EECS 489

Computer Networks

BGP

Announcements

- Final Exam
  - December 17, 8:00am-10:00am
  - Alternate December 17, 11:00am-1:00pm
- Exam Review
  - December 9
- Social Networking
  - December 4

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

An AS advertises ("exports") its best routes to one or more IP prefixes

Each AS selects the "best" route it hears advertised for a prefix

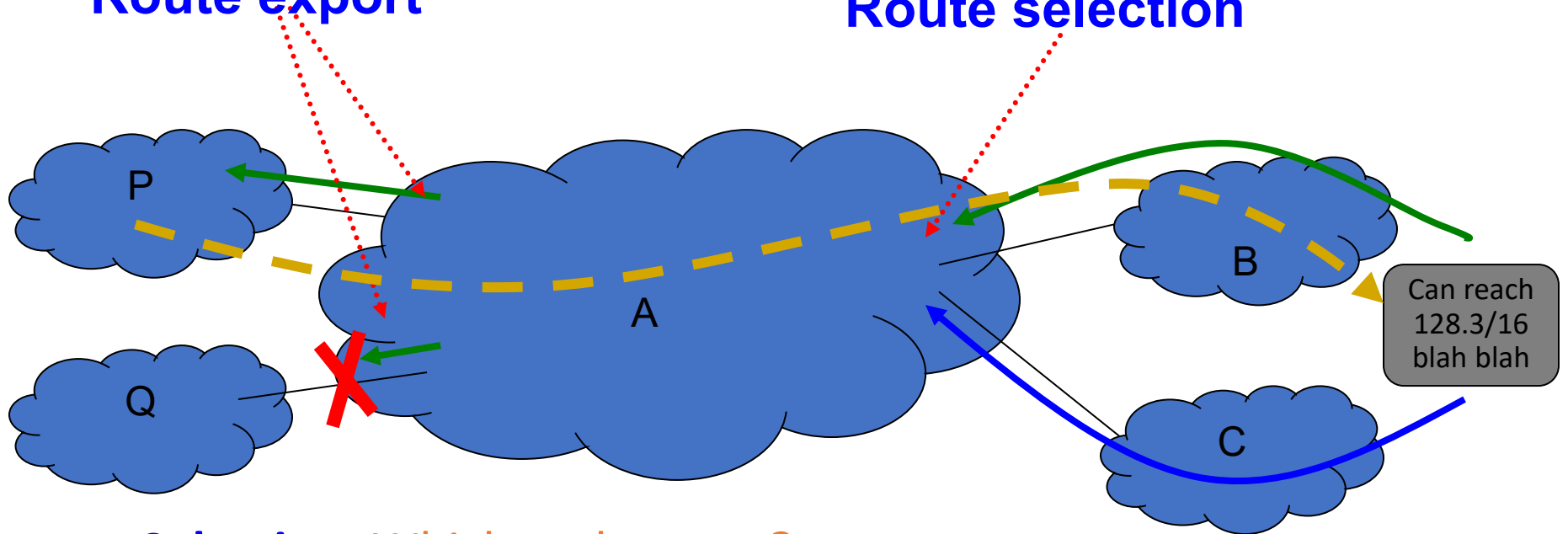# BGP inspired by Distance-Vector with four differences

- 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)
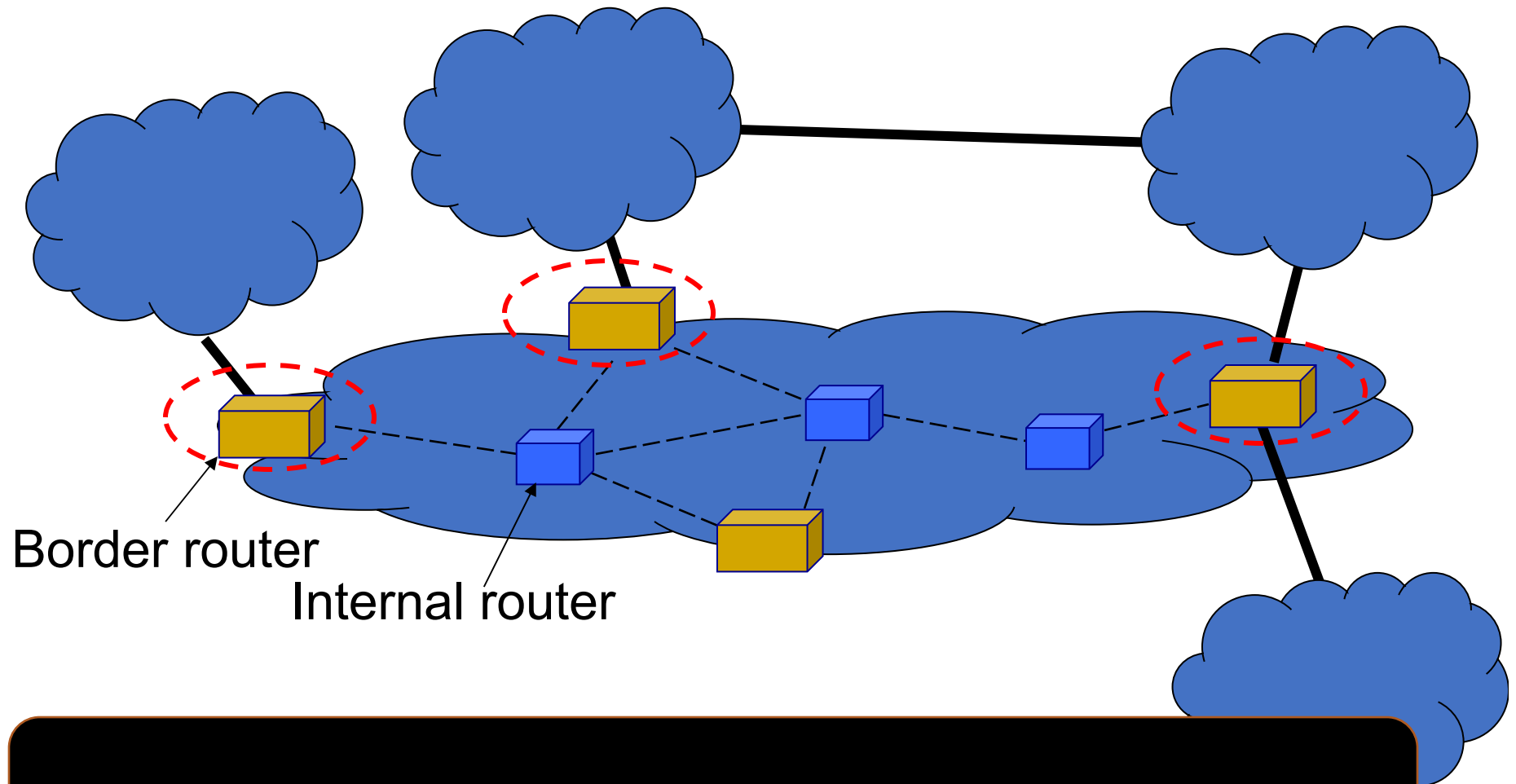
Gao-Rexford

Providers

Peers

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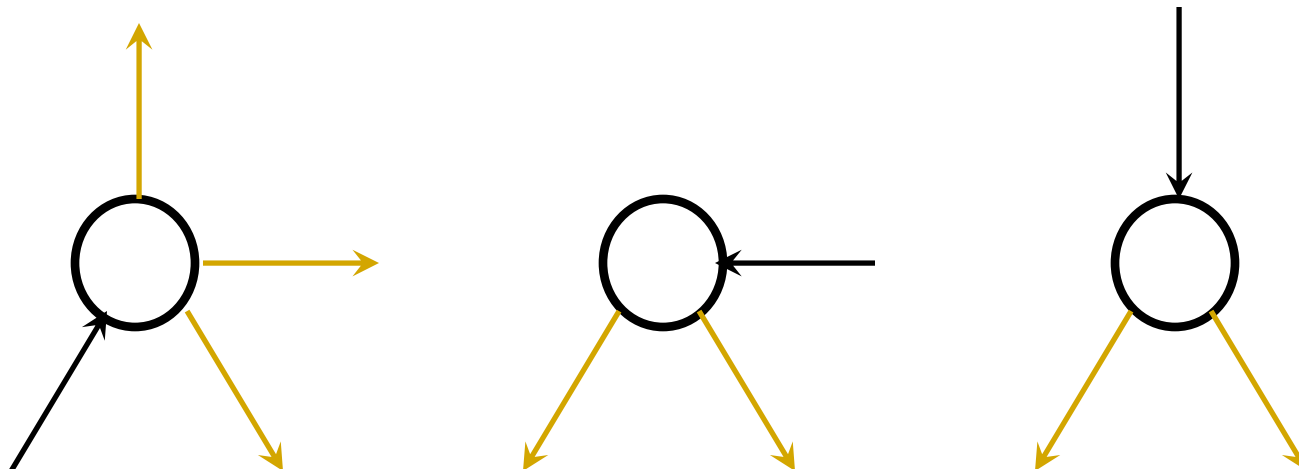
With Gao-Rexford, the AS policy graph is a
DAG (directed acyclic graph) and routes are "valley free"

BGP Protocol details

Who speaks BGP?

Border router

Internal router

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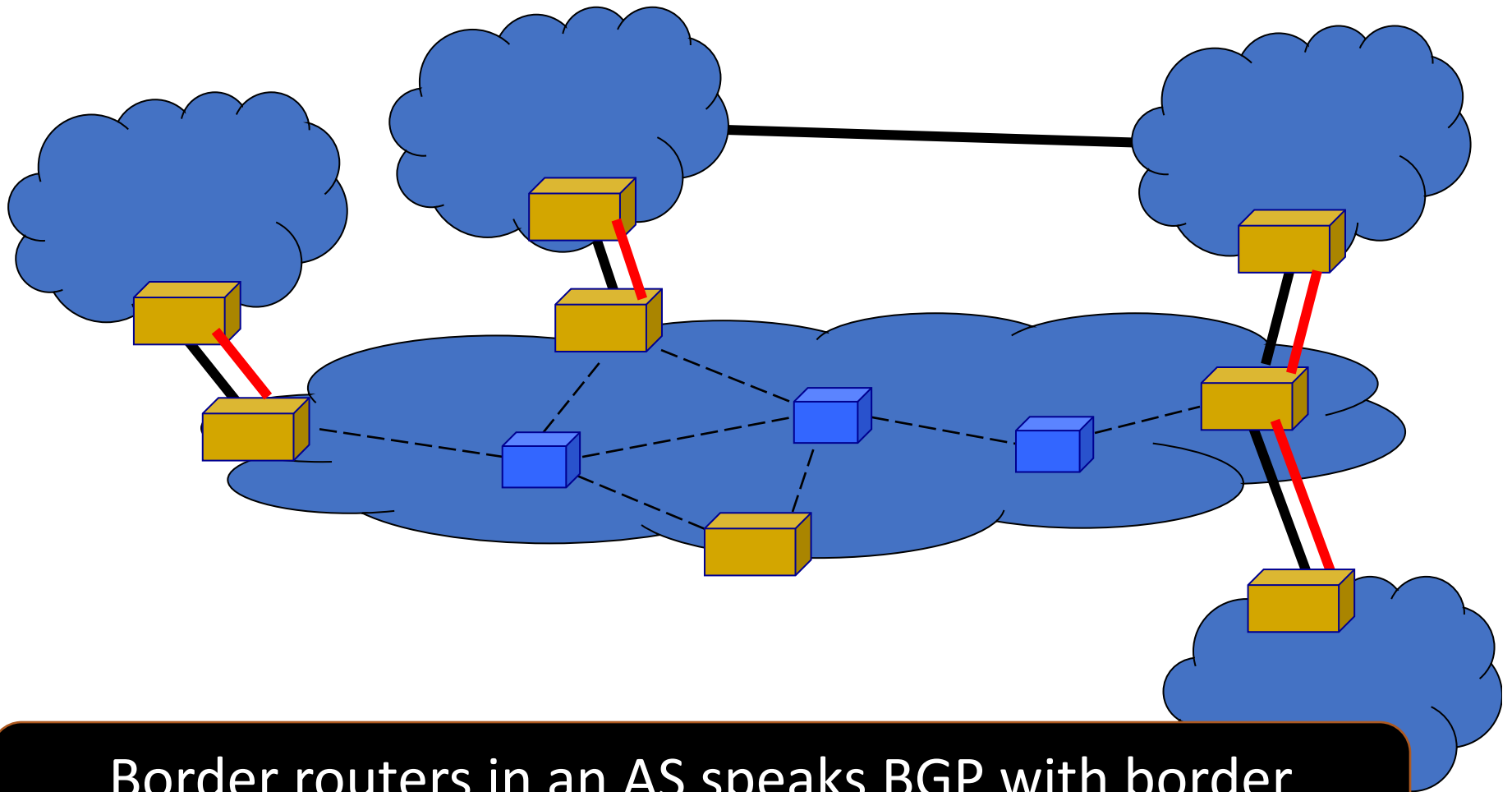
Border routers in an AS speaks BGP with border routers in other ASes using eBGP sessions

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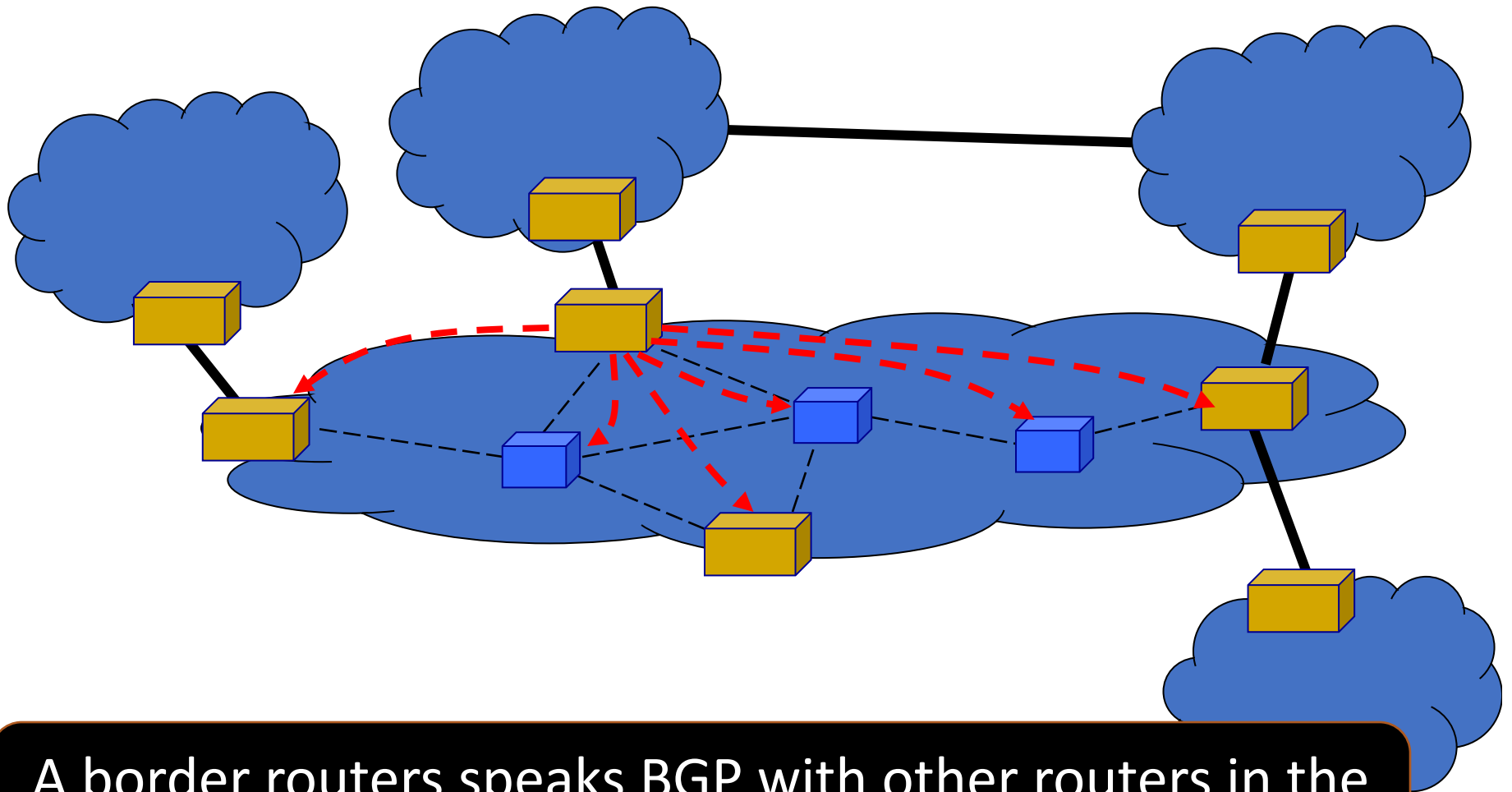
A border routers speaks BGP with other routers in the same AS using iBGP sessions

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
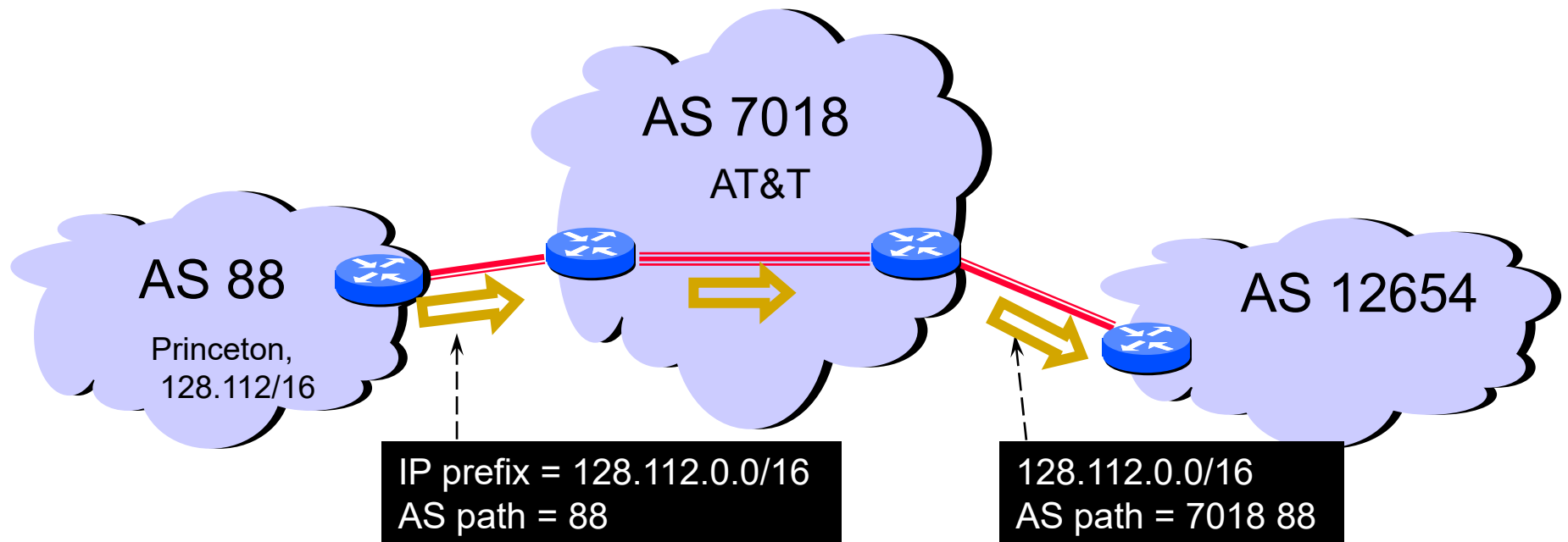
- **Keep-alive**
  - Inform neighbor that connection is still viable

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)

AS 7018
AT&T

AS 88

Princeton,
128.112/16

AS 12654

IP prefix = 128.112.0.0/16
AS path = 88

128.112.0.0/16
AS path = 7018 88

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
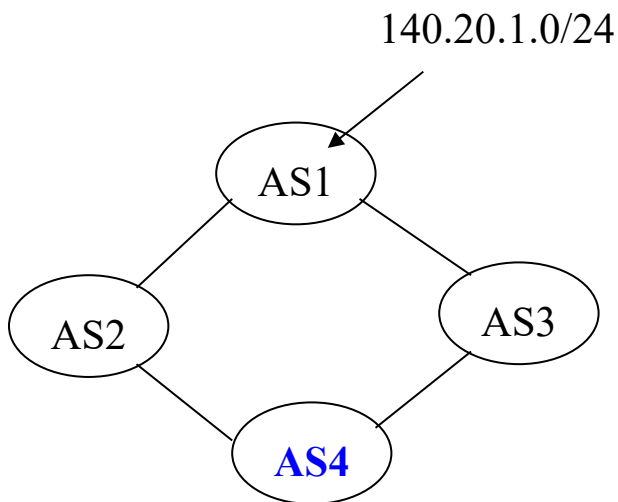
140.20.1.0/24

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
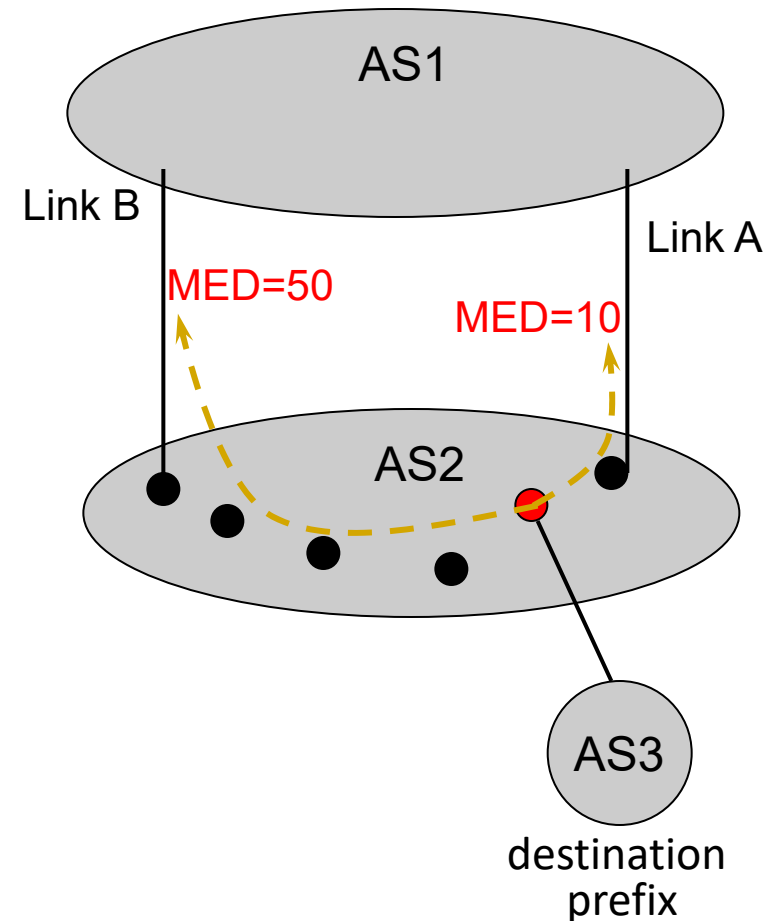
Attributes: (4) IGP cost

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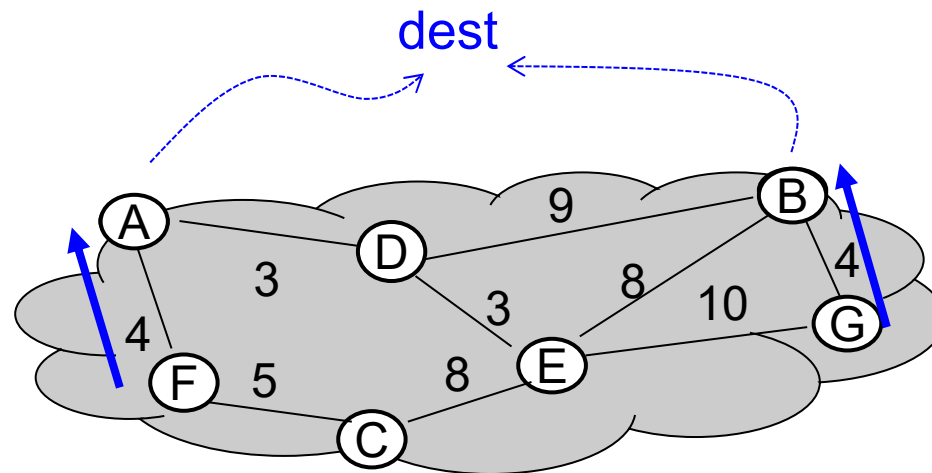
Using attributes

- 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

Open ended programming.
Constrained only by vendor configuration language

Control plane

BGP
Updates

| Apply Import Policies | Best Route Selection | Best Route Table | Apply Export Policies |

BGP
Updates

Data plane

forwarding
Entries

Data
packets

IP Forwarding Table

Data
packets
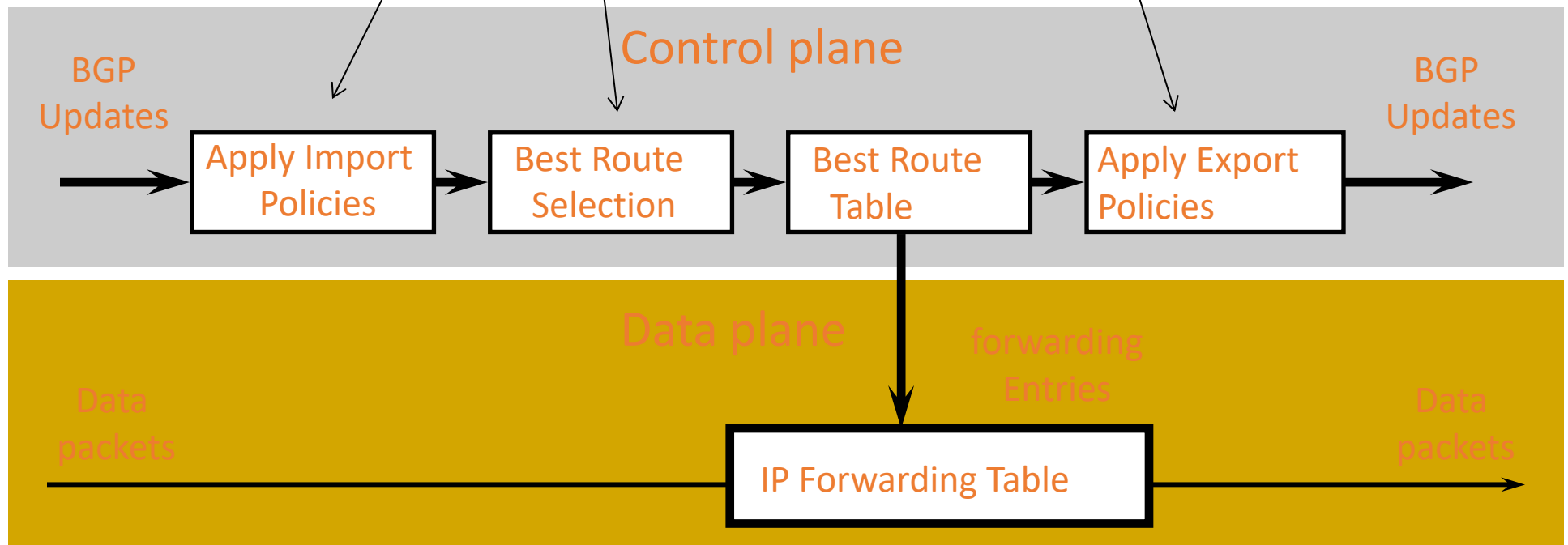
5-minute break!

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
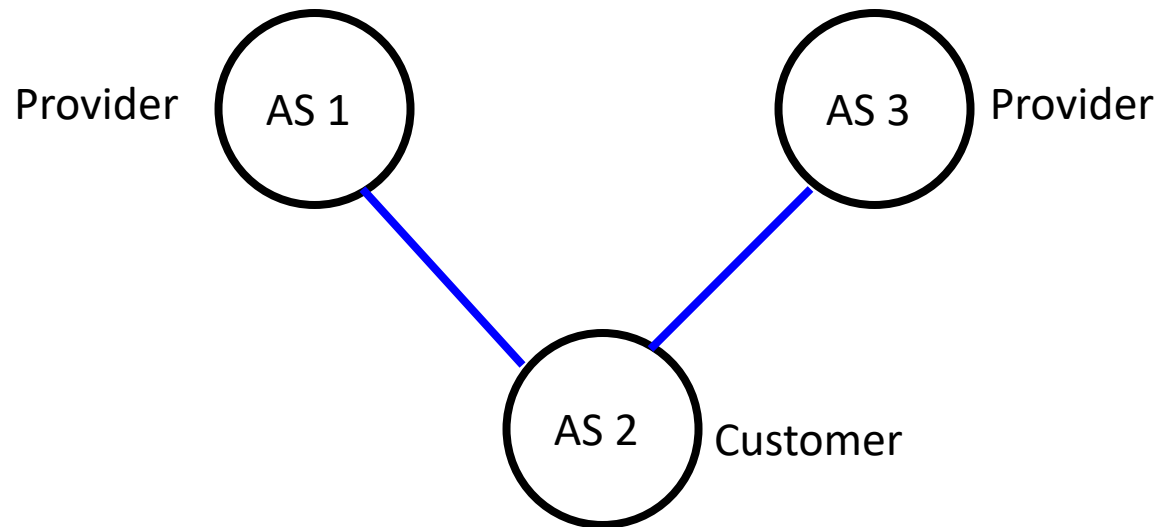
Security

- 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
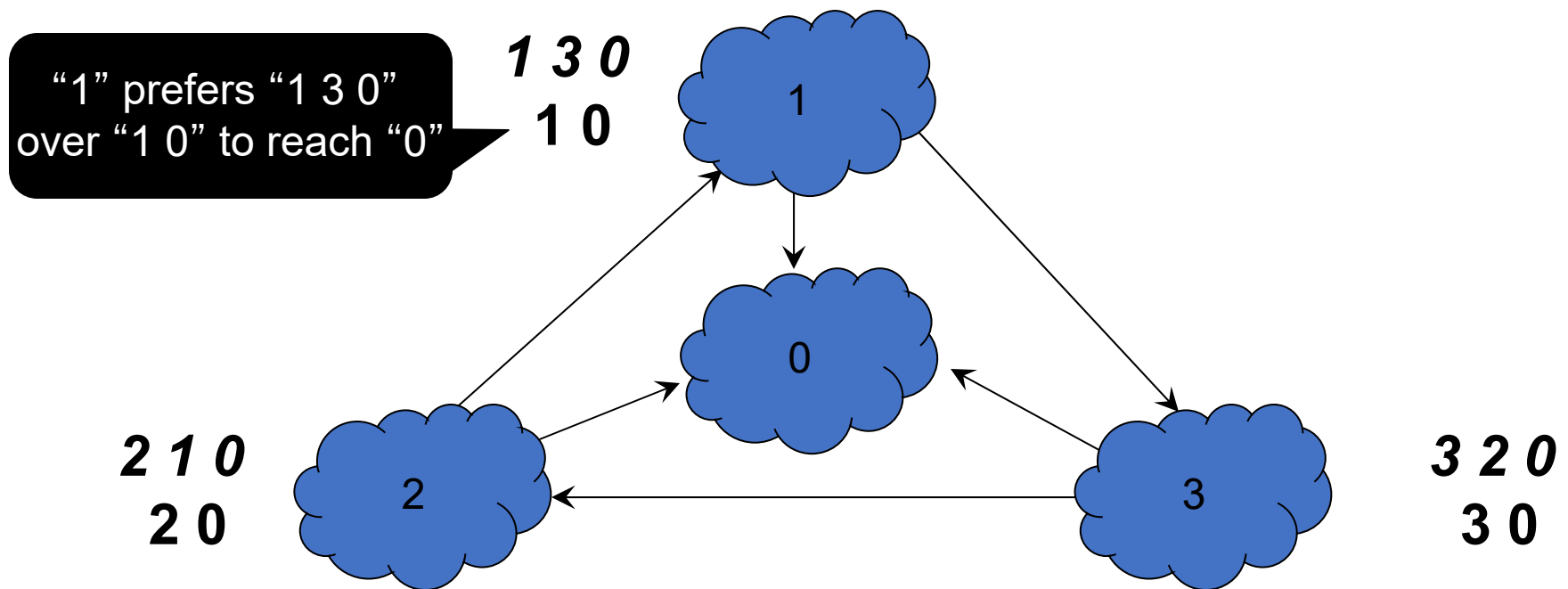
Step-by-step of policy oscillation

- Initially: nodes 1, 2, 3 know only shortest path to 0
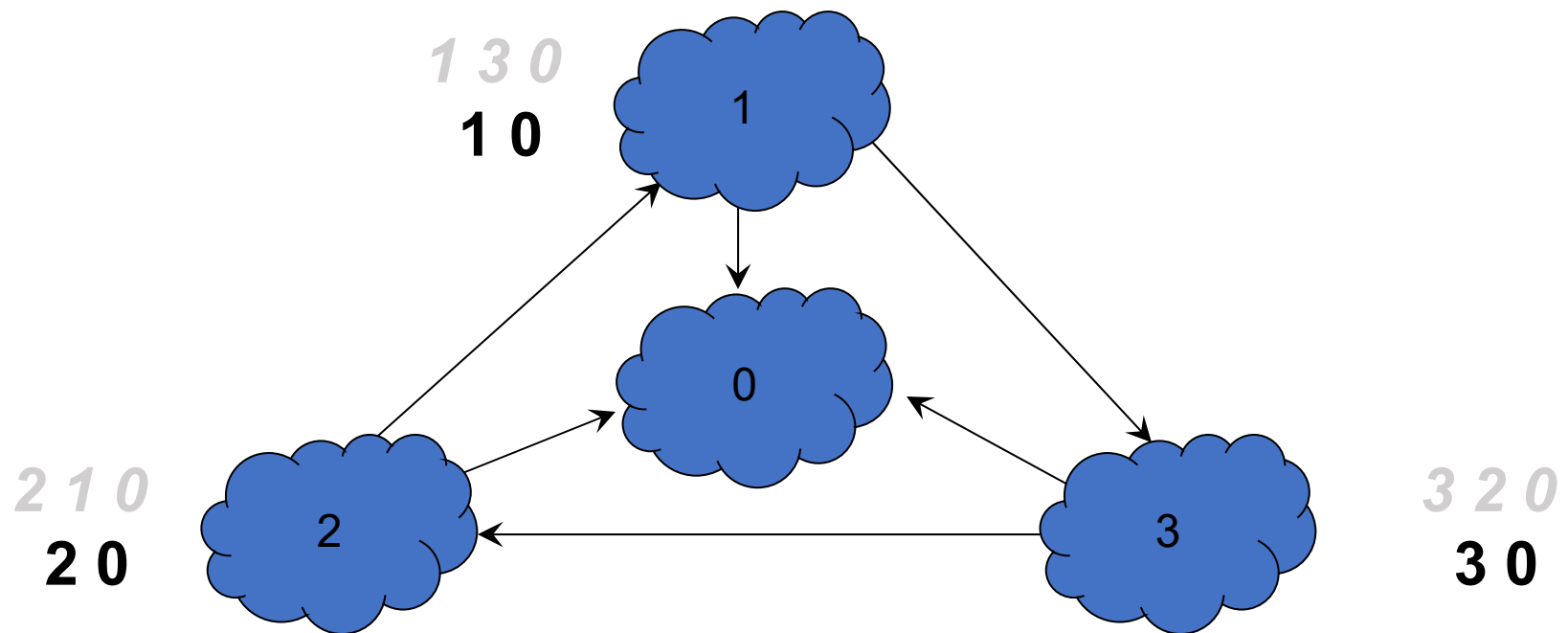
Step-by-step of policy oscillation

- 1 **advertises** its path 1 0 to 2
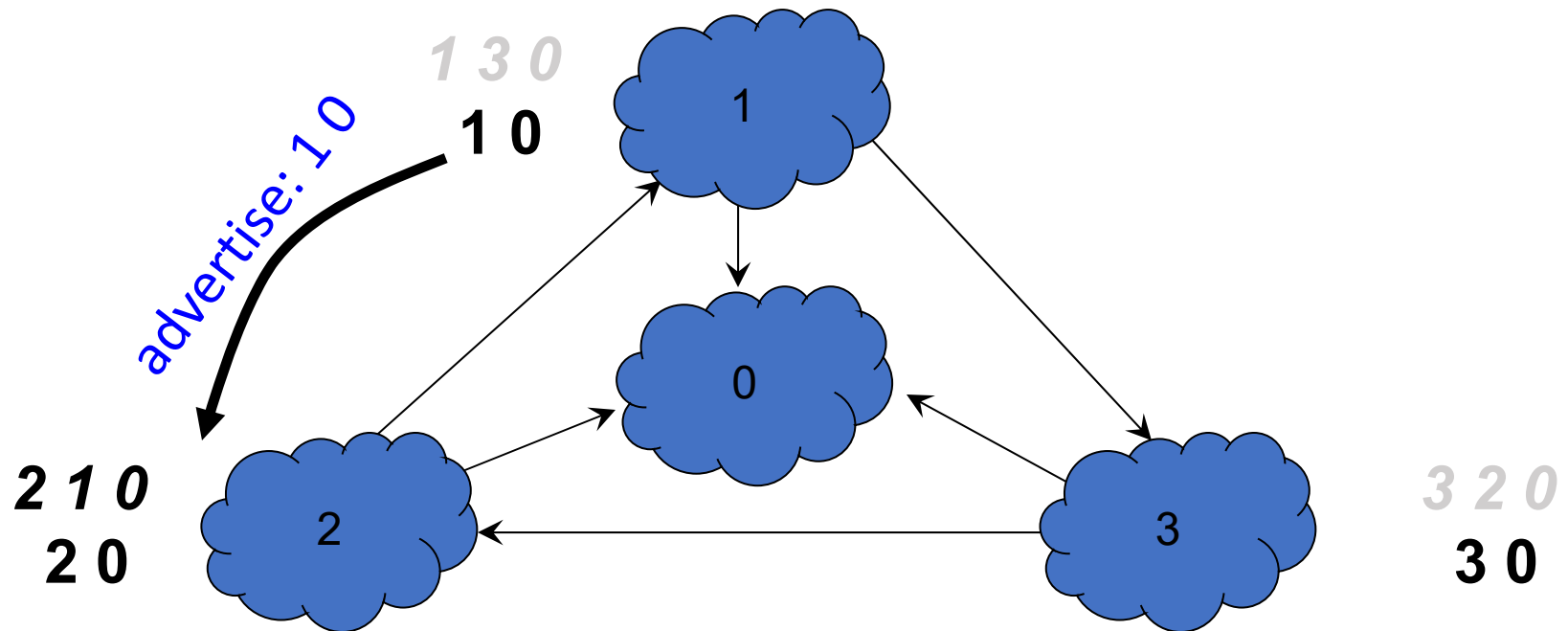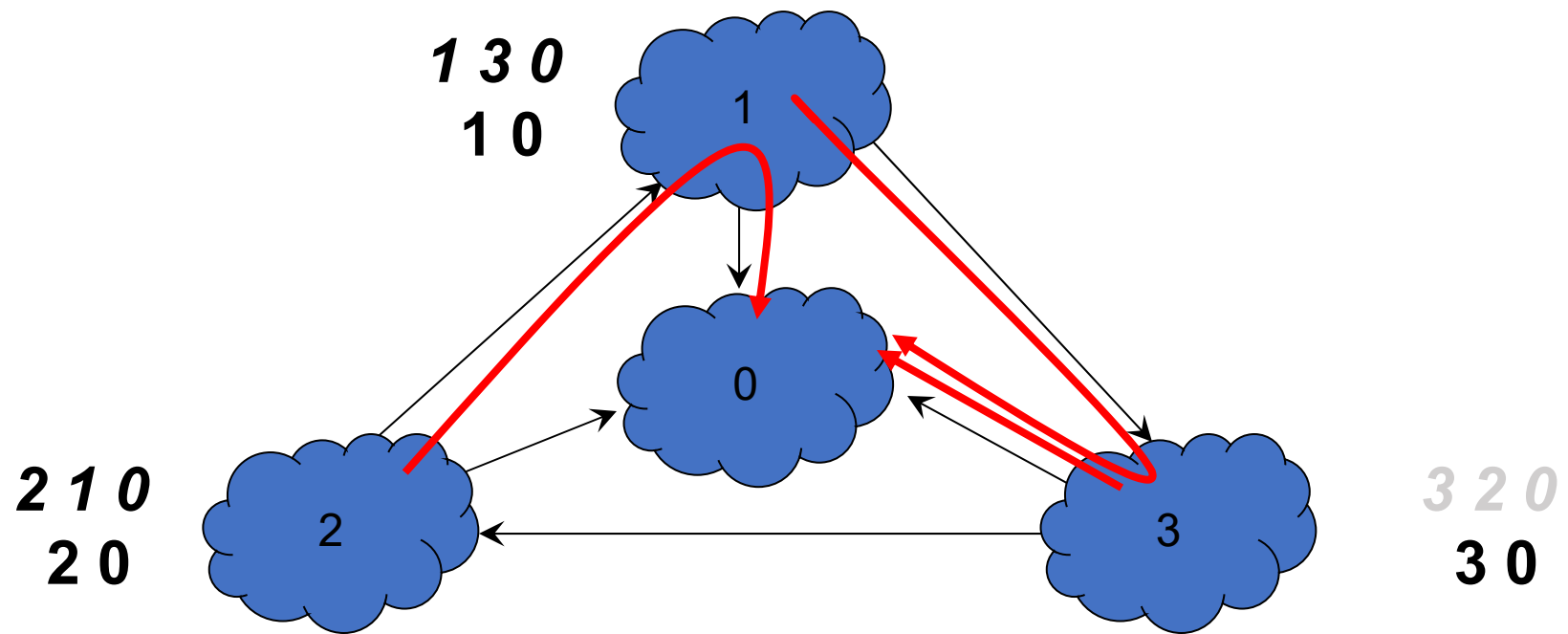
Step-by-step of policy oscillation
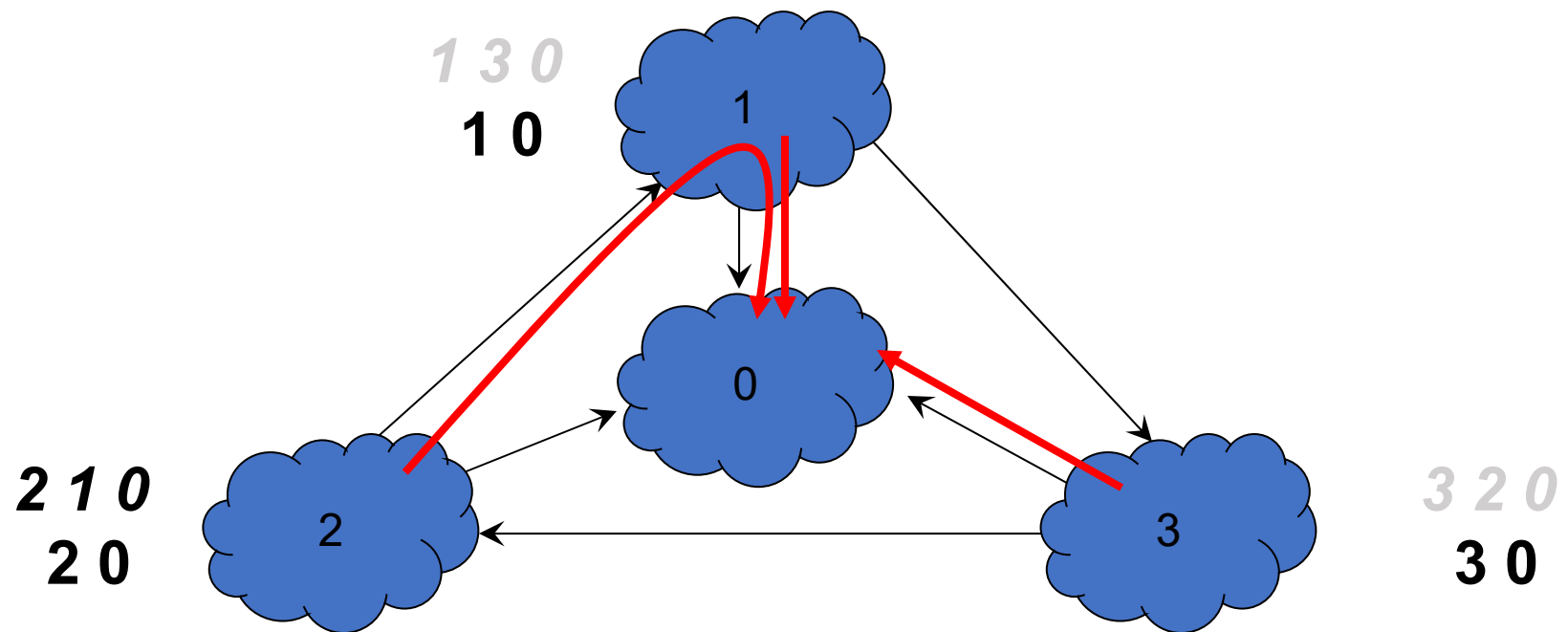
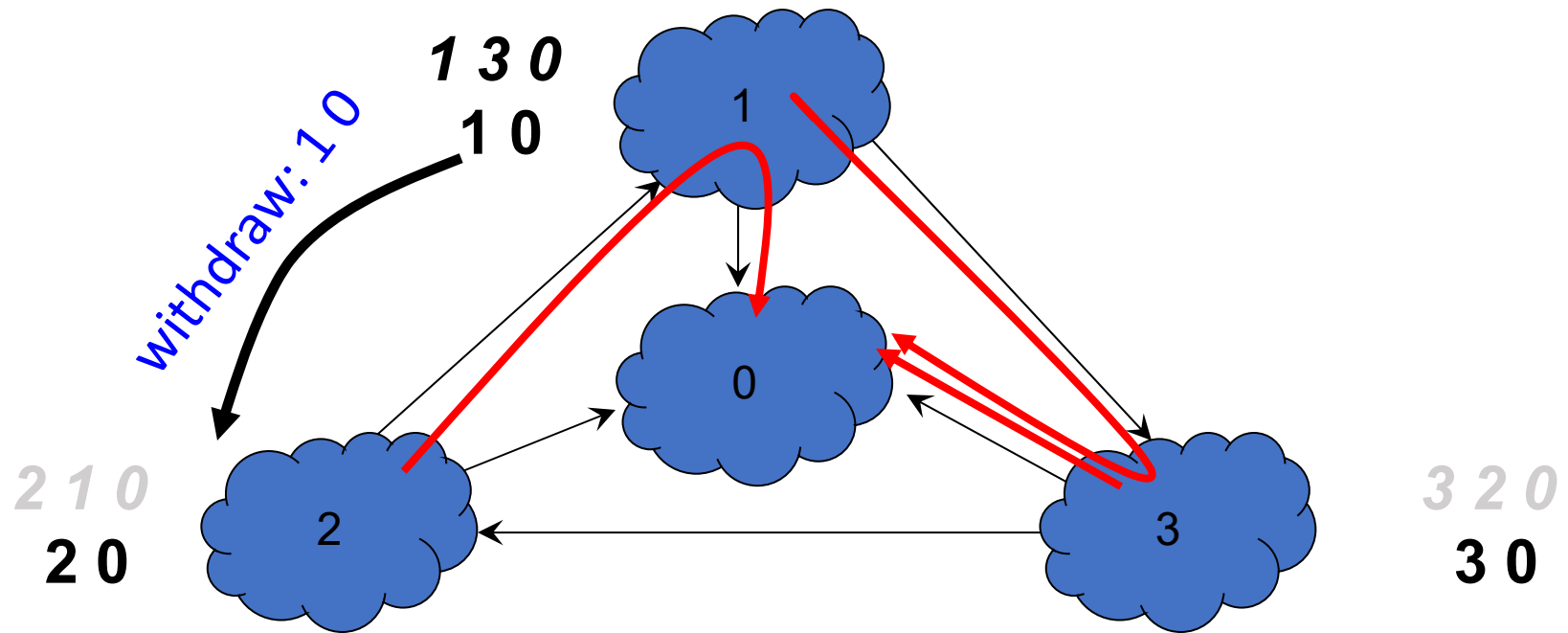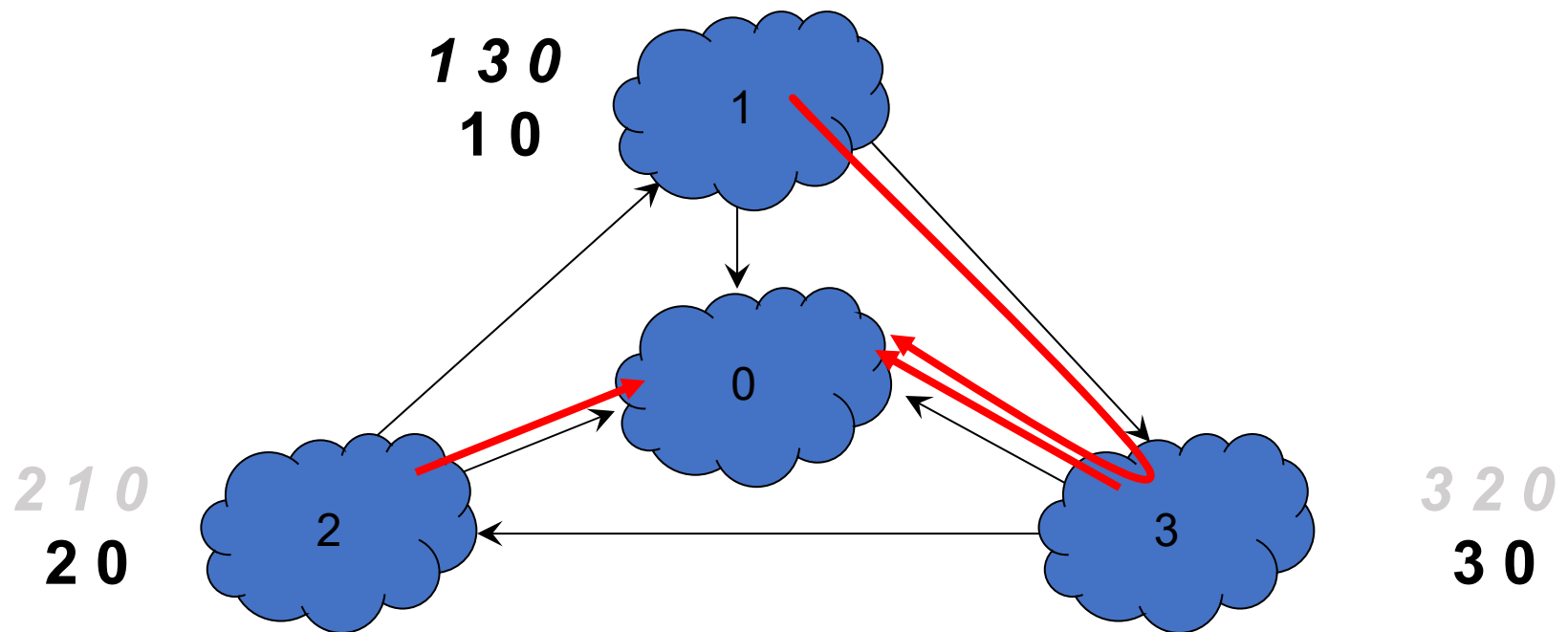# Step-by-step of policy oscillation

- 3 **advertises** its path 3 0 to 1
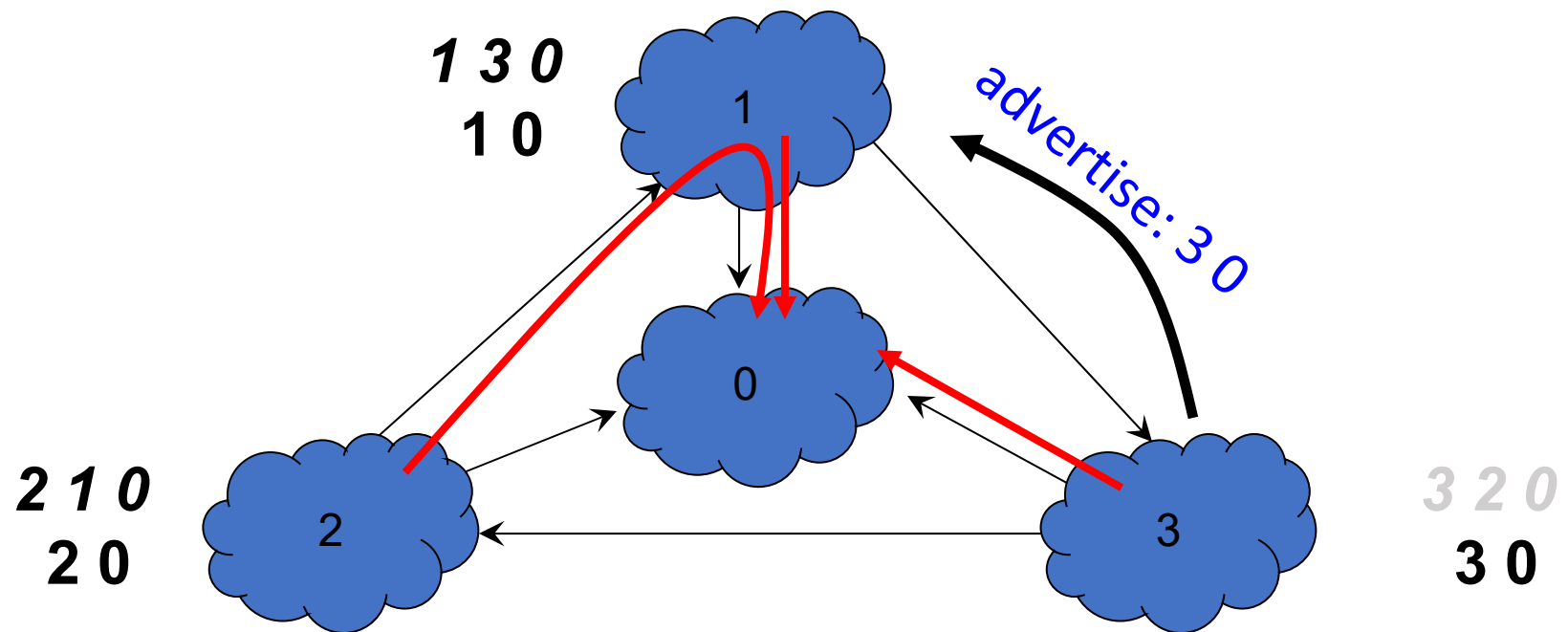
Step-by-step of policy oscillation

Step-by-step of policy oscillation
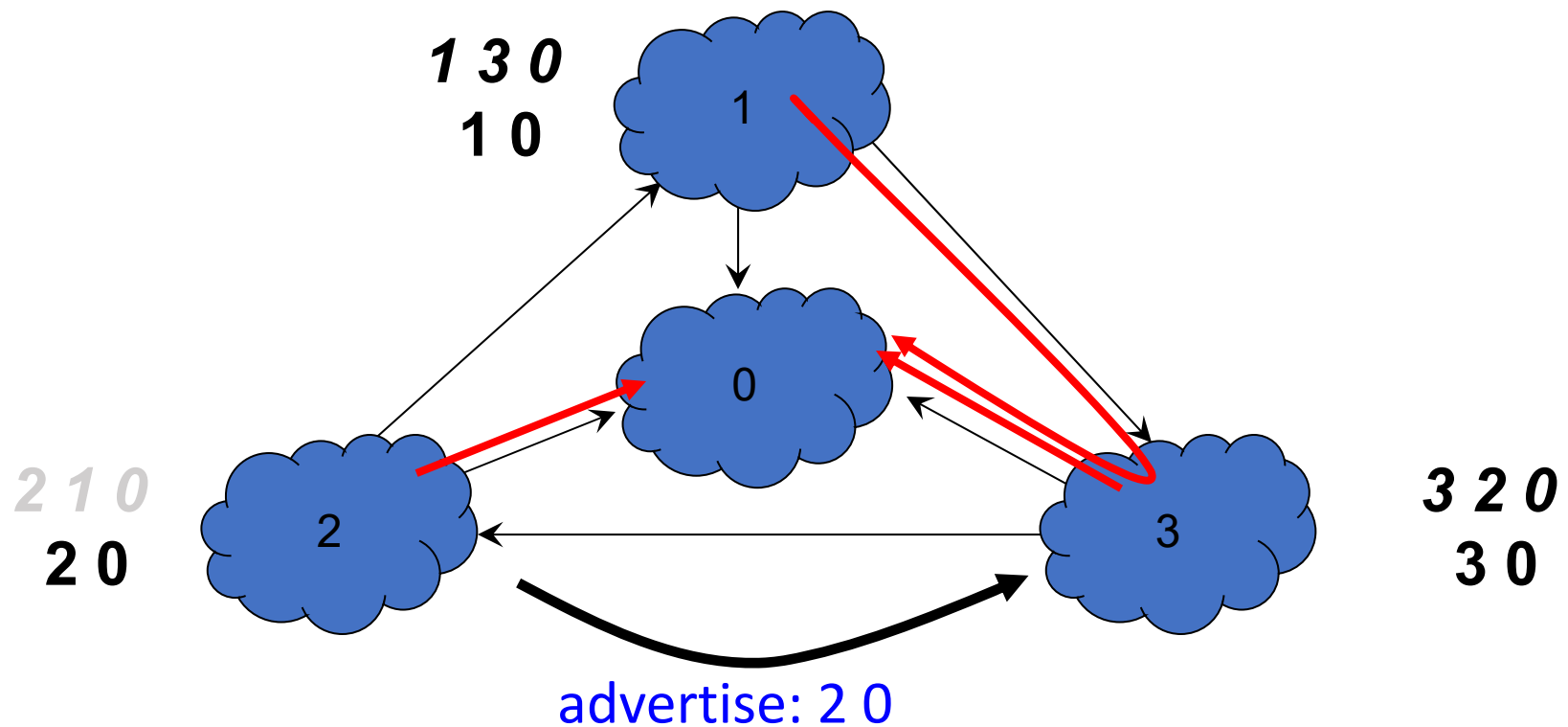
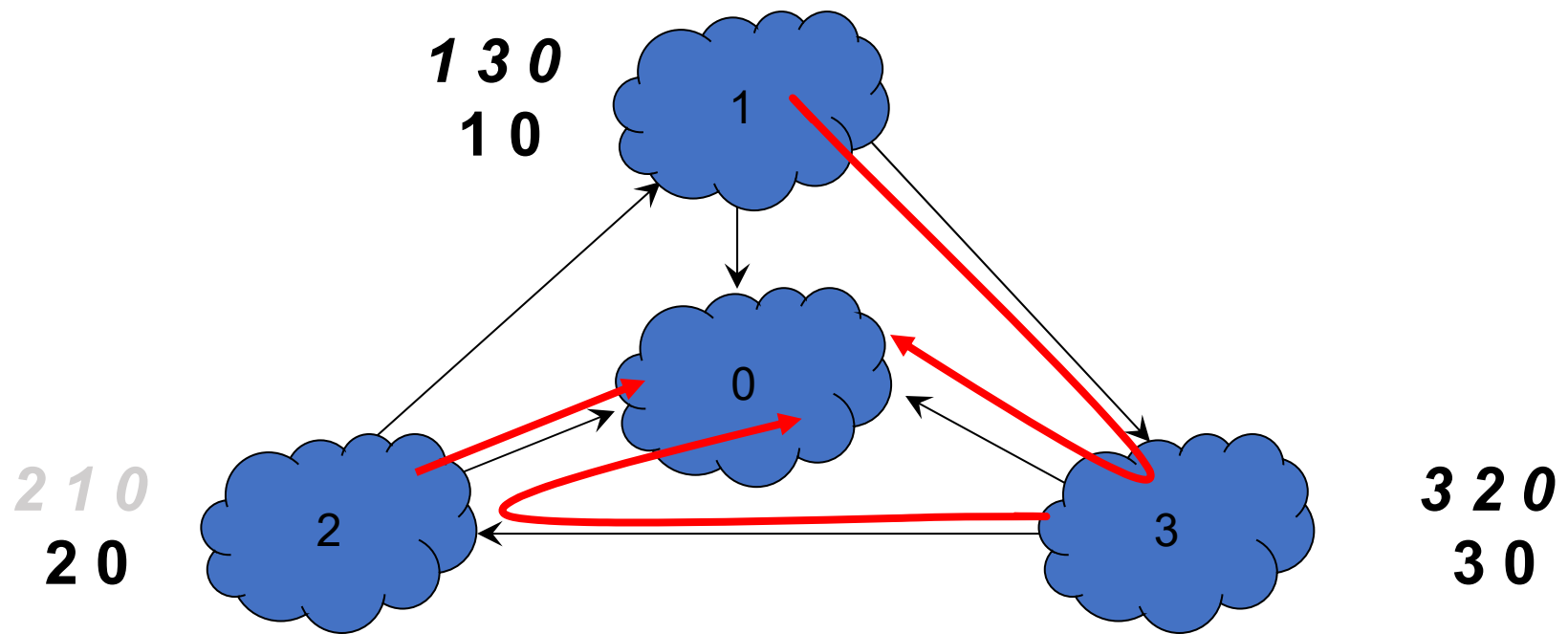- 1 **withdraws** its path 1 0 from 2

Step-by-step of policy oscillation

Step-by-step of policy oscillation
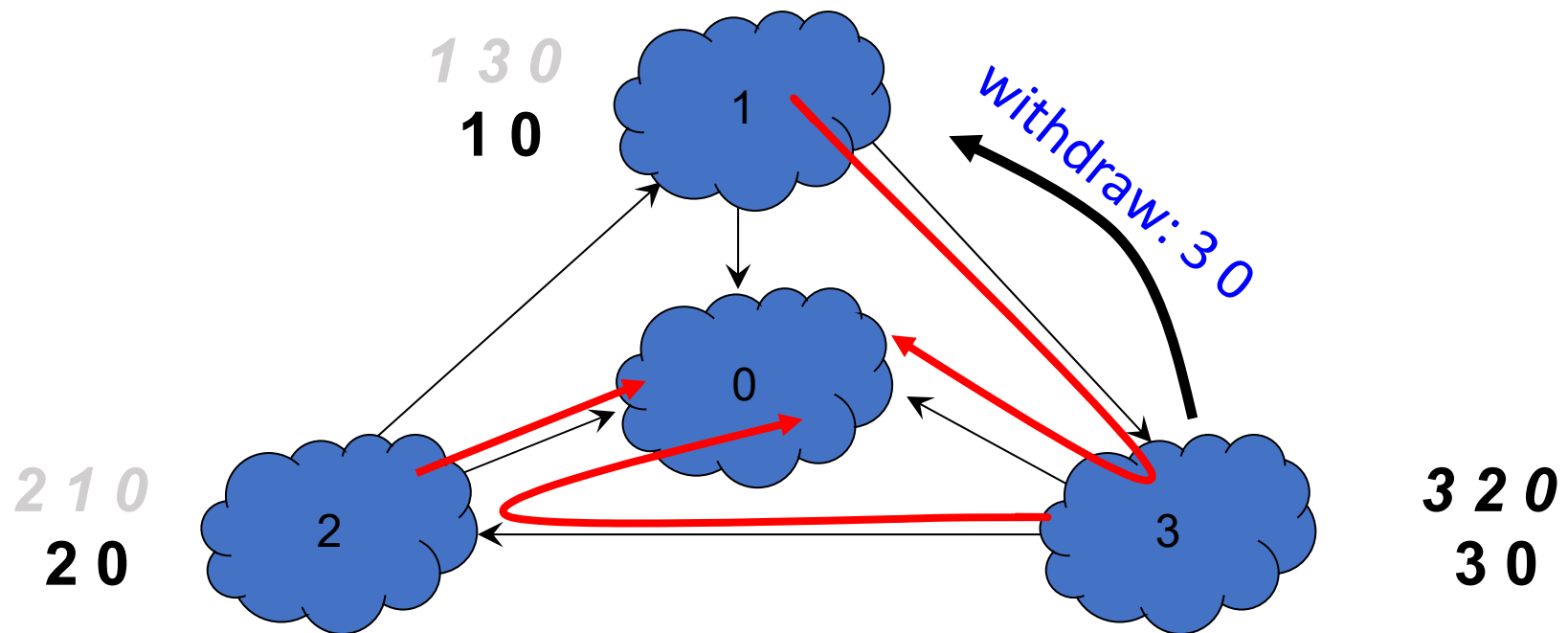
- 2 **advertises** its path 2 0 to 3
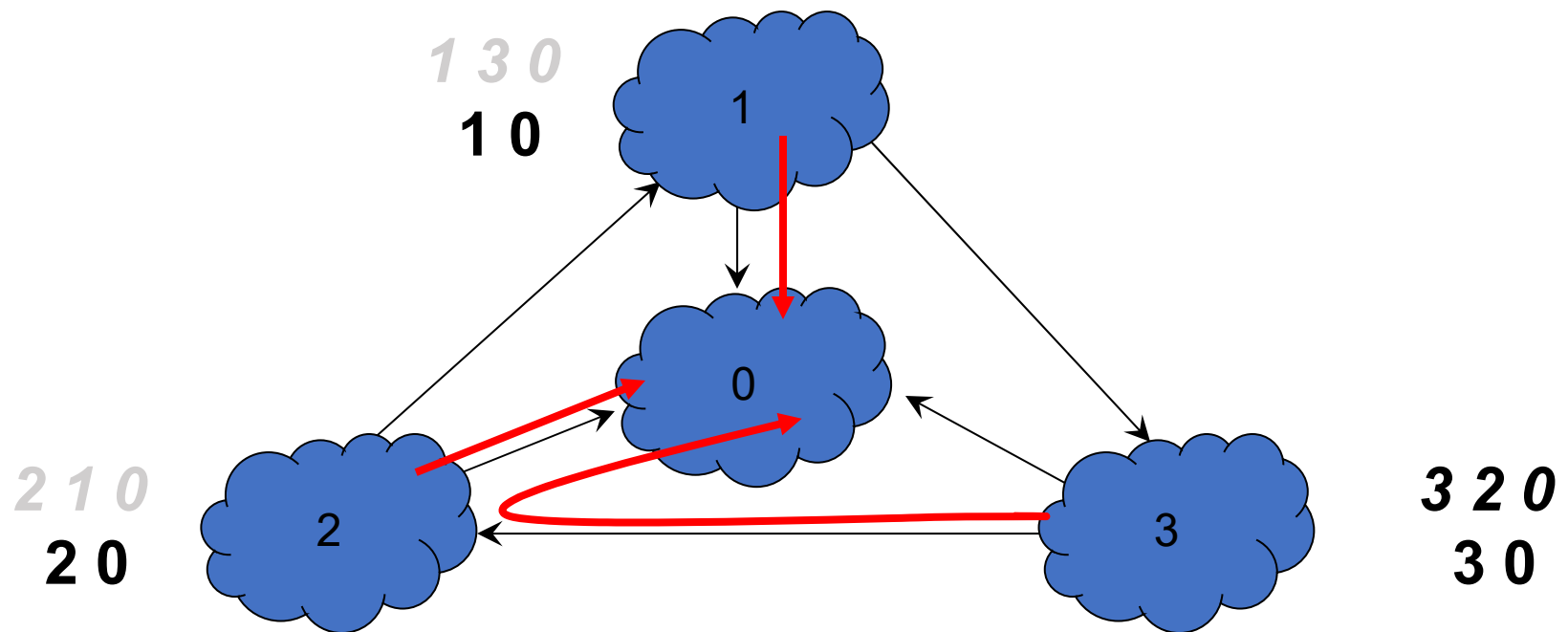
Step-by-step of policy oscillation

Step-by-step of policy oscillation

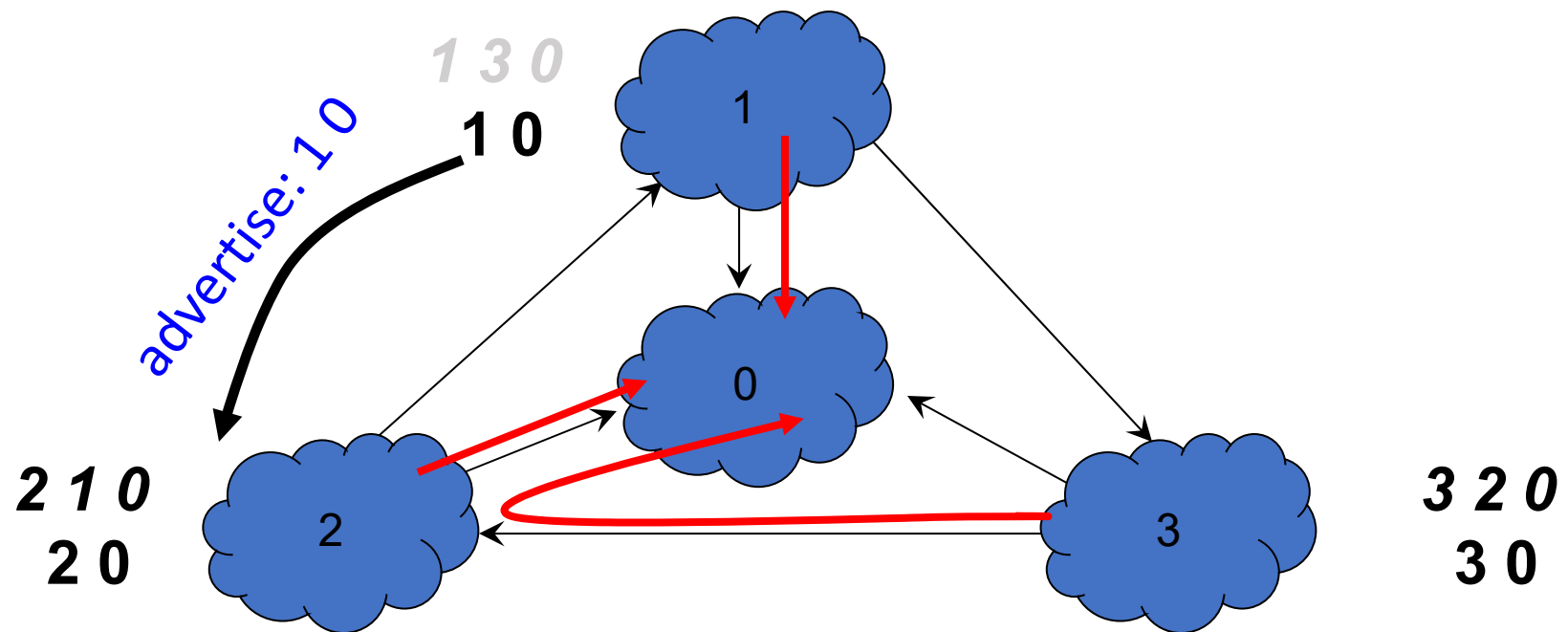- 3 **withdraws** its path 3 0 from 1

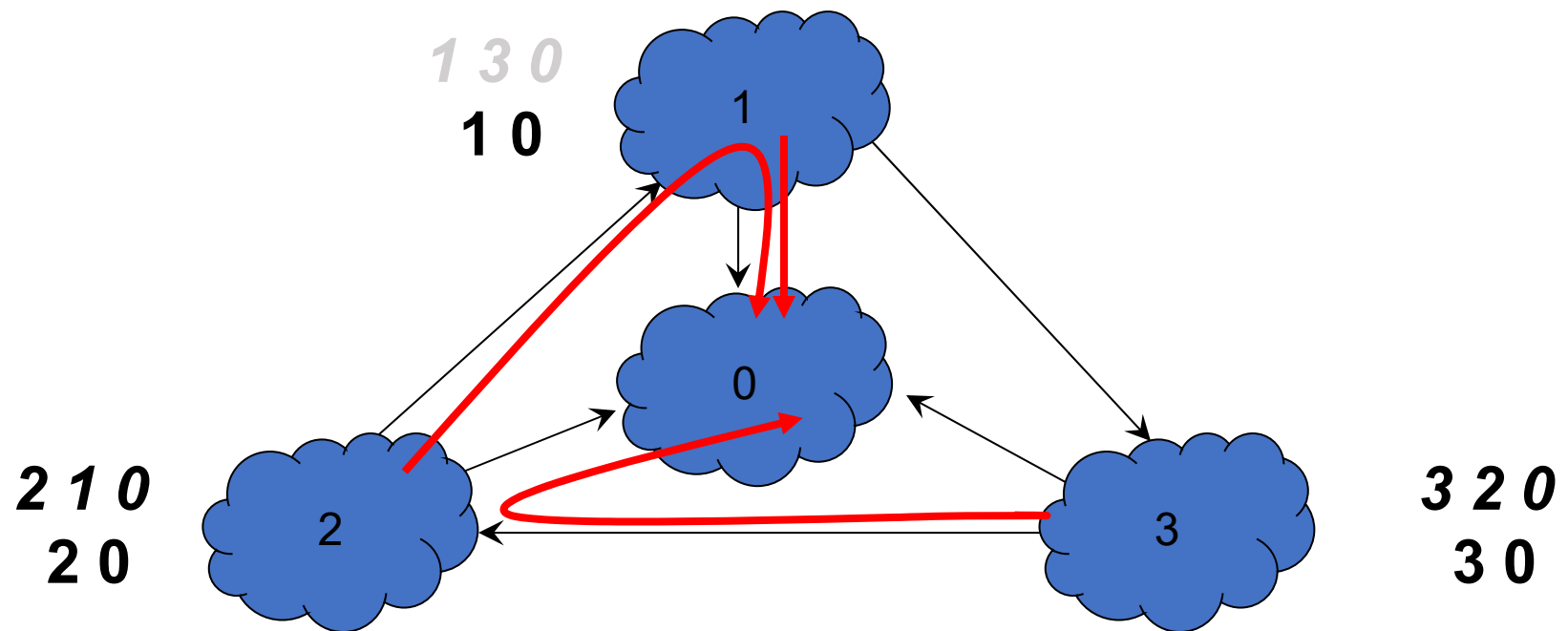# Step-by-step of policy oscillation

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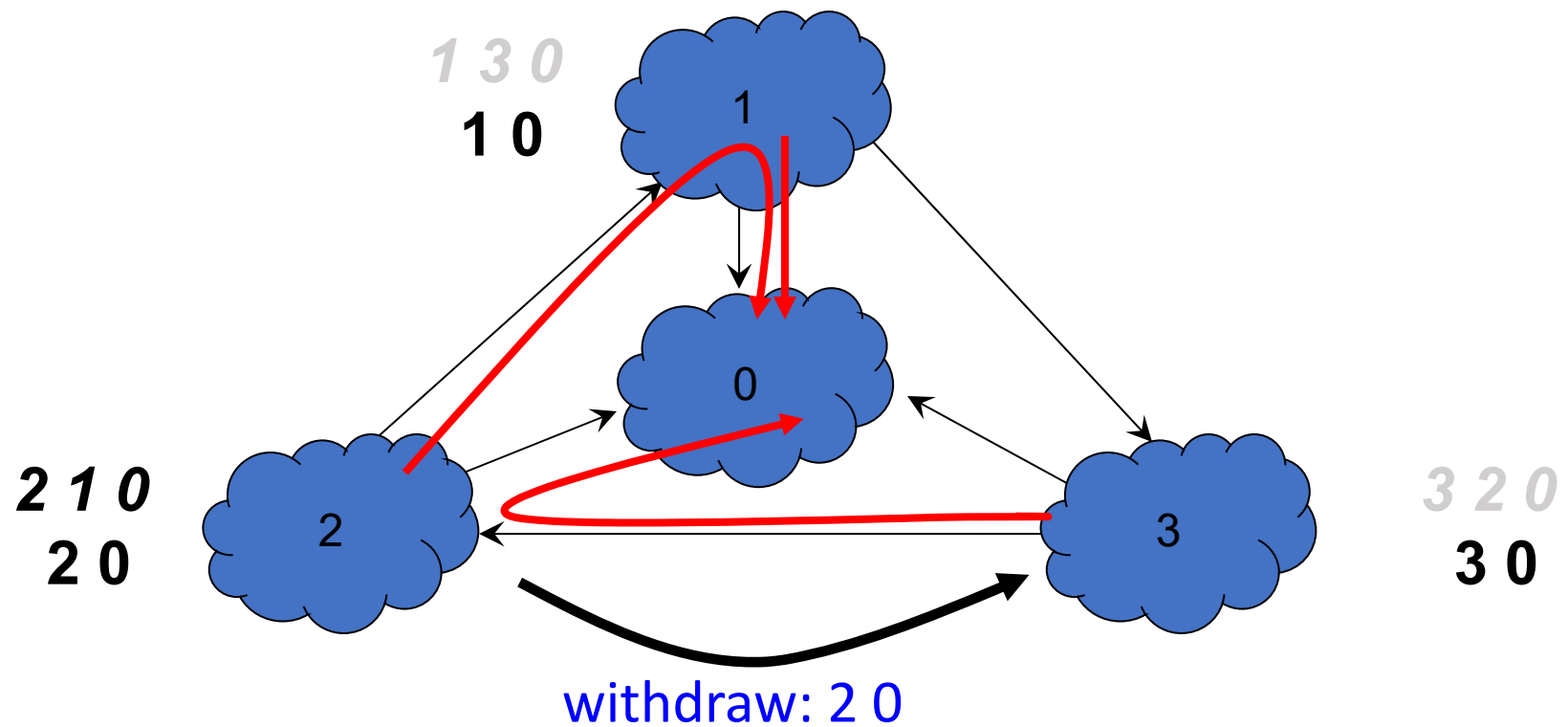
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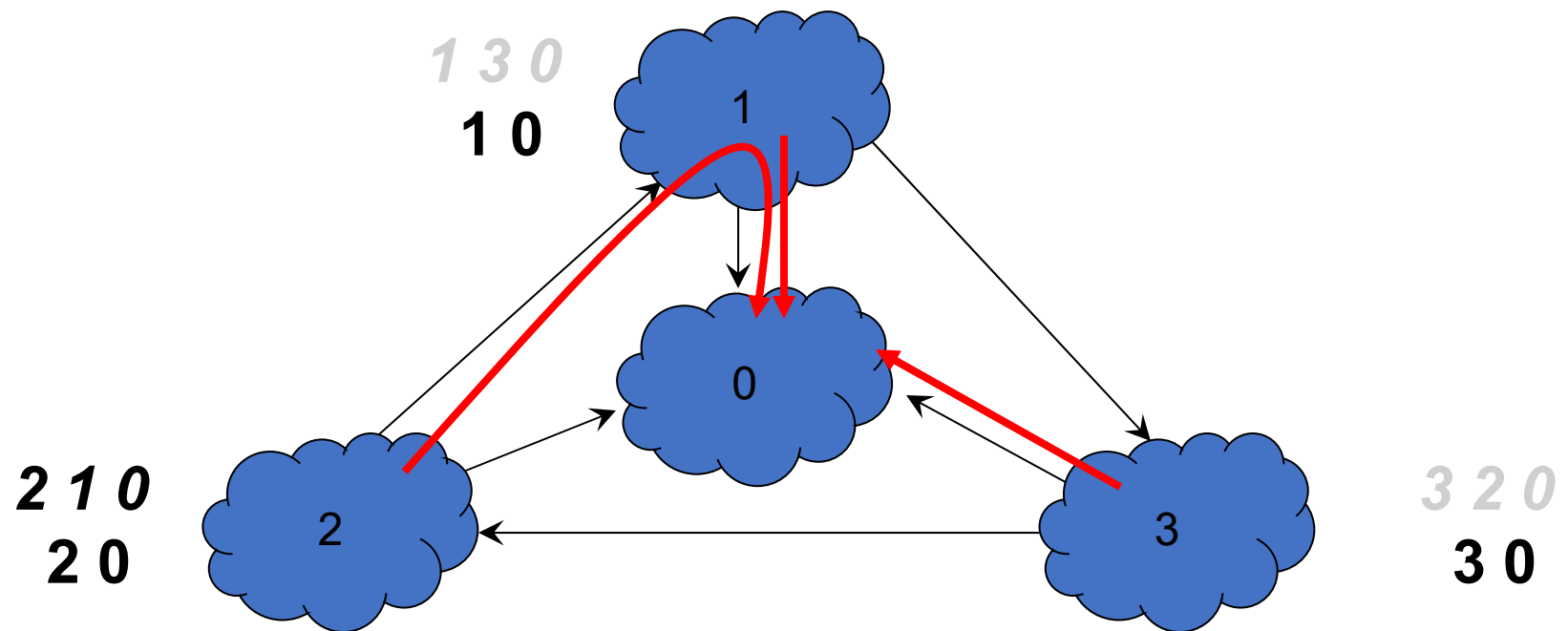
Step-by-step of policy oscillation

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

BGP says that path **4 1** is better than path **3 2 1**

AS 3

AS 2

AS 1

AS 4
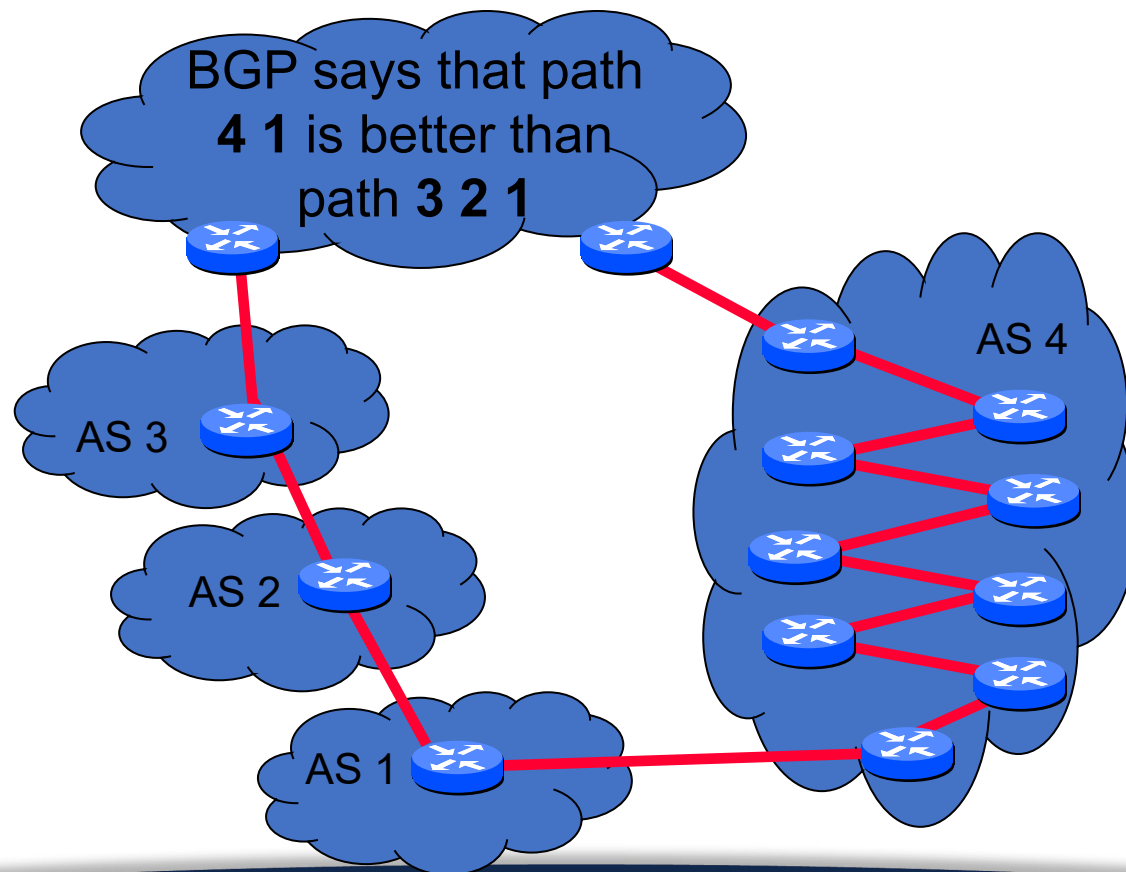
Real performance issue: Slow convergence

- 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

Lecture Quiz – Due Wednesday at Midnight

- https://forms.gle/PZ7TXkiCfnAGiits6

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)