EN.601.414/614 Computer Networks

BGP

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Spring 2019 (MW 3:00-4:15pm in Shaffer 301)

https://github.com/xinjin/course-net

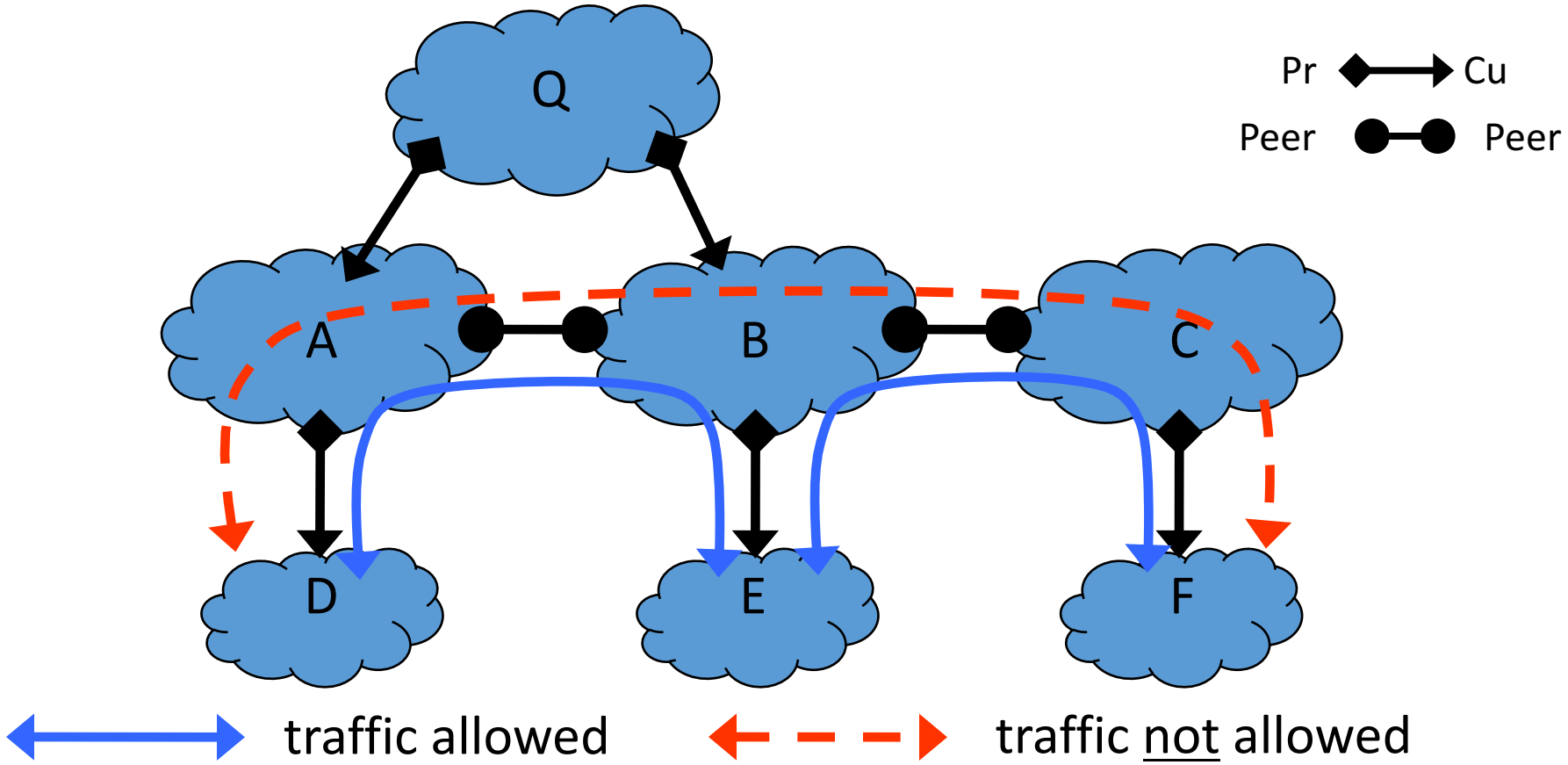
Agenda

- **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

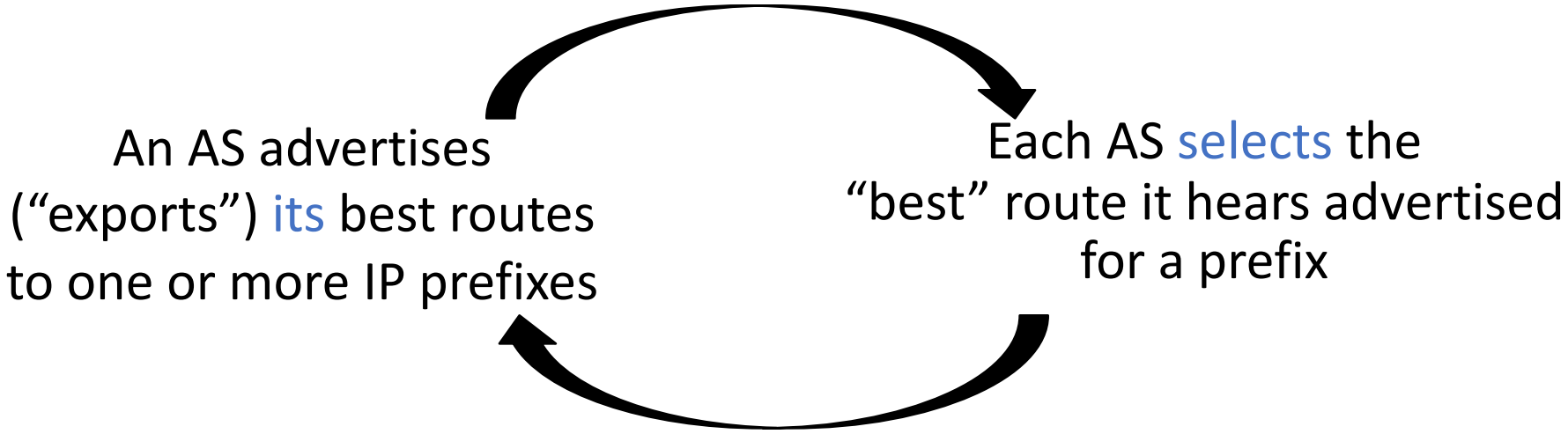
Routing follows the money!



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

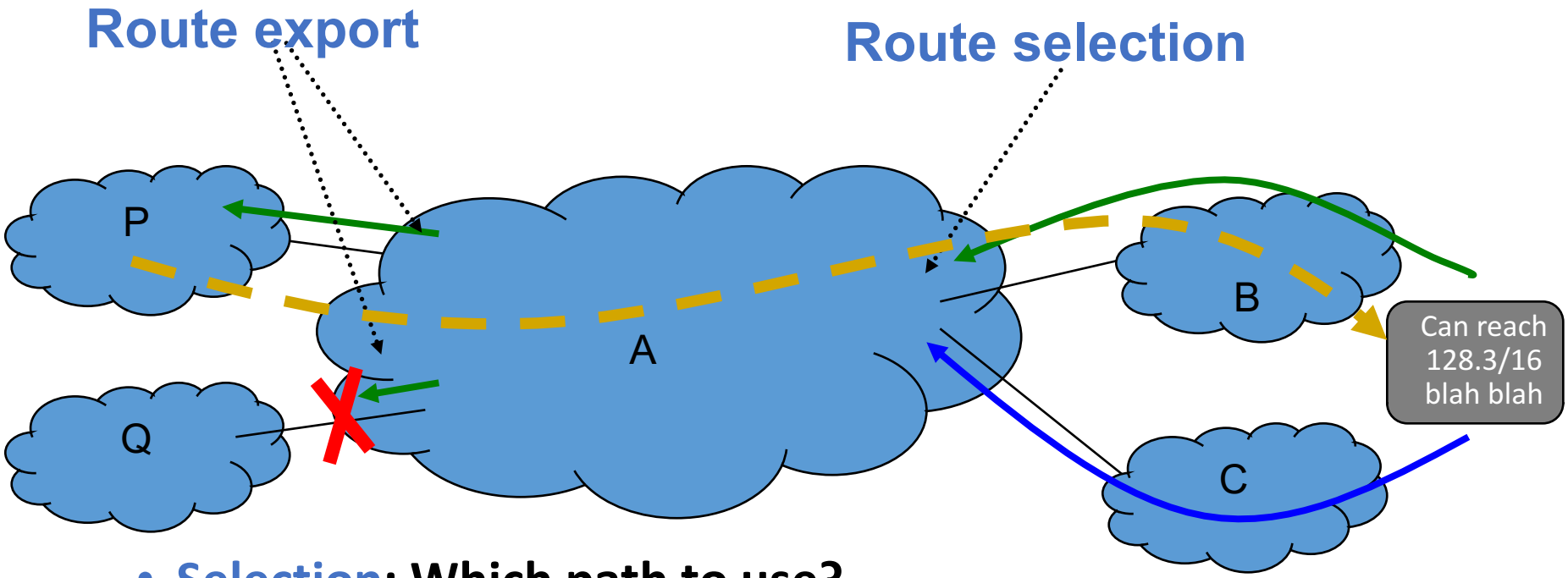


BGP inspired by Distance-Vector with four differences

- **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

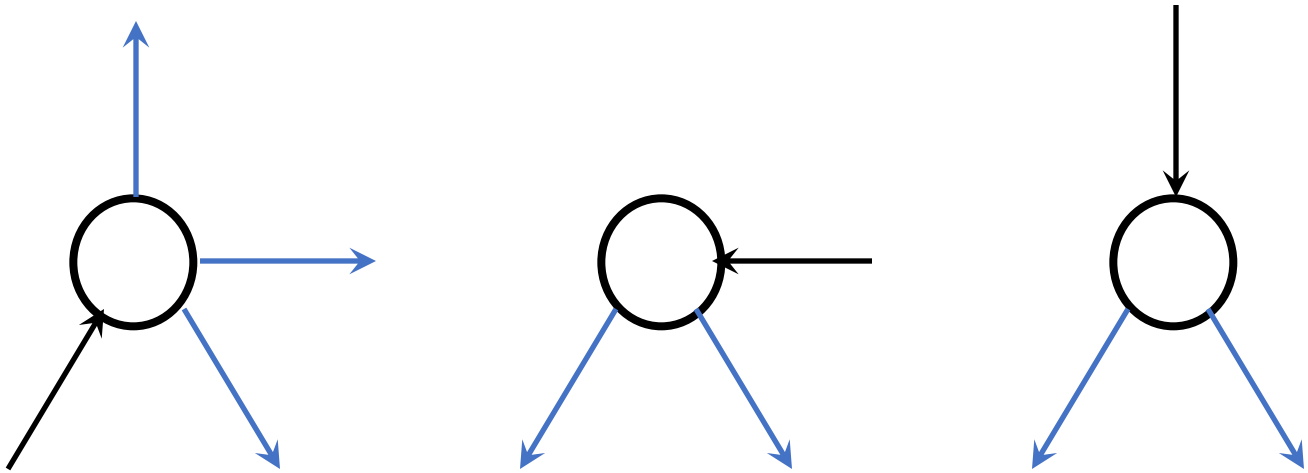
We'll refer to these as the "Gao-Rexford" rules (capture common – but not required! – practice)

Gao-Rexford

Providers

Peers

Customers

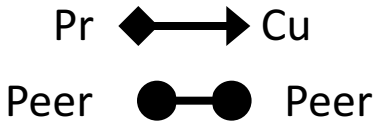


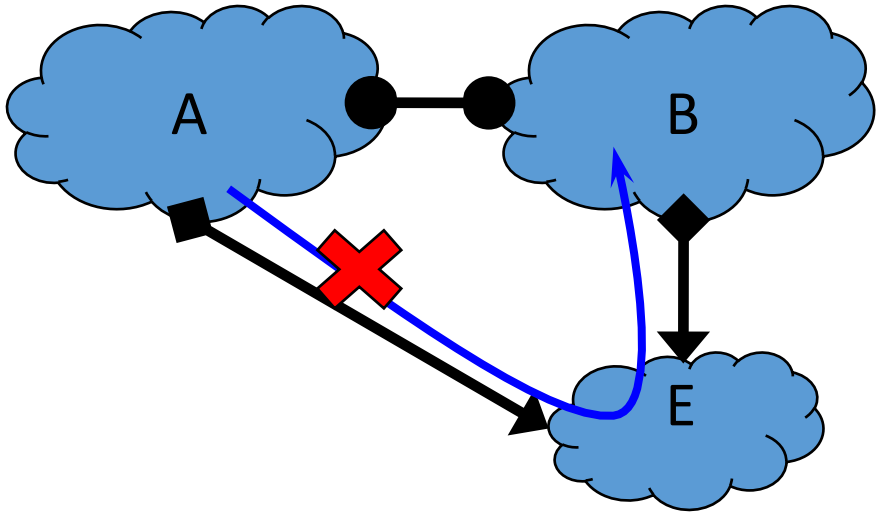
With Gao-Rexford, the AS policy graph is a
DAG (directed acyclic graph) and routes are “valley free”

Valley-Free Routing

- **Number links as (+1, 0, -1) for customer-to-provider, peer and provider-to-customer**
- **In any path should only see sequence of +1, followed by at most one 0, followed by sequence of -1**

Example: Valley-Free Routing

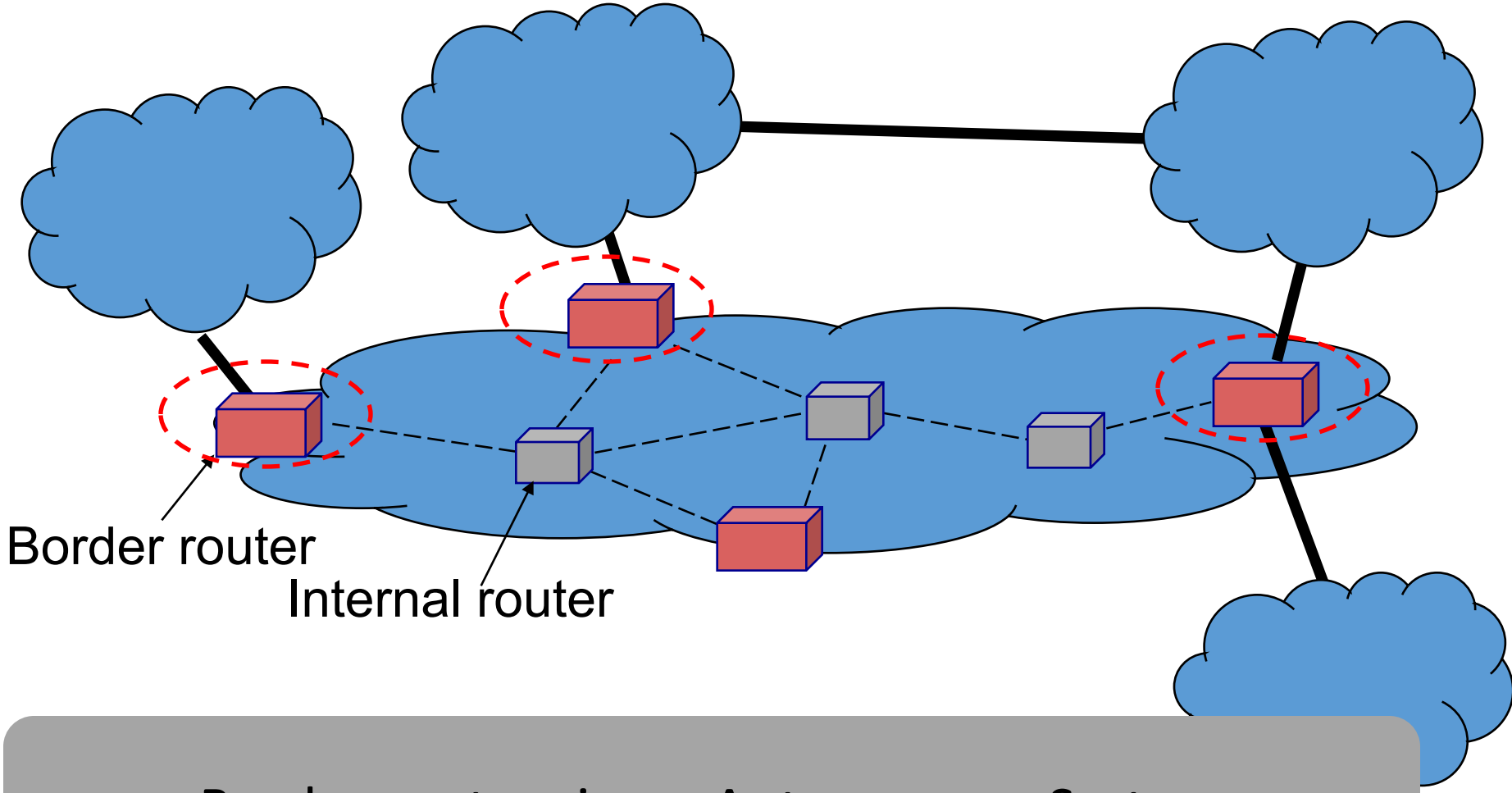




- The path is (-1, +1). It is not valley-free.

BGP Protocol details

Who speaks BGP?

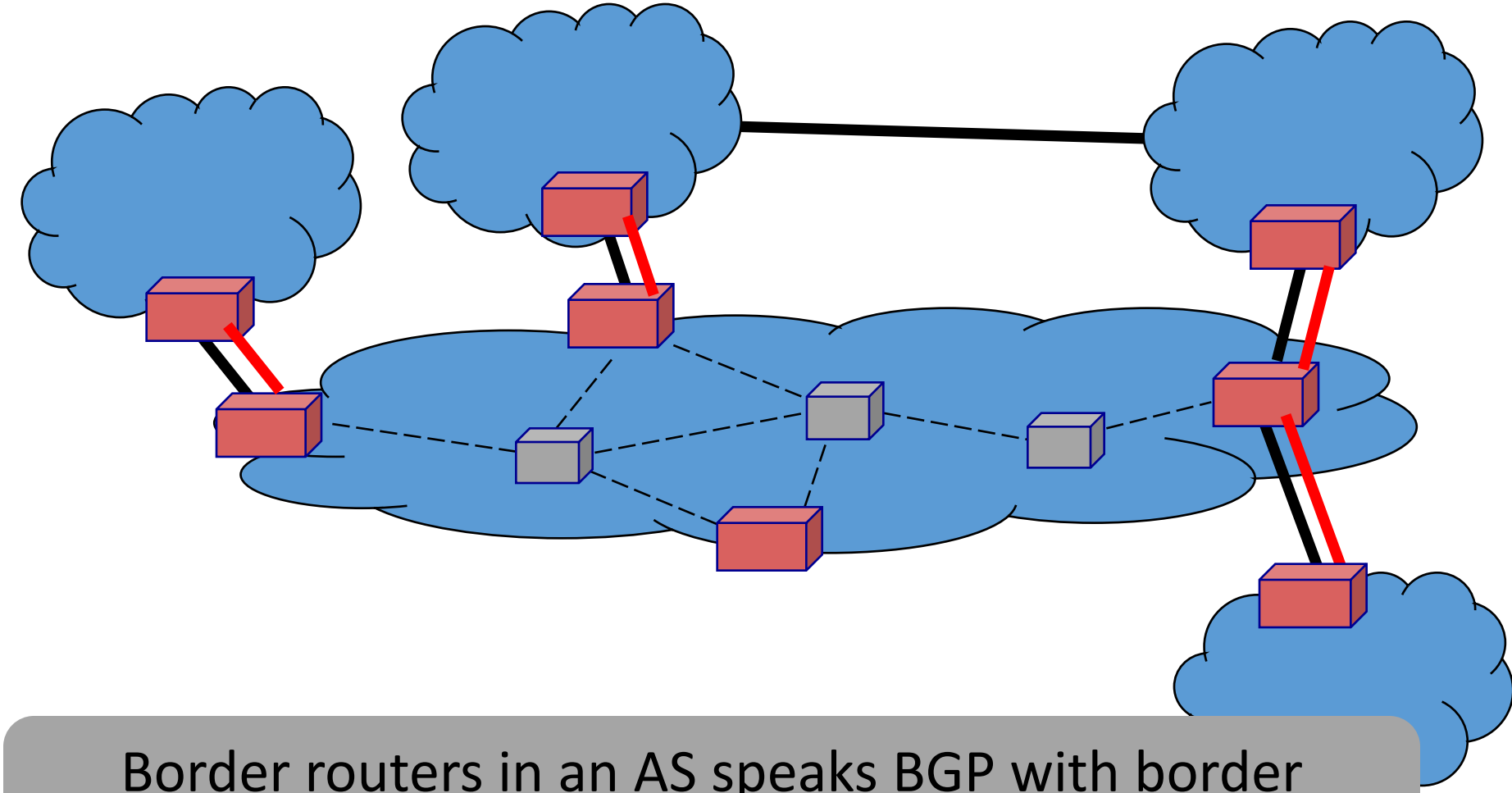


Border routers in an Autonomous System

What does “speak BGP” mean?

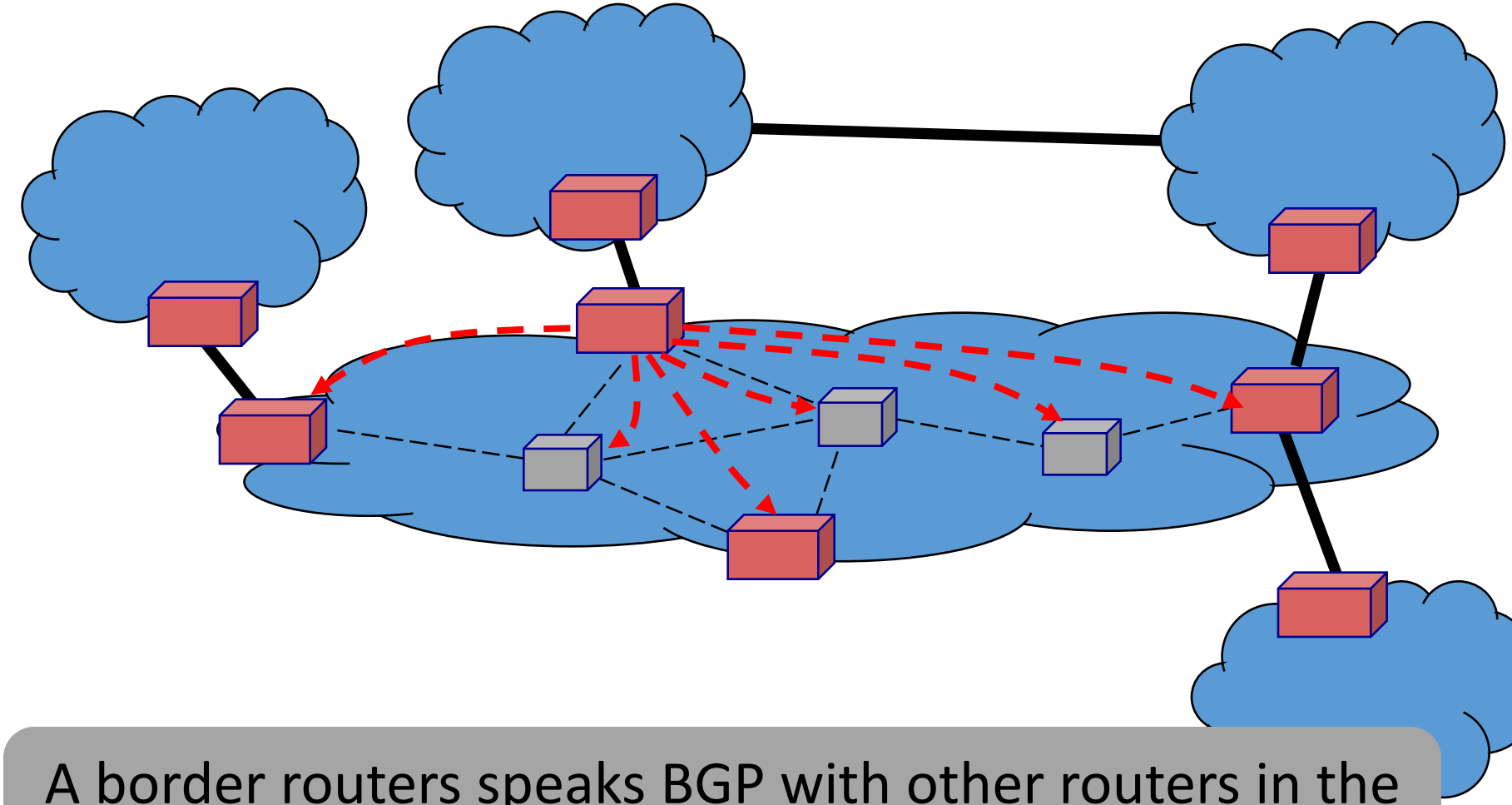
- **Implement the BGP protocol standard**
  - Read more here: http://tools.ietf.org/html/rfc4271
- **Specifies what messages to exchange with other BGP “speakers”**
  - Message types (e.g., route advertisements, updates)
  - Message syntax
- **How to process these messages**
  - E.g., “when you receive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

BGP sessions: External



Border routers in an AS speaks 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

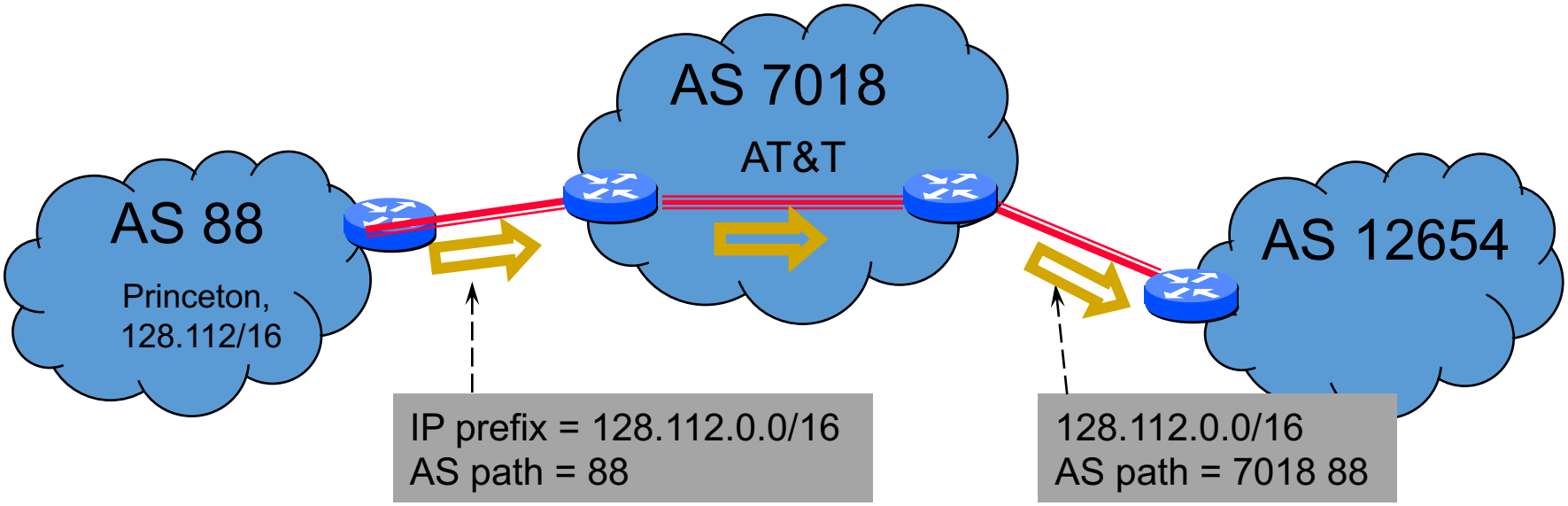
- **Format <IP prefix: route attributes>**
  - Attributes describe properties of the route
- **Two kinds of updates**
  - Announcements: new routes or changes to existing routes
  - Withdrawal: remove routes that no longer exist

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

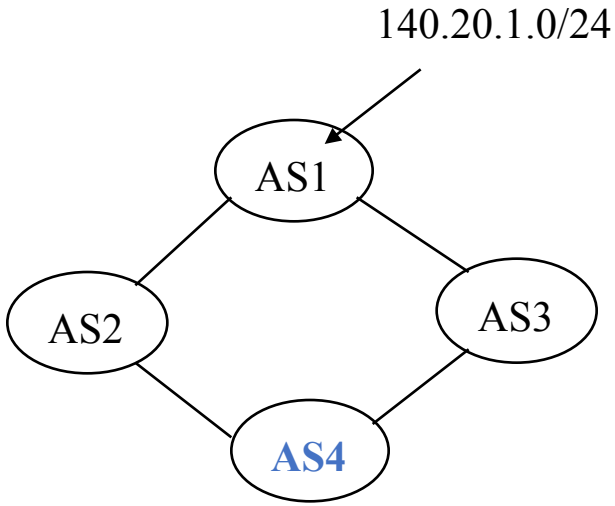
Attributes: (1) ASPATH

- **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**

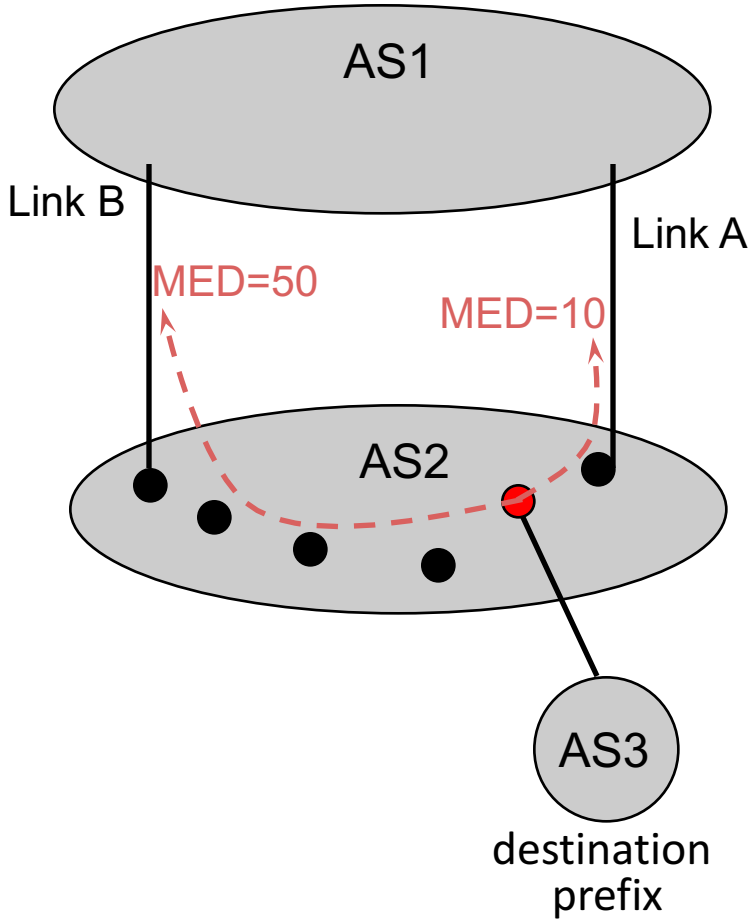


BGP table at AS4:

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

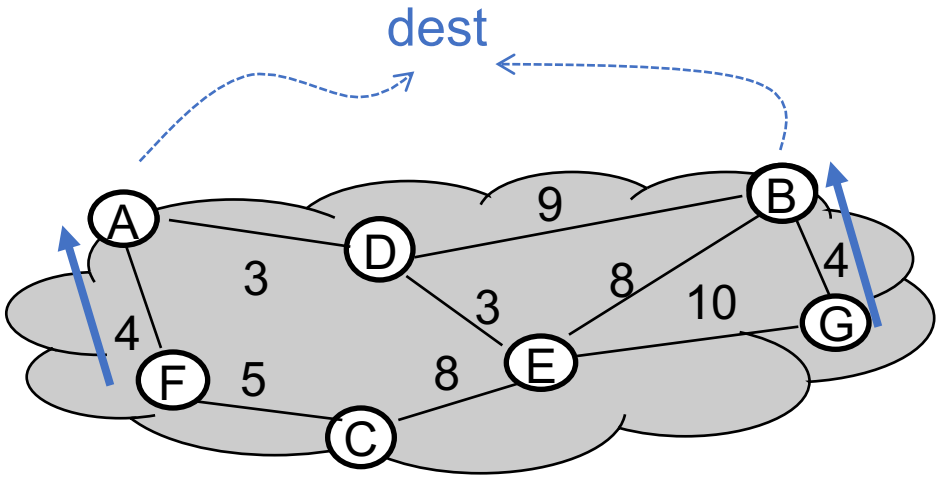
Attributes: (3) MED

- **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

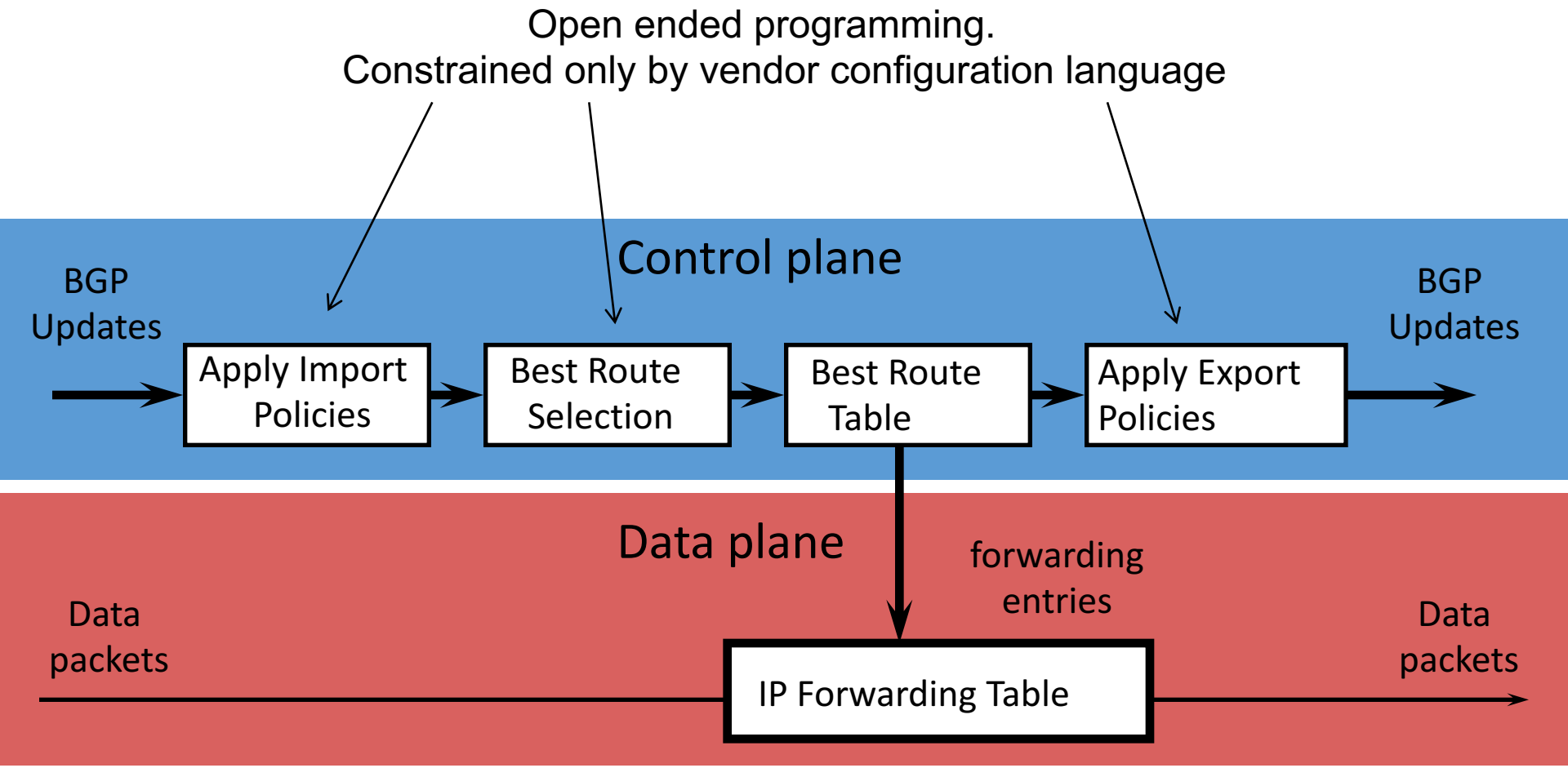


Using attributes

- **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



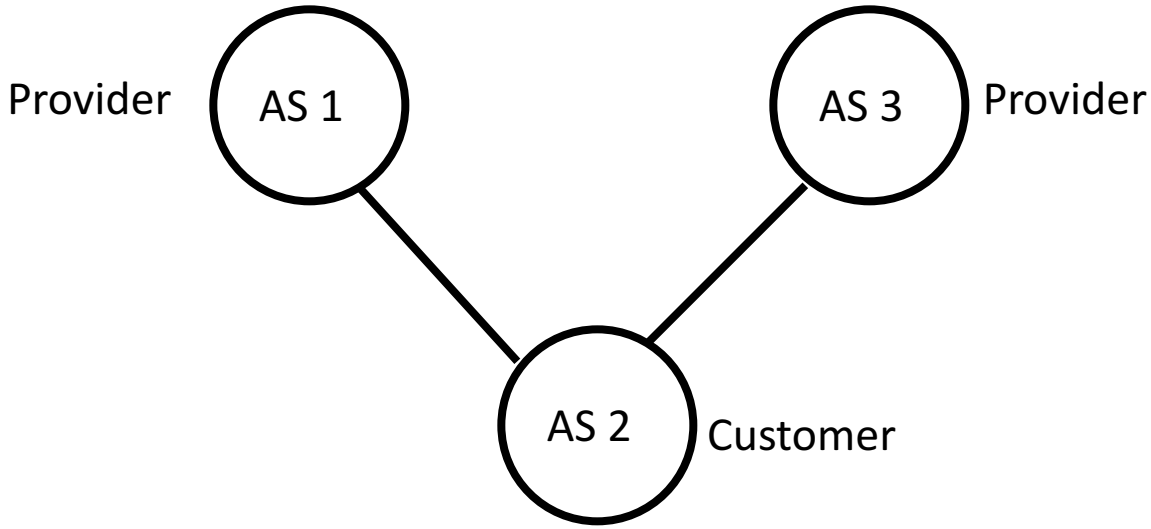
BGP issues in practice

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**



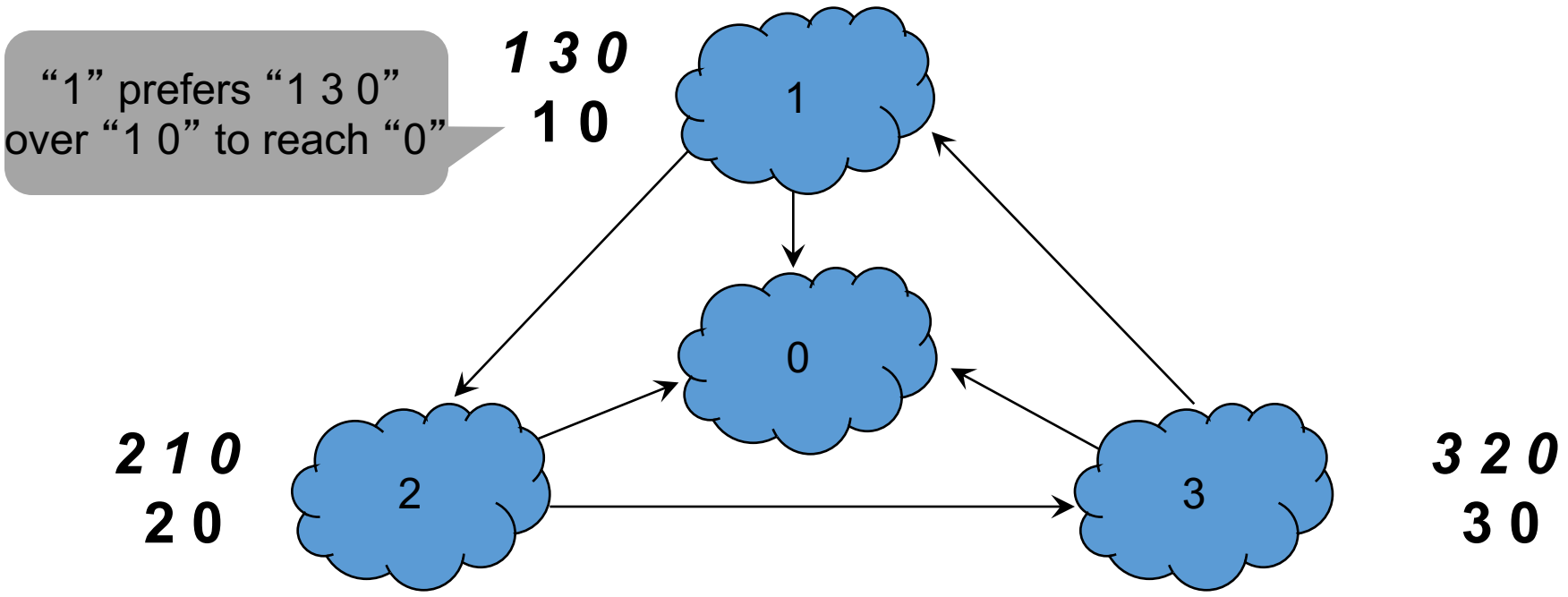
Security

- **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

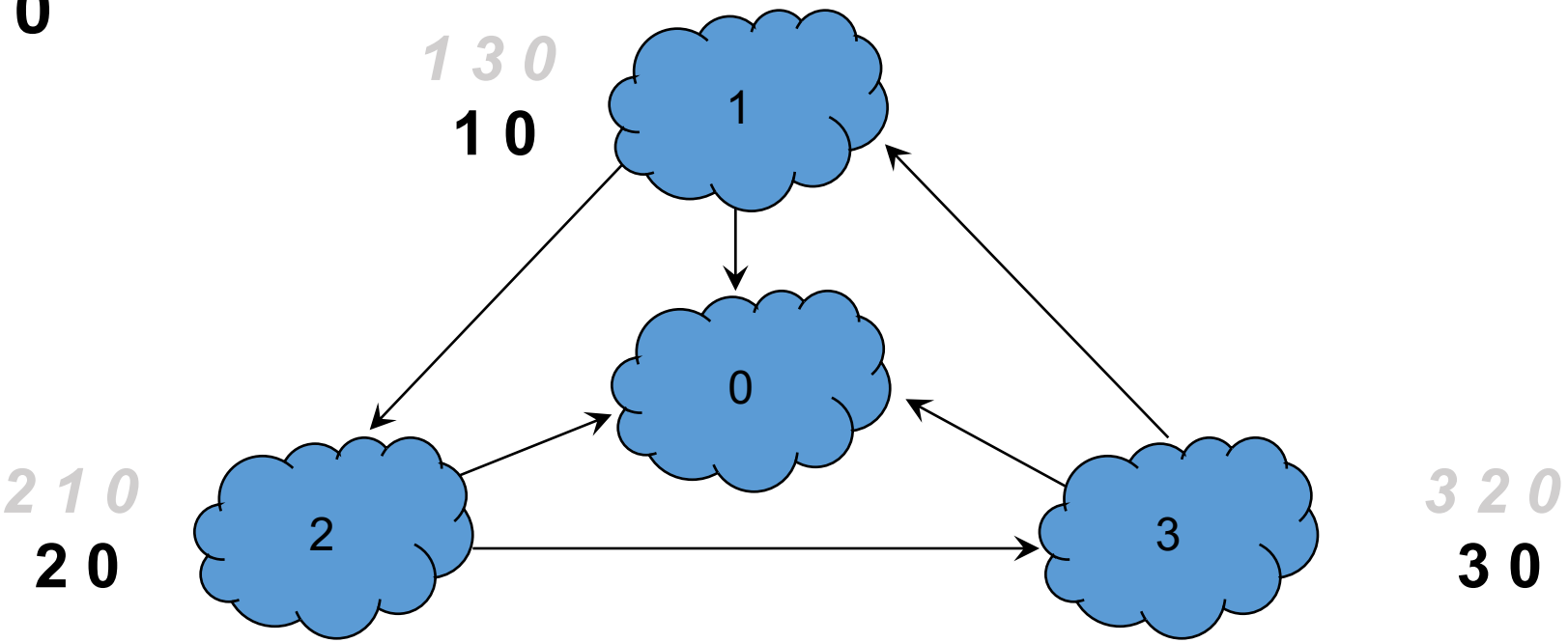
- **If all AS policies follow "Gao-Rexford" rules, BGP is guaranteed to converge**
  - A set of rules that decide the preferences of routes, e.g., prefer a route via a customer over a route via a provider or peer
- **For arbitrary policies, BGP may fail to converge!**

Example of policy oscillation



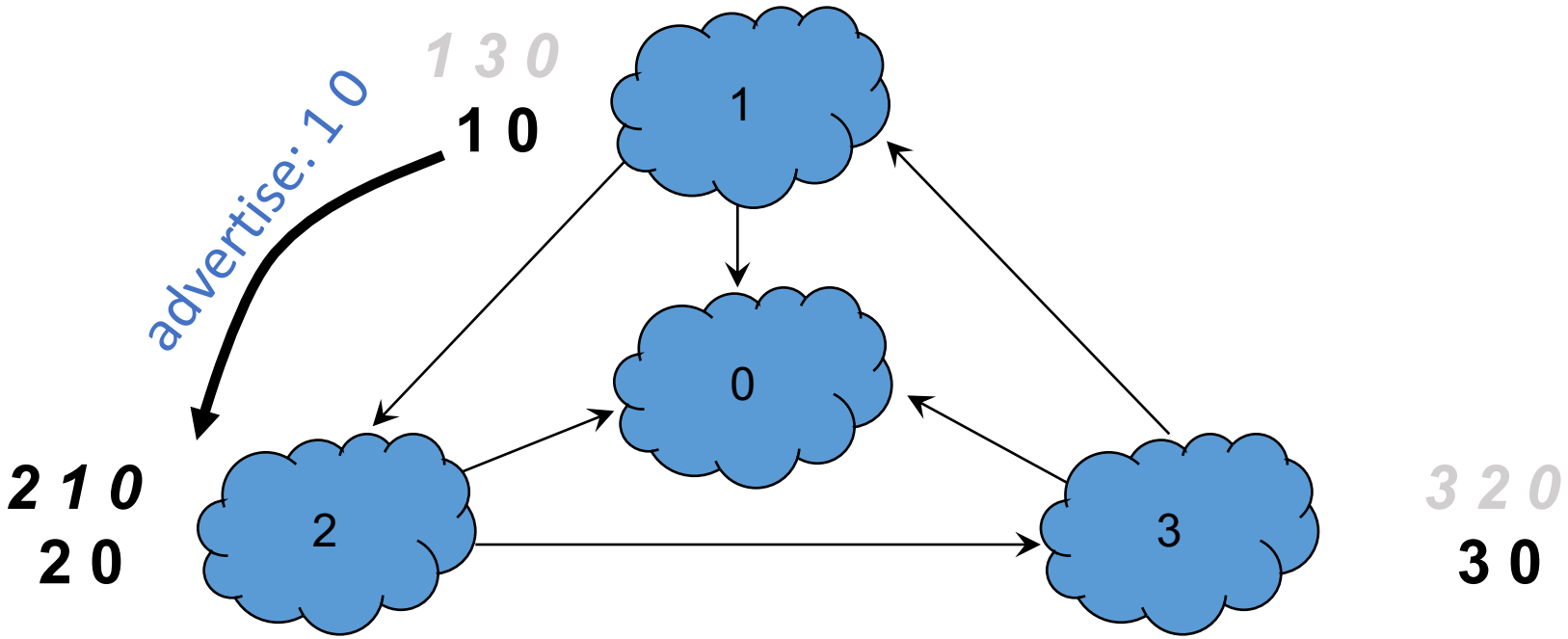
Step-by-step of policy oscillation

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

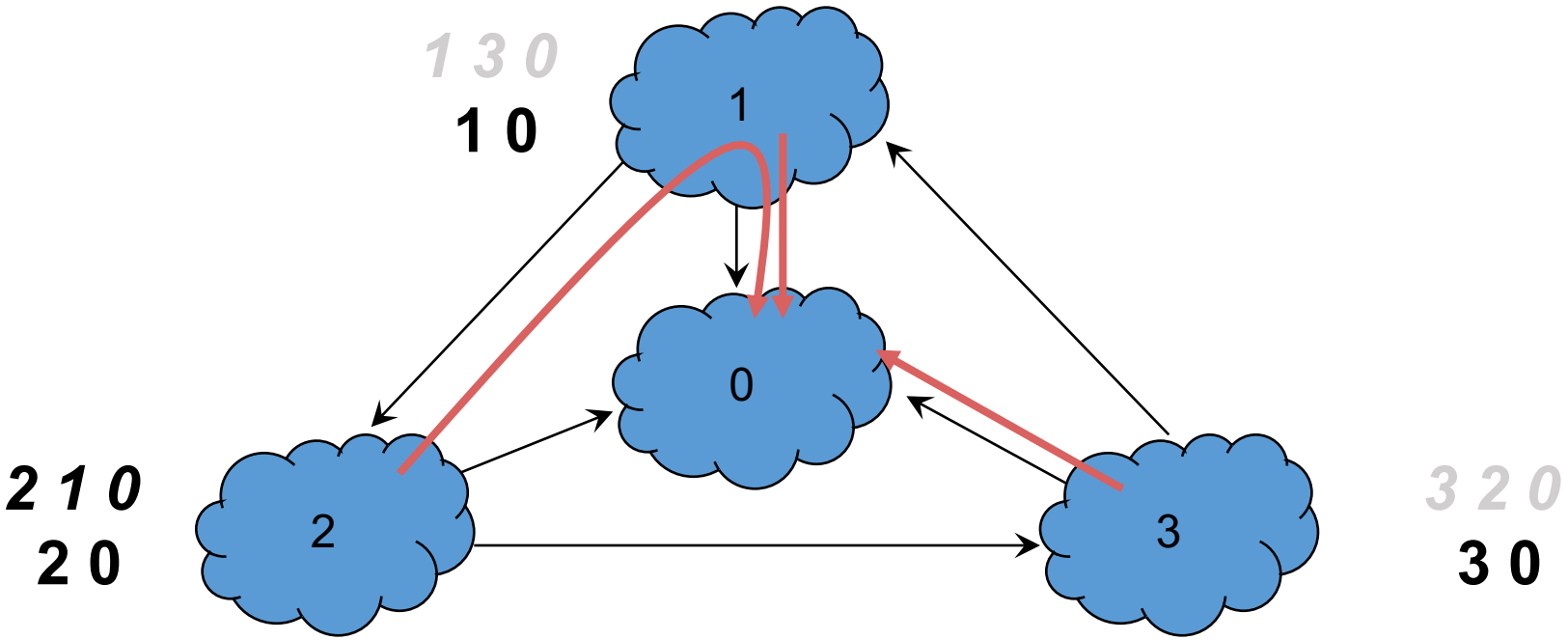


Step-by-step of policy oscillation

- **1 advertises its path 1 0 to 2**

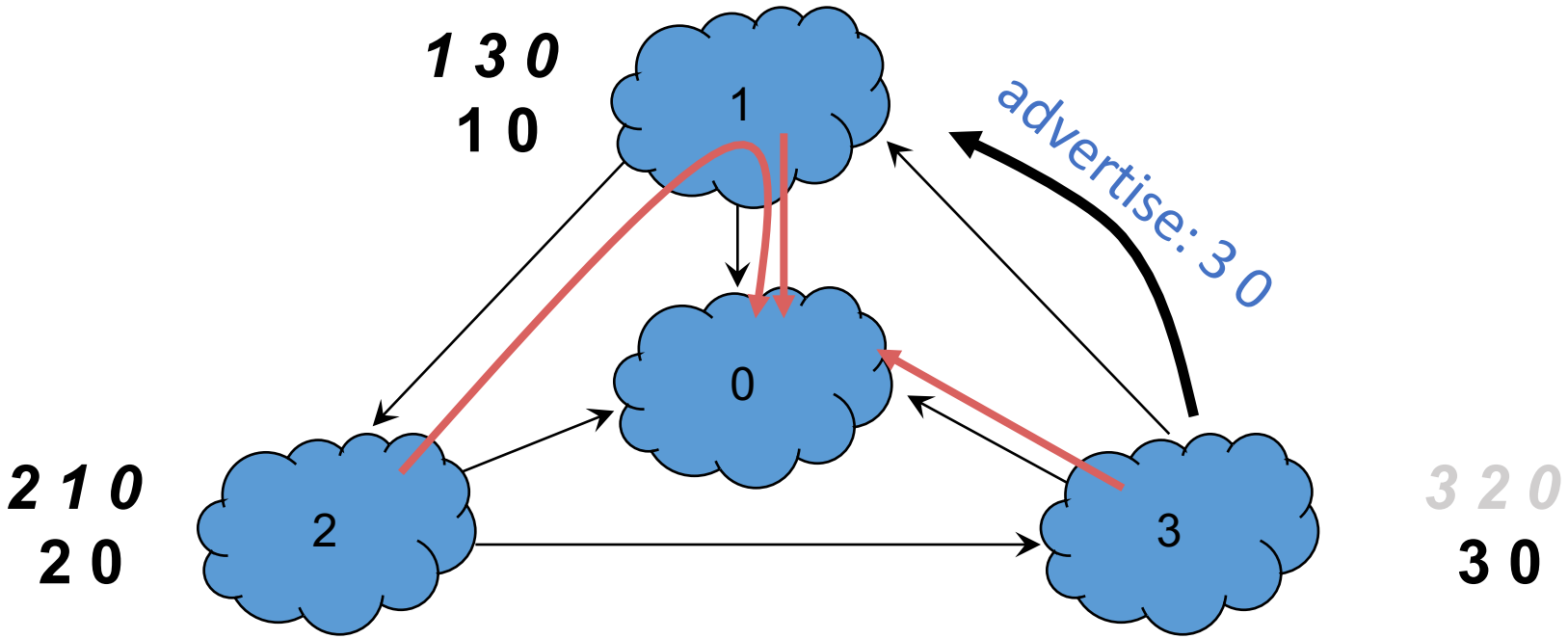


Step-by-step of policy oscillation

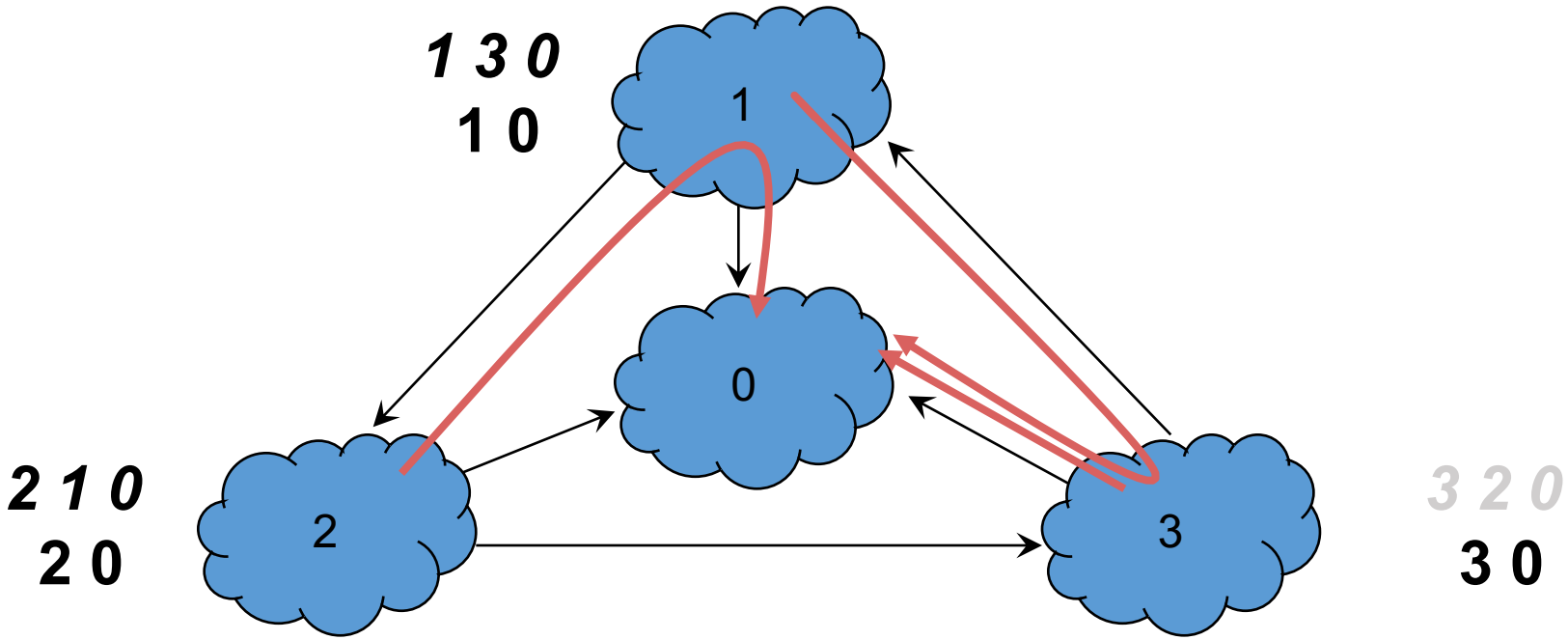


Step-by-step of policy oscillation

- **3 advertises its path 3 0 to 1**

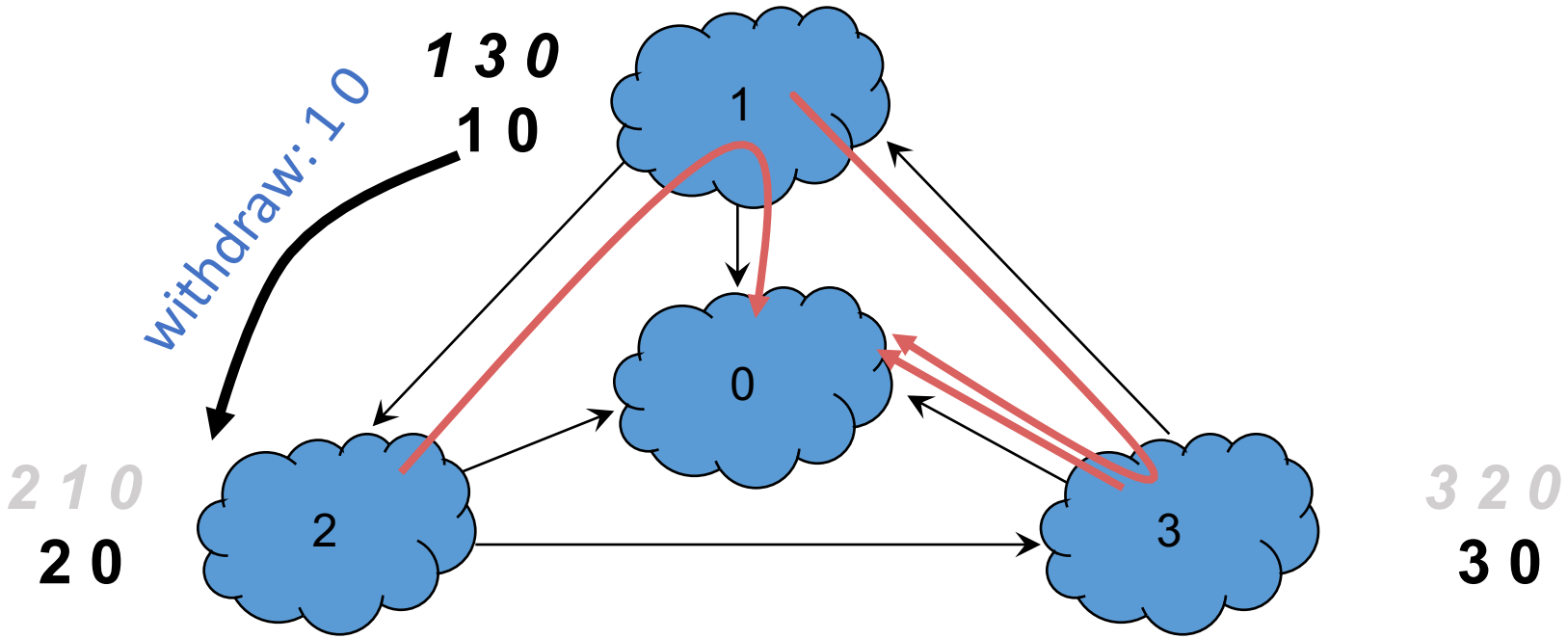


Step-by-step of policy oscillation

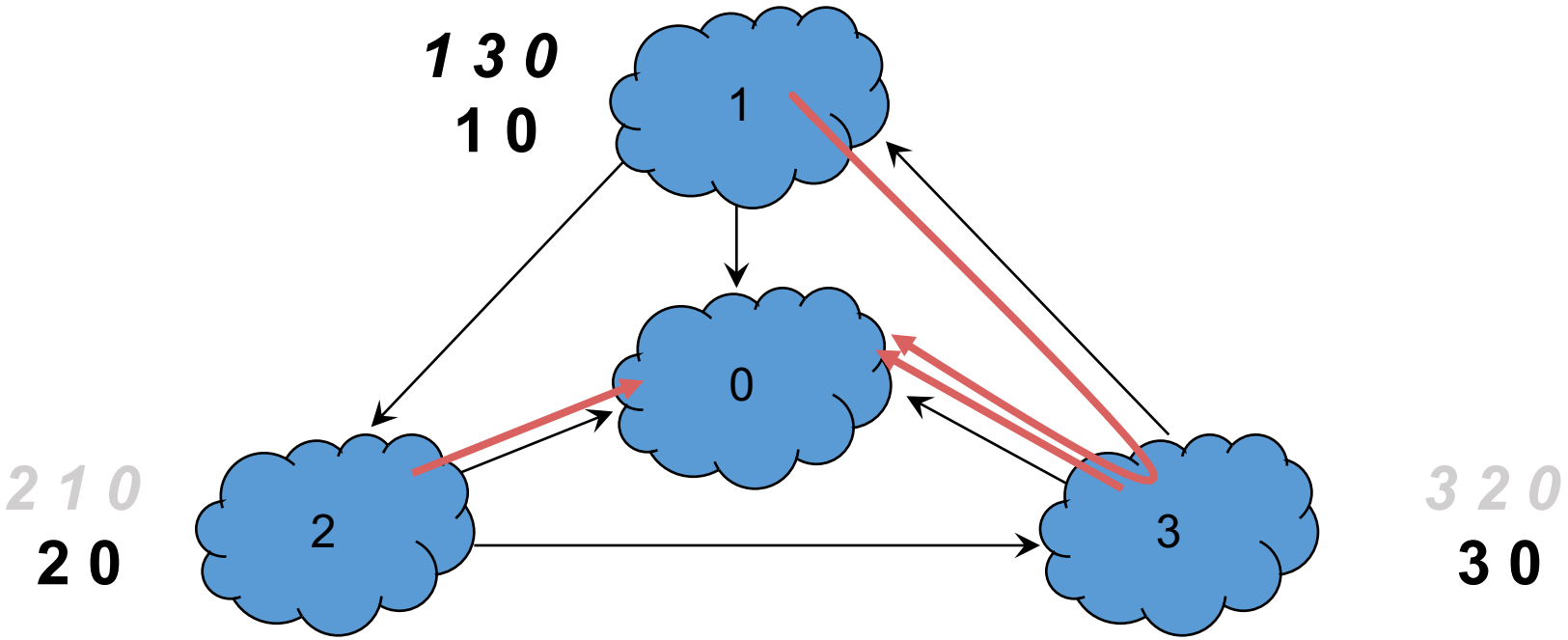


Step-by-step of policy oscillation

- **1 withdraws its path 1 0 from 2**

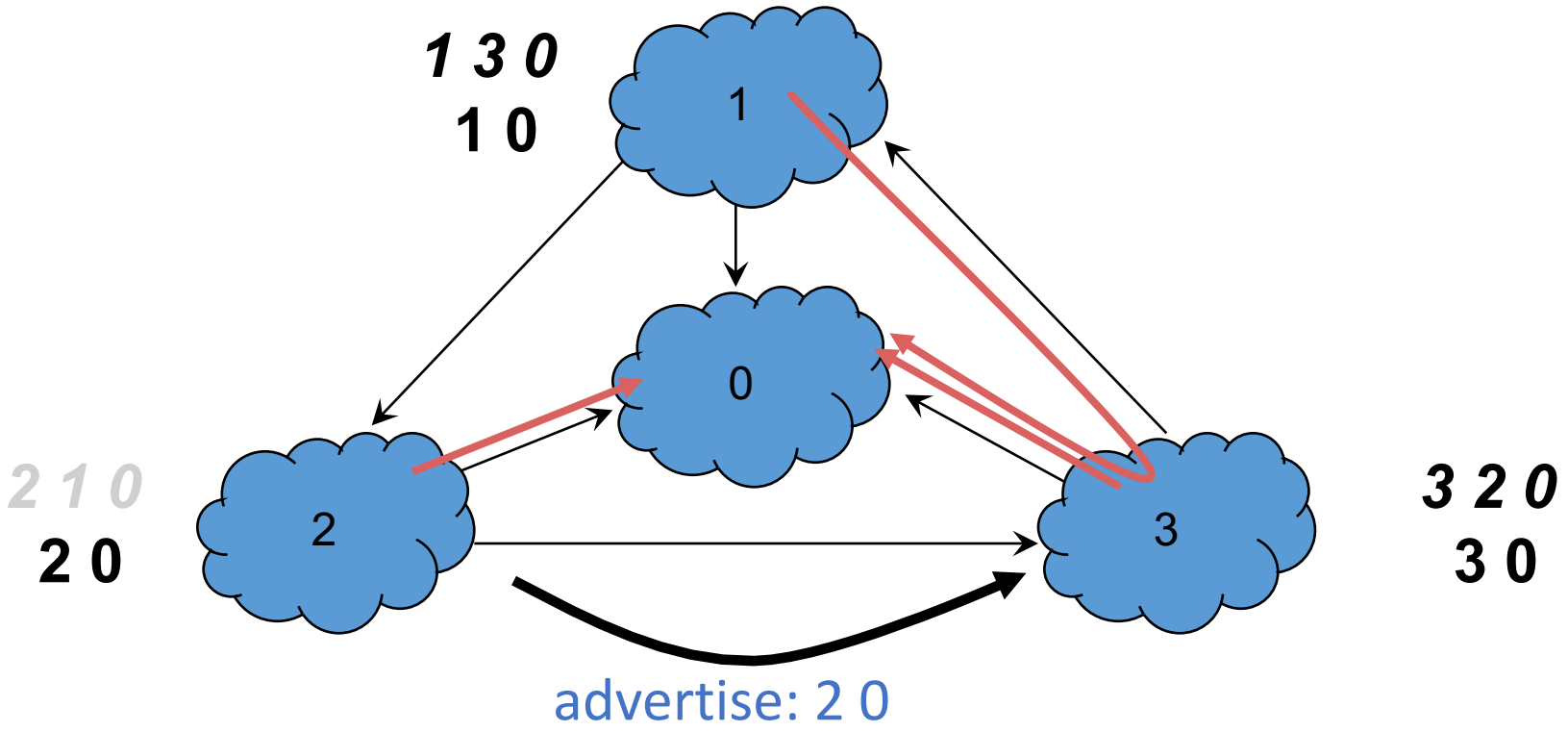


Step-by-step of policy oscillation

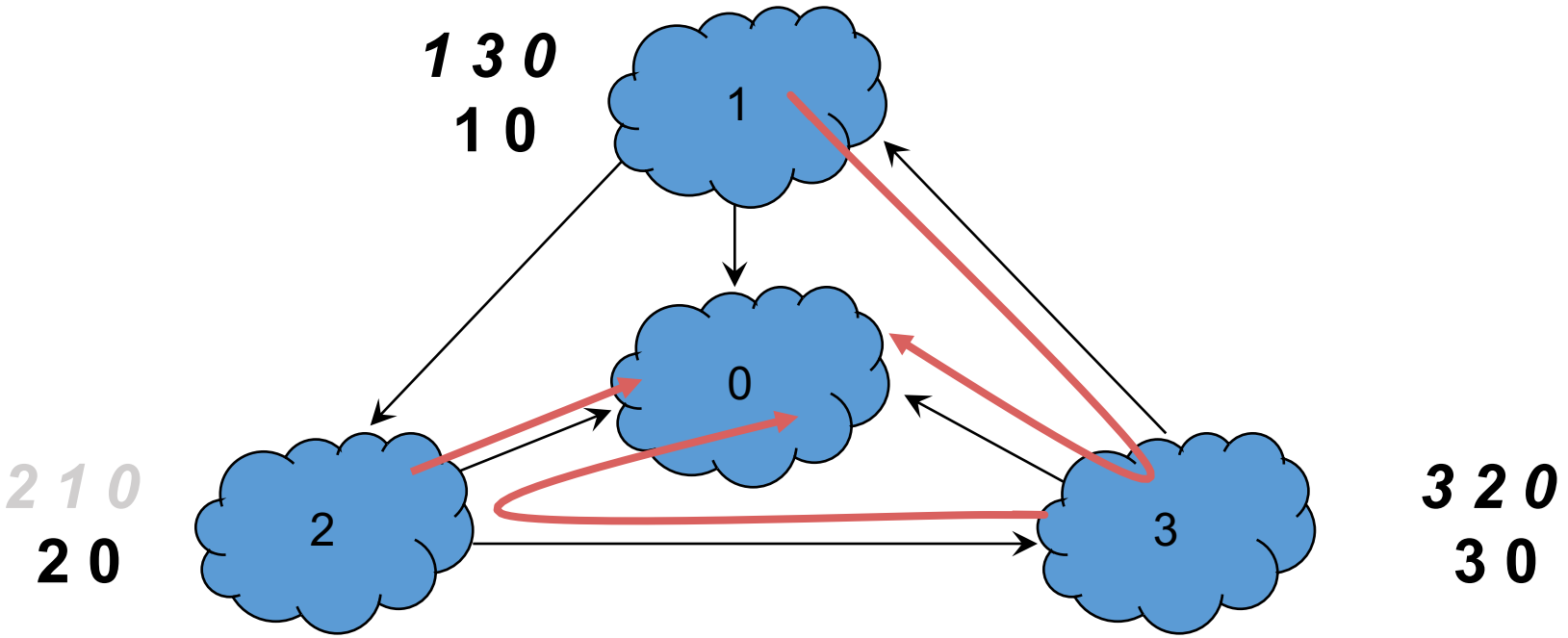


Step-by-step of policy oscillation

- **2 advertises its path 2 0 to 3**

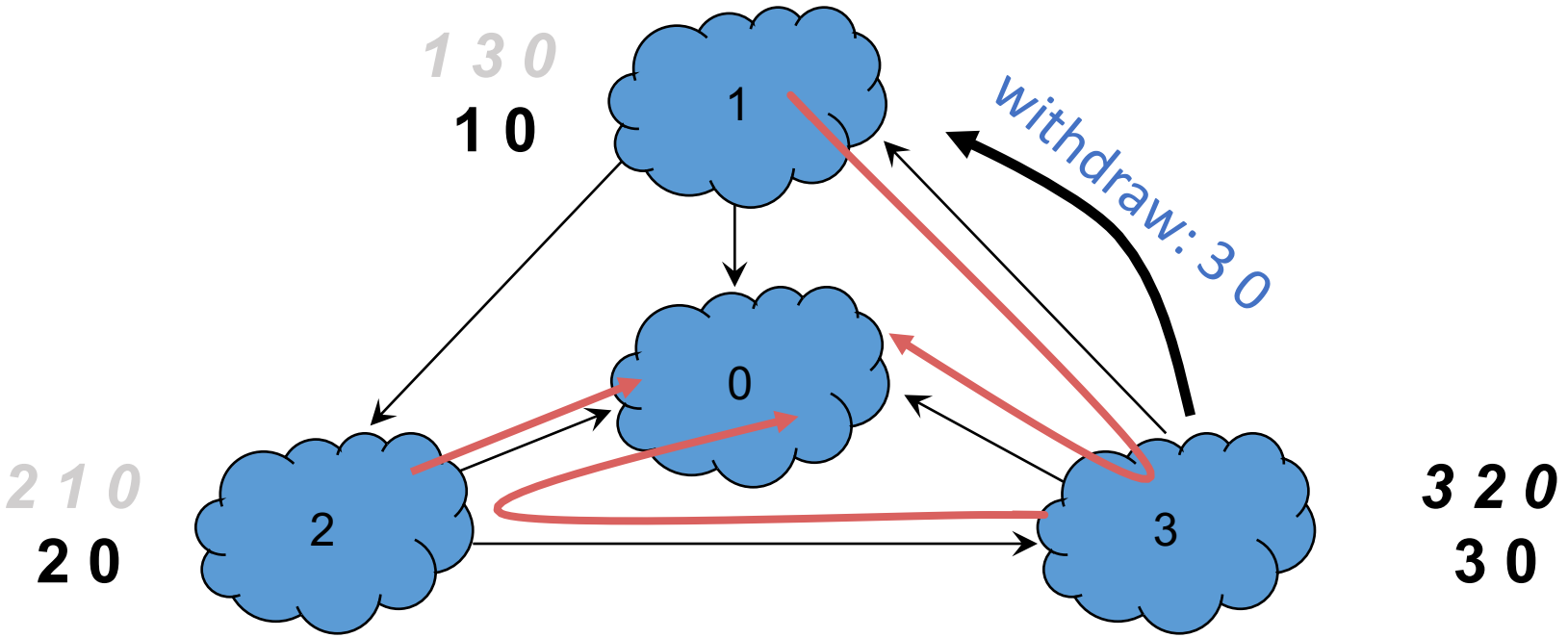


Step-by-step of policy oscillation

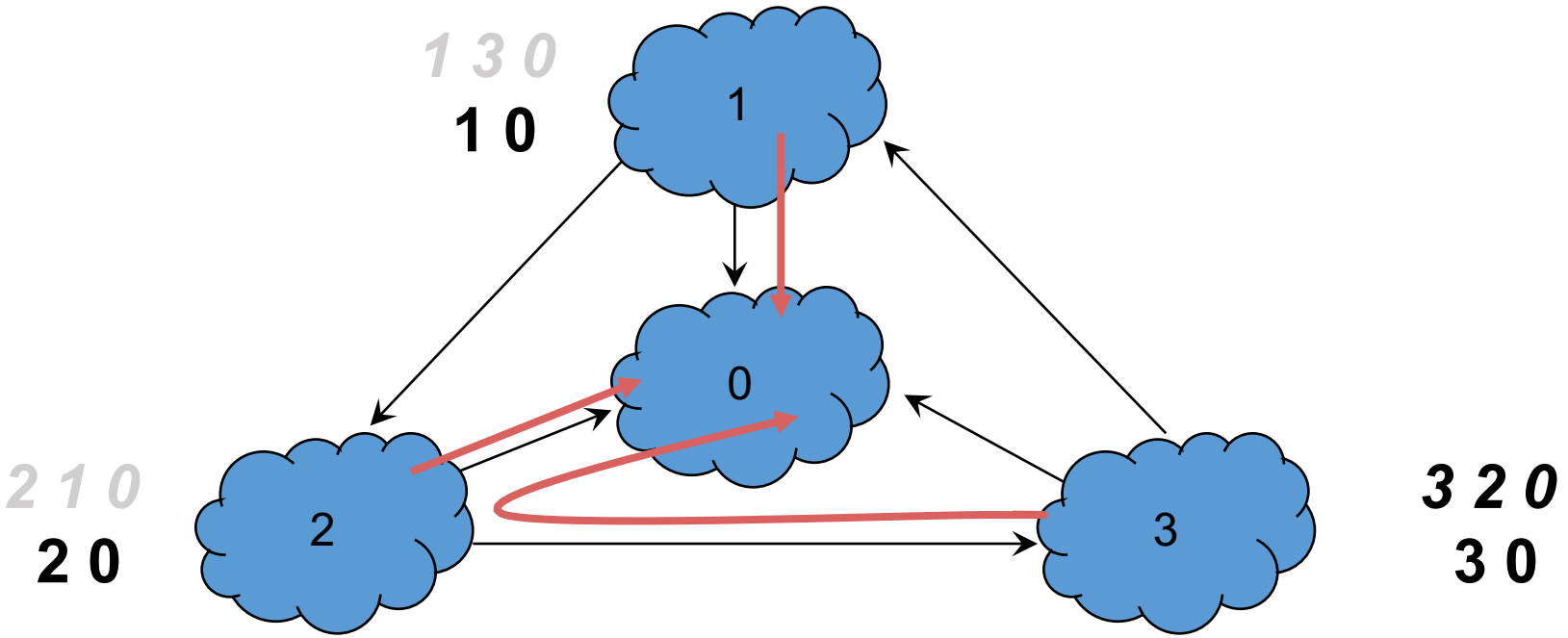


Step-by-step of policy oscillation

- **3 withdraws its path 3 0 from 1**



Step-by-step of policy oscillation



Step-by-step of policy oscillation

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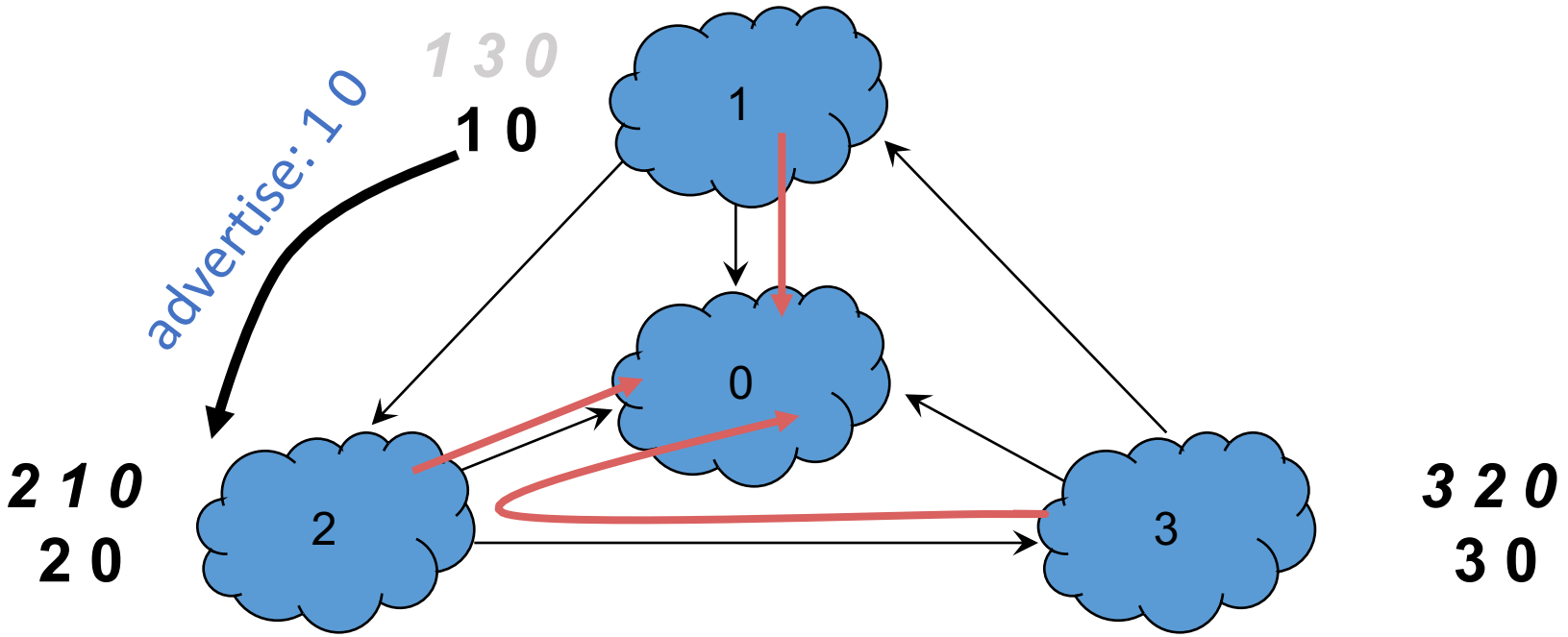
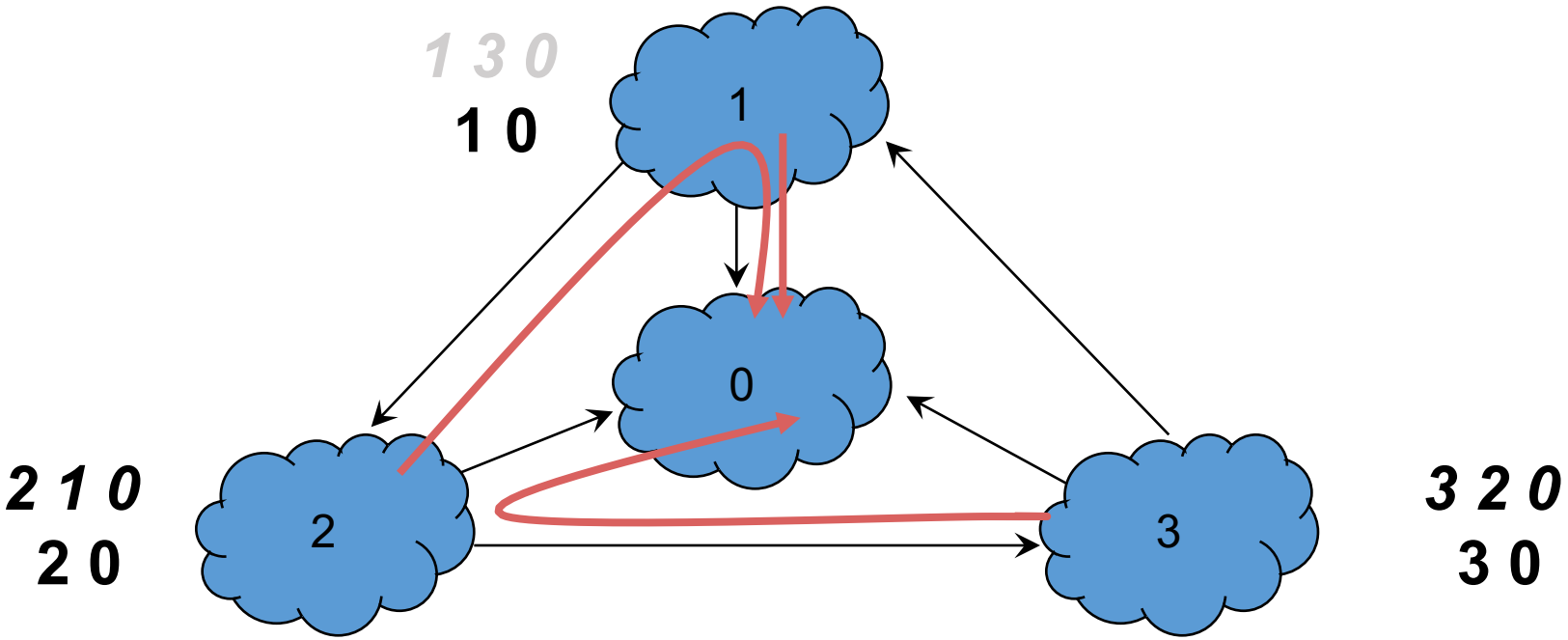
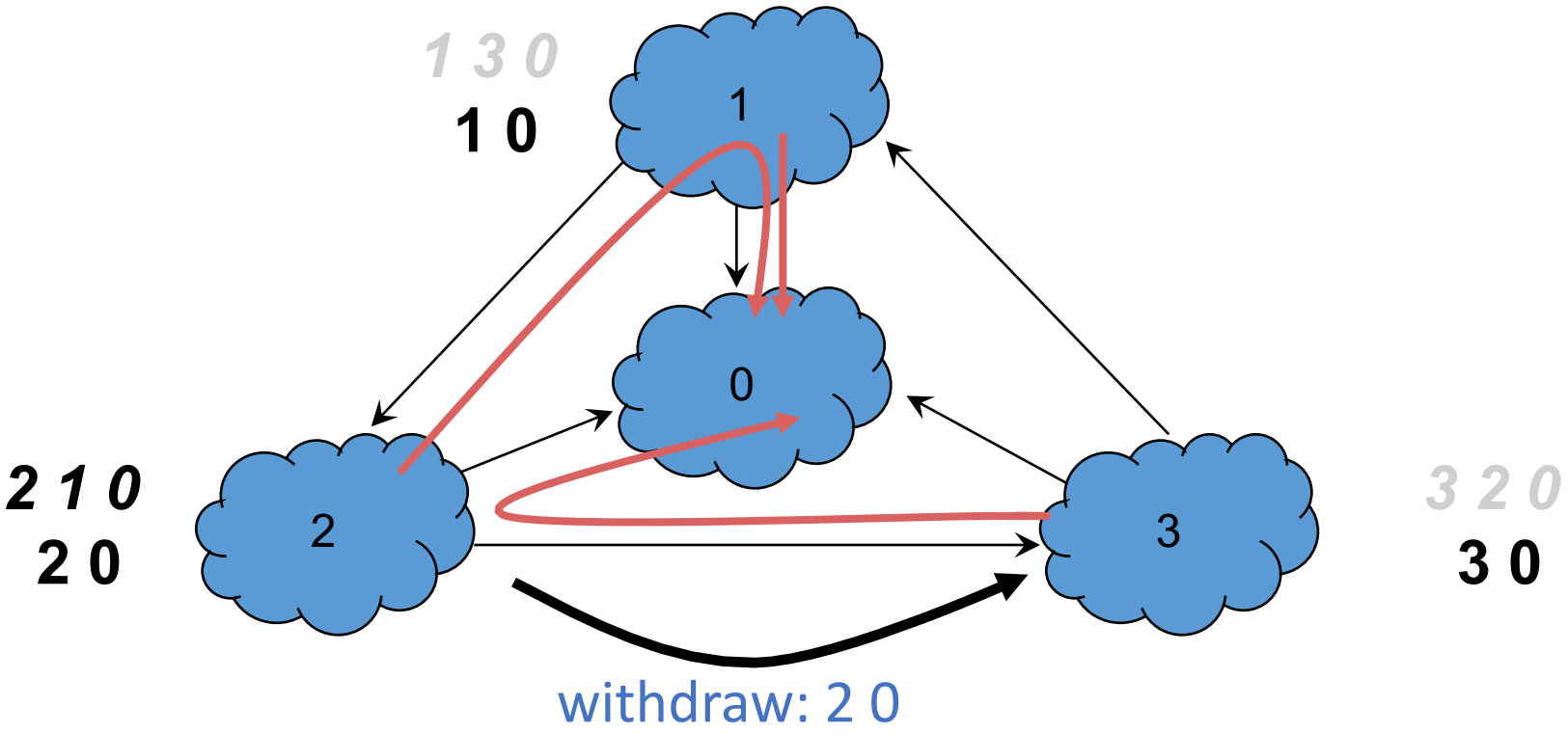


Step-by-step of policy oscillation

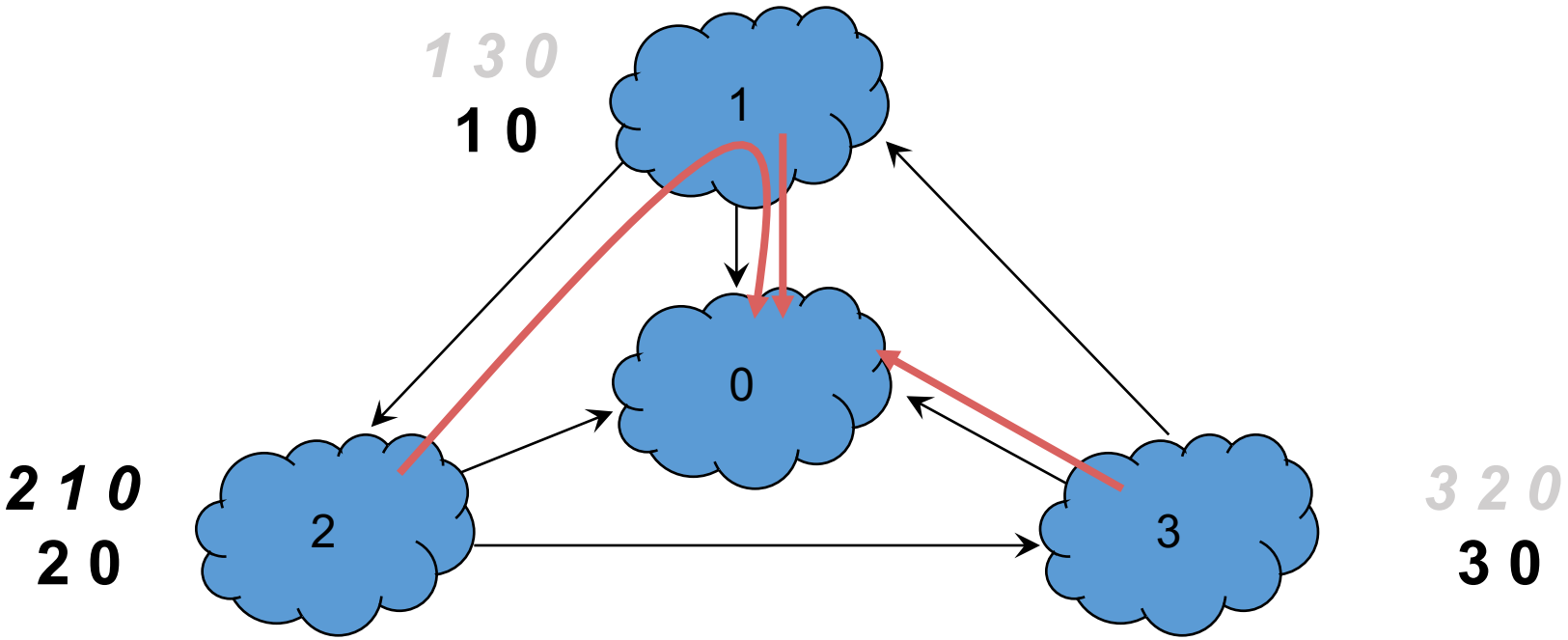


Step-by-step of policy oscillation

- **2 withdraws its path 2 0 from 3**



We're back to where we started



Convergence

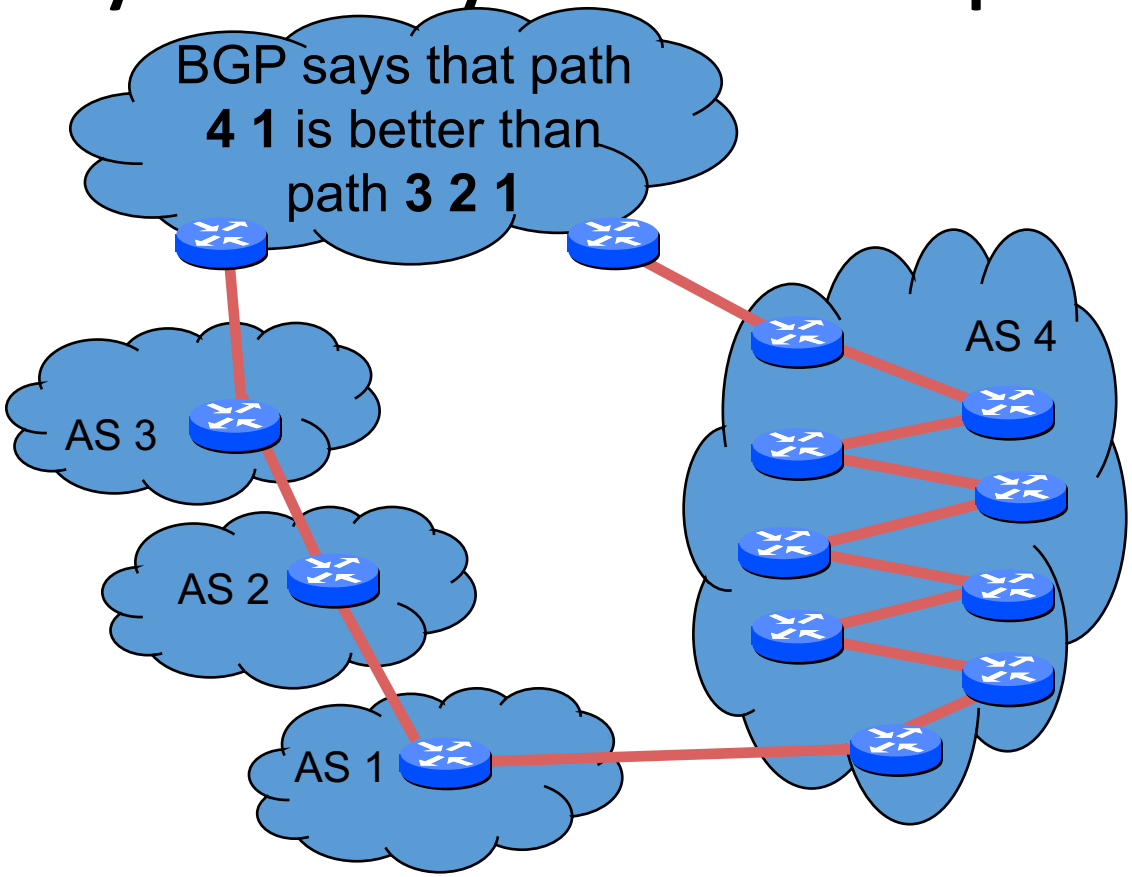
- **If all AS policies follow "Gao-Rexford" rules, BGP is guaranteed to converge**
- **For arbitrary policies, BGP may fail to converge!**

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 are still very common**
  - Check out https://bgpstream.com/

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 lecture: Programmable Networks**

Thanks!
Q&A