

# Routing Basics



## ISP Workshops



# Routing Concepts

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- IPv4 & IPv6
- Routing
- Forwarding
- Some definitions
- Policy options
- Routing Protocols

# IPv4

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- Internet still uses IPv4
  - (legacy protocol)
  - Addresses are 32 bits long
  - Addresses are written as decimal with each 8-bit range separated by a “.”
  - Range from 1.0.0.0 to 223.255.255.255
  - 0.0.0.0 to 0.255.255.255 and 224.0.0.0 to 255.255.255.255 have “special” uses
- IPv4 address has a network portion and a host portion

# IPv6

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- Internet is starting to use IPv6
  - Addresses are 128 bits long
  - Addresses are written as hexadecimal with each 16-bit range separated by ":"
  - Internet addresses range from 2000::/16 to 3FFF::/16
  - The remaining IPv6 range is reserved or has "special" uses
- IPv6 address has a network portion and a host portion

# IP address format

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- Address and subnet mask
  - IPv4 written as
    - 12.34.56.78 255.255.255.0 *or*
    - 12.34.56.78/24
  - IPv6 written as
    - 2001:DB8:A::1/64
  - **mask** represents the number of network bits in the address
    - Usually referred to as the subnet size
  - The remaining bits are the host bits

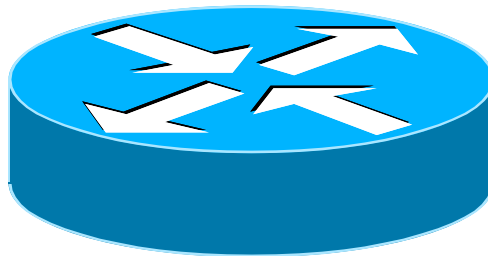
# IP subnets

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- IPv4 example – 12.34.56.78/24
  - 32 bits in an IPv4 address
    - 24 bits for the network portion
    - Leaves 8 bits for the host portion
    - 8 bits means there are  $2^8$  possible hosts on this subnet
  
- IPv6 example – 2001:DB8:A::1/64
  - 128 bits in an IPv6 address
    - 64 bits for the network portion
    - Leaves 64 bits for the host portion
    - 64 bits means there are  $2^{64}$  possible hosts on this subnet

# What does a router do?

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# A day in a life of a router

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find path

forward packet, forward packet, forward packet, forward packet...

find alternate path

forward packet, forward packet, forward packet, forward packet...

repeat until powered off

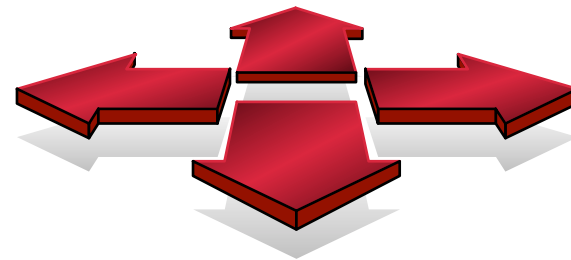




# Routing versus Forwarding

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



# IP Routing – finding the path

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- Path derived from information received from a routing protocol
- Several alternative paths may exist
  - Best path stored in **forwarding** table
- Decisions are updated periodically or as topology changes (event driven)
- Decisions are based on:
  - Topology, policies and metrics (hop count, filtering, delay, bandwidth, etc.)

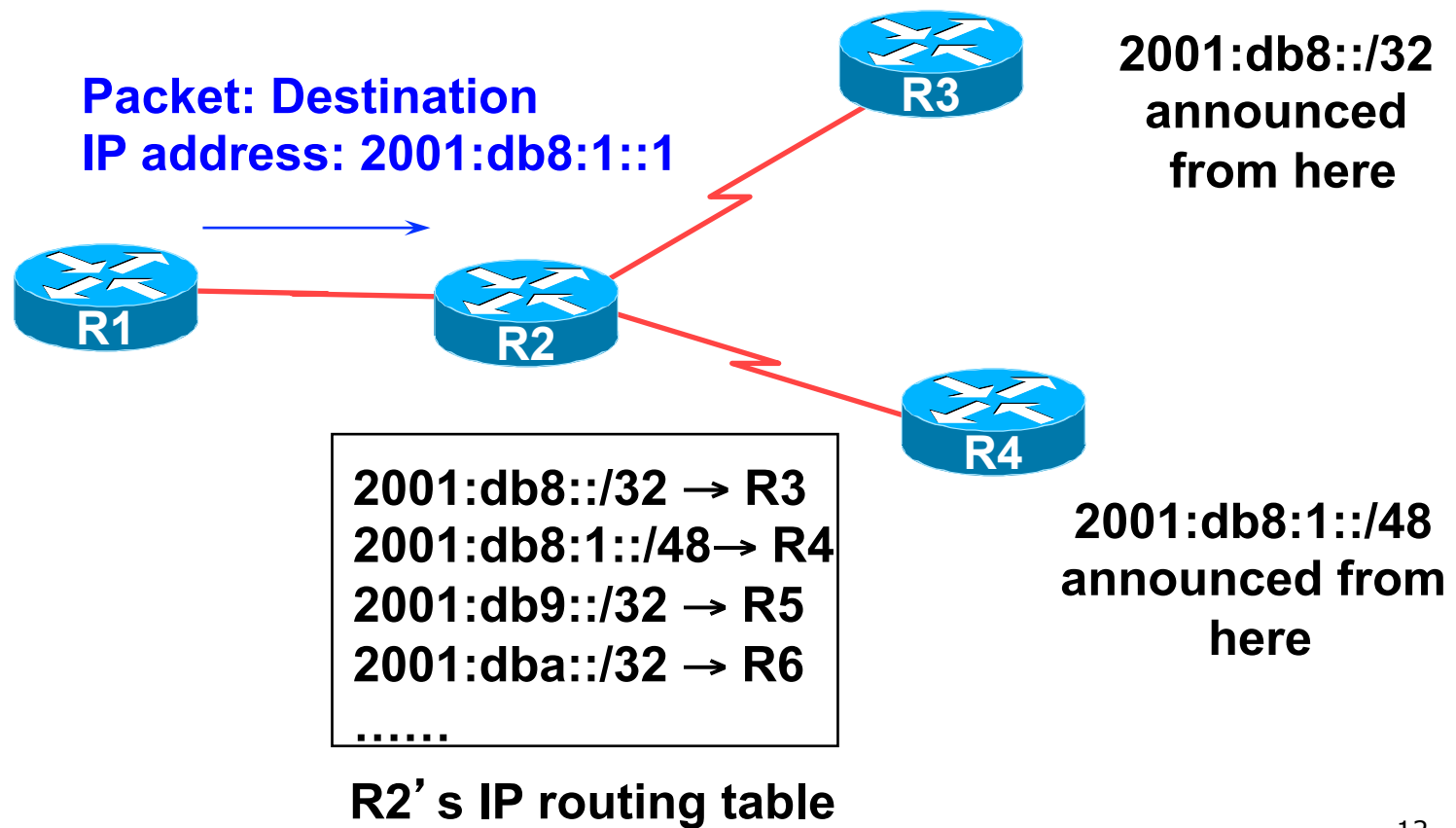
# IP route lookup

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- Based on destination IP address
- “longest match” routing
  - More specific prefix preferred over less specific prefix
  - **Example:** packet with destination of 2001:DB8:1::1/128 is sent to the router announcing 2001:DB8:1::/48 rather than the router announcing 2001:DB8::/32.

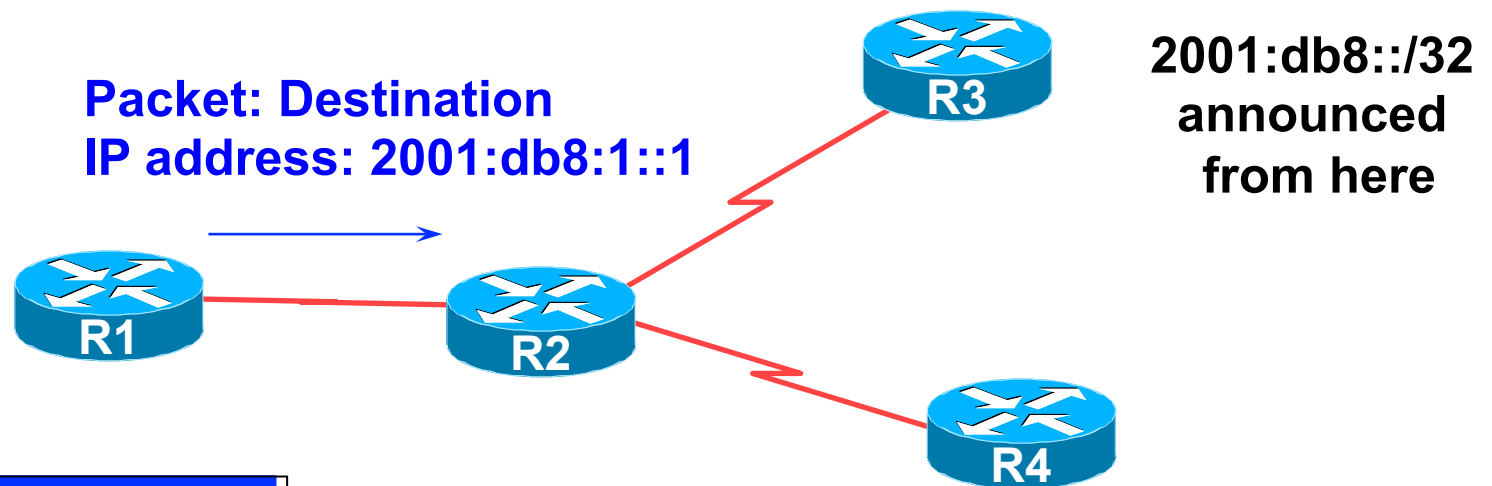
# IP route lookup

- Based on destination IP address



# IP route lookup: Longest match routing

- Based on destination IP address



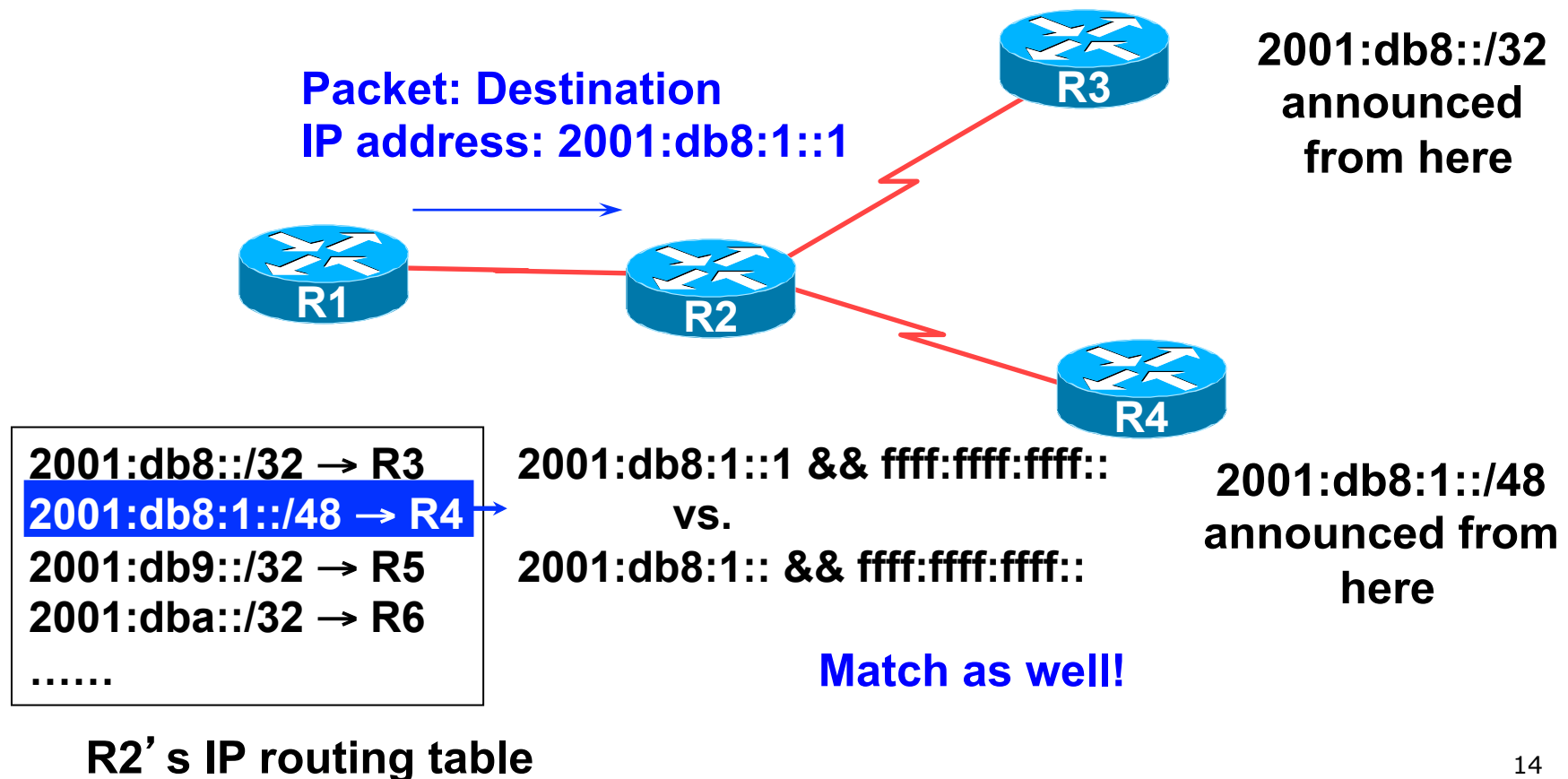
**2001:db8::/32 → R3**  
2001:db8:1::/48 → R4  
2001:db9::/32 → R5  
2001:dba::/32 → R6  
.....

2001:db8:1::1 && ffff:ffff::  
vs.  
2001:db8:: && ffff:ffff::  
**Match!**

R2' s IP routing table

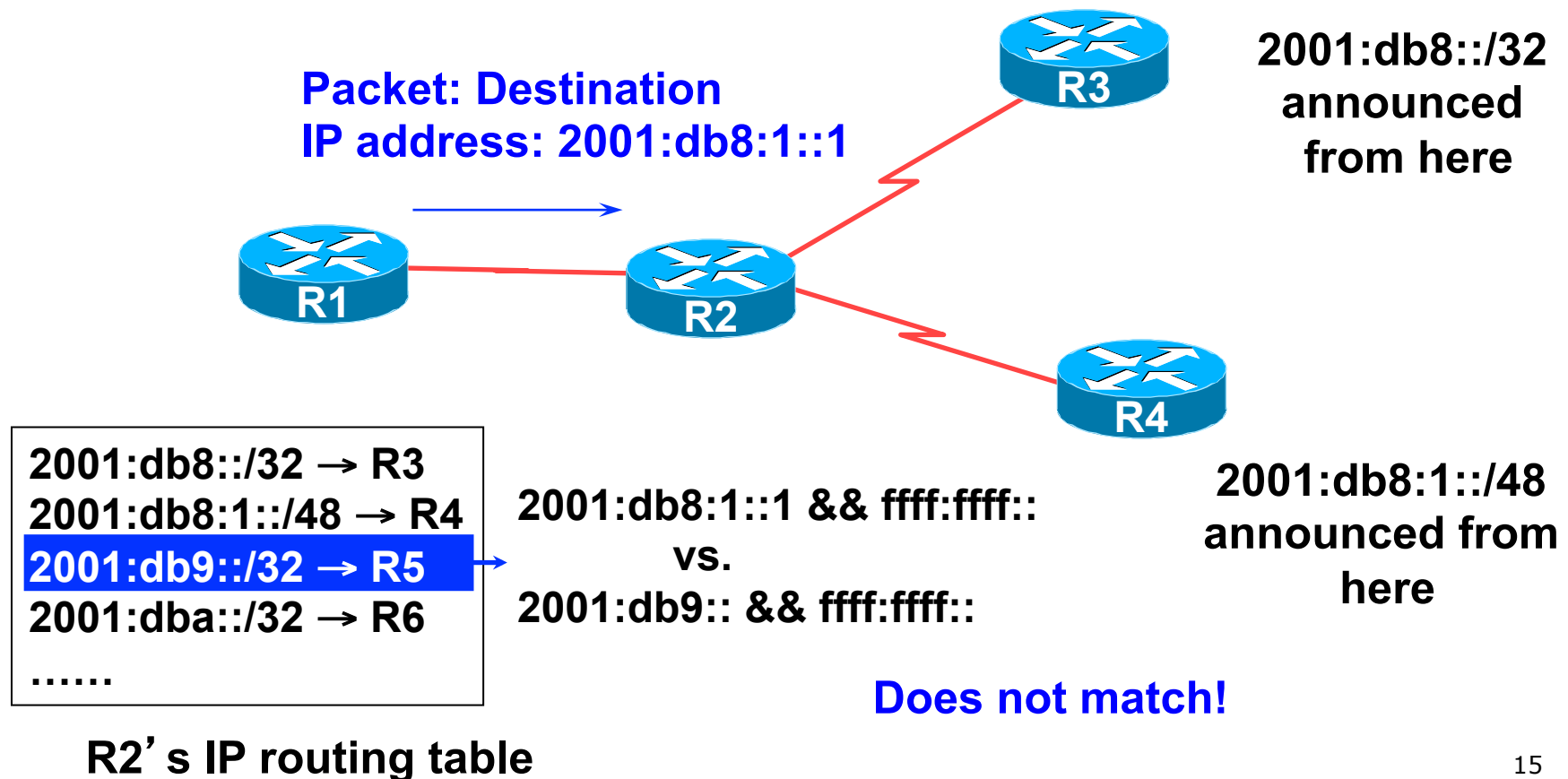
# IP route lookup: Longest match routing

- Based on destination IP address



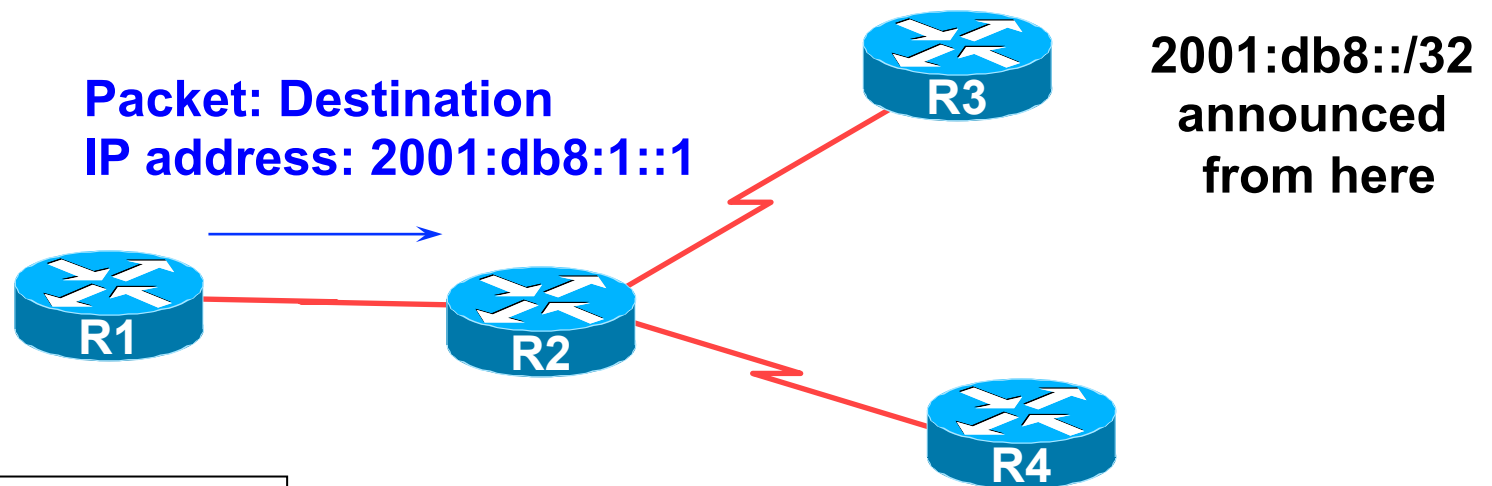
# IP route lookup: Longest match routing

- Based on destination IP address



# IP route lookup: Longest match routing

- Based on destination IP address



2001:db8::/32 → R3
2001:db8:1::/48 → R4
2001:db9::/32 → R5
2001:dba::/32 → R6
.....

2001:db8:1::1 && ffff:ffff::

vs.

2001:dba:: && ffff:ffff::

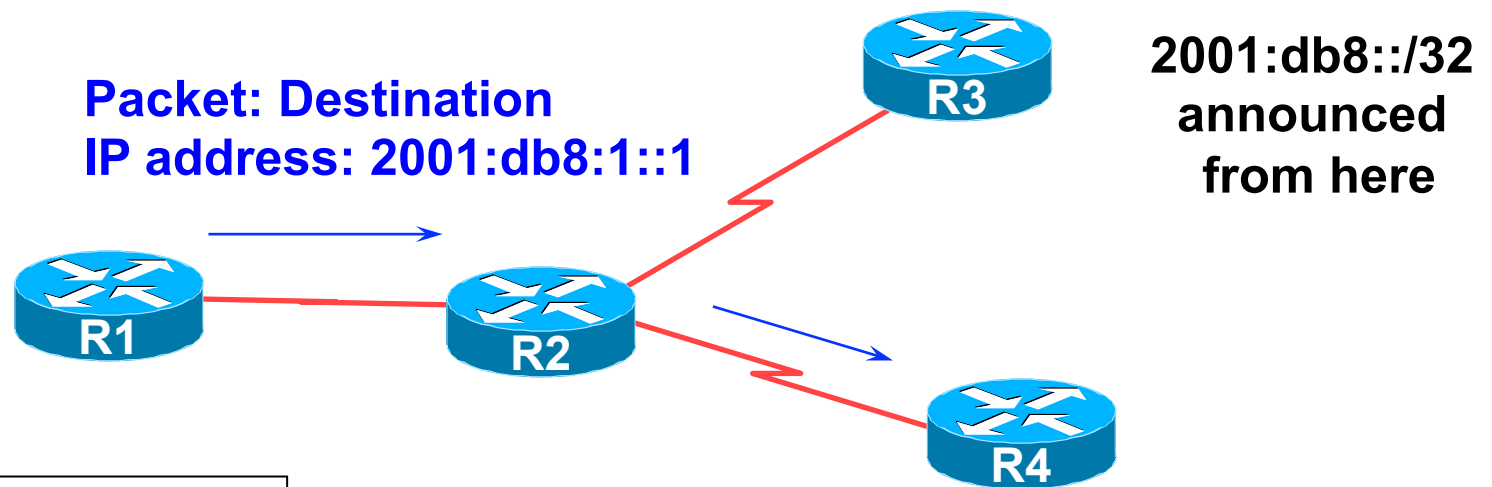
Does not match!

R2' s IP routing table



# IP route lookup: Longest match routing

- Based on destination IP address



2001:db8::/32 → R3
2001:db8:1::/48 → R4
2001:db9::/32 → R5
2001:dba::/32 → R6
.....

Longest match, 48 bit netmask

R2' s IP routing table

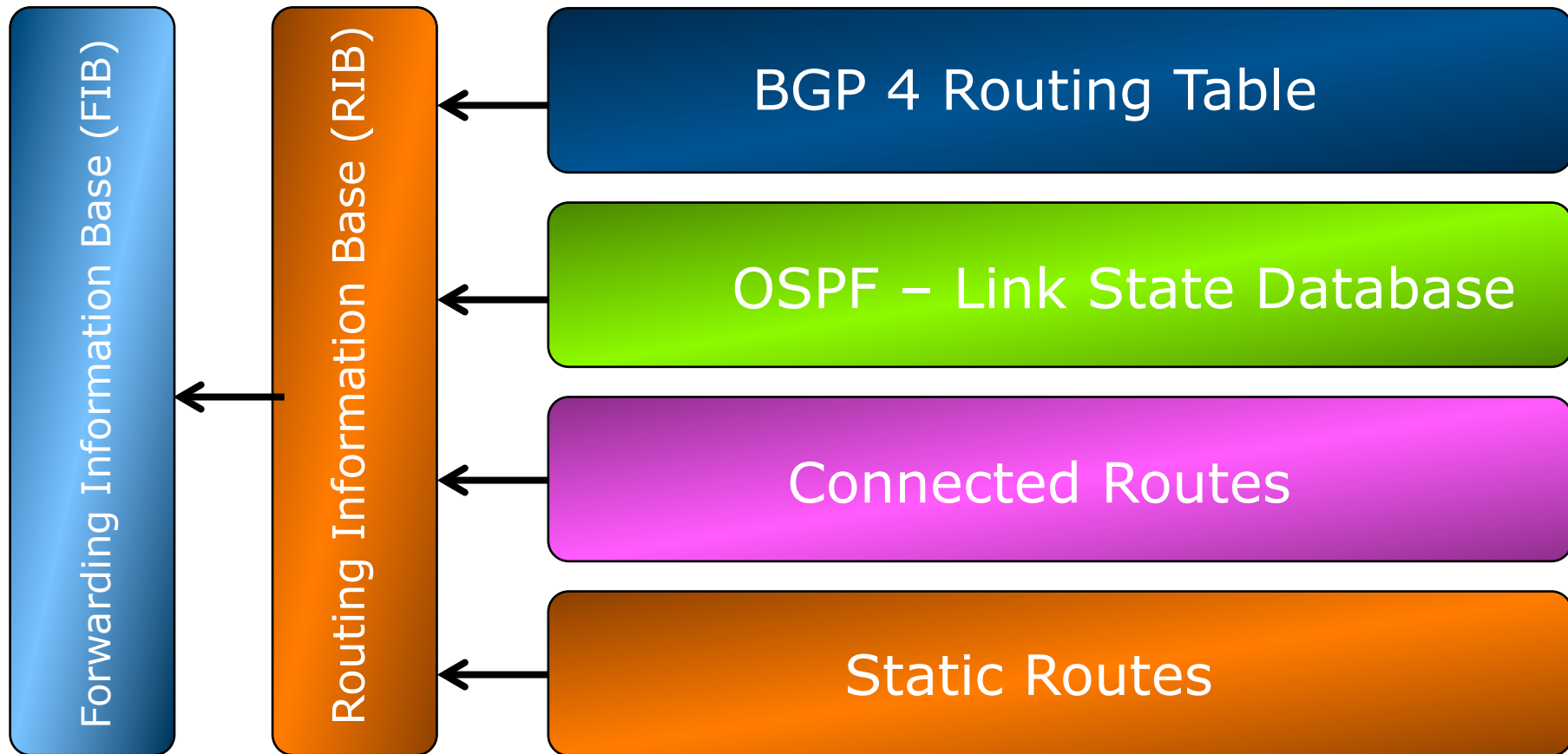
# IP Forwarding

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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 usually aided by special hardware

# Routing Tables Feed the Forwarding Table

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# RIBs and FIBs

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## □ FIB is the Forwarding Table

- It contains destinations and the interfaces to get to those destinations
- Used by the router to figure out where to send the packet
- Careful! Some people still call this a route!
- Cisco IOS: "show ip cef"

## □ RIB is the Routing Table

- It contains a list of all the destinations and the various next hops used to get to those destinations – and lots of other information too!
- One destination can have lots of possible next-hops – only the best next-hop goes into the FIB
- Cisco IOS: "show ip 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

# 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

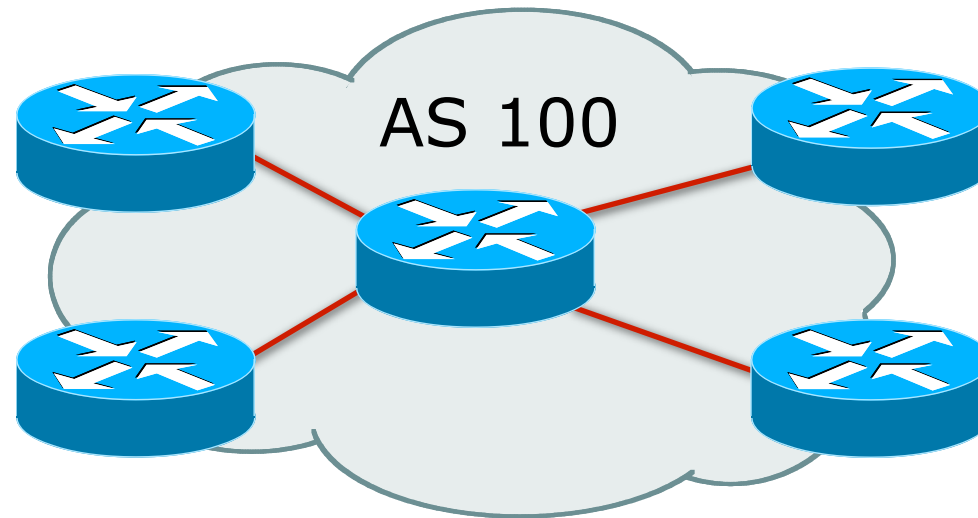
# Ingress Traffic

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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 addressing and AS's
  - 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



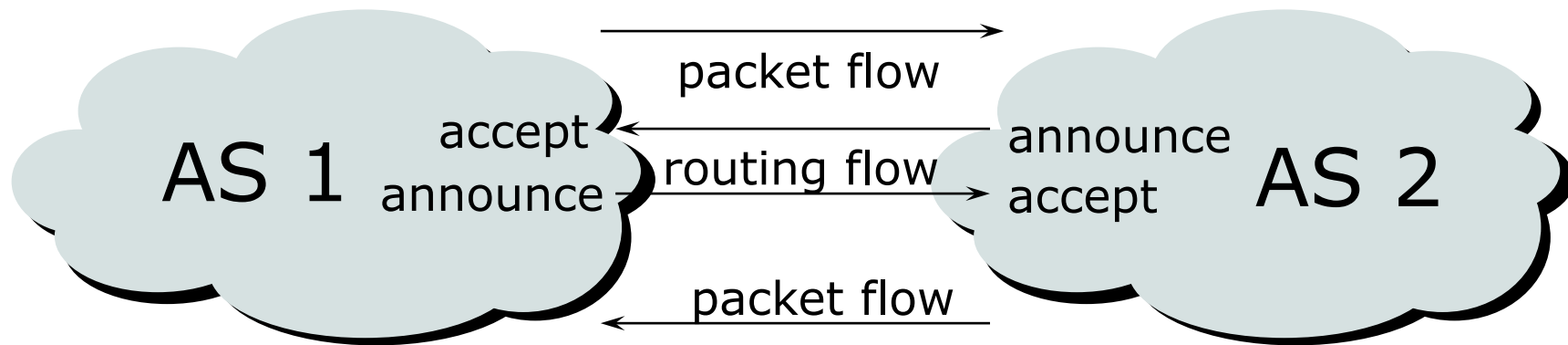
# Definition of terms

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- **Neighbours**
  - AS's 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 AS's or within one AS which exchange routing and policy information

# Routing flow and packet flow

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For networks in AS1 and AS2 to communicate:

- AS1 must announce to AS2
- AS2 must accept from AS1
- AS2 must announce to AS1
- AS1 must accept from AS2

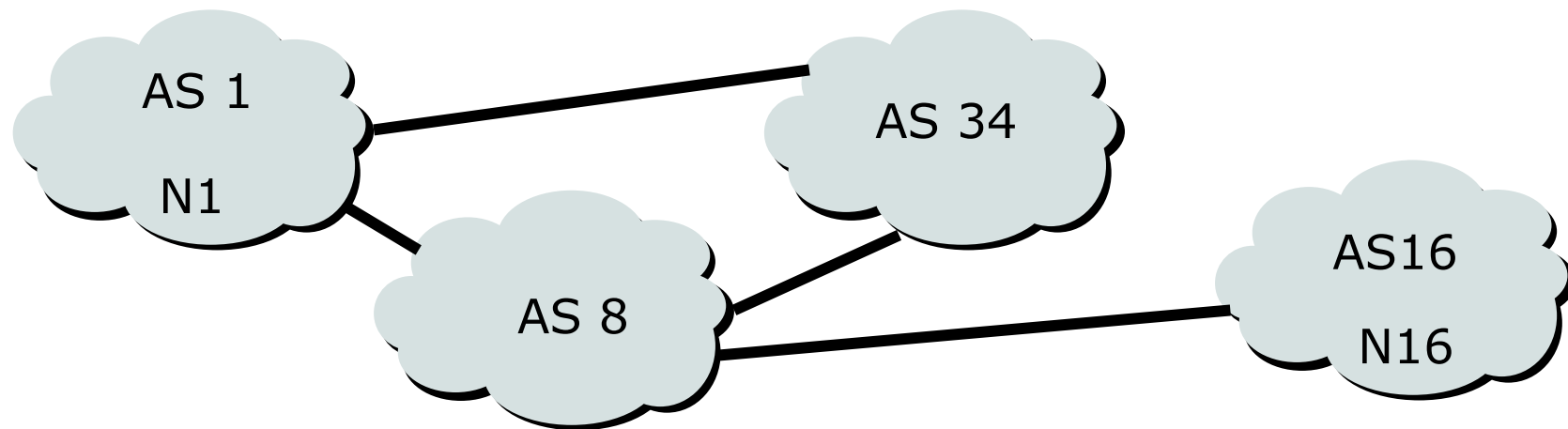
# Routing flow and Traffic flow

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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

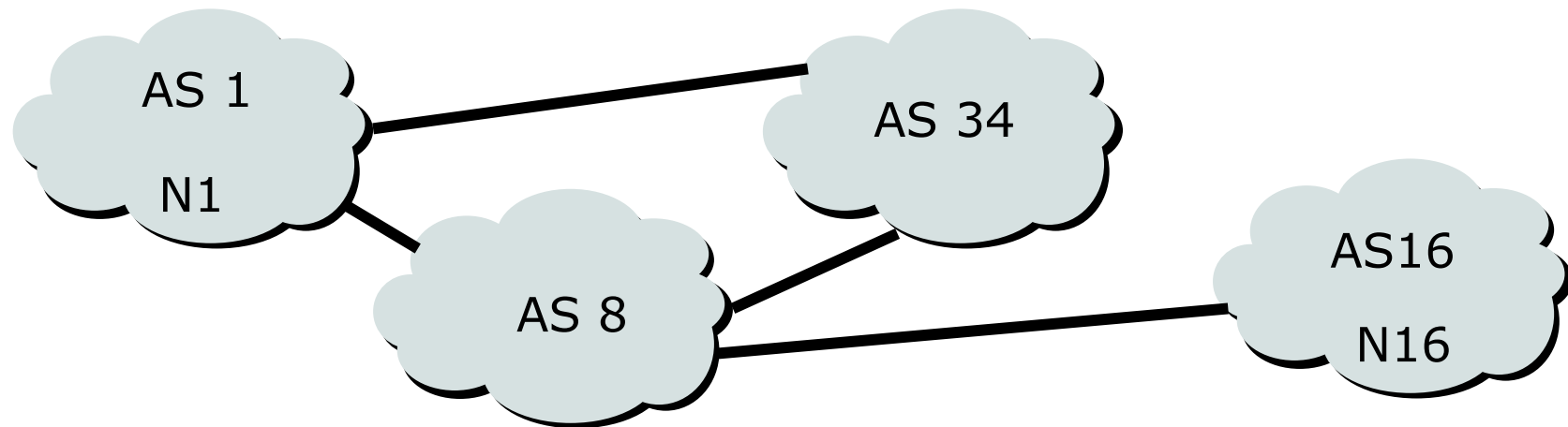
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- For net N1 in AS1 to send traffic to net N16 in AS16:
  - AS16 must originate and announce N16 to AS8.
  - AS8 must accept N16 from AS16.
  - AS8 must announce N16 to AS1 or AS34.
  - AS1 must accept N16 from AS8 or AS34.
- For two-way packet flow, 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.

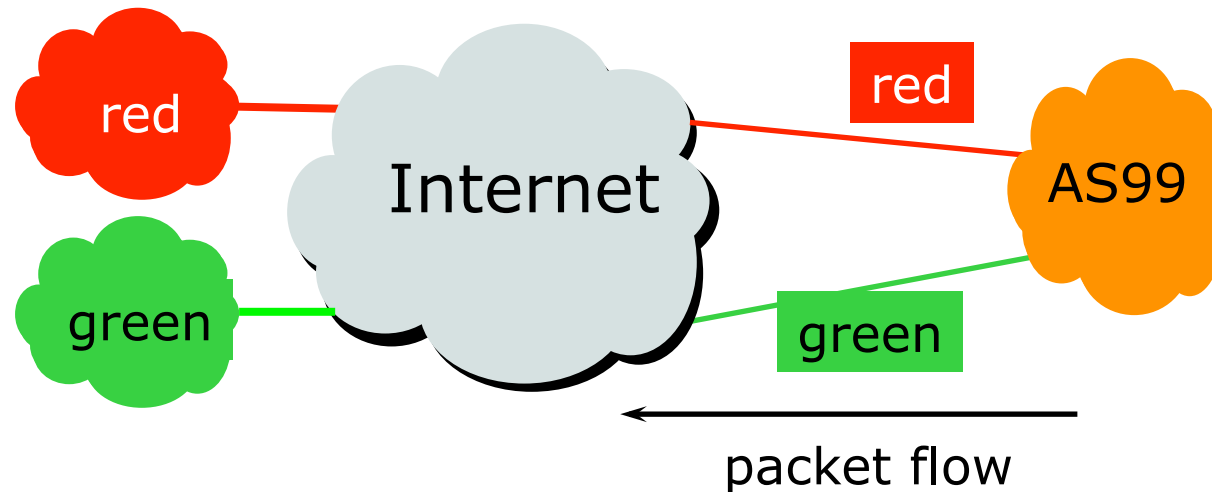
# Routing Policy

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- Used to control traffic flow in and out of an ISP network
- ISP 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

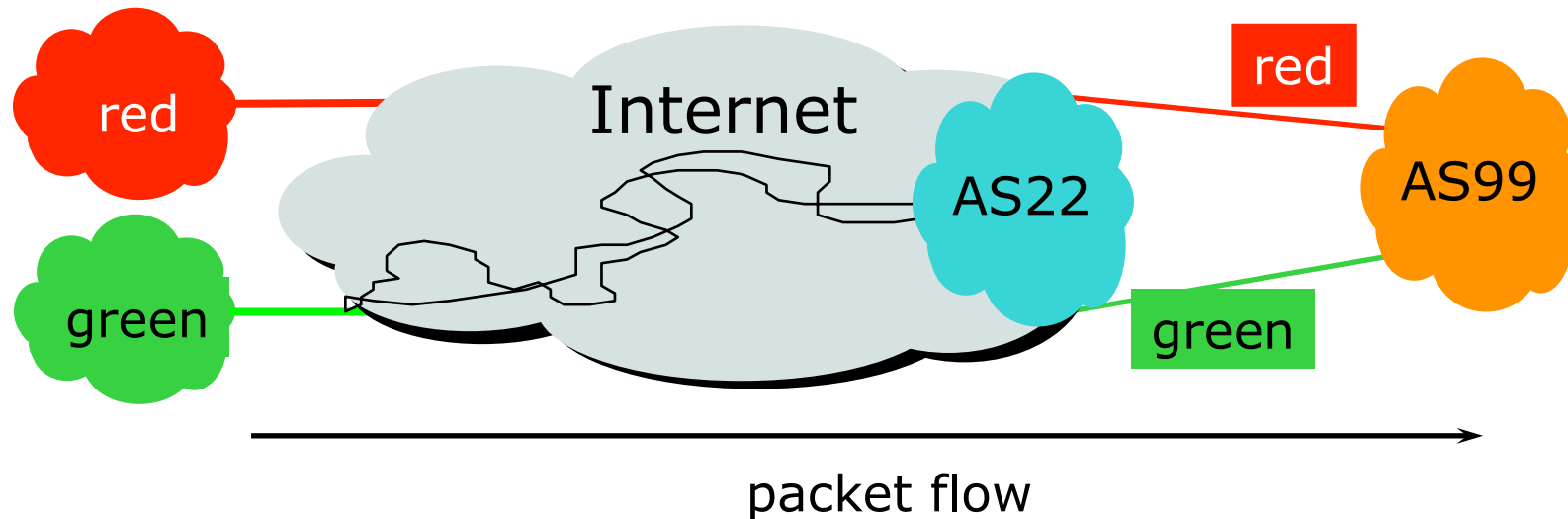
# Routing Policy Limitations

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- ❑ AS99 uses red link for traffic to the red AS and the green link for remaining traffic
- ❑ To implement this policy, AS99 has to:
  - Accept routes originating from the red AS on the red link
  - Accept all other routes on the green link

# Routing Policy Limitations



- ❑ AS99 would like packets coming from the green AS to use the green link.
- ❑ But unless AS22 cooperates in pushing traffic from the green AS down the green link, there is very little that AS99 can do to achieve this aim



# Routing Policy Issues

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- January 2016:
  - 25800 IPv6 prefixes & 580000 IPv4 prefixes
    - Not realistic to set policy on all of them individually
  - 52500 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 AS' s 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 ISPs who connect to each other's networks
- ❑ How does an ISP in Kenya tell an ISP in Japan what customers they have?
- ❑ And how does that ISP send data packets to the customers of the ISP in Japan, 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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- ISP in Kenya could buy a direct connection to the ISP in Japan
  - But this doesn't scale – thousands of ISPs, would need thousands of connections, and cost would be astronomical
- Instead, ISP in Kenya tells his neighbouring ISPs what customers he has
  - And the neighbouring ISPs pass this information on to their neighbours, and so on
  - This process repeats until the information reaches the ISP 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 ISPs can provide connectivity to each other
  - We have the Internet we see today

## 4: How Does Routing Work?

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- ISP in Kenya doesn't actually tell his neighbouring ISPs the names of the customers
  - (network equipment does not understand names)
- Instead, he has received an IP address block as a member of the Regional Internet Registry serving Kenya
  - His customers have received address space from this address block as part of their "Internet service"
  - And he announces this address block to his neighbouring ISPs – 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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- ISP backbone scaling
  - Hierarchy
  - Limiting scope of failure
  - Only used for ISP'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
- Current EGP is 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 AS's together

# Interior versus Exterior Routing Protocols

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## □ Interior

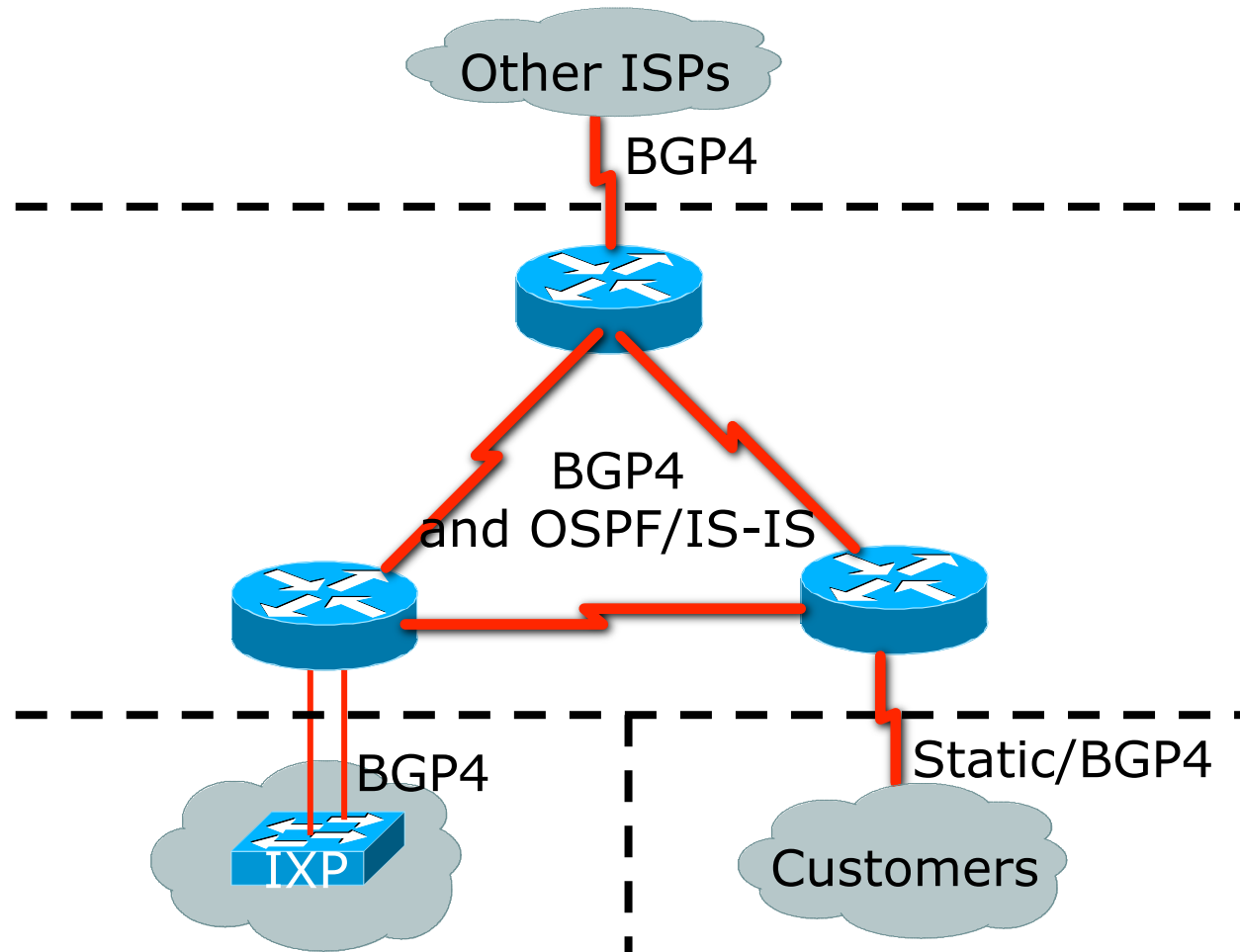
- Carries ISP infrastructure addresses only
- ISPs aim to keep the IGP small for efficiency and scalability

## □ Exterior

- Carries customer prefixes
- Carries Internet prefixes
- EGPs are independent of ISP network topology

# Hierarchy of Routing Protocols

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# FYI: Default Administrative Distances

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

# Routing Basics



ISP Workshops