

# Routing Basics

## ISP Workshops



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# Acknowledgements

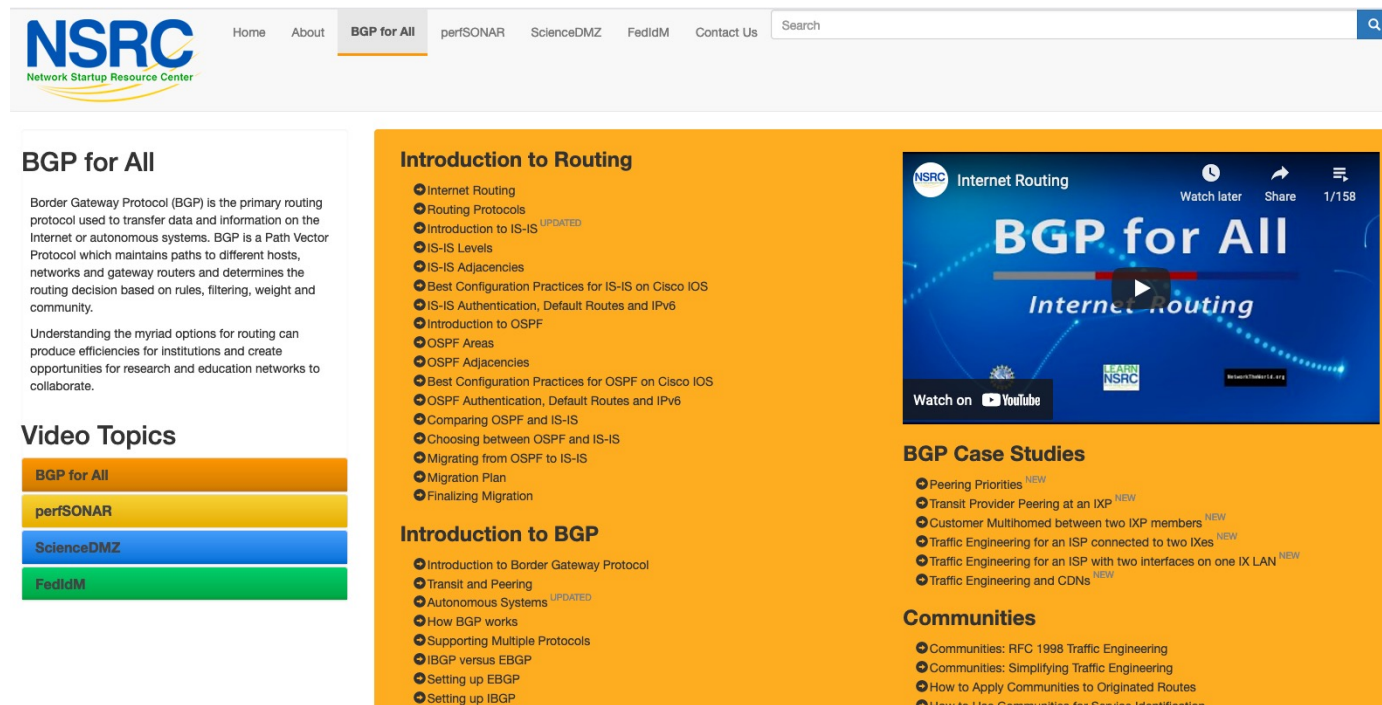
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- This material originated from the Cisco ISP/IXP Workshop Programme developed by Philip Smith & Barry Greene
- Use of these materials is encouraged as long as the source is fully acknowledged and this notice remains in place
- Bug fixes and improvements are welcomed
  - Please email *workshop (at) bgp4all.com*

Philip Smith

# BGP Videos

- NSRC has made a video recording of this presentation, as part of a library of BGP videos for the whole community to use:
  - [https://learn.nsrc.org/bgp#intro\\_to\\_routing](https://learn.nsrc.org/bgp#intro_to_routing)



The screenshot shows the NSRC (Network Startup Resource Center) website. The navigation bar includes links for Home, About, BGP for All (highlighted), perfSONAR, ScienceDMZ, FedIdM, and Contact Us, along with a search bar. The main content area is divided into three columns:

- BGP for All:** A section with a description of BGP as the primary routing protocol and a list of video topics. The 'BGP for All' topic is highlighted in orange.
- Introduction to Routing:** A list of 17 video topics, including 'Internet Routing', 'Routing Protocols', 'Introduction to IS-IS', 'IS-IS Levels', 'IS-IS Adjacencies', 'Best Configuration Practices for IS-IS on Cisco IOS', 'OSPF Areas', 'OSPF Adjacencies', 'Best Configuration Practices for OSPF on Cisco IOS', 'OSPF Authentication, Default Routes and IPv6', 'Comparing OSPF and IS-IS', 'Choosing between OSPF and IS-IS', 'Migrating from OSPF to IS-IS', 'Migration Plan', and 'Finalizing Migration'.
- Introduction to BGP:** A list of 6 video topics, including 'Introduction to Border Gateway Protocol', 'Transit and Peering', 'Autonomous Systems', 'How BGP works', 'Supporting Multiple Protocols', and 'IBGP versus EBGp'.

On the right side, there is a video player for 'BGP for All' with a play button and a 'Watch on YouTube' button. Below the video player, there are sections for 'BGP Case Studies' (listing topics like 'Peering Priorities', 'Transit Provider Peering at an IXP', 'Customer Multihomed between two IXP members', 'Traffic Engineering for an ISP connected to two IXes', 'Traffic Engineering for an ISP with two interfaces on one IX LAN', and 'Traffic Engineering and CDNs') and 'Communities' (listing topics like 'Communities: RFC 1998 Traffic Engineering', 'Communities: Simplifying Traffic Engineering', 'How to Apply Communities to Originated Routes', and 'How to Use Communities for Service Identification').

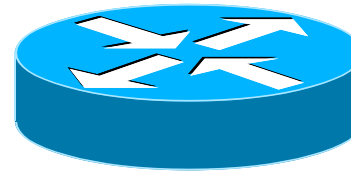
# Routing Concepts

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- Routers
- Routing
- Forwarding
- Some definitions
- Policy options
- Routing Protocols

# What is a Router?

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- A router is a layer 3 device
- Used for interconnecting networks at layer 3
- A router generally has at least two interfaces
  - With VLANs a router can have only one interface (known as “router on a stick”)
- A router looks at the destination address in the IP packet, and decides how to forward it

# The Routing Table

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- ❑ Each router/host has a *routing table*, indicating the path or the next hop for a given destination host or a network
- ❑ The router/host tries to match the destination address of a packet against entries in the routing table
- ❑ If there is a match, the router forwards it to the corresponding gateway router or directly to the destination host
- ❑ Default route is taken if no other entry matches the destination address

# The Routing Table

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<b>Destination</b>	<b>Next-Hop</b>	<b>Interface</b>
10.40.0.0/16	192.248.40.60	Ethernet0
192.248.0.140/30	Directly connected	Serial1
192.248.40.0/26	Directly connected	Ethernet0
192.248.0.0/17	192.248.0.141	Serial1
203.94.73.202/32	192.248.40.3	Ethernet0
203.115.6.132/30	Directly connected	Serial0
Default	203.115.6.133	Serial0

Typical routing table on a simple edge router

# IP Routing – finding the path

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- ❑ Routing table entry (the path) is created by the administrator (static) or received from a routing protocol (dynamic)
- ❑ More than one routing protocol may run on a router
  - Each routing protocol builds its own routing table (Local RIB)
- ❑ Several alternative paths may exist
  - Best path selected for the router's Global routing table (RIB)
- ❑ Decisions are updated periodically or as topology changes (event driven)
- ❑ Decisions are based on:
  - Topology, policies and metrics (hop count, filtering, delay, bandwidth, etc.)



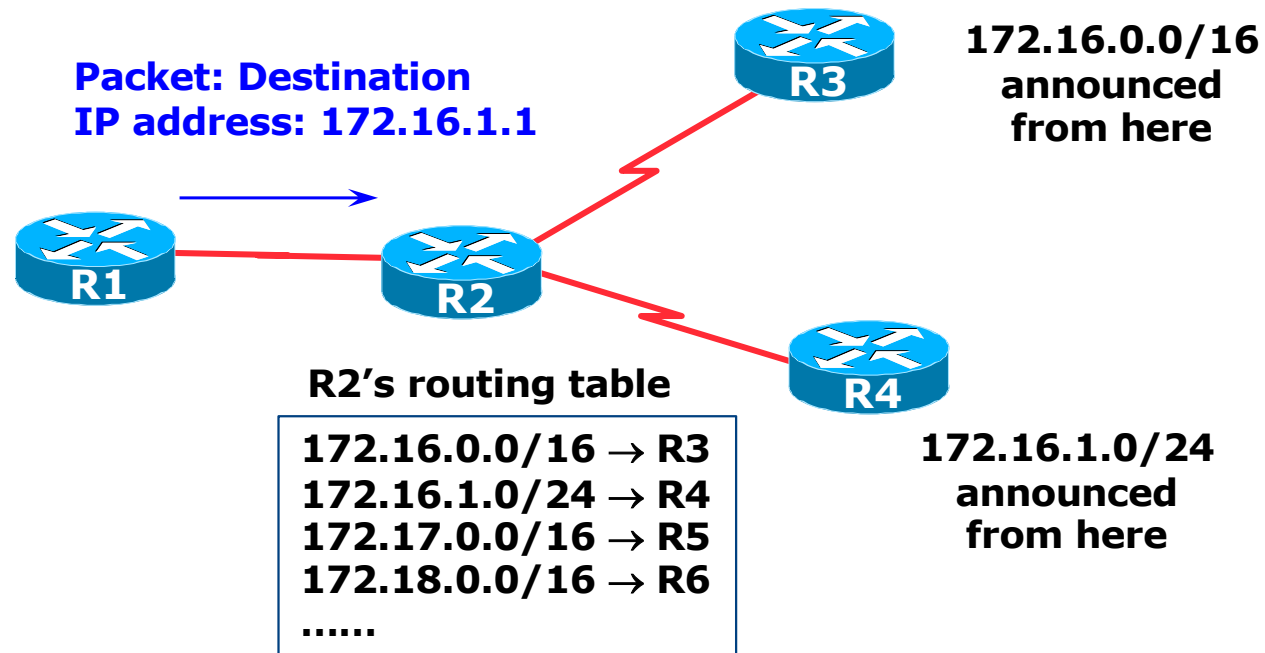
# IP route lookup

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- Based on destination IP address
- “longest match” routing
  - More specific prefix preferred over less specific prefix
  - **Example:**
    - A packet with destination of 172.16.1.1/32 is sent to the router announcing 172.16.1.0/24 rather than the router announcing 172.16.0.0/16.

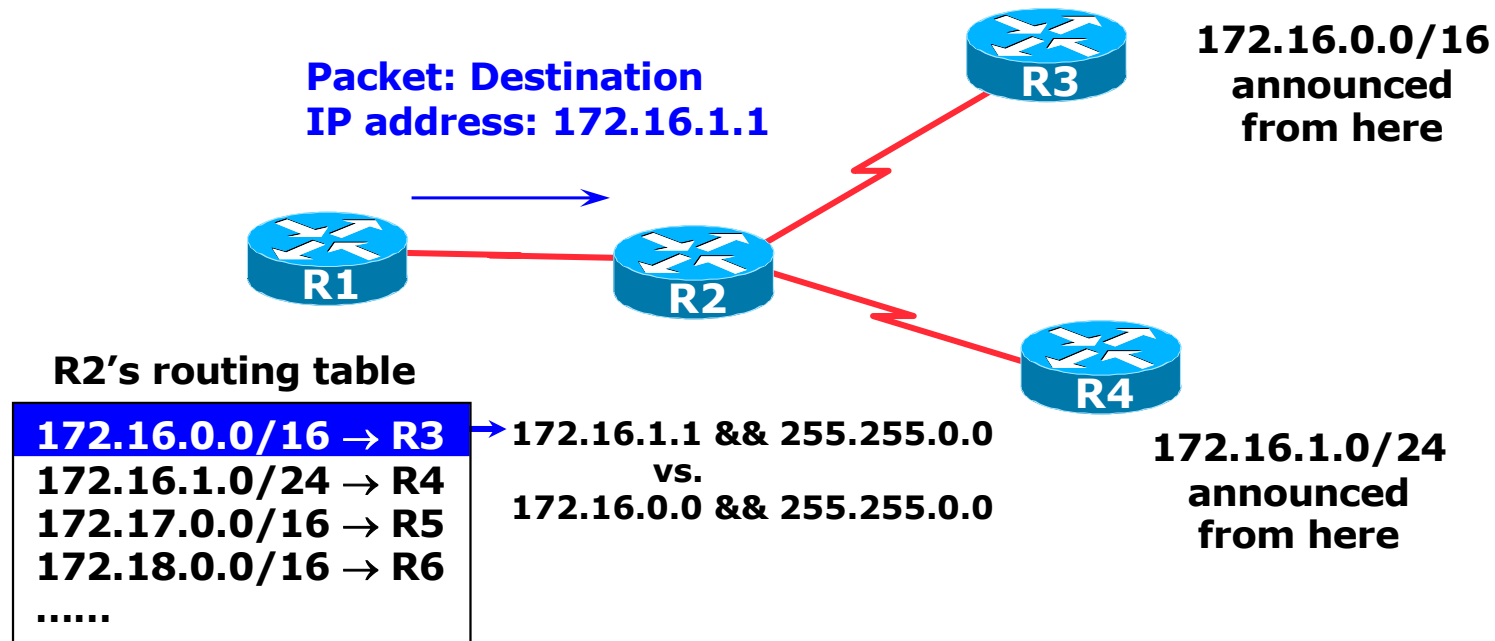
# IP route lookup

- Based on destination IP address



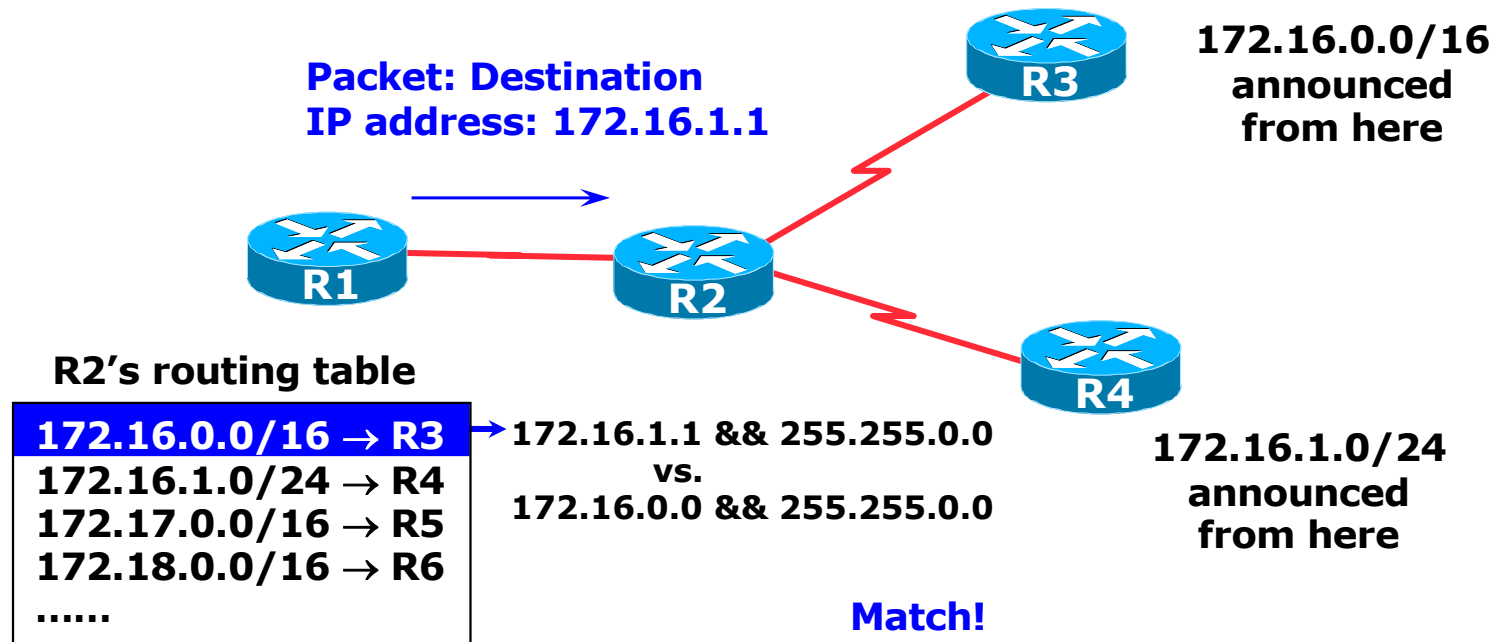
# IP route lookup: Longest match routing

- Based on destination IP address



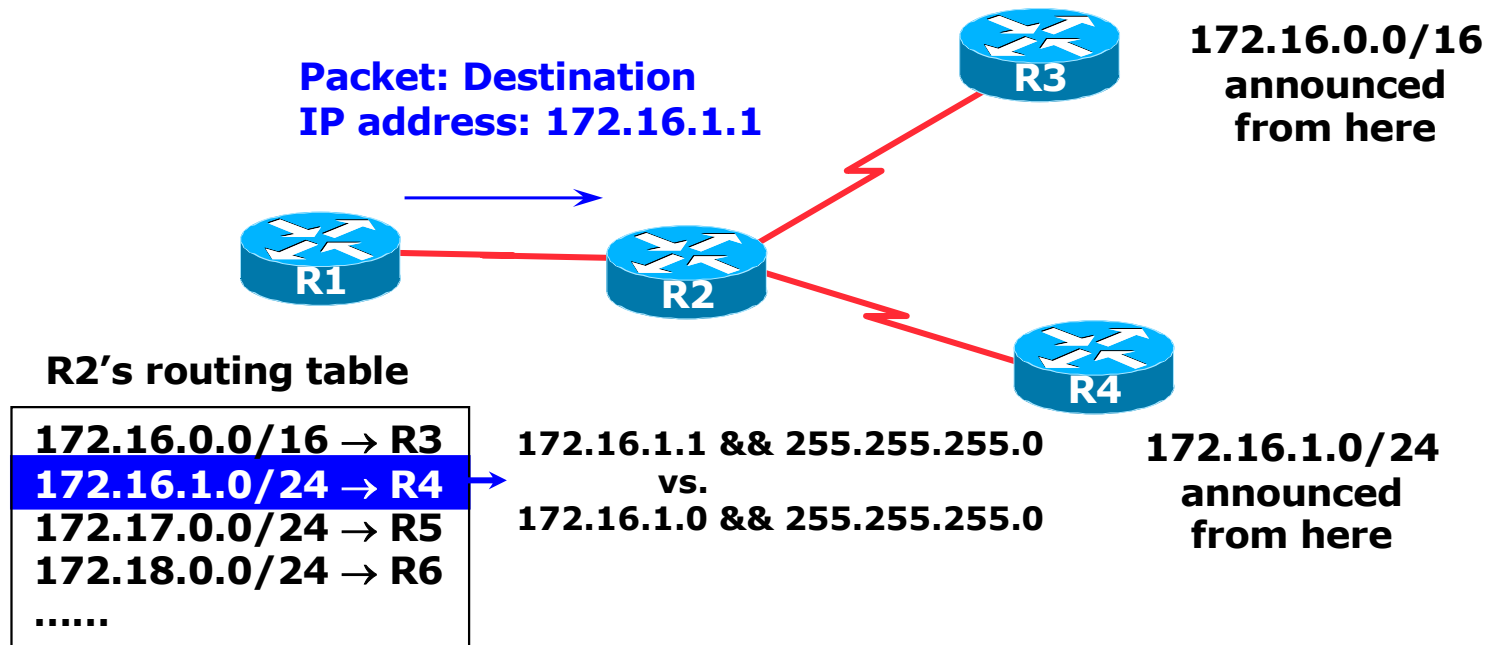
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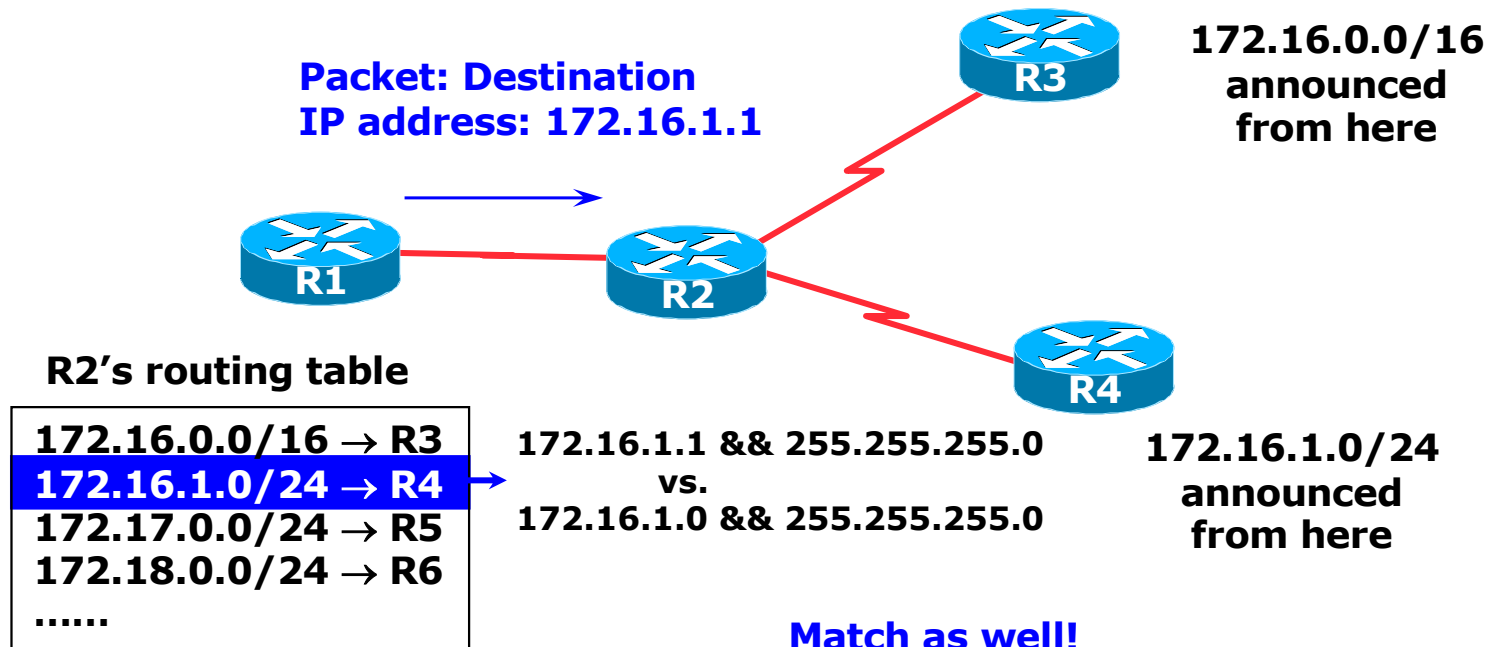
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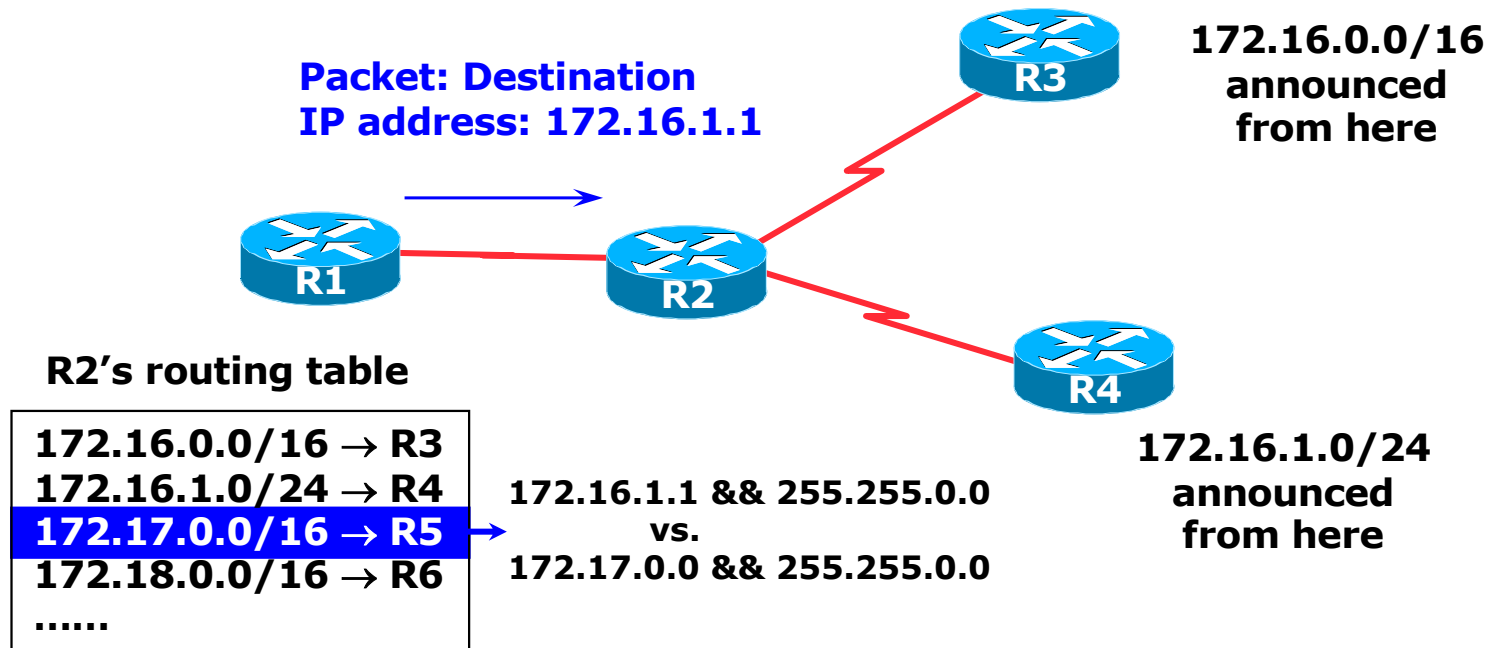
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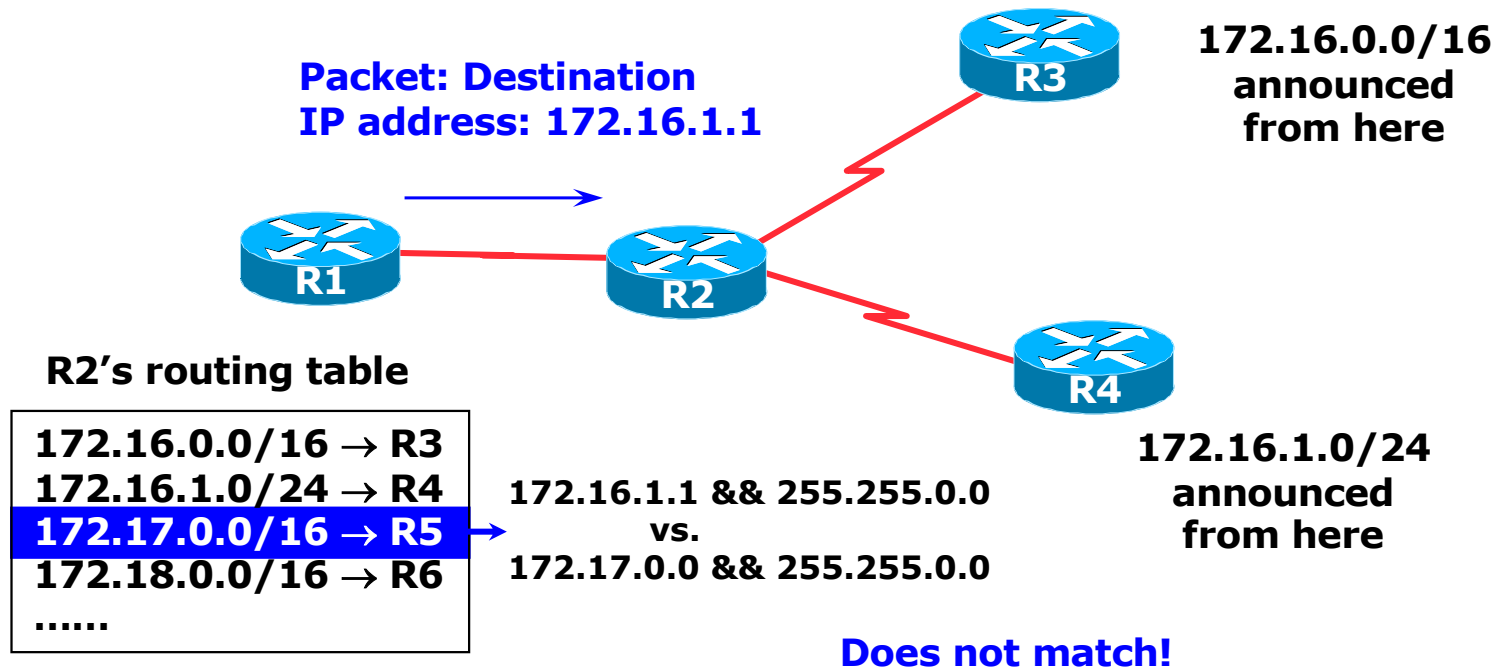
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# IP route lookup: Longest match routing

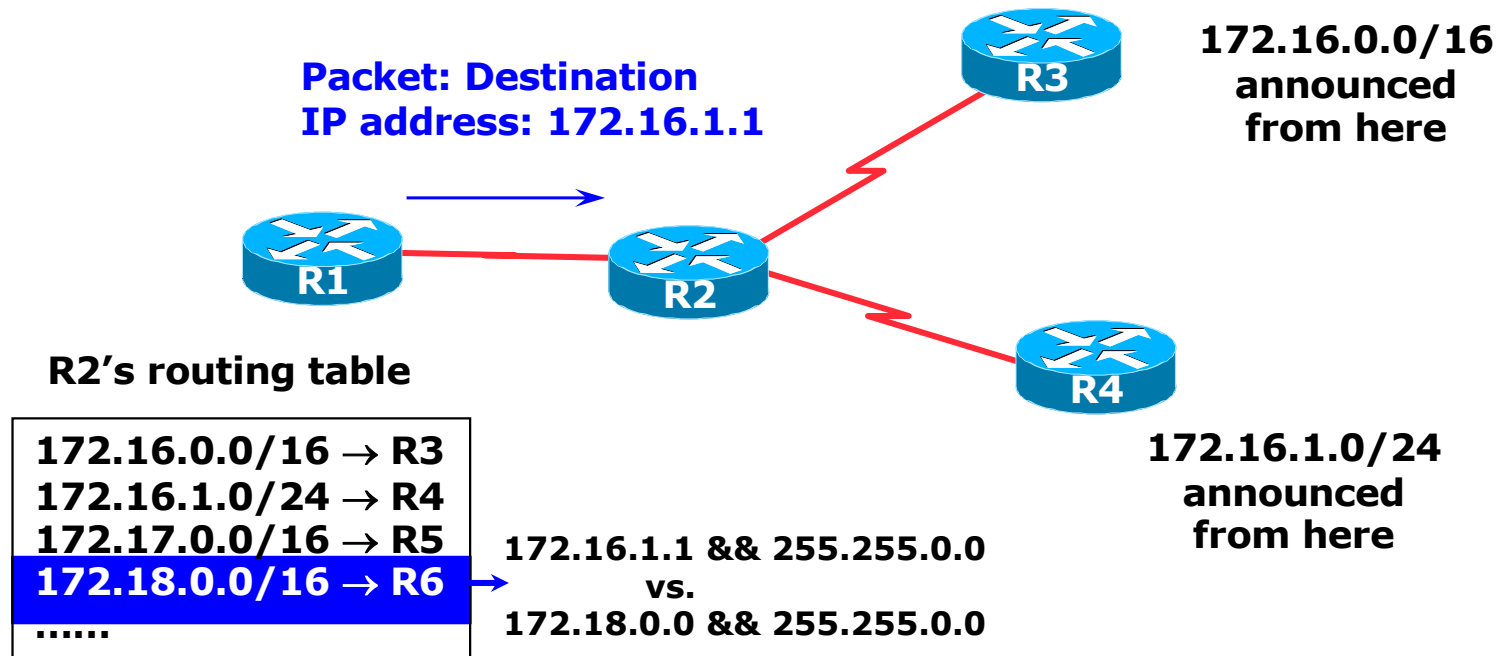
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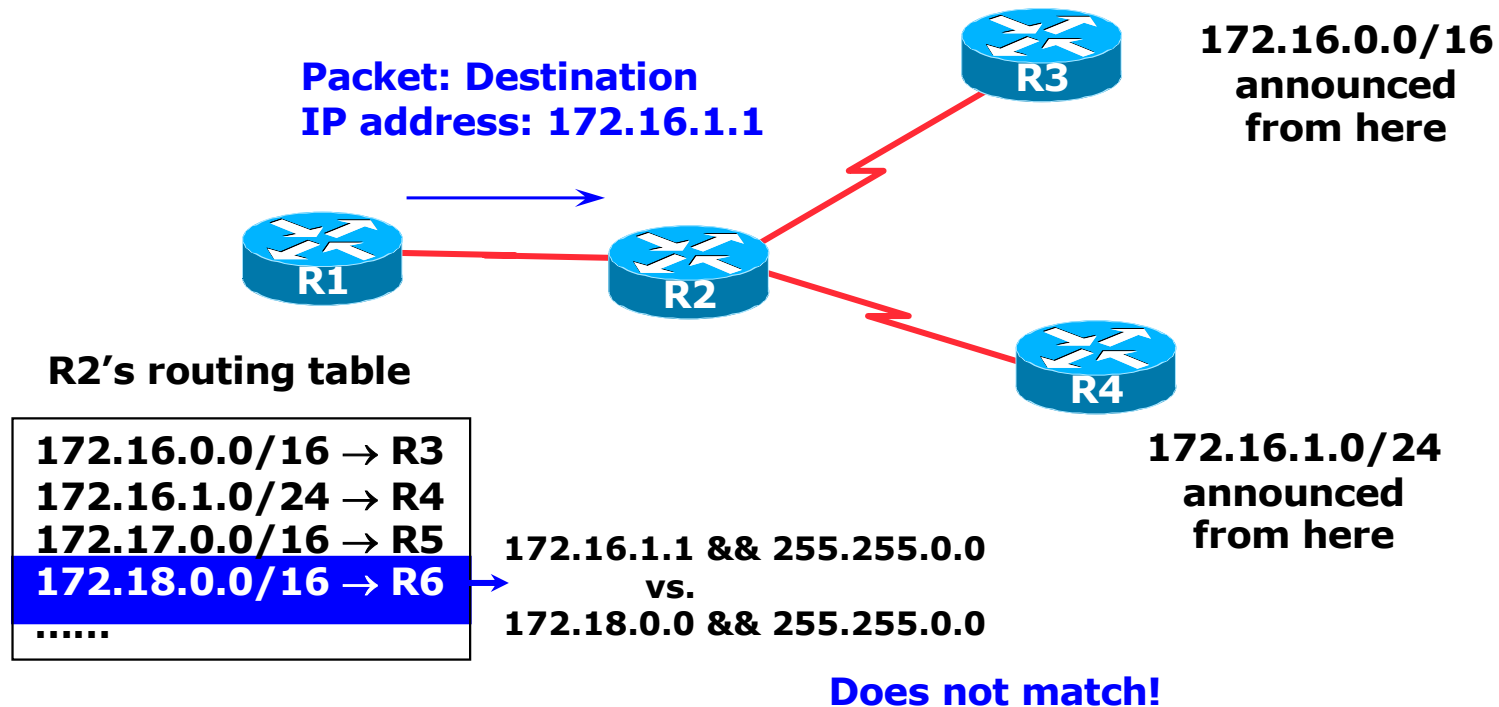
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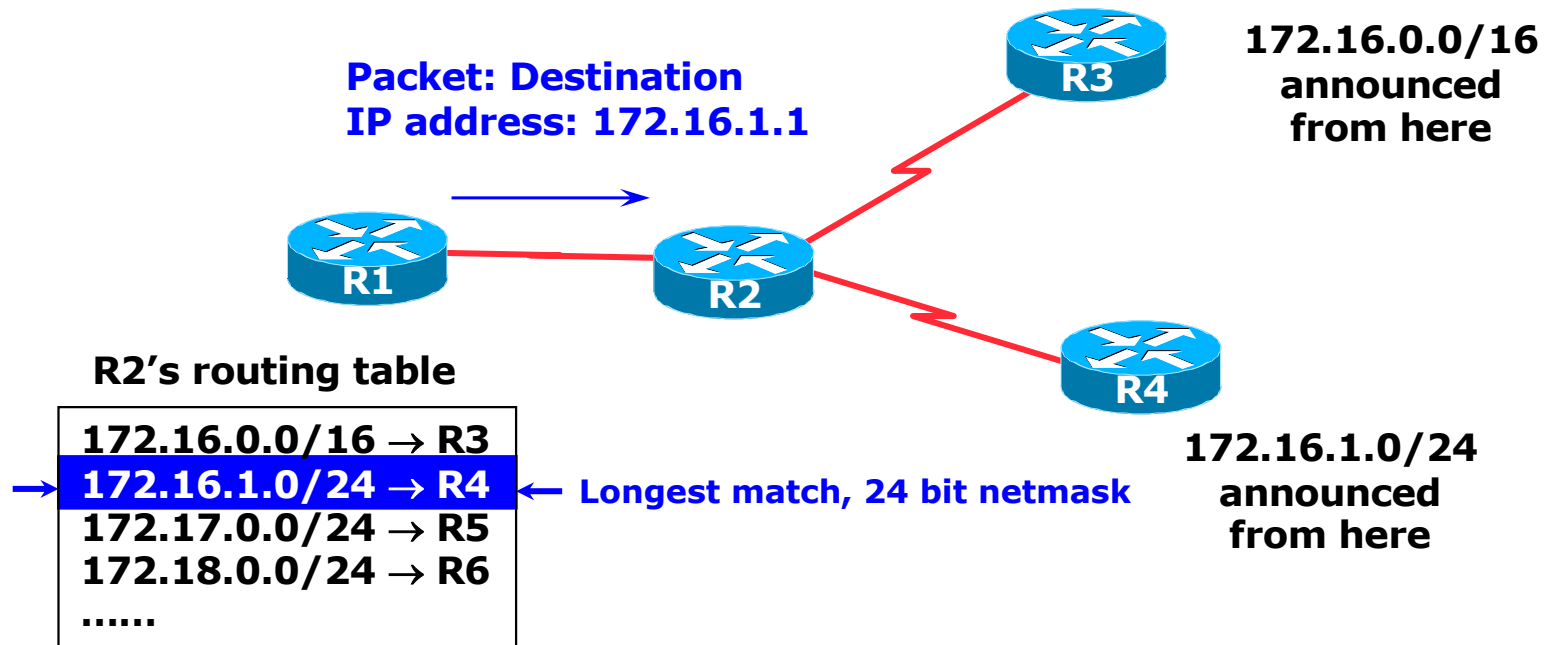
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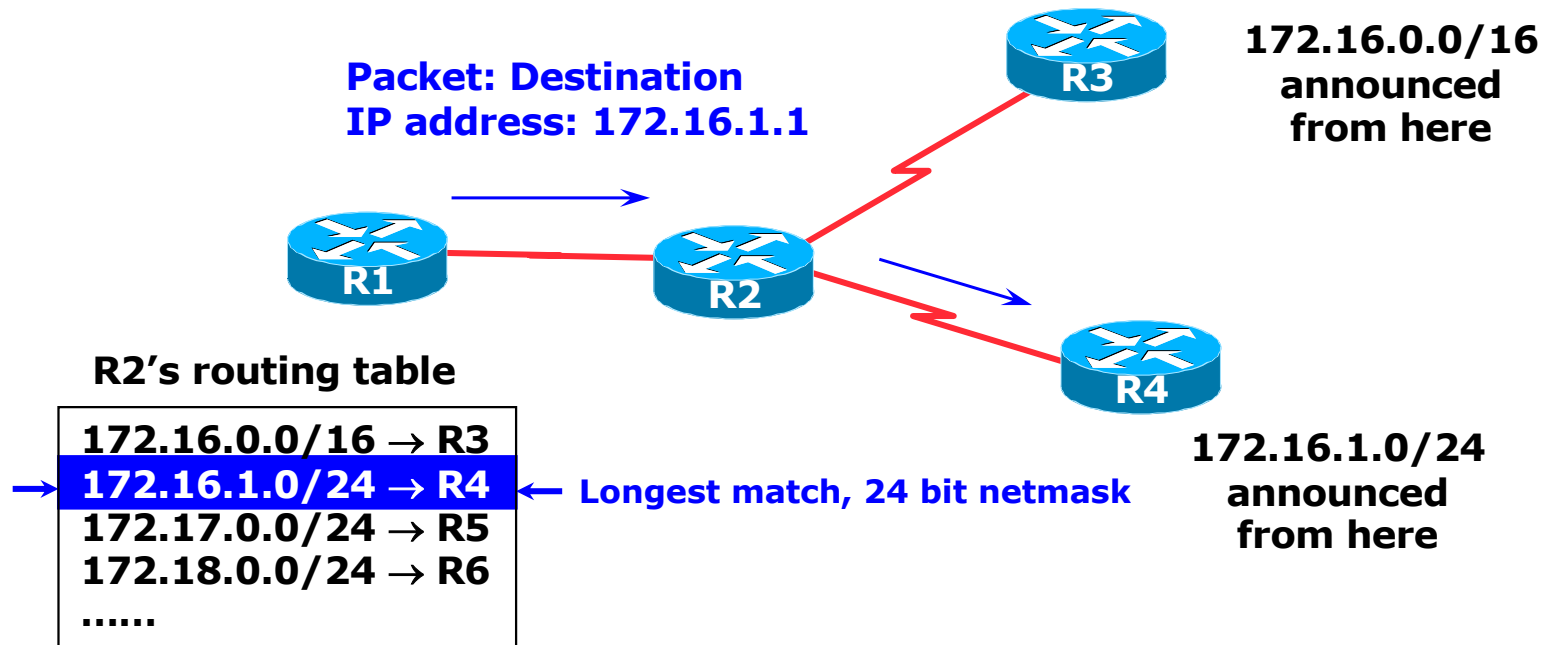
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# IP route lookup: Longest match routing

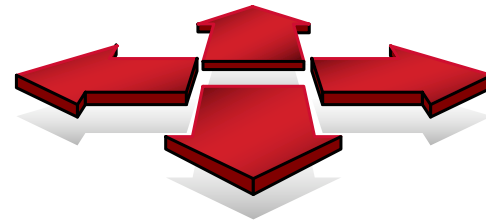
- Based on destination IP address



# Routing versus Forwarding

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



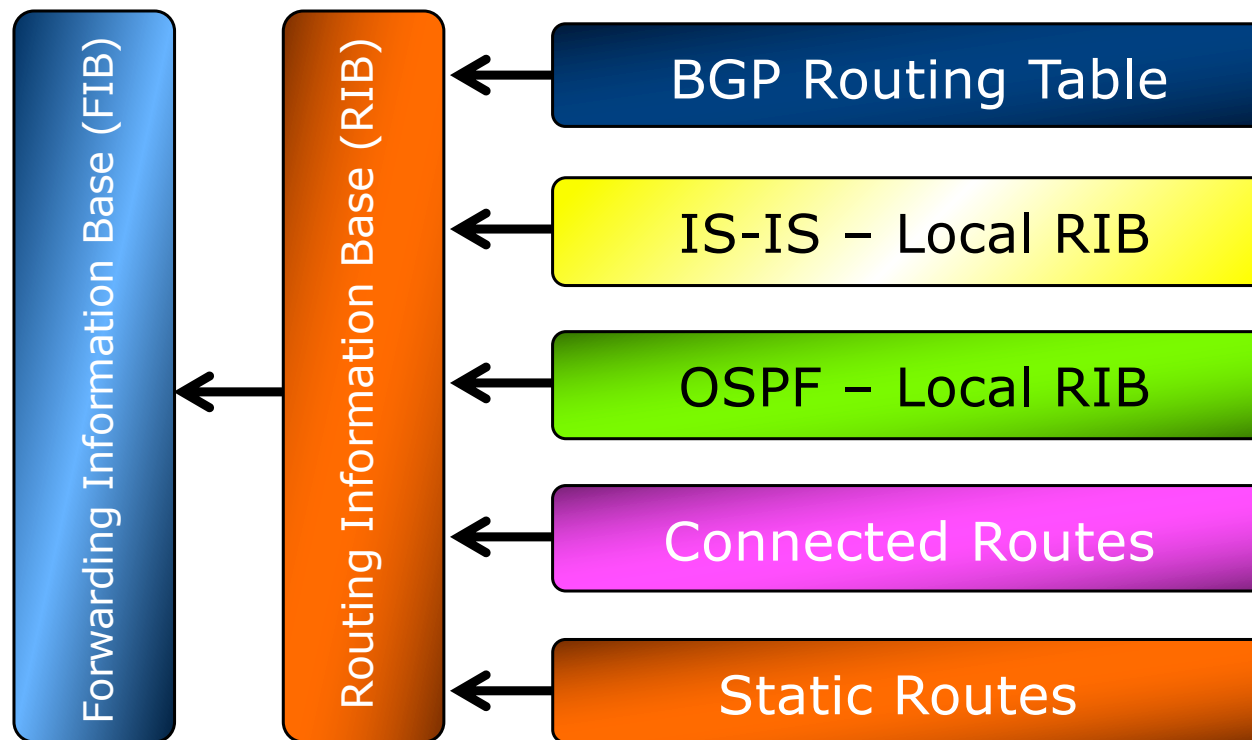
# IP Forwarding

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- Router decides which interface a packet is sent to
- Forwarding table populated by routing process
- Forwarding decisions:
  - Destination address
  - Class of service (fair queuing, precedence, others)
  - Local requirements (packet filtering)
- Forwarding is done by specialised hardware
  - Low-end/budget routers still do CPU-based forwarding

# Routing Tables Feed the Forwarding Table

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# The FIB

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## □ FIB is the Forwarding Table

- It contains destinations, the interfaces and the next-hops to get to those destinations
- It is built from the router's Global RIB
- Used by the router to determine where to send the packet
- Cisco IOS: `show ip cef`
- Juniper JunOS: `show route forwarding-table`



# The Global RIB

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- The Global RIB is the Routing Table
  - Built from the routing tables/RIBs of the routing protocols and static routes on the router
    - Routing protocol priority varies per vendor – see addendum
  - It contains all the known destinations and the next-hops used to get to those destinations
  - One destination can have lots of possible next-hops – only the best next-hop goes into the Global RIB
  - The Global RIB is used to build the FIB
  - Cisco IOS: `show ip route`
  - Juniper JunOS: `show route`

# Explicit versus Default Routing

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- Default:
  - Simple, cheap (CPU, memory, bandwidth)
  - No overhead
  - Low granularity (metric games)
- Explicit: (default free zone)
  - Complex, expensive (CPU, memory, bandwidth)
  - High overhead
  - High granularity (every destination known)
- Hybrid:
  - Minimise overhead
  - Provide useful granularity
  - Requires some filtering knowledge

} Our Goal

# Egress Traffic

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- How packets leave your network
- Egress traffic depends 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

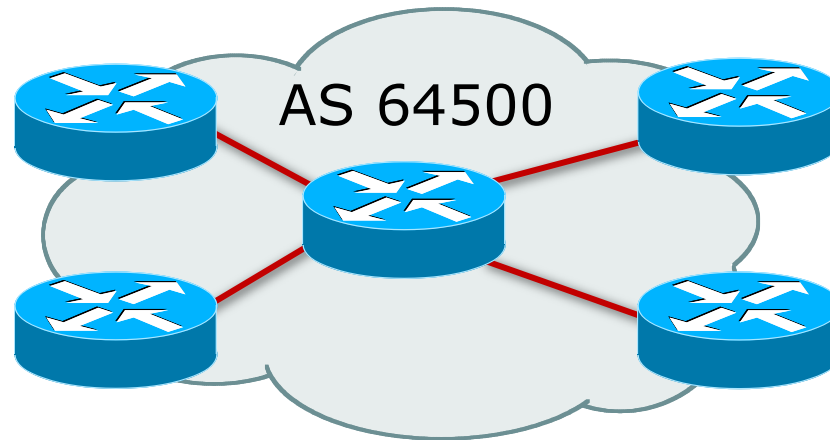
# Ingress Traffic

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- How packets get to your network and your customers' networks
- Ingress traffic depends on:
  - What information you send and to whom
  - Based on your IP addressing and originating networks
  - Based on others' policy (what they accept from you and what they do with it)

# Autonomous System (AS)

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- ❑ Collection of networks with same routing policy
- ❑ Single routing protocol
- ❑ Usually under single ownership, trust and administrative control

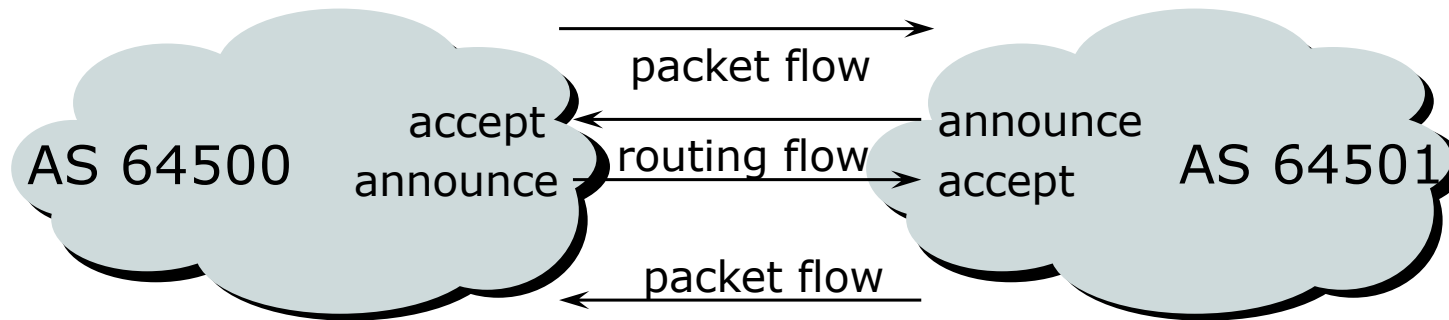
# Definition of terms

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- **Neighbours**
  - ASes which directly exchange routing information
  - Routers which exchange routing information
- **Announce**
  - Send routing information to a neighbour
- **Accept**
  - Receive and use routing information sent by a neighbour
- **Originate**
  - Insert routing information into external announcements (usually as a result of the IGP)
- **Peers**
  - Routers in neighbouring ASes or within one AS which exchange routing and policy information

# Routing flow and packet flow

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For networks in AS645400 and AS64501 to communicate:

AS64500 must announce to AS64501

AS64501 must accept from AS64500

AS64501 must announce to AS64500

AS64500 must accept from AS64501

# Routing flow and Traffic flow

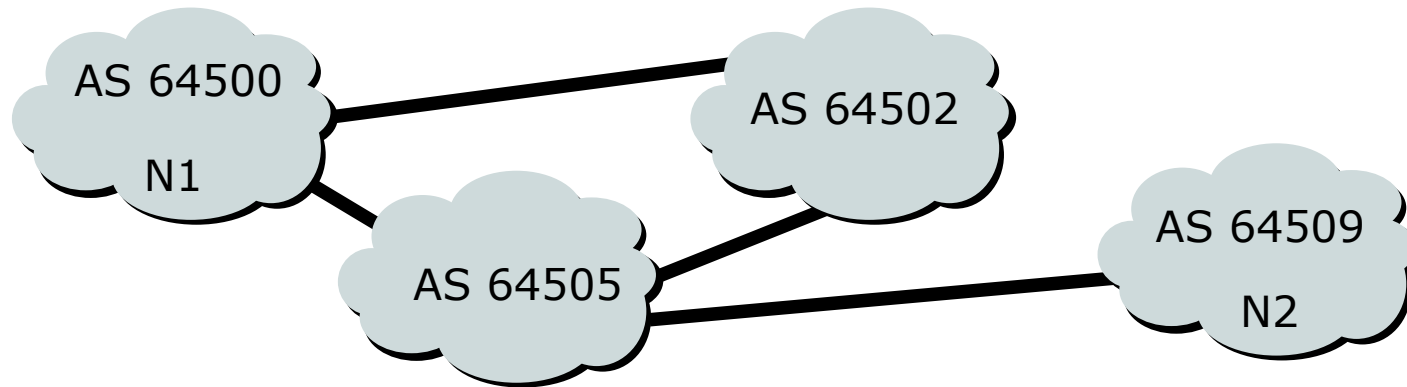
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- Traffic flow is always in the opposite direction of the flow of Routing information
  - Filtering outgoing routing information inhibits traffic flow inbound
  - Filtering inbound routing information inhibits traffic flow outbound



# Routing Flow/Packet Flow: With multiple ASes

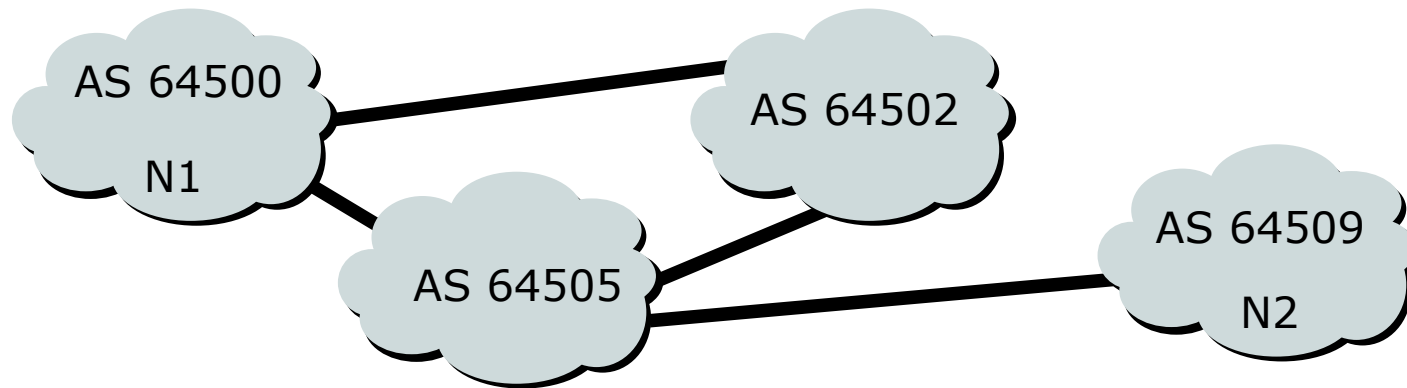
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- For net N1 in AS64500 to send traffic to net N2 in AS64509:
  - AS64509 must originate and announce N2 to AS64505.
  - AS64505 must accept N2 from AS64509.
  - AS64505 must announce N2 to AS64500 or AS64502.
  - AS64500 must accept N2 from AS64505 or AS64502.
- For two-way packet flow, similar policies must exist for N1

# Routing Flow/Packet Flow: With multiple ASes

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- As more and more paths are implemented between sites it is easy to see how policies can become quite complex.

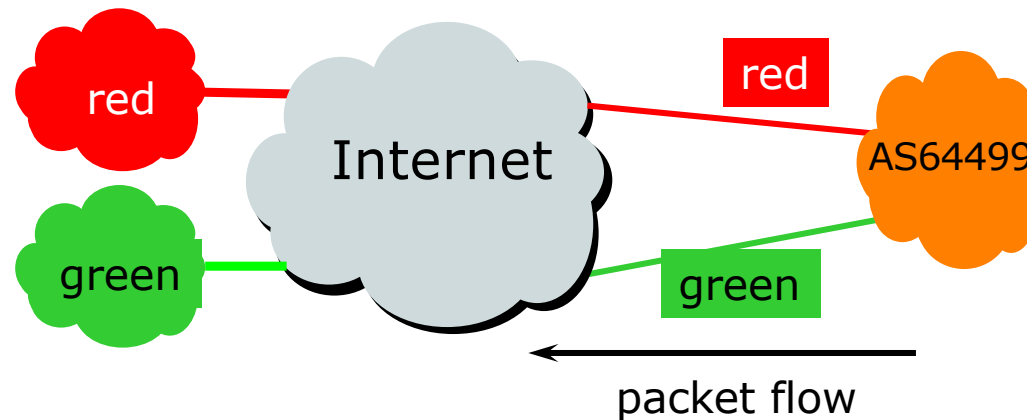
# Routing Policy

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- Used to control traffic flow in and out of a network
- The network operator makes decisions on what routing information to accept and discard from its neighbours
  - Individual routes
  - Routes originated by specific ASes
  - Routes traversing specific ASes
  - Routes belonging to other groupings
    - Groupings which you define as you see fit

# Routing Policy Limitations

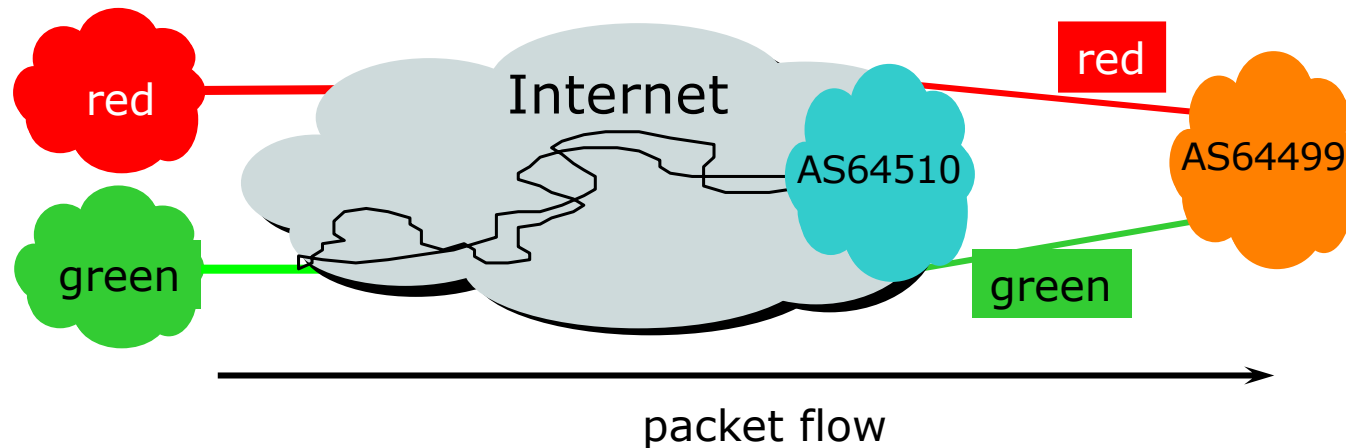
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- ❑ AS64499 uses red link for traffic to the red AS and the green link for remaining traffic
- ❑ To implement this policy, AS64499 has to:
  - Accept routes originating from the red AS on the red link
  - Accept all other routes on the green link

# Routing Policy Limitations

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- ❑ AS64499 would like packets coming from the green AS to use the green link.
- ❑ But unless AS64510 cooperates in pushing traffic from the green AS down the green link, there is very little that AS64499 can do to achieve this aim

# Routing Policy Issues

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- May 2022:
  - 146000 IPv6 prefixes & 898000 IPv4 prefixes
    - Not realistic to set policy on all of them individually
  - 73100 origin AS's
    - Too many to try and create individual policies for
- Routes tied to a specific AS or path may be unstable regardless of connectivity
- Solution: Groups of ASes are a natural abstraction for filtering purposes

# Routing Protocols



We now know what routing means...  
...but what do the routers get up to?  
And why are we doing this anyway?

# 1: How Does Routing Work?

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- Internet is made up of the Network Operators who connect to each other's networks
- How does an operator in Kenya tell an operator in Japan what end-site customers they have?
- And how does that operator send data packets to the customers of the Japanese operator, and get responses back
  - After all, as on a local ethernet, two way packet flow is needed for communication between two devices



## 2: How Does Routing Work?

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- The operator in Kenya could buy a direct connection to the operator in Japan
  - But this doesn't scale – there are thousands of distinct networks, would need thousands of connections, and cost would be astronomical
- Instead, the operator in Kenya tells his neighbouring operators what end-sites they have
  - And the neighbouring operators pass this information on to their neighbours, and so on
  - This process repeats until the information reaches the operator in Japan

## 3: How Does Routing Work?

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- This process is called "Routing"
- The mechanisms used are called "Routing Protocols"
- Routing and Routing Protocols ensures that
  - The Internet can scale
  - Thousands of network operators can provide connectivity to each other
  - We have the Internet we see today

## 4: How Does Routing Work?

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- The Network Operator in Kenya doesn't actually tell its neighbouring operators the names of the end-sites
  - (network equipment does not understand names)
- Instead, it has received an IP address block as a member of the Regional Internet Registry serving Kenya
  - Its customers have received address space from this address block as part of their "Internet service"
  - And it announces this address block to its neighbouring operators – this is called announcing a "route"

# Routing Protocols

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- Routers use “routing protocols” to exchange routing information with each other
  - **IGP** is used to refer to the process running on routers inside an ISP’s network
  - **EGP** is used to refer to the process running between routers bordering directly connected ISP networks

# What is an IGP?

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- Interior Gateway Protocol
- Within an Autonomous System
- Carries information about internal infrastructure prefixes
- Two widely used IGPs:
  - OSPF
  - IS-IS

# Why Do We Need an IGP?

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- Network Operator backbone scaling
  - Hierarchy
  - Limiting scope of failure
  - Only used for operator's **infrastructure** addresses, not customers or anything else
  - Design goal is to **minimise** number of prefixes in IGP to aid scalability and rapid convergence

# What Is an EGP?

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- Exterior Gateway Protocol
- Used to convey routing information between Autonomous Systems
- De-coupled from the IGP
- There is only one EGP: BGP

# Why Do We Need an EGP?

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- Scaling to large network
  - Hierarchy
  - Limit scope of failure
- Define Administrative Boundary
- Policy
  - Control reachability of prefixes
  - Merge separate organisations
  - Connect multiple IGPs



# Interior versus Exterior Routing Protocols

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## □ Interior

- Automatic neighbour discovery
- Generally trust your IGP routers
- Prefixes go to all IGP routers
- Binds routers in one AS together

## □ Exterior

- Specifically configured peers
- Connecting with outside networks
- Set administrative boundaries
- Binds ASes together

# Interior versus Exterior Routing Protocols

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## □ Interior

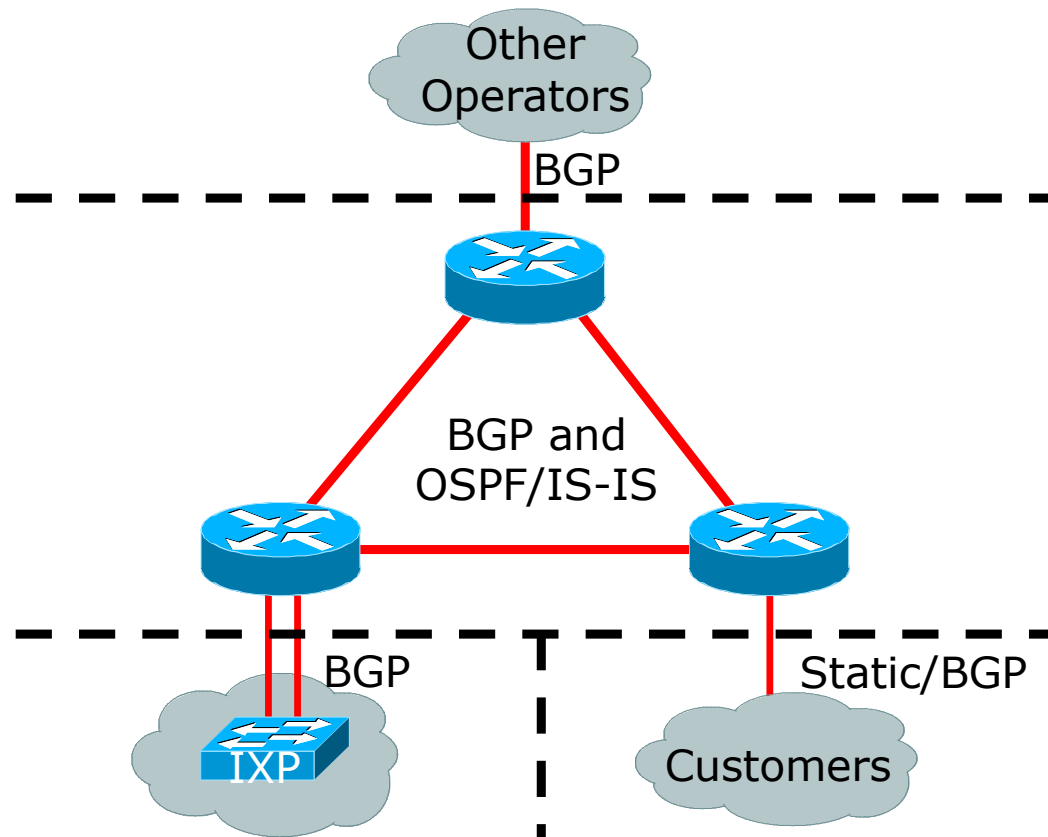
- Carries network infrastructure addresses only
- Network operators aim to keep the IGP small for efficiency and scalability

## □ Exterior

- Carries customer prefixes
- Carries Internet prefixes
- EGPs are independent of the operator's network topology

# Hierarchy of Routing Protocols

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# FYI: Default Administrative Distances

Route Source	Cisco	Juniper	Huawei	Brocade	Nokia	Mikrotik
<b>Connected Interface</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Static Route</b>	<b>1</b>	<b>5</b>	<b>60</b>	<b>1</b>	<b>1</b>	<b>1</b>
EIGRP Summary Route	5	N/A	?	N/A	N/A	N/A
<b>External BGP</b>	<b>20</b>	<b>170</b>	<b>255</b>	<b>20</b>	<b>170</b>	<b>20</b>
Internal EIGRP Route	90	N/A	?	N/A	N/A	N/A
IGRP	100	N/A	?	N/A	N/A	N/A
<b>OSPF</b>	<b>110</b>	<b>10</b>	<b>10</b>	<b>110</b>	<b>10</b>	<b>110</b>
<b>IS-IS</b>	<b>115</b>	<b>18</b>	<b>15</b>	<b>115</b>	<b>18</b>	N/A
RIP	120	100	100	120	100	120
EGP	140	N/A	N/A	N/A	N/A	N/A
External EIGRP	170	N/A	?	N/A	N/A	N/A
<b>Internal BGP</b>	<b>200</b>	<b>170</b>	<b>255</b>	<b>200</b>	<b>130</b>	<b>200</b>
Unknown	255	255	?	255	?	

# Routing Basics



ISP Workshops