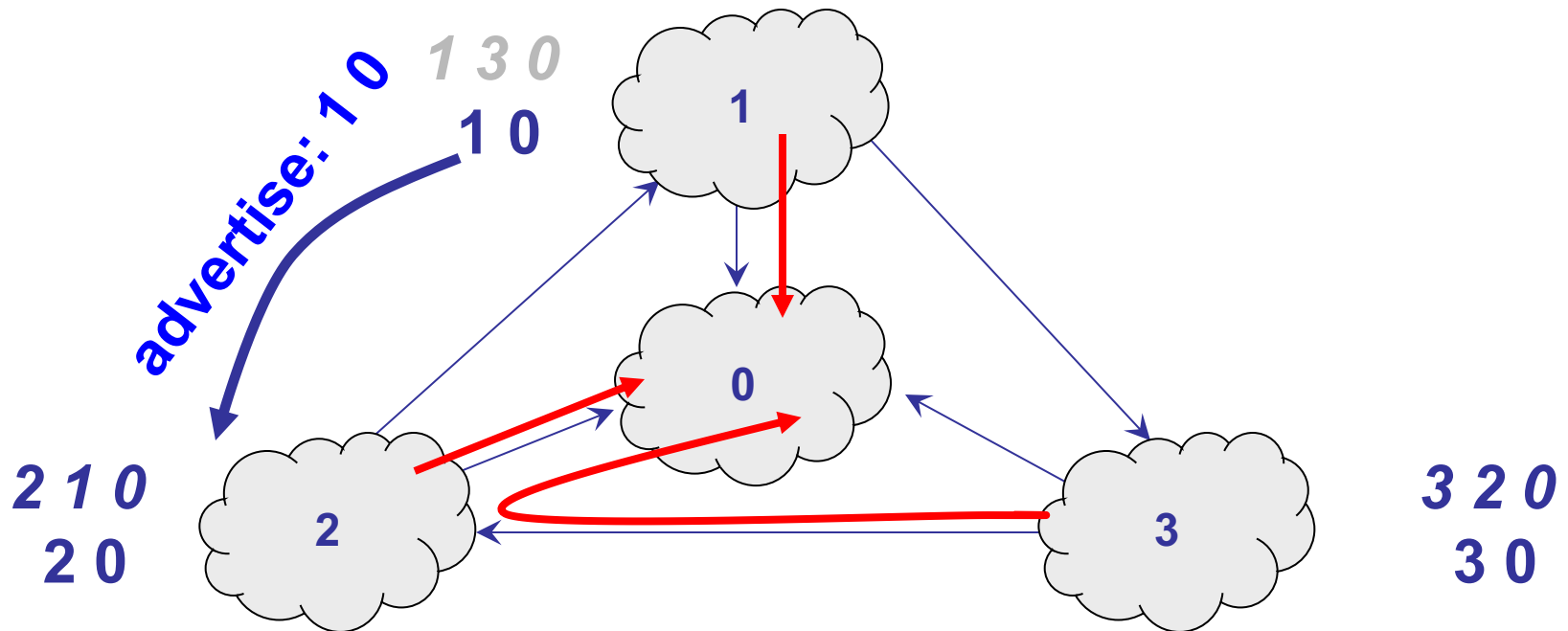


Step-by-step of policy oscillation

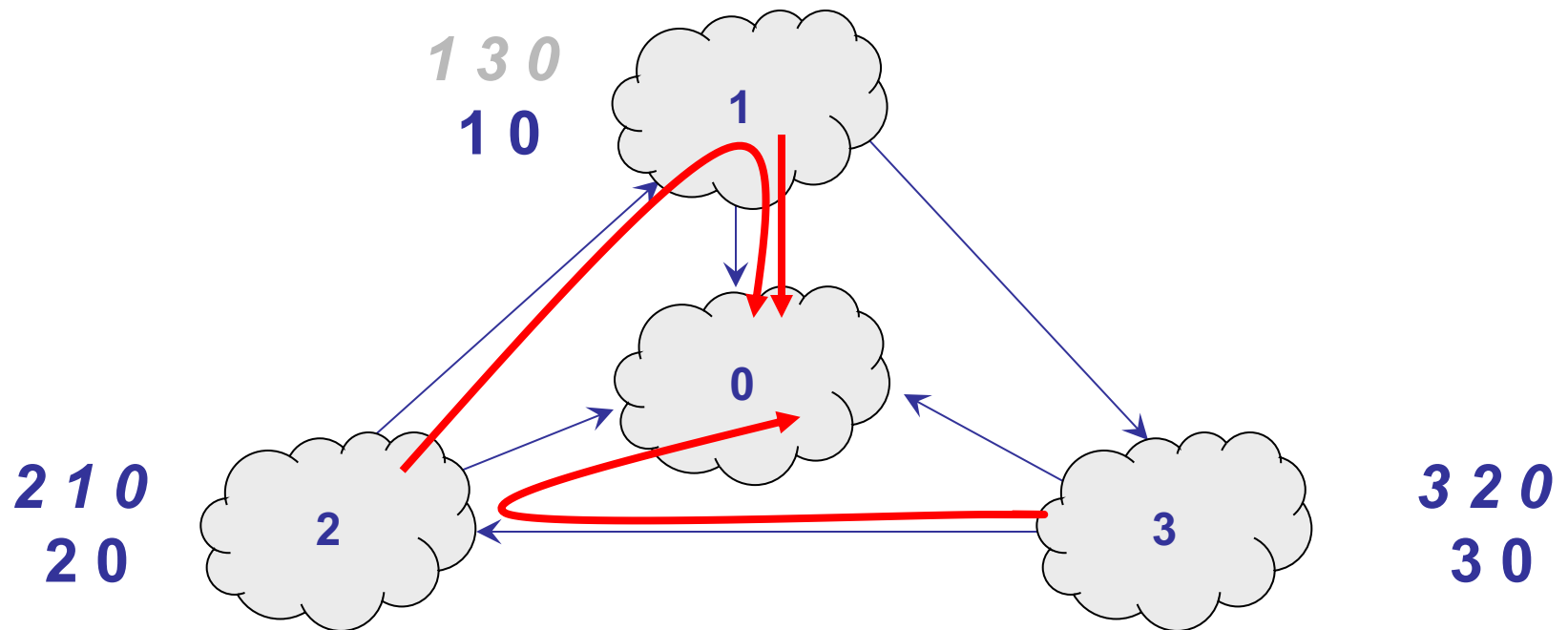


Step-by-step of policy oscillation

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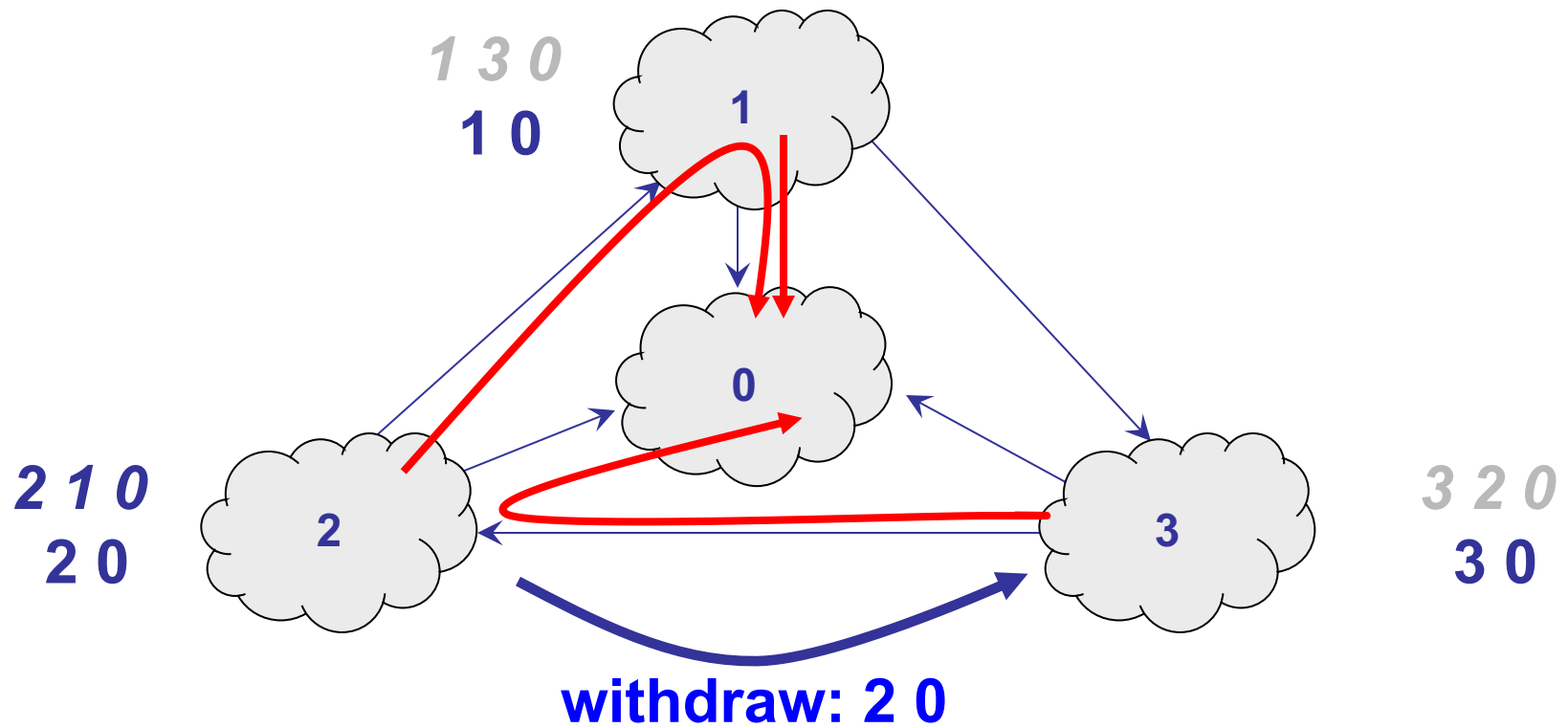


Step-by-step of policy oscillation

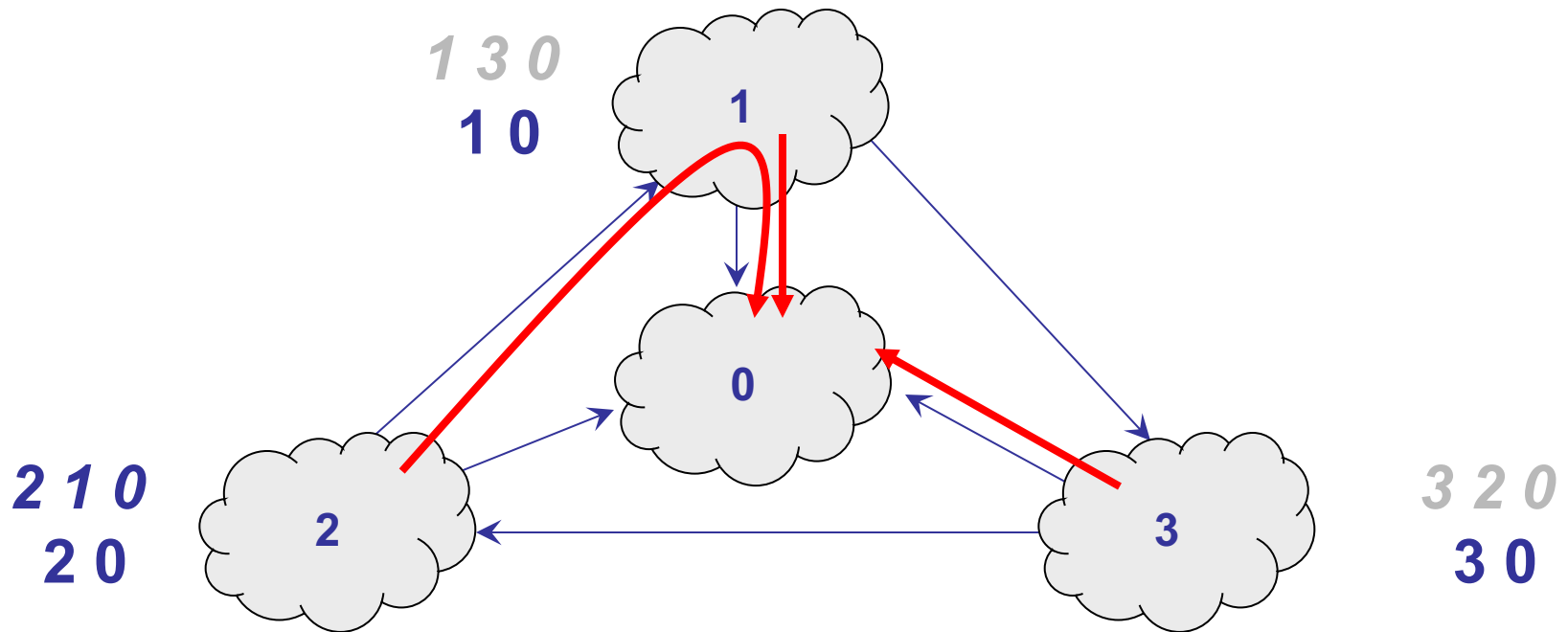


Step-by-step of policy oscillation

- 2 withdraws its path 2 0 from 3



We're back to where we started



Convergence

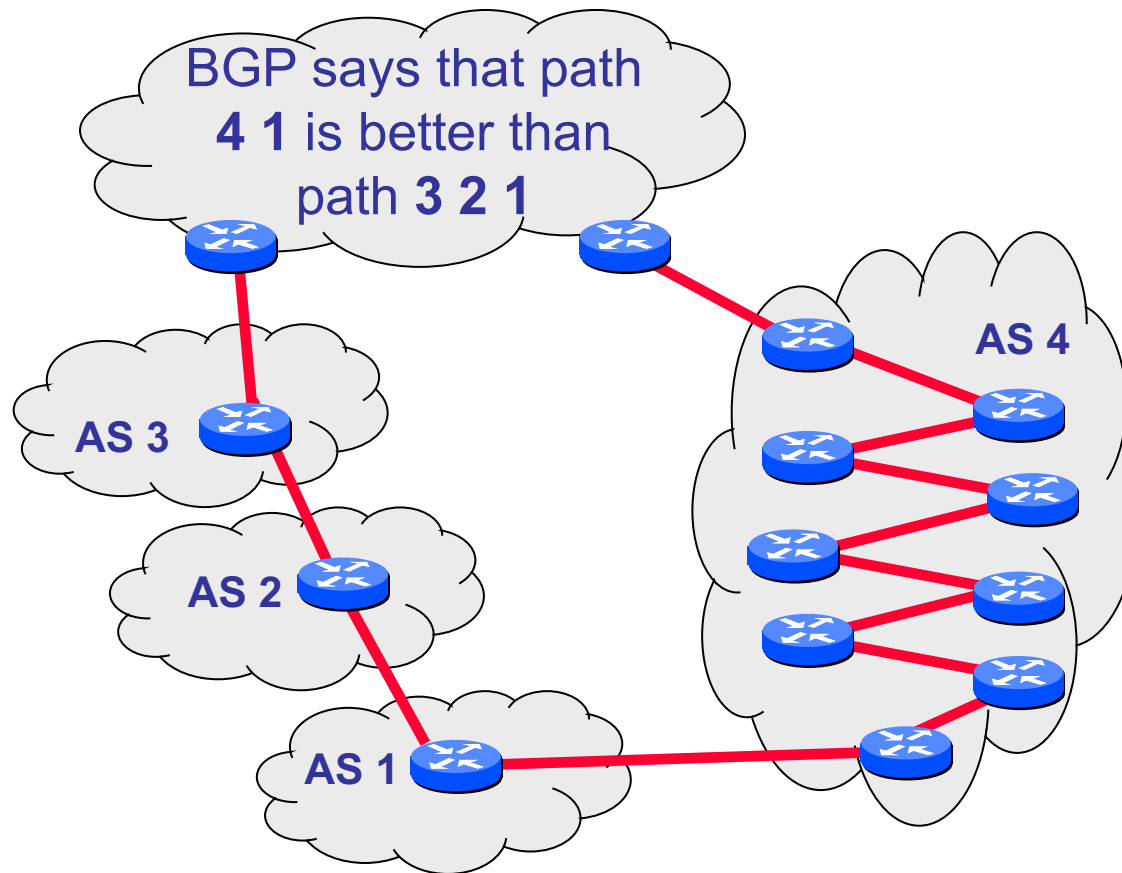
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Performance nonissues

- Internal routing
 - Domains typically use “hot potato” routing
 - Not always optimal, but economically expedient
- Policy is not always about performance
 - Policy-driven paths aren’t the shortest
- AS path length can be misleading
 - 20% of paths inflated by at least 5 router hops

AS path length can be misleading

- An AS may have many router-level hops



Real performance issue: Slow convergence

- BGP outages are biggest source of Internet problems
- Most popular paths are very stable
- Outages and other issues are very common
 - Check out <https://radar.cloudflare.com/routing>

BGP misconfigurations

- BGP protocol is bloated yet underspecified
 - Lots of attributes
 - Lots of leeway in how to set and interpret attributes
 - Necessary to allow autonomy, diverse policies
 - » But also gives operators plenty of rope
- Configuration is mostly manual and ad hoc
 - Disjoint per-router configuration to effect AS-wide policy

Summary

- Network layer deals with data plane (forwarding) and control plane (routing)
- Control plane deals with intra-domain routing (LS and DV) and inter-domain routing (BGP)
- Next class: SDN