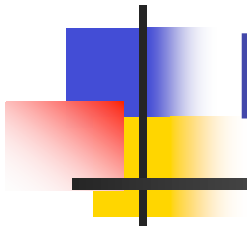
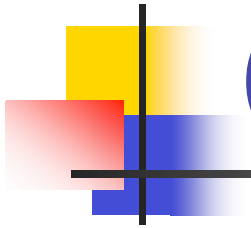


Border Gateway Protocol – BGP4

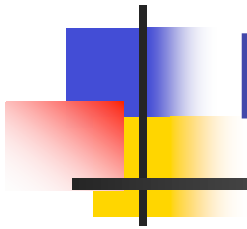
Philip Smith

E2 Workshop, AfNOG2007

Border Gateway Protocol (BGP4)

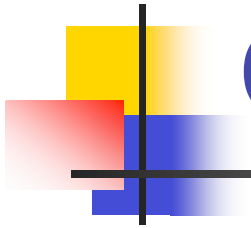


- Part 0: Why use BGP?
- Part 1: Forwarding and Routing (review)
- Part 2: Interior and Exterior Routing
- Part 3: BGP Building Blocks
- Part 4: Configuring BGP
- Case Study 1, Exercise 1: Single upstream
- Part 5: BGP Protocol Basics
- Part 6: BGP Protocol - more detail
- Case Study 2, Exercise 2: Local peer
- Part 7: Routing Policy and Filtering
- Exercise 3: Filtering on AS-path
- Exercise 4: Filtering on prefix-list
- Part 8: More detail than you want
- Exercise 5: Interior BGP
- Part 9: BGP and Network Design



BGP Part 0

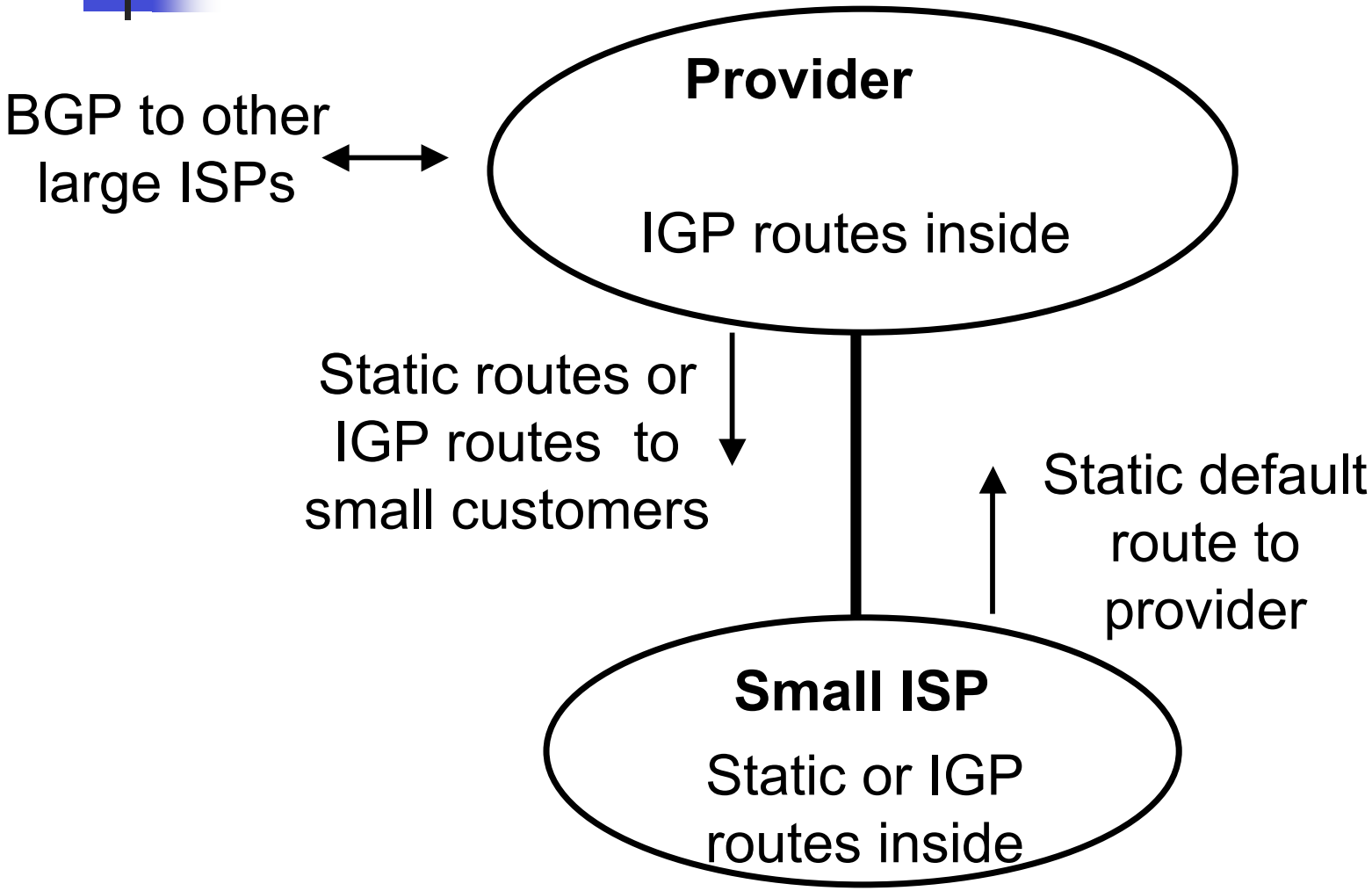
Why use BGP?



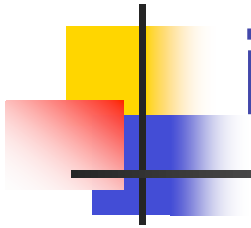
Consider a typical small ISP

- Local network in one country
- May have multiple POPs in different cities
- Line to Internet
  - International line providing transit connectivity
  - Very, very expensive international line
- Doesn’t yet need BGP

Small ISP with one upstream provider

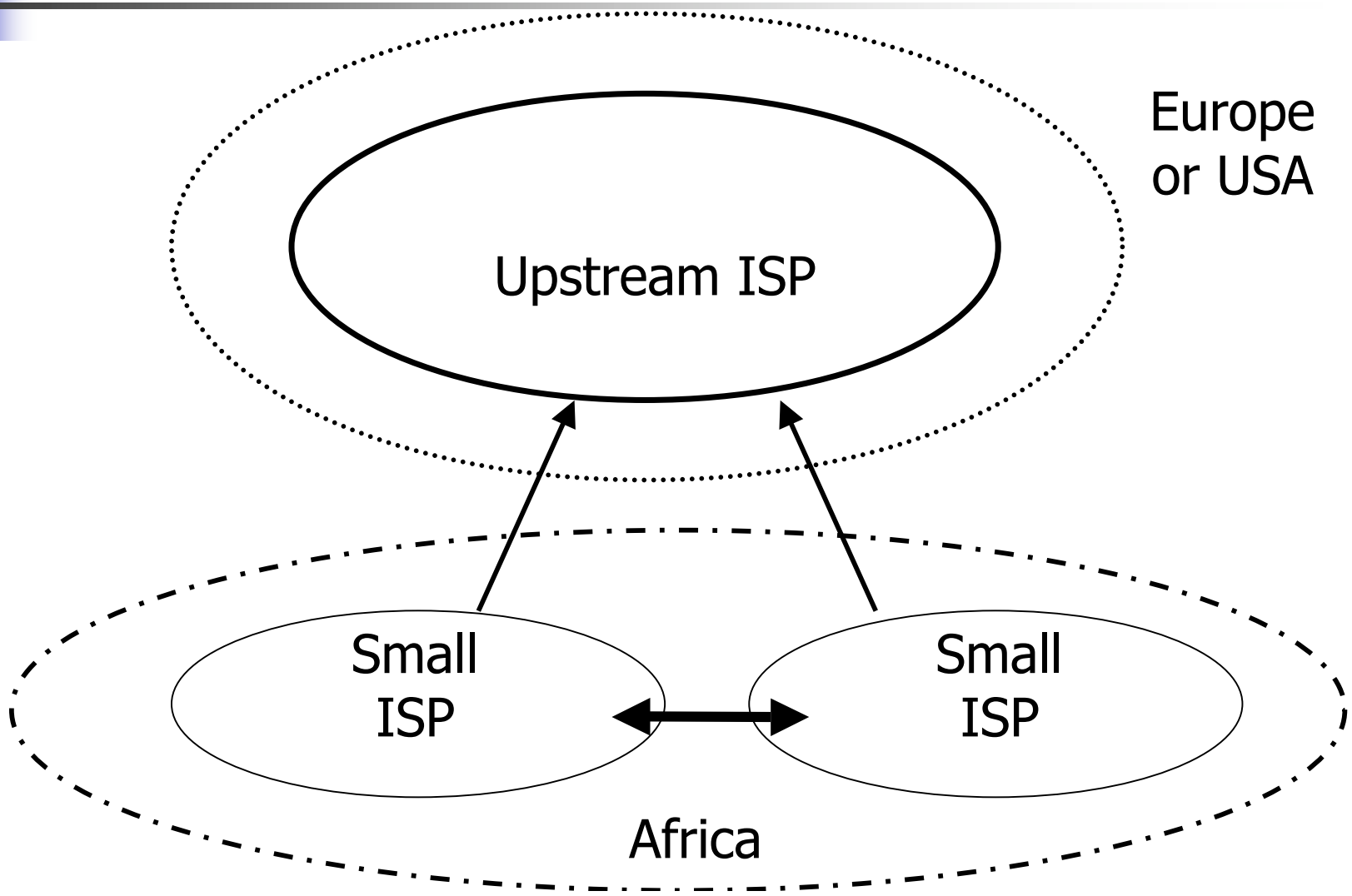


What happens with other ISPs in the same country

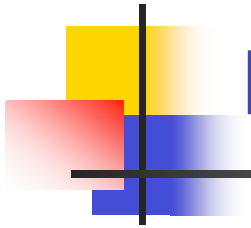


- Similar setup
- Traffic between you and them goes over
  - Your expensive line
  - Their expensive line
- Traffic can be significant
  - Your customers want to talk to their customers
  - Same language/culture
  - Local email, discussion lists, web sites

Keeping Local Traffic Local

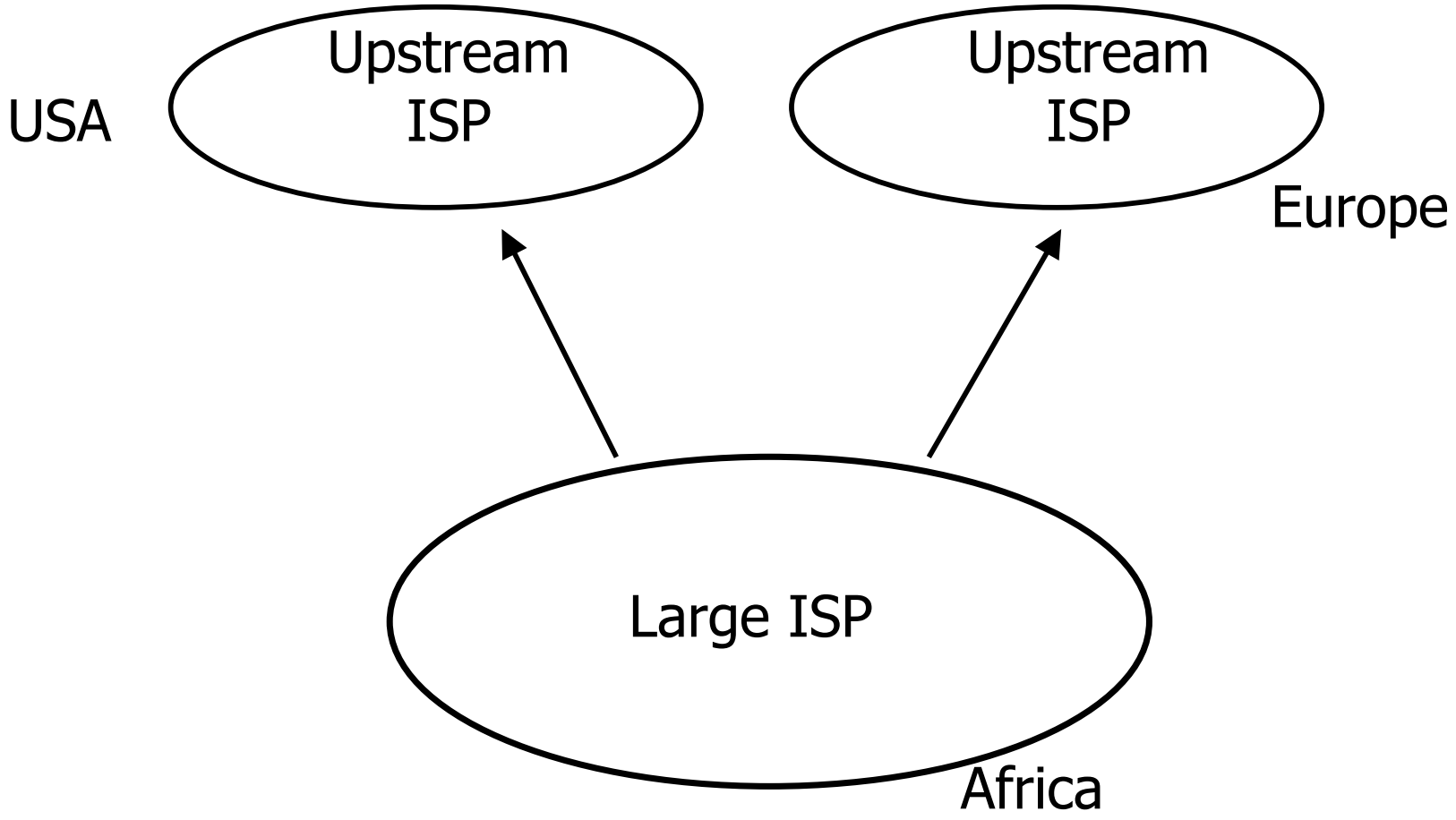


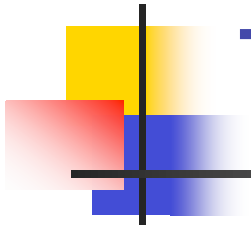
Consider a larger ISP with multiple upstreams



- Large ISP multi-homes to two or more upstream providers
  - multiple connections
  - to achieve:
    - redundancy
    - connection diversity
    - increased speeds
  - Use BGP to choose a different upstream for different destination addresses

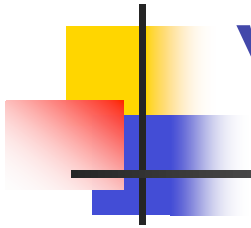
A Large ISP with more than one upstream provider





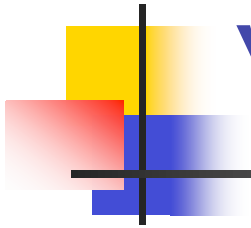
Terminology: “Policy”

- Where do you want your traffic to go?
  - It is difficult to get what you want, but you can try
- Control of how you accept and send routing updates to neighbours
  - Prefer cheaper connections
  - Prefer connections with better latency
  - Load-sharing, etc



“Policy” (continued)

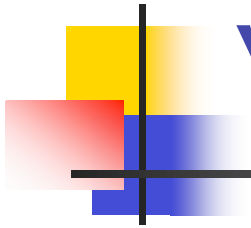
- Implementing policy:
  - Accepting routes from some ISPs and not others
  - Sending some routes to some ISPs and not to others
  - Preferring routes from some ISPs over those from other ISPs



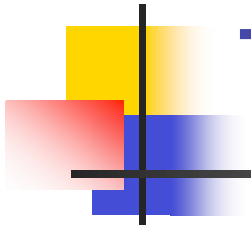
“Policy” Implementation

- You want to use a local line to talk to the customers of other local ISPs
  - local peering
- You do not want other local ISPs to use your expensive international lines
  - no free transit!
- So you need some sort of control over routing policies
- BGP can do this

Terminology: "Peering" and "Transit"

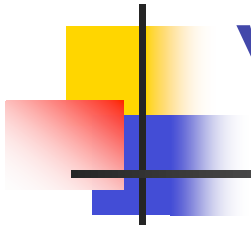


- **Peering**: getting connectivity to the network of other the ISP
  - … and just that network, no other networks
  - Frequently at zero cost (zero-settlement)
- **Transit**: getting connectivity though the network of the other ISP to other networks
  - … getting connectivity to rest of world (or part thereof)
  - Usually at cost (customer-provider relationship)



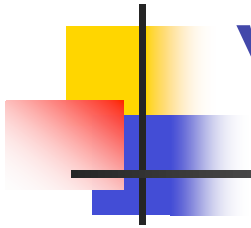
Terminology: “Aggregation”

- Combining of several smaller blocks of address space into a larger block
- For example:
  - 192.168.4.0/24 and 192.168.5.0/24 are contiguous address blocks
  - They can be combined and represented as 192.168.4.0/23…
  - …with no loss of information!



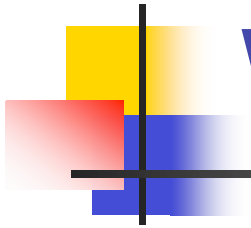
“Aggregation” (continued)

- Useful because it hides detailed information about the local network:
  - The outside world needs to know about the range of addresses in use
  - The outside world does **not** need to know about the small pieces of address space used by different customers inside your network



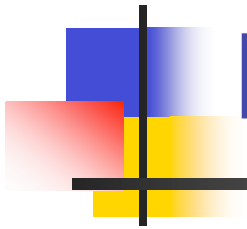
“Aggregation” (continued)

- A jigsaw puzzle makes up a picture which is easier to see when the puzzle is complete!
- Aggregation is very necessary when using BGP to “talk” to the Internet



Summary: Why do I need BGP?

- Multi-homing – connecting to multiple providers
  - upstream providers
  - local networks – regional peering to get local traffic
- Policy discrimination
  - controlling how traffic flows
  - do not accidentally provide transit to non-customers

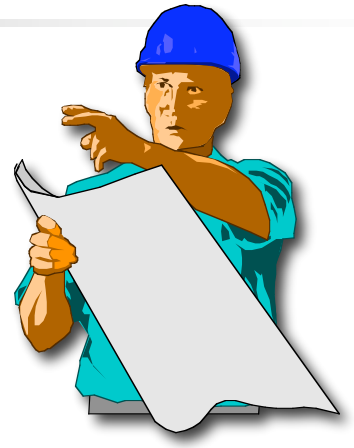


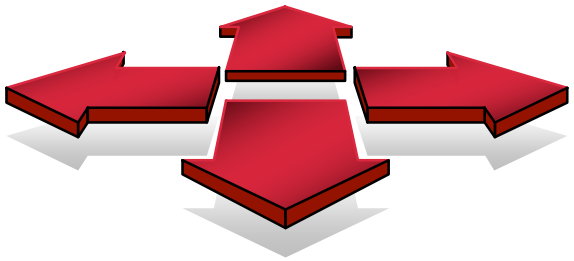
BGP Part 1

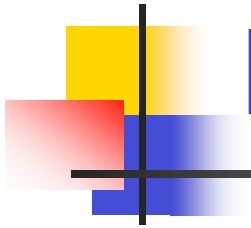
Forwarding and Routing

Routing versus Forwarding

- Routing = building maps and giving directions
- Forwarding = moving packets between interfaces according to the "directions"

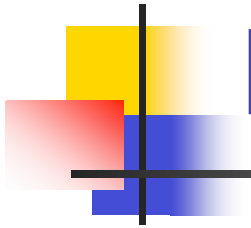






Routing Table/RIB

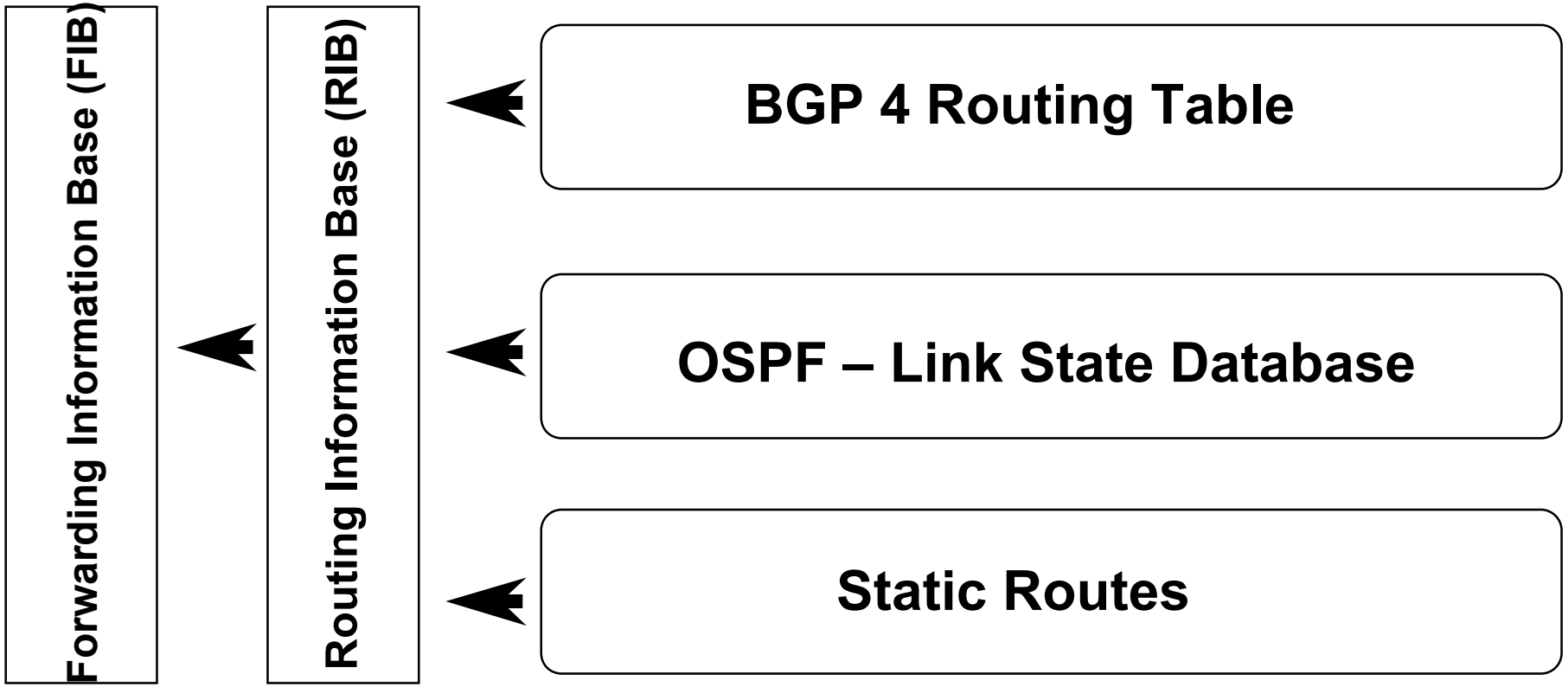
- Routing table is managed by a routing protocol (e.g. OSPF or BGP)
- Often called the RIB – Routing Information Base
- Each routing protocol has its own way of managing its own routing tables
- Each routing protocol has a way of exchanging information between routers using the same protocol

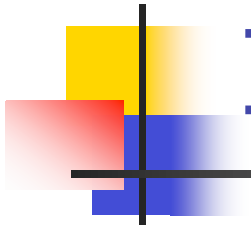


Forwarding Table/FIB

- Forwarding table determines how packets are sent through the router
- Often called the FIB – Forwarding Information Base
- Made from routing table built by routing protocols
  - Best routes from routing tables are installed
- Performs the lookup to find next-hop and outgoing interface
- Switches the packet with new encapsulation as per the outgoing interface

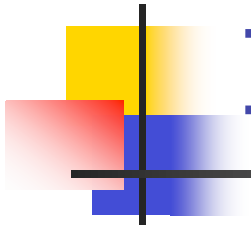
Routing Tables Feed the Forwarding Table





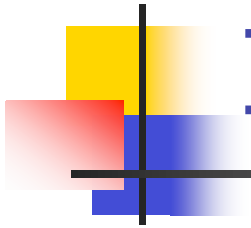
IP Routing

- Each router or host makes its own routing decisions
- Sending machine does not have to determine the entire path to the destination
- Sending machine just determines the next-hop along the path (based on destination IP address)
  - This process is repeated until the destination is reached, or there's an error
- Forwarding table is consulted (at each hop) to determine the next-hop



IP Routing

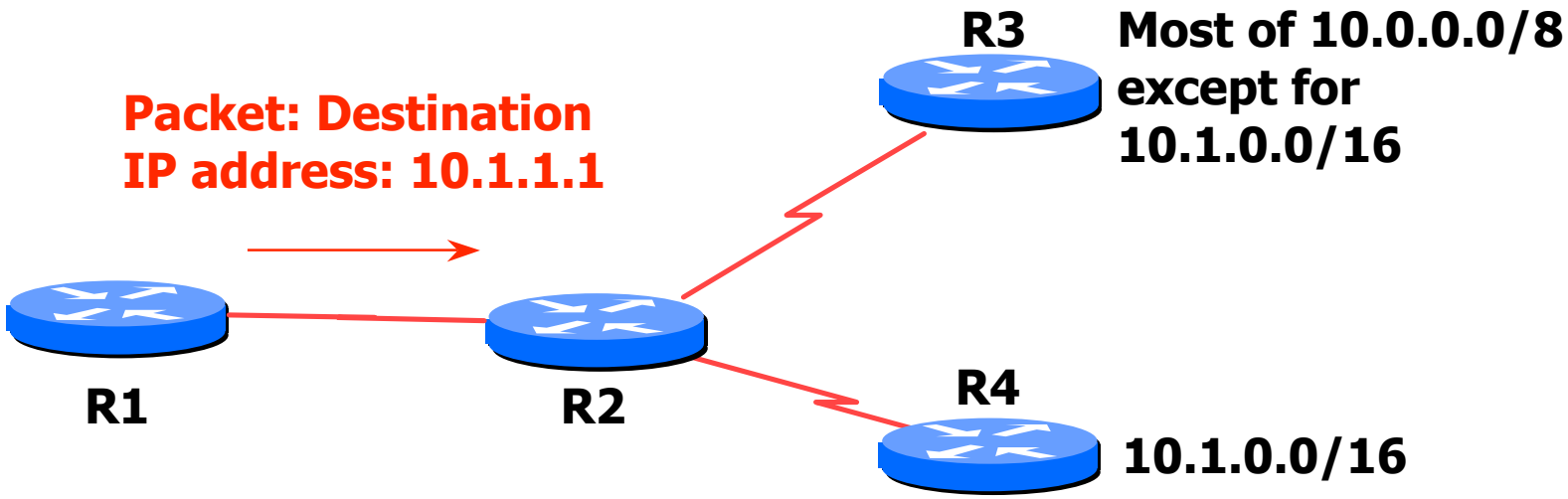
- Classless routing
  - route entries include
    - destination
    - next-hop
    - mask (prefix-length) indicating size of address space described by the entry
- Longest match
  - for a given destination, find longest prefix match in the routing table
  - example: destination is 35.35.66.42
    - routing table entries are 35.0.0.0/8, 35.35.64.0/19 and 0.0.0.0/0
    - All these routes match, but the /19 is the longest match



IP routing

- Default route
  - where to send packets if there is no entry for the destination in the routing table
  - most machines have a single default route
  - often referred to as a default gateway
  - 0.0.0.0/0
    - matches all possible destinations, but is usually not the longest match

IP route lookup: Longest match routing

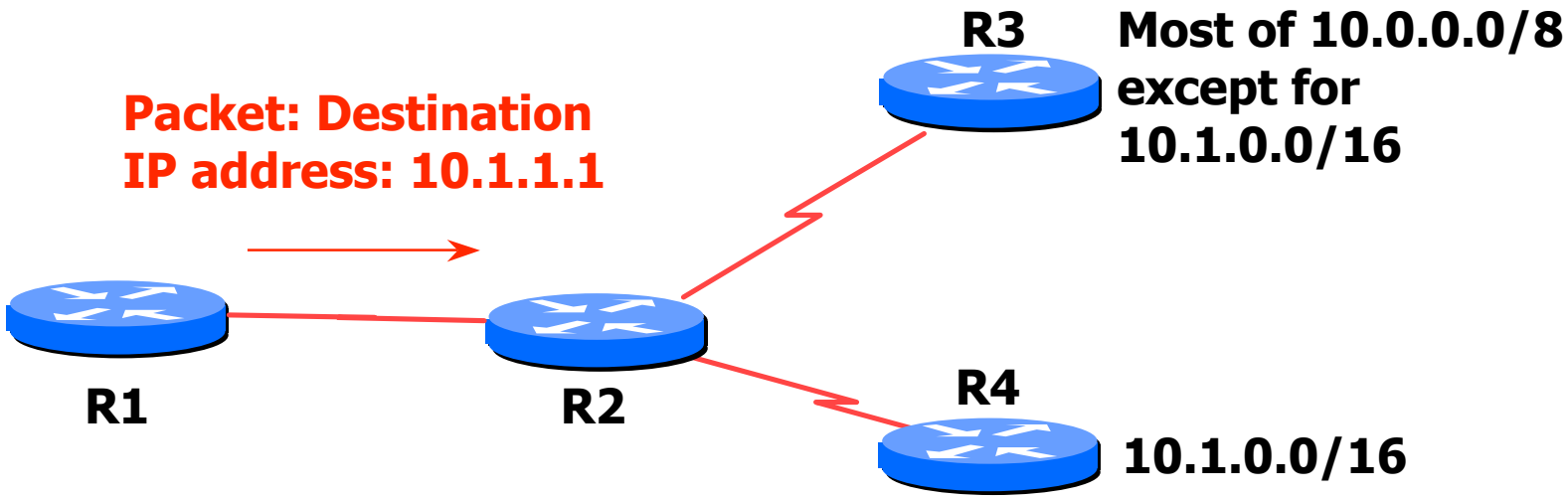


Based on destination IP address

R2's IP forwarding table

10.0.0.0/8 → R3
10.1.0.0/16 → R4
20.0.0.0/8 → R5
0.0.0.0/0 → R1

IP route lookup: Longest match routing

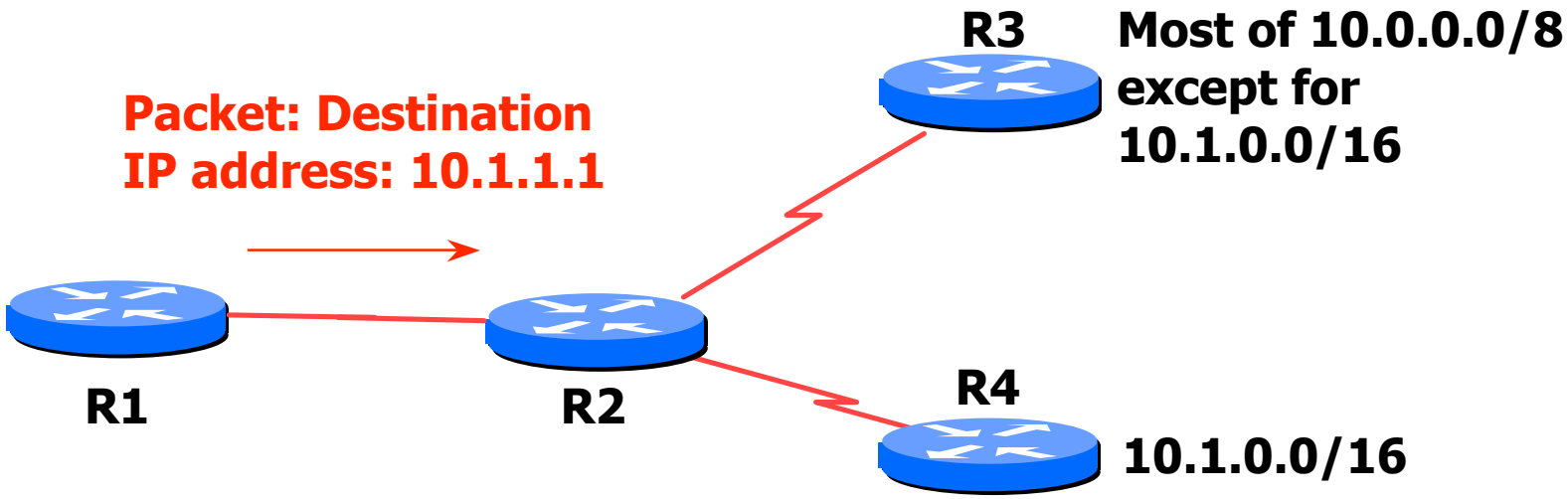


Based on destination IP address

R2's IP forwarding table

10.0.0.0/8 → R3 10.1.0.0/16 → R4 20.0.0.0/8 → R5 0.0.0.0/0 → R1	**10.1.1.1 & FF.00.00.00** **vs.** **10.0.0.0 & FF.00.00.00** **Match! (length 8)**

IP route lookup: Longest match routing



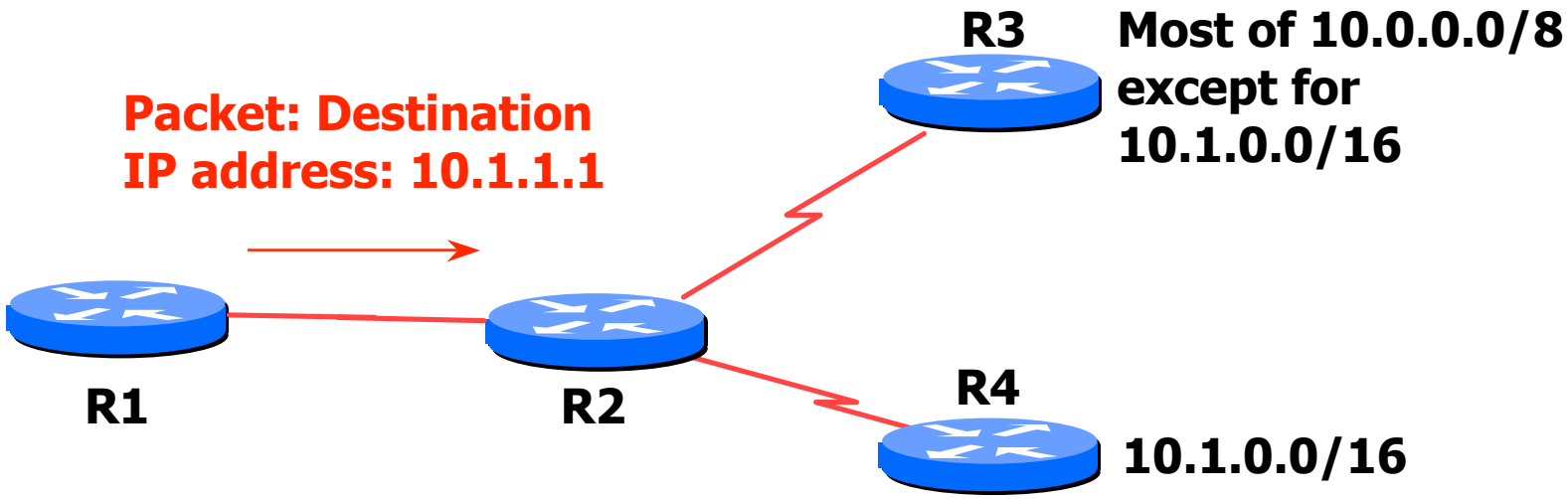
Based on destination IP address

R2's IP forwarding table

10.0.0.0/8 → R3
10.1.0.0/16 → R4
20.0.0.0/8 → R5
0.0.0.0/0 → R1

10.1.1.1 & FF.FF.00.00
vs.
10.1.0.0 & FF.FF.00.00
Match! (length 16)

IP route lookup: Longest match routing



Based on destination IP address

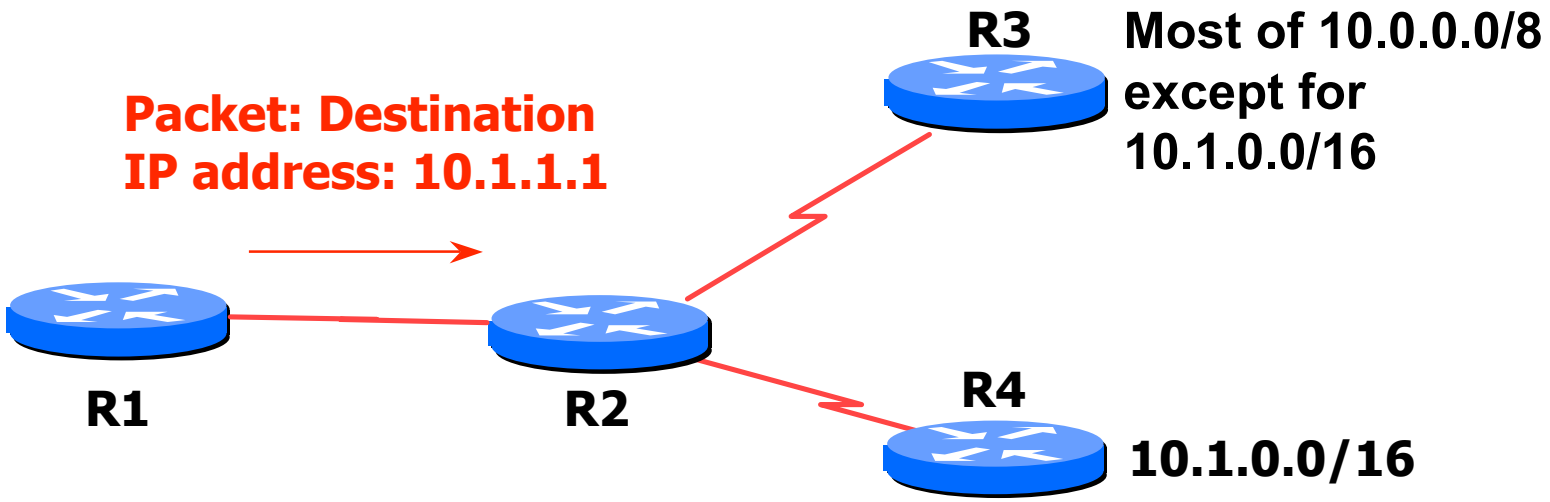
R2's IP forwarding table

10.0.0.0/8 → R3
10.1.0.0/16 → R4
20.0.0.0/8 → R5
0.0.0.0/0 → R1

→

10.1.1.1 & FF.00.00.00
vs.
20.0.0.0 & FF.00.00.00
No Match!

IP route lookup: Longest match routing



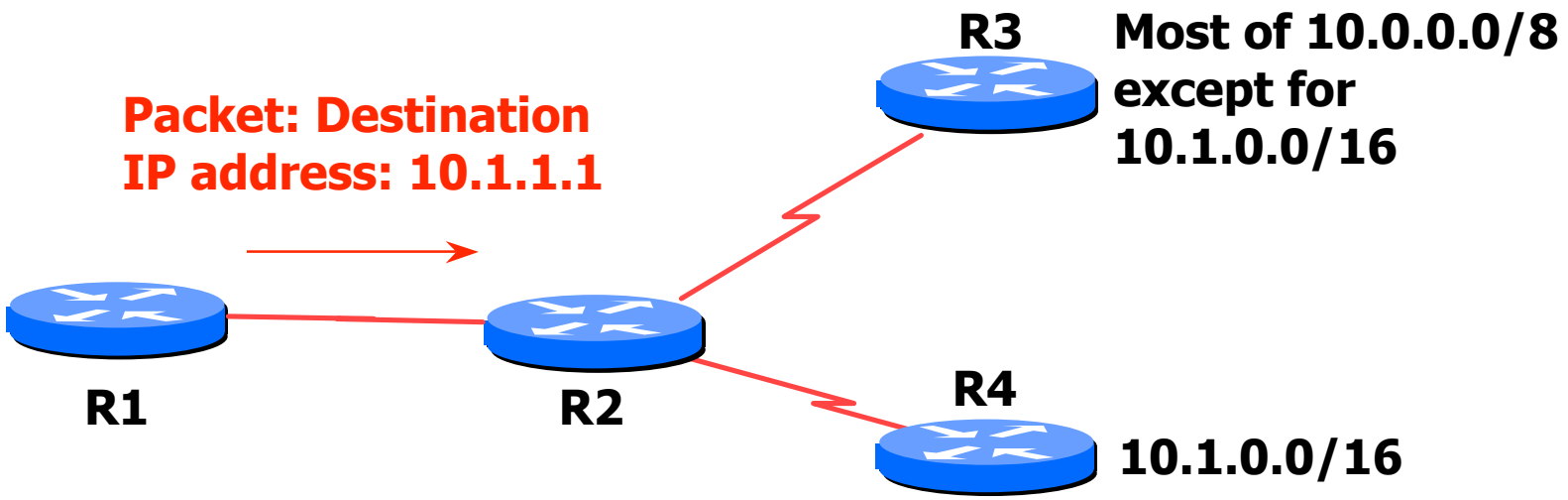
Based on destination IP address

R2's IP forwarding table

10.0.0.0/8 → R3
10.1.0.0/16 → R4
20.0.0.0/8 → R5
0.0.0.0/0 → R1

10.1.1.1 & 00.00.00.00
vs.
0.0.0.0 & 00.00.00.00
Match! (length 0)

IP route lookup: Longest match routing

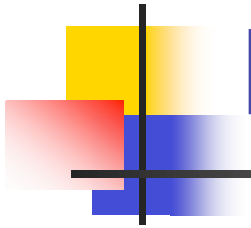


Based on destination IP address

R2's IP forwarding table

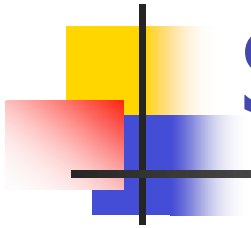
10.0.0.0/8 → R3
10.1.0.0/16 → R4
20.0.0.0/8 → R5
0.0.0.0/0 → R1

This is the longest matching prefix (length 16). "R2" will send the packet to "R4".



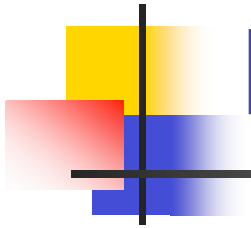
IP route lookup: Longest match routing

- Most specific/longest match always wins!!
  - Many people forget this, even experienced ISP engineers
- Default route is 0.0.0.0/0
  - Can handle it using the normal longest match algorithm
  - Matches everything. Always the shortest match.



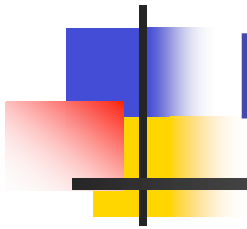
Static vs. Dynamic routing

- Static routes
  - Set up by administrator
  - Changes need to be made by administrator
  - Only good for small sites and star topologies
  - Bad for every other topology type
- Dynamic routes
  - Provided by routing protocols
  - Changes are made automatically
  - Good for network topologies which have redundant links (most!)



Dynamic Routing

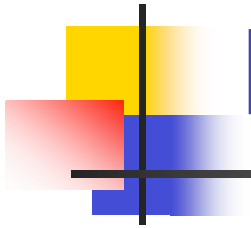
- Routers compute routing tables dynamically based on information provided by other routers in the network
- Routers communicate topology to each other via different protocols
- Routers then compute one or more next hops for each destination – trying to calculate the most optimal path
- Automatically repairs damage by choosing an alternative route (if there is one)



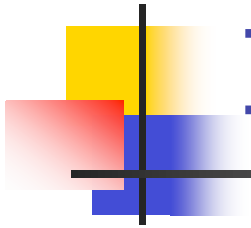
BGP Part 2

Interior and Exterior Routing

Interior vs. Exterior Routing Protocols

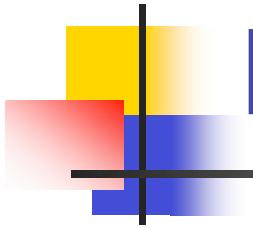


- Interior gateway protocol (IGP)
  - Automatic neighbour discovery
  - Under control of a single organisation
  - Generally trust your IGP routers
  - Routes go to all IGP routers
  - Usually not filtered
- Exterior gateway protocol (EGP)
  - Specifically configured peers
  - Connecting with outside networks
  - Neighbours are not trusted
  - Set administrative boundaries
  - Filters based on policy



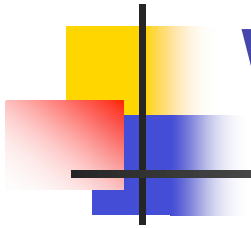
IGP

- Interior Gateway Protocol
- Within a network/autonomous system
- Carries information about internal prefixes
- Examples – OSPF, ISIS, EIGRP, RIP



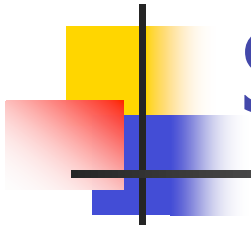
EGP

- Exterior Gateway Protocol
- Used to convey routing information between networks/ASes
- De-coupled from the IGP
- Current EGP is BGP4



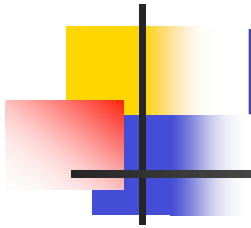
Why Do We Need an EGP?

- Scaling to large network
  - Hierarchy
  - Limit scope of failure
- Define administrative boundary
- Policy
  - Control reachability to prefixes



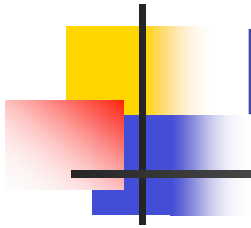
Scalability and policy issues

- Just getting direct line is not enough
- Need to work out how to do routing
  - Need to get local traffic between ISP's/peers
  - Need to make sure the peer ISP doesn't use us for transit
  - Need to control what networks to announce, what network announcements to accept to upstreams and peers



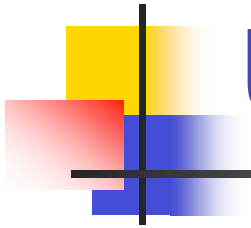
Scalability: Not using static routes

- **`ip route their_net their_gw`**
- Does not scale
- Millions of networks around the world



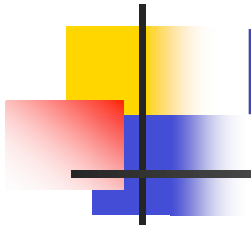
Scalability: Not using IGP (OSPF)

- Serious operational consequences:
  - If the other ISP has a routing problem, you will have problems too
  - Your network prefixes could end up in the other ISP's network — and vice-versa
  - Very hard to filter routes so that we don't inadvertently give transit



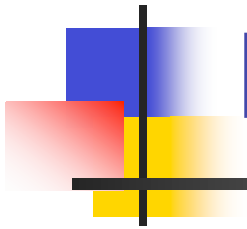
Using BGP instead

- BGP = Border Gateway Protocol
- BGP is an **exterior** routing protocol
- Focus on routing **policy**, not topology
- BGP can make ‘groups’ of networks (Autonomous Systems)
- Good route filtering capabilities
- Ability to isolate from other’s problems



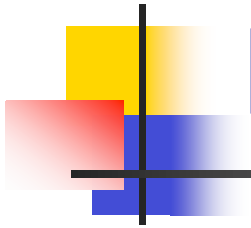
Border Gateway Protocol

- A Routing Protocol used to exchange routing information between networks
  - exterior gateway protocol
- Described in RFC4271
  - RFC4276 gives an implementation report on BGP-4
  - RFC4277 describes operational experiences using BGP-4
- The Autonomous System is BGP's fundamental operating unit
  - It is used to uniquely identify networks with a common routing policy



BGP Part 3

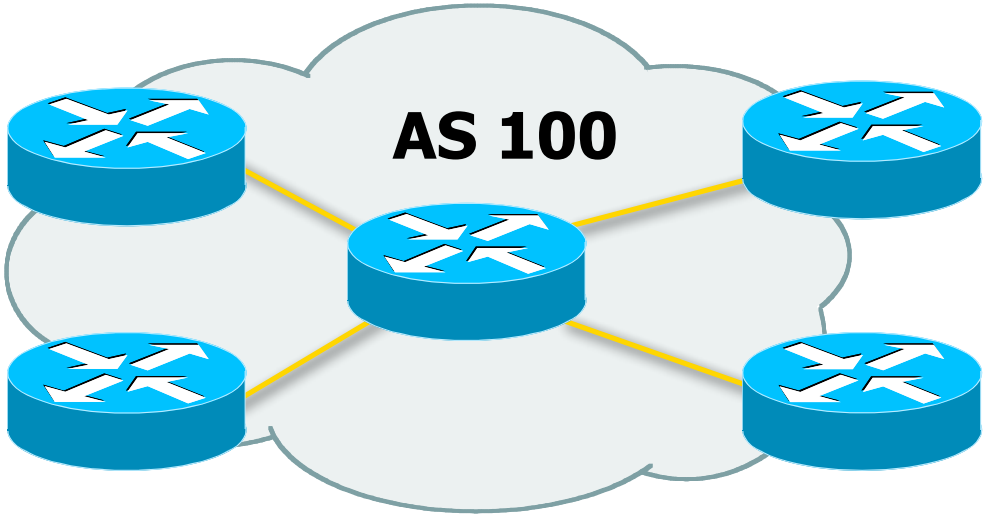
BGP Building Blocks



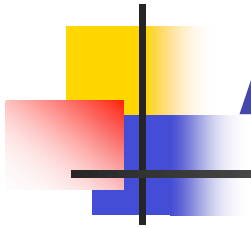
BGP Building Blocks

- Autonomous System (AS)
- Types of Routes
- IGP/EGP
- DMZ
- Policy
- Egress
- Ingress

Autonomous System (AS)

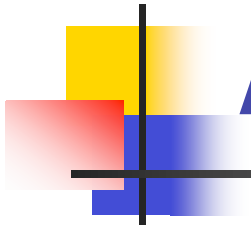


- Collection of networks with same policy
- Single routing protocol
- Usually under single administrative control
- IGP to provide internal connectivity



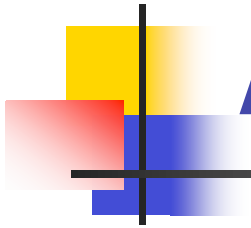
Autonomous System (AS)

- Autonomous systems is a misnomer
  - Not much to do with freedom, independence, …
- Just a handle for a group of networks that is under the same administrative control
- Identified by an AS number



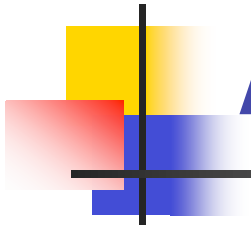
Autonomous System (AS)

- Identified by 'AS number'
  - example: AS16907 (ISPKenya)
- Examples:
  - Service provider
  - Multi-homed customers
  - Anyone needing policy discrimination for networks with different routing policies
- Single-homed network (one upstream provider) does not need an AS number
  - Treated like part of upstream AS



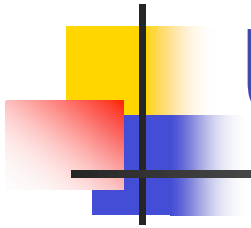
Autonomous System Numbers

- 16-bit integer
- 0 and 65535 are reserved
- 1 to 64511 are for public use
  - Assigned by registry, just like IP addresses
  - Current ASN allocations up to 43007 have been made to the RIRs
  - Around 24500 are visible in the Internet
- Remaining AS numbers (64512-65534) are for private use
  - see RFC1930 for details



Autonomous System Numbers

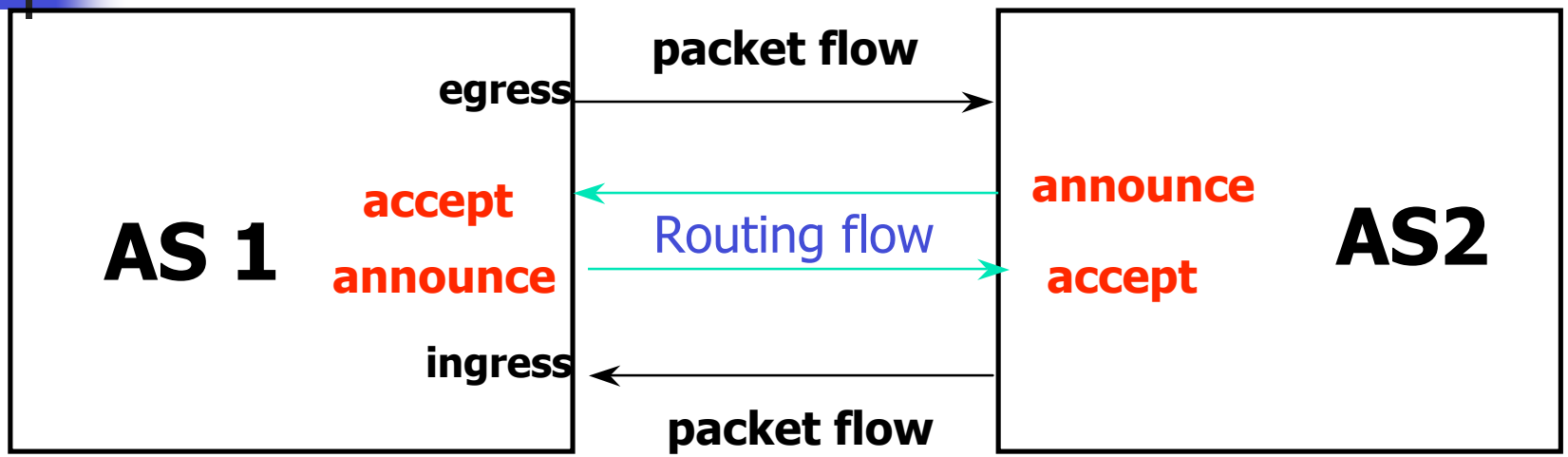
- 32-bit ASNs are here now
  - www.ietf.org/internet-drafts/draft-ietf-idr-as4bytes-13.txt
  - www.ietf.org/internet-drafts/draft-michaelson-4byte-as-representation-02.txt
  - www.ietf.org/internet-drafts/draft-rekhter-as4octet-ext-community-01.txt
  - www.apnic.net/docs/policy/proposals/prop-032-v002.html
  - With AS 23456 reserved for the transition
  - Implementations on Quagga and OpenBGPd



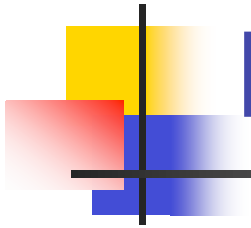
Using AS numbers

- BGP can filter on AS numbers
  - Get all networks of the other ISP using one handle
  - Include future new networks without having to change routing filters
    - AS number for new network will be same
  - Can use AS numbers in filters with regular expressions
- BGP actually does routing computation on IP numbers

Routing flow and packet flow

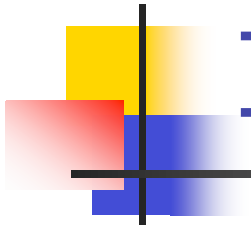


- For networks in AS1 and AS2 to communicate:
  - AS1 must announce routes to AS2
  - AS2 must accept routes from AS1
  - AS2 must announce routes to AS1
  - AS1 must accept routes from AS2



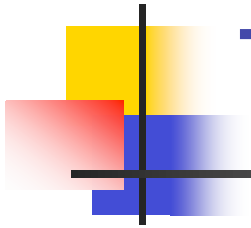
Egress Traffic

- Packets exiting the network
- Based on:
  - Route availability (what others send you)
  - Route acceptance (what you accept from others)
  - Policy and tuning (what you do with routes from others)
  - Peering and transit agreements



Ingress Traffic

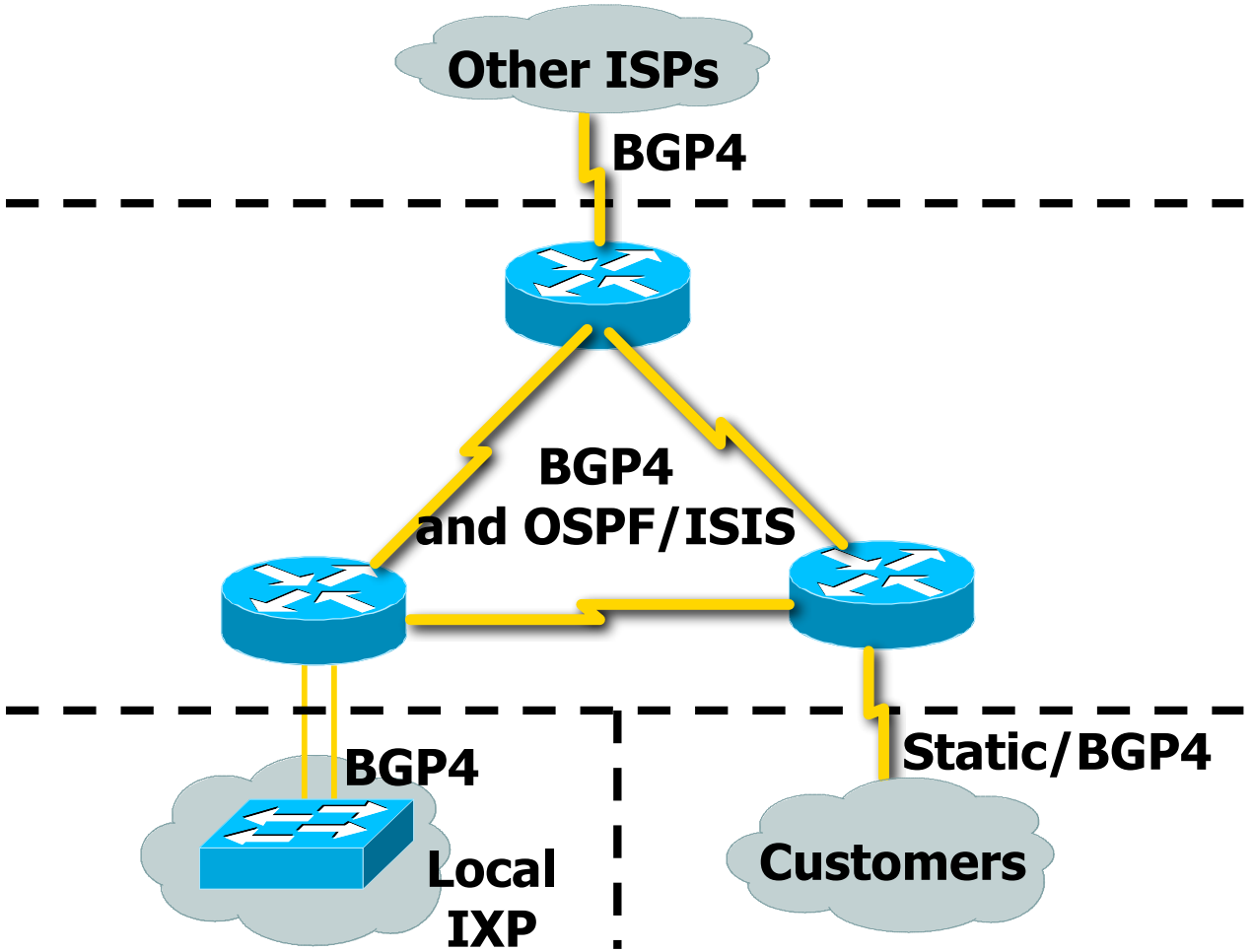
- Packets entering your network
- Ingress traffic depends on:
  - What information you send and to whom
  - Based on your addressing and ASes
  - Based on others' policy (what they accept from you and what they do with it)



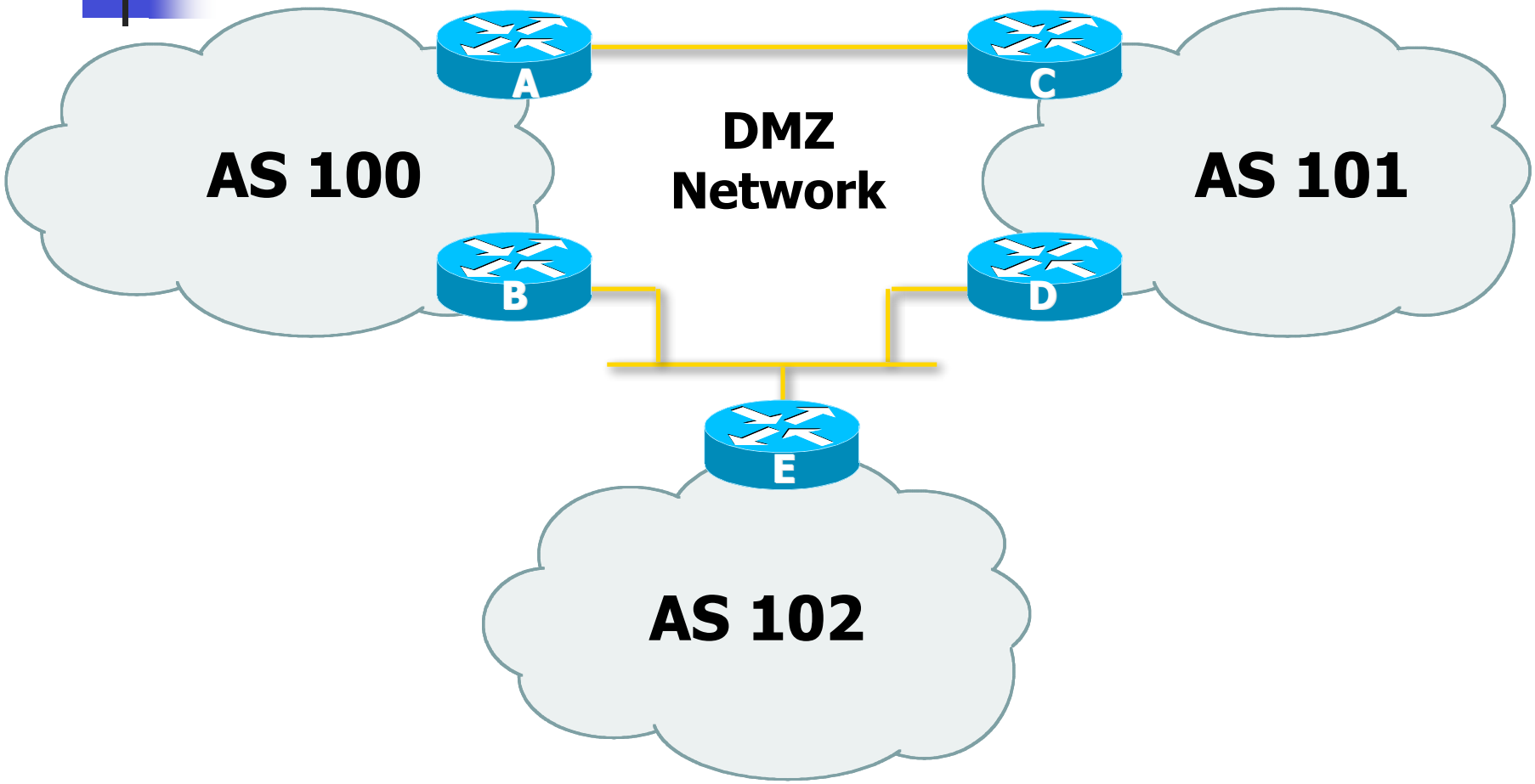
Types of Routes

- Static Routes
  - configured manually
- Connected Routes
  - created automatically when an interface is ‘up’
- Interior Routes
  - Routes within an AS
  - learned via IGP (e.g. OSPF)
- Exterior Routes
  - Routes exterior to AS
  - learned via EGP (e.g. BGP)

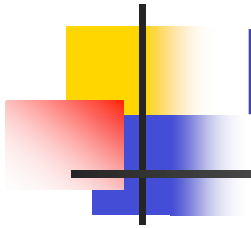
Hierarchy of Routing Protocols



DeMarcation Zone (DMZ)

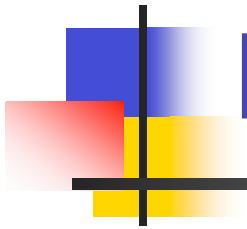


- Shared network between ASes



Basics of a BGP route

- Seen from output of “show ip bgp”
- Prefix and mask — what IP addresses are we talking about?
  - 192.168.0.0/16 or 192.168.0.0/255.255.0.0
- Origin – How did the route originally get into BGP?
  - “?” — incomplete, “e” — EGP, “i” — IGP
- AS Path – what ASes did the route go through before it got to us?
  - “701 3561 1”

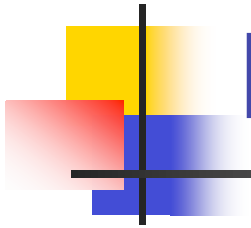


BGP Part 4

Configuring BGP

Basic commands

Getting routes into BGP



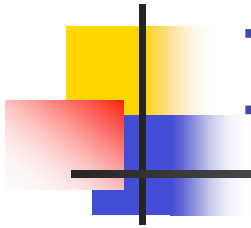
Basic BGP commands

Configuration commands

```
router bgp <AS-number>
 no auto-summary
 no synchronization
 neighbor <ip address> remote-as <as-number>
```

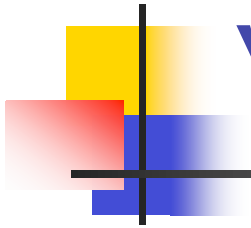
Show commands

```
show ip bgp summary
show ip bgp neighbors
show ip bgp neighbor <ip address>
```



Inserting prefixes into BGP

- Two main ways to insert prefixes into BGP
  - network command
  - redistribute static
- Both require the prefix to be in the routing table

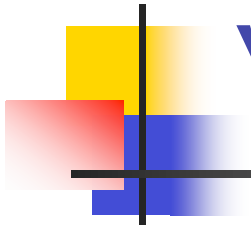


“network” command

- Configuration Example

```
router bgp 1
 network 105.32.4.0 mask 255.255.254.0
ip route 105.32.4.0 255.255.254.0 serial 0
```

- matching route must exist in the routing table before network is announced!
- Prefix will have Origin code set to “IGP”

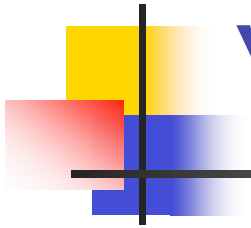


"redistribute static"

- Configuration Example:

```
router bgp 1
 redistribute static
ip route 105.32.4.0 255.255.254.0 serial0
```

- Static route must exist before redistribute command will work
- Forces origin to be "incomplete"
- Care required!
  - This will redistribute *all* static routes into BGP
  - Redistributing without using a filter is dangerous



“redistribute static”

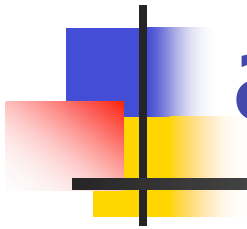
- Care required with redistribution
  - redistribute <routing-protocol> means everything in the <routing-protocol> will be transferred into the current routing protocol
  - will not scale if uncontrolled
  - best avoided if at all possible
  - redistribute normally used with “route-maps” and under tight administrative control
    - “route-map” is used to apply policies in BGP, so is a kind of filter

Aggregates and Null0

- Remember: matching route must exist in routing table before it will be announced by BGP

```
router bgp 1
 network 105.32.0.0 mask 255.255.0.0
ip route 105.32.0.0 255.255.0.0 null0 250
```

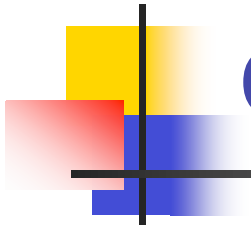
- Static route to null0 often used for aggregation
  - Packets will be sent here if there is no more specific match in the routing table
  - Distance of 250 ensures last resort
- Often used to nail up routes for stability
  - Can't flap! ☺



BGP Case Study 1 and Exercise 1

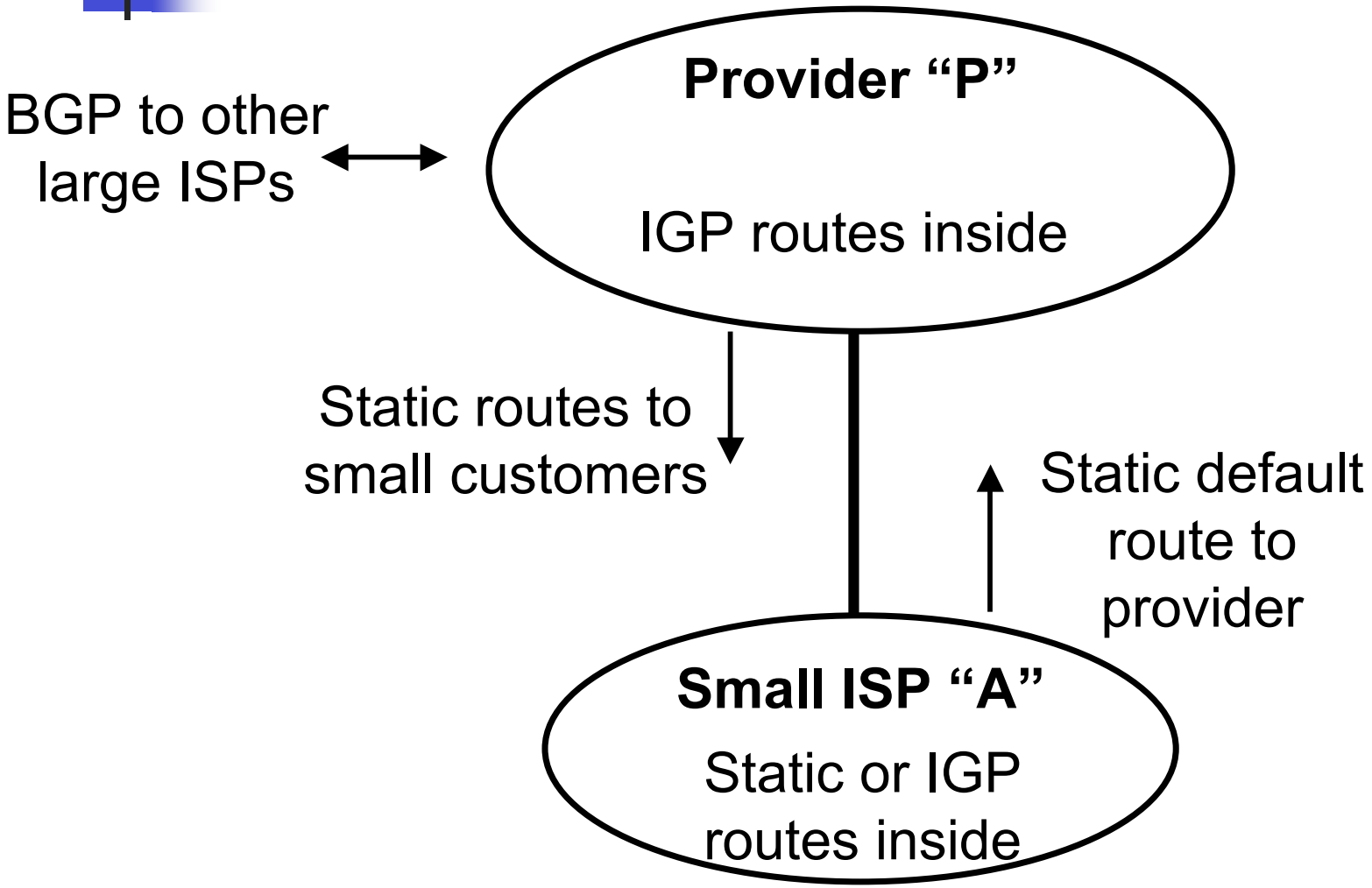
Small ISP with one upstream provider

Case Study 1: Small ISP with one upstream provider

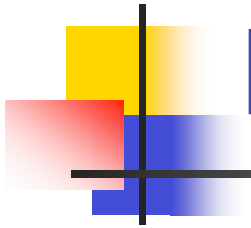


- Local network
- May have multiple POPs
- Line to Internet
  - International line providing transit connectivity
  - Very, very expensive

Case Study 1: Small ISP with one upstream provider

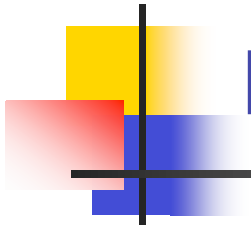


Case Study 1: Routing Protocols



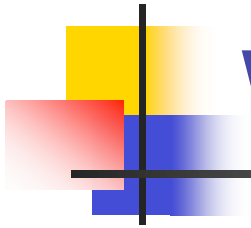
- Static routes or IGP inside small ISP “A”
- Static default route from small ISP “A” to upstream provider “P”
- IGP inside upstream provider “P”
- The two IGPs do not know about each other
- BGP between upstream provider “P” and outside world

Case Study 1: BGP is not needed



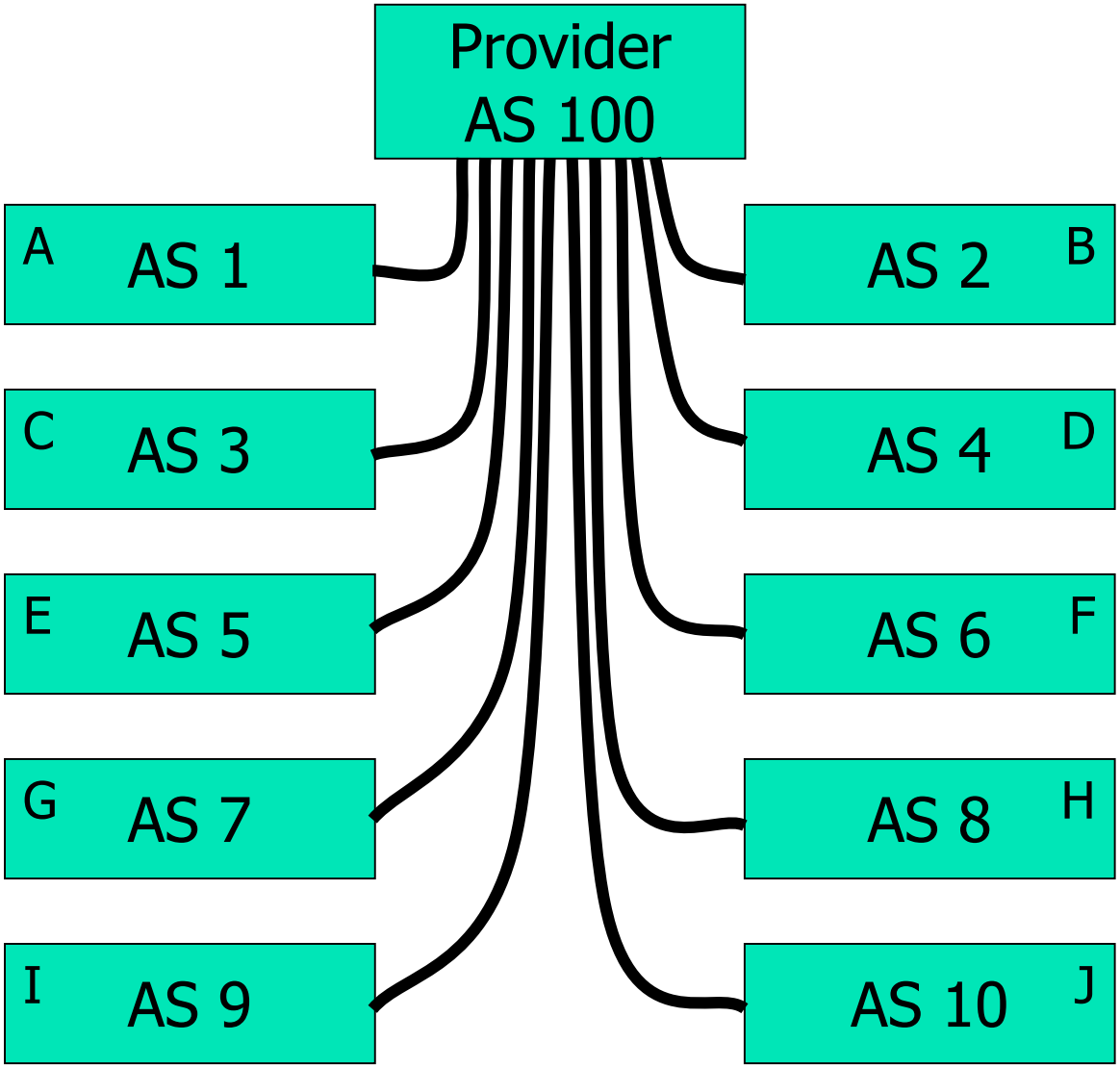
- No need for BGP between small ISP “A” and upstream provider “P”
- The outside world does not need to care about the link between provider “P” and customer “A”
- Hiding that information from the outside world helps with scaling
- **We will do an exercise using BGP even though it is not needed**

Exercise 1: Upstream provider with small customers

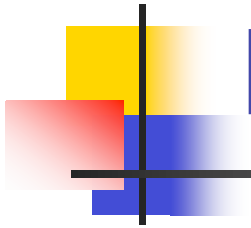


- This is not a realistic exercise
- In reality, a single-homed network would not use BGP
- Exercise 2 will be more realistic, adding a connection between two small ISPs in the same country

Exercise 1: Upstream provider & small customers

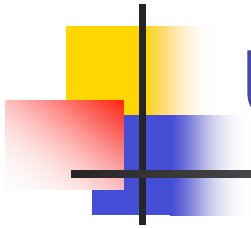


Exercise 1: BGP configuration

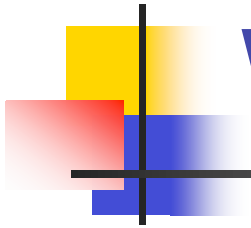


- Refer to “BGP cheat sheet”
- Connect cable to upstream provider
- “router bgp” for your AS number
- BGP “network” statement for your network
- BGP “neighbor” for upstream provider (IP address 196.200.220.12, remote AS 100)

Exercise 1: Transit through upstream provider



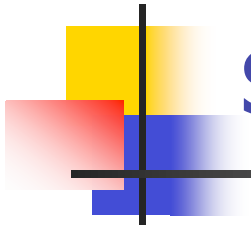
- Instructors configure AS 100 to send you all routes to other classroom ASes, and a default route
  - You can send traffic through AS 100 to more distant destinations
  - In other words, AS 100 provides “transit” service to you



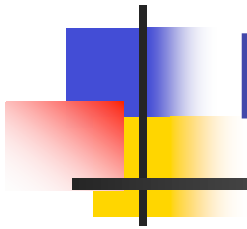
Exercise 1: What you should see

- You should see routes to all other classroom networks.
- Try “show ip route” to see routing table
- Try “show ip bgp” to see BGP table
- Look at the “next hop” and “AS path”
- Try some pings and traceroutes.

Exercise 1: Did BGP "network" statement work?



- BGP "network" statement has no effect unless route exists in IGP (or static route)
- You might need to add a static route to make it work
  - ip route x.x.x.x m.m.m.m Null0 250



BGP Part 5

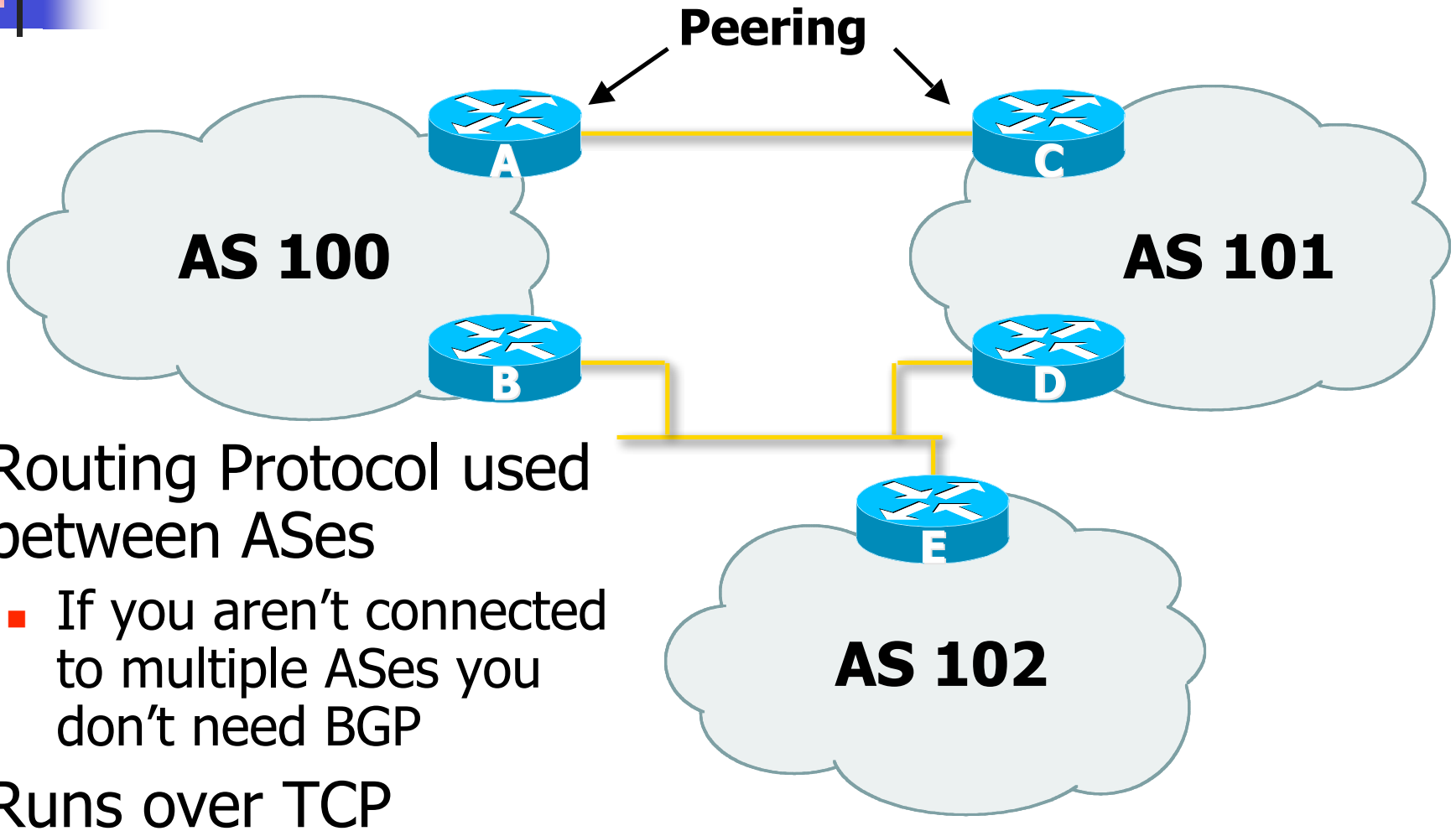
BGP Protocol Basics

Terminology

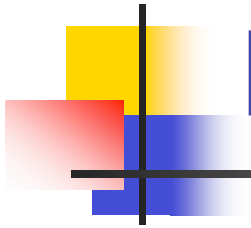
General Operation

Interior/Exterior BGP

BGP Protocol Basics

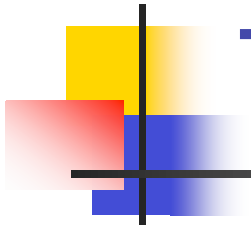


- Routing Protocol used between ASes
  - If you aren't connected to multiple ASes you don't need BGP
- Runs over TCP



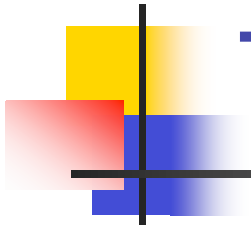
BGP Protocol Basics

- Uses Incremental updates
  - sends one copy of the RIB at the beginning, then sends changes as they happen
- Path Vector protocol
  - keeps track of the AS path of routing information
- Many options for policy enforcement



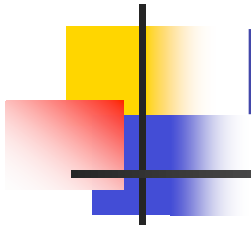
Terminology

- Neighbour
  - Configured BGP peer
- NLRI/Prefix
  - NLRI – network layer reachability information
  - Reachability information for an IP address & mask
- Router-ID
  - 32 bit integer to uniquely identify router
  - Comes from Loopback or Highest IP address configured on the router
- Route/Path
  - NLRI advertised by a neighbour



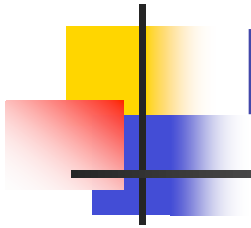
Terminology

- Transit – carrying network traffic across a network, usually for a fee
- Peering – exchanging routing information and traffic
  - your customers and your peers' customers network information only.
  - not your peers' peers; not your peers' providers.
- Peering also has another meaning:
  - BGP neighbour, whether or not transit is provided
- Default – where to send traffic when there is no explicit route in the routing table



BGP Basics …

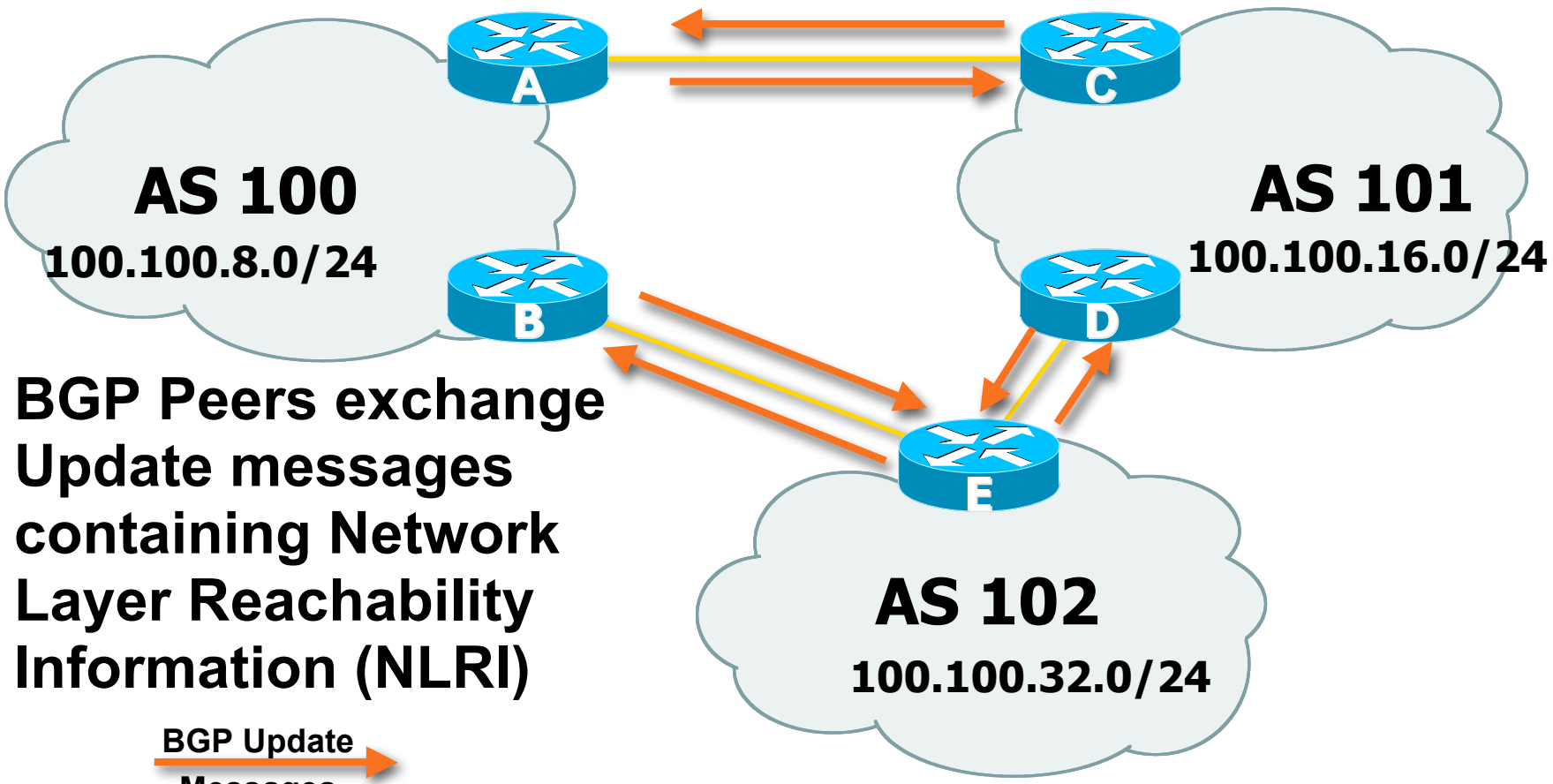
- Each AS originates a set of NLRI (routing announcements)
- NLRI is exchanged between BGP peers
- Can have multiple paths for a given prefix
- BGP picks the best path and installs in the IP forwarding table
- Policies applied (through attributes) influences BGP path selection



Interior BGP vs. Exterior BGP

- Interior BGP (iBGP)
  - Between routers in the same AS
  - Often between routers that are far apart
  - Should be a full mesh: every iBGP router talks to all other iBGP routers in the same AS
- Exterior BGP (eBGP)
  - Between routers in different ASes
  - Almost always between directly-connected routers (ethernet, serial line, etc.)

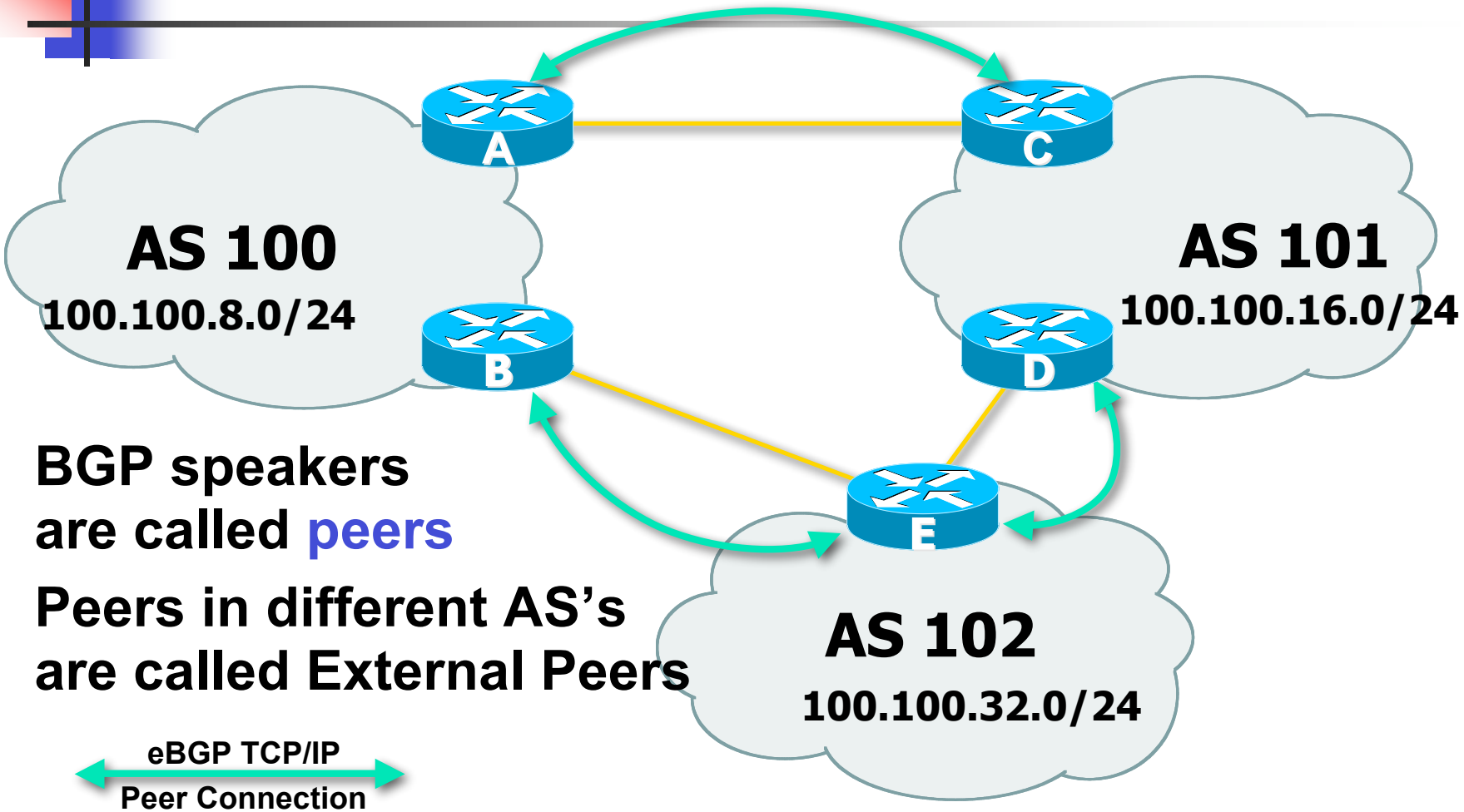
BGP Peers



BGP Peers exchange Update messages containing Network Layer Reachability Information (NLRI)

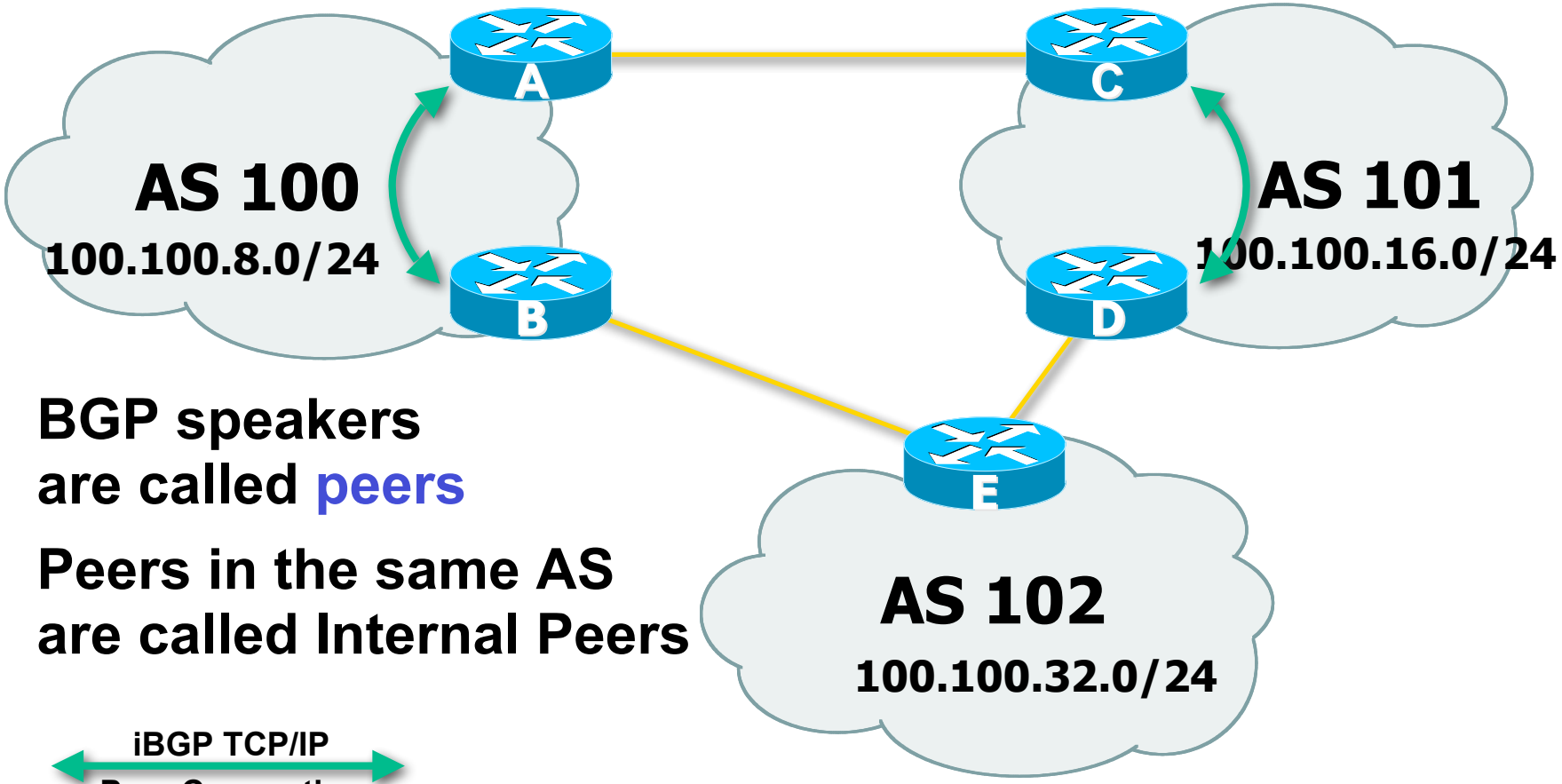
BGP Update Messages

BGP Peers – External (eBGP)



Note: eBGP Peers normally should be directly connected.

BGP Peers – Internal (iBGP)



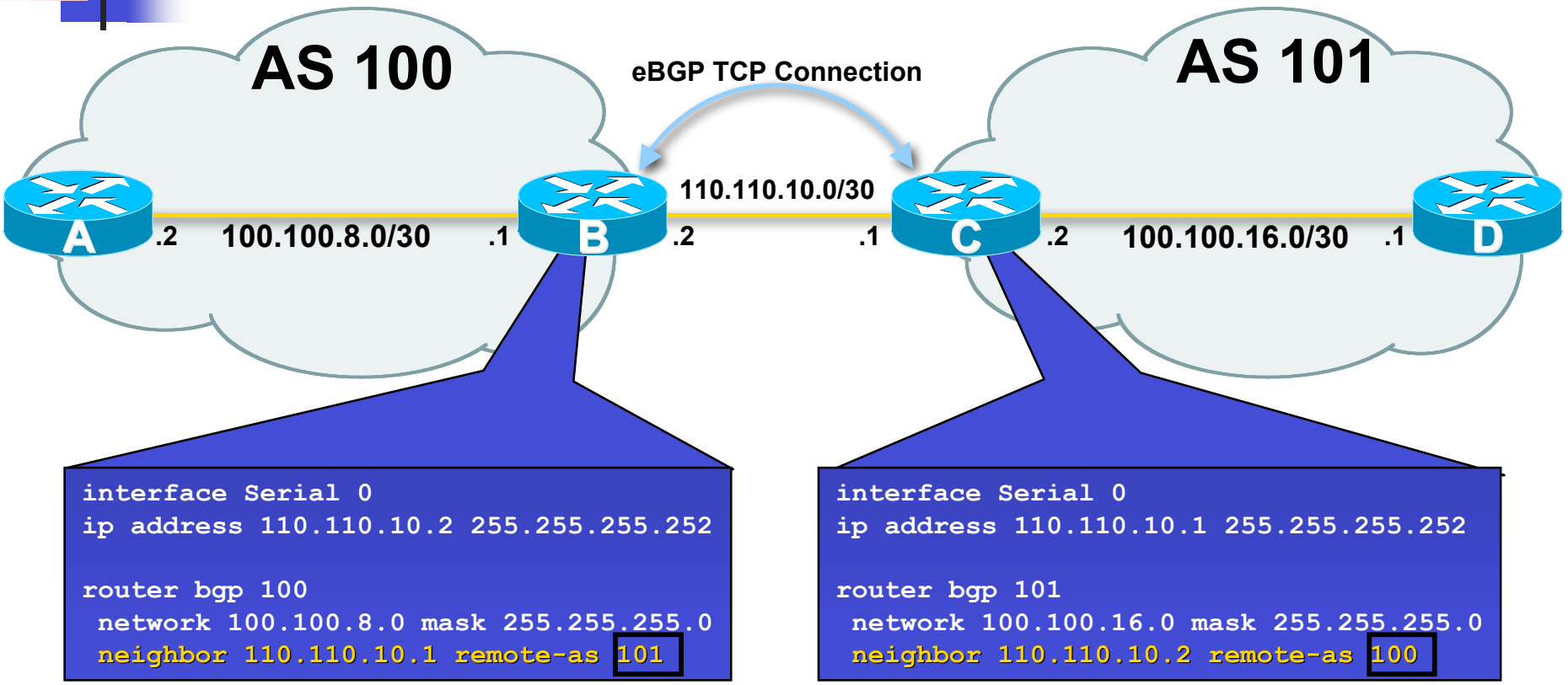
BGP speakers are called peers

Peers in the same AS are called Internal Peers

iBGP TCP/IP Peer Connection

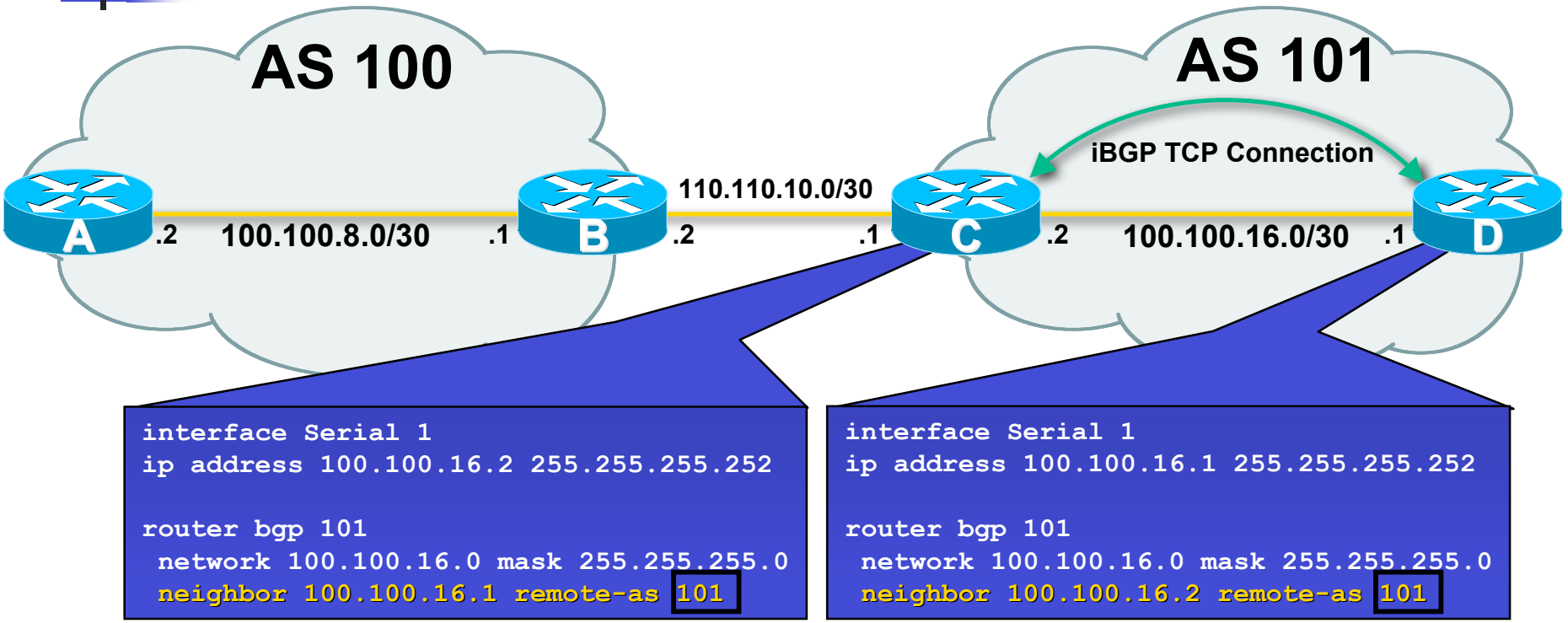
Note: iBGP Peers don't have to be directly connected.

Configuring eBGP peers



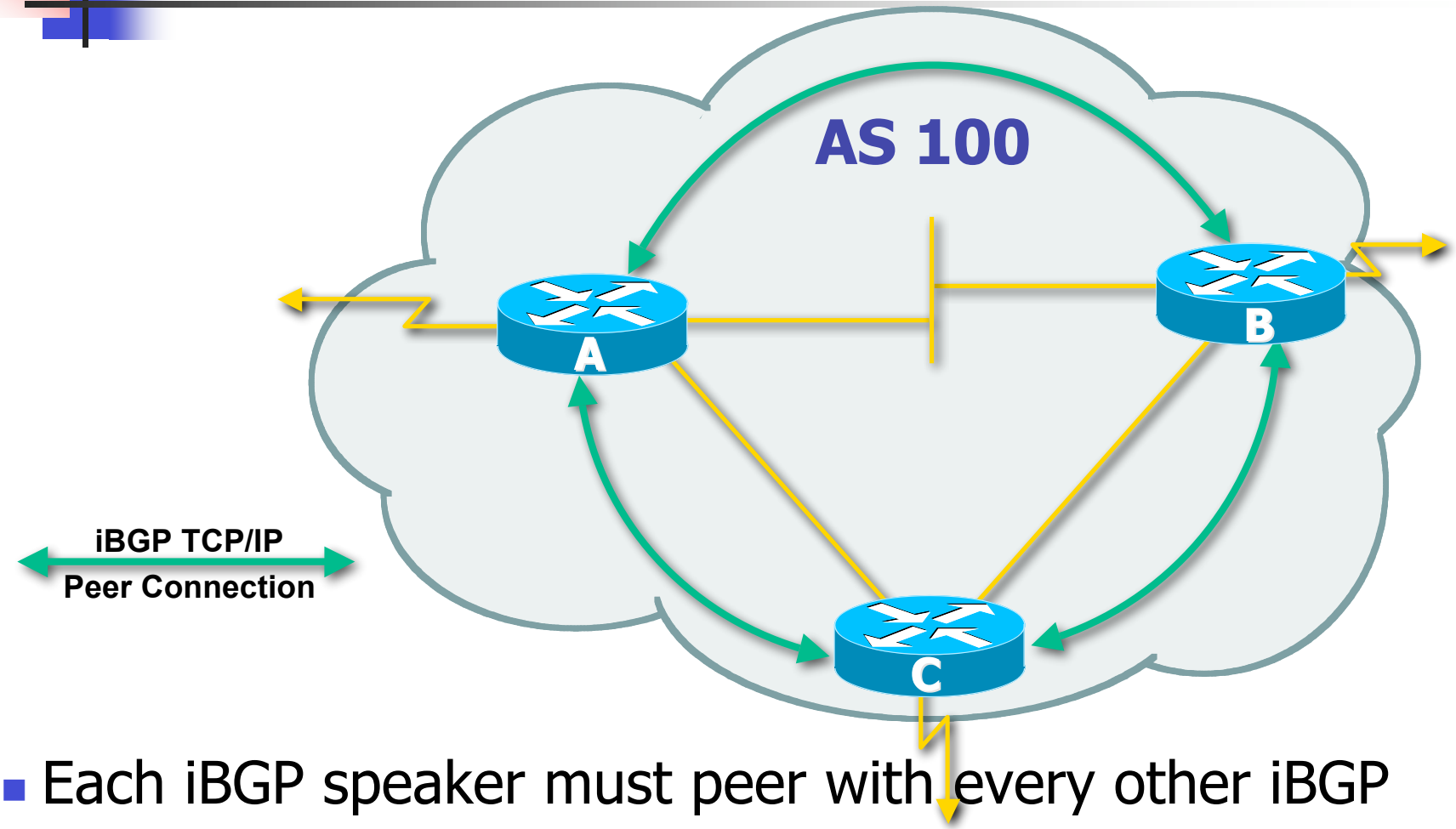
- BGP peering sessions are established using the BGP "neighbor" command
  - eBGP is configured when AS numbers are different

Configuring iBGP peers



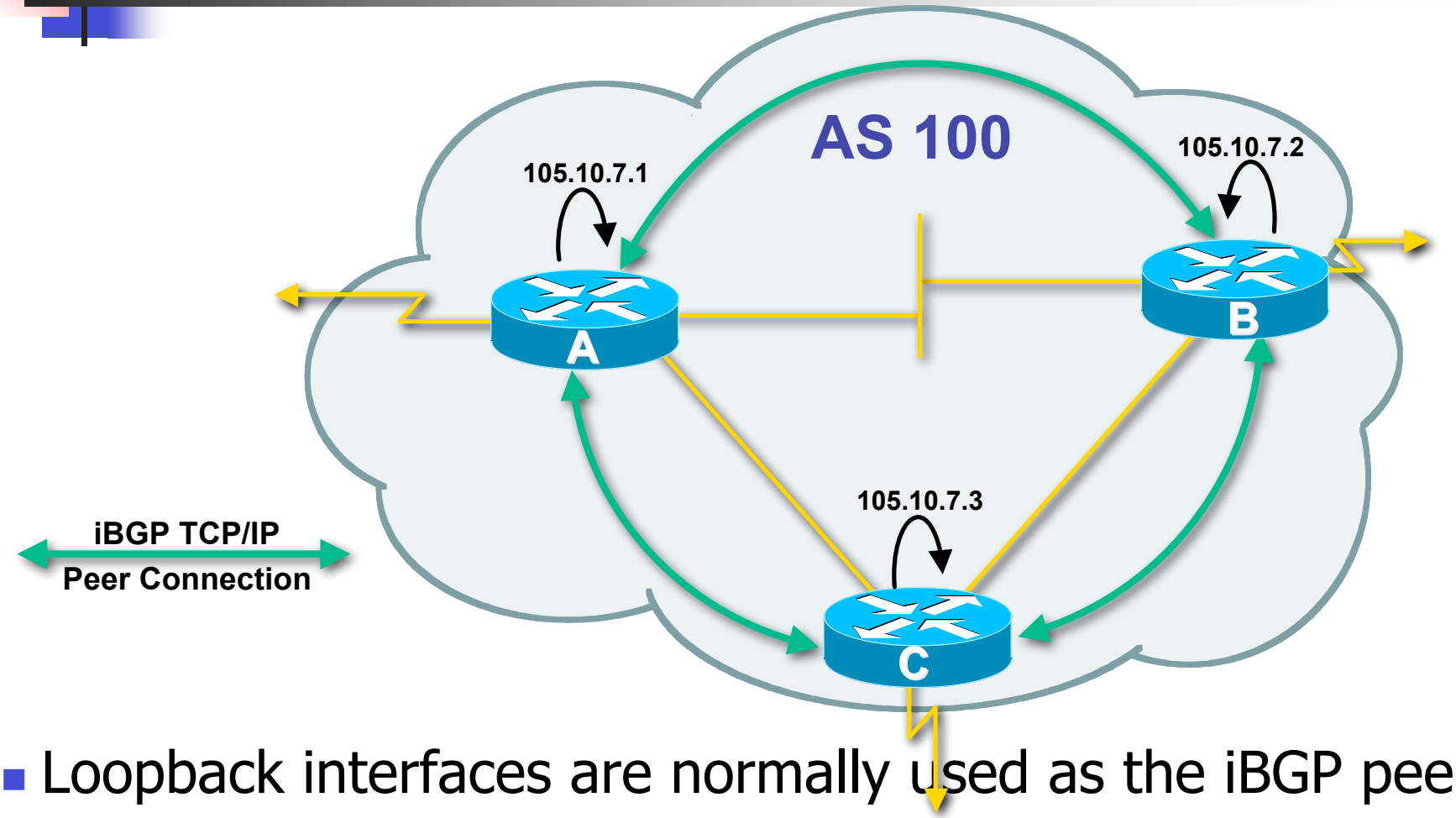
- BGP peering sessions are established using the BGP "neighbor" command
  - iBGP is configured when AS numbers are the same

Configuring iBGP peers: Full mesh



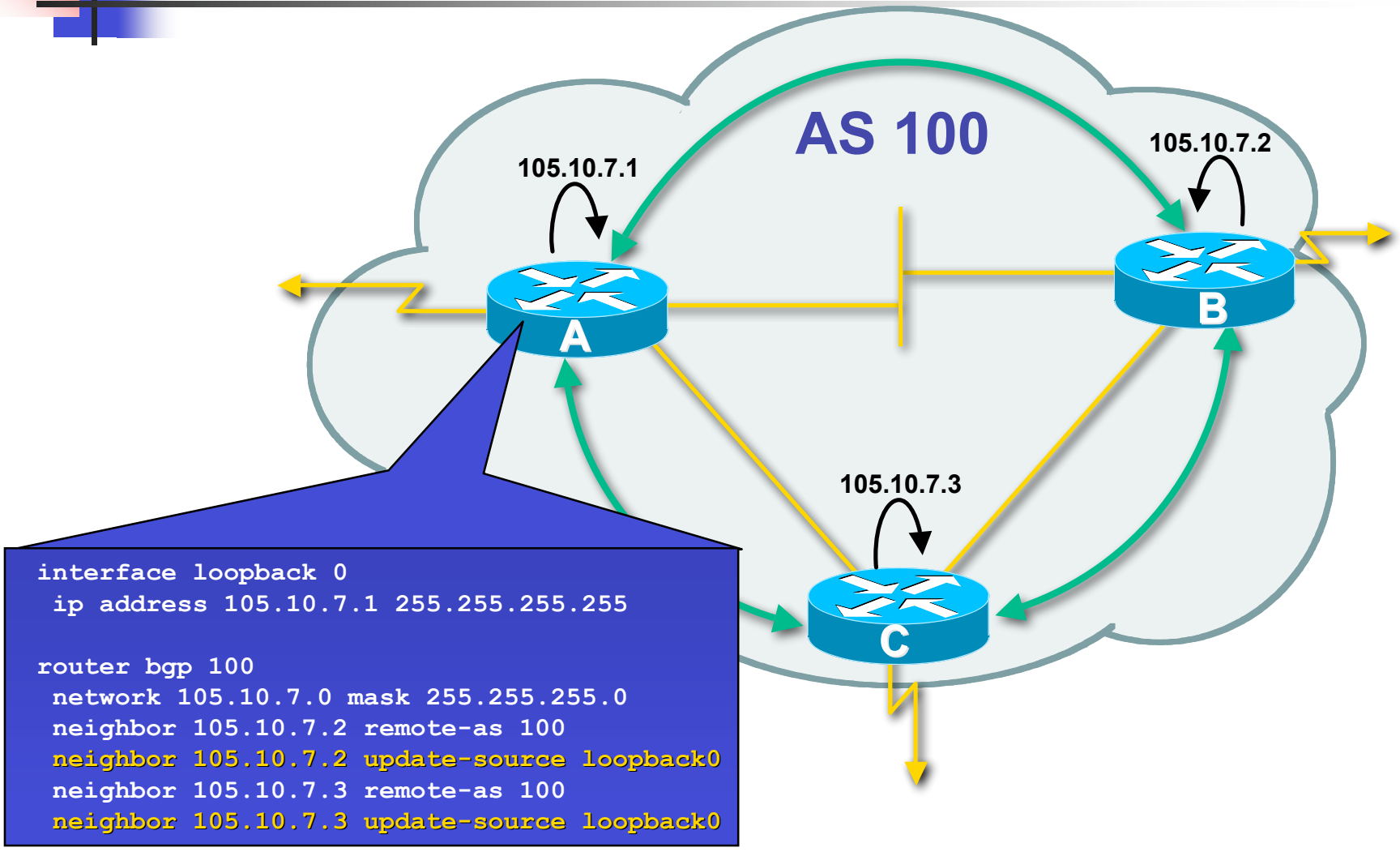
- Each iBGP speaker must peer with every other iBGP speaker in the AS

Configuring iBGP peers: Loopback interface

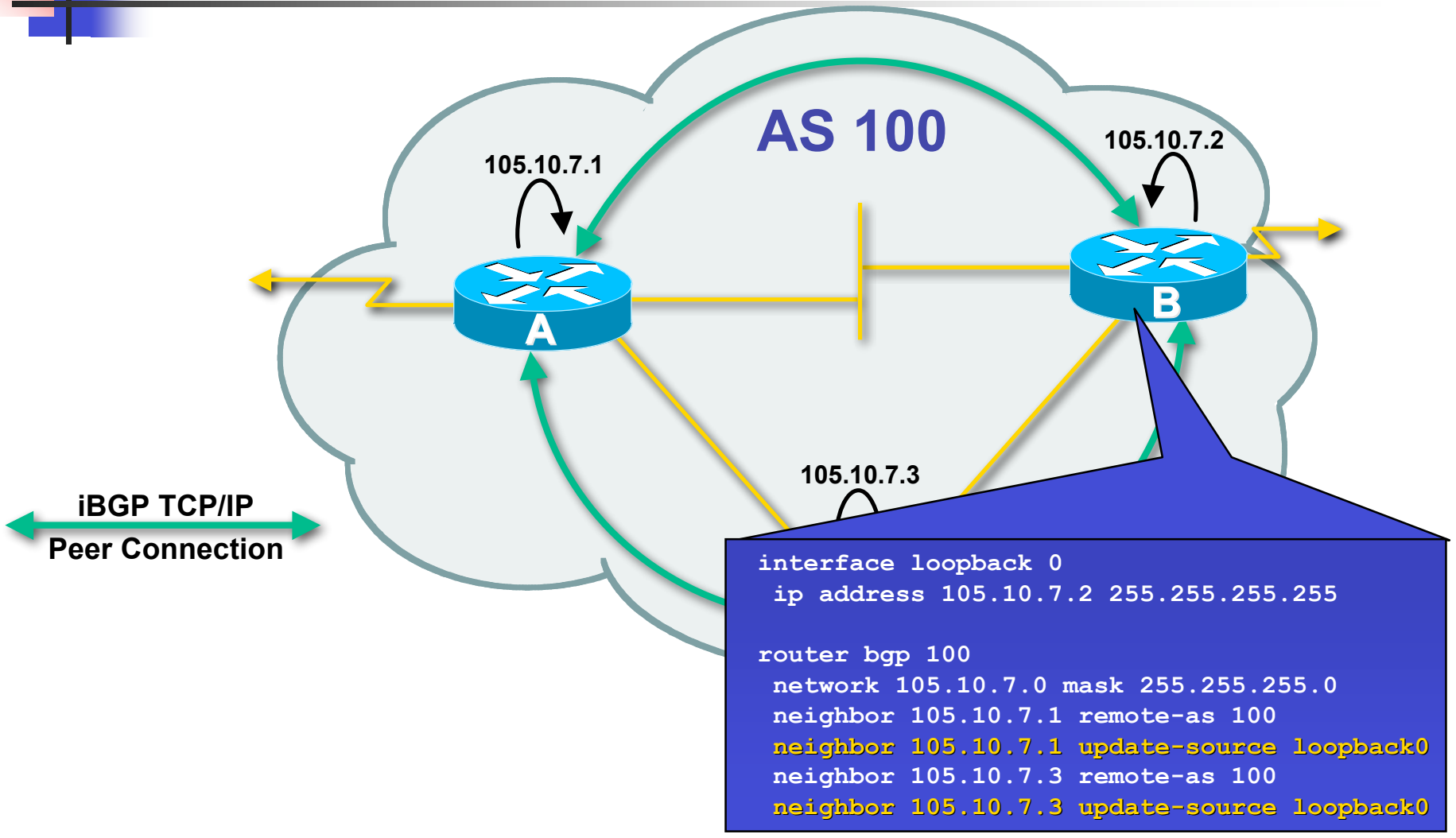


- Loopback interfaces are normally used as the iBGP peer connection end-points

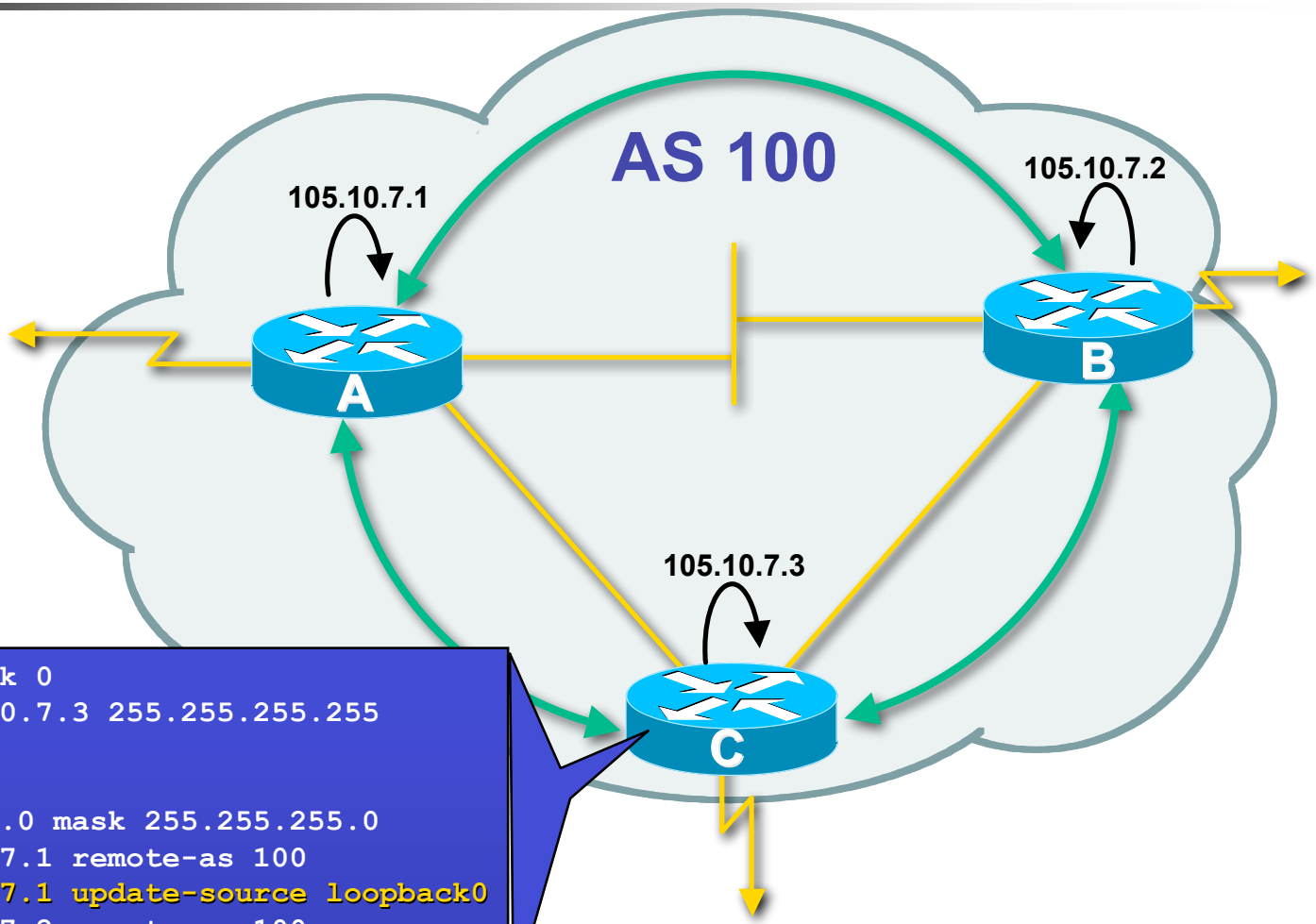
Configuring iBGP peers



Configuring iBGP peers

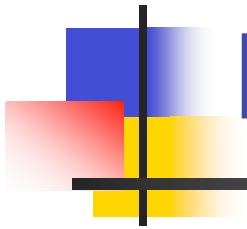


Configuring iBGP peers



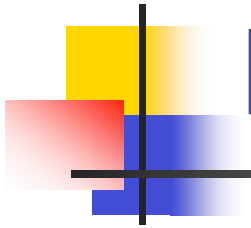

```
interface loopback 0
 ip address 105.10.7.3 255.255.255.255

router bgp 100
 network 105.10.7.0 mask 255.255.255.0
 neighbor 105.10.7.1 remote-as 100
 neighbor 105.10.7.1 update-source loopback0
 neighbor 105.10.7.2 remote-as 100
 neighbor 105.10.7.2 update-source loopback0
```



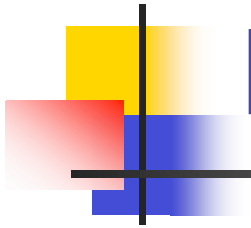
BGP Part 6

BGP Protocol – A little more detail



BGP Updates — NLRI

- Network Layer Reachability Information
- Used to advertise feasible routes
- Composed of:
  - Network Prefix
  - Mask Length

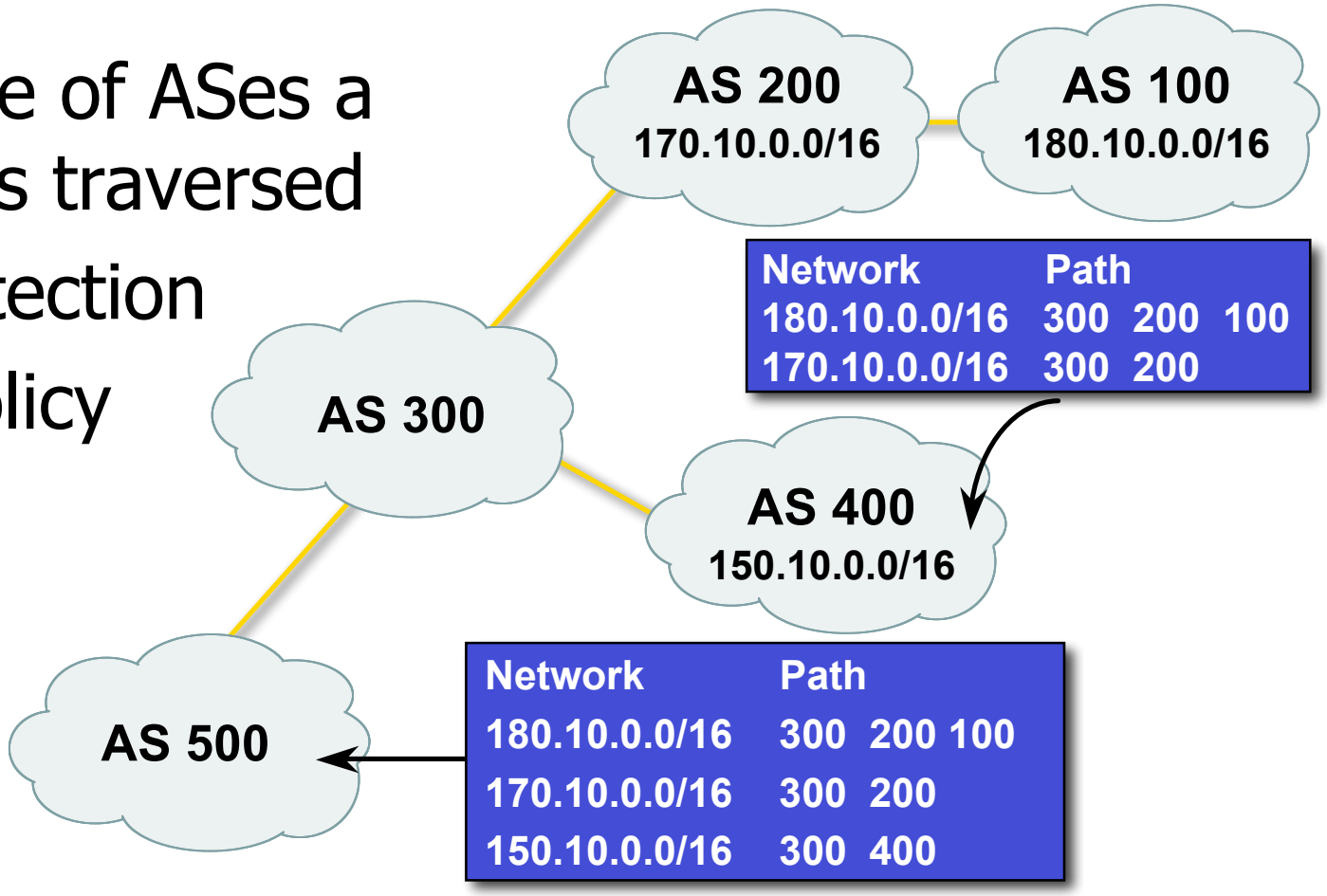


BGP Updates — Attributes

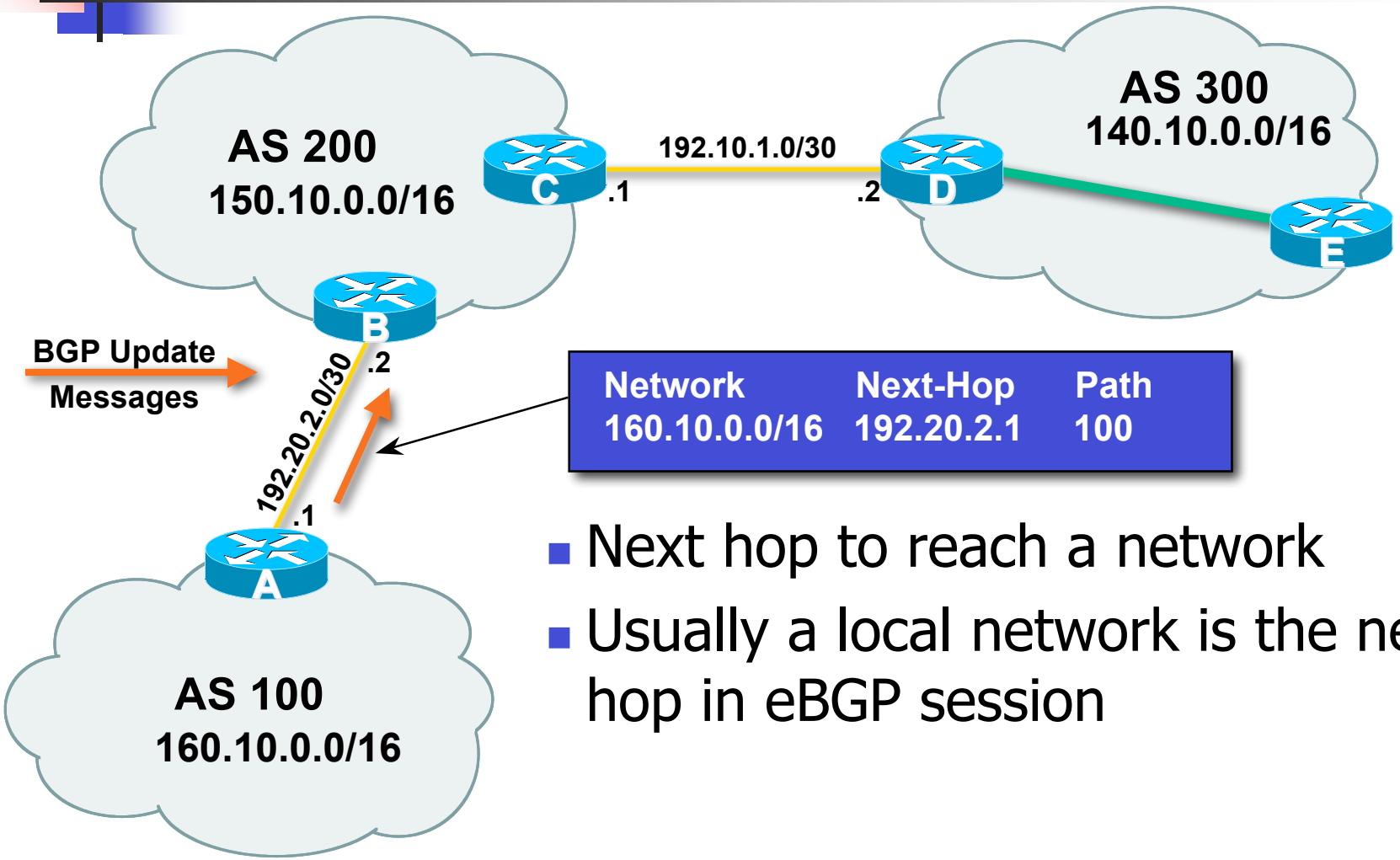
- Used to convey information associated with NLRI
  - AS path
  - Next hop
  - Local preference
  - Multi-Exit Discriminator (MED)
  - Community
  - Origin
  - Aggregator

AS-Path Attribute

- Sequence of ASes a route has traversed
- Loop detection
- Apply policy

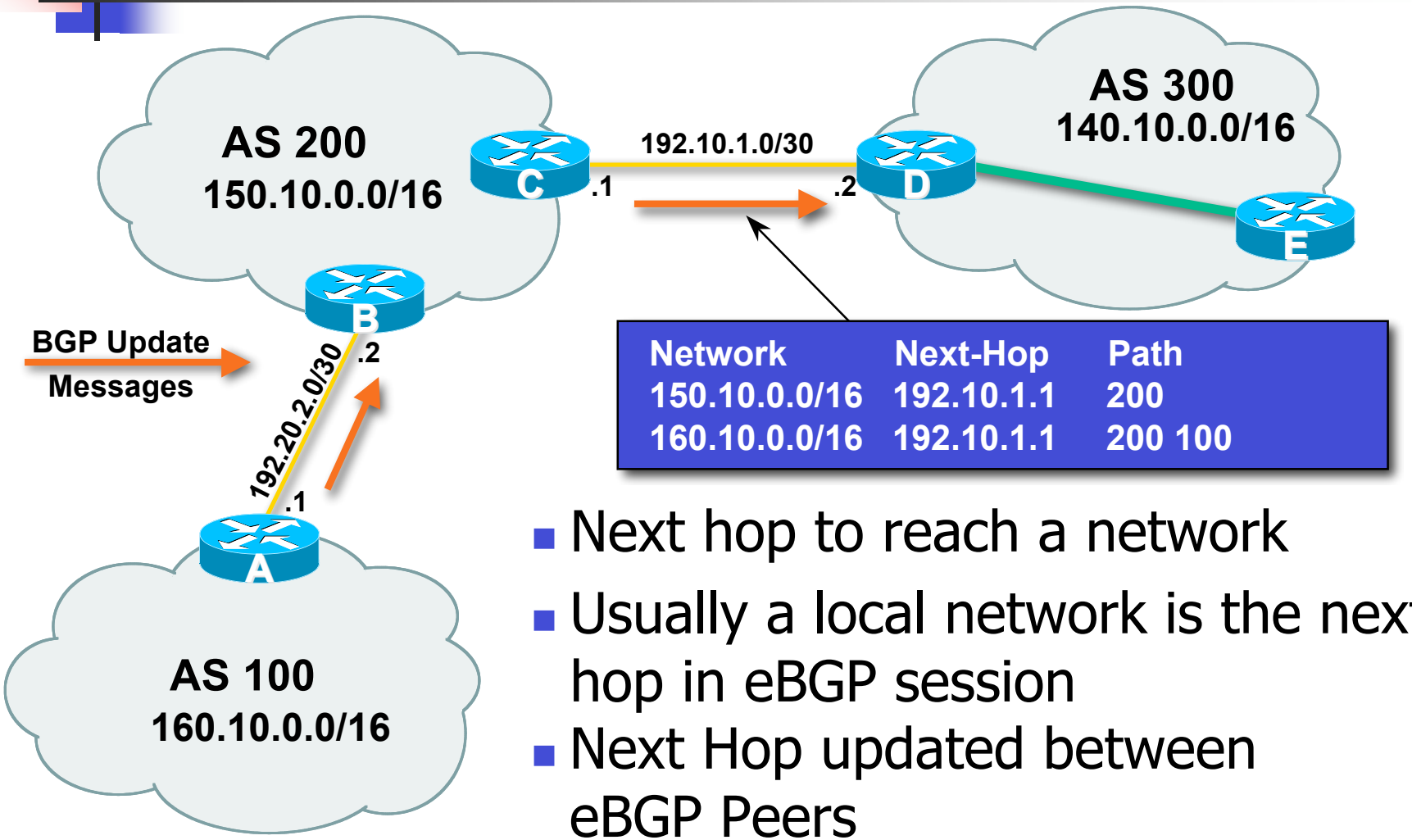


Next Hop Attribute



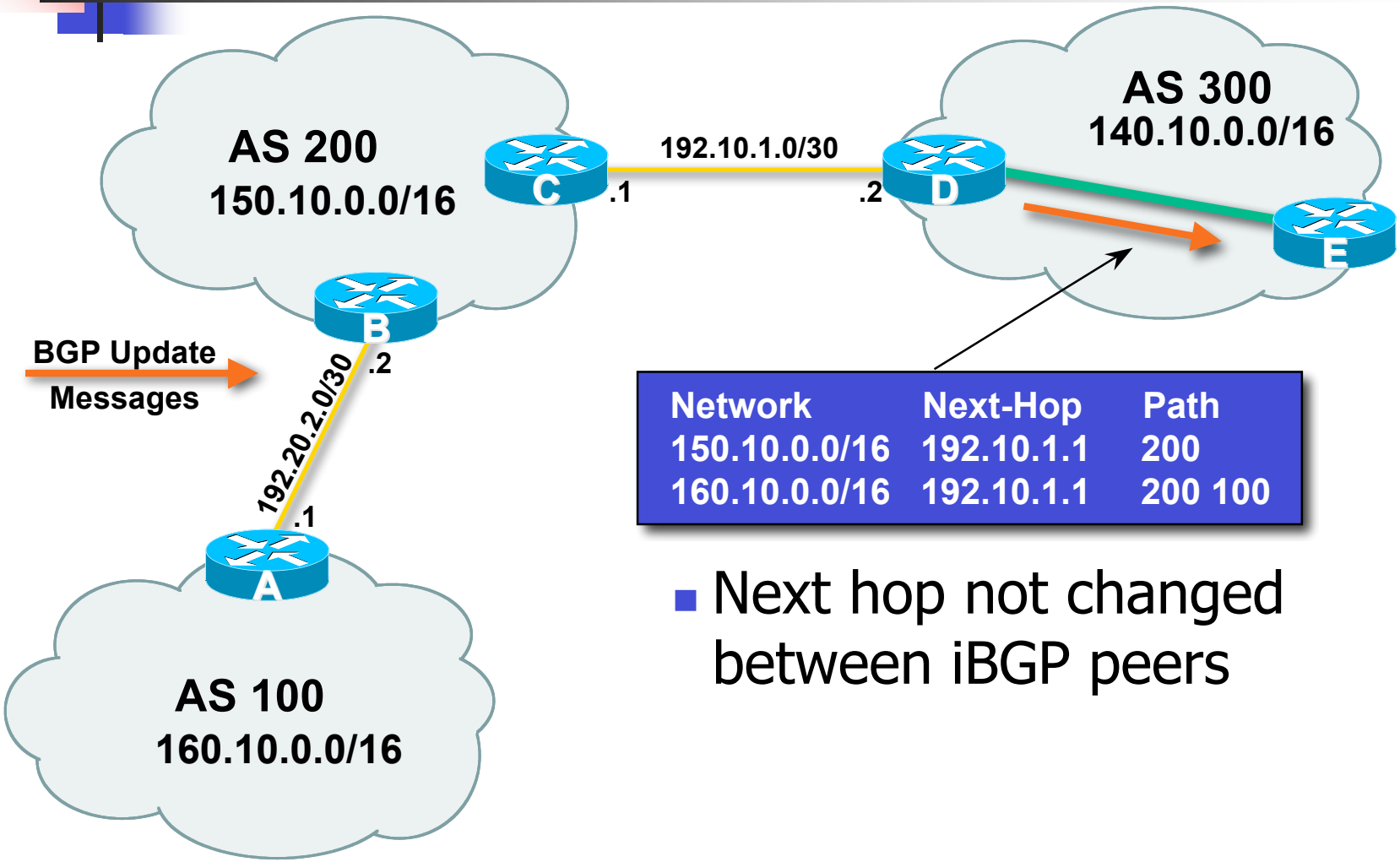
- Next hop to reach a network
- Usually a local network is the next hop in eBGP session

Next Hop Attribute

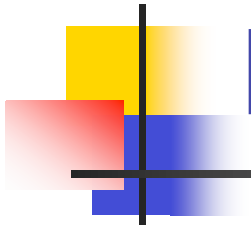


- Next hop to reach a network
- Usually a local network is the next hop in eBGP session
- Next Hop updated between eBGP Peers

Next Hop Attribute

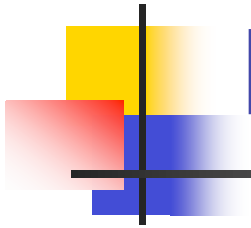


- Next hop not changed between iBGP peers



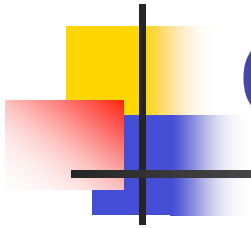
Next Hop Attribute (more)

- IGP is used to carry route to next hops
- Recursive route look-up
  - BGP looks into IGP to find out next hop information
  - BGP is not permitted to use a BGP route as the next hop
- Unlinks BGP from actual physical topology
- Allows IGP to make intelligent forwarding decision



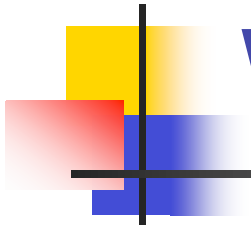
Next Hop Best Practice

- Cisco IOS default is for external next-hop to be propagated unchanged to iBGP peers
  - This means that IGP has to carry external next-hops
  - Forgetting means external network is invisible
  - With many eBGP peers, it is extra load on IGP
- ISPs change external next-hop to be that of the local router
  - neighbor x.x.x.x next-hop-self



Community Attribute

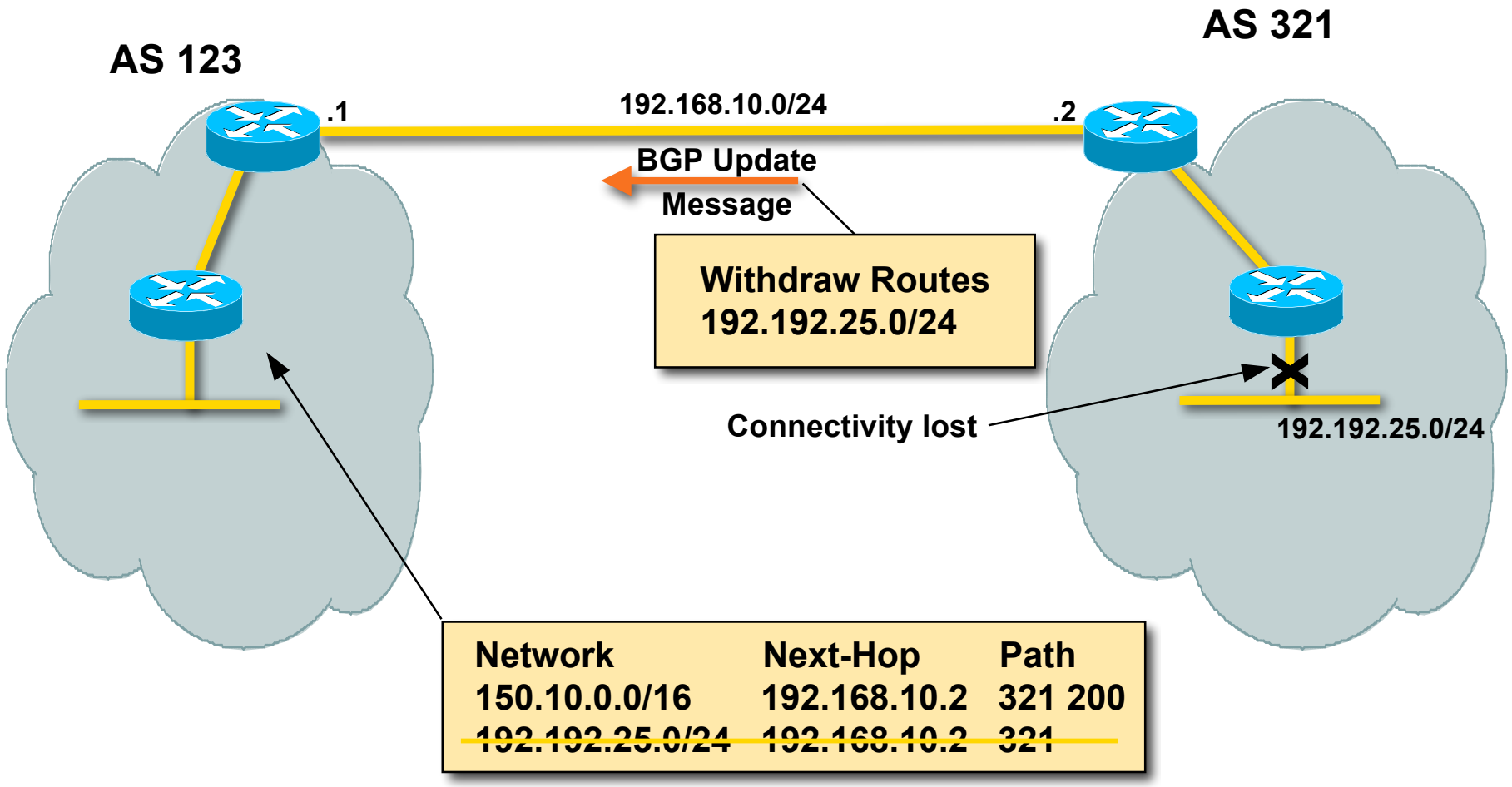
- 32-bit number
- Conventionally written as two 16-bit numbers separated by colon
  - First half is usually an AS number
  - That AS determines the meaning (if any) of the second half
- Carried in BGP protocol messages
  - Used by administratively-defined filters
  - Not directly used by BGP protocol (except for a few “well known” communities)



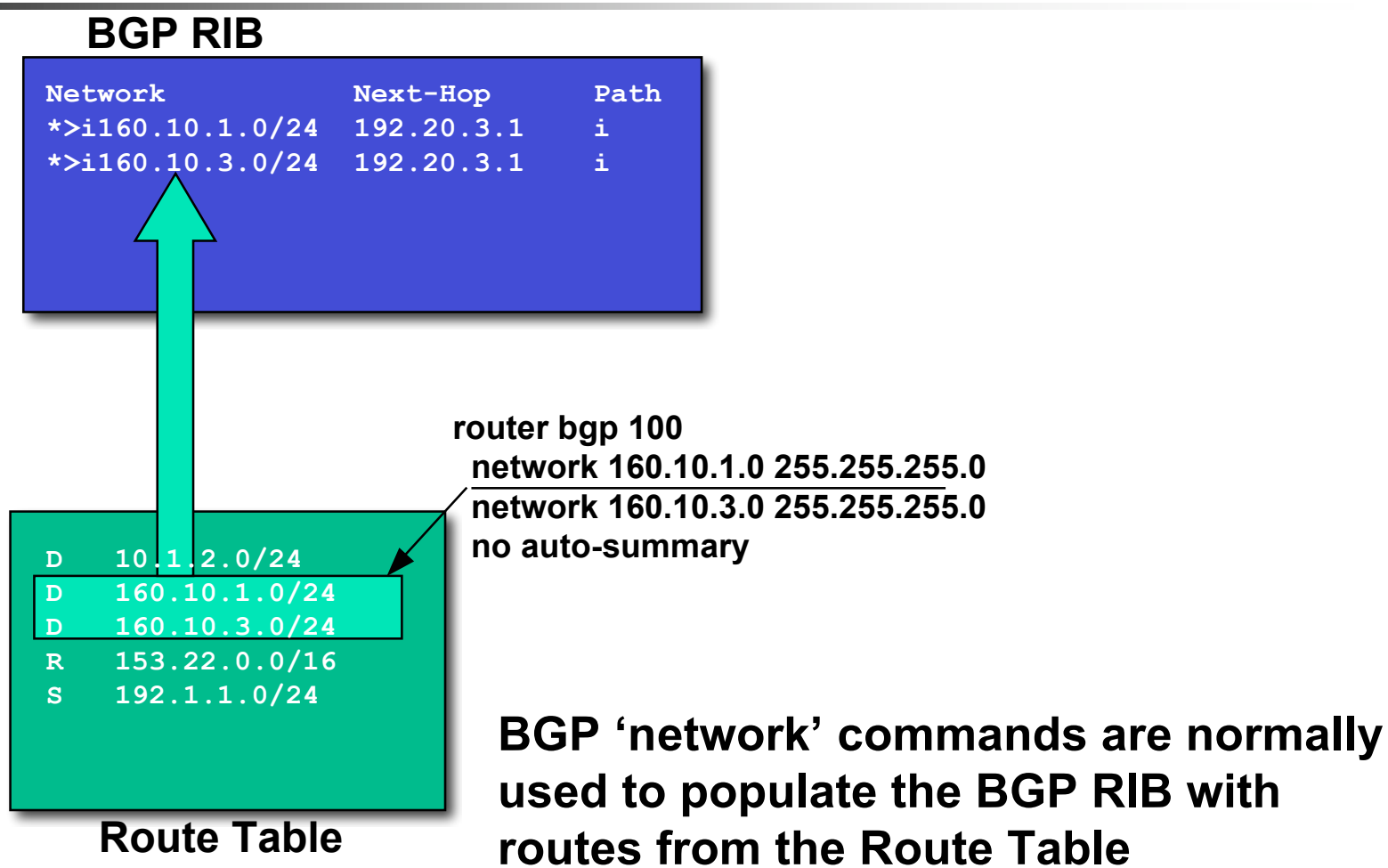
BGP Updates: Withdrawn Routes

- Used to “withdraw” network reachability
- Each withdrawn route is composed of:
  - Network Prefix
  - Mask Length

BGP Updates: Withdrawn Routes

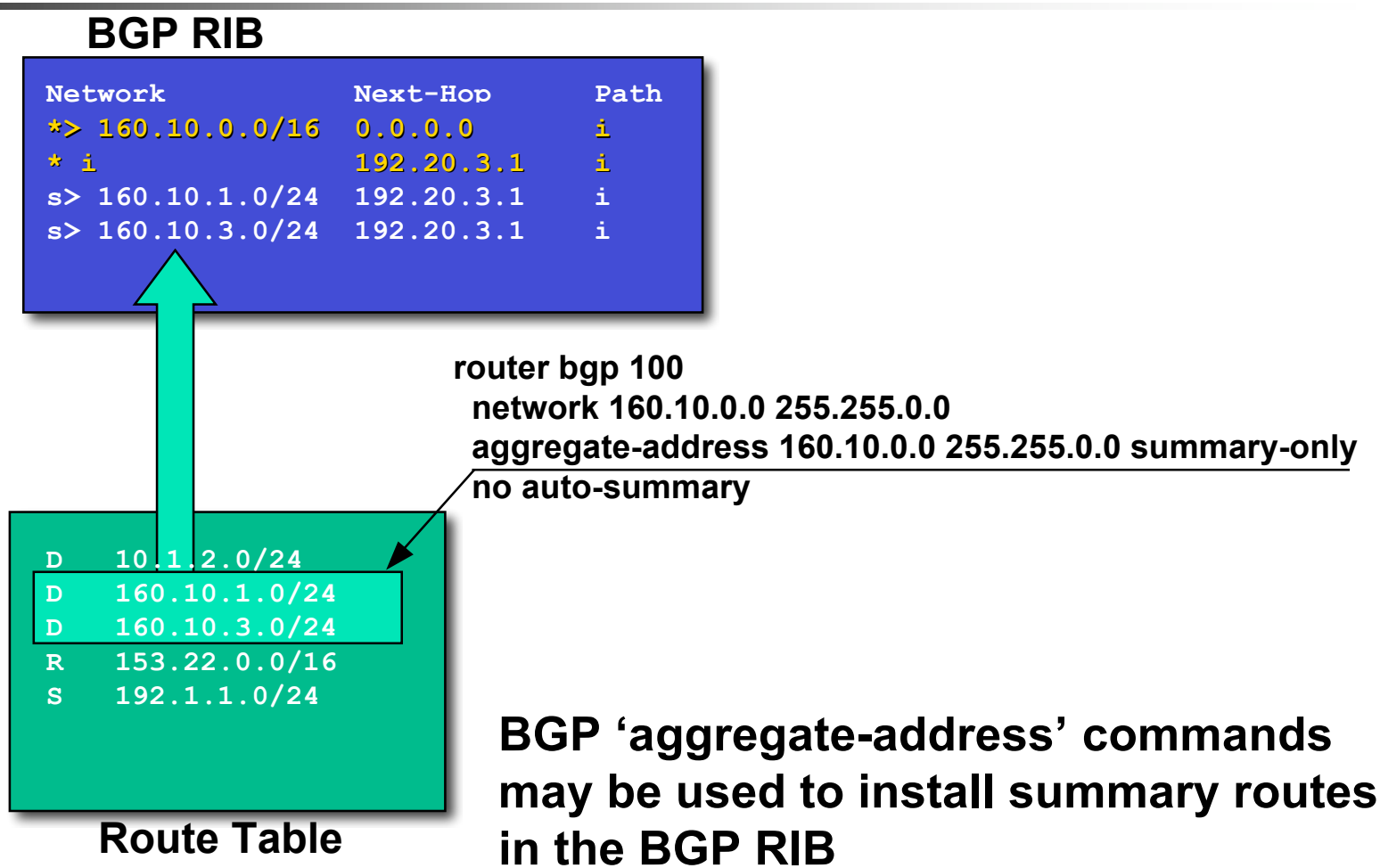


BGP Routing Information Base



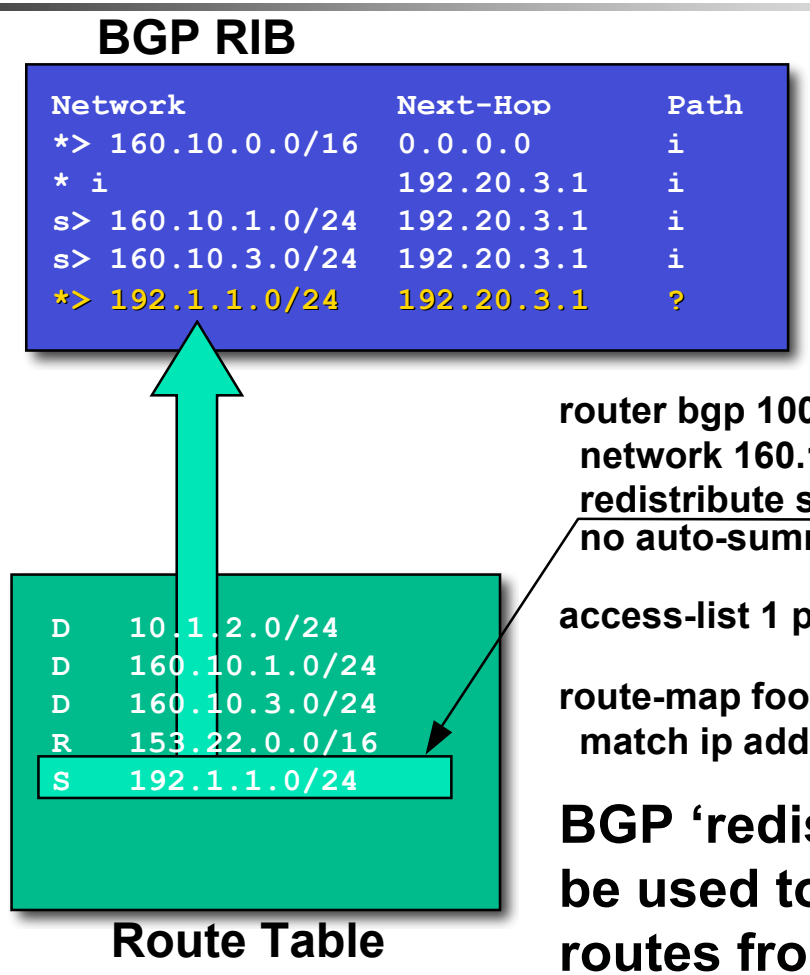
BGP ‘network’ commands are normally used to populate the BGP RIB with routes from the Route Table

BGP Routing Information Base



BGP 'aggregate-address' commands may be used to install summary routes in the BGP RIB

BGP Routing Information Base



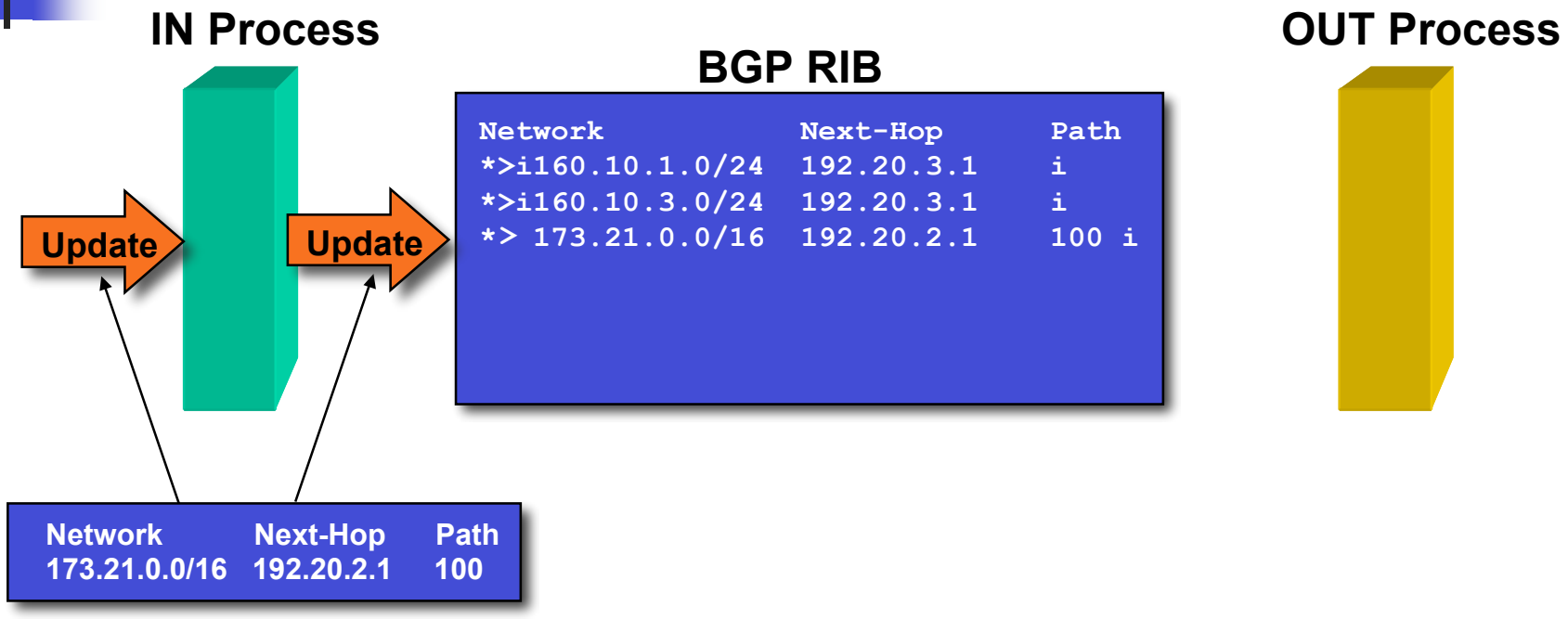

```
router bgp 100
  network 160.10.0.0 255.255.0.0
  redistribute static route-map foo
  no auto-summary

access-list 1 permit 192.1.0.0 0.0.255.255

route-map foo permit 10
  match ip address 1
```

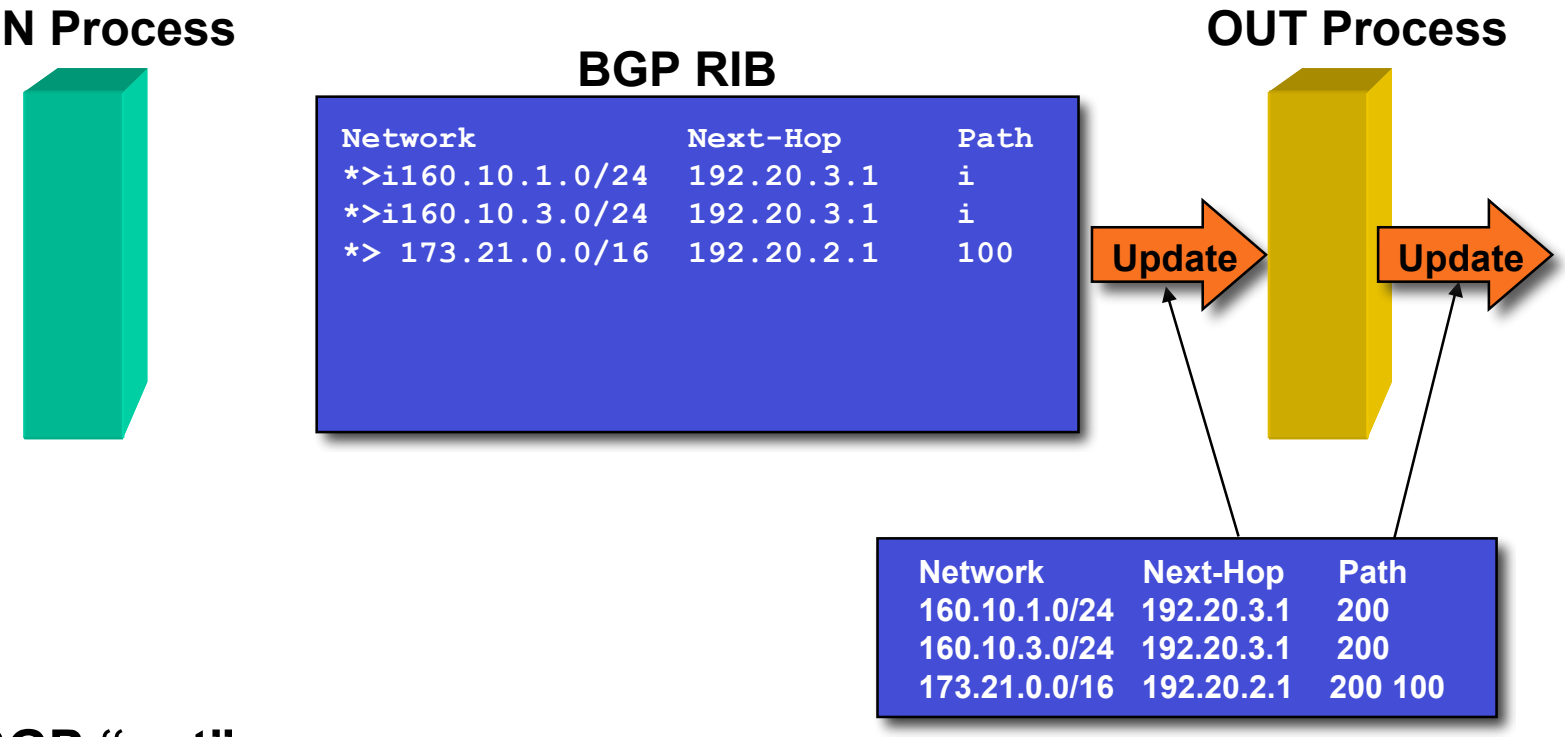
BGP ‘redistribute’ commands can also be used to populate the BGP RIB with routes from the Route Table

BGP Routing Information Base



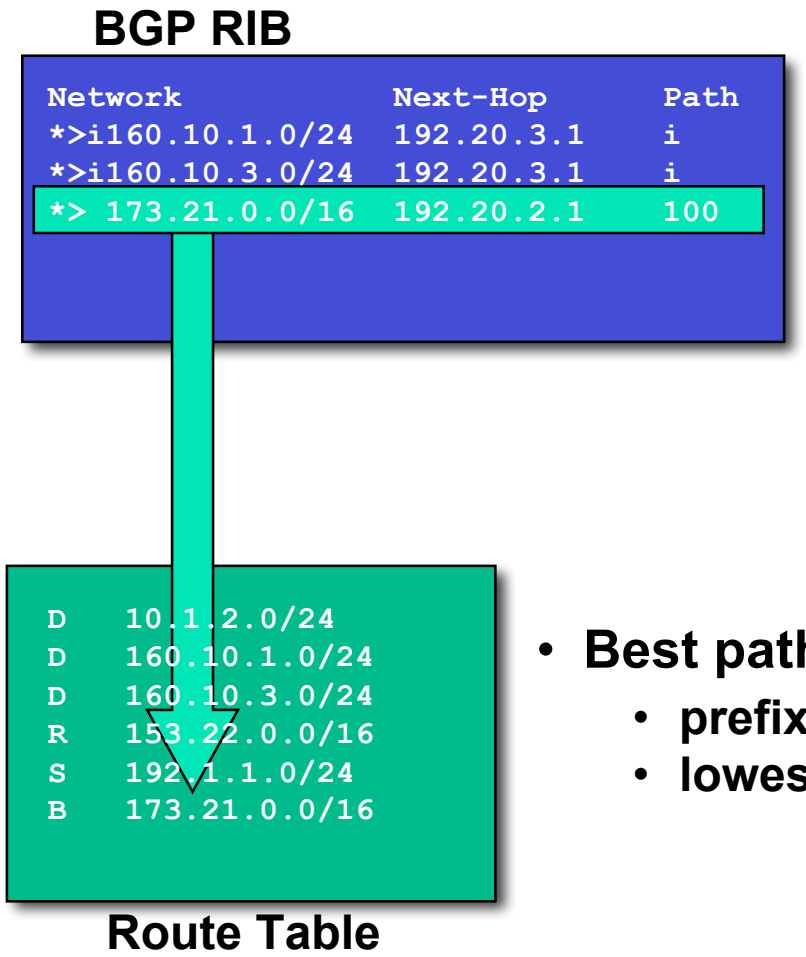
- BGP “in” process
  - receives path information from peers
  - results of BGP path selection placed in the BGP table
  - “best path” flagged (denoted by “>”)

BGP Routing Information Base



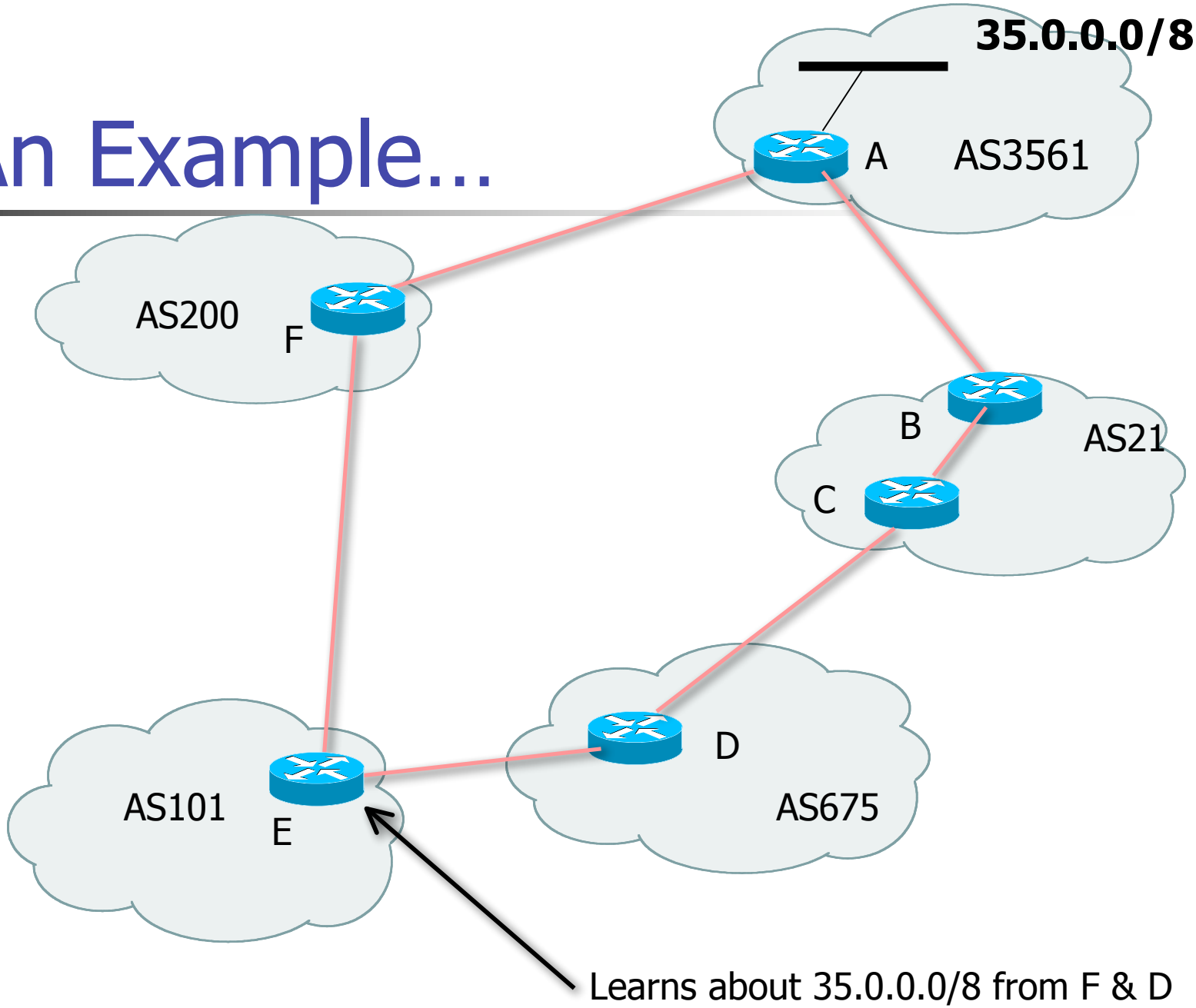
- BGP “out” process
  - builds update using info from RIB
  - may modify update based on config
  - Sends update to peers

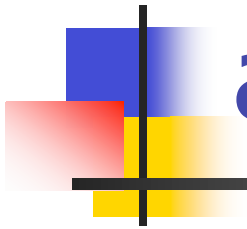
BGP Routing Information Base



- **Best paths installed in routing table if:**
  - **prefix and prefix length are unique**
  - **lowest “protocol distance”**

An Example…

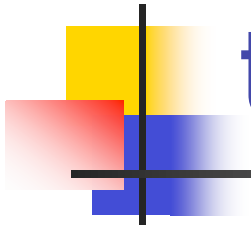

35.0.0.0/8
A
AS3561
AS200
F
B
AS21
C
D
AS675
AS101
E
Learns about 35.0.0.0/8 from F & D



BGP Case Study 2 and Exercise 2

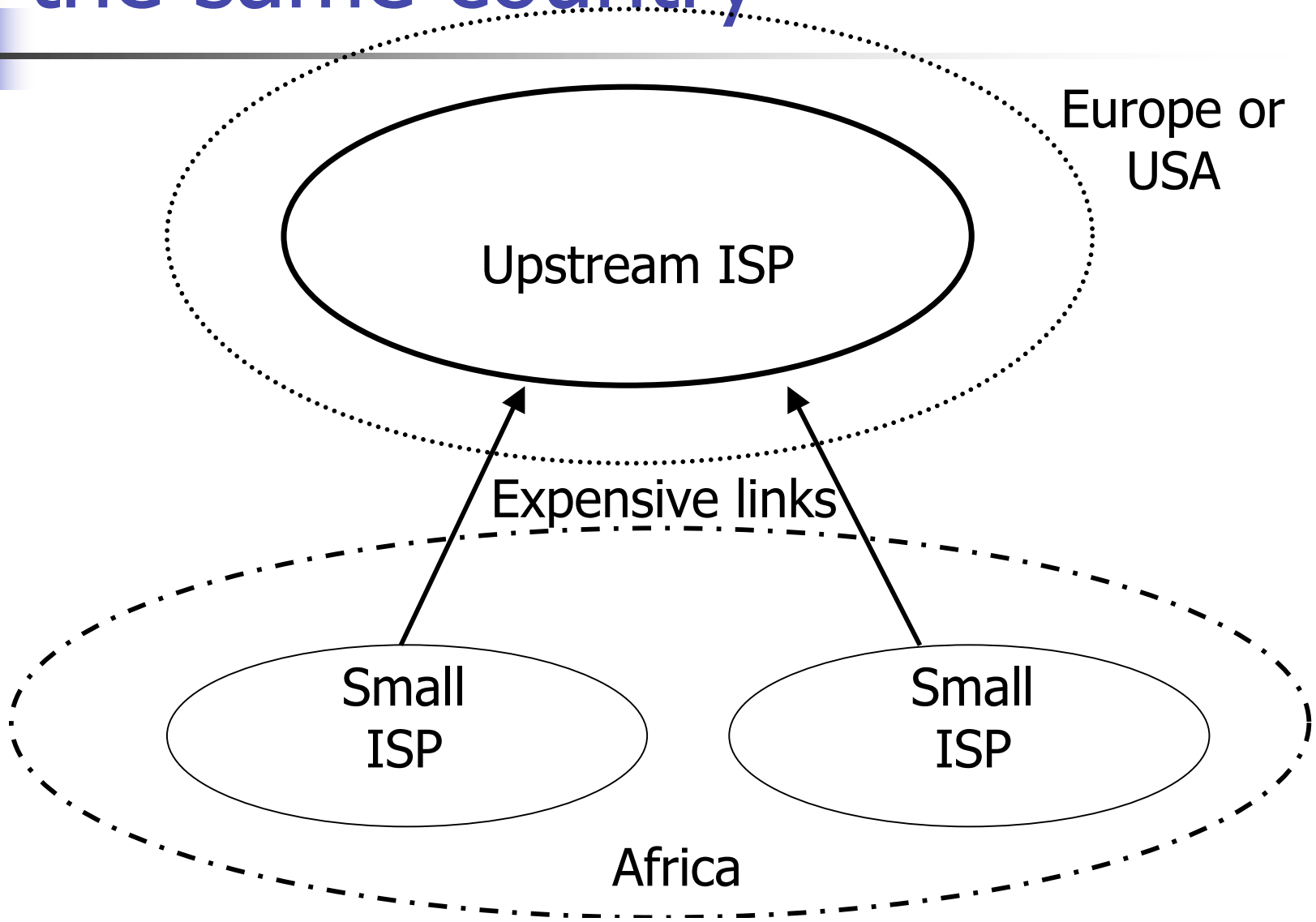
Small ISPs in the same locality connect to each other

Case Study 2: Another ISP in the same country

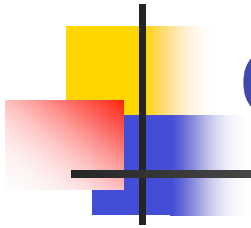


- Similar setup
- Traffic between you and them goes over
  - Your expensive line
  - Their expensive line
- Traffic can be significant
  - Same language/culture
  - Traffic between your and their customers
- This wastes money

Case Study 2: Another ISP in the same country

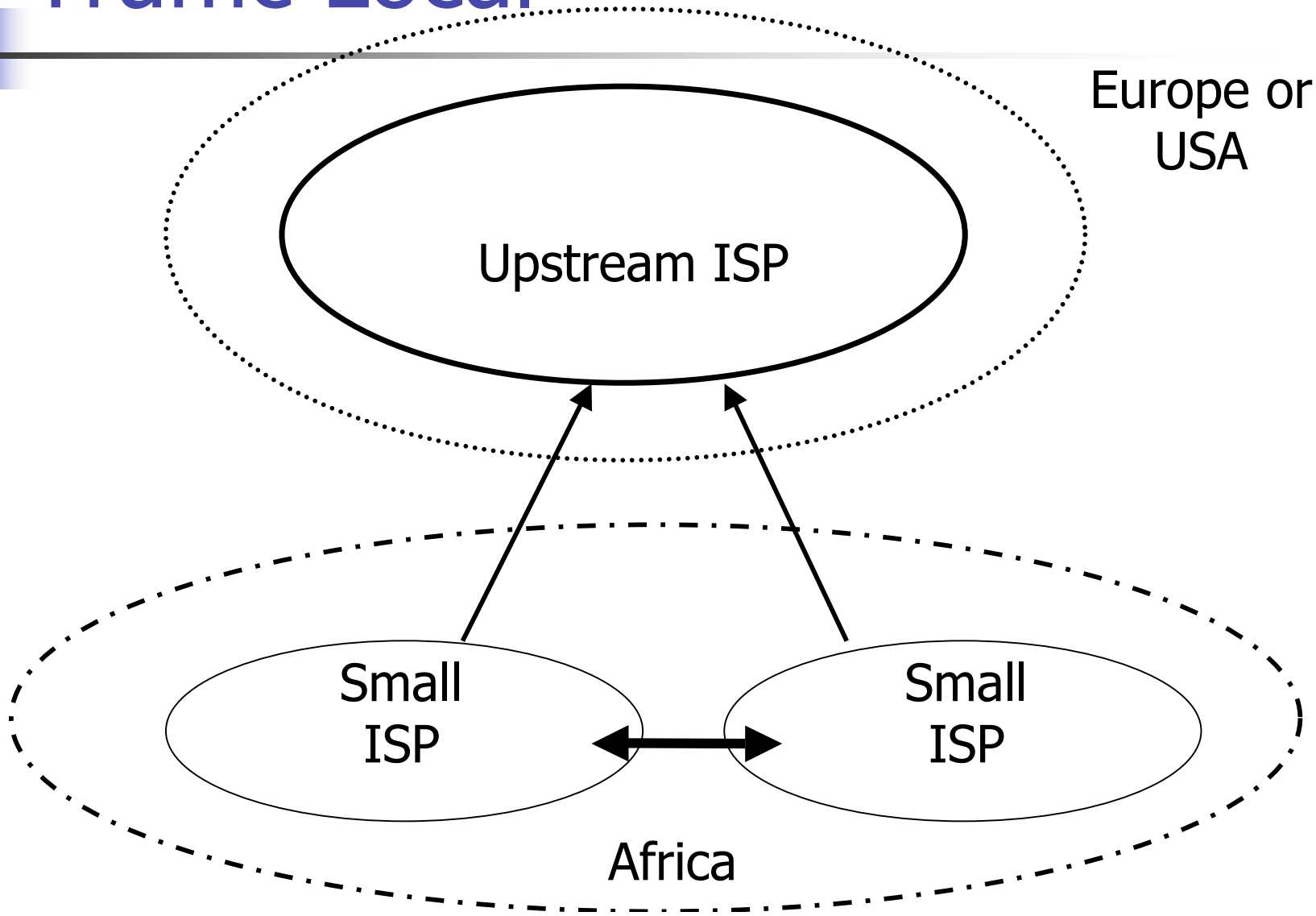


Case Study 2: Bringing down costs

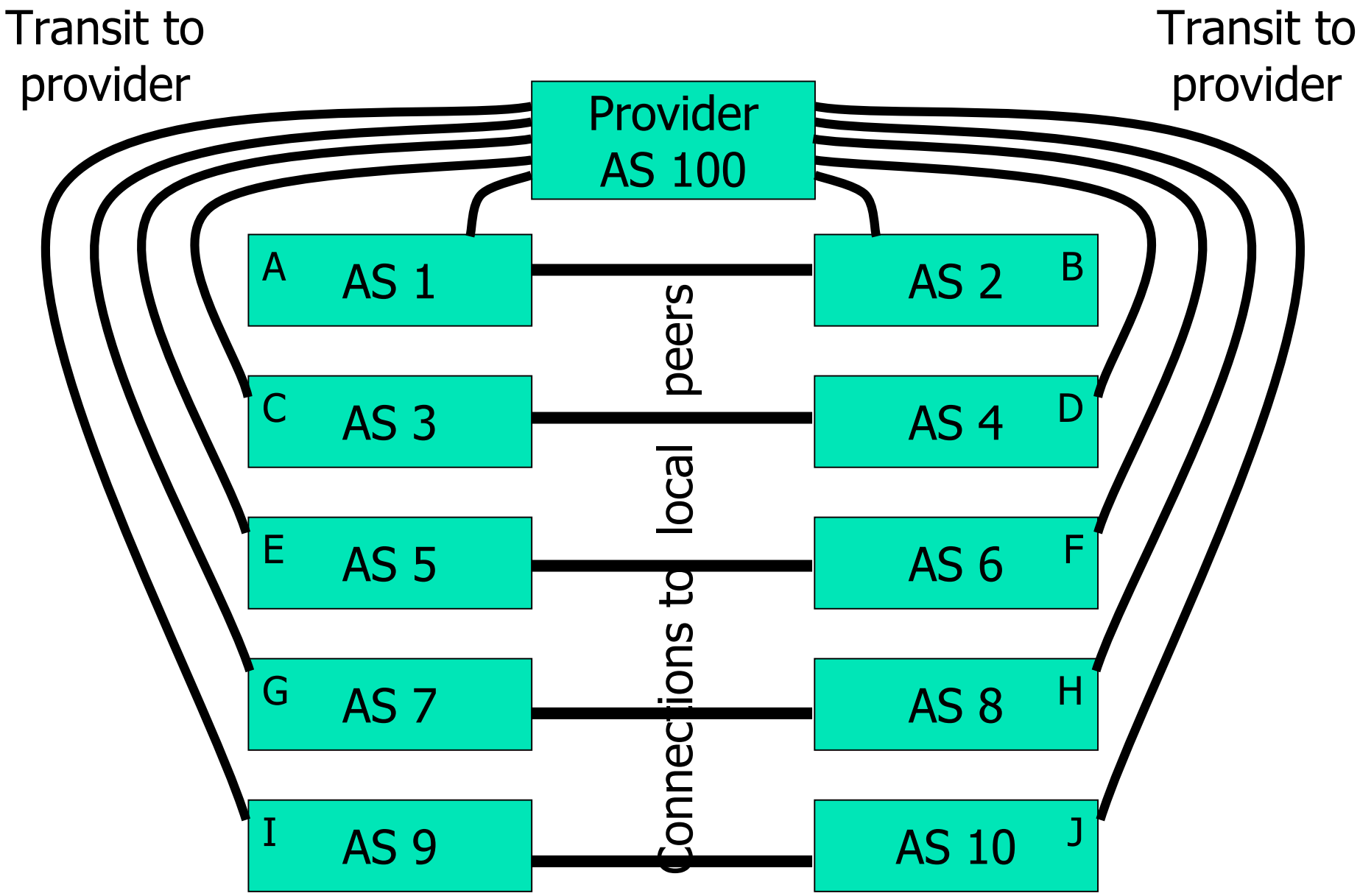


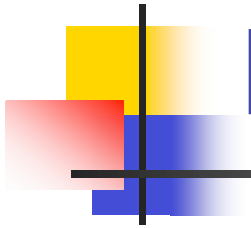
- Local (national) links are usually much cheaper than international ones
- Might be interesting to get direct link between you and them
  - Saving traffic on expensive lines
    - better performance, cheaper
  - No need to send traffic to other ISP down the street via New York!

Case Study 2: Keeping Local Traffic Local



Exercise 2: Connect to another local ISP

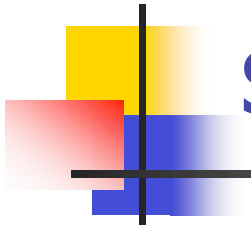




Exercise 2: BGP configuration

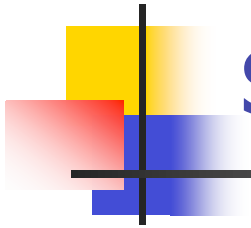
- Refer to “BGP cheat sheet”.
- Add to previous configuration.
- Connect cable to local peer.
- No filters yet.

Exercise 2: What you should see



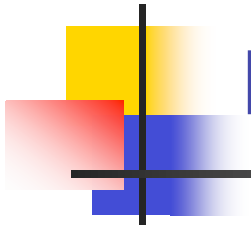
- You should see multiple routes to each destination
  - direct route to your peer
  - transit route through provider (AS 100)
  - any more?

Exercise 2: What you should see

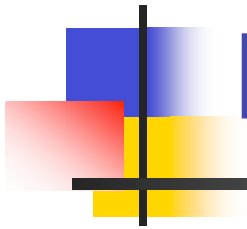


- Try “show ip route” to see forwarding table
- Try “show ip bgp” to see BGP information
- Look at the “next hop” and “AS path”
- Try some pings and traceroutes.

Exercise 2: Do you see transit routes through your peers?



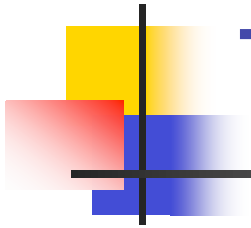
- Are your peer ASes sending you transit routes as well as peering routes?
  - Do you want transit through them?
- Are you sending transit routes to your peers?
  - Do you want your peers to have transit through you?
- We will fix this later



BGP Part 7

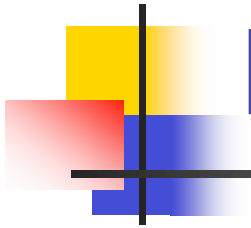
Routing Policy

Filtering



Terminology: "Policy"

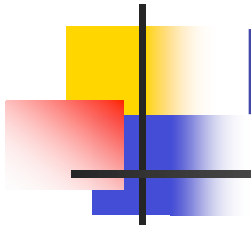
- Where do you want your traffic to go?
  - It is difficult to get what you want, but you can try
- Control of how you accept and send routing updates to neighbors
  - prefer cheaper connections, load-sharing, etc.
- Accepting routes from some ISPs and not others
- Sending some routes to some ISPs and not others
- Preferring routes from some ISPs over others



Routing Policy

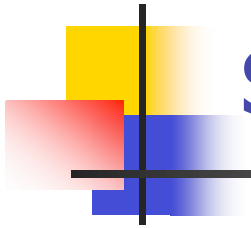
- Why?
  - To steer traffic through preferred paths
  - Inbound/Outbound prefix filtering
  - To enforce Customer-ISP agreements
- How?
  - AS based route filtering – filter list
  - Prefix based route filtering – prefix list
  - BGP attribute modification – route maps
  - Complex route filtering – route maps

Filter list rules: Regular Expressions



- Regular Expression is a pattern to match against an input string
- Used to match against AS-path attribute
- ex: ^3561_.*_100_.*_1$
- Flexible enough to generate complex filter list rules

Regular expressions (cisco specific)



- **^** matches start
- **$** matches end
- **_** matches start, or end, or space (boundary between words or numbers)
- **.*** matches anything (0 or more characters)
- **[abc]** matches a, or b, or c.
- There are many more possibilities

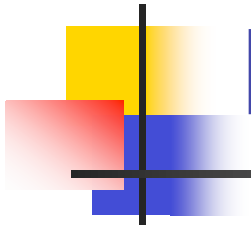
Filter list – using as-path access list

```
ip as-path access-list 1 permit _3561$
ip as-path access-list 2 deny _35$
ip as-path access-list 2 permit .*

router bgp 100
 neighbor 171.69.233.33 remote-as 33
 neighbor 171.69.233.33 filter-list 1 in
 neighbor 171.69.233.33 filter-list 2 out
```

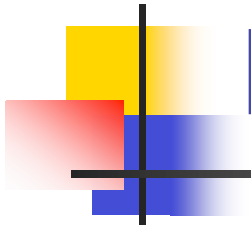
Listen to routes originated by AS 3561. Implicit deny everything else inbound.

Don’t announce routes originated by AS 35, but announce everything else (outbound).



Policy Control – Prefix Lists

- Per neighbor prefix filter
  - incremental configuration
- High performance access list
- Inbound or Outbound
- Based upon network numbers (using CIDR address/mask format)
- First relevant “allow” or “deny” rule wins
- Implicit Deny All as last entry in list



Prefix Lists – Examples

- Deny default route

  `ip prefix-list Example deny 0.0.0.0/0`

- Permit the prefix 35.0.0.0/8

  `ip prefix-list Example permit 35.0.0.0/8`

- Deny the prefix 172.16.0.0/12, and all more-specific routes

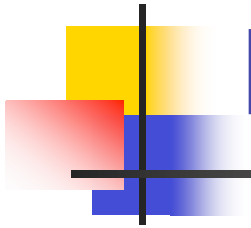
  `ip prefix-list Example deny 172.16.0.0/12 ge 12`

  "ge 12" means "prefix length /12 or longer". For example, 172.17.0.0/16 will also be denied.

- In 192.0.0.0/8, allow any /24 or shorter prefixes

  `ip prefix-list Example permit 192.0.0.0/8 le 24`

  This will not allow any /25, /26, /27, /28, /29, /30, /31 or /32



Prefix Lists – More Examples

- In 192/8 deny /25 and above

  `ip prefix-list Example deny 192.0.0.0/8 ge 25`

  This denies all prefix sizes /25, /26, /27, /28, /29, /30, /31 and /32 in the address block 192.0.0.0/8

  It has the same effect as the previous example

- In 192/8 permit prefixes between /12 and /20

  `ip prefix-list Example permit 192.0.0.0/8 ge 12 le 20`

  This denies all prefix sizes /8, /9, /10, /11, /21, /22 and higher in the address block 193.0.0.0/8

- Permit all prefixes

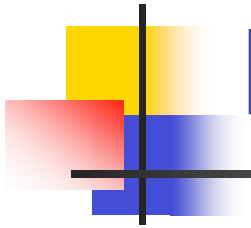
  `ip prefix-list Example 0.0.0.0/0 le 32`

Policy Control Using Prefix Lists

- Example Configuration

```
router bgp 200
 network 215.7.0.0
 neighbor 220.200.1.1 remote-as 210
 neighbor 220.200.1.1 prefix-list PEER-IN in
 neighbor 220.200.1.1 prefix-list PEER-OUT out
!
ip prefix-list PEER-IN deny 218.10.0.0/16
ip prefix-list PEER-IN permit 0.0.0.0/0 le 32
ip prefix-list PEER-OUT permit 215.7.0.0/16
ip prefix-list PEER-OUT deny 0.0.0.0/0 le 32
```

  - Accept everything except our network from our peer
  - Send only our network to our peer



Policy Control – Route Maps

- A route-map is like a "program" for Cisco IOS
- Has "line" numbers, like programs
- Each line is a separate condition/action
- Concept is basically:

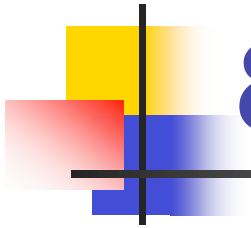
  if *match* then do *expression* and *exit*

  else

  if *match* then do *expression* and *exit*

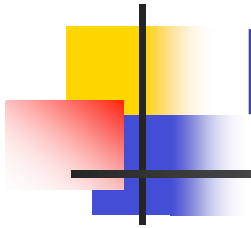
  else *etc*

Route-map match & set clauses



- Match Clauses
  - AS-path
  - Community
  - IP address
- Set Clauses
  - AS-path prepend
  - Community
  - Local-Preference
  - MED
  - Origin
  - Weight
  - Others...

Route Map: Example One



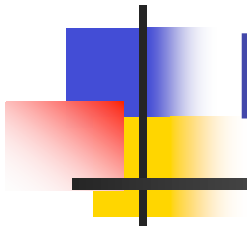
```
router bgp 300
 neighbor 2.2.2.2 remote-as 100
 neighbor 2.2.2.2 route-map SETCOMMUNITY out
!
route-map SETCOMMUNITY permit 10
 match ip address 1
 match community 1
 set community 300:100
!
access-list 1 permit 35.0.0.0
ip community-list 1 permit 100:200
```

Route Map: Example Two

- Example Configuration as AS PATH prepend

```
router bgp 300
 network 215.7.0.0
 neighbor 2.2.2.2 remote-as 100
 neighbor 2.2.2.2 route-map SETPATH out
!
route-map SETPATH permit 10
 set as-path prepend 300 300
```

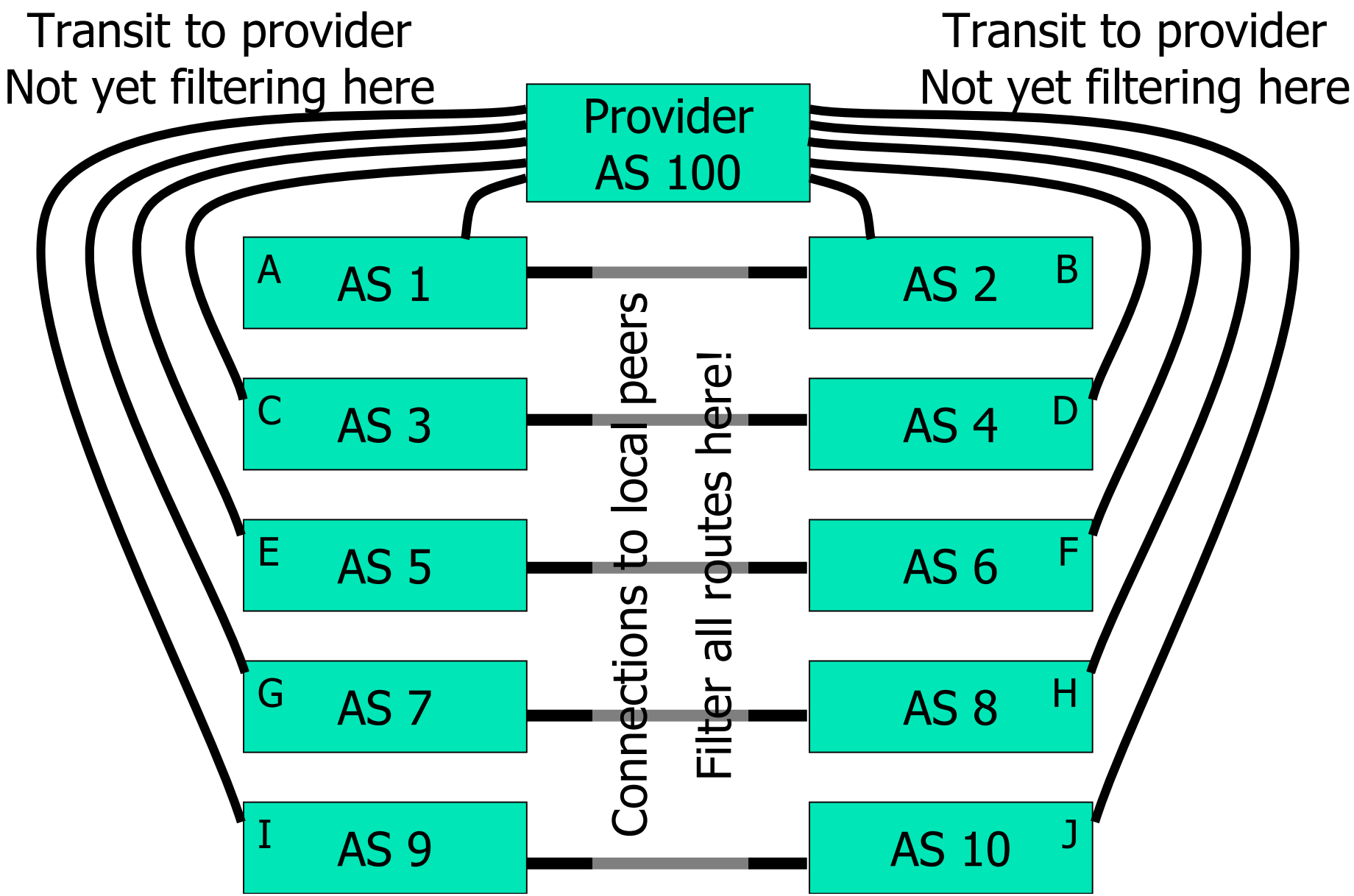
- Use your own AS number for prepending
  - Otherwise BGP loop detection will cause disconnects



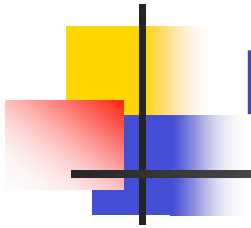
BGP Exercise 3

Filtering peer routes using AS-path regular expression

Exercise 3: Filtering peer routes using AS-path

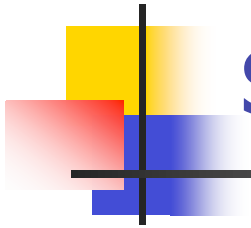


Exercise 3: Filtering peer routes using AS-path

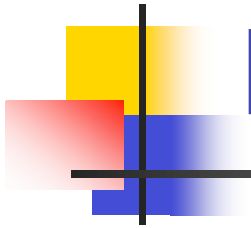


- Create “ip as-path access-list <number>” to match your peer’s routes
  - ip as-path access-list 1 permit ^1$
- Apply the filters
  - “neighbor <address> filter-list <number> in”

Exercise 3: What you should see

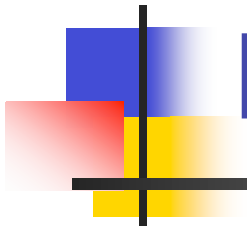


- From peers: only their routes, no transit
  - They send all routes, but you filter
- To peers: your routes and transit routes
  - They should ignore the transit routes
  - But it's bad that you send transit routes
- From upstream: all routes
- To upstream: all routes
  - This is bad



Exercise 3: Did it work?

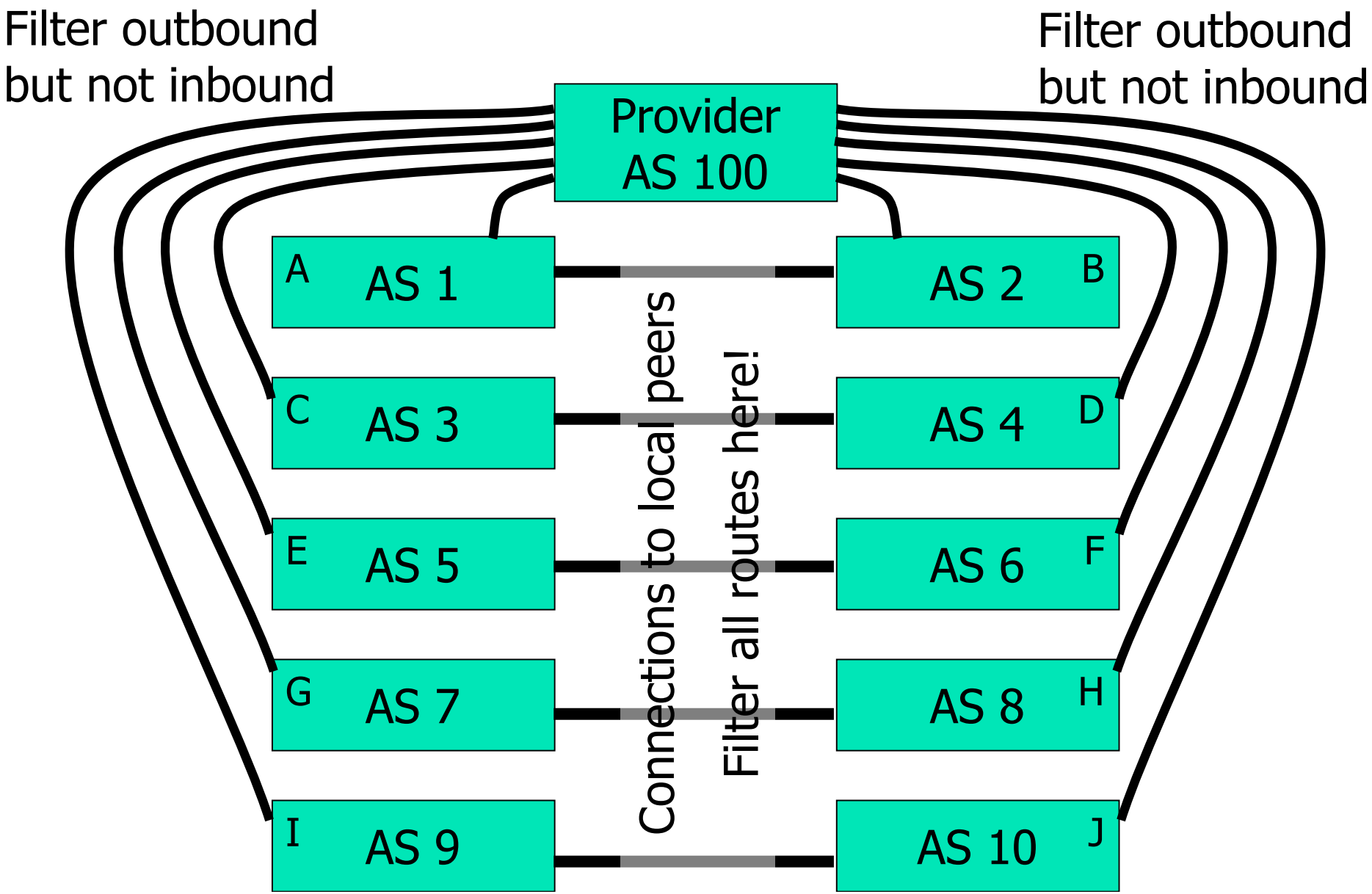
- “show ip route” – your forwarding table
- “show ip bgp” – your BGP table
- “show ip bgp neighbor xxx received-routes” – from your neighbour before filtering
- “show ip bgp neighbor xxx routes” – from neighbour, after filtering
- “show ip bgp neighbor advertised-routes” – to neighbour, after filtering



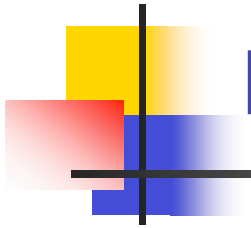
BGP Exercise 4

Filtering peer routes using prefix-lists

Exercise 4: Filtering peer routes using prefix-lists

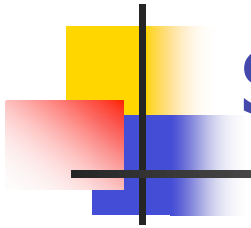


Exercise 4: Filtering peer routes using prefix-list



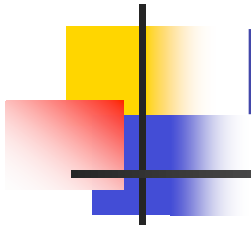
- Create "ip prefix-list my-routes" to match your own routes
- Create "ip prefix-list peer-as-xxx" to match your peer's routes
- Apply the filters to your peers
  - "neighbor xxx prefix-list my-routes out"
  - "neighbor xxx prefix-list peer-as-xxx in"
- Apply the outbound filter to your upstream provider

Exercise 4: What you should see



- From peers: only their routes, no transit
- To peers: only your routes, no transit
- From upstream: all routes
- To upstream: only your routes, no transit

- We still trust the upstream provider too much. Should filter it too!
  - See “ip prefix-list sanity-filter” in cheat sheet



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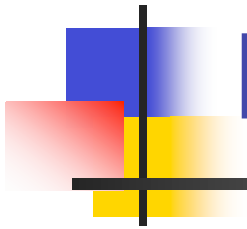
- “show ip bgp neighbor xxx advertised-routes” - to neighbour, after filtering



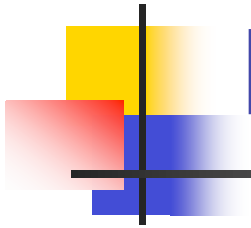
BGP Part 8

More detail than you want

BGP Attributes

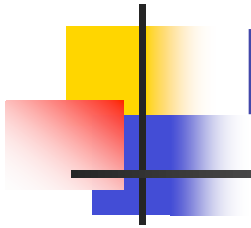
Synchronization

Path Selection



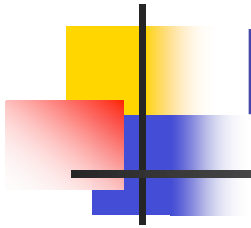
BGP Path Attributes: Why ?

- Encoded as Type, Length & Value (TLV)
- Transitive/Non-Transitive attributes
- Some are mandatory
- Used in path selection
- To apply policy for steering traffic



BGP Attributes

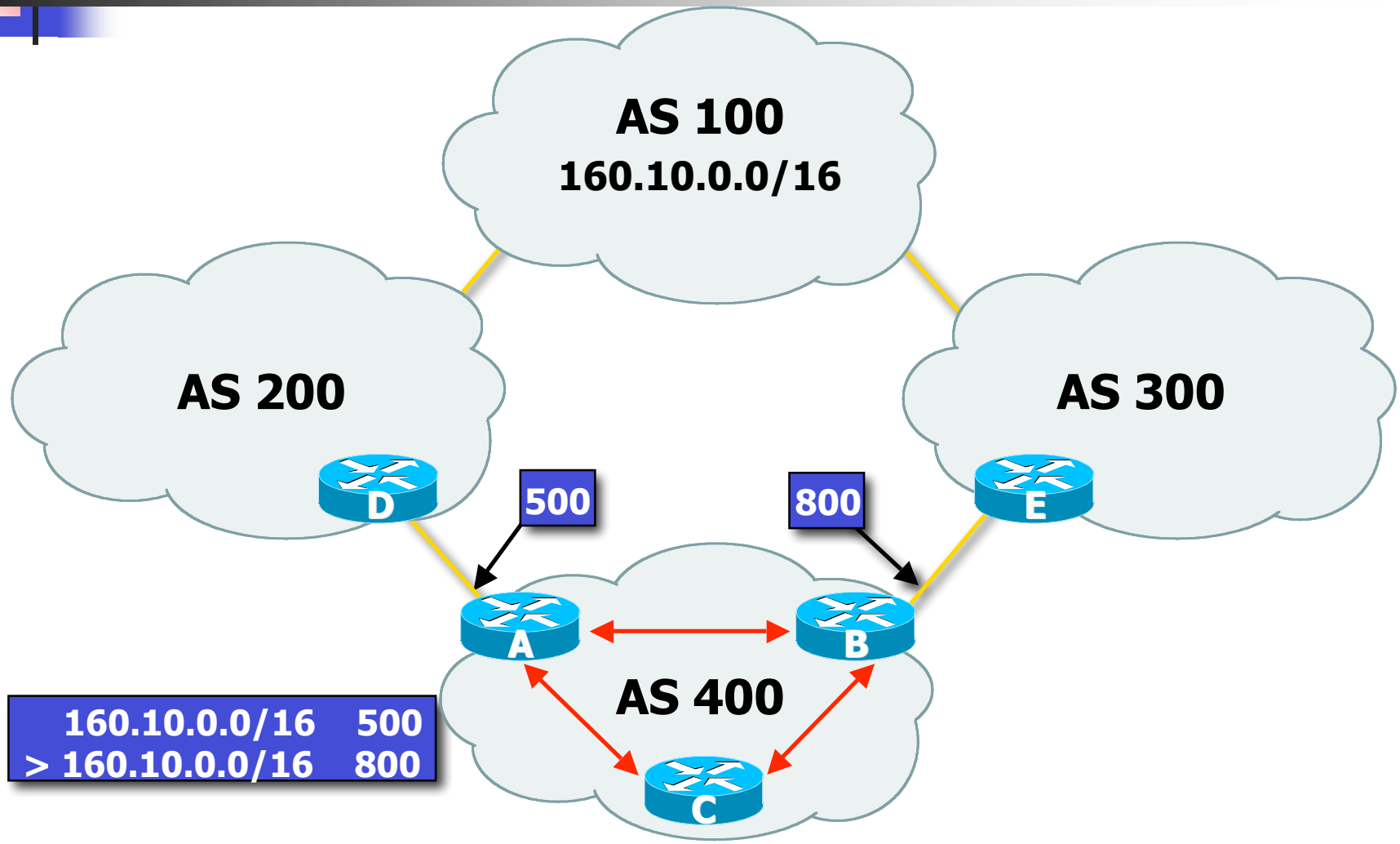
- Used to convey information associated with NLRI
  - AS path
  - Next hop
  - Local preference
  - Multi-Exit Discriminator (MED)
  - Community
  - Origin
  - Aggregator

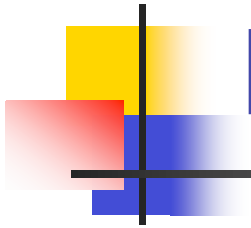


Local Preference

- Not used by eBGP, mandatory for iBGP
- Default value of 100 on Cisco IOS
- Local to an AS
- Used to prefer one exit over another
- Path with highest local preference wins

Local Preference

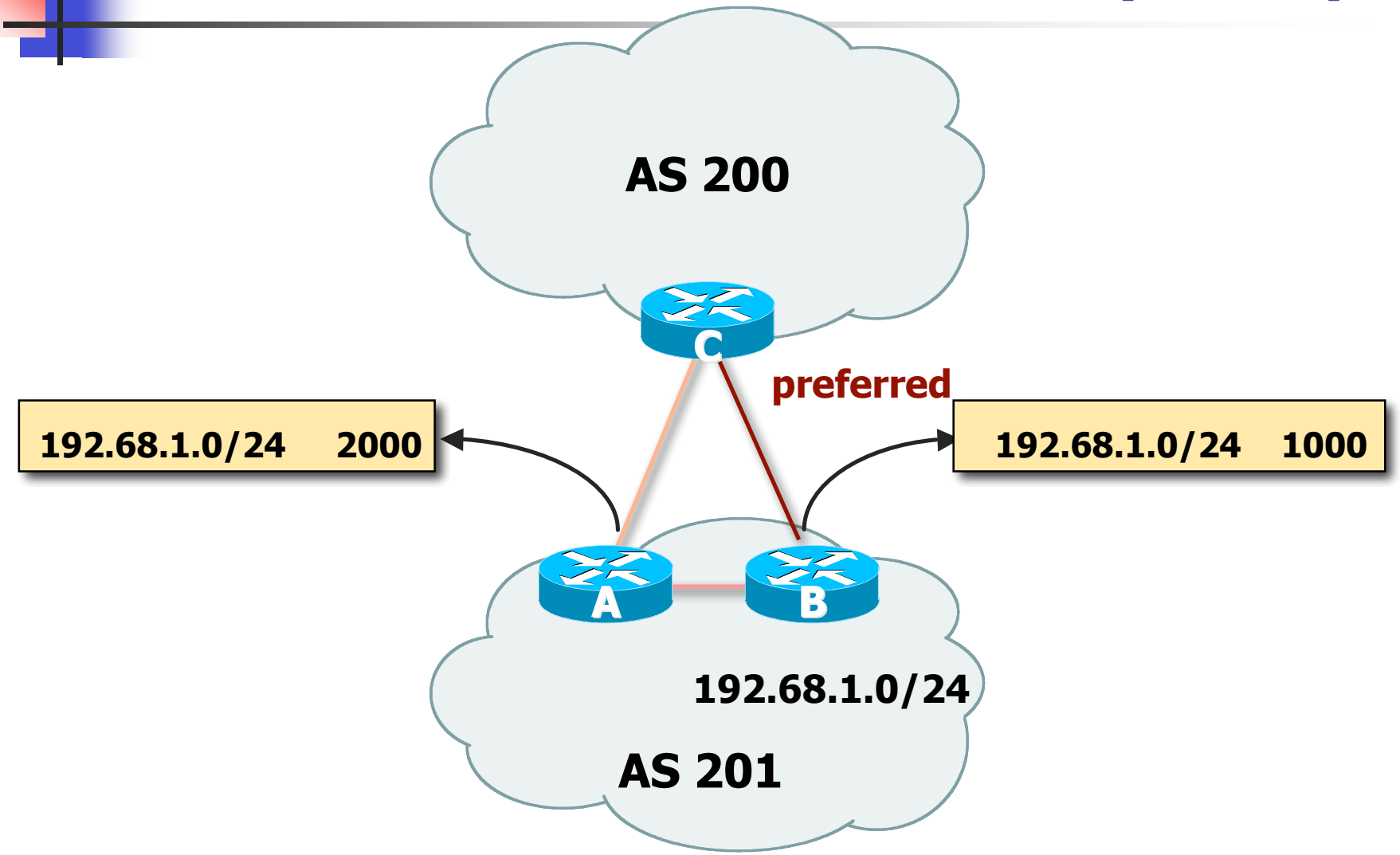


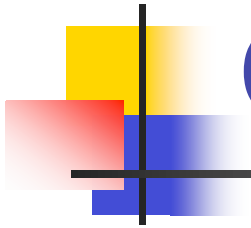


Multi-Exit Discriminator

- Non-transitive
- Represented as a numerical value
  - Range 0x0 – 0xffffffff
- Used to convey relative preference of entry points to an AS
- Comparable if the paths are from the same AS
- Path with the lowest MED wins
- IGP metric can be conveyed as MED

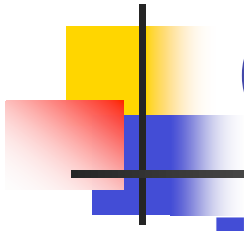
Multi-Exit Discriminator (MED)





Origin

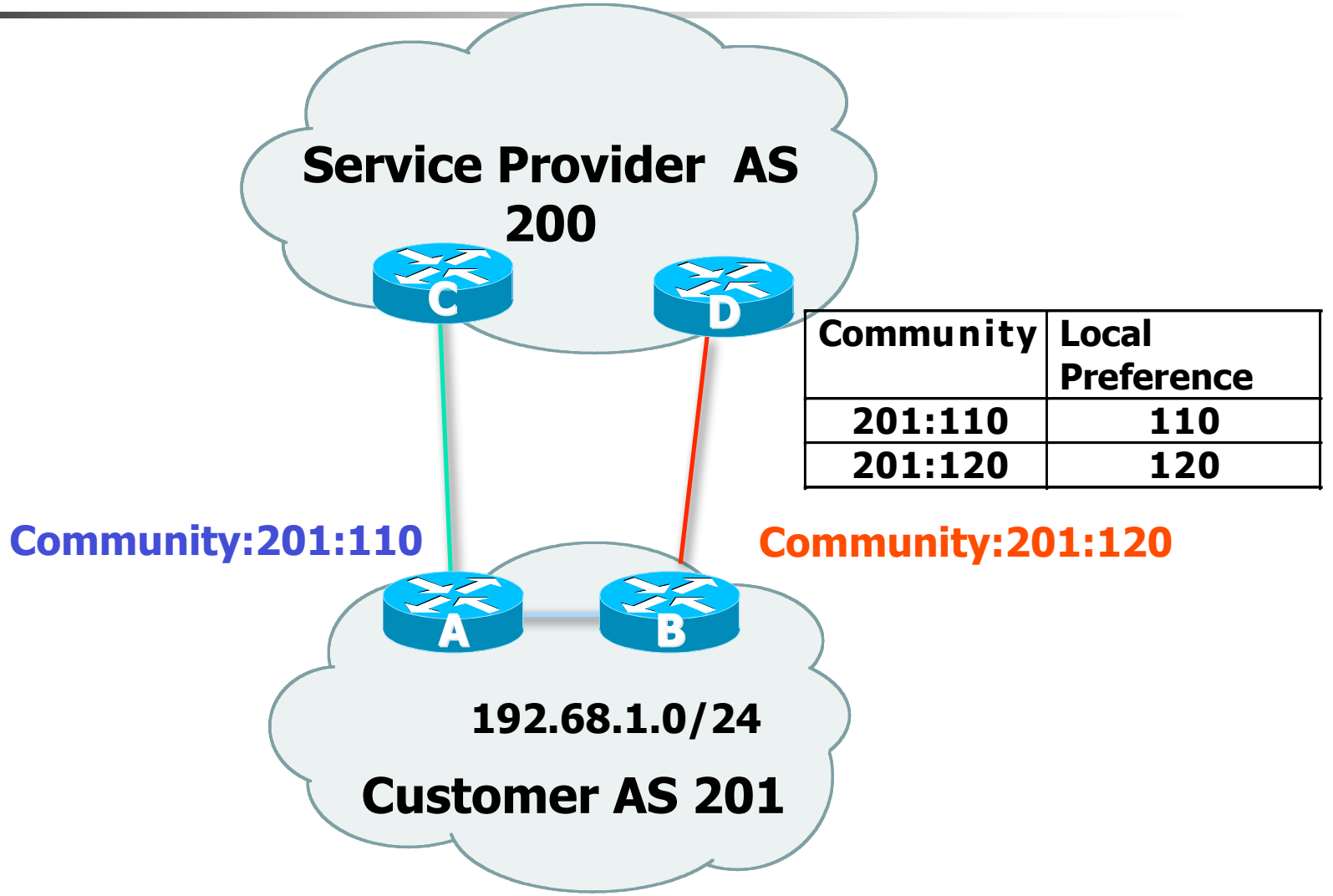
- Conveys the origin of the prefix
- Three values:
  - IGP – from BGP network statement
    - E.g. – *network 35.0.0.0*
  - EGP – redistributed from EGP (not used today)
  - Incomplete – redistributed from another routing protocol
    - E.g. – *redistribute static*
- IGP < EGP < incomplete
  - Lowest origin code wins



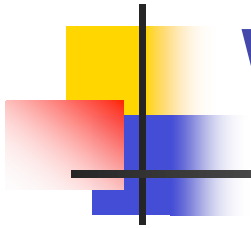
Communities

- Transitive, Non-mandatory
- Represented as a numeric value
  - 0x0 – 0xffffffff
  - Internet convention is ASn:<0-65535>
- Used to group destinations
- Each destination could be member of multiple communities
- Flexibility to scope a set of prefixes within or across AS for applying policy

Communities

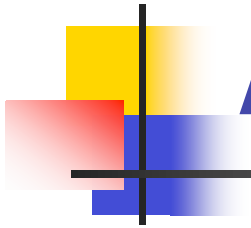


Community	Local Preference
201:110	110
201:120	120



Weight

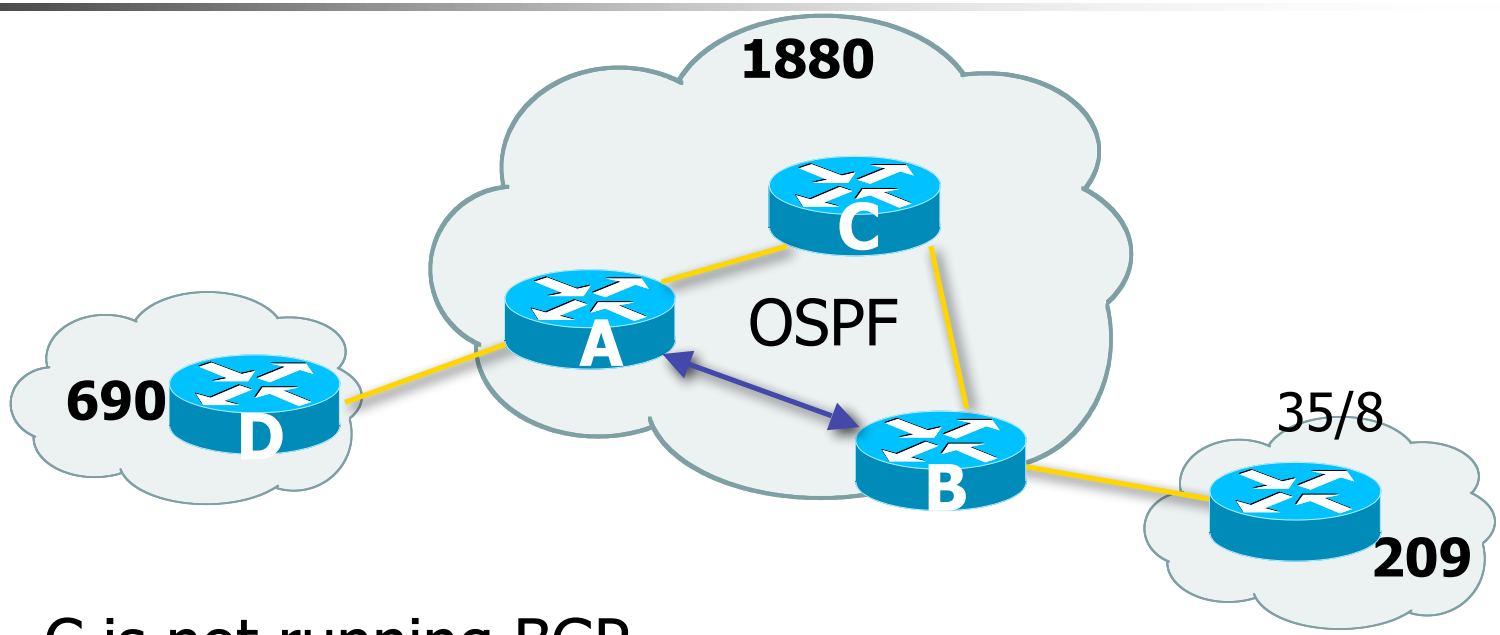
- Not really an attribute
- Used when there is more than one route to same destination
- Local to the router on which it is assigned, and not propagated in routing updates
- Default is 32768 for paths that the router originates and zero for other paths
- Routes with a higher weight are preferred when there are multiple routes to the same destination



Administrative Distance

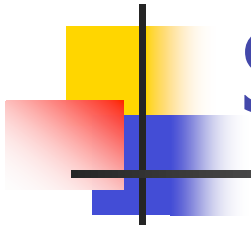
- Routes can be learned via more than one protocol
  - Used to discriminate between them
- Route with lowest distance installed in forwarding table
- BGP defaults
  - Local routes originated on router: 200
  - iBGP routes: 200
  - eBGP routes: 20
- Does not influence the BGP path selection algorithm but influences whether BGP learned routes enter the forwarding table

Synchronization



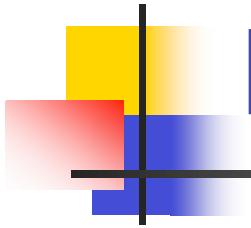
- C is not running BGP
- A won't advertised 35/8 to D until the IGP is in sync
- Turn synchronization off!

```
router bgp 1880
 no synchronization
```



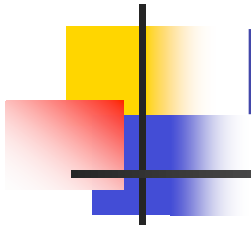
Synchronization

- In Cisco IOS, BGP does not advertise a route before all routers in the AS have learned it via an IGP
  - Default in IOS prior to 12.4; very unhelpful to most ISPs
- Disable synchronization if:
  - AS doesn't pass traffic from one AS to another, or
  - All transit routers in AS run BGP, or
  - iBGP is used across backbone
- You should always use iBGP
  - so, always use "no synchronization"



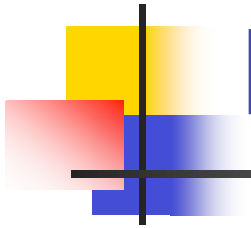
BGP route selection (bestpath)

- Route has to be synchronized
  - Only if synchronization is enabled
  - Prefix must be in forwarding table
- Next-hop has to be accessible
  - Next-hop must be in forwarding table
- Largest weight
- Largest local preference



BGP route selection (bestpath)

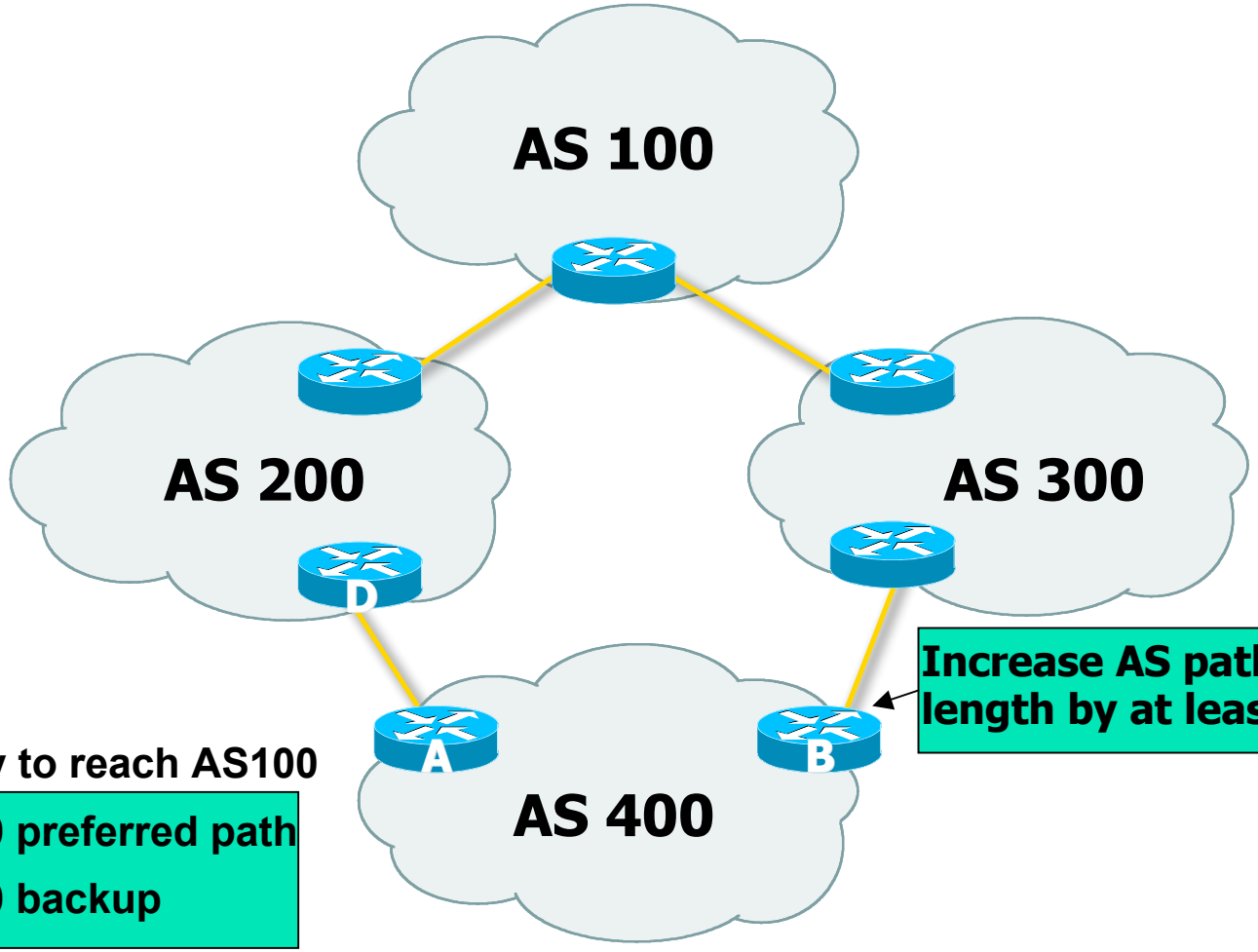
- Locally sourced
  - Via redistribute or network statement
- Shortest AS path length
  - Number of ASes in the AS-PATH attribute
- Lowest origin
  - IGP < EGP < incomplete
- Lowest MED
  - Compared from paths from the same AS



BGP route selection (bestpath)

- External before internal
  - Choose external path before internal
- Closest next-hop
  - Lower IGP metric, nearest exit to router
- Lowest router ID
- Lowest IP address of neighbour

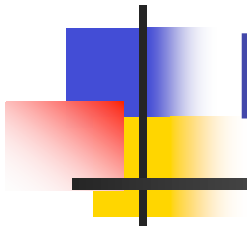
BGP Route Selection...



Increase AS path attribute length by at least 1

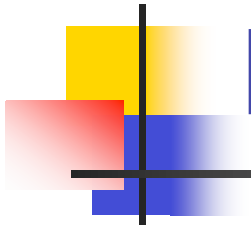
AS 400's Policy to reach AS100

- AS 200 preferred path
- AS 300 backup



BGP Exercise 5

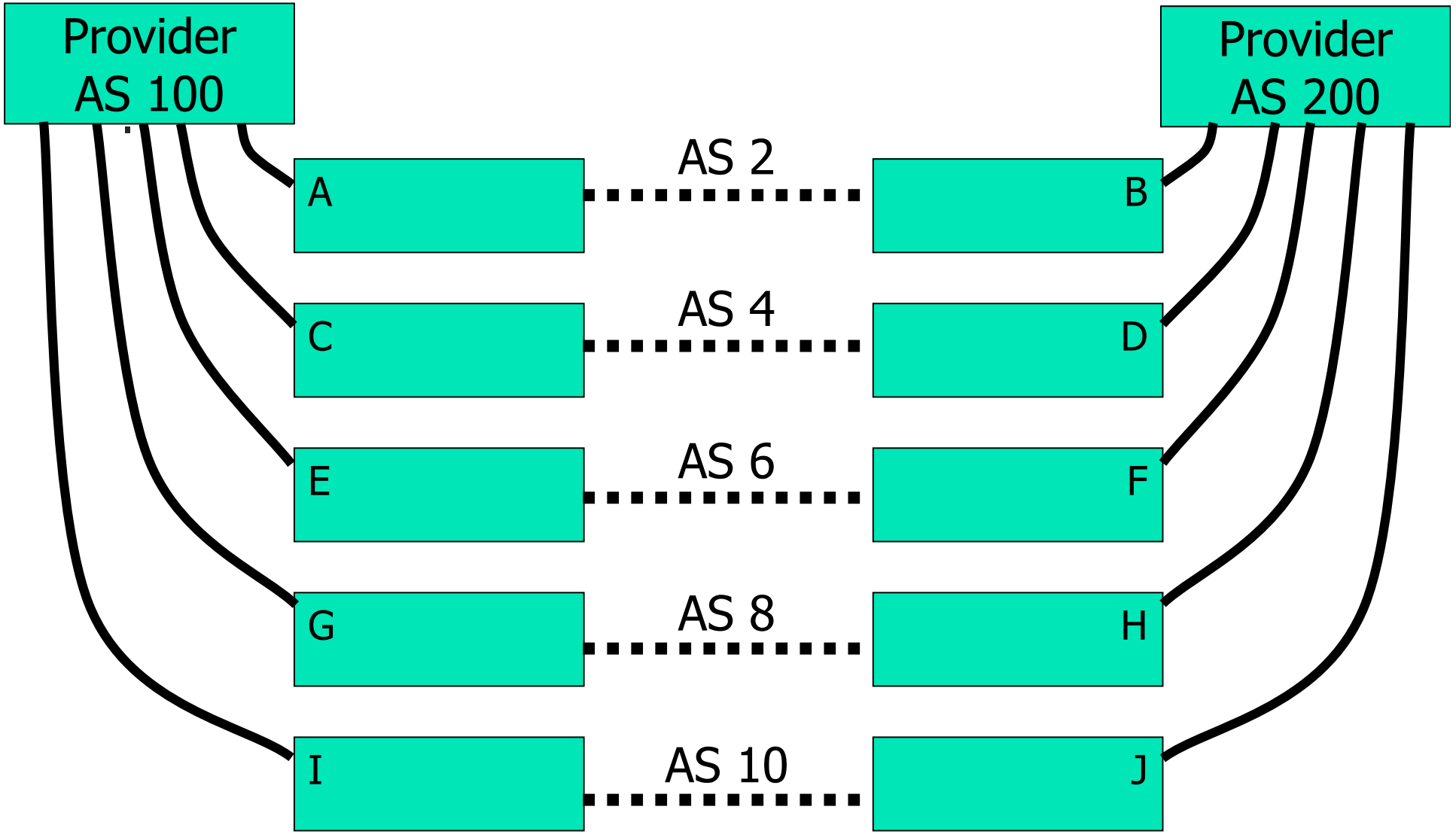
Internal BGP (iBGP)

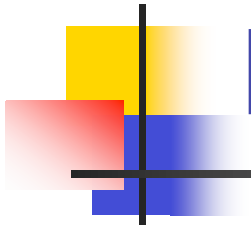


Exercise 5: Configure iBGP

- Tables join into pairs, with two routers per AS
- Each AS has two upstream providers
- OSPF and iBGP within your AS
- eBGP to your upstream provider
- Filter everything!

Exercise 5: Configure iBGP

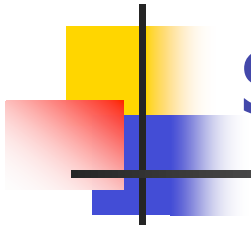




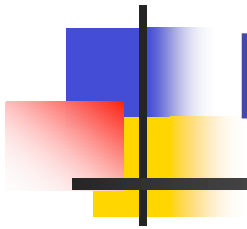
Exercise 5: Configure iBGP

- The two routers in your AS should talk iBGP to each other
  - no filtering here
  - use “update-source loopback 0”
- One of your routers talks eBGP to AS 100, and one talks to AS 200.
  - Filter!
  - Send only your routes
  - Accept all except bogus routes (“sanity-filter”)

Exercise 5: What you should see

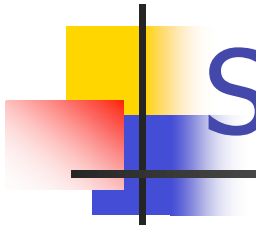


- Directly from AS 100: routes to entire classroom
- Directly from AS 200: routes to entire classroom
- From your iBGP neighbour: indirect routes through AS 100 or AS 200 to entire classroom
- Which route do you prefer?



BGP Part 9

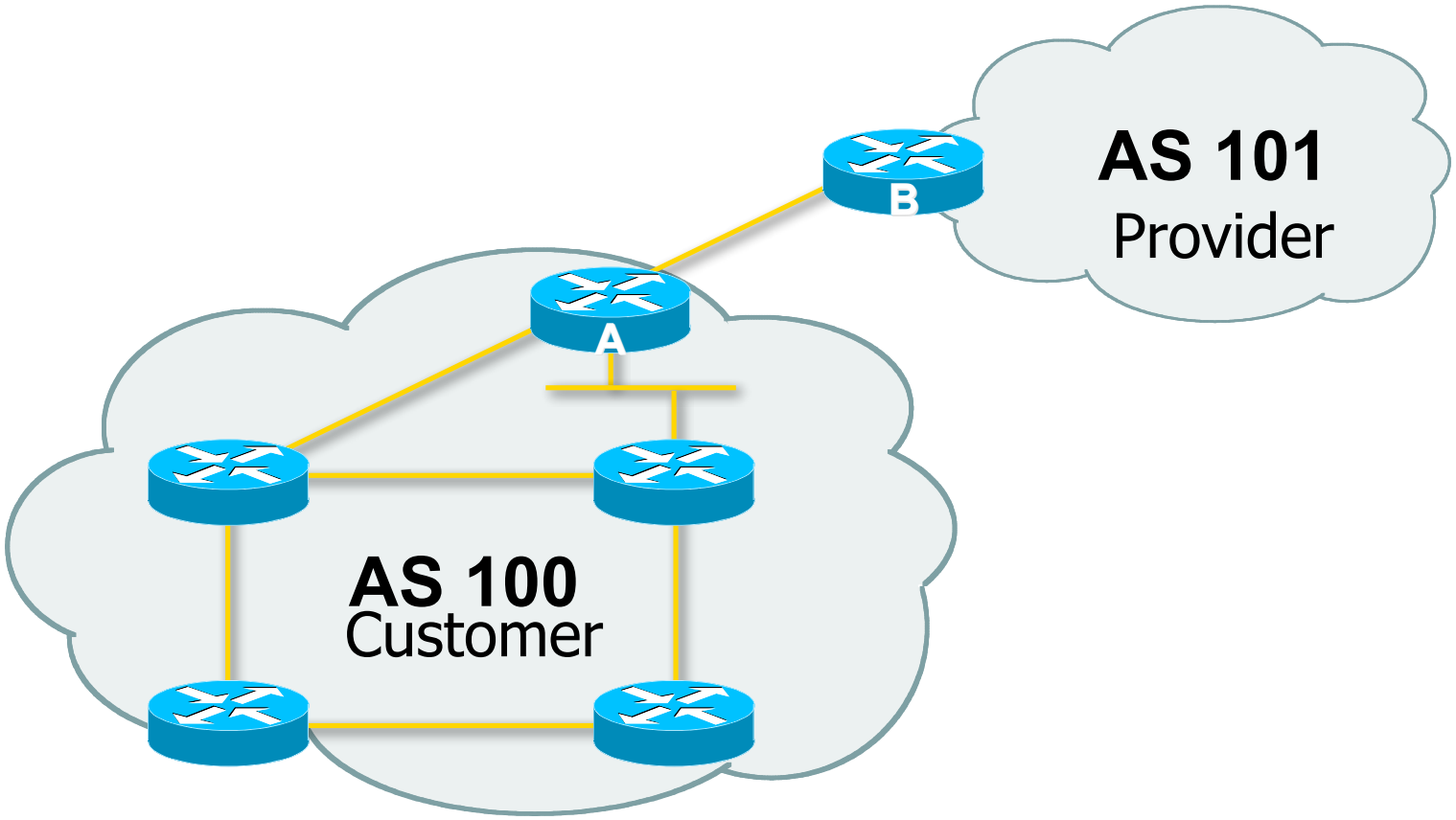
BGP and Network Design

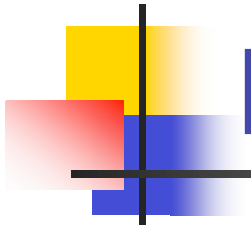


Stub AS

- Enterprise network, or small ISP
- Typically no need for BGP
- Point default towards the ISP
- ISP advertises the stub network to Internet
- Policy confined within ISP policy

Stub AS

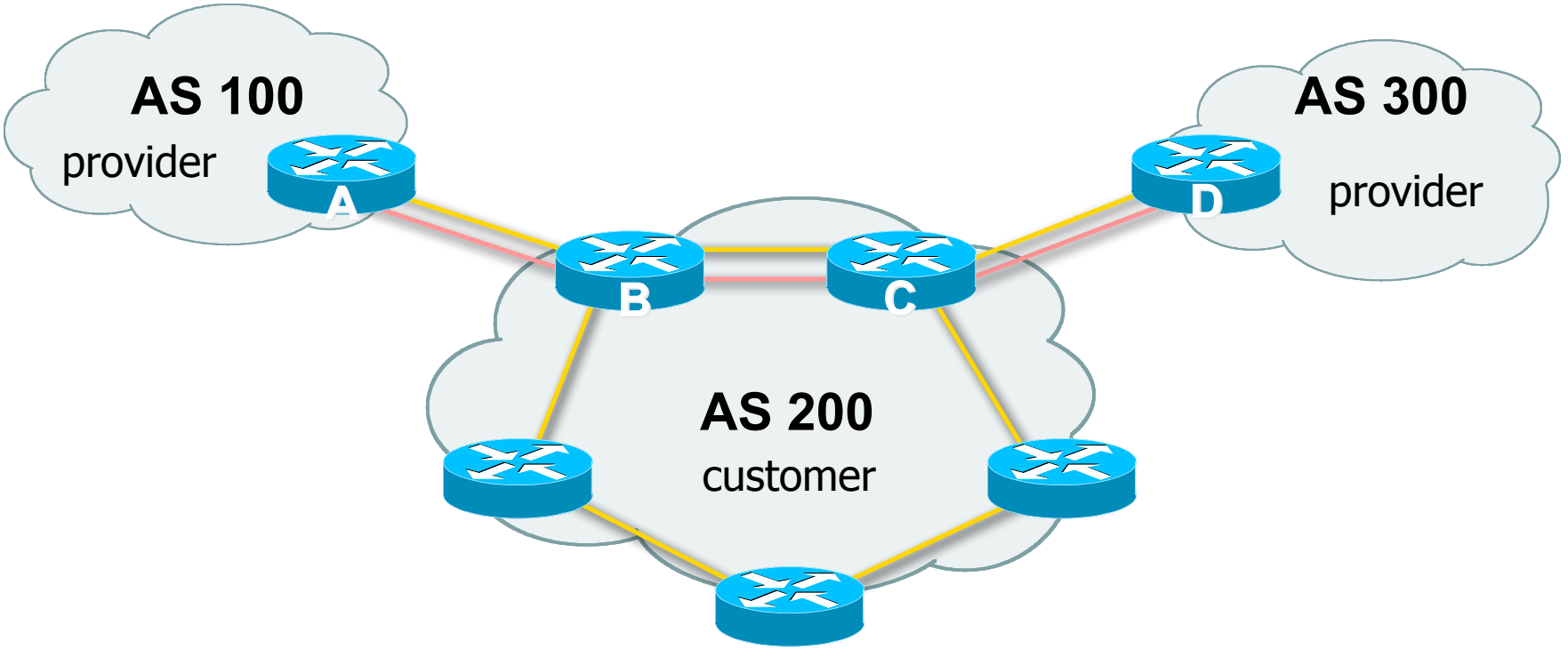




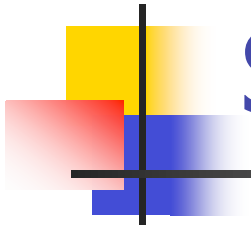
Multi-homed AS

- Enterprise network or small ISP
- Only border routers speak BGP
- iBGP only between border routers
- Rest of network either has:
  - exterior routes redistributed in a controlled fashion into IGP…
  - …or use defaults (much preferred!)

Multi-homed AS



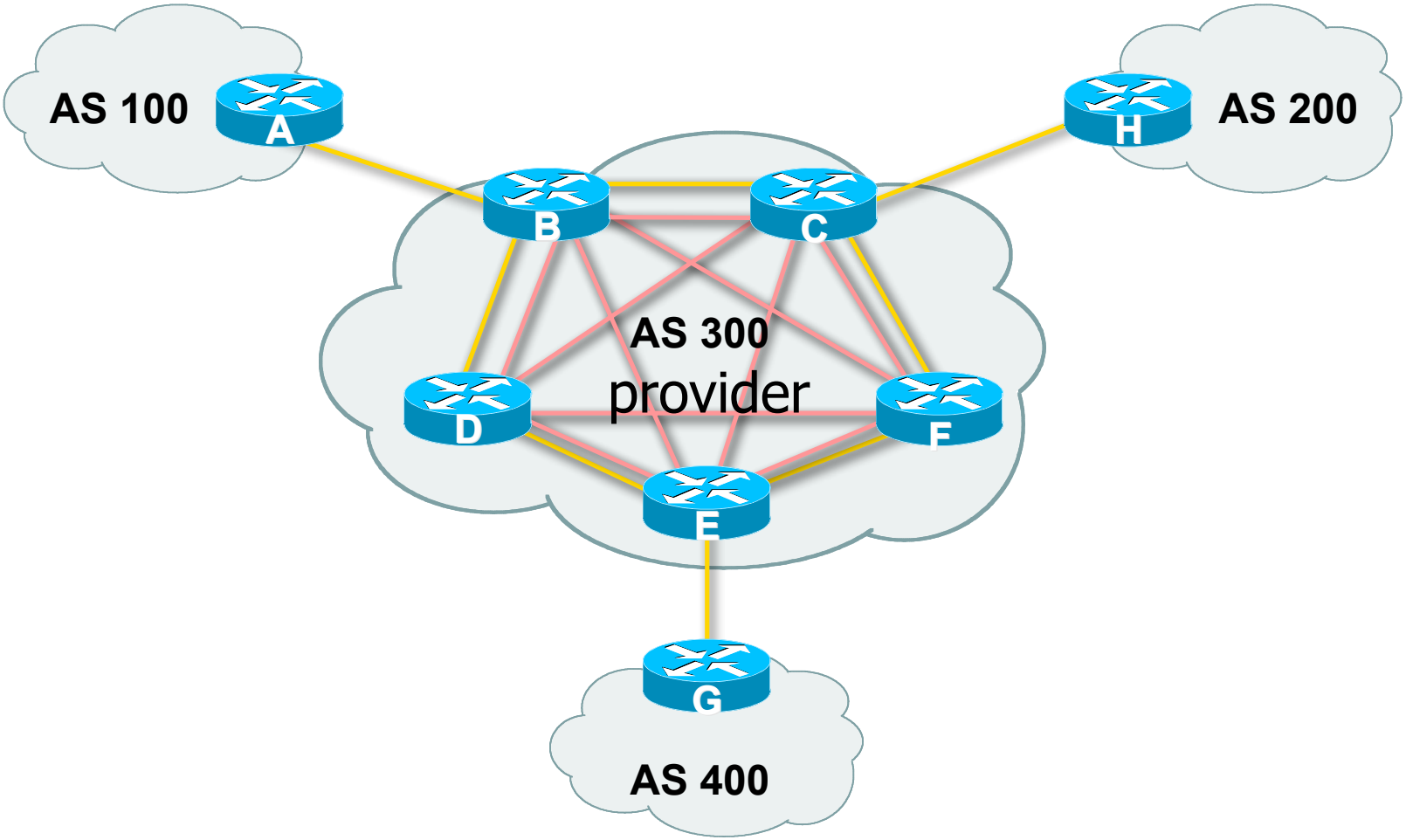
- More details on multihoming coming up...



Service Provider Network

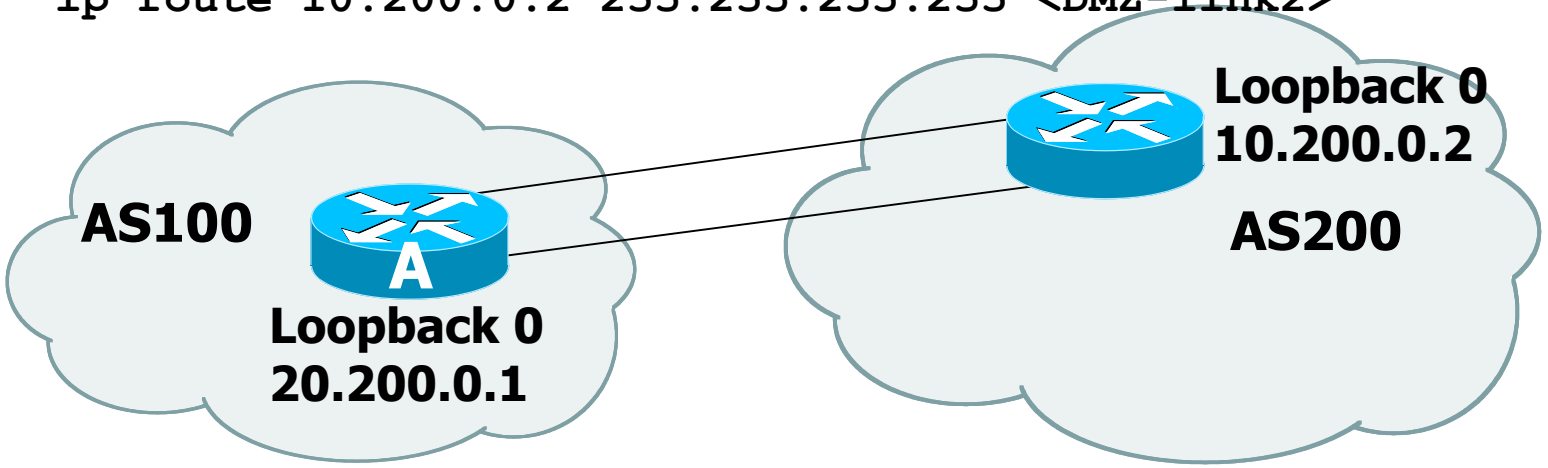
- iBGP used to carrier exterior routes
  - No redistribution into IGP
- IGP used to track topology inside your network
- Full iBGP mesh required
  - Every router in ISP backbone should talk iBGP to every other router
  - This has scaling problems, and solutions (e.g. route reflectors)

Common Service Provider Network



Load-sharing – single path

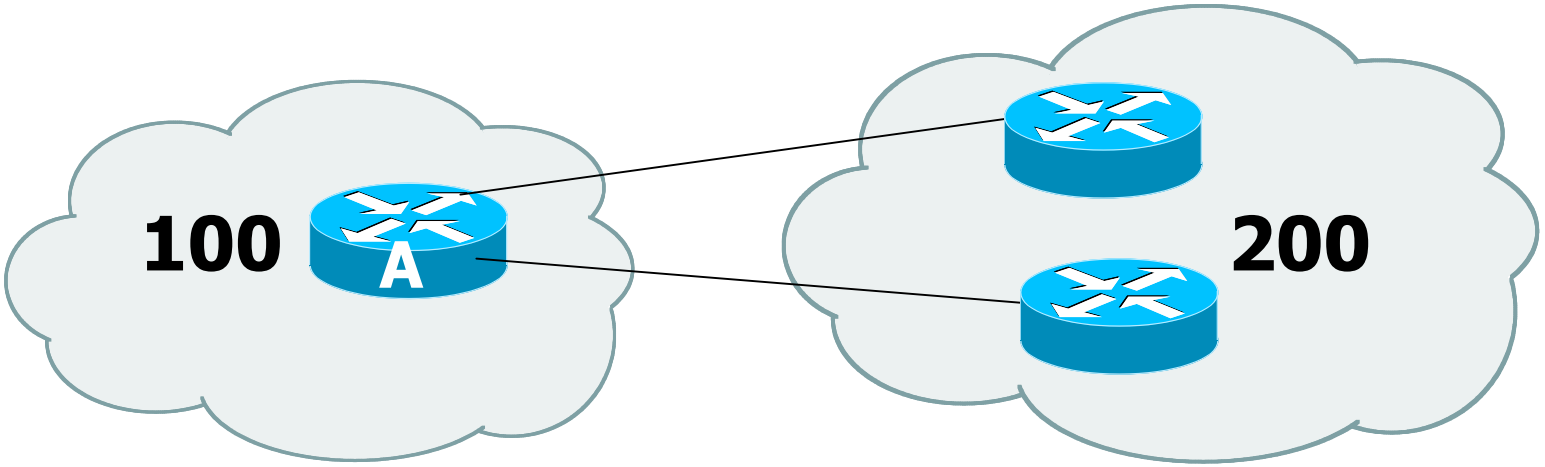
```
Router A:
interface loopback 0
 ip address 20.200.0.1 255.255.255.255
!
router bgp 100
 neighbor 10.200.0.2 remote-as 200
 neighbor 10.200.0.2 update-source loopback0
 neighbor 10.200.0.2 ebgp-multihop 2
!
ip route 10.200.0.2 255.255.255.255 <DMZ-link1>
ip route 10.200.0.2 255.255.255.255 <DMZ-link2>
```



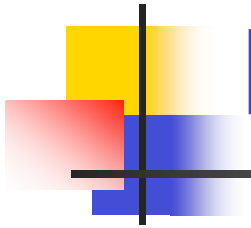
Load-sharing – multiple paths from the same AS

Router A:

```
router bgp 100
 neighbor 10.200.0.1 remote-as 200
 neighbor 10.300.0.1 remote-as 200
 maximum-paths 2
```

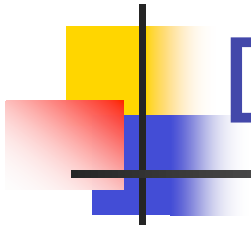


Note: A still only advertises one "best" path to ibgp peers



Redundancy – Multi-homing

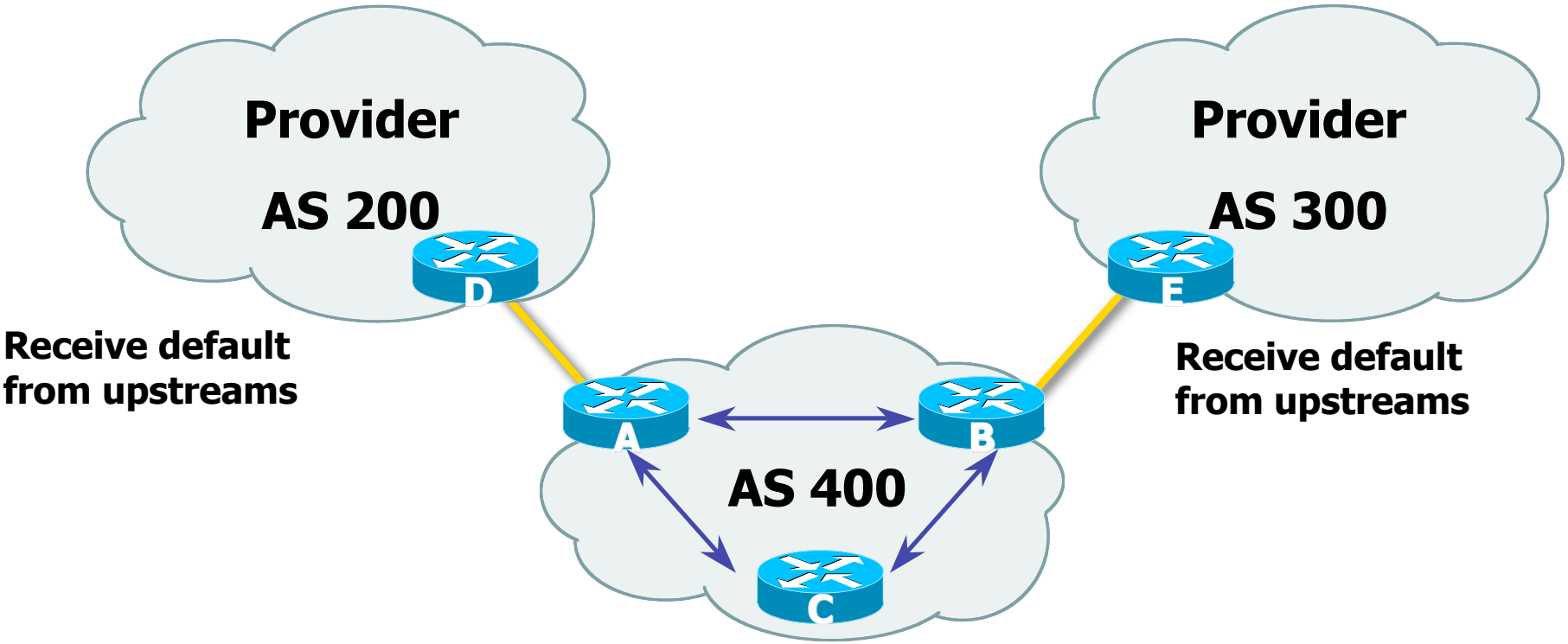
- Reliable connection to Internet
- 3 common cases of multi-homing
  - default from all providers
  - customer + default from all providers
  - full routes from all providers
- Address Space
  - comes from upstream providers, or
  - allocated directly from registries



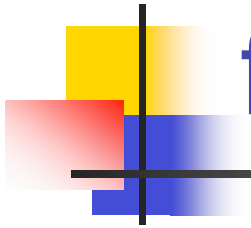
Default from all providers

- Low memory/CPU solution
- Provider sends BGP default
  - provider is selected based on IGP metric
- Inbound traffic decided by providers' policy
  - Can influence using outbound policy, example: AS-path prepend

Default from all providers

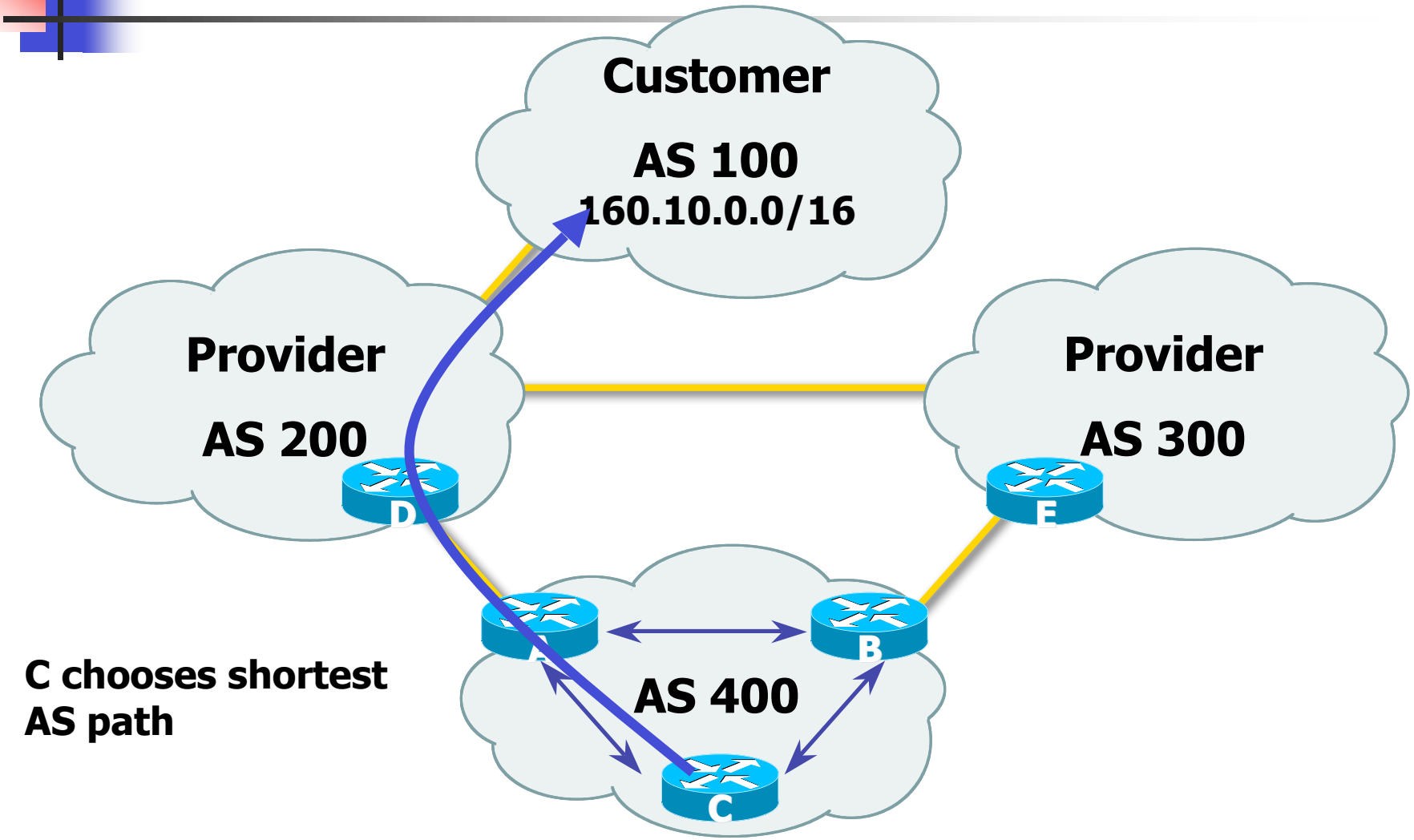


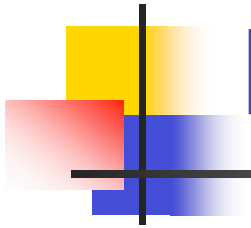
Customer prefixes plus default from all providers



- Medium memory and CPU solution
- Granular routing for customer routes, default for the rest
  - Route directly to customers as those have specific policies
- Inbound traffic decided by providers' policies
  - Can influence using outbound policy

Customer routes from all providers

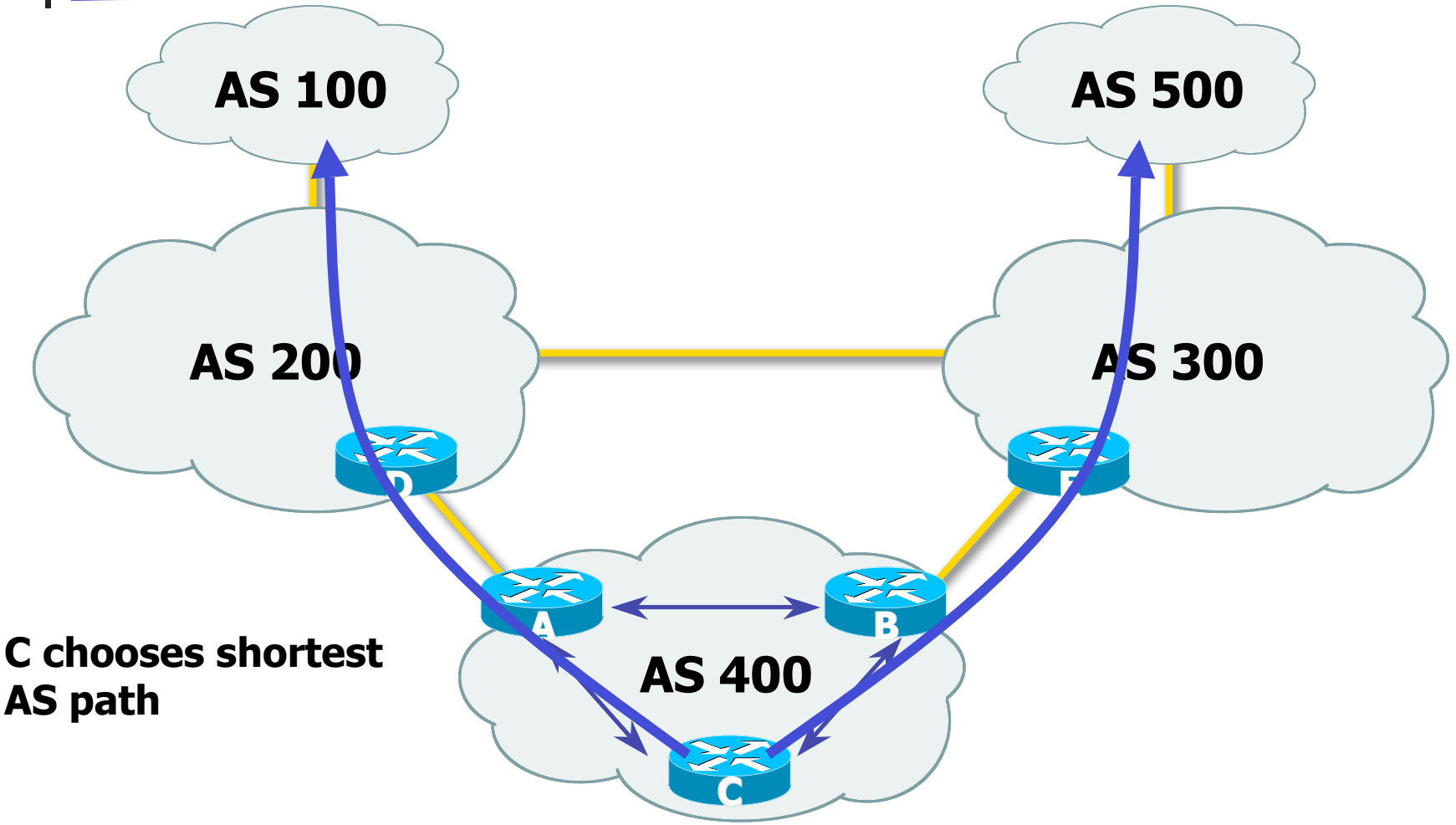




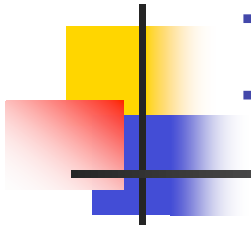
Full routes from all providers

- More memory/CPU
- Fine grained routing control
- Usually transit ASes take full routes
- Usually pervasive BGP

Full routes from all providers



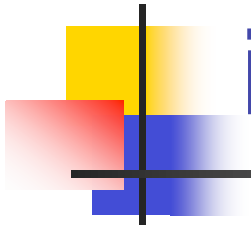
C chooses shortest AS path



Best Practices IGP in Backbone

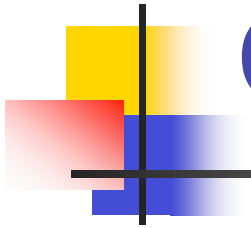
- IGP connects your backbone together, not your clients' routes
  - Clients' routes go into iBGP
  - Hosting and service LANs go into iBGP
  - Dial/Broadband/Wireless pools go into iBGP
- IGP must converge quickly
  - The fewer prefixes in the IGP the better
- IGP should carry netmask information – OSPF, IS-IS, EIGRP

Best Practices
iBGP in Backbone



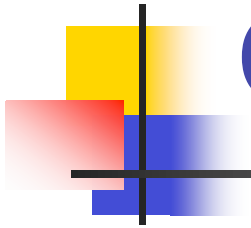
- iBGP runs between all routers in backbone
- Configuration essentials:
  - Runs between loopbacks
  - Next-hop-self
  - Send-community
  - Passwords
  - All non-infrastructure prefixes go here

Best Practices... Connecting to a customer



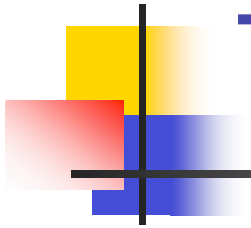
- Static routes
  - You control directly
  - No route flaps
- Shared routing protocol or leaking
  - Strongly discouraged
  - You must filter your customers info
  - Route flaps
- BGP for multi-homed customers
  - Private AS for those who multihome on to your backbone
  - Public AS for the rest

Best Practices... Connecting to other ISPs

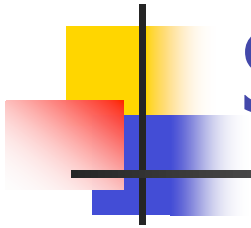


- Advertise only what you serve
- Take back as little as you can
- Take the shortest exit
- Aggregate your routes!!
  - Consult RIPE-399 document for recommendations:
  - http://www.ripe.net/docs/ripe-399.html
- FILTER! FILTER! FILTER!

Best Practices... The Internet Exchange



- Long distance connectivity is:
  - Expensive
  - Slow (speed of light limitations)
  - Congested
- Connect to several providers at a single point
  - Cheap
  - Fast
- More details later!



Summary

- BGP Building Blocks
- BGP Protocol Basics
- BGP Path Attributes
- BGP Path Computation
- Typical BGP topologies
- Routing Policy
- Redundancy/Load sharing
- Best current practices