

FIT1047 - Week 9

Networks: Network and Transport layers



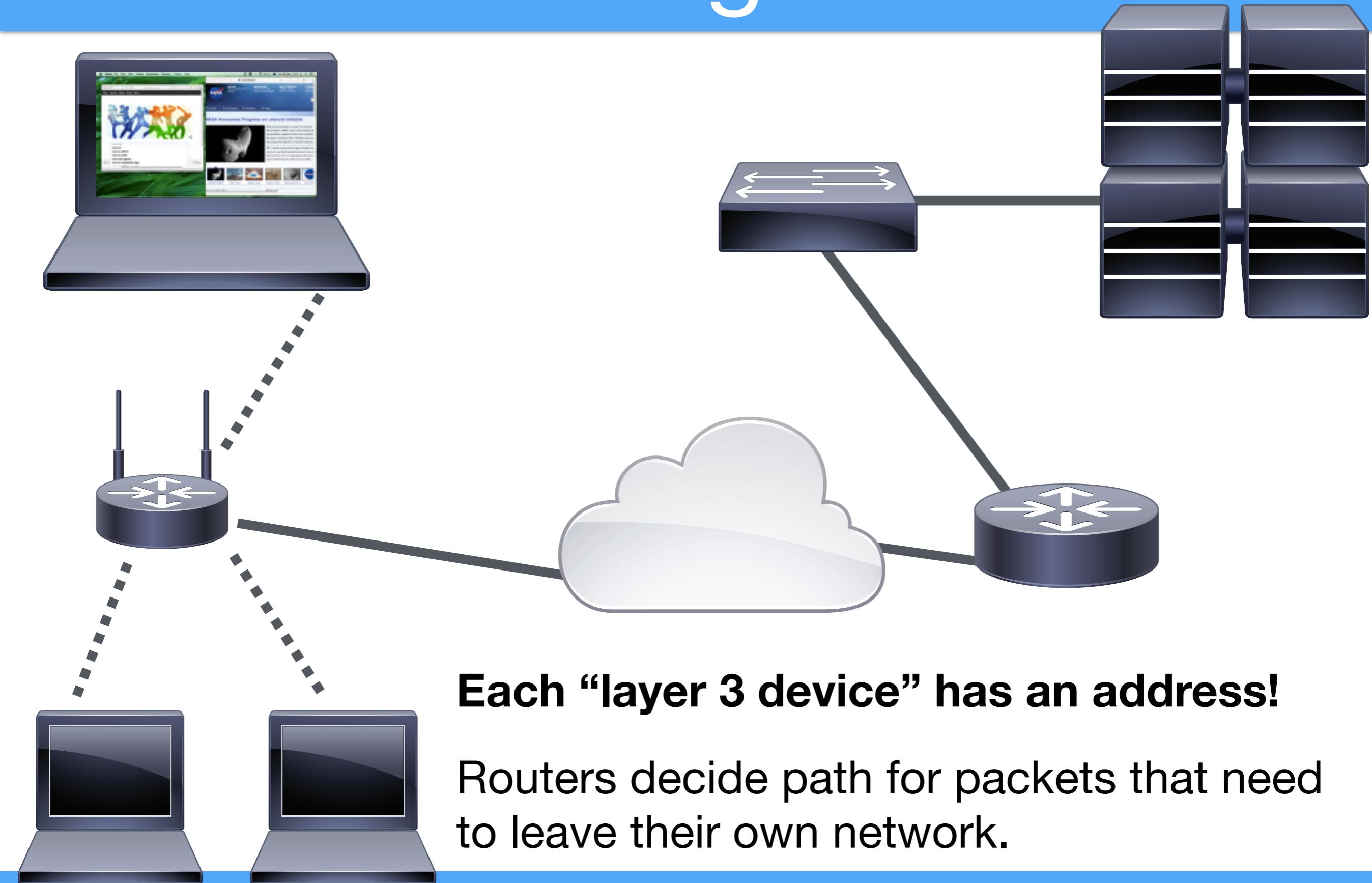
MONASH University

Goals for this week

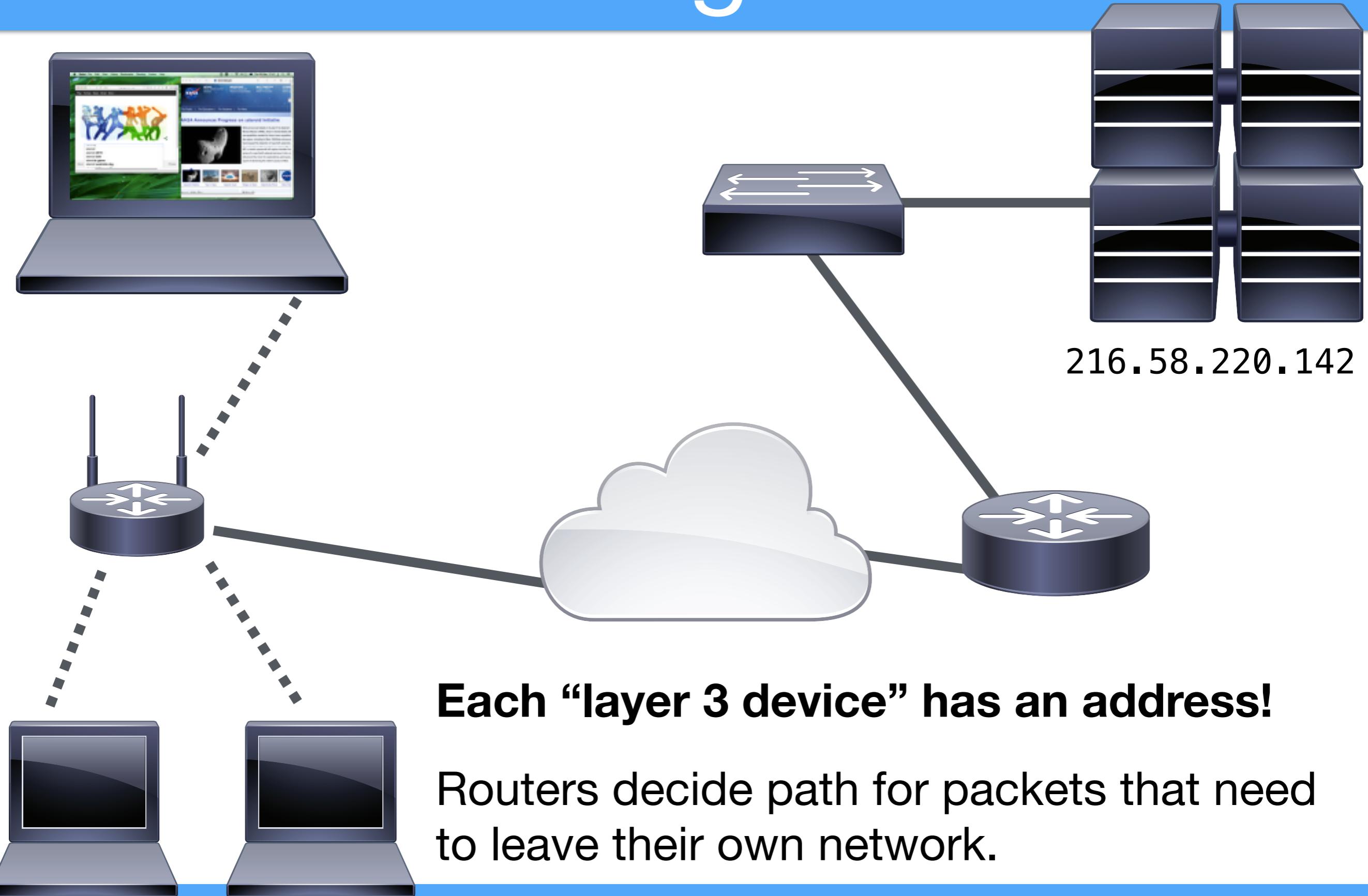
- See how **routers connect different networks**
- Understand how the transport layer makes sure messages **arrive correctly** and at the **right process**
- Study the **structure of the Internet**

The Network Layer: Addresses

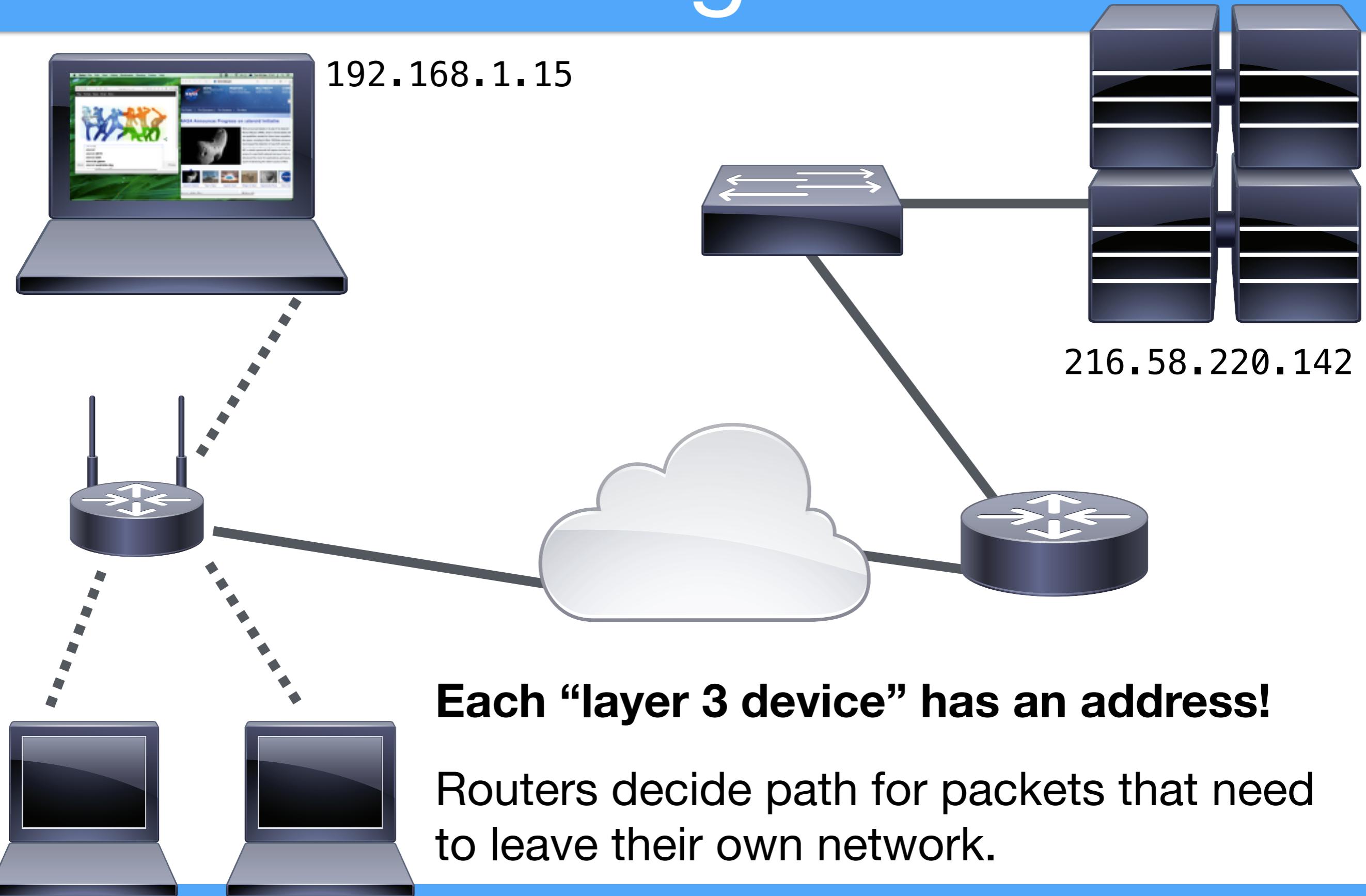
Addressing devices



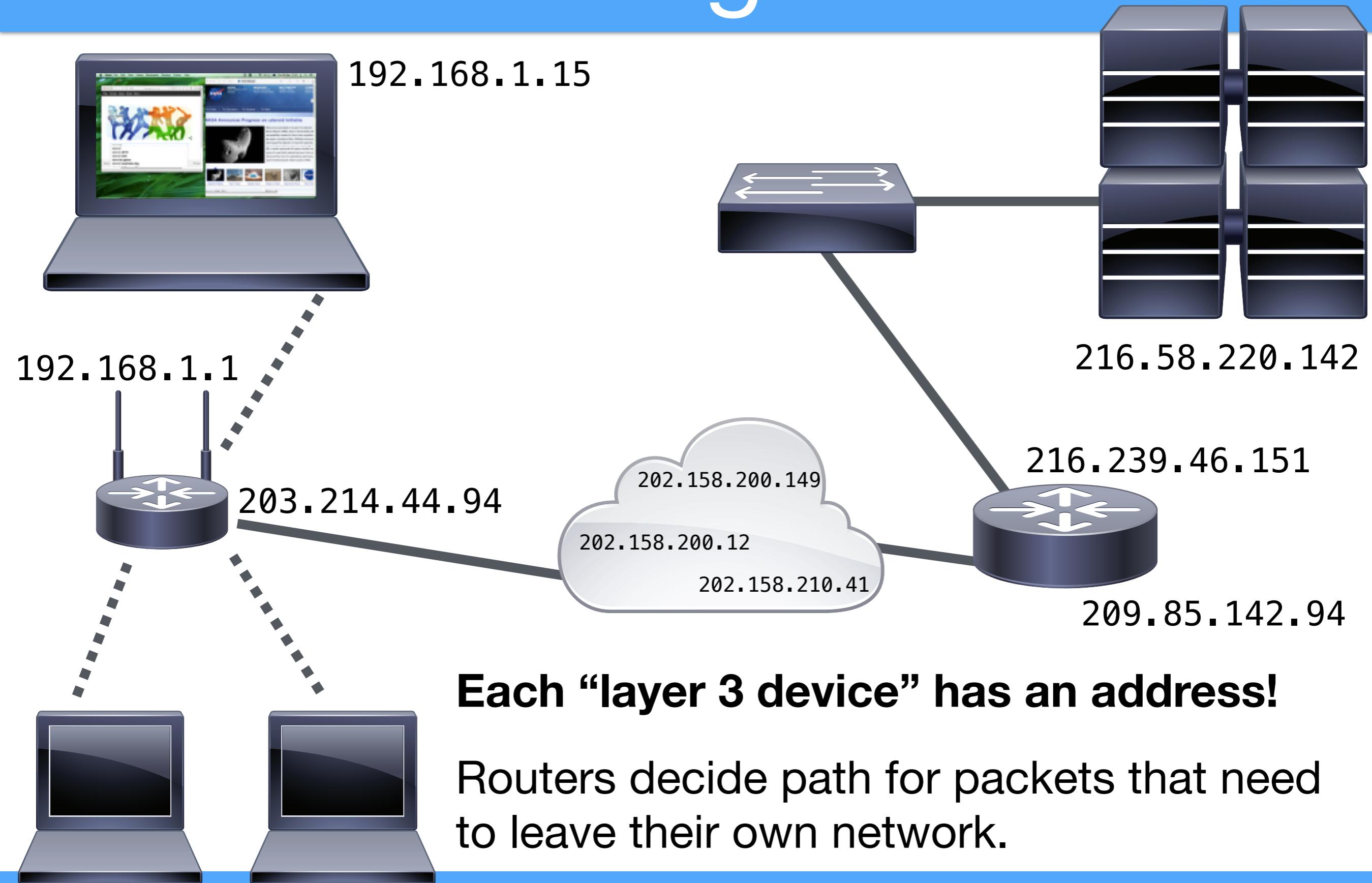
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Addressing devices



IP version 4 addresses

32 bit addresses

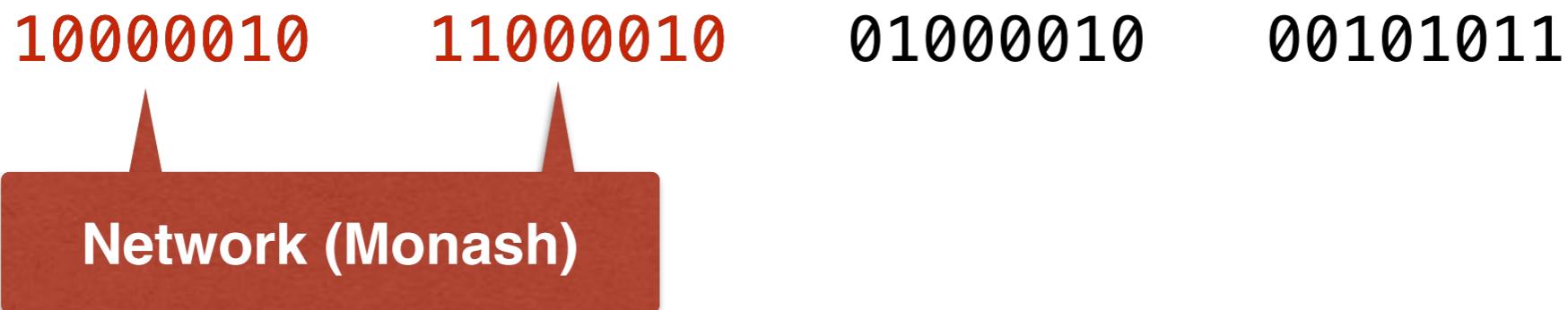
- Written using “dotted decimal” notation
- Example: 130.194.66.43

10000010 11000010 01000010 00101011

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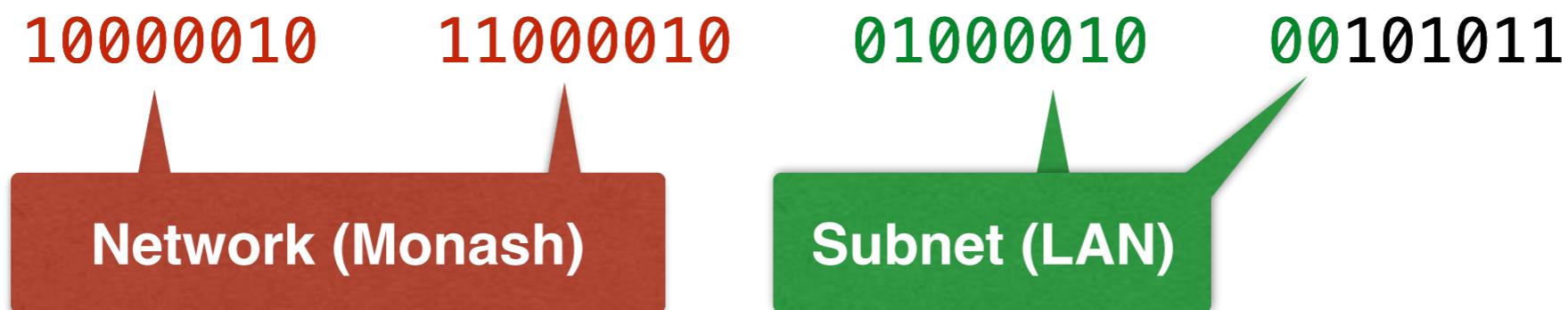
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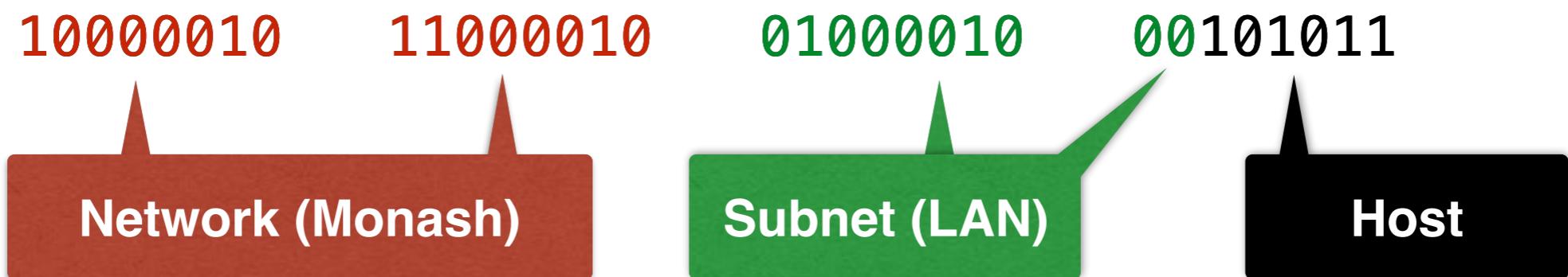
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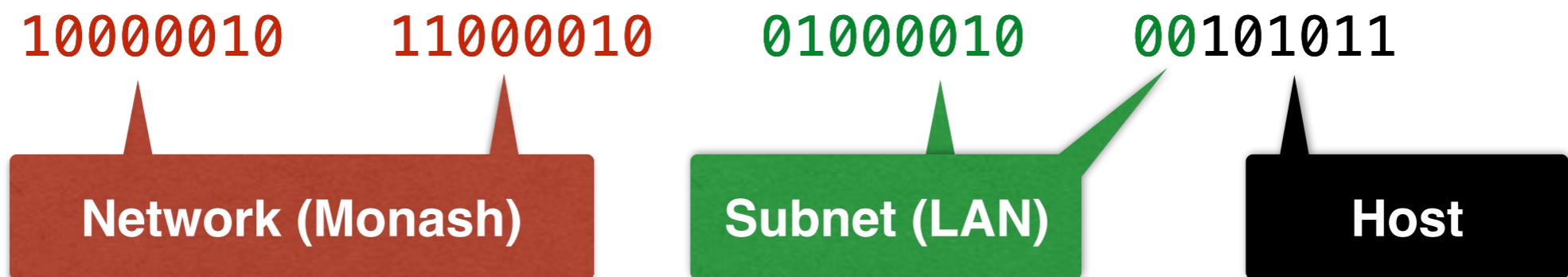
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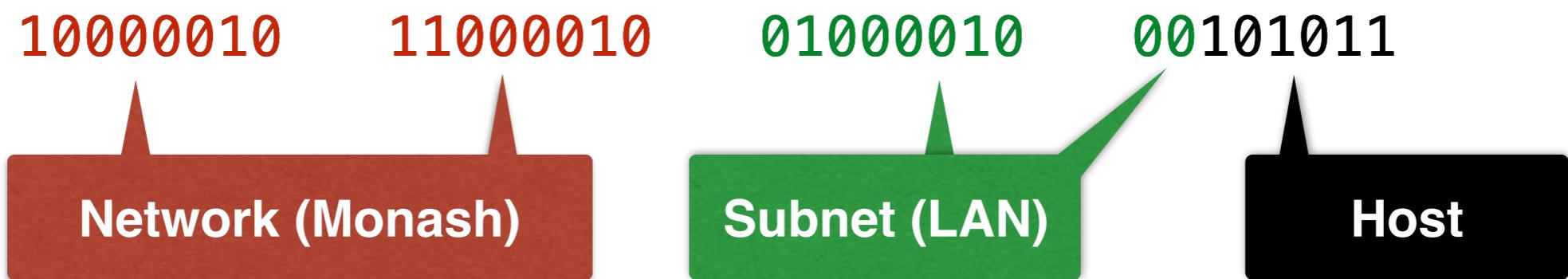
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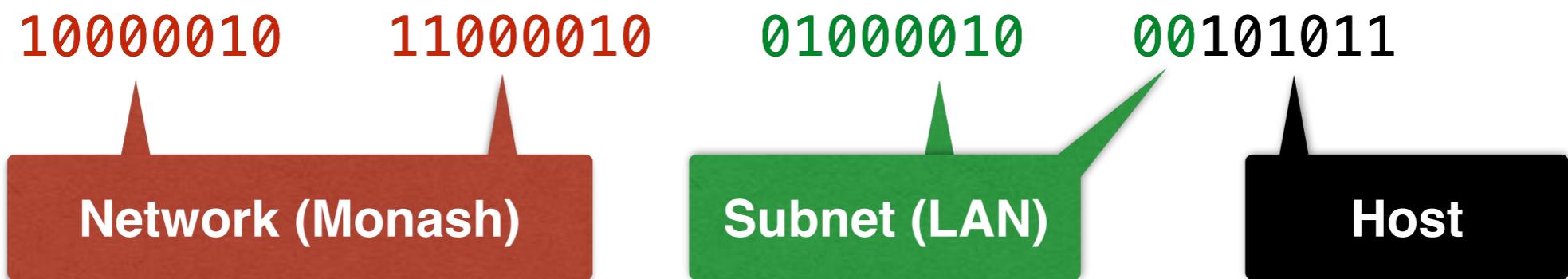
Hierarchy used for routing

- You can immediately see if a destination address is in the same subnet!
- Subnet mask: **255.255.192.0 or /22**

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no. of bits in network +
subnet

Network Classes

Subnet masks often expressed using dotted notation

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Previously used hierarchy:

- Class A: /8 (e.g. IBM, MIT, AT&T, Apple, ...)
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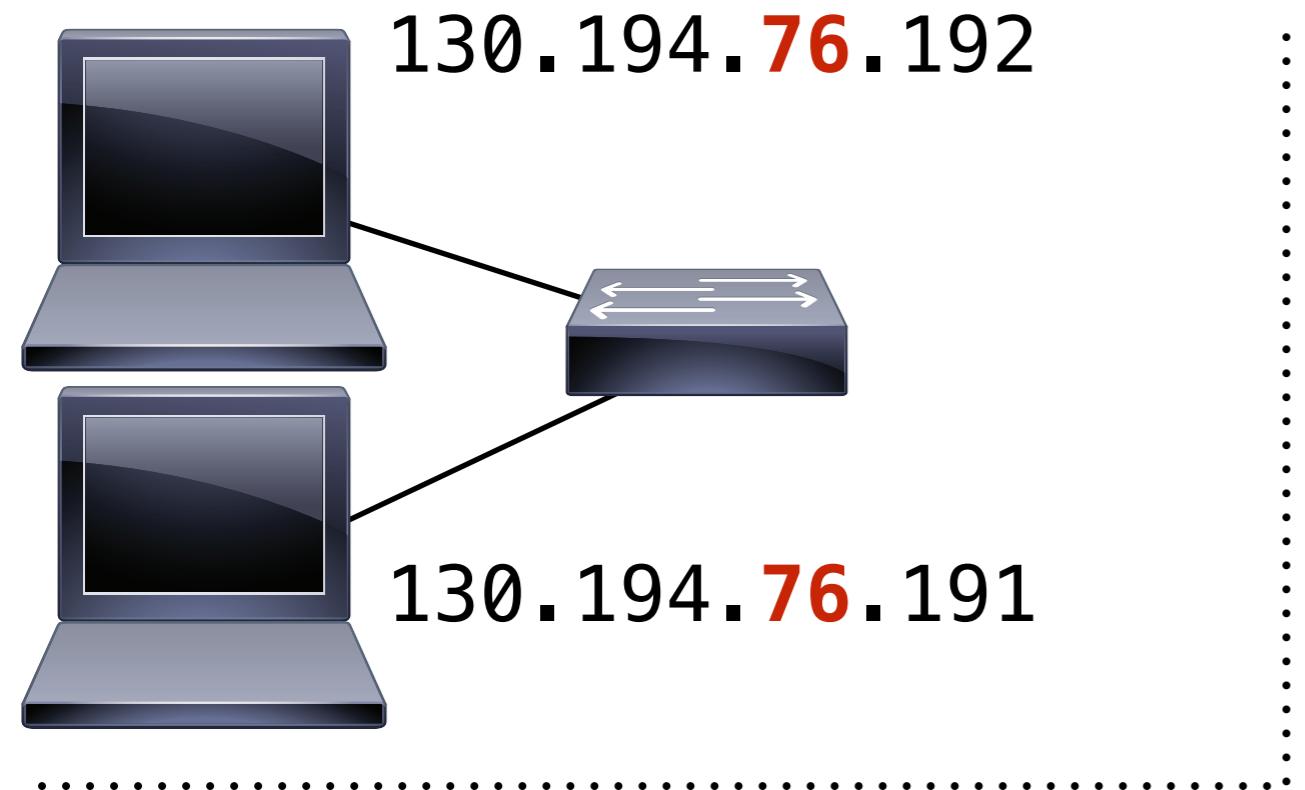
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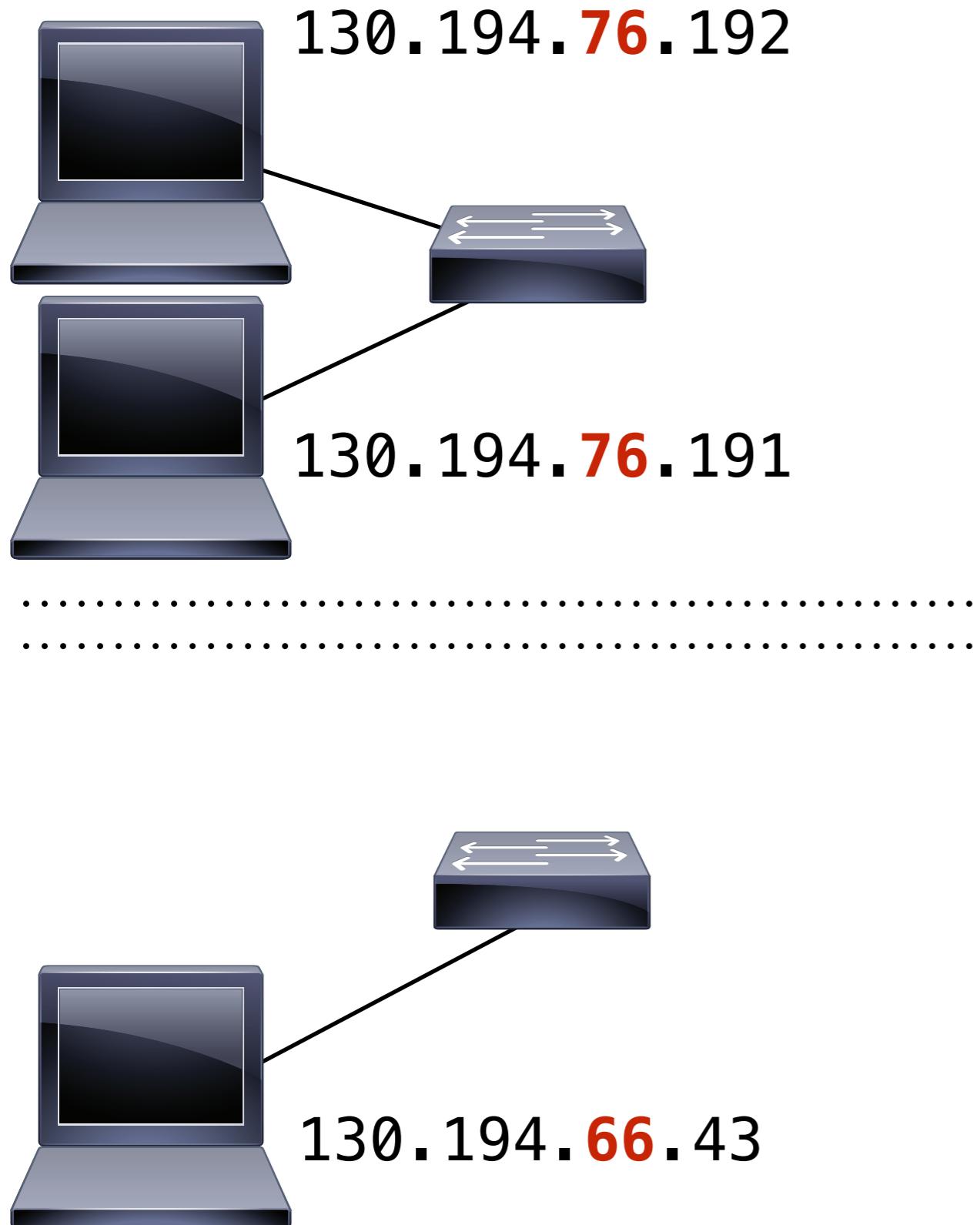
Now: classless

- e.g. /22, which can also be written as 255.255.252.0

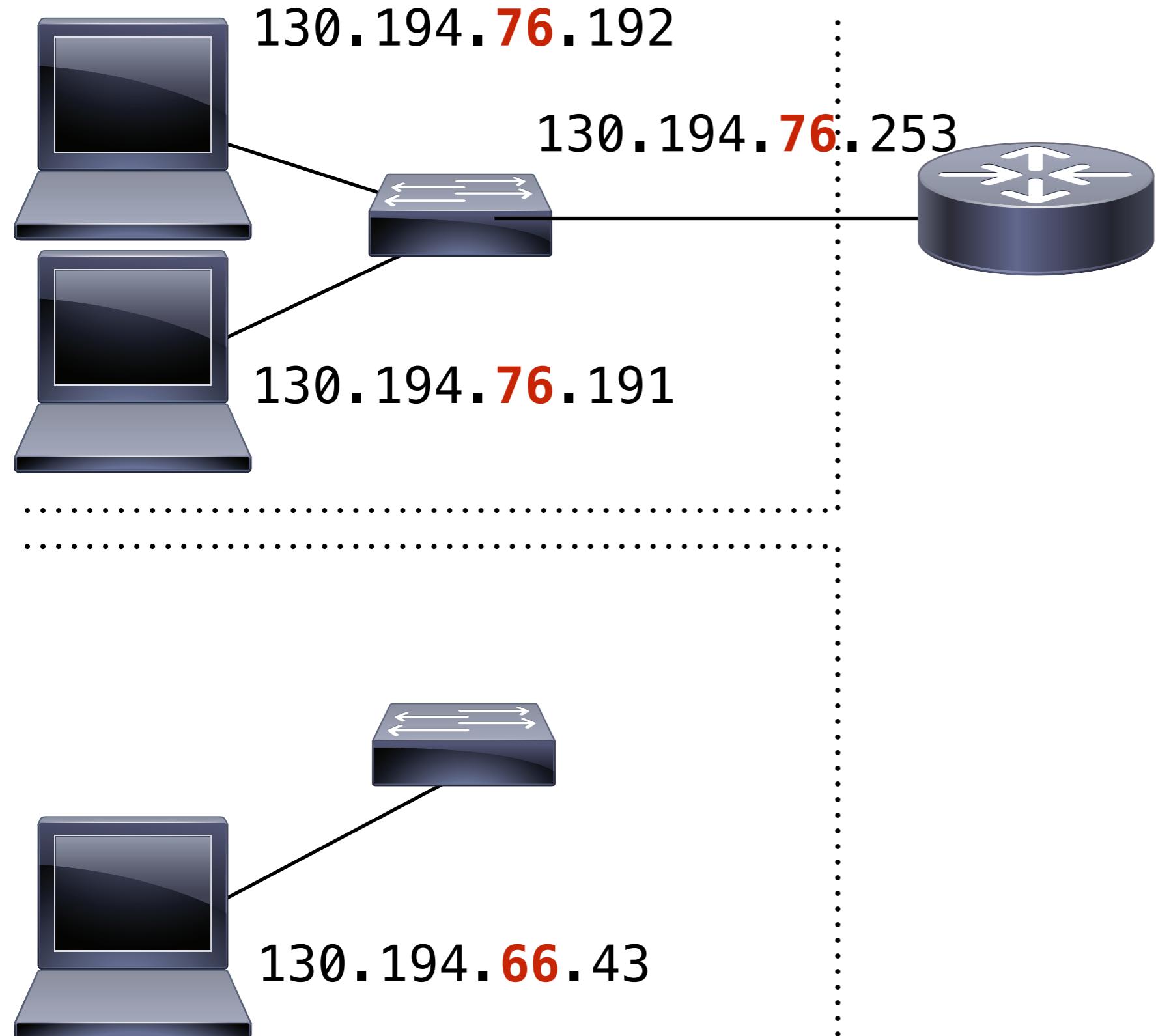
Subnets



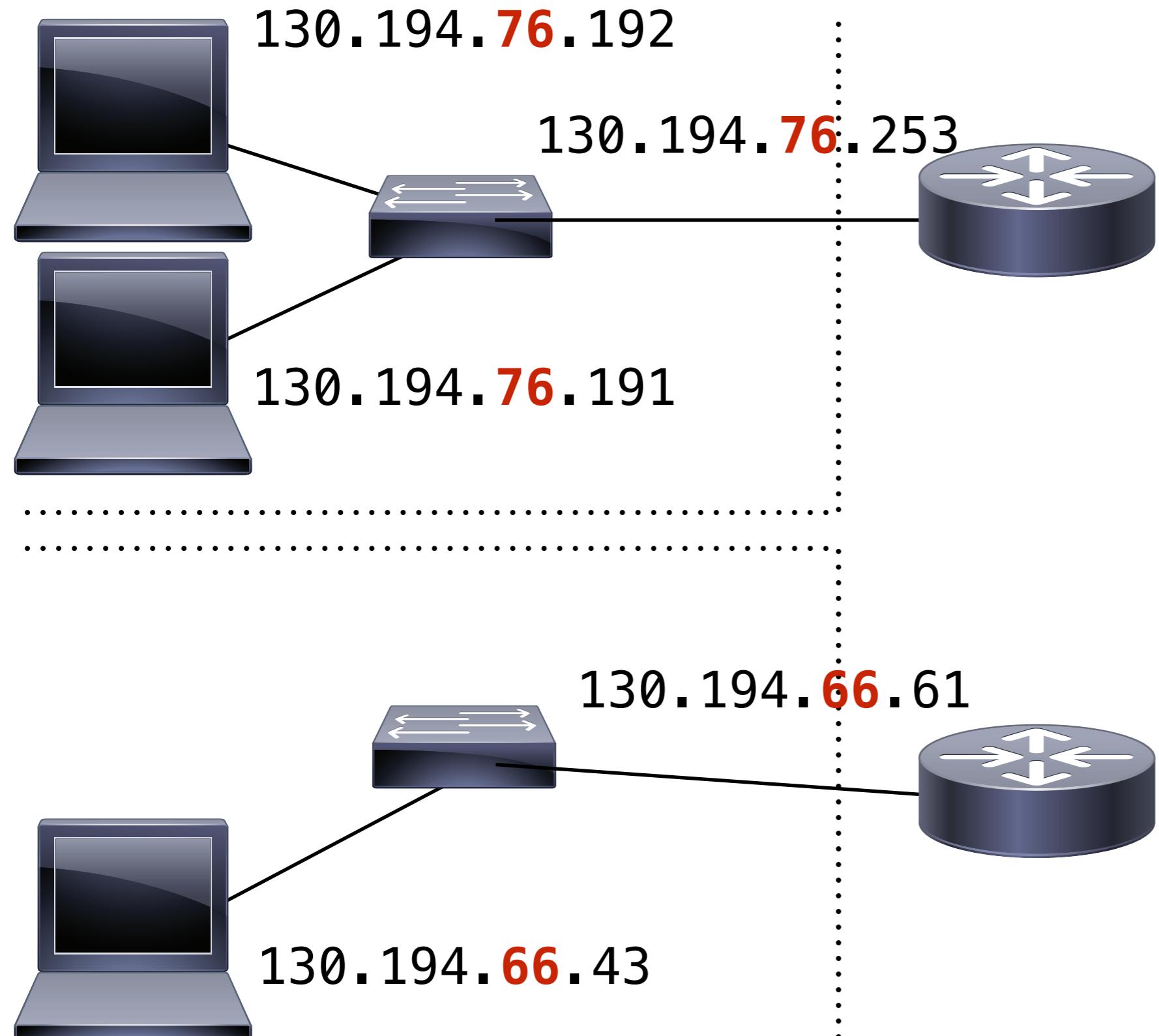
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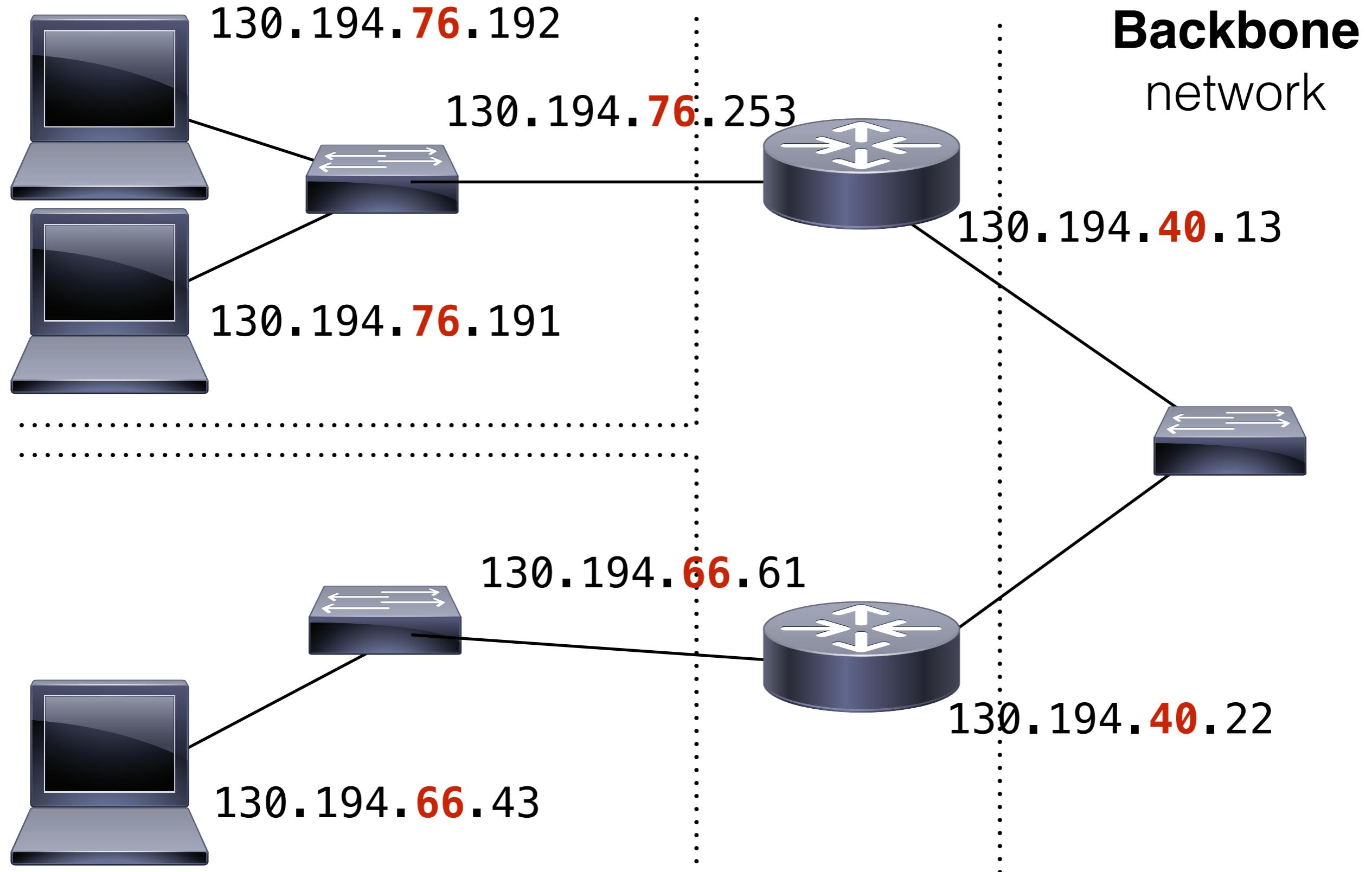
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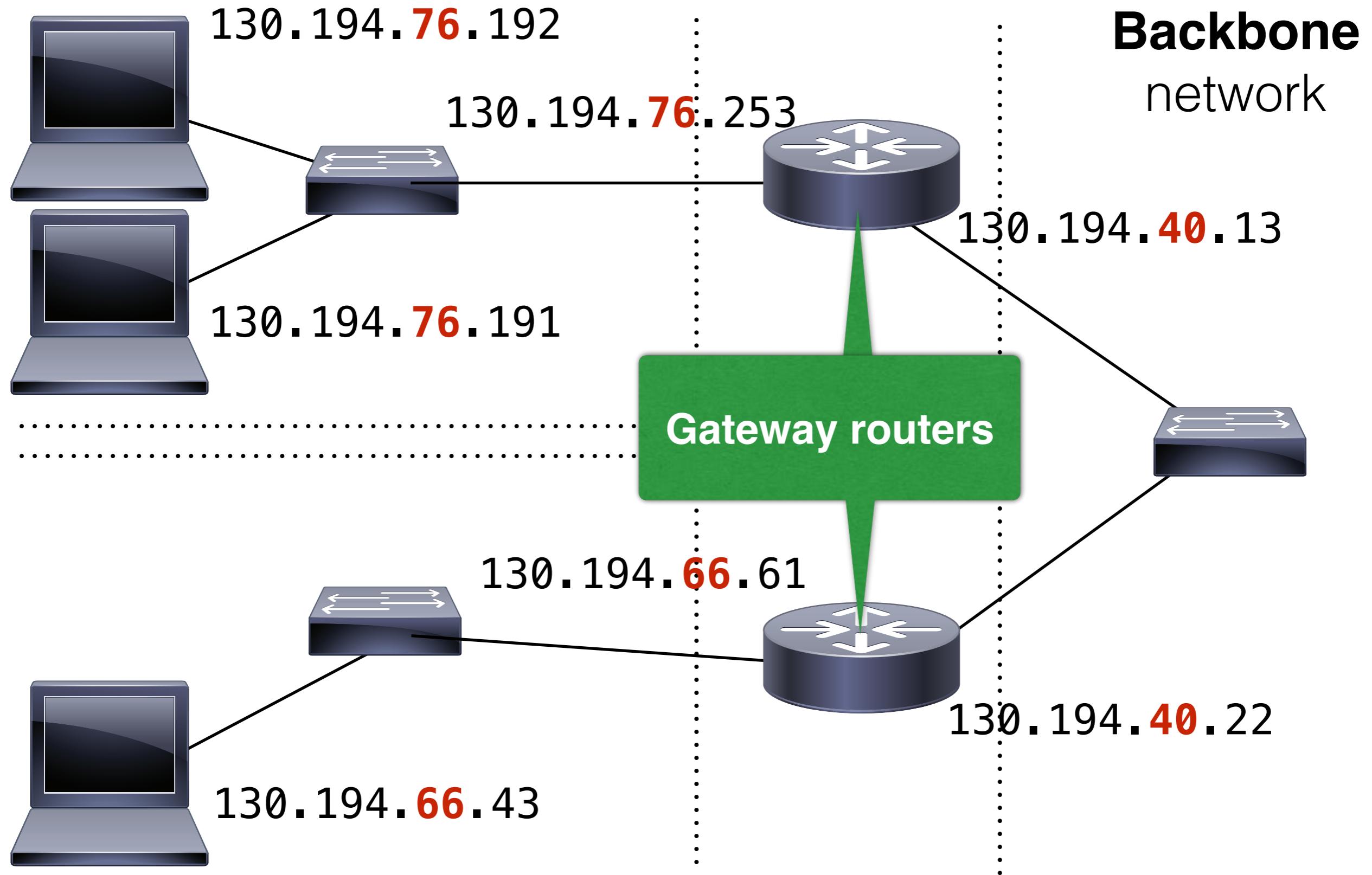
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IP version 6

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IPv6

- “new” version of the IP protocol (from 1998...)
- 128 bits per address
- so that's four times more, right?

IP version 6

$2^{128} =$

IP version 6

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340,282,366,920,938,463,463,374,607,431,768,211,456

(340 undecillion)

IPv6 addresses

IP version 6

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A bit excessive?

- At least 7 addresses for every atom of every person on earth
- 665,570,793,348,866,943,898,599 addresses per square meter of the surface of the earth

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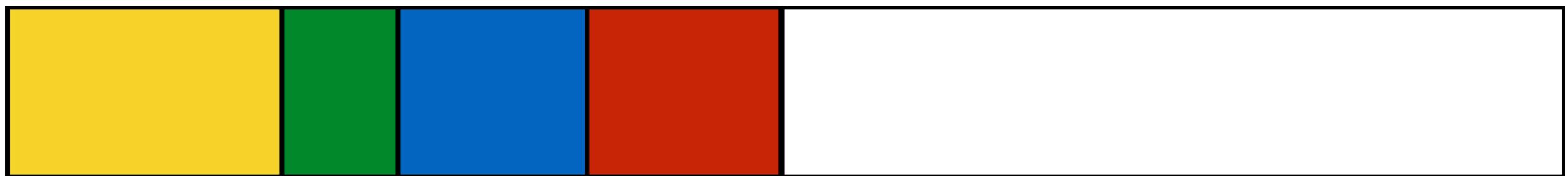
Required!

- The huge space is used to create **hierarchies**
- This makes it easy to assign whole subnets

IP version 6 address space

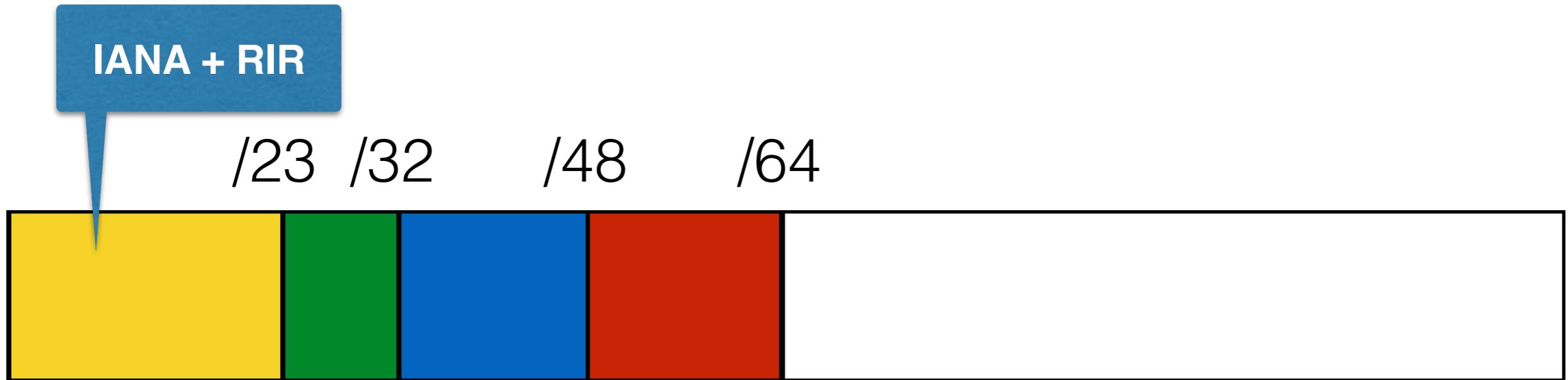
Typical allocation:

/23 /32 /48 /64



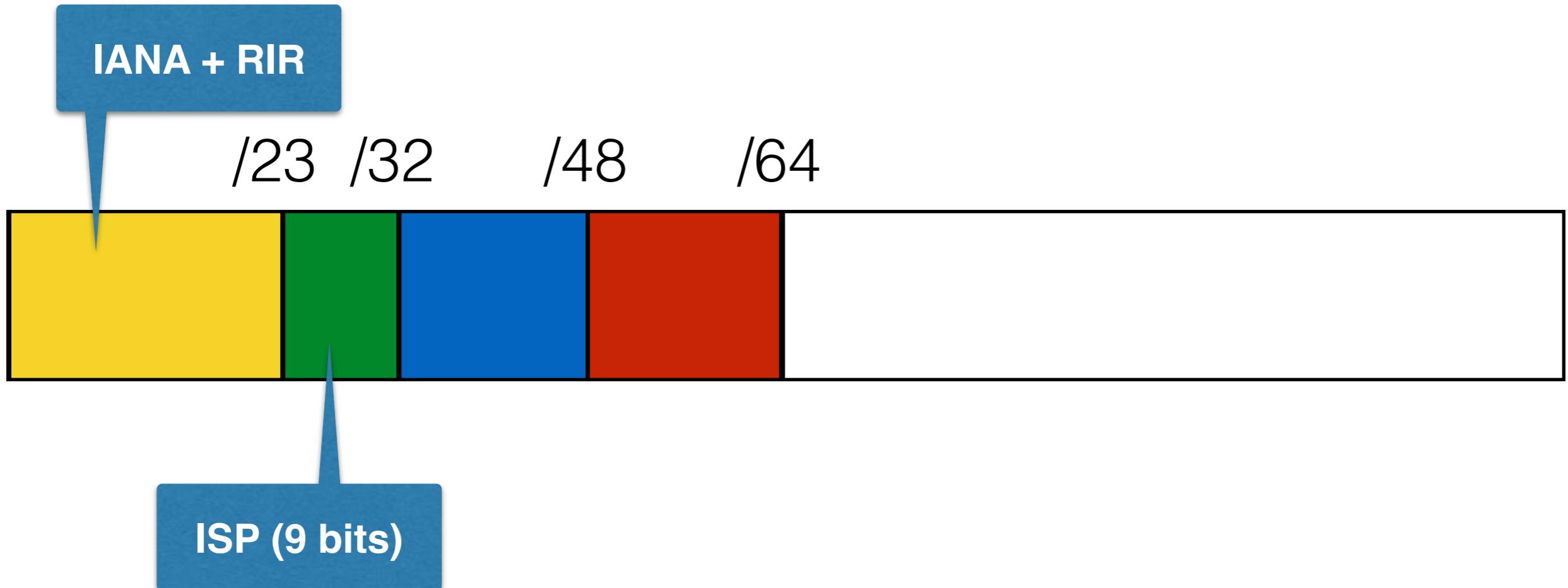
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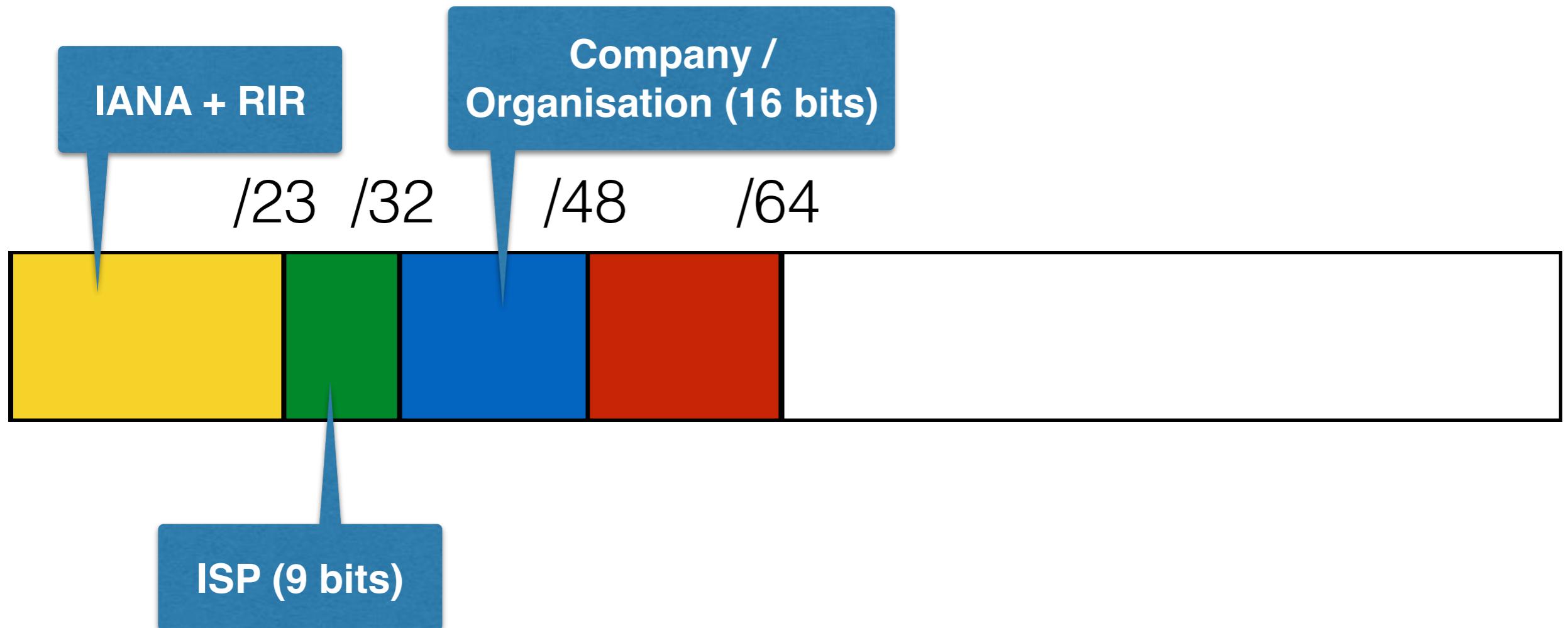
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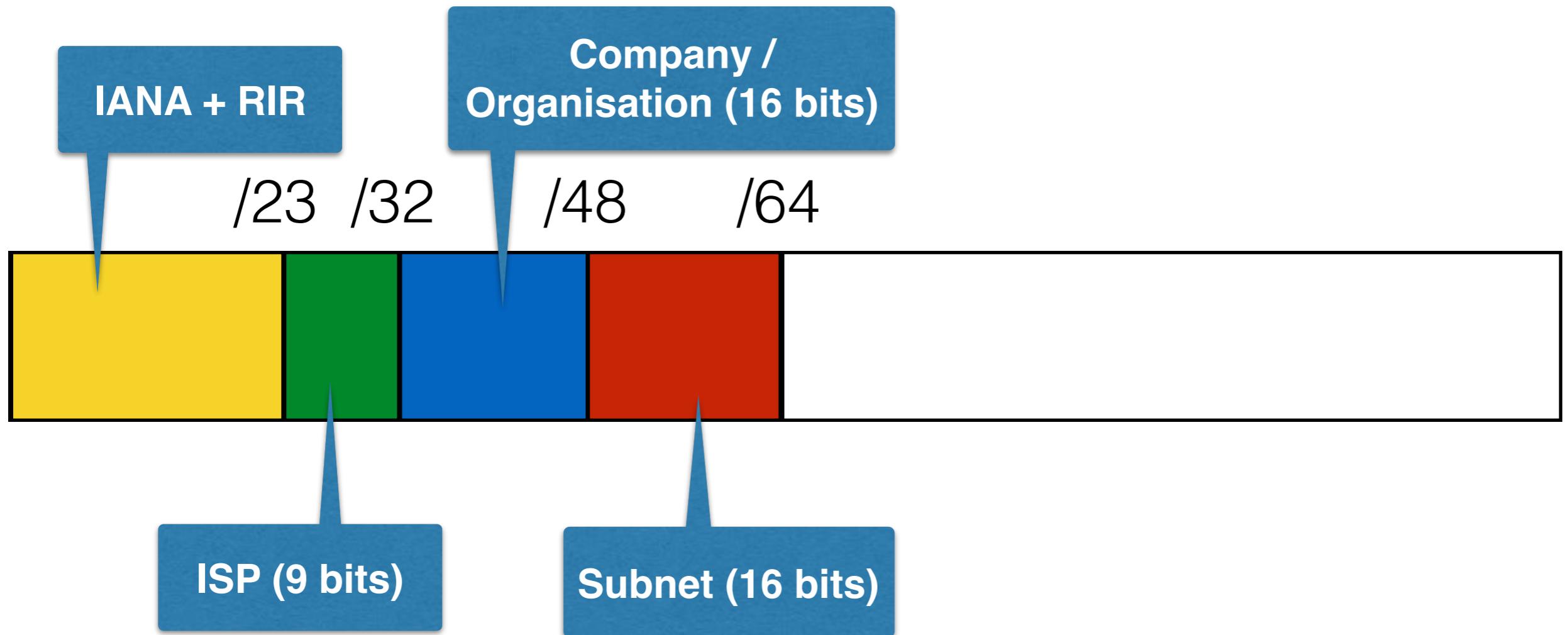
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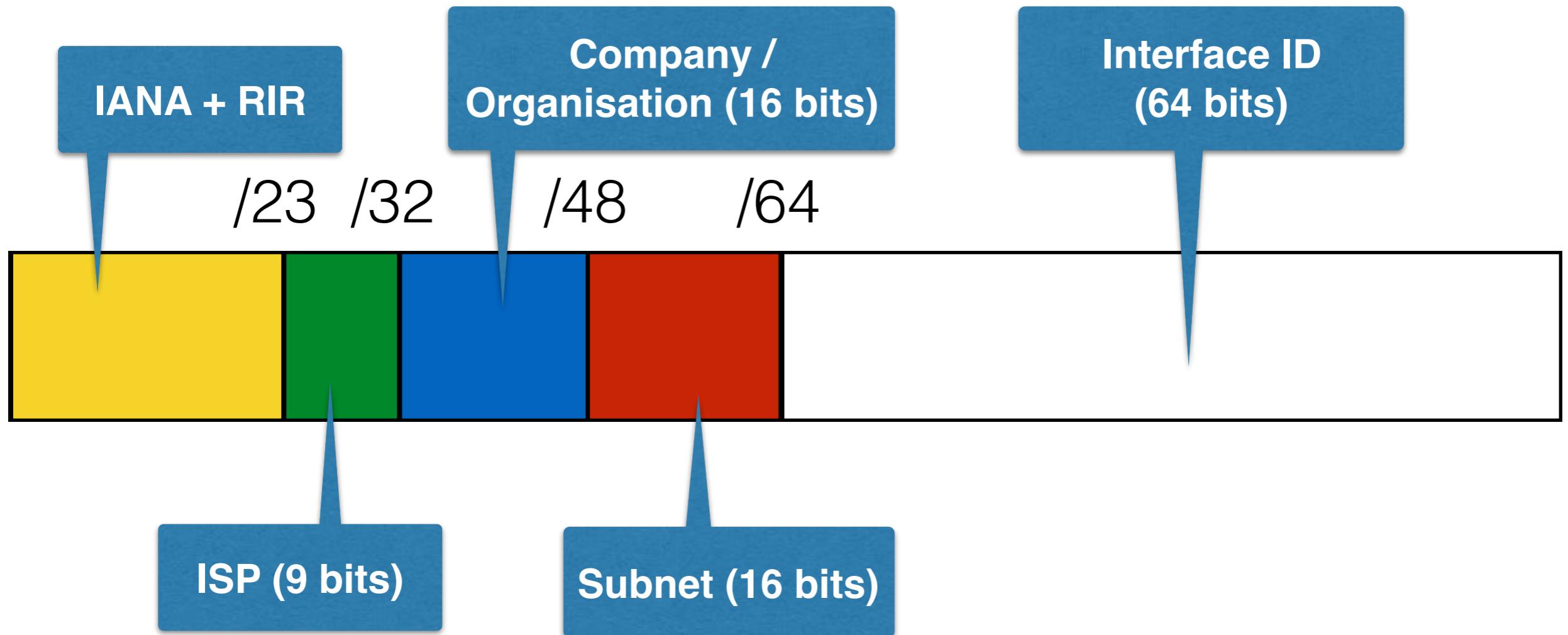
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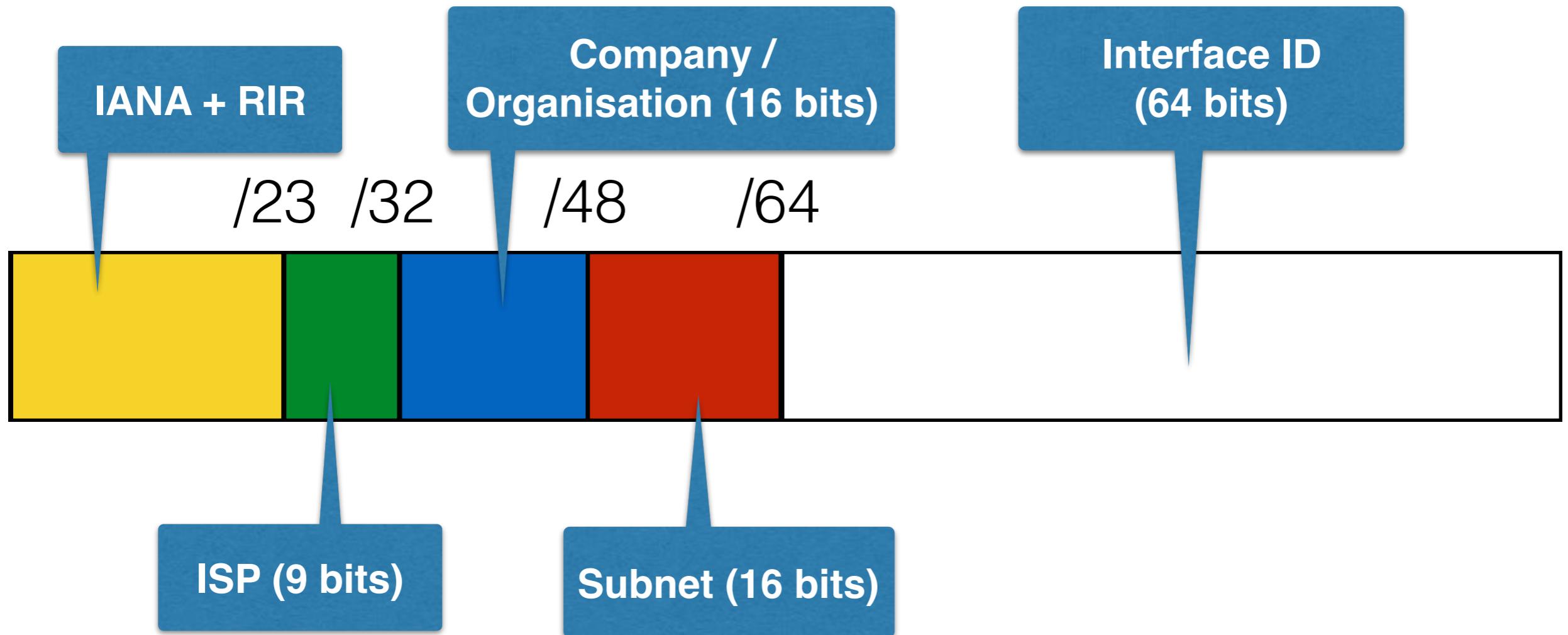
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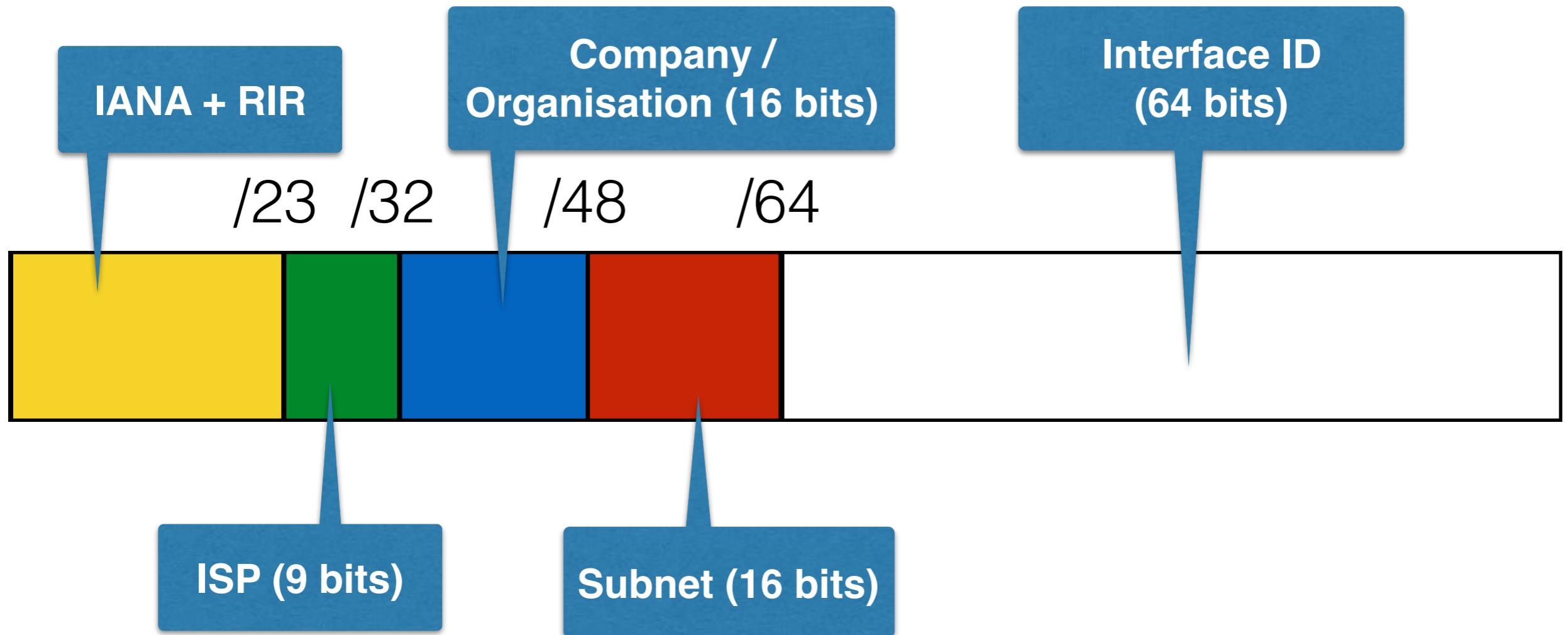
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2^{32} times more addresses than IPv4 in Interface ID alone!

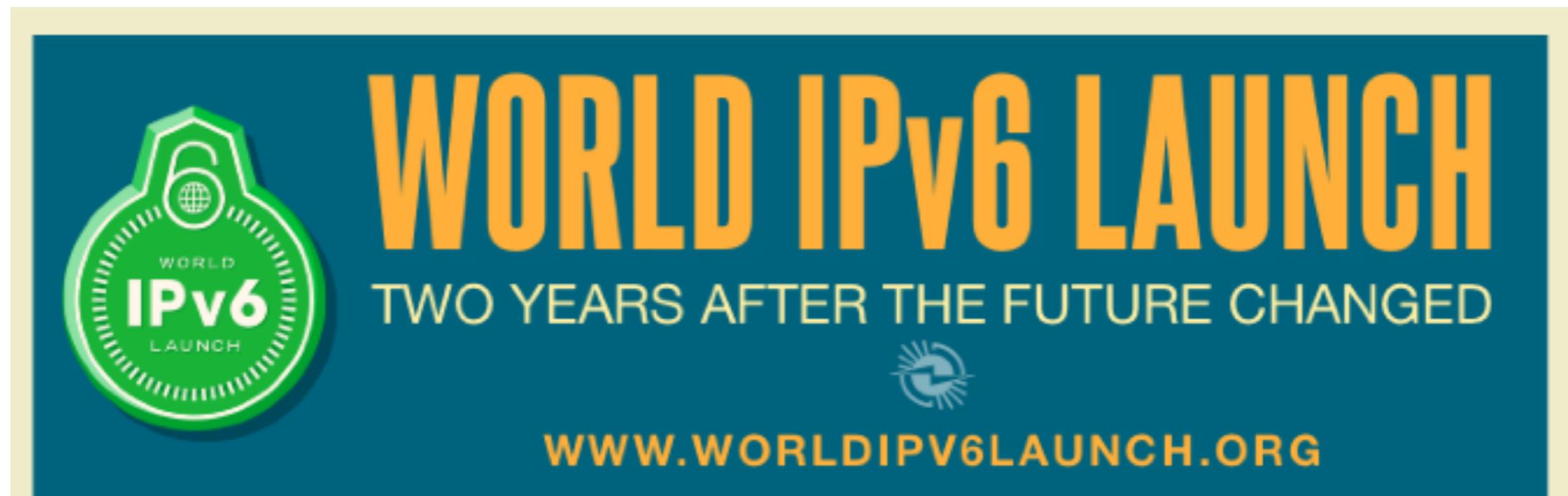
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Every company can run more than 65,000 different LANs

IPv6 transition



LAUNCHING THE FUTURE

On 6 June 2012, thousands of websites, Internet service providers, and router manufacturers launched a new era for the Internet by participating at the start of World IPv6 Launch, marking a major milestone in the global deployment of the newest edition of Internet Protocol (IP).

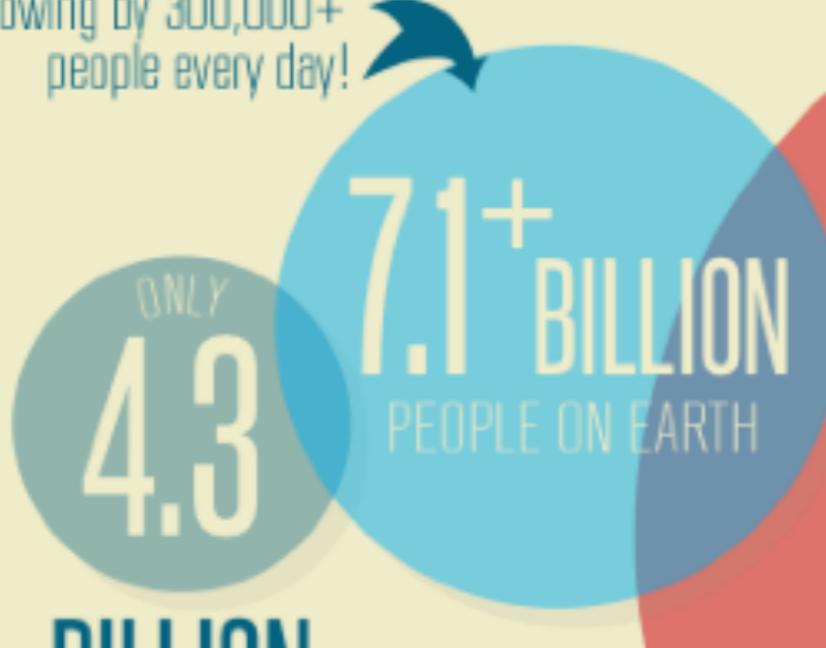
Two years later, IPv6 continues to spread, providing the world enough IP addresses to go around, and ensuring the Internet's continued growth as an innovation and economic development platform.

IPv6 MAKES ROOM FOR THE INTERNET TO GROW!

IPv6 transition

THE OLD SYSTEM IS RUNNING OUT OF ROOM:

And growing by 300,000+
people every day!



7.1+ BILLION
PEOPLE ON EARTH

BY 2020 THERE WILL BE:
50 BILLION
DEVICES ONLINE

That's 10+ times more devices
than IPv4 addresses!

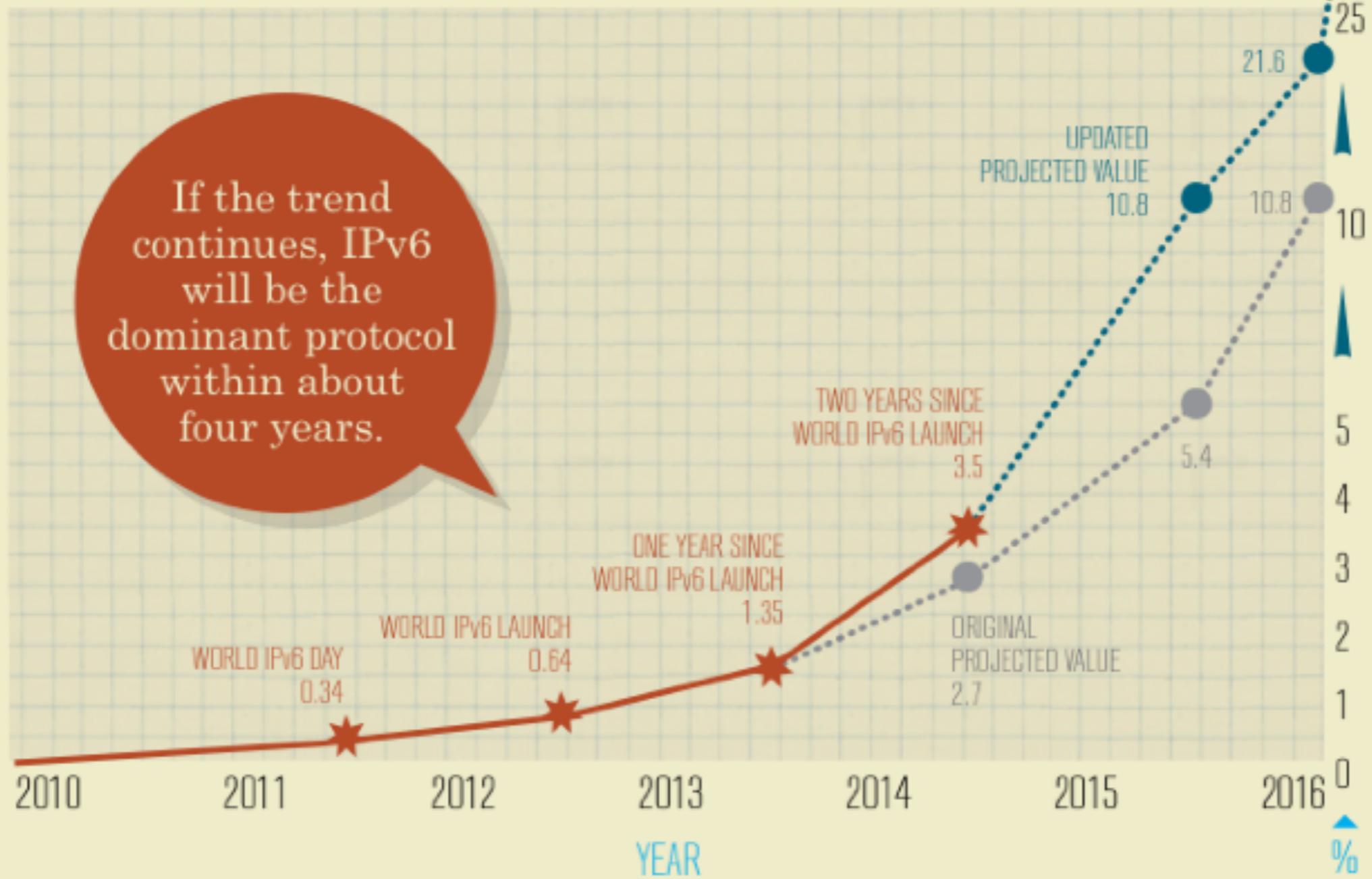
Past the Tipping Point:

Regional Internet Registries (RIRs) manage the allocation and registration of Internet number resources for 5 regions in the world and some of them are already out of IPv4 addresses, with the next soon to follow.

IPv6 transition

IPv6 MOMENTUM

IPv6 usage is increasing more rapidly than predicted just two years ago. Since World IPv6 Launch began in 2012, IPv6 connectivity has more than tripled amongst Google users.



Address resolution

Assume we browse to <http://www.google.com.au>

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This is known as address resolution.

Address resolution: Application Layer

DNS (Domain Name System)

- Application layer protocol for address resolution
- Client sends request to DNS server to get IP address registered for a name

Address resolution: Application Layer

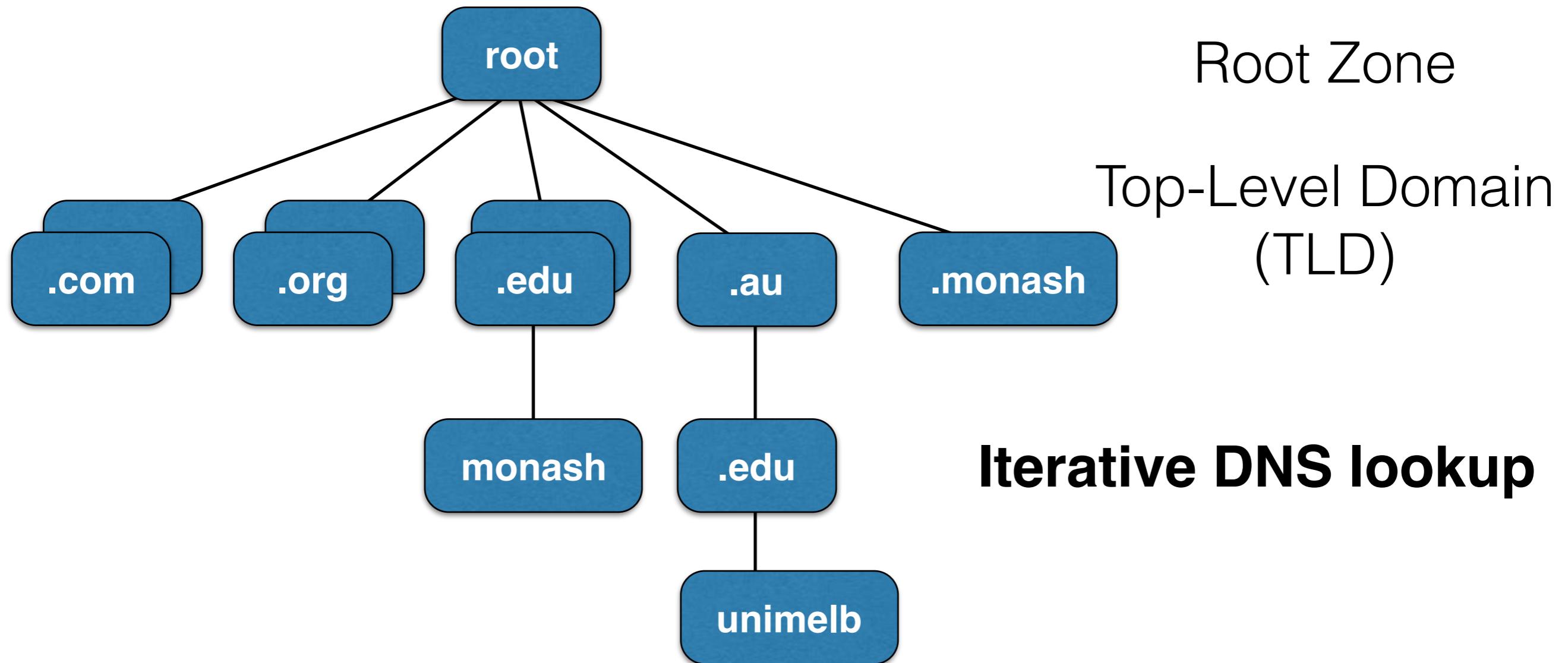
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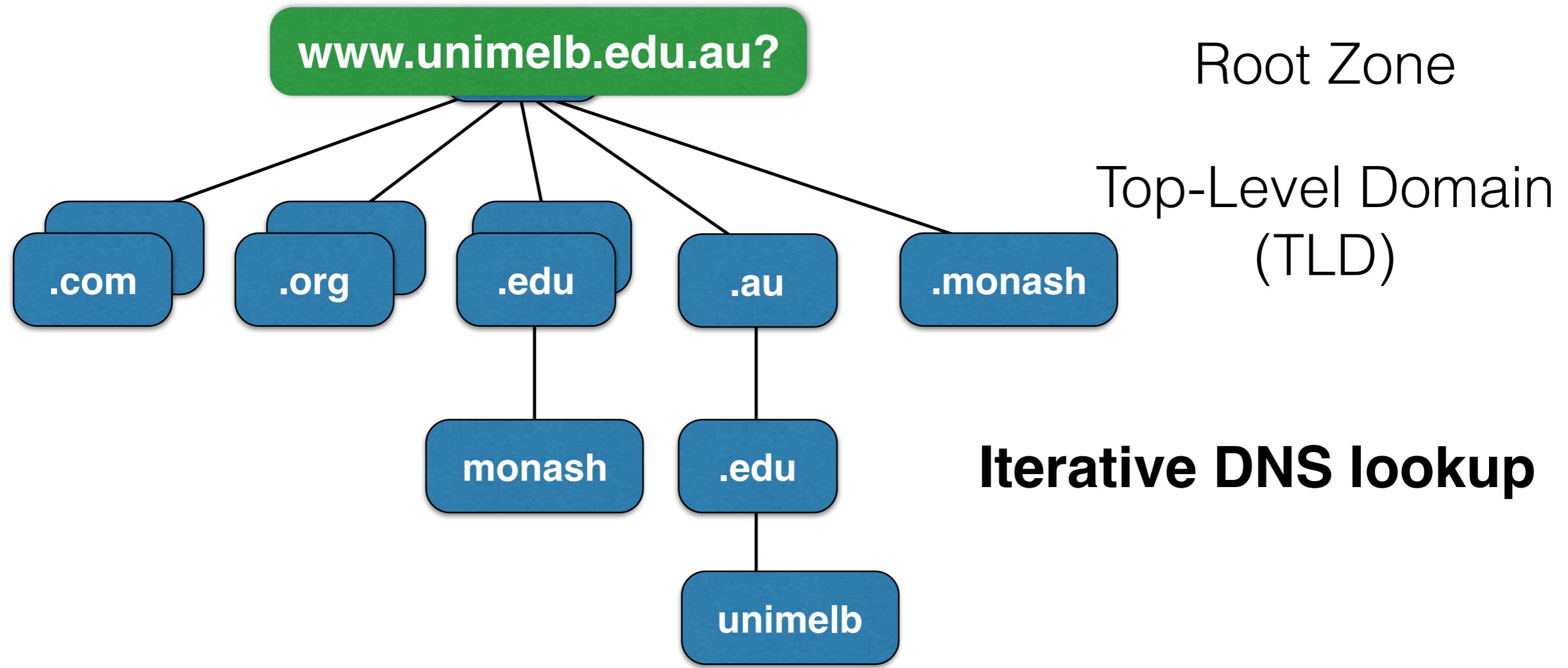
DNS Servers

- Implement a **distributed database** of names
- Are organised in a **hierarchy** reflecting the **structure** of the domain names

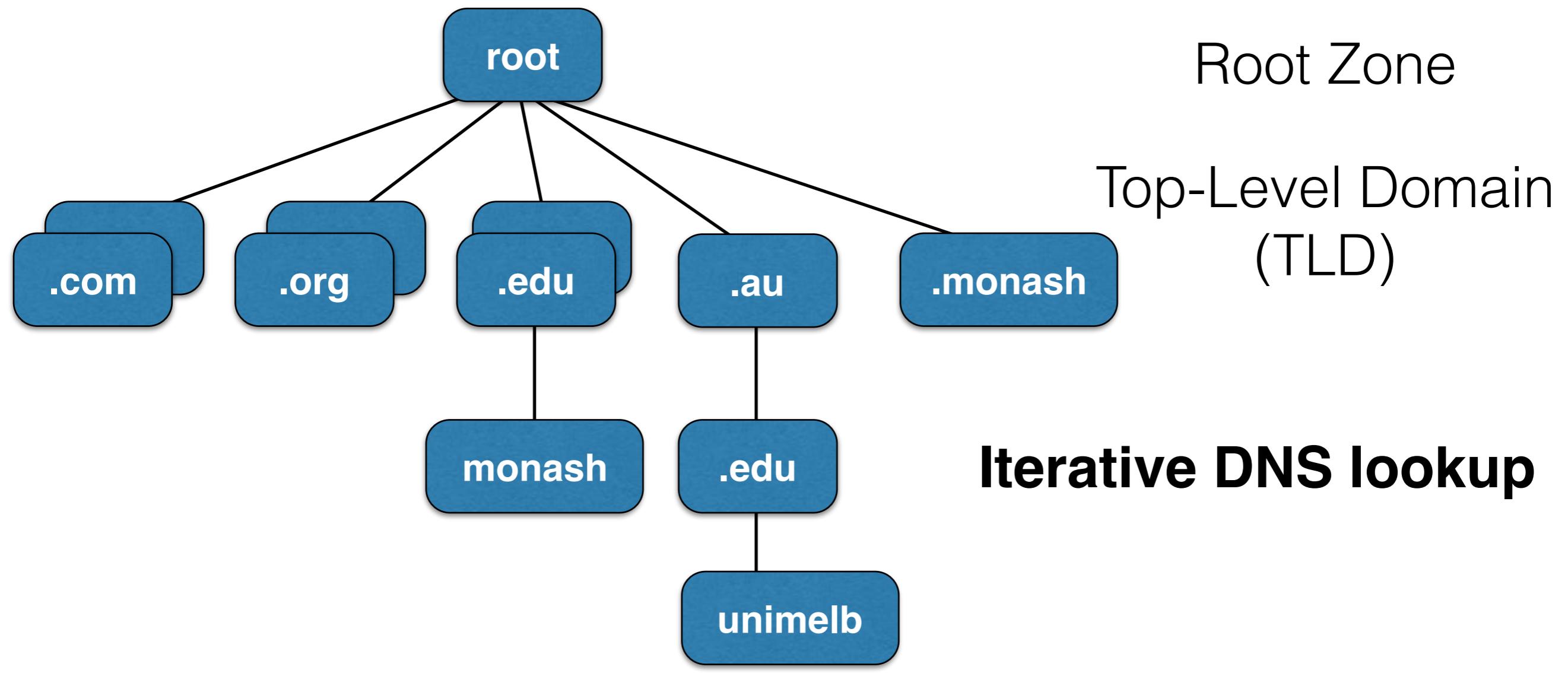
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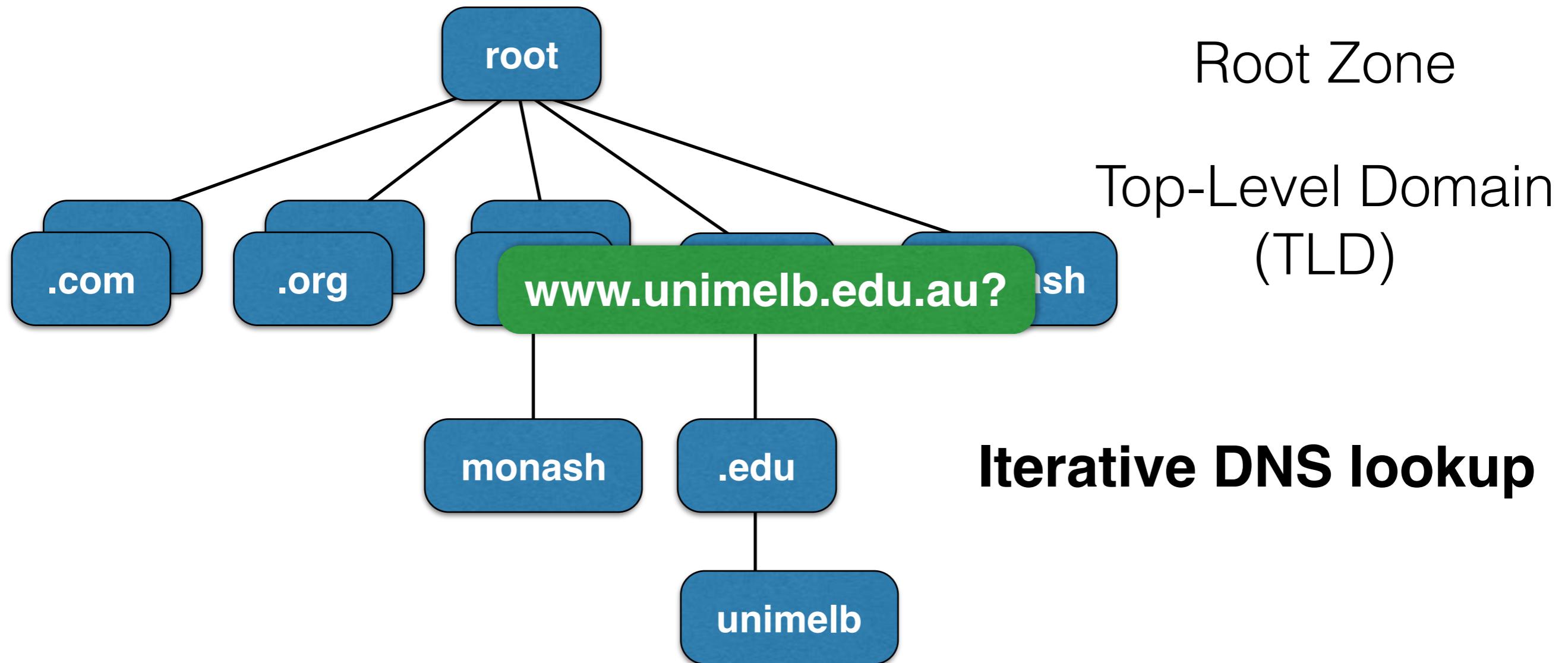


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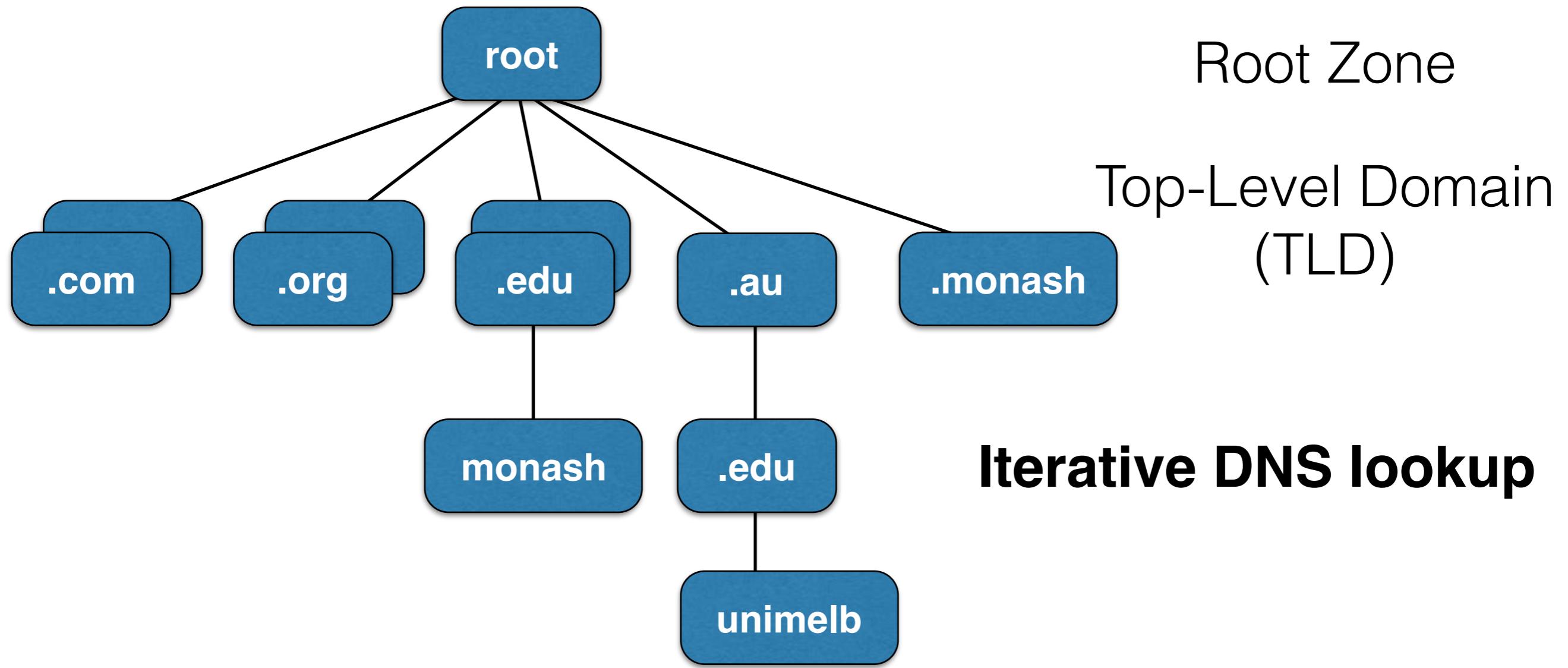
ask z.au

DNS



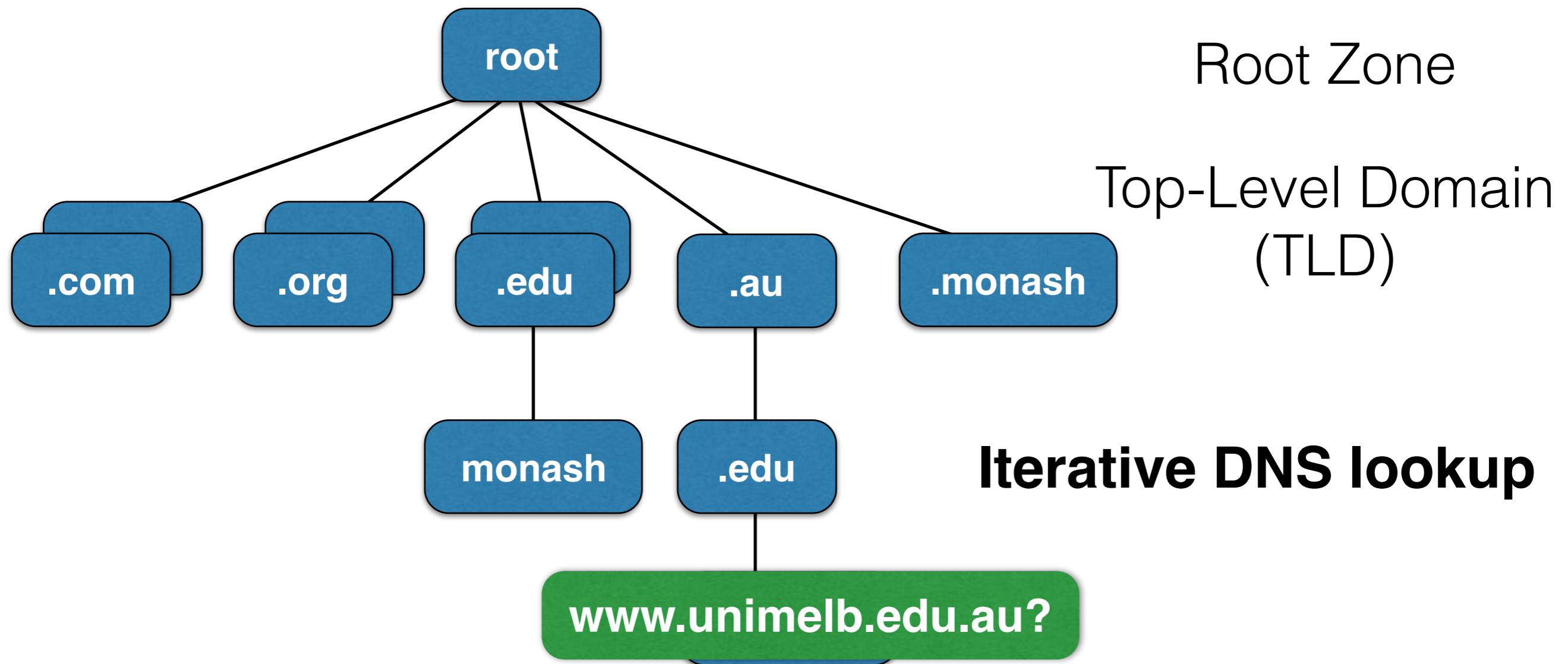
Iterative DNS lookup

DNS

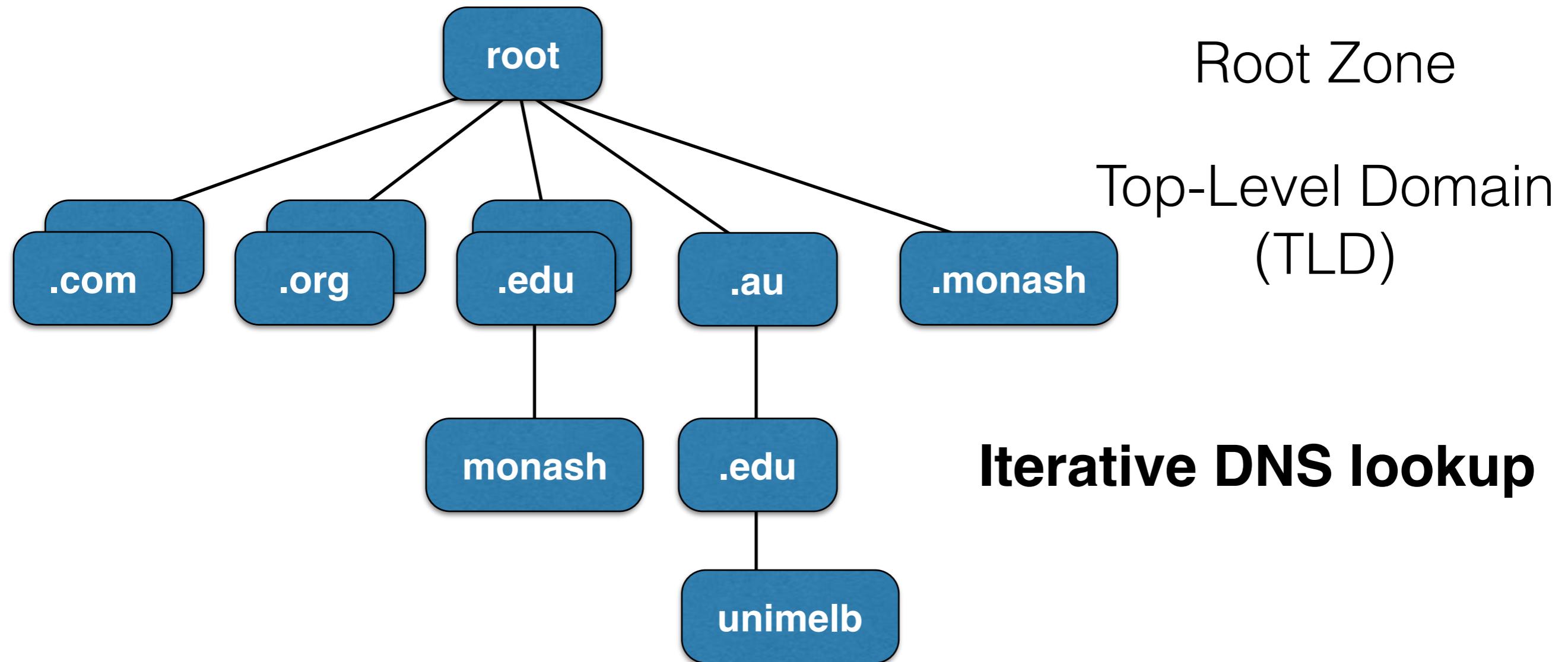


ask edns-396.unimelb.edu.au

DNS

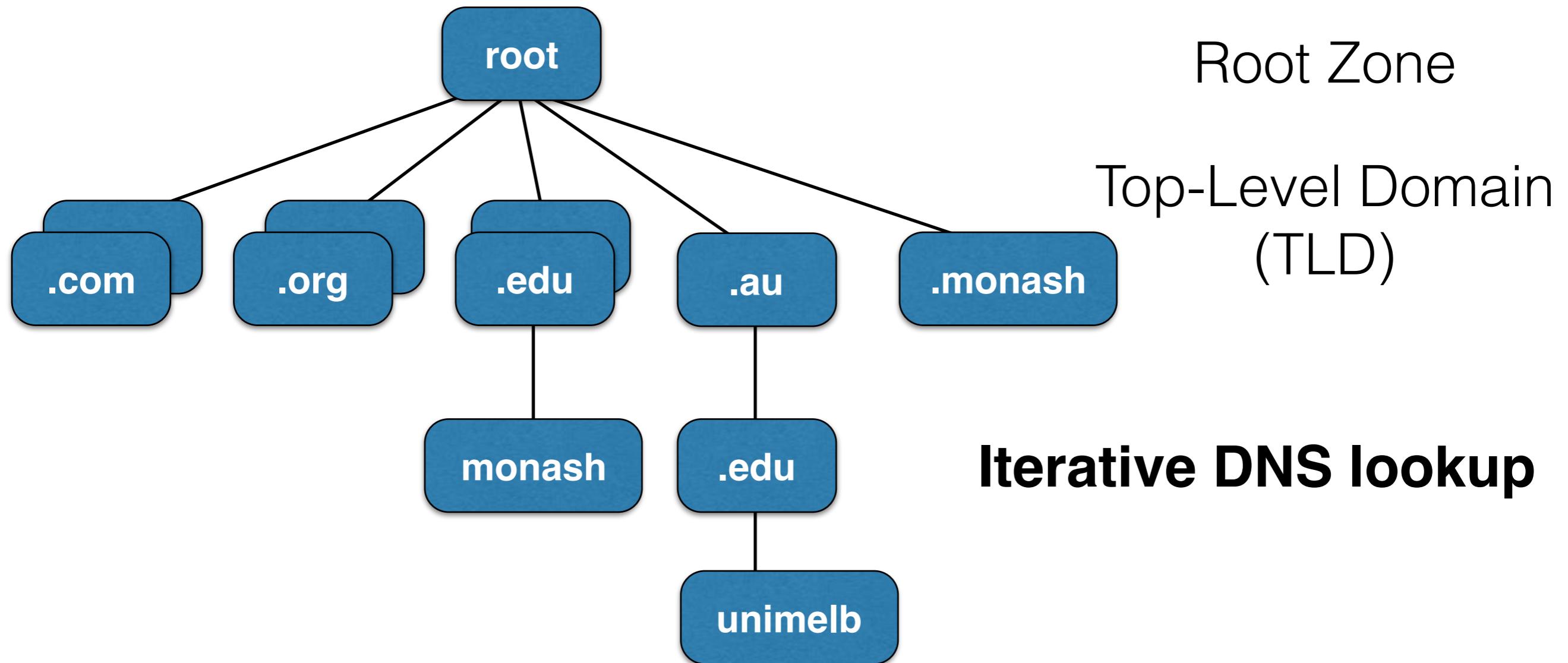


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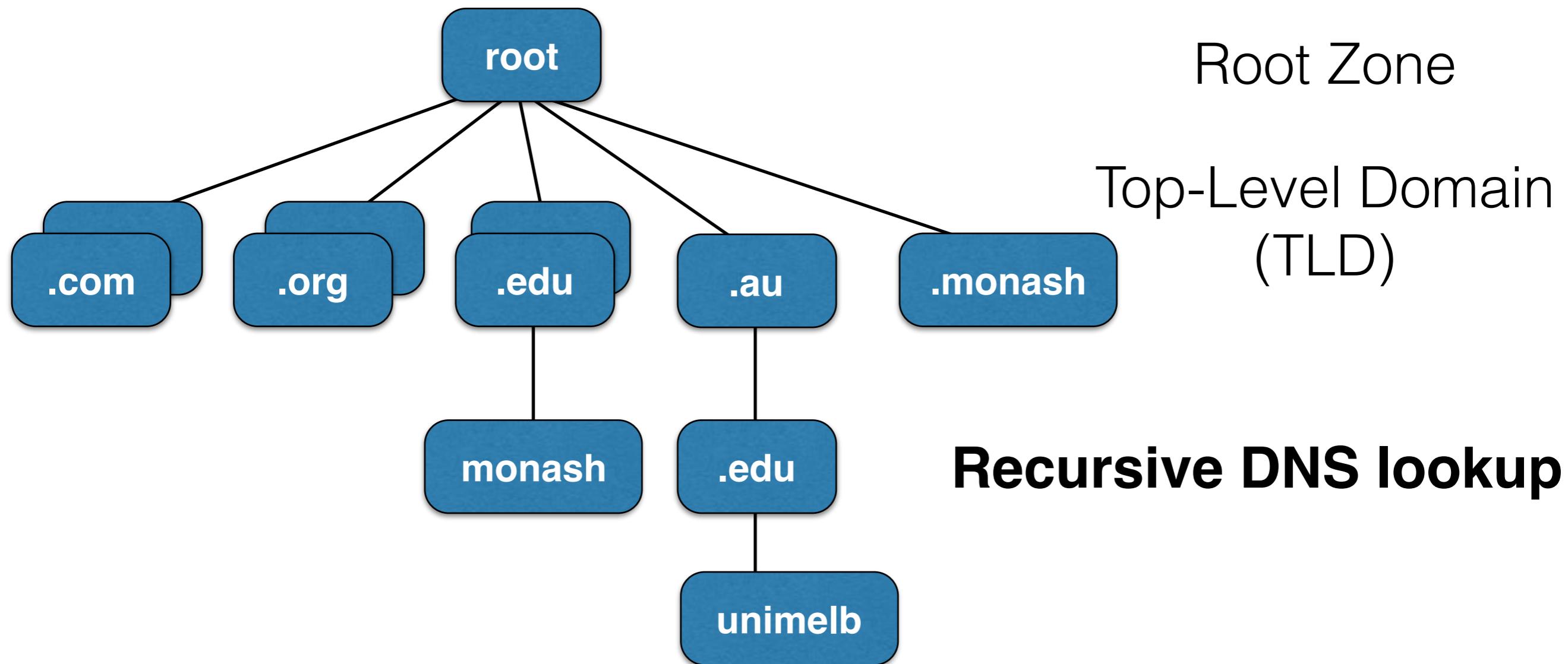


124.47.170.46

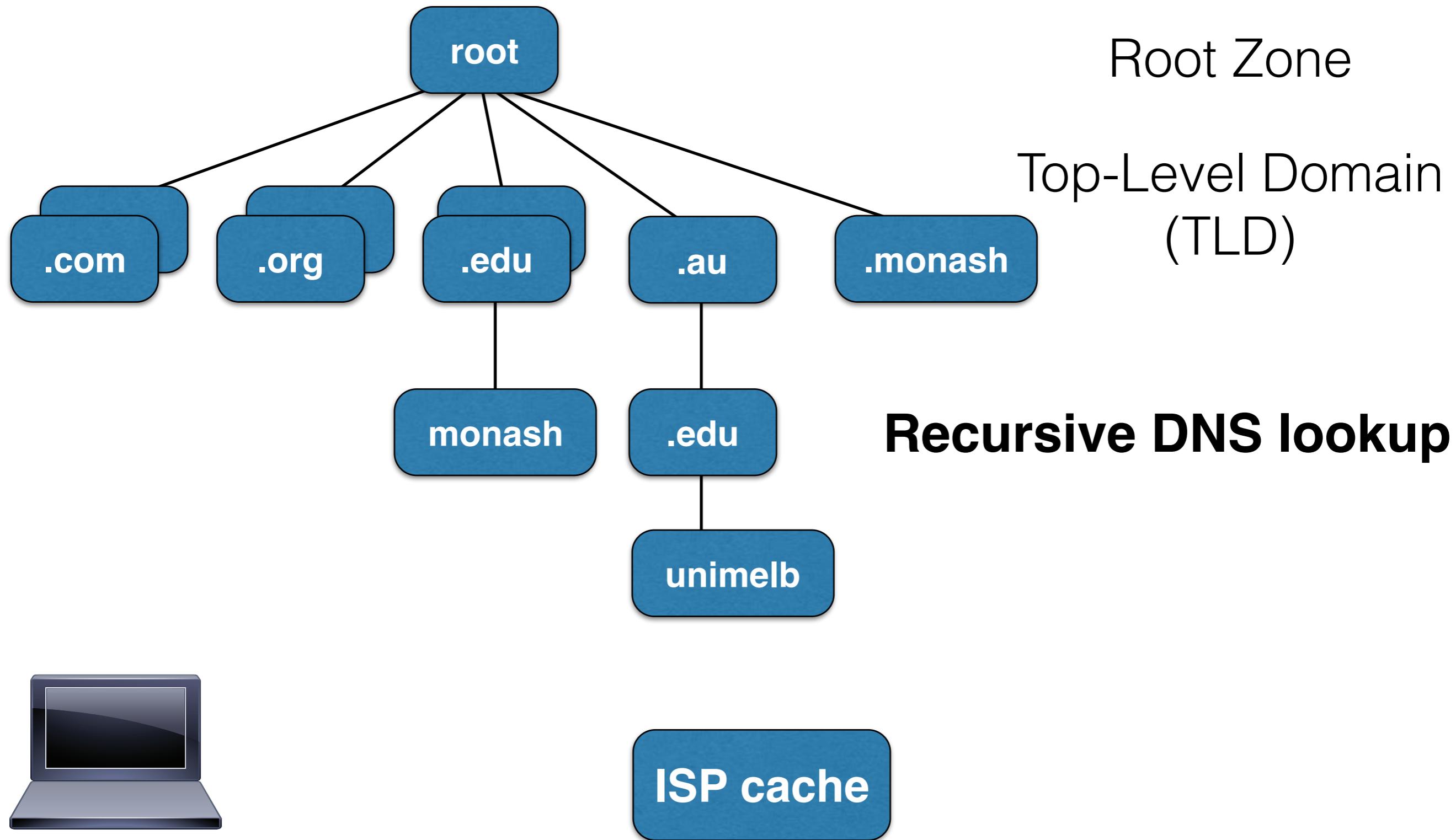
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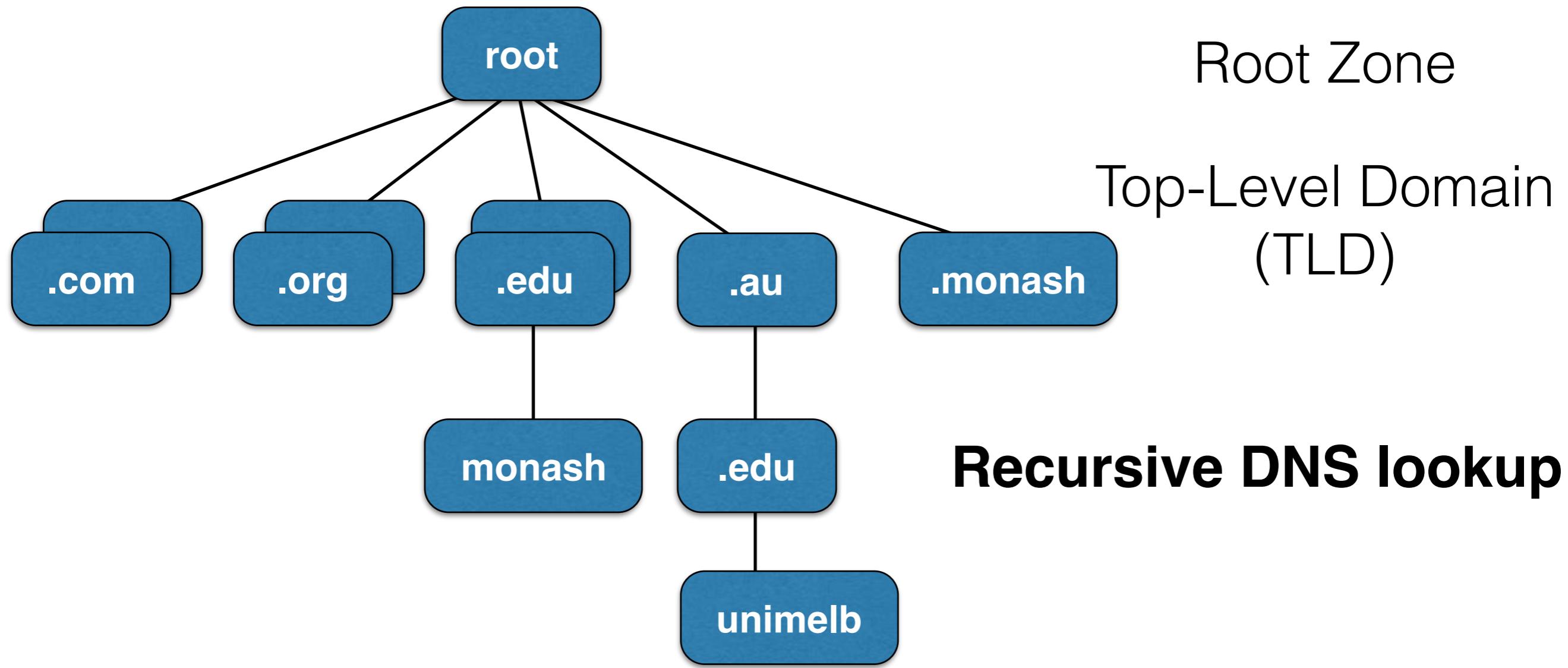
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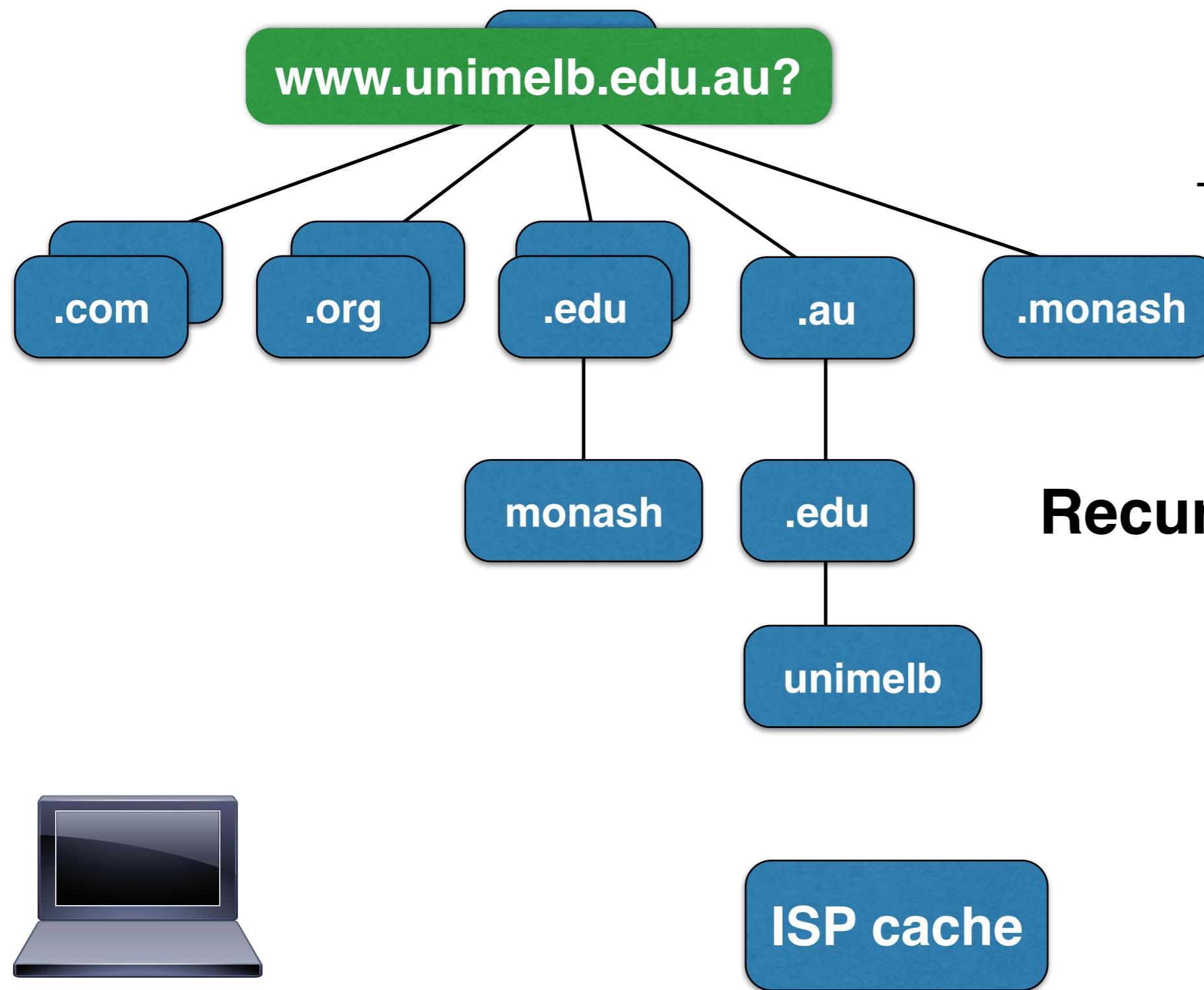
www.unimelb.edu.au?

Root Zone

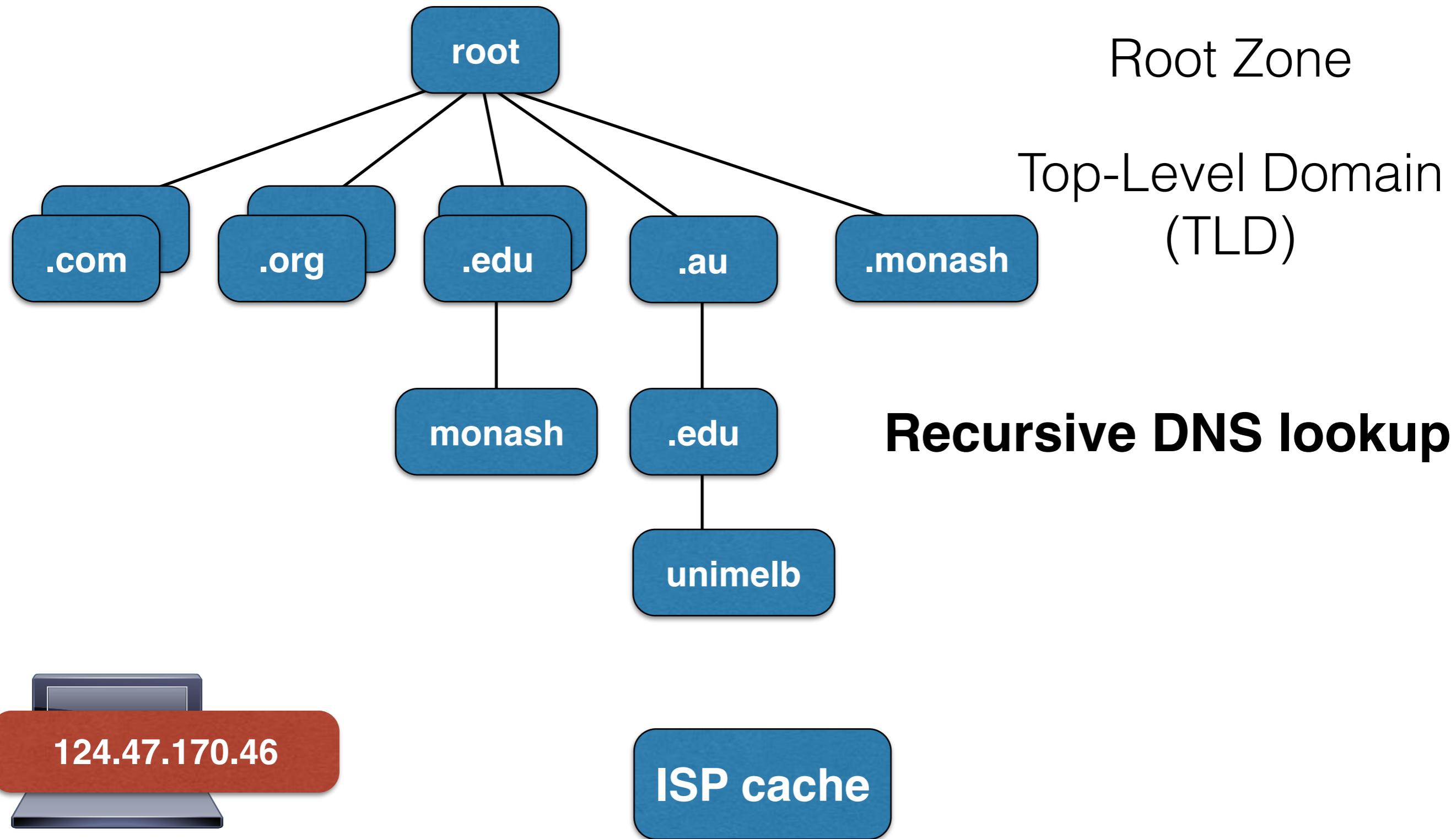
Top-Level Domain
(TLD)

Recursive DNS lookup

DNS

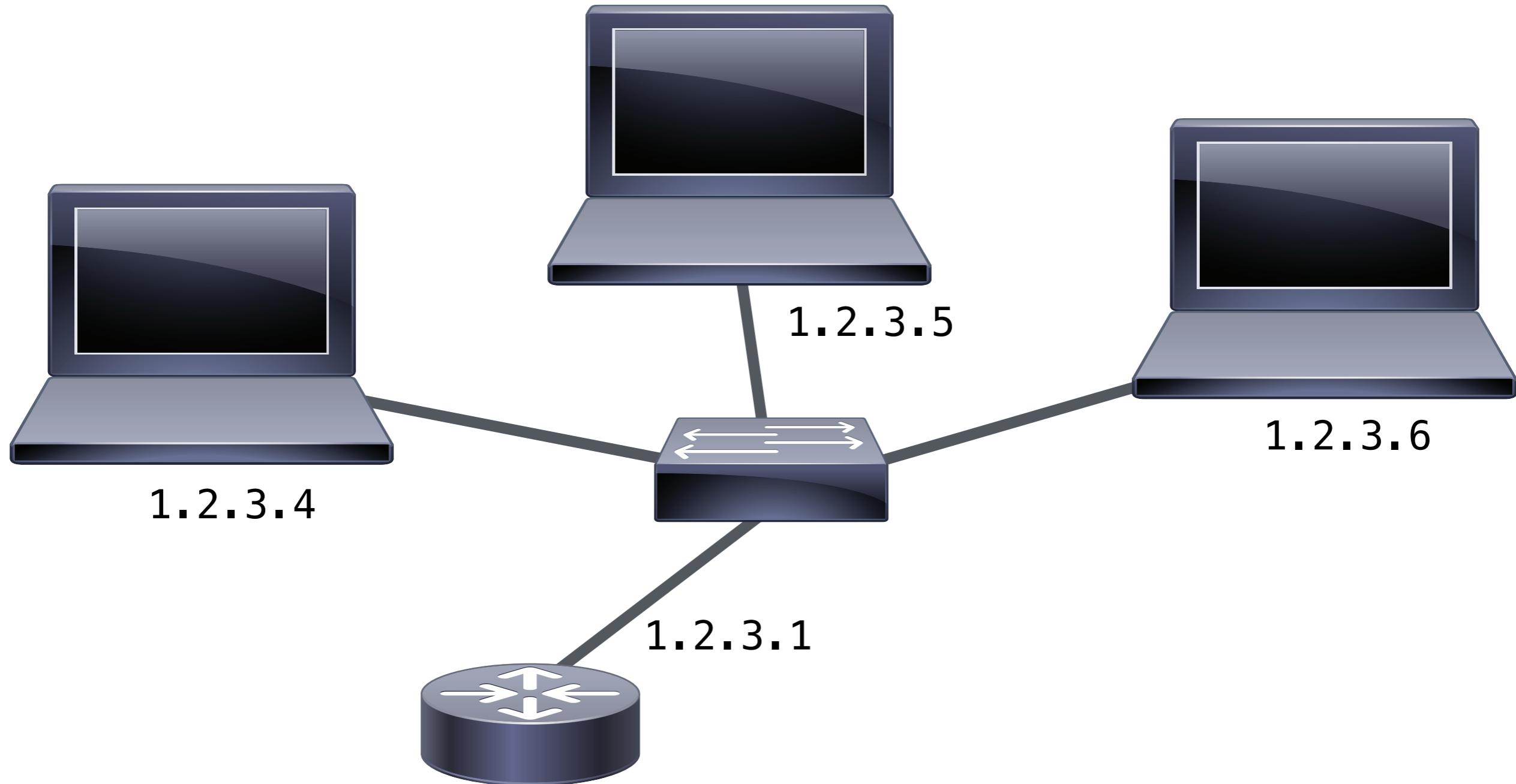


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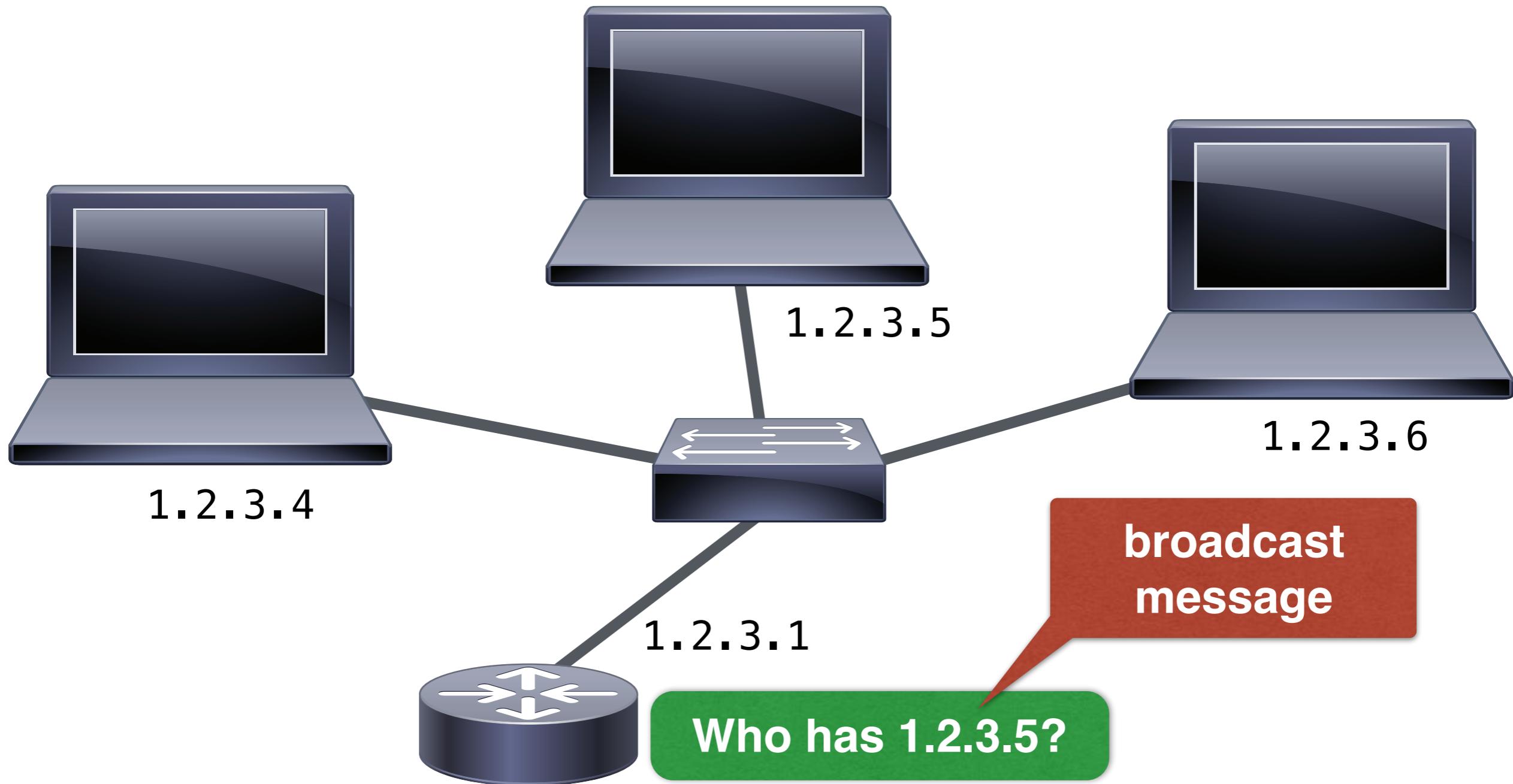
Address resolution: Data Link Layer

How to find the MAC address for an IP address:



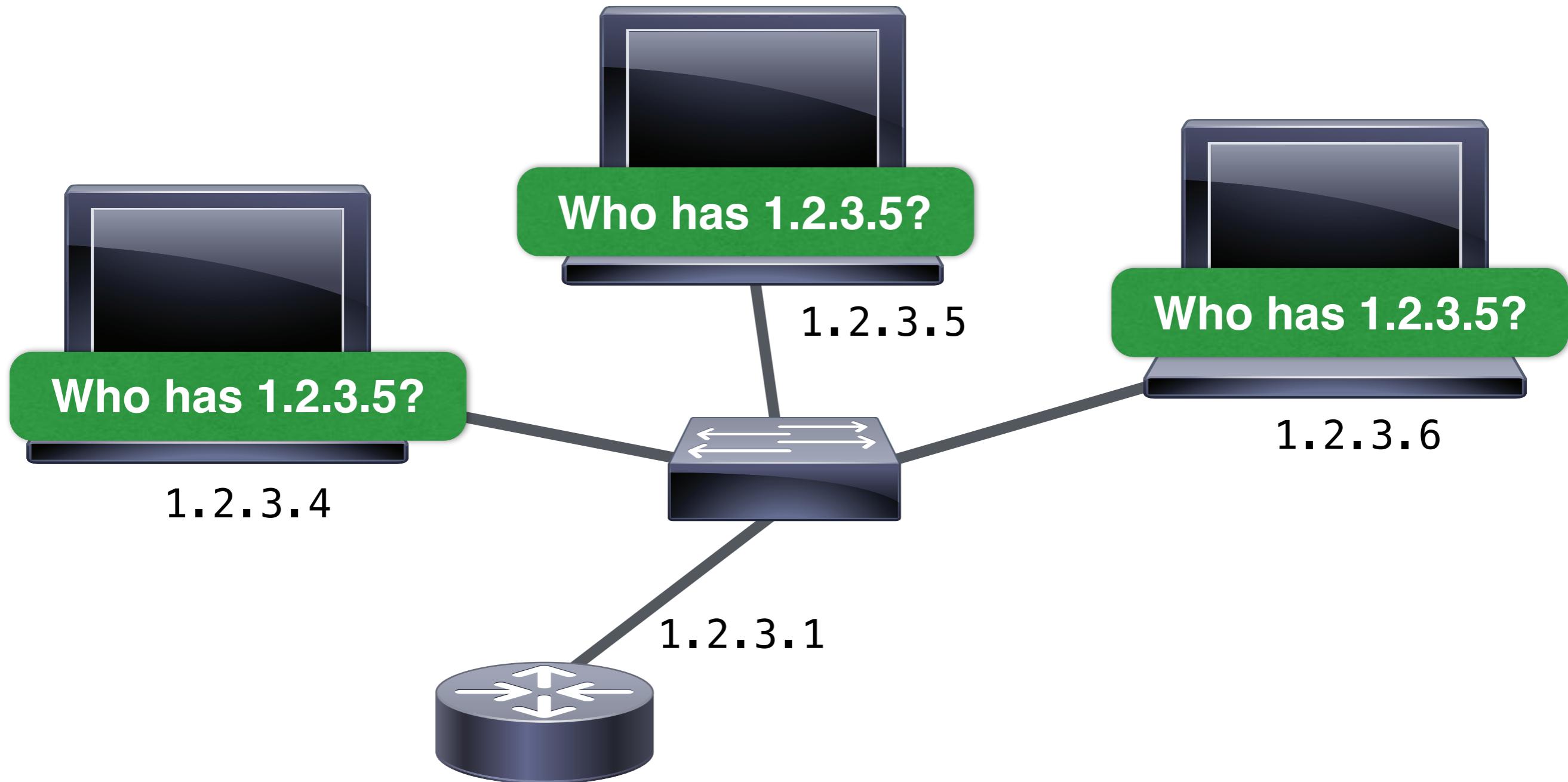
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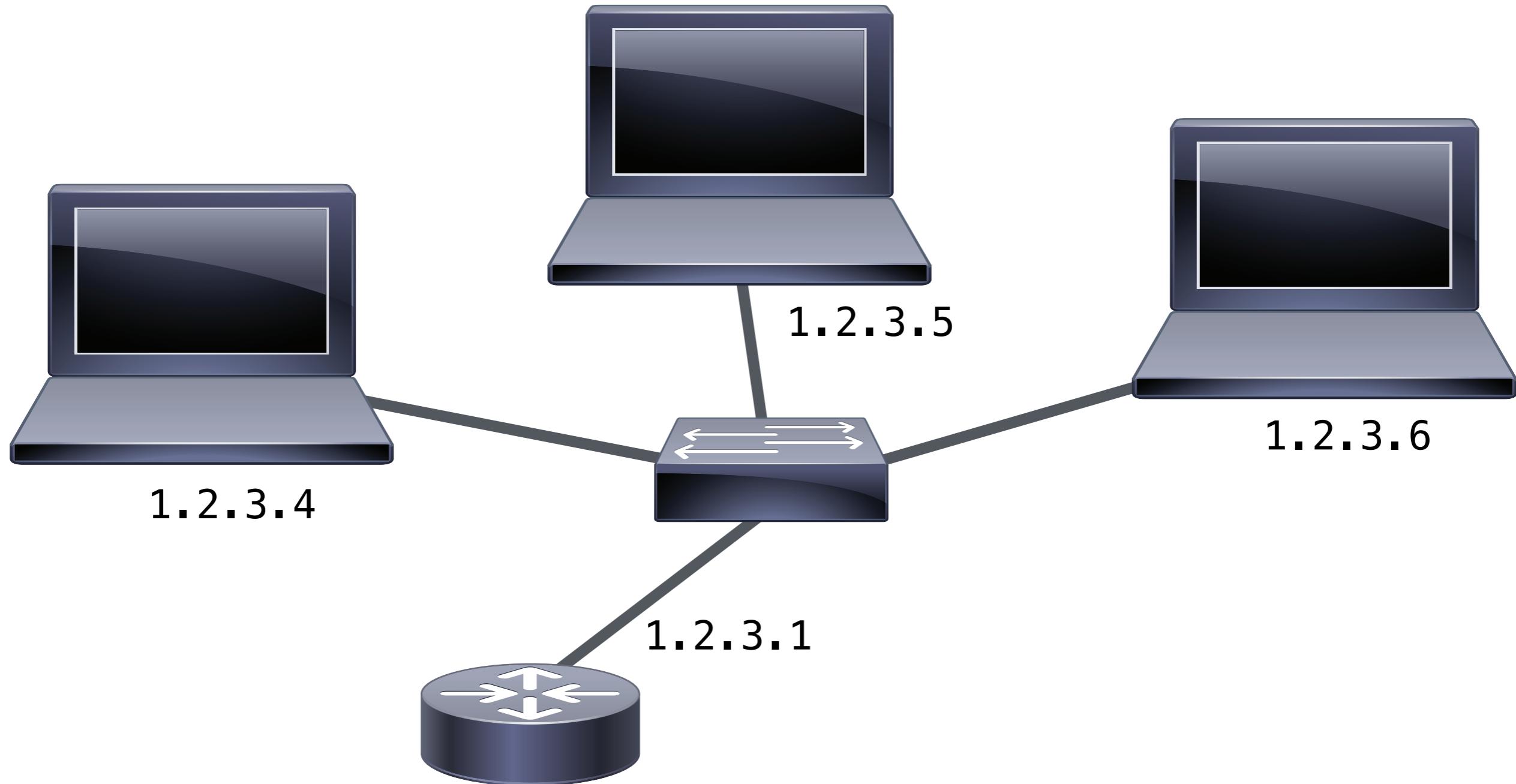
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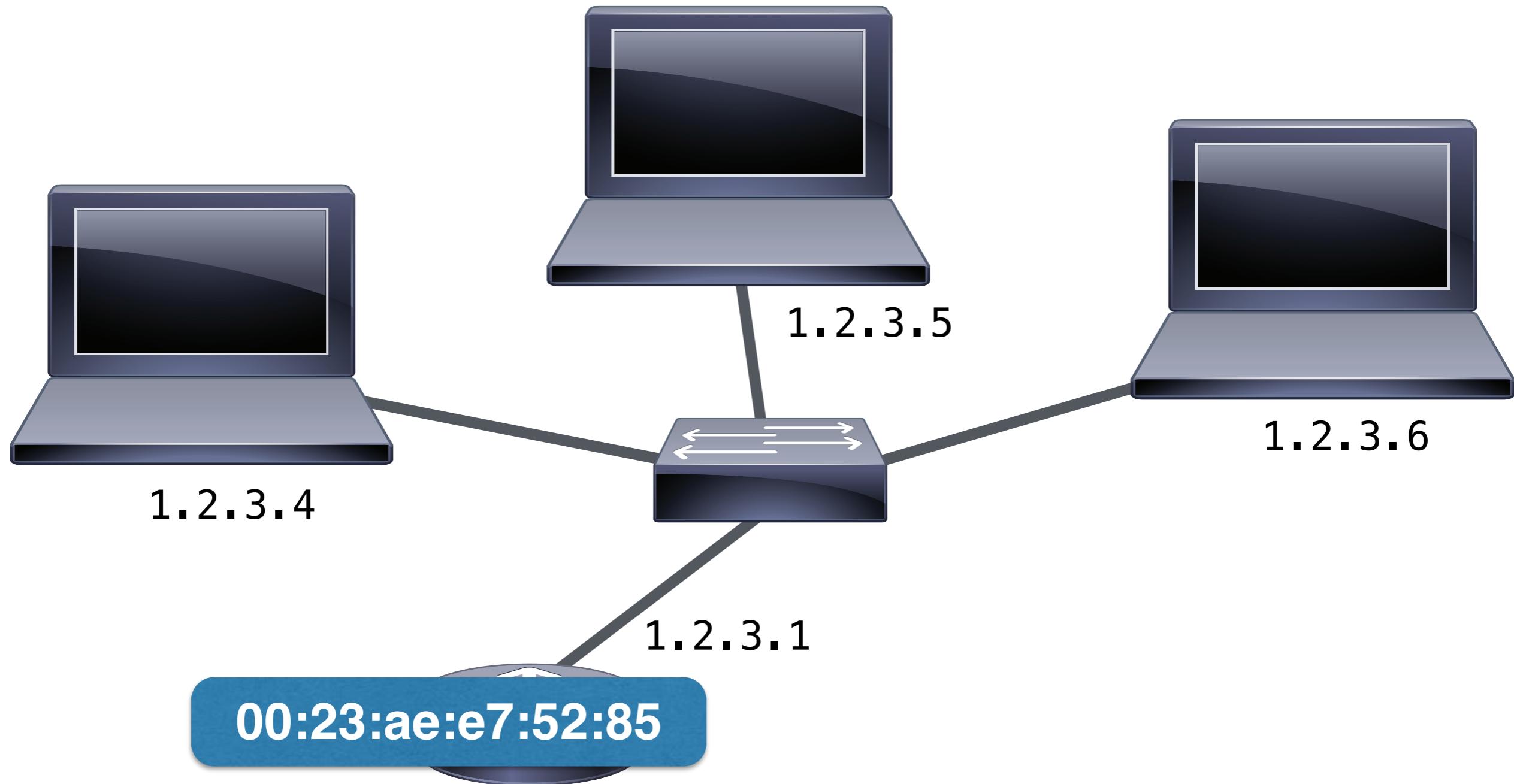
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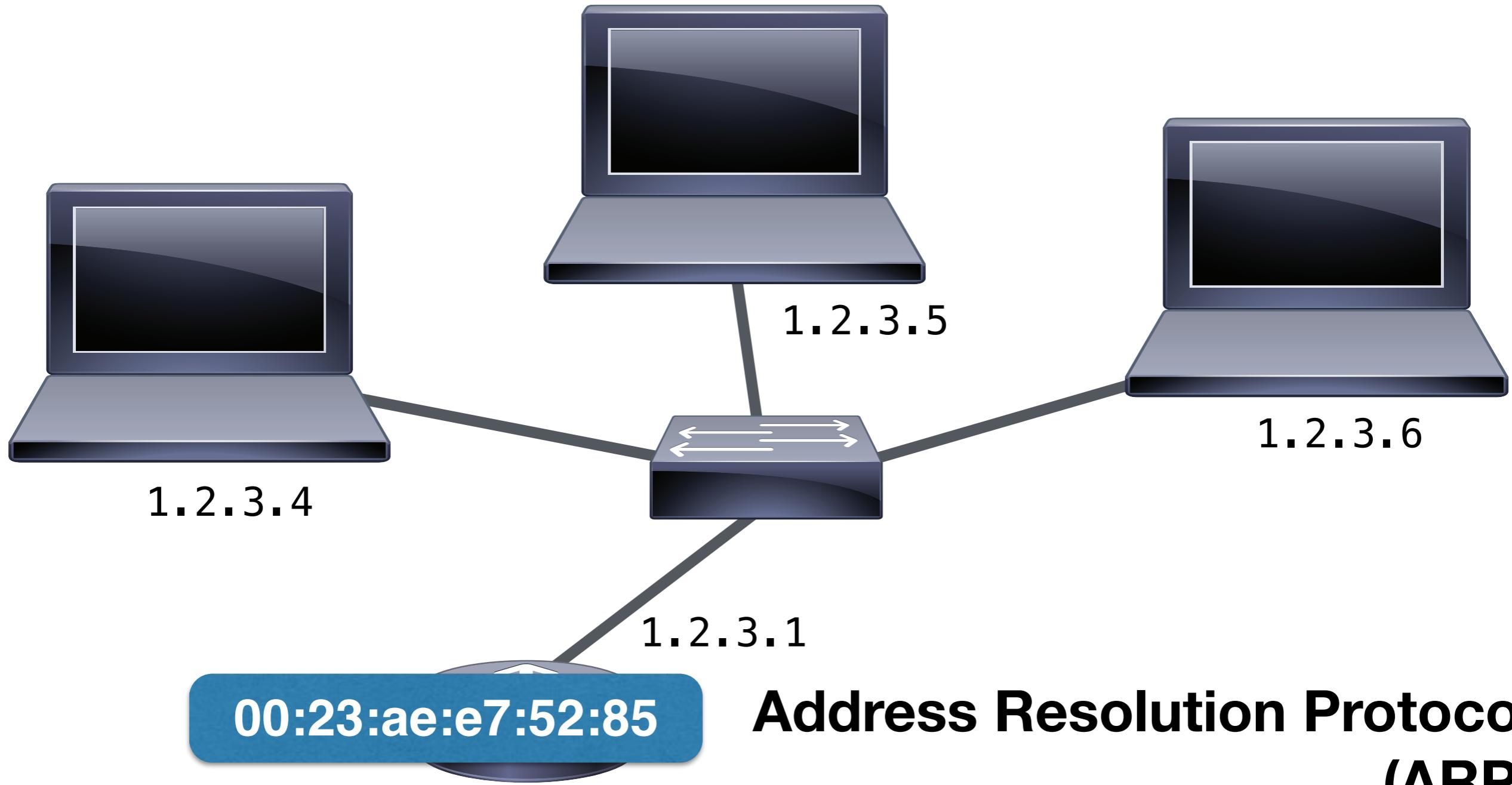
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The Network Layer: Routing

Routers

Routers connect networks

- Internet is a network of networks!
- Most important piece of Internet infrastructure

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A router is a layer 3 device

- one IP address per **interface**, i.e. typically per subnet it is connected to
- Clients send packets to routers **if destination is outside their own subnet**
- Routers use IP address to determine **where the packet is sent next**

Routing tables

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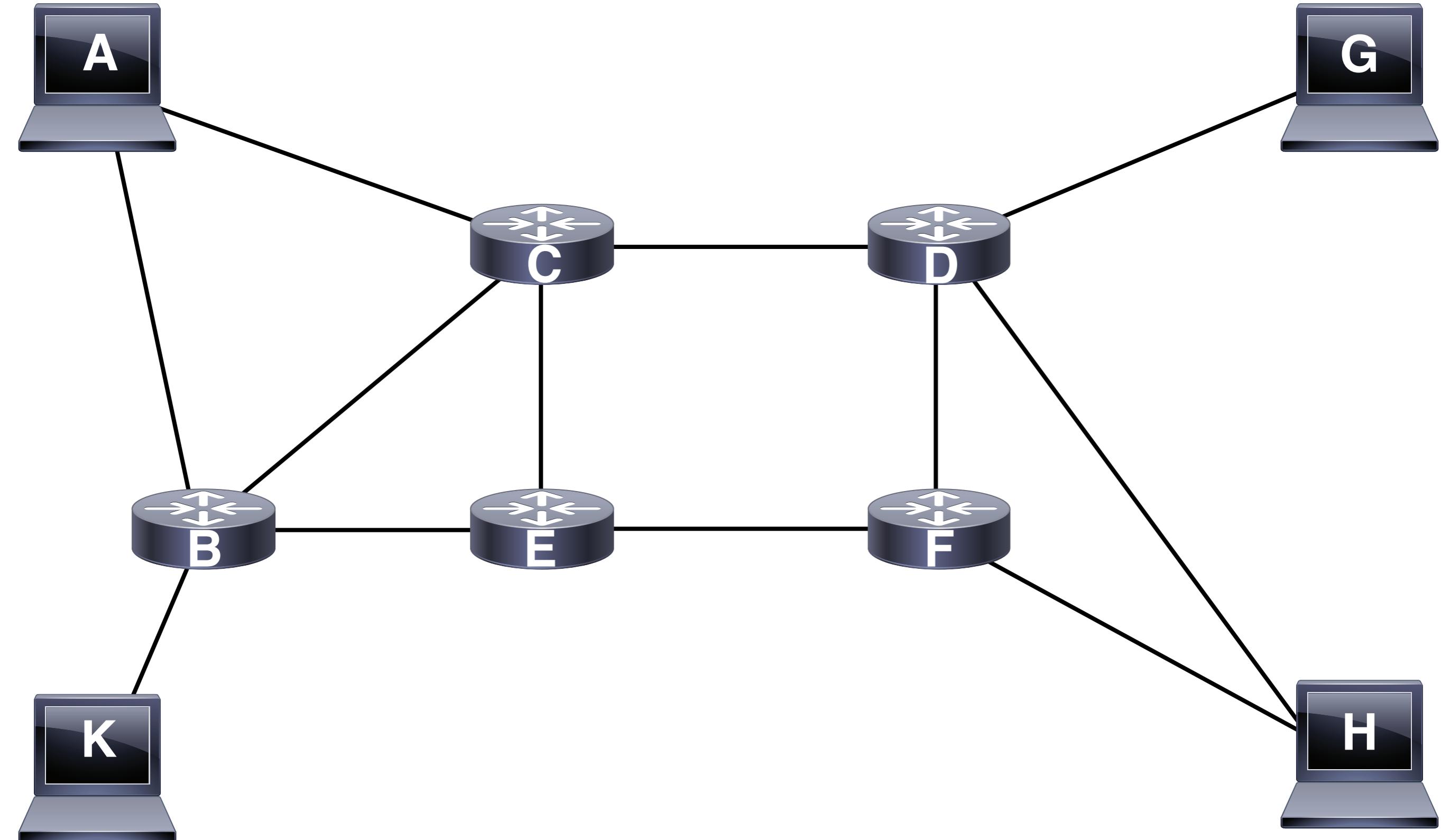
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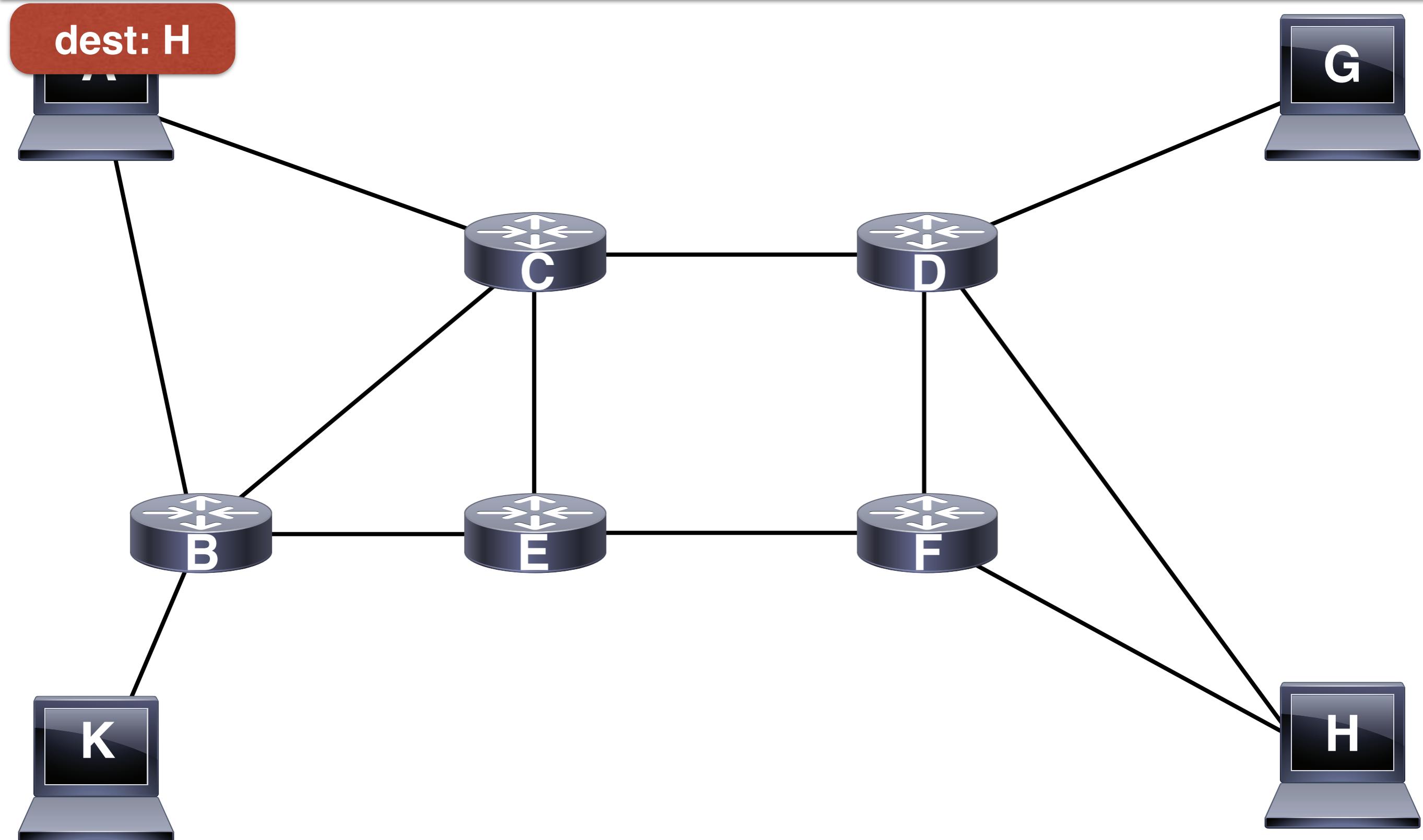
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- if no default gateway configured: **packet can't be routed**

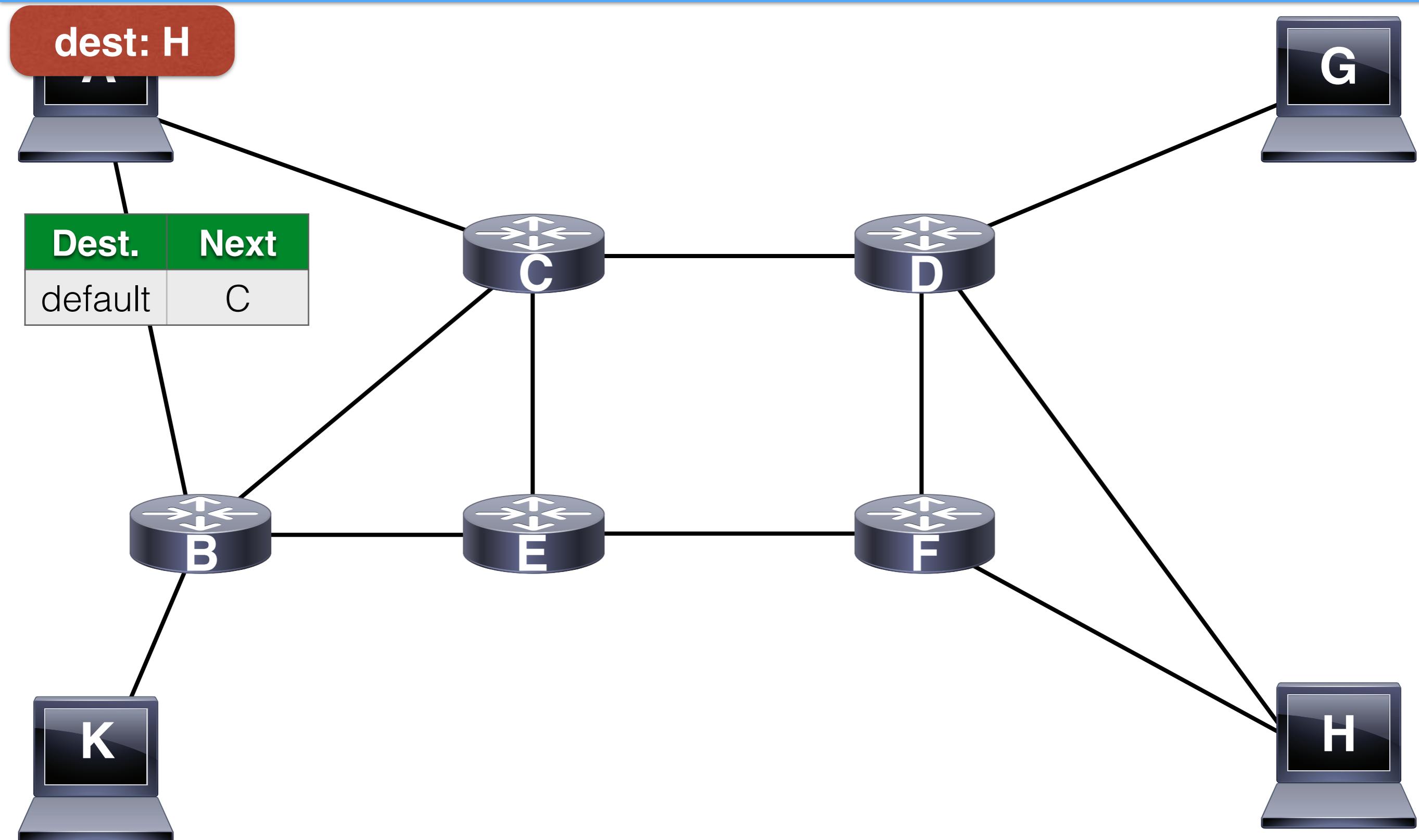
Routing example



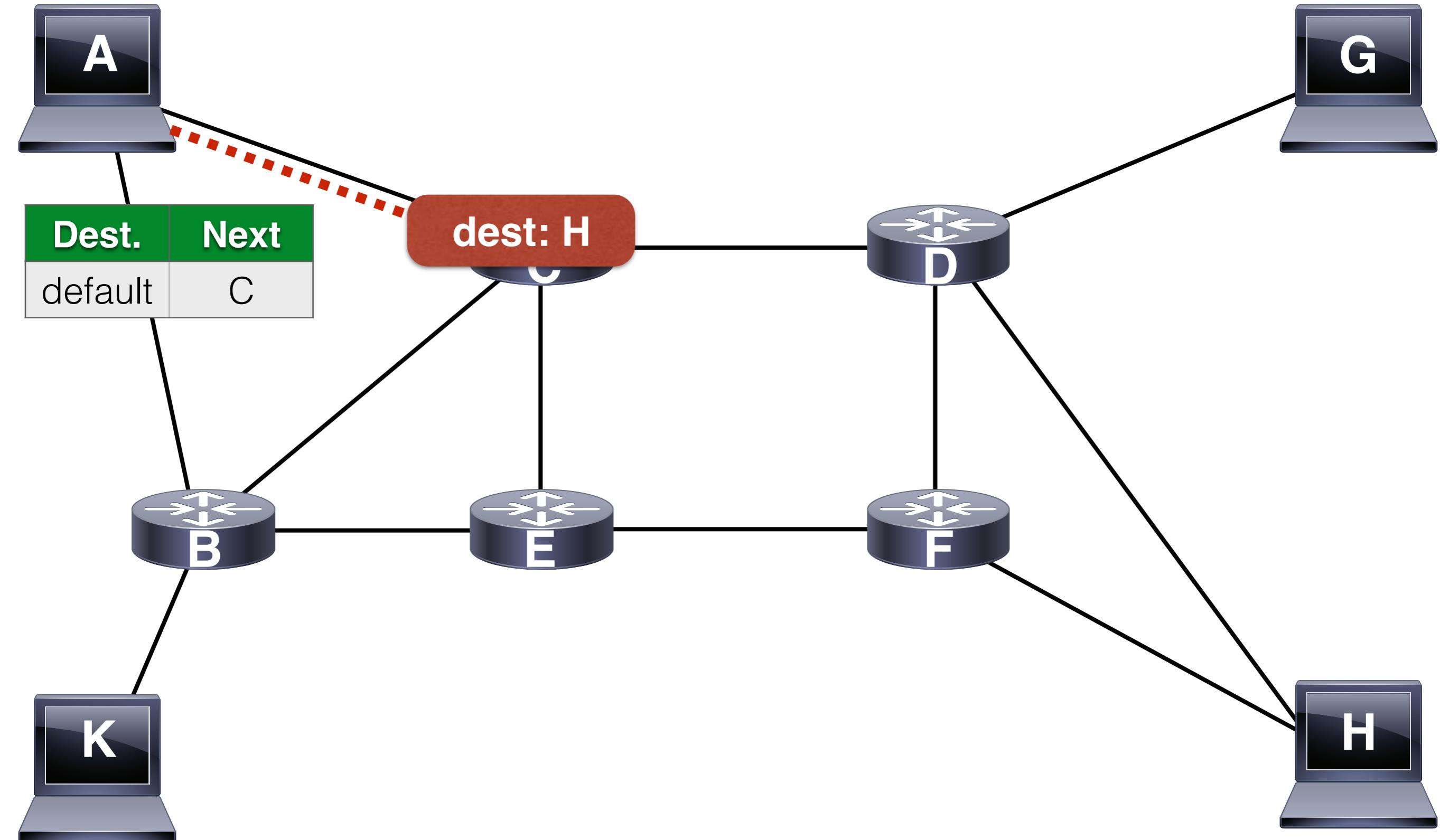
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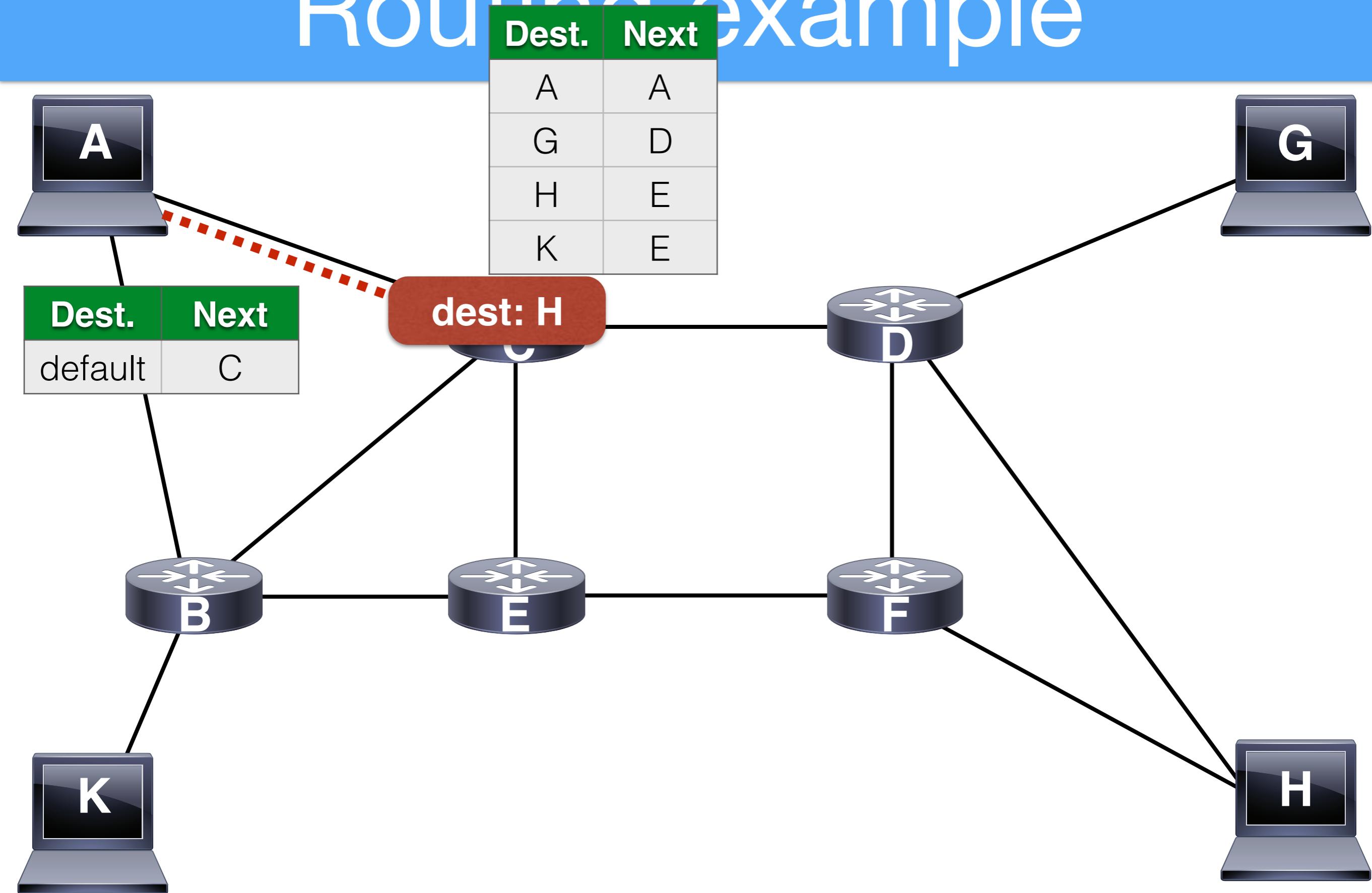
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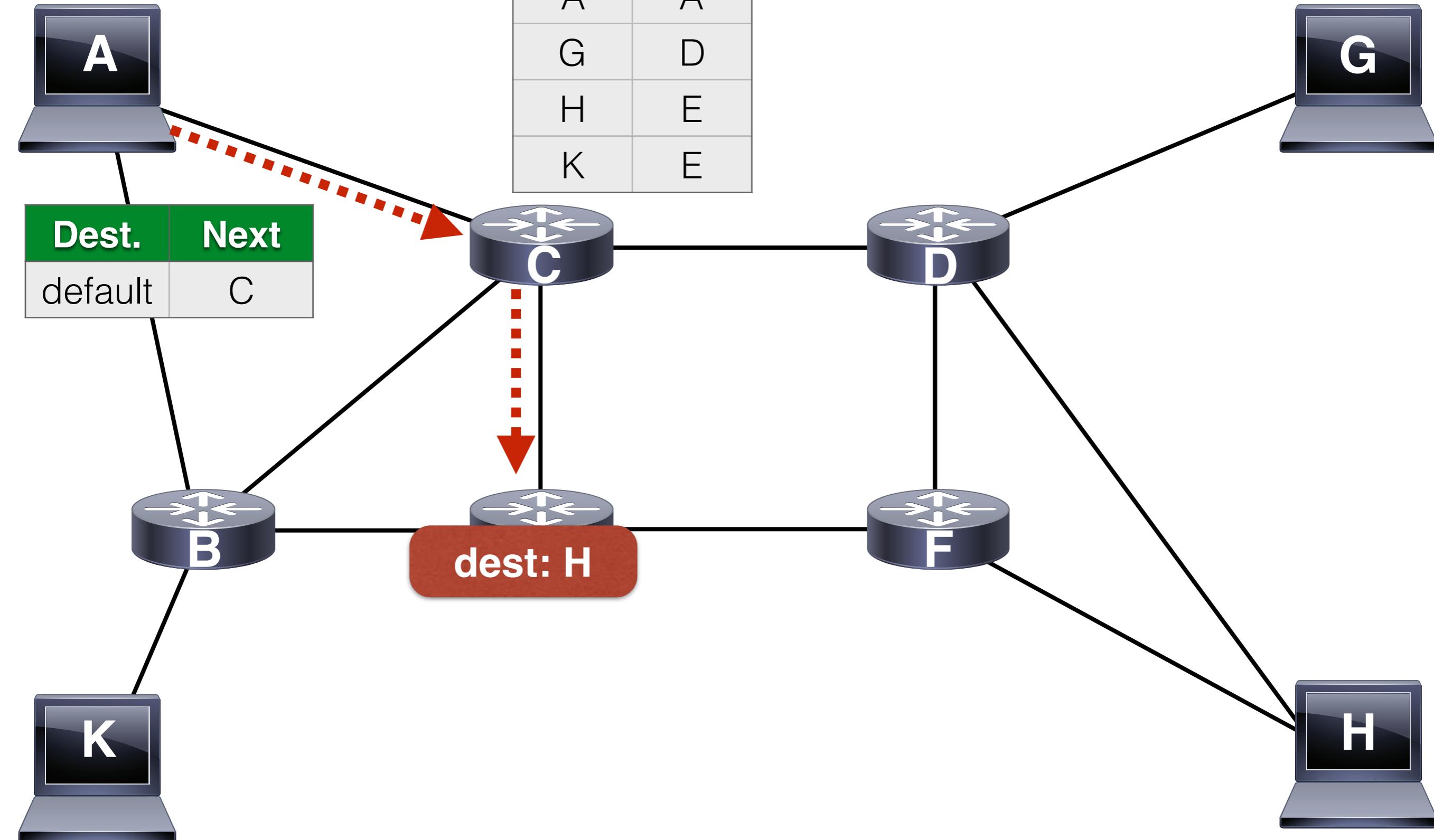
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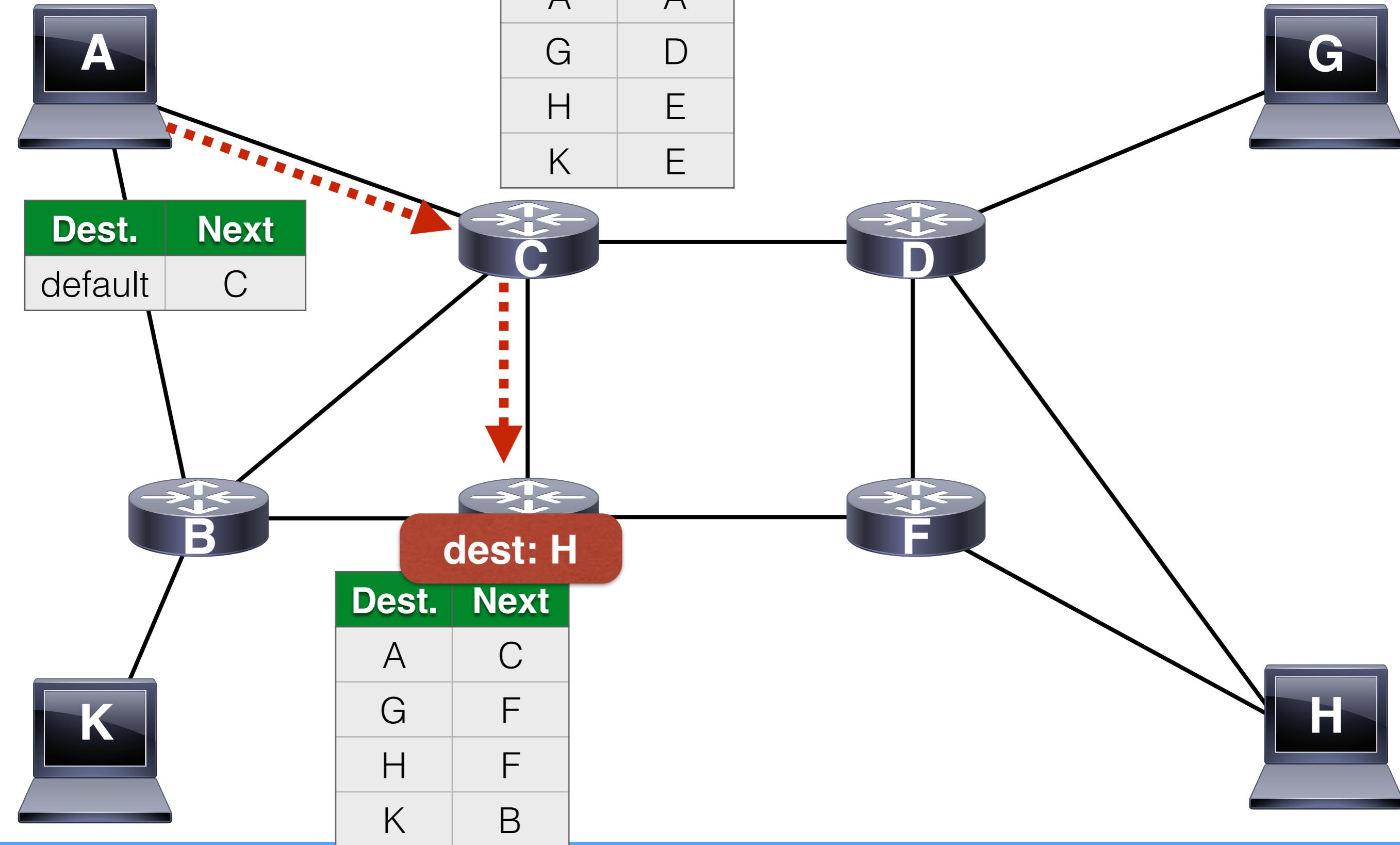
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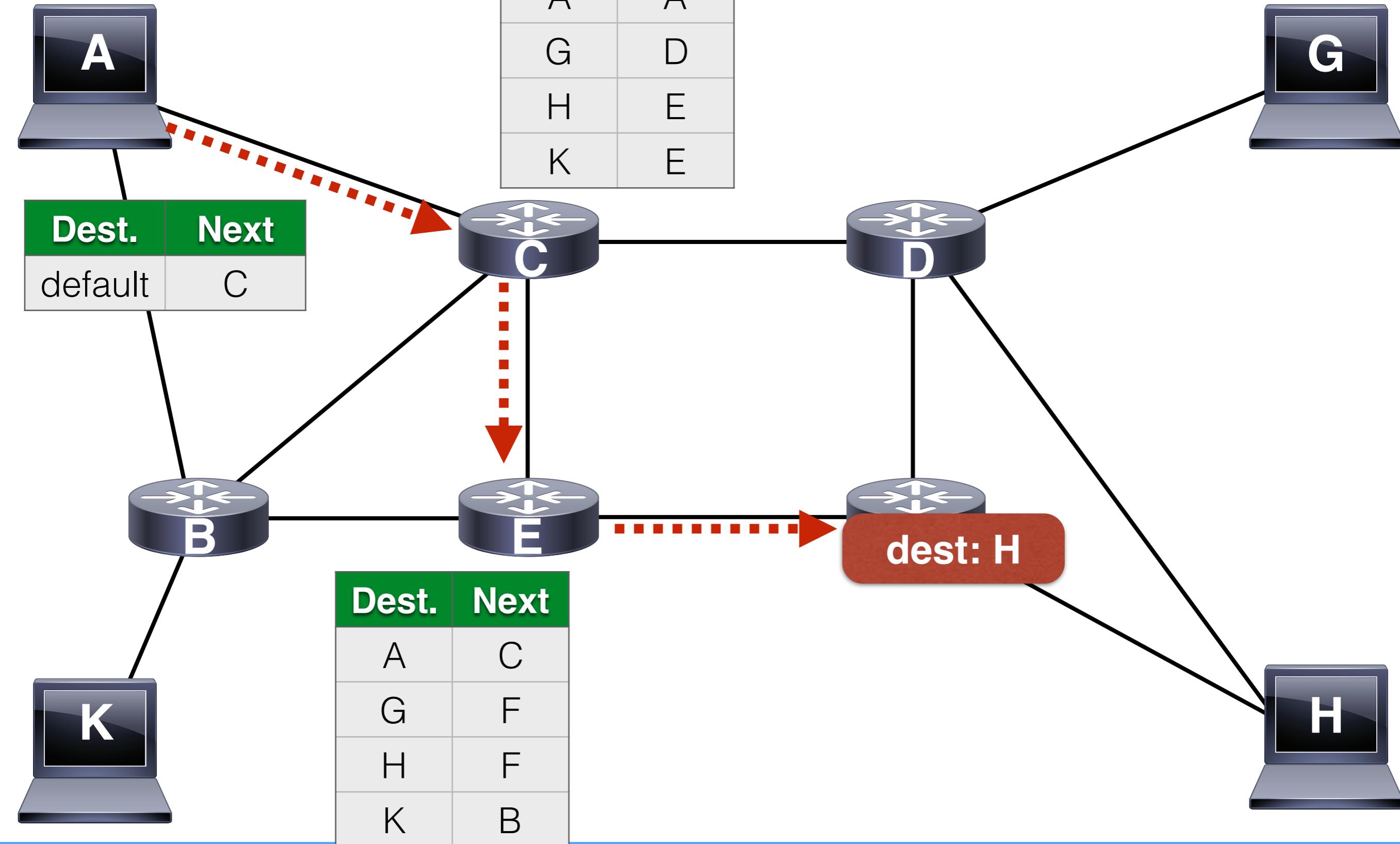
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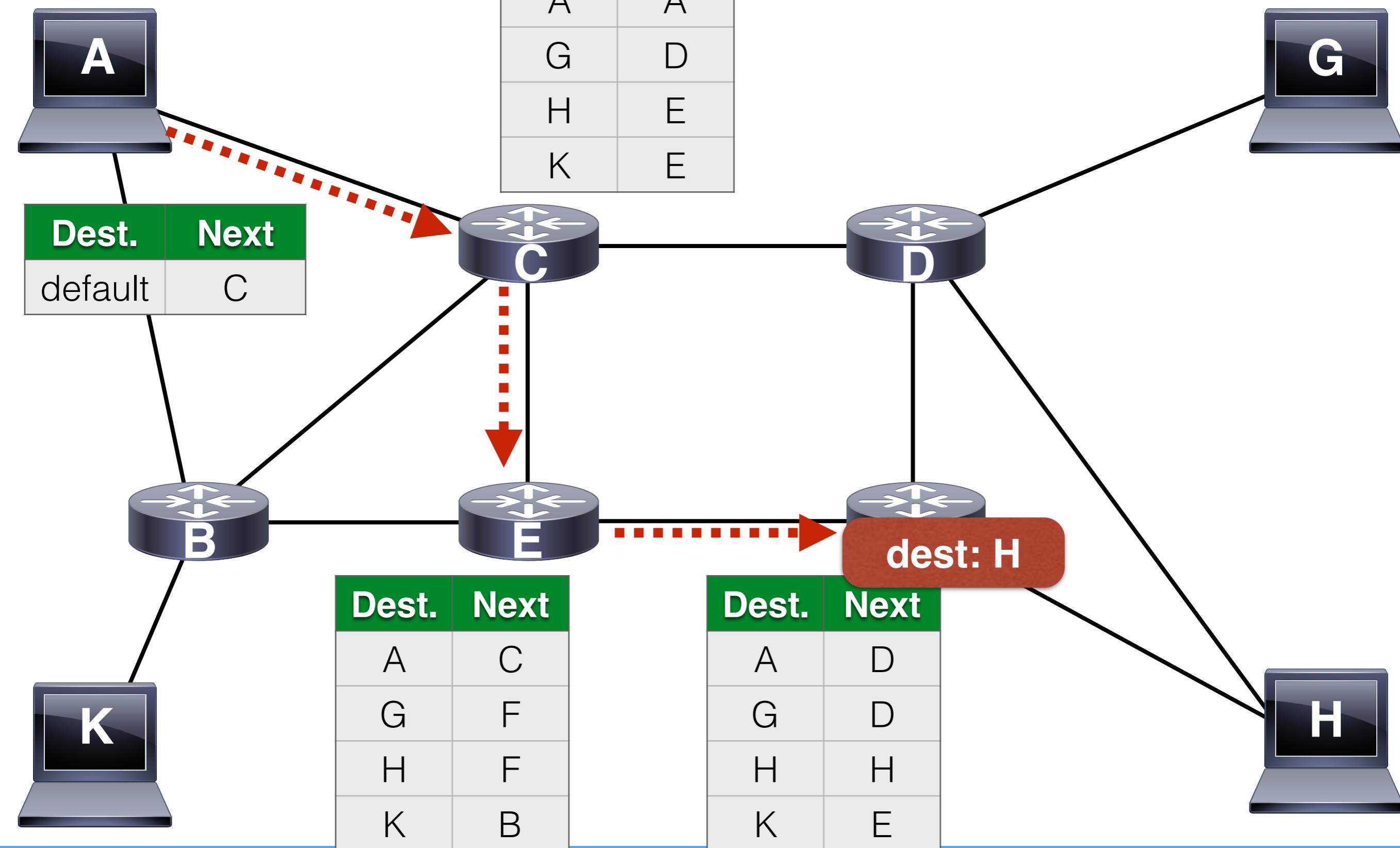
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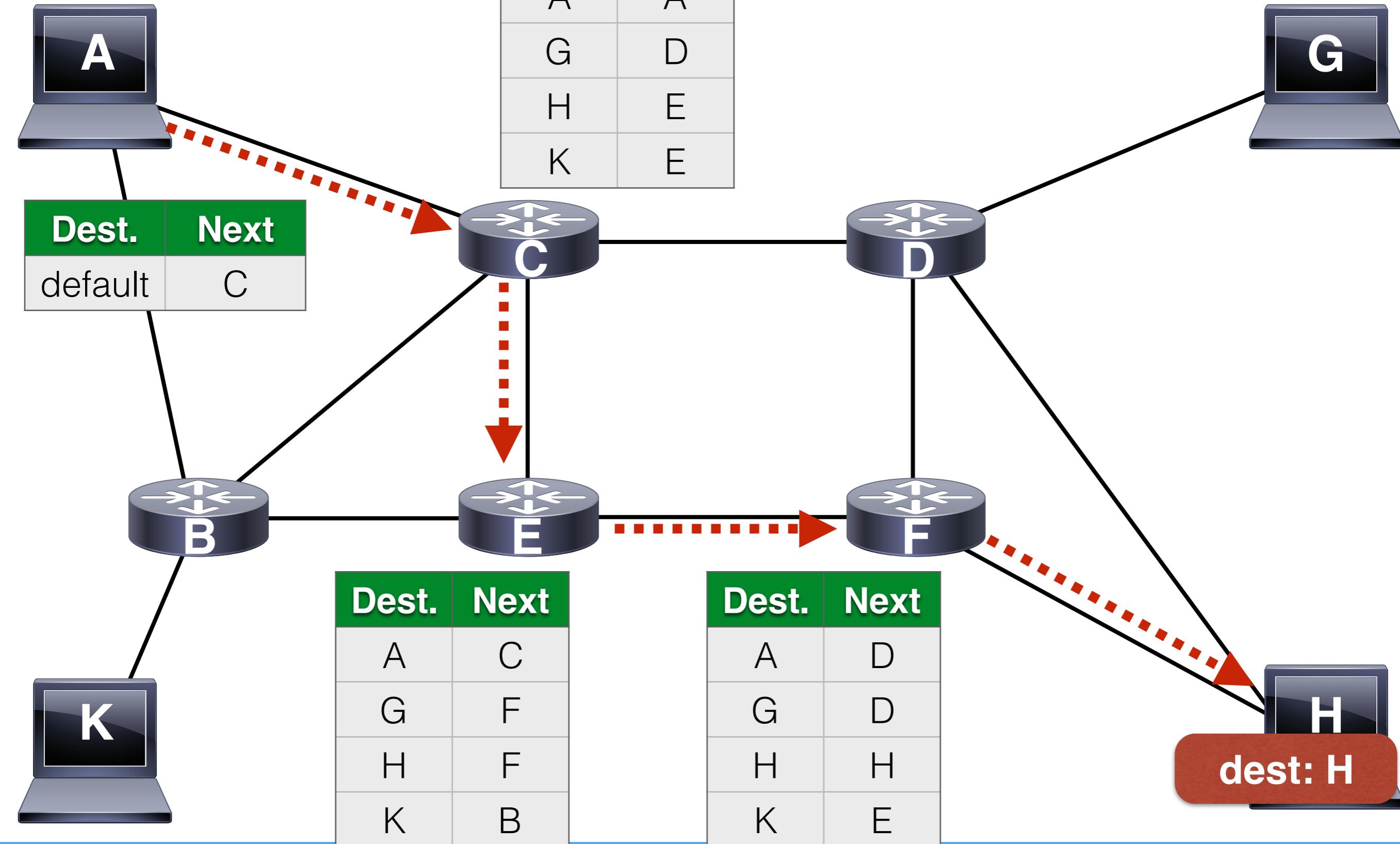
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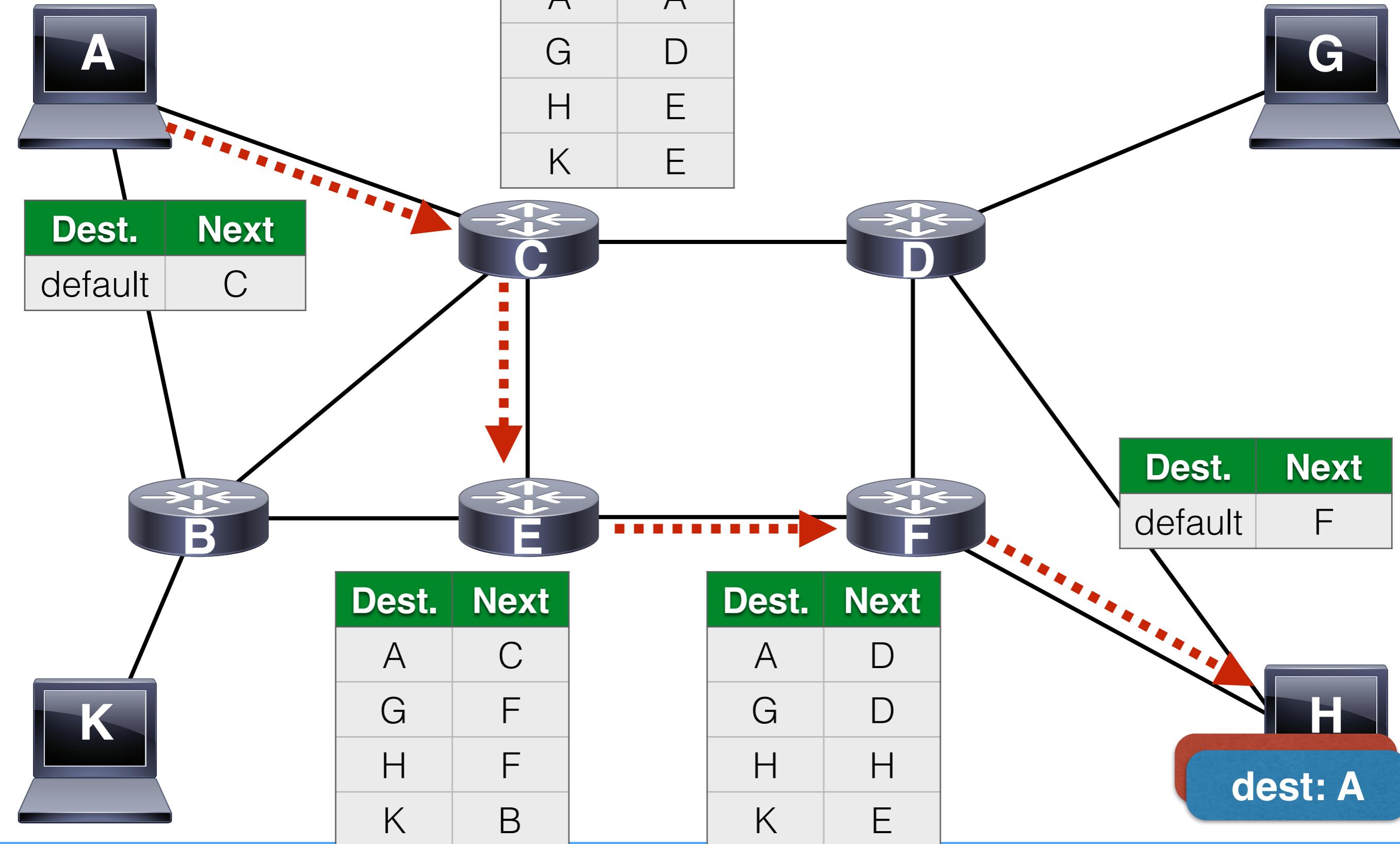
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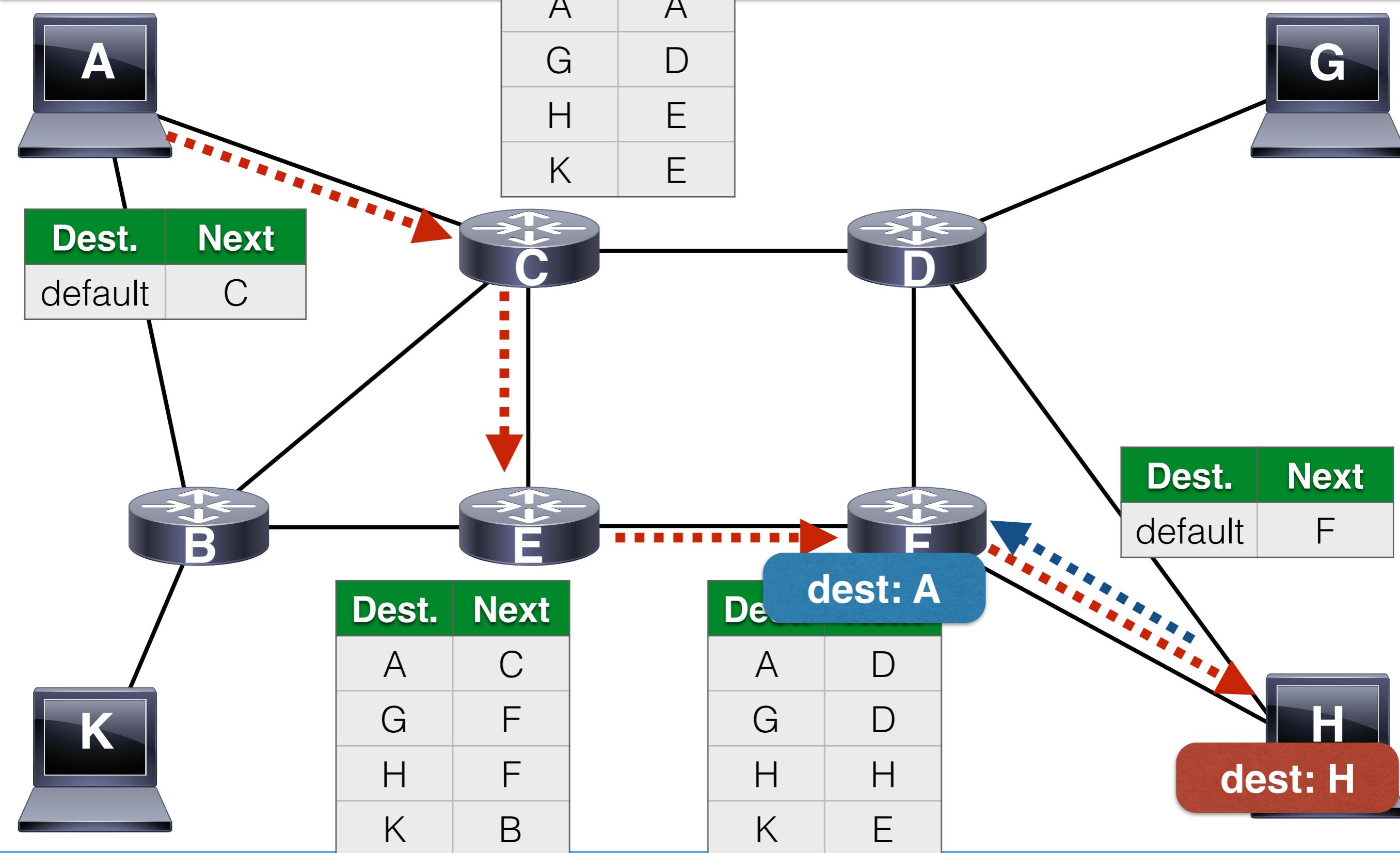
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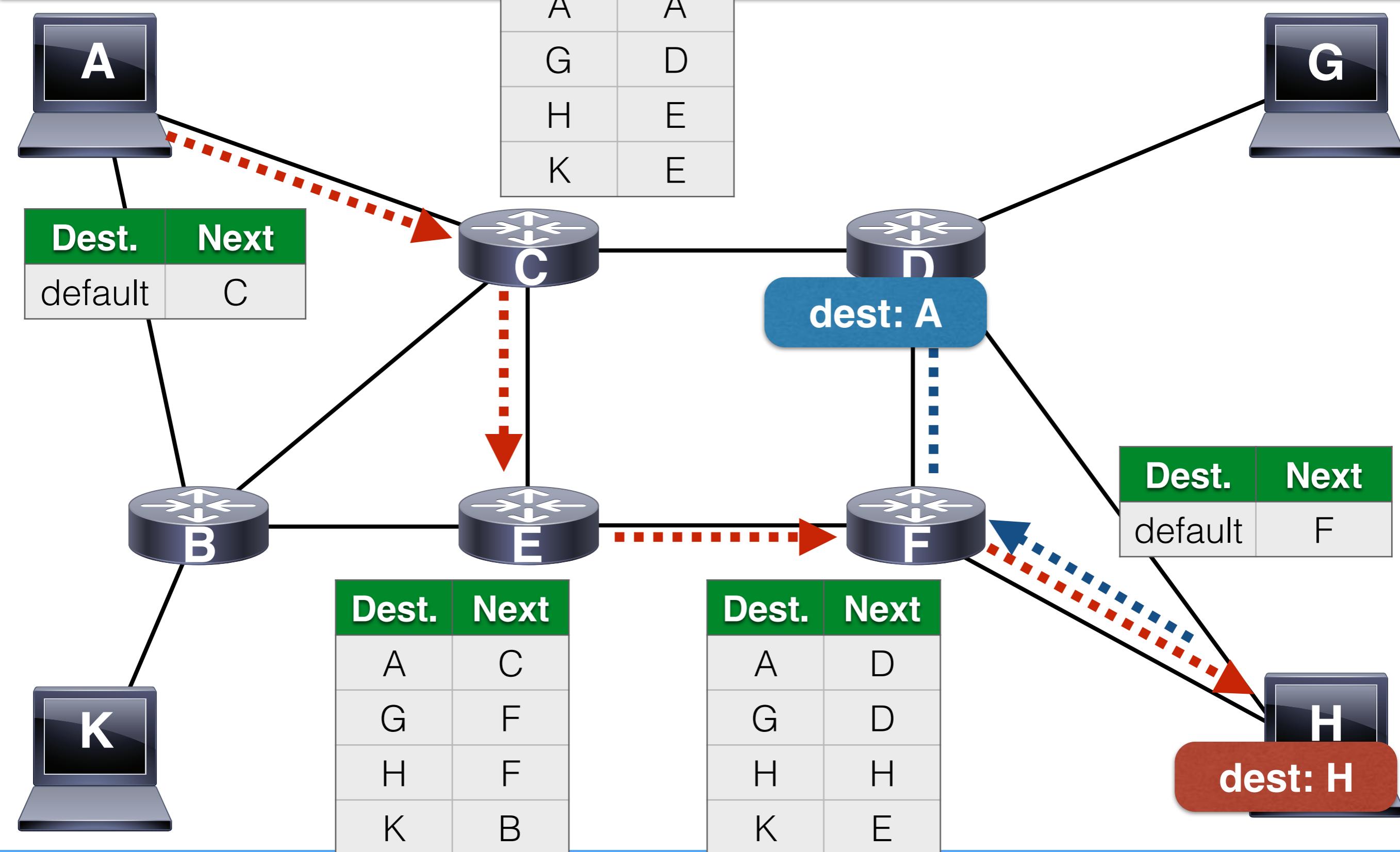
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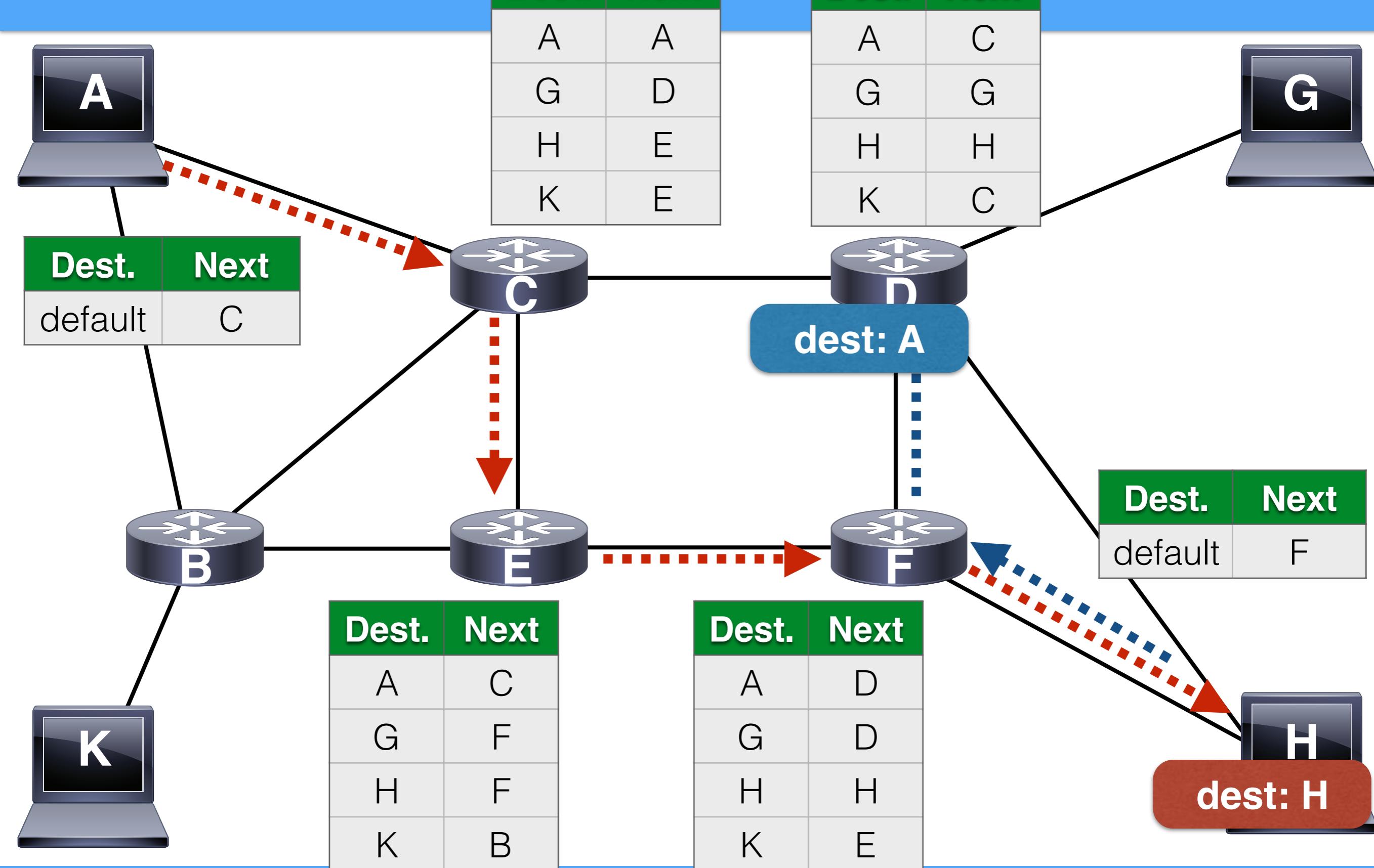
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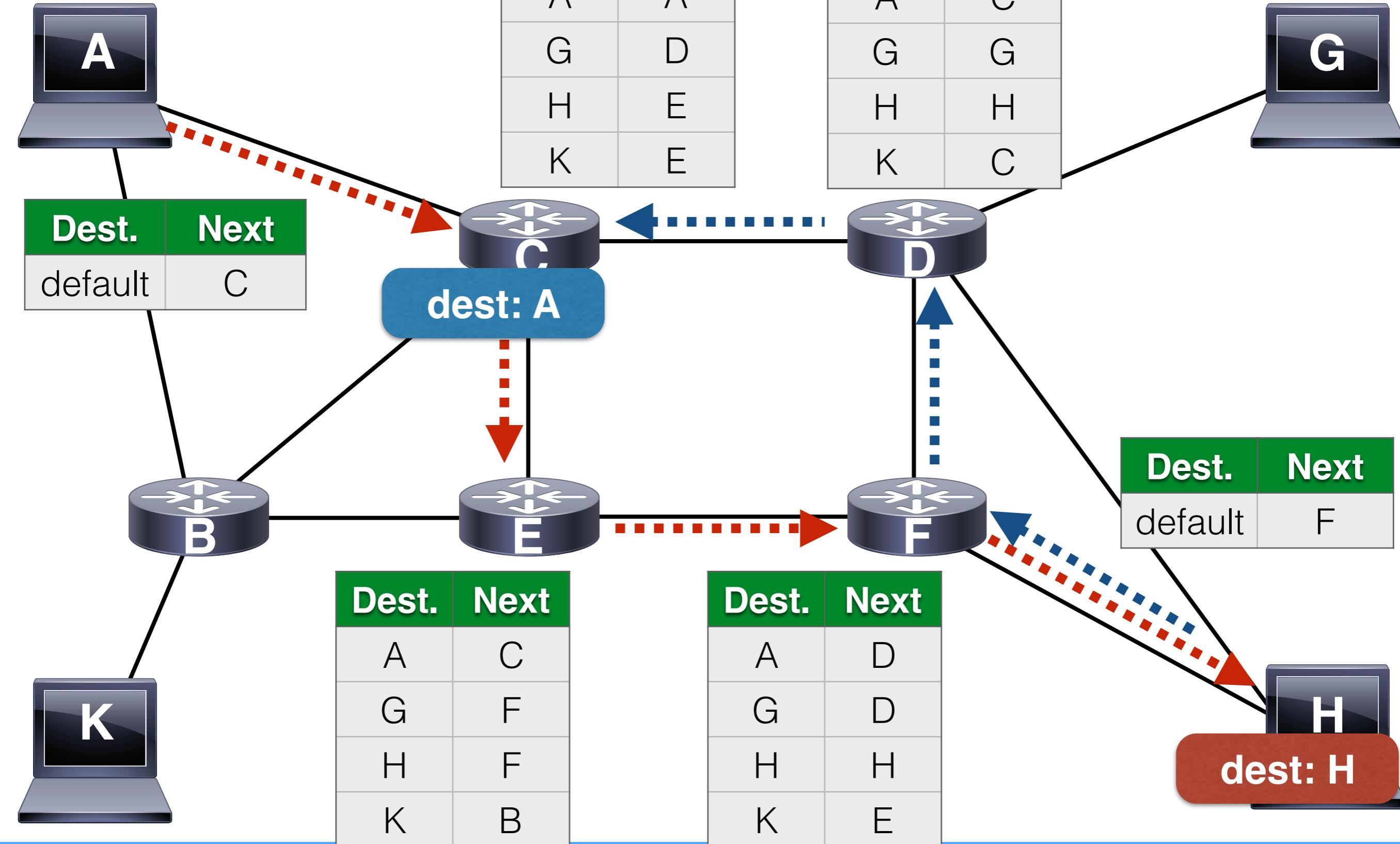
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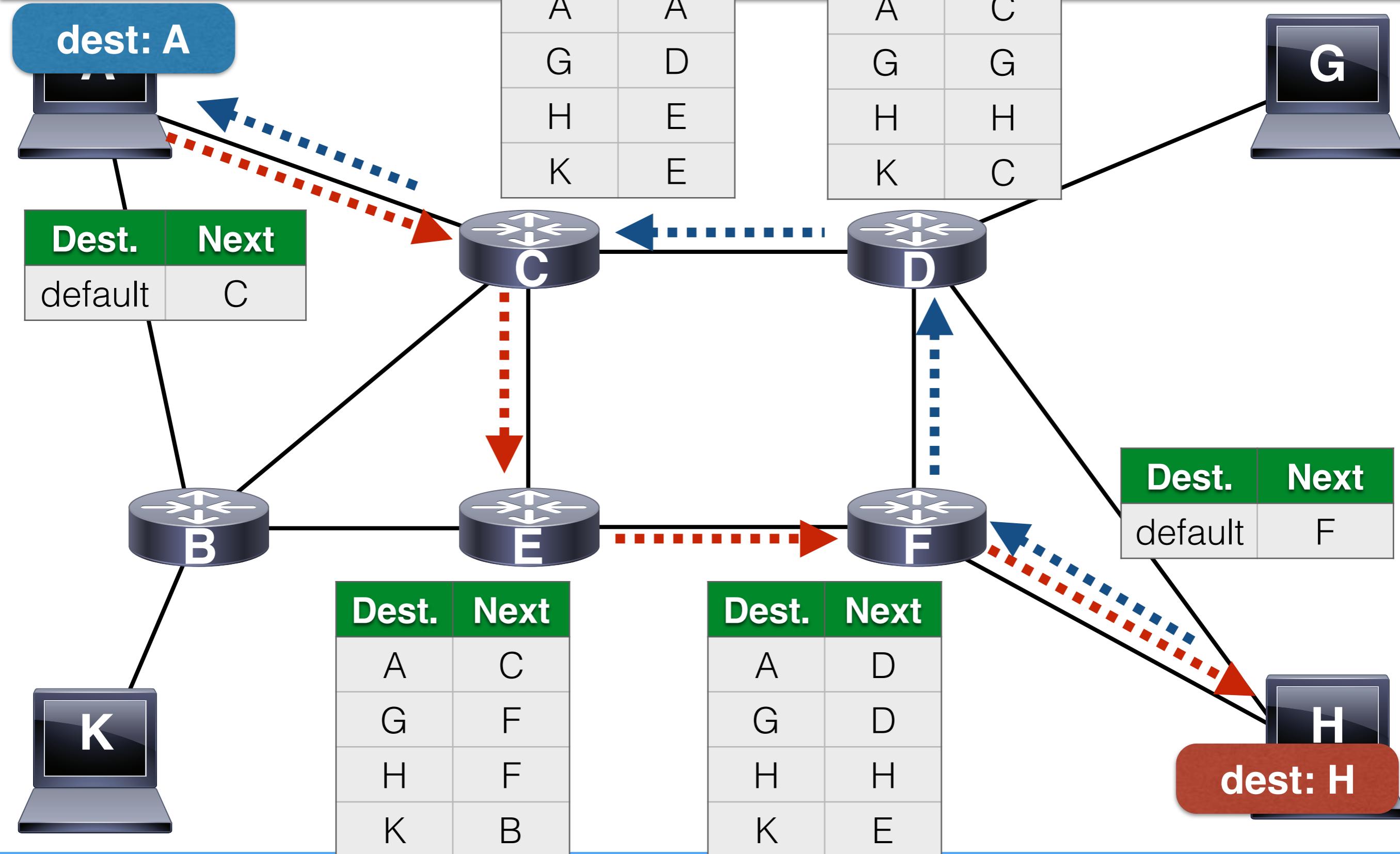
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Routing example

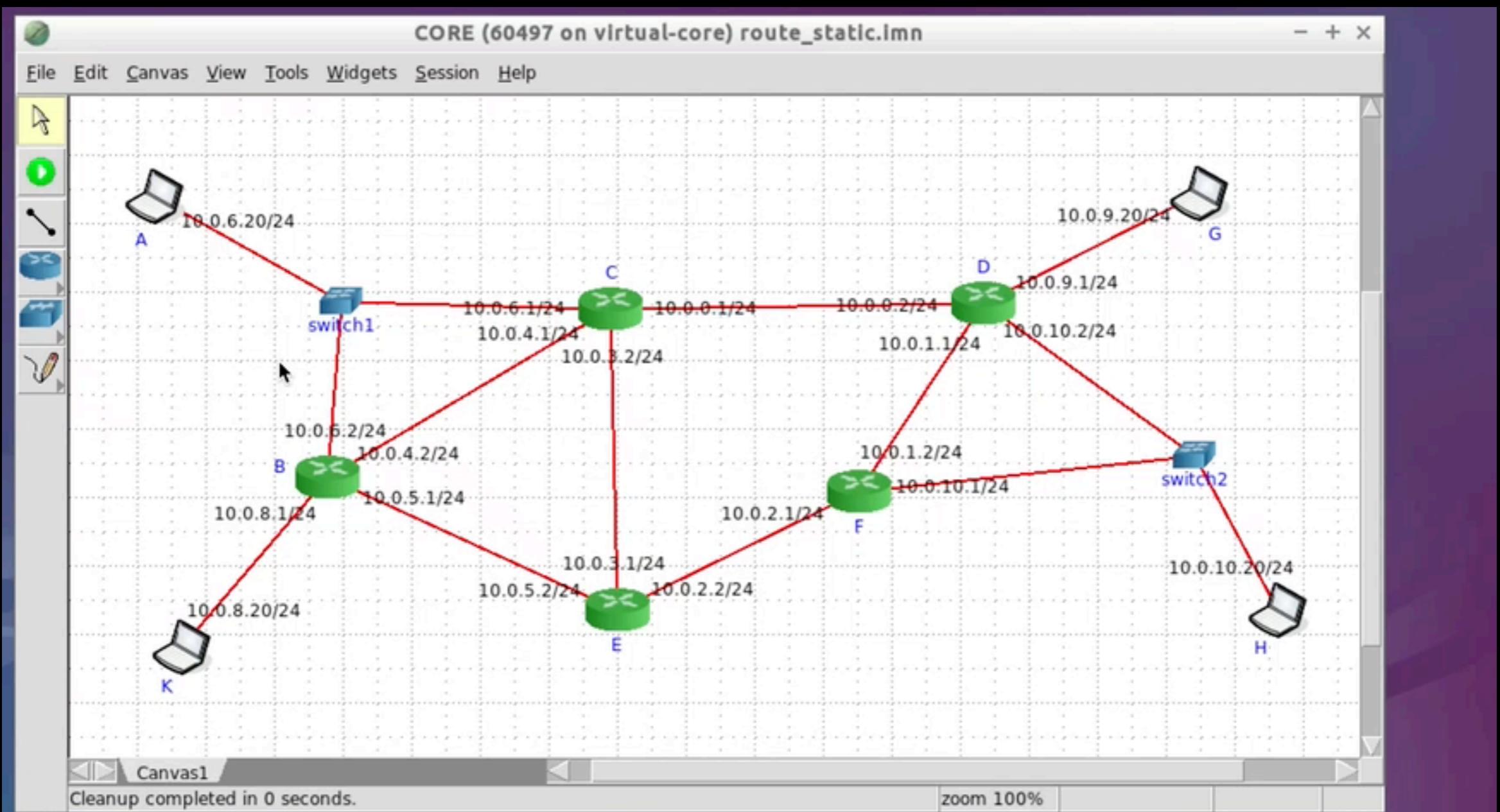


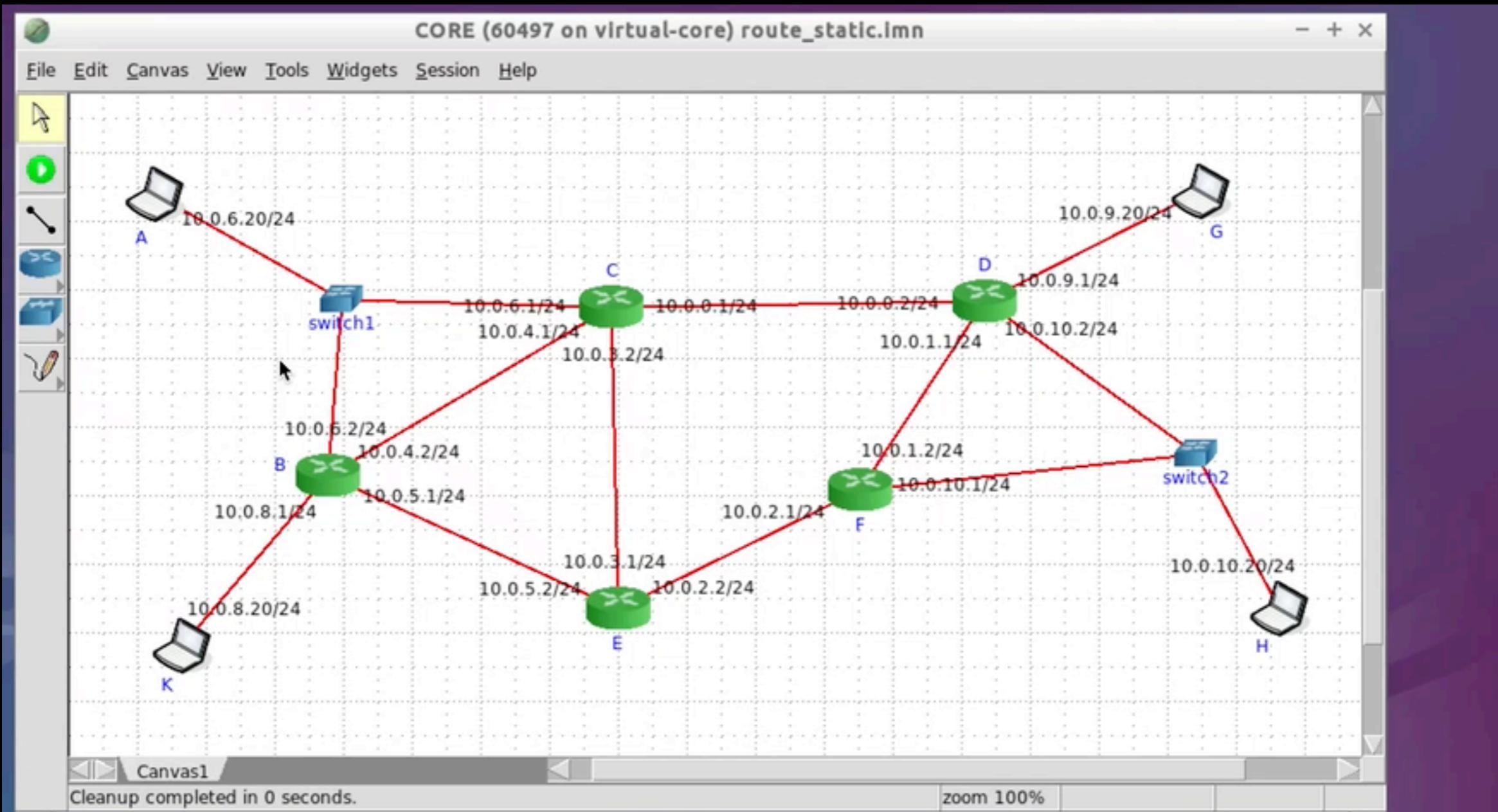
Types of routing

Static routing

- Network manager prepares **fixed routing tables**
- Manually updated when the network changes
- Used in simple networks that don't change a lot

Static routing demo





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Dynamic routing

- Routers **exchange information** to build routing tables **dynamically**
- Initial tables can be set up by network managers

Dynamic routing algorithms

Distance vector

- Exchange information about **distance to destination**, choose **shortest route**
- EIGRP (Enhanced Interior Gateway Routing Protocol)
- RIP (Routing Information Protocol)
- BGP (Border Gateway Protocol)

Dynamic routing algorithms

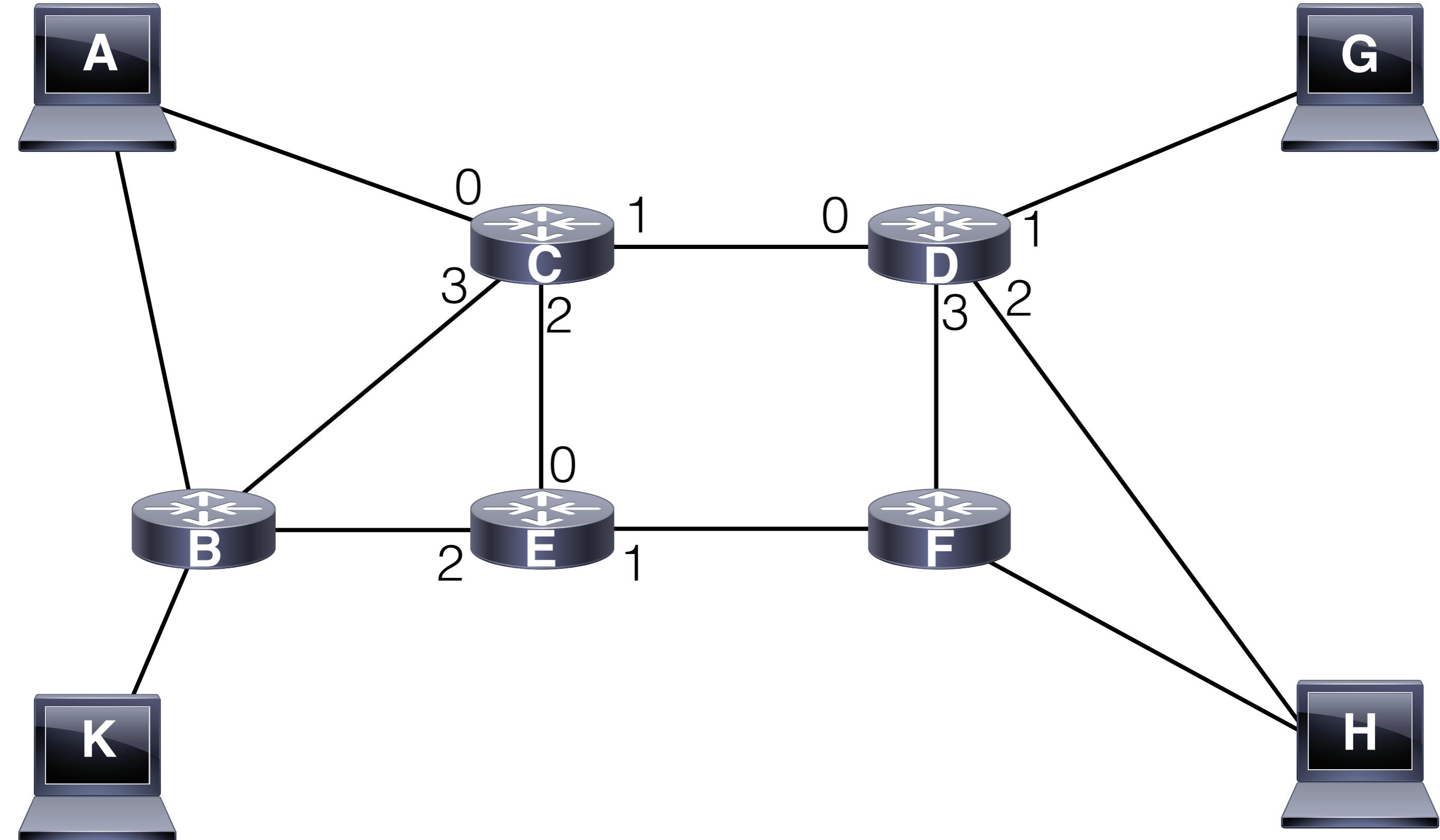
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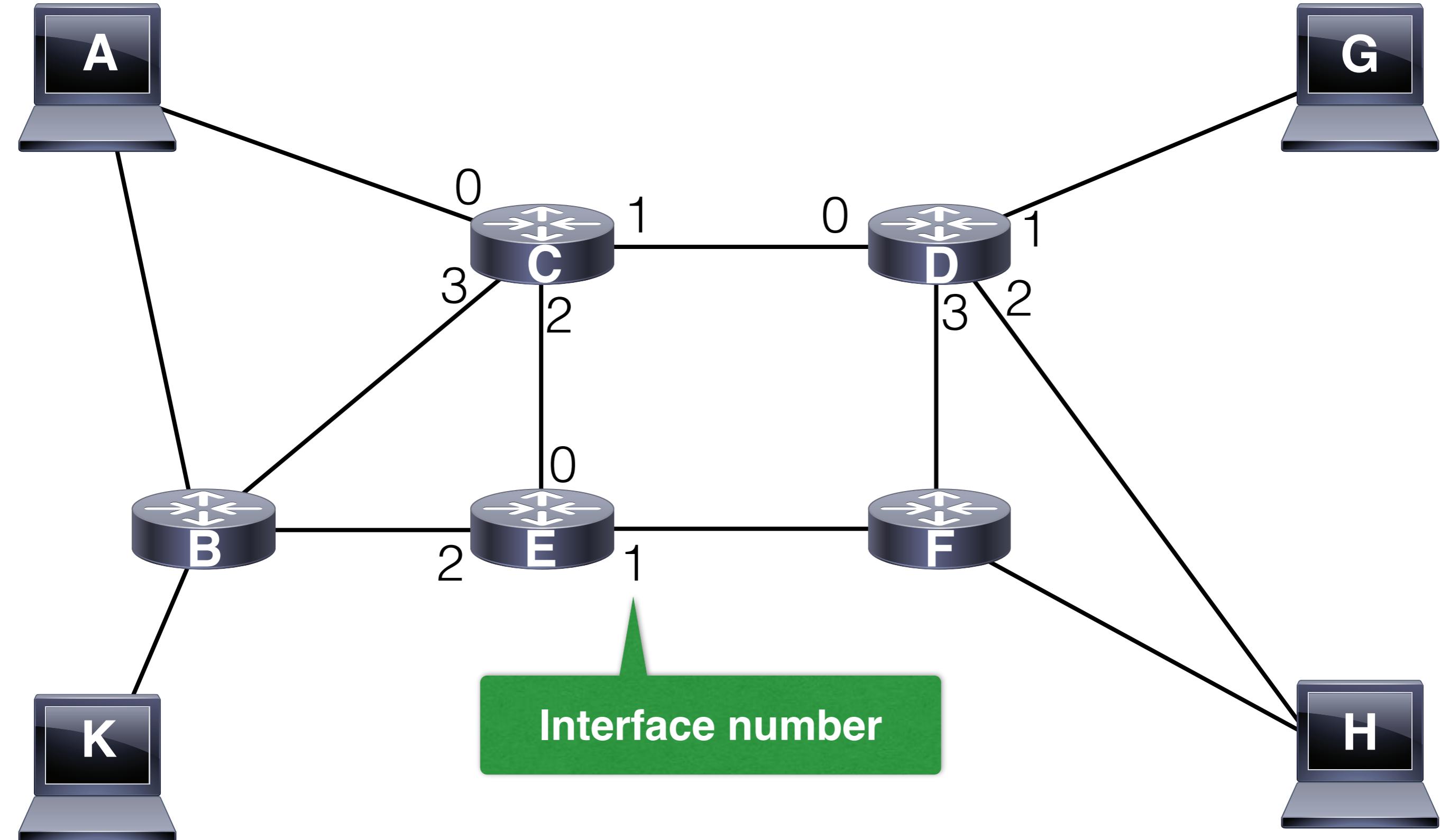
Link state

- Exchange information about **quality of links**, choose **fastest route**
- OSPF (Open Shortest Path First)

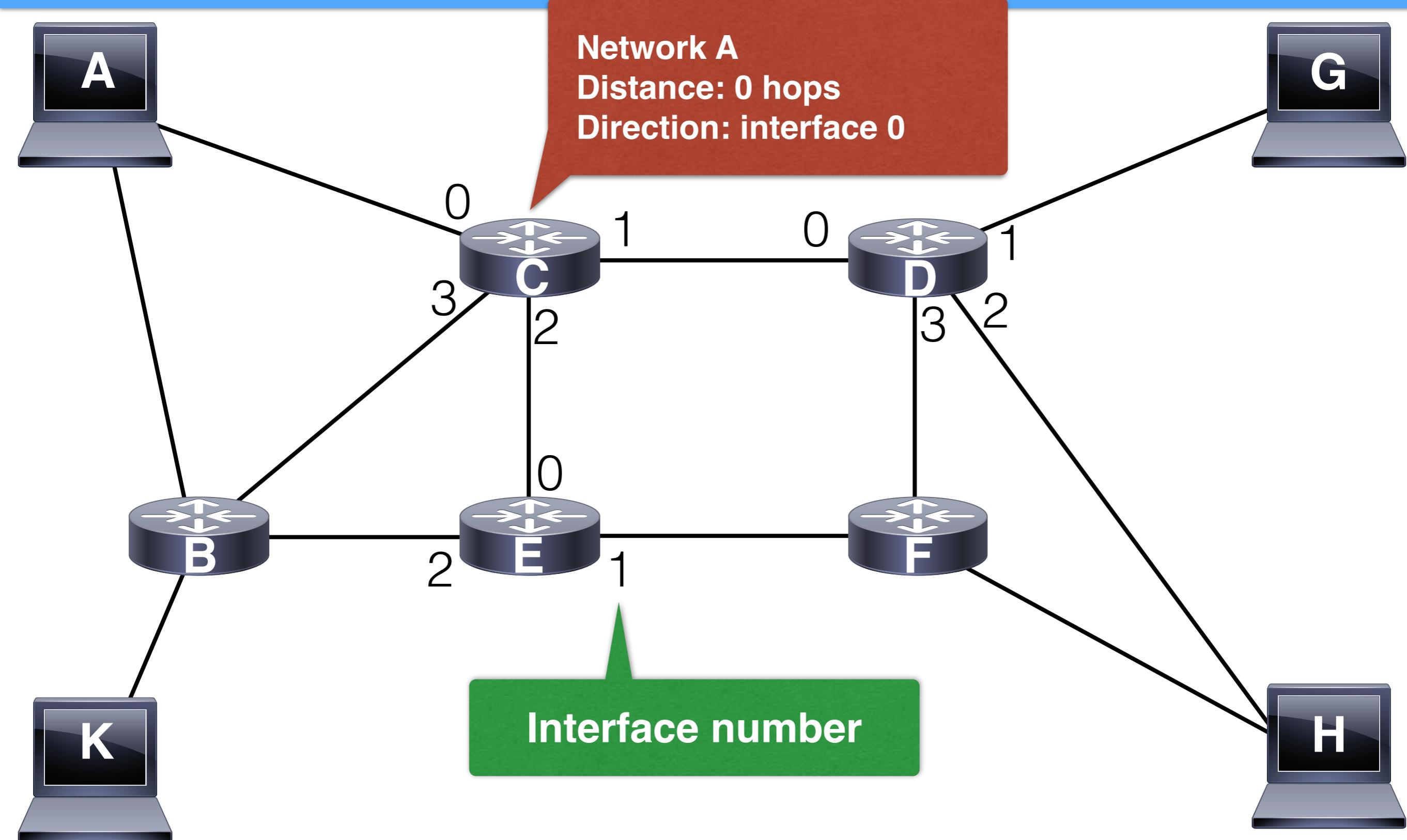
Distance vector routing



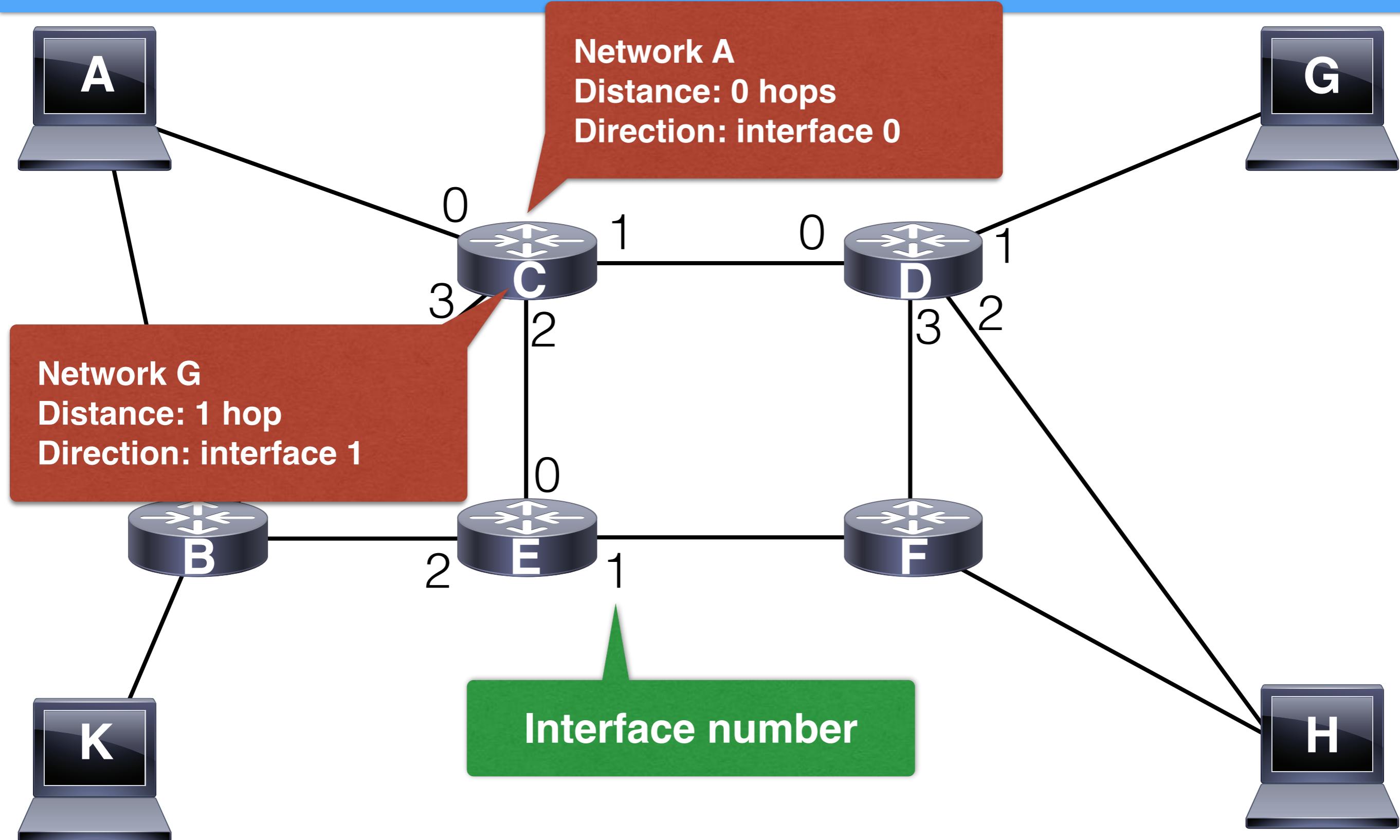
Distance vector routing



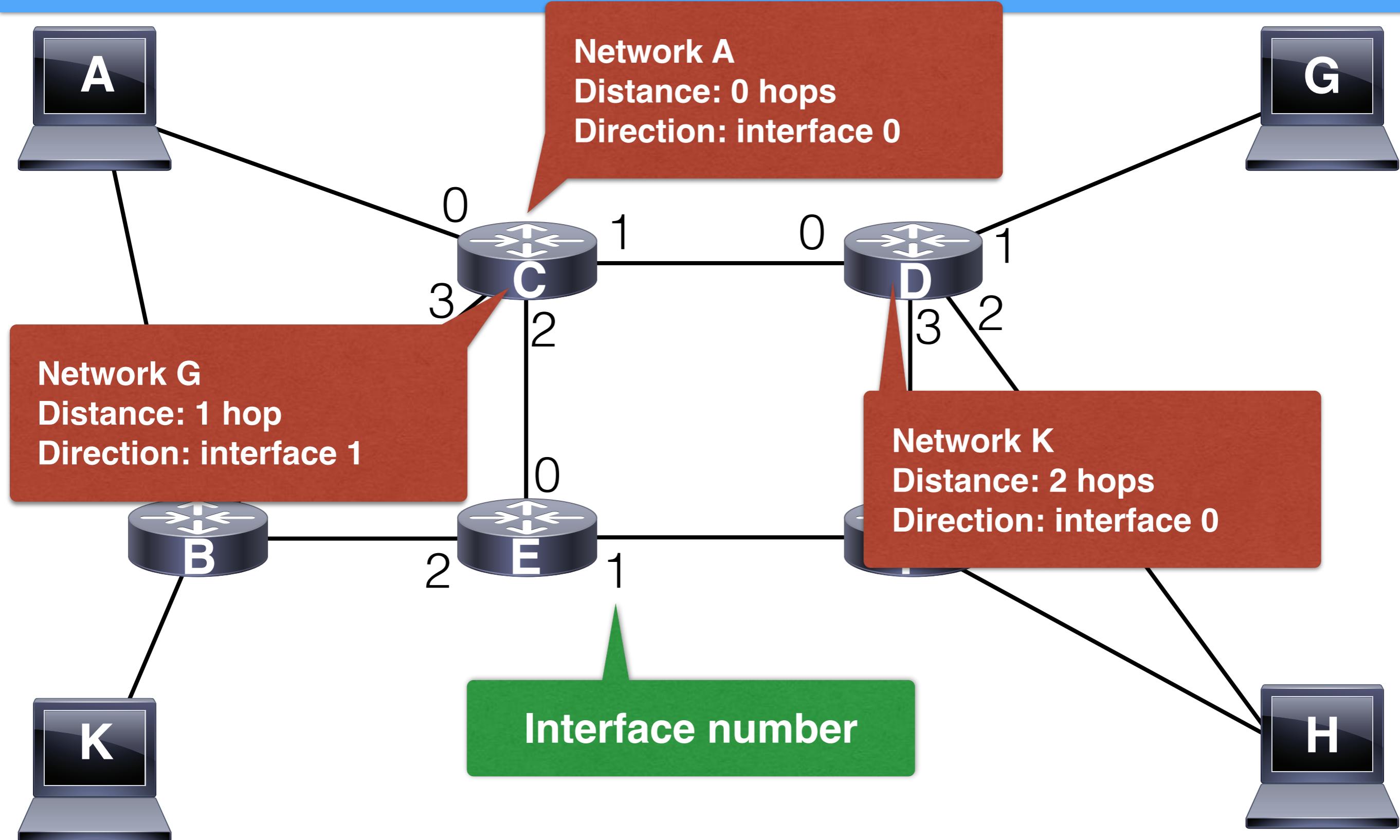
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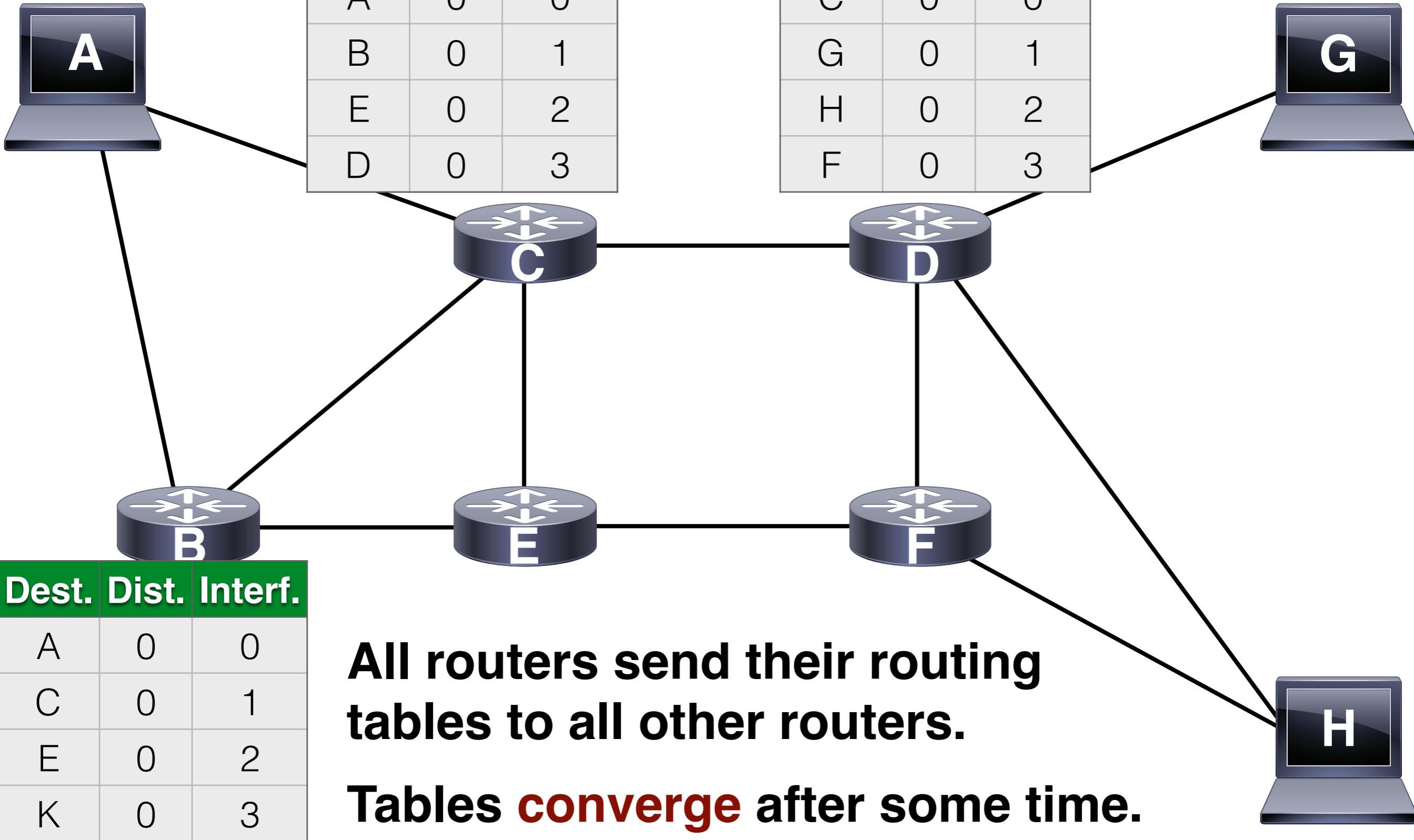
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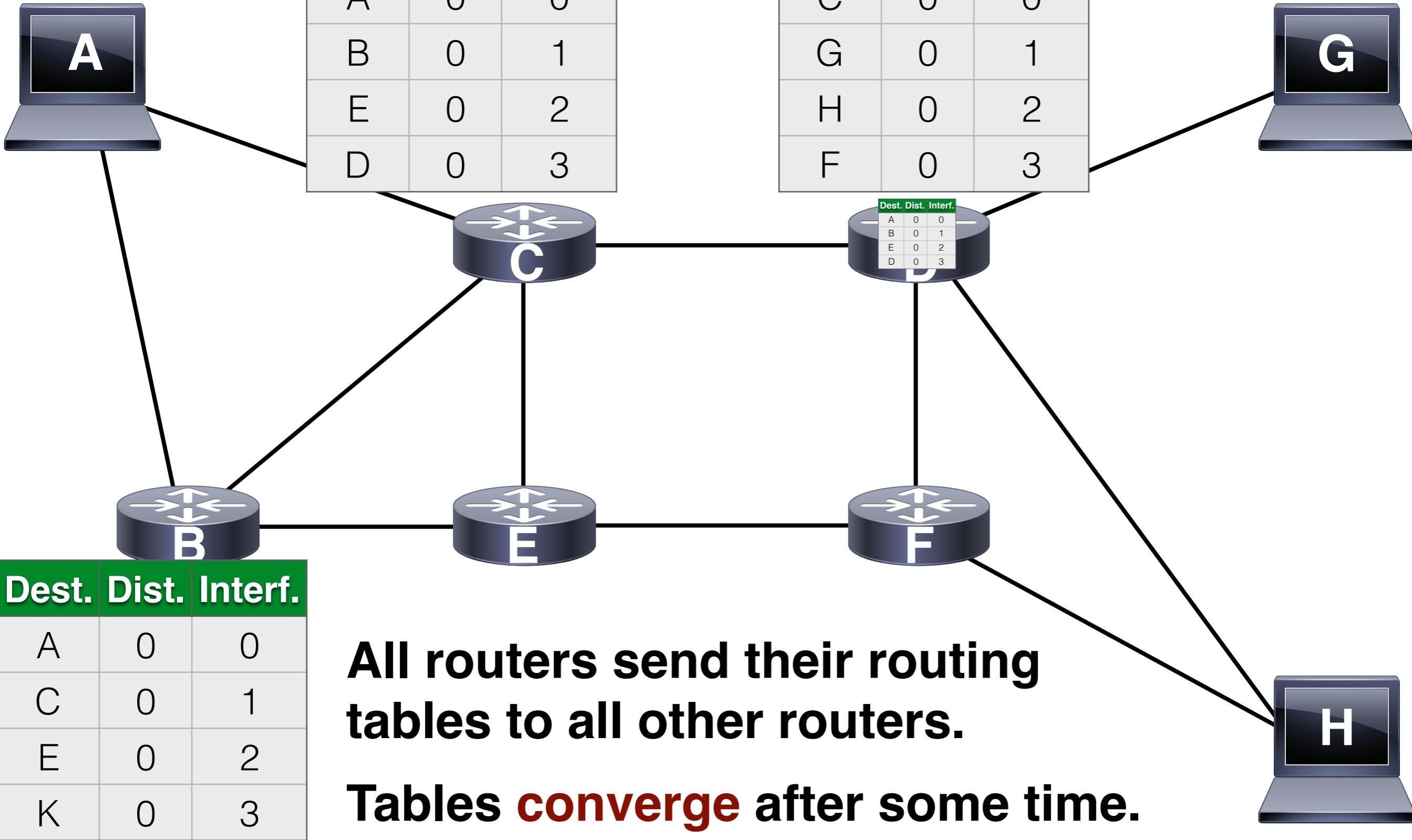
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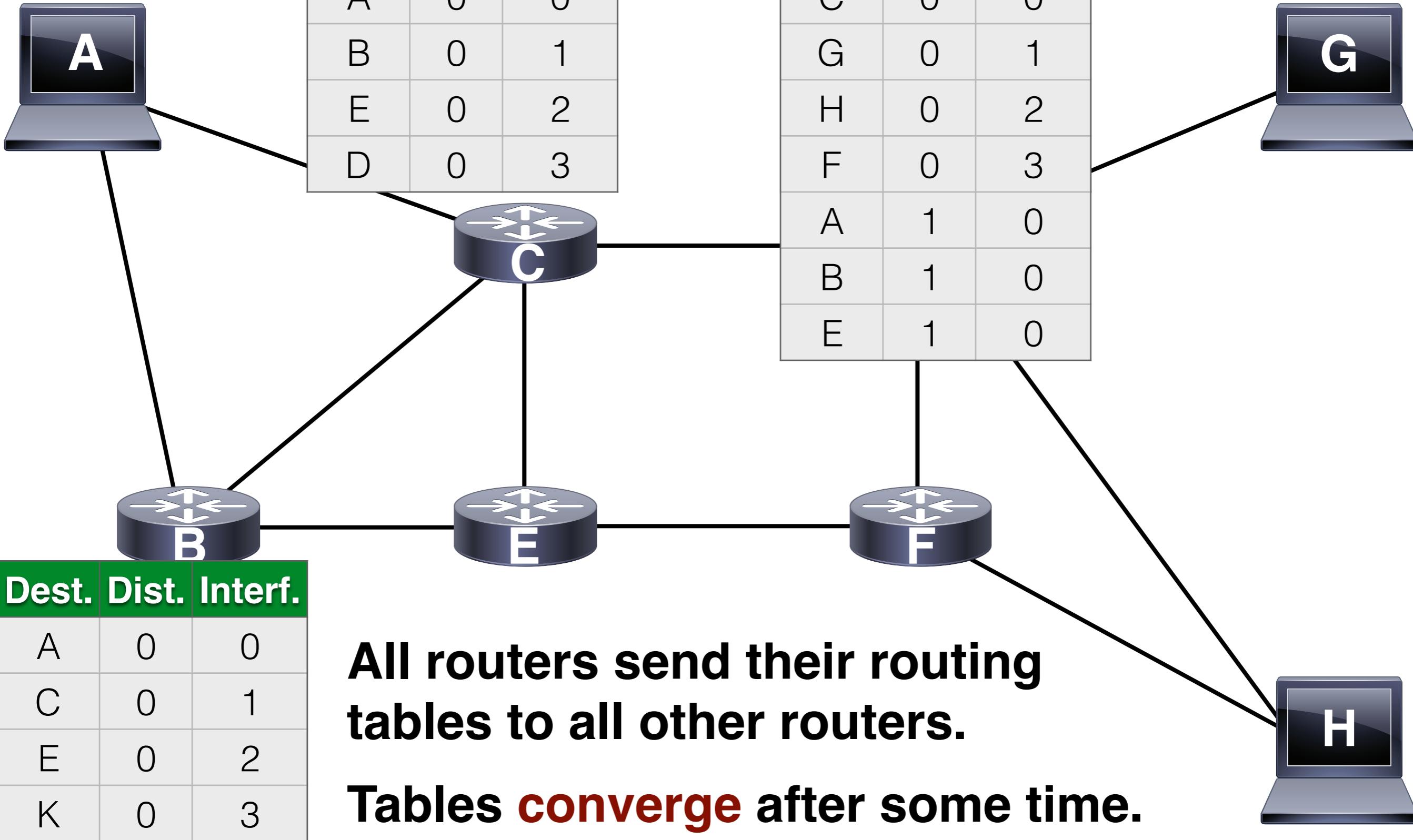
Routing Information Protocol (RIP)



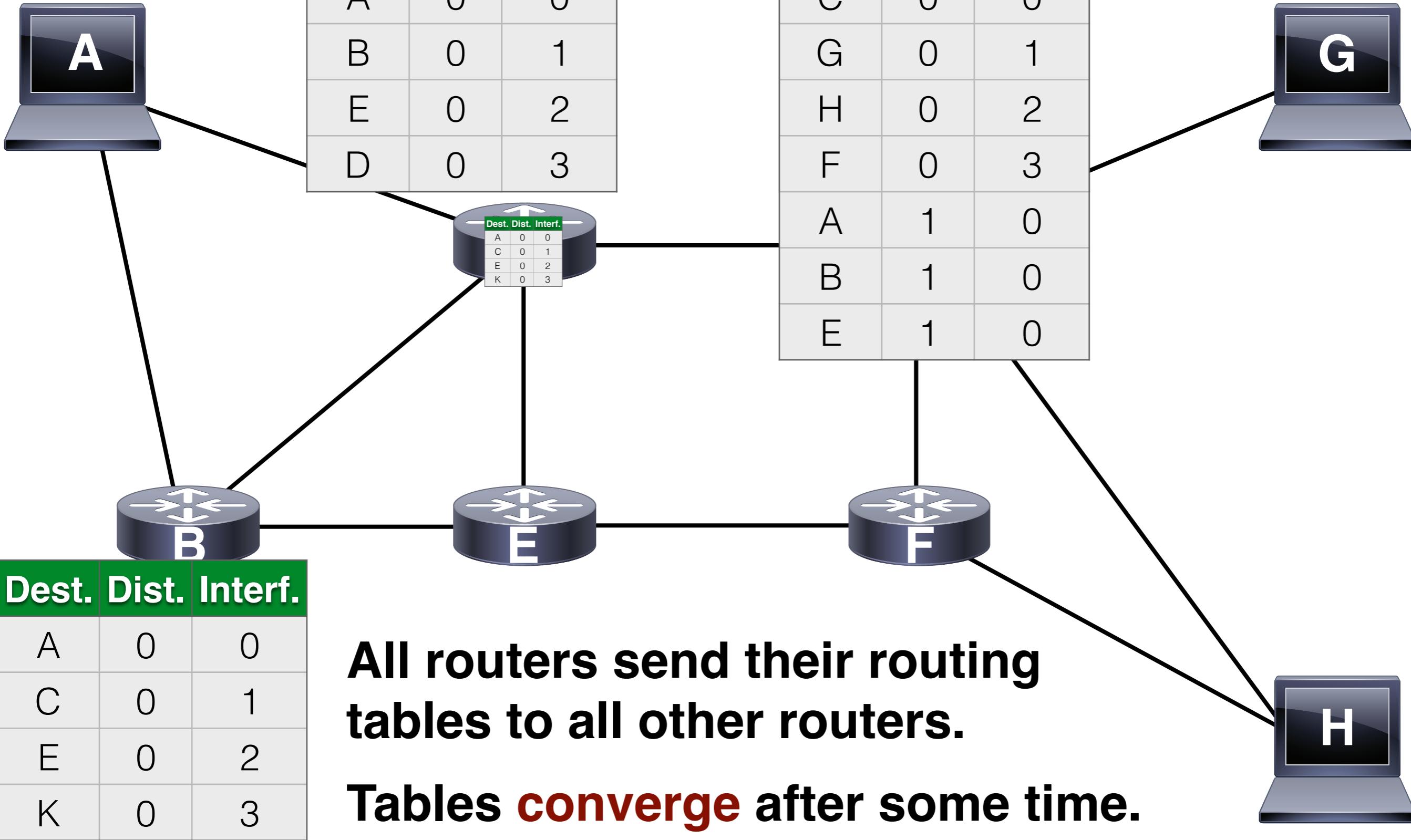
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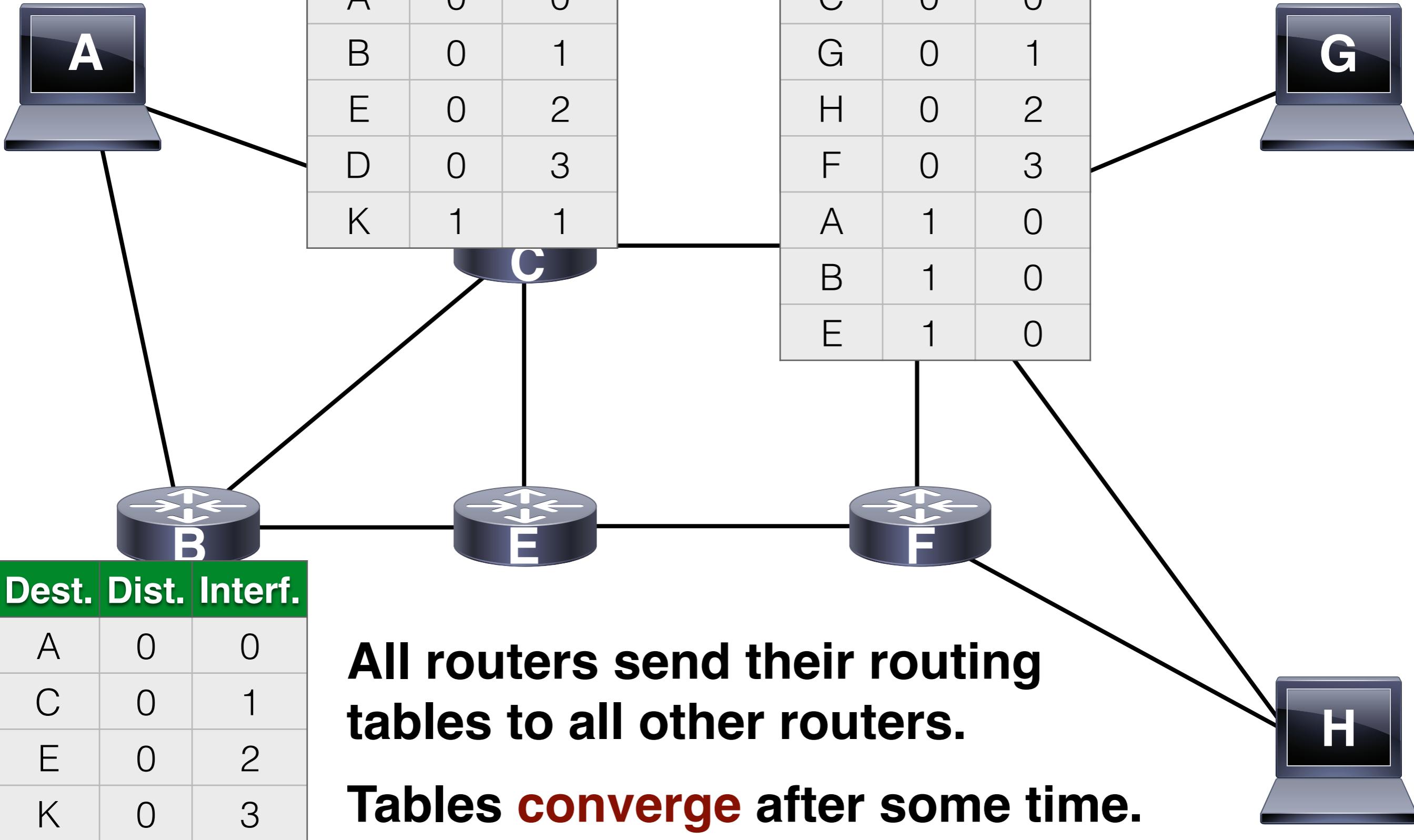
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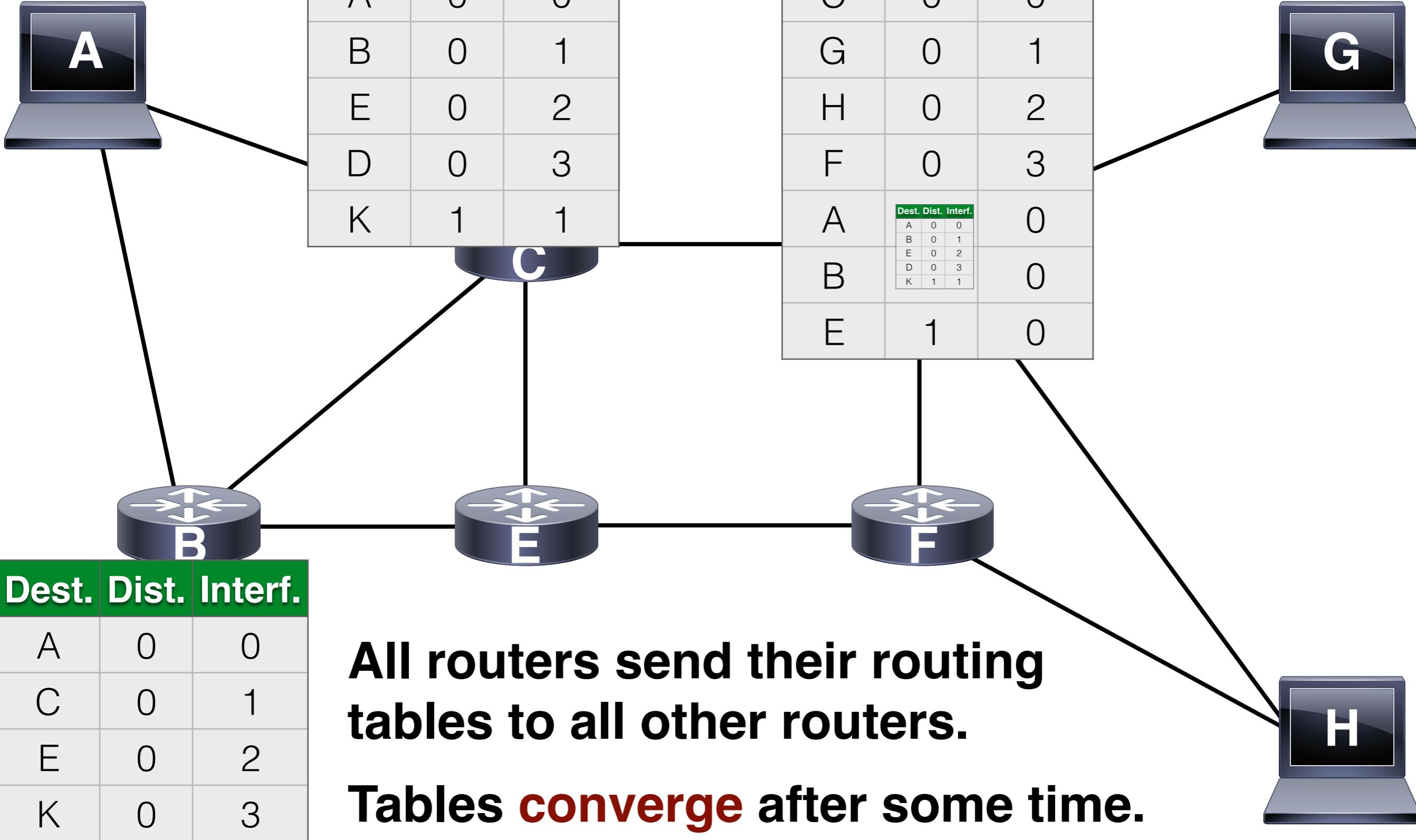
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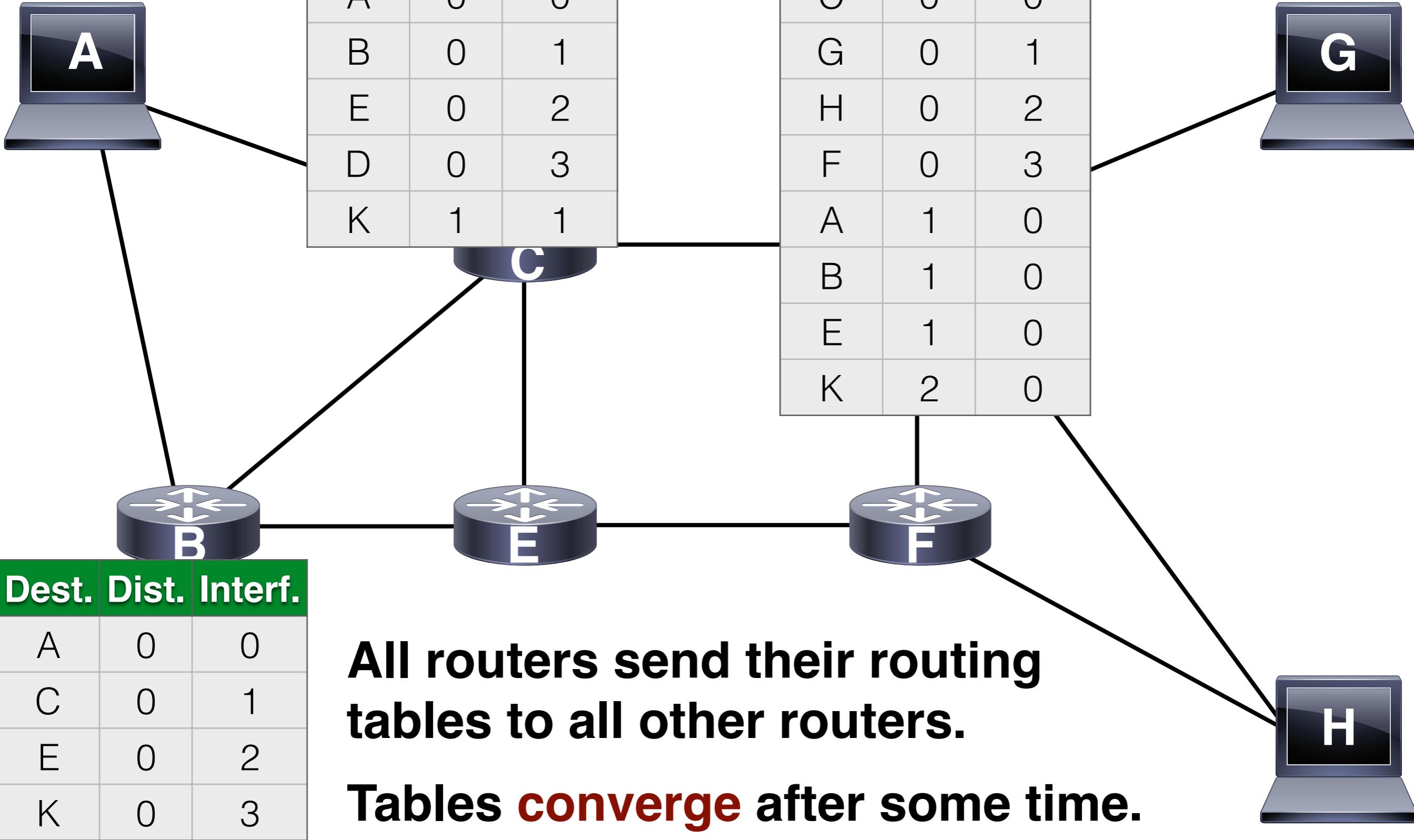
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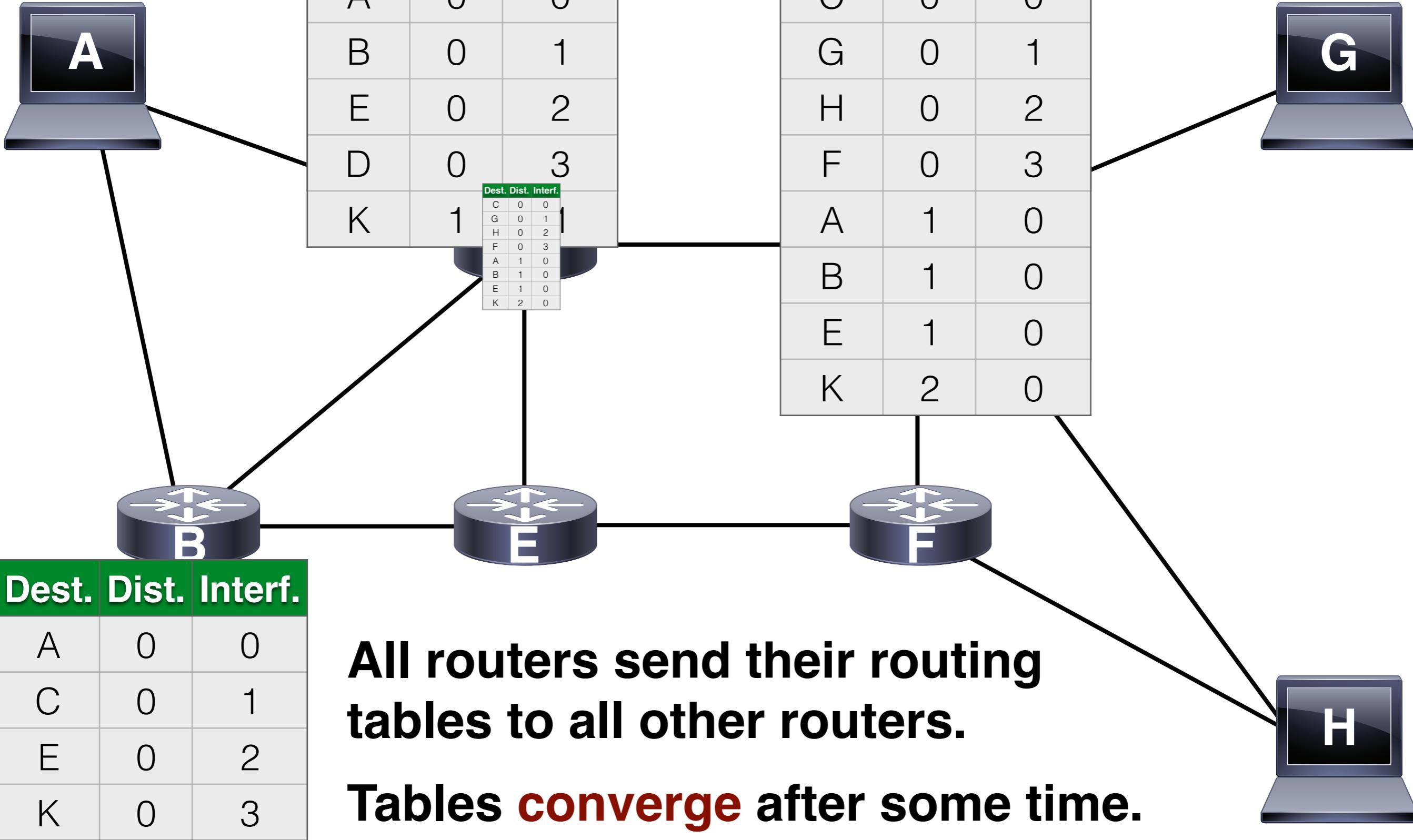
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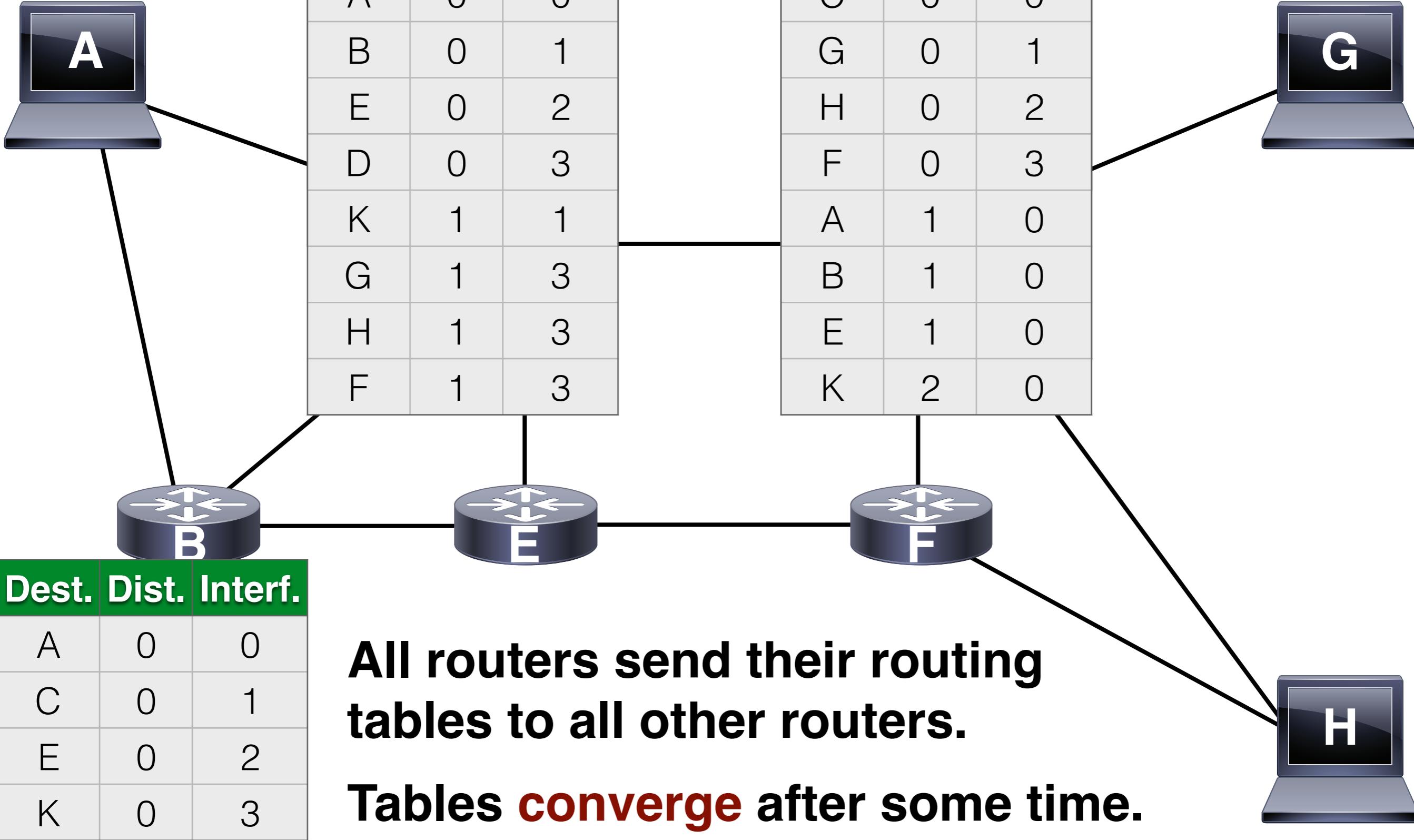
Routing Information Protocol (RIP)



Routing Information Protocol (RIP)



Routing Information Protocol (RIP)



Routing Information Protocol (RIP)

Distance = hop count

- Max. hop count 15
- Avoids loops

Only used in small networks

- At most 15 hops
- Updates transmit whole routing table
- Can be slow to converge

Link-state routing

Link-state routing

Routers exchange information about **connectivity**

- not just routing table (best routes)
- but **all** of the network it knows about
- use a **metric** (usually link speed) to describe the **quality** of each connection
- each router can **independently** compute best route to every subnet

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Most common protocol: OSPF

(video available on Moodle in case you're interested)

Transport Layer

Transmission Control Protocol (TCP)

Connection-oriented

- A **virtual circuit** is established between two devices
- To the application it always looks like a **point-to-point full duplex** connection
- Messages split into **segments** for transmission

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Used by e.g. HTTP, SMTP, IMAP, SSH

Addressing applications

The image displays two separate browser windows. The left window is a Safari browser showing the Google homepage. The search bar at the top has the word 'asteroid' typed into it. Below the search bar, there is a list of suggested search terms: 'Asteroid', 'asteroid', 'asteroid 2015', 'asteroid belt', 'asteroids game', and 'asteroid australia day'. The right window is also a Safari browser showing the NASA website. The URL 'www.nasa.gov' is visible in the address bar. The main content area features a large blue banner with the NASA logo and the text 'NASA Announces Progress on Asteroid Initiative'. Below the banner is a black and white photograph of a large, irregularly shaped asteroid against a dark background. To the right of the image, there is a detailed text summary of the news article.

Why does the HTTP response arrive in this browser window and not the other one?

FIT1047

33

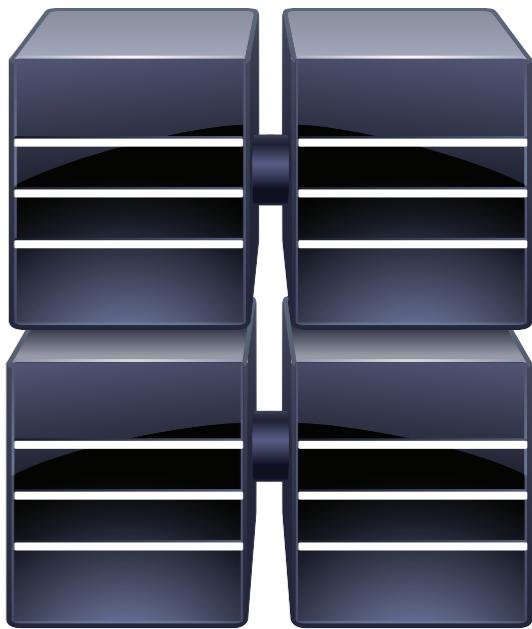
Addressing applications



130.194.77.37

<http://www.google.com.au>

216.58.220.99



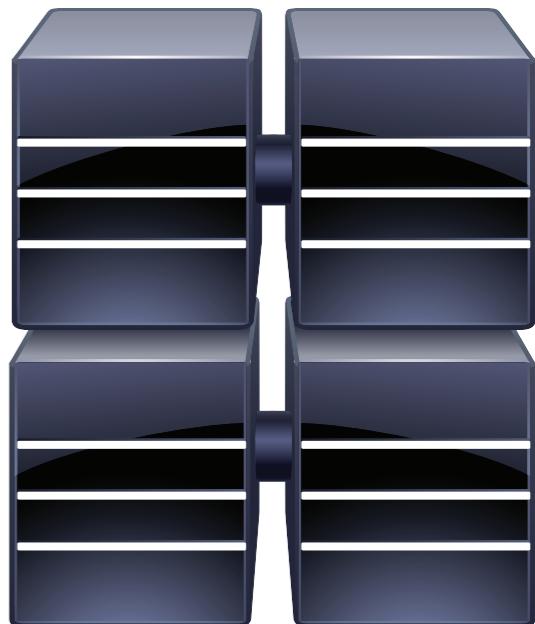
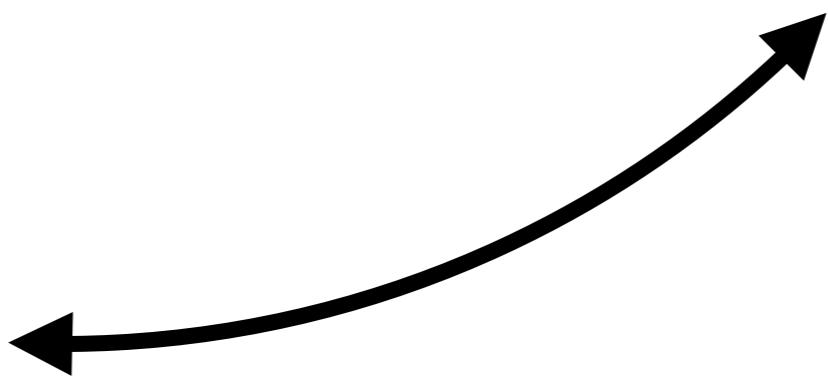
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130.194.77.37:57017

http://www.google.com.au

216.58.220.99:80



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216.58.220.99:80

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Random client port,
one per connection



Addressing applications

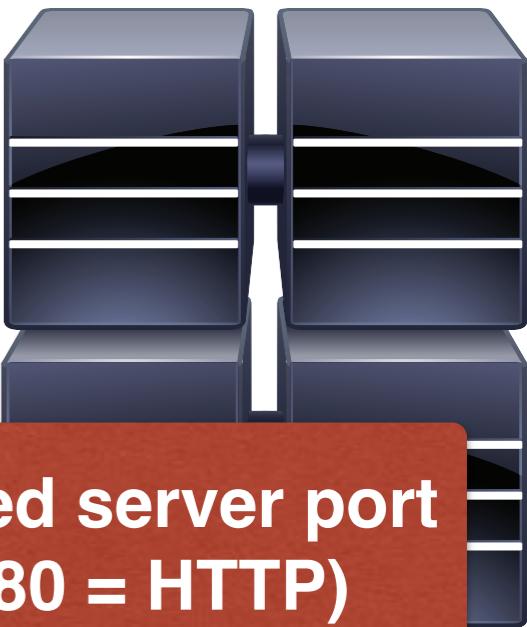


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216.58.220.99:80

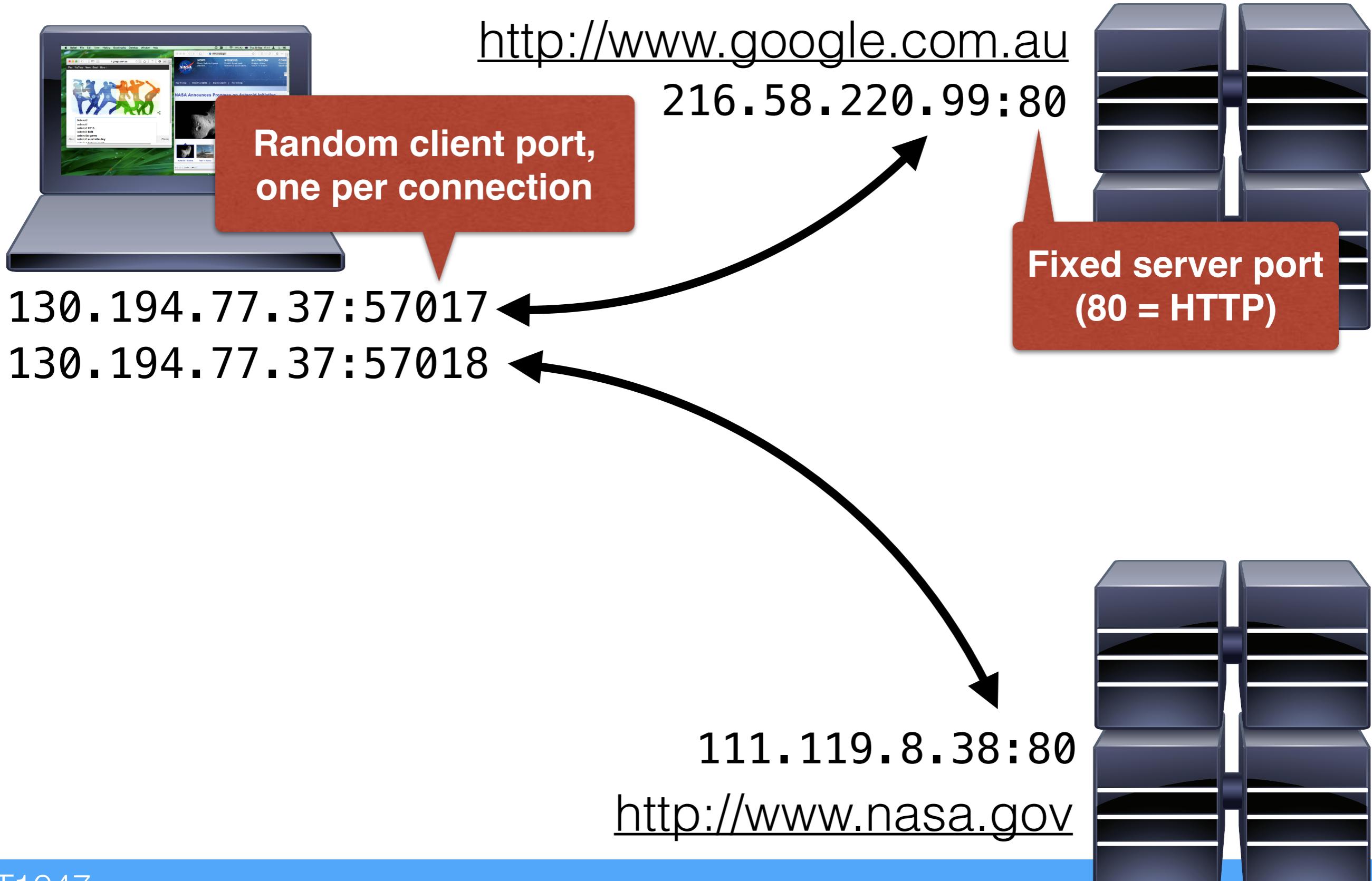
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Fixed server port
(80 = HTTP)

Addressing applications



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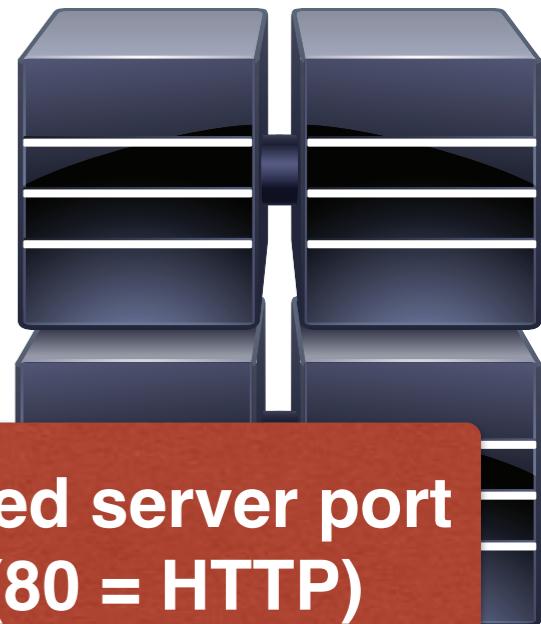
216.58.220.99:80

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130.194.77.37:57017

130.194.77.37:57018

130.194.77.37:57019



Fixed server port
(80 = HTTP)

130.194.11.146:25
smtp.monash.edu

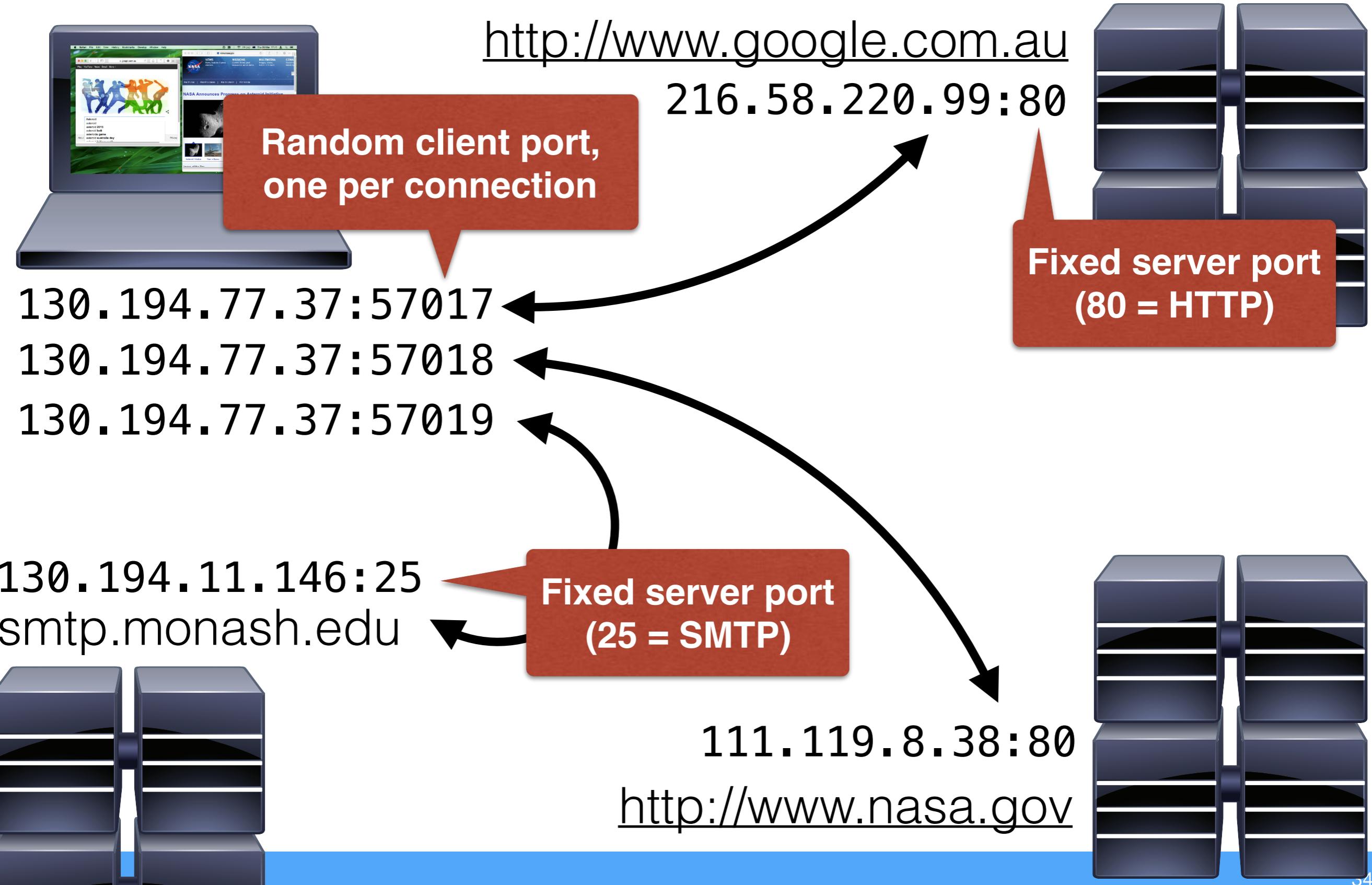


111.119.8.38:80

http://www.nasa.gov



Addressing applications



One address per layer

One address per layer

Application Layer

- URL (e.g. <http://www.csse.monash.edu>)

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Data Link Layer (Ethernet)

- MAC address (e.g. 00:23:ae:e7:52:85)
- used for sending frames in a LAN

TCP ARQ

Error control

- Data Link Layer **discards** frames that have errors
- Frames may not arrive at all
- But TCP should be a **reliable channel!**

TCP ARQ

Error control

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- But TCP should be a **reliable channel!**

Solution: Automatic Repeat ReQuest

- Exchange **acknowledgements (ACK)**, letting sender know that packets were received correctly
- Sender re-transmits if no ACK within certain time

TCP ARQ

When we send a TCP packet, it includes two numbers.

Sequence number:

- how many bytes we've already transmitted (before this one)

Acknowledgement number:

- how many bytes we've received from the other side

Sender can therefore check how many bytes have been received correctly!

Establishing a connection

Three-way handshake:

Establishing a connection

Three-way handshake:

- Client sends a **SYN** packet with **random sequence number A**

Establishing a connection

Three-way handshake:

- Client sends a **SYN** packet with **random sequence number A**
- Server replies with **SYN, ACK, acknowledgement number A+1, and random sequence number B**

Establishing a connection

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- Server replies with **SYN, ACK, acknowledgement number A+1, and random sequence number B**
- Client sends **ACK** with **sequence number A+1 and acknowledgement number B+1**

Closing a connection

Four-way handshake:

Closing a connection

Four-way handshake:

- Computer A (client or server!) sends a **FIN** packet

Closing a connection

Four-way handshake:

- Computer A (client or server!) sends a **FIN** packet
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Necessary because TCP is full duplex!

TCP session

Client

Server

TCP session

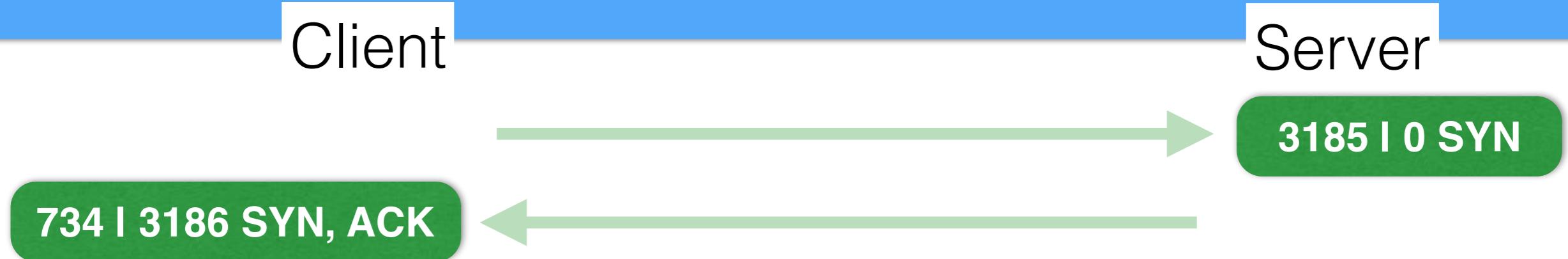
Client

Server

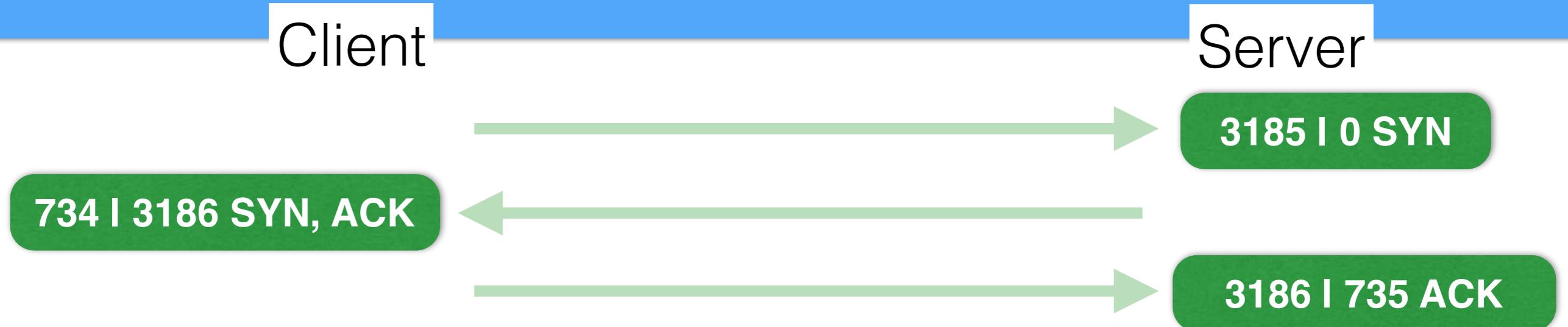
3185 | 0 SYN



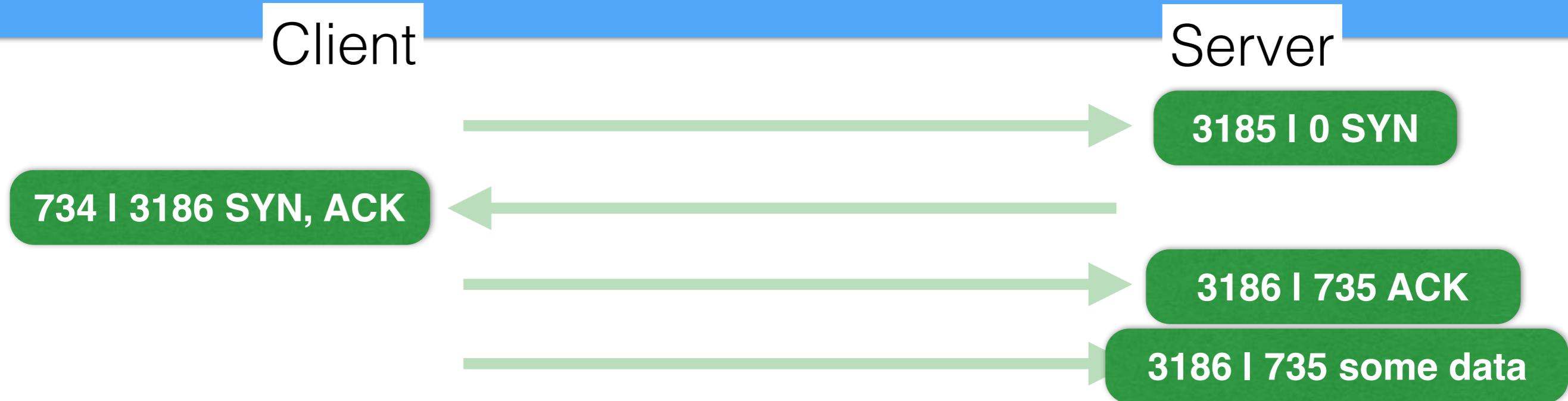
TCP session



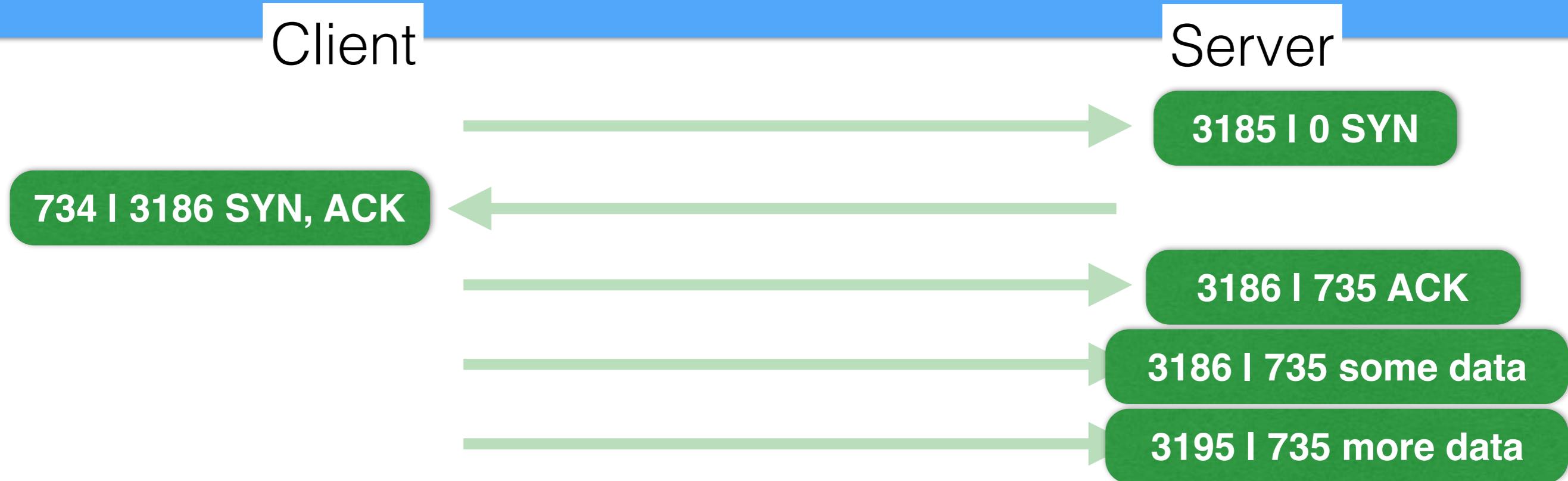
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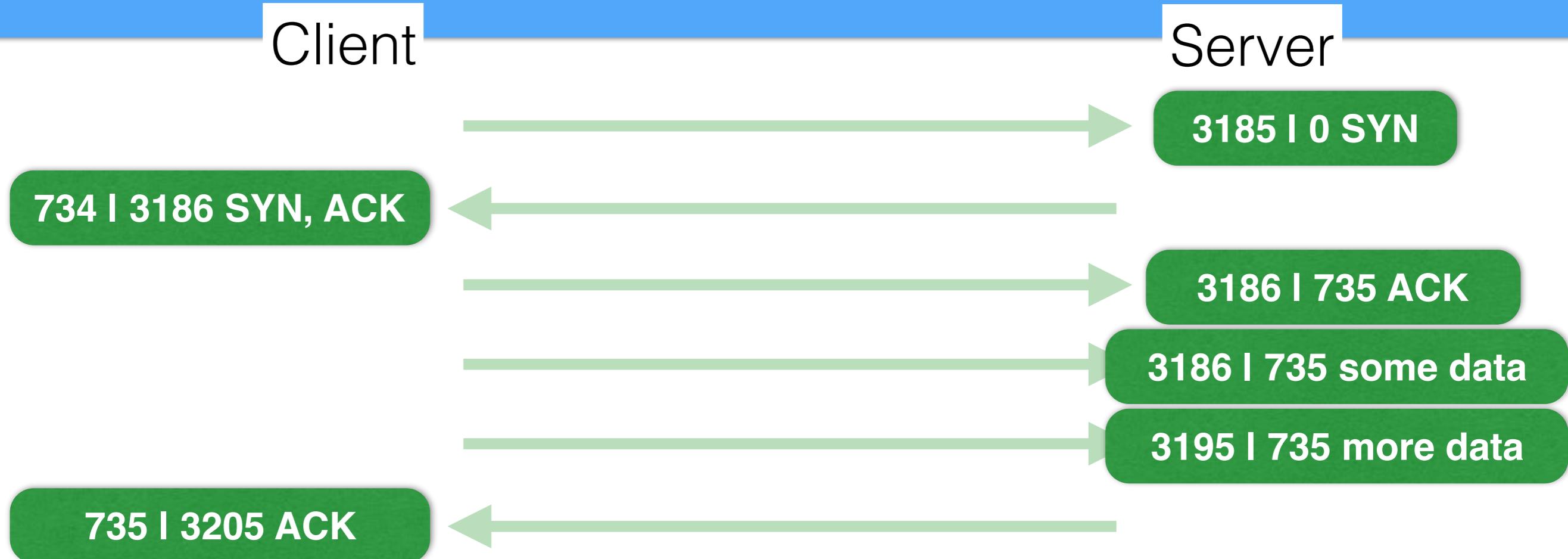
TCP session



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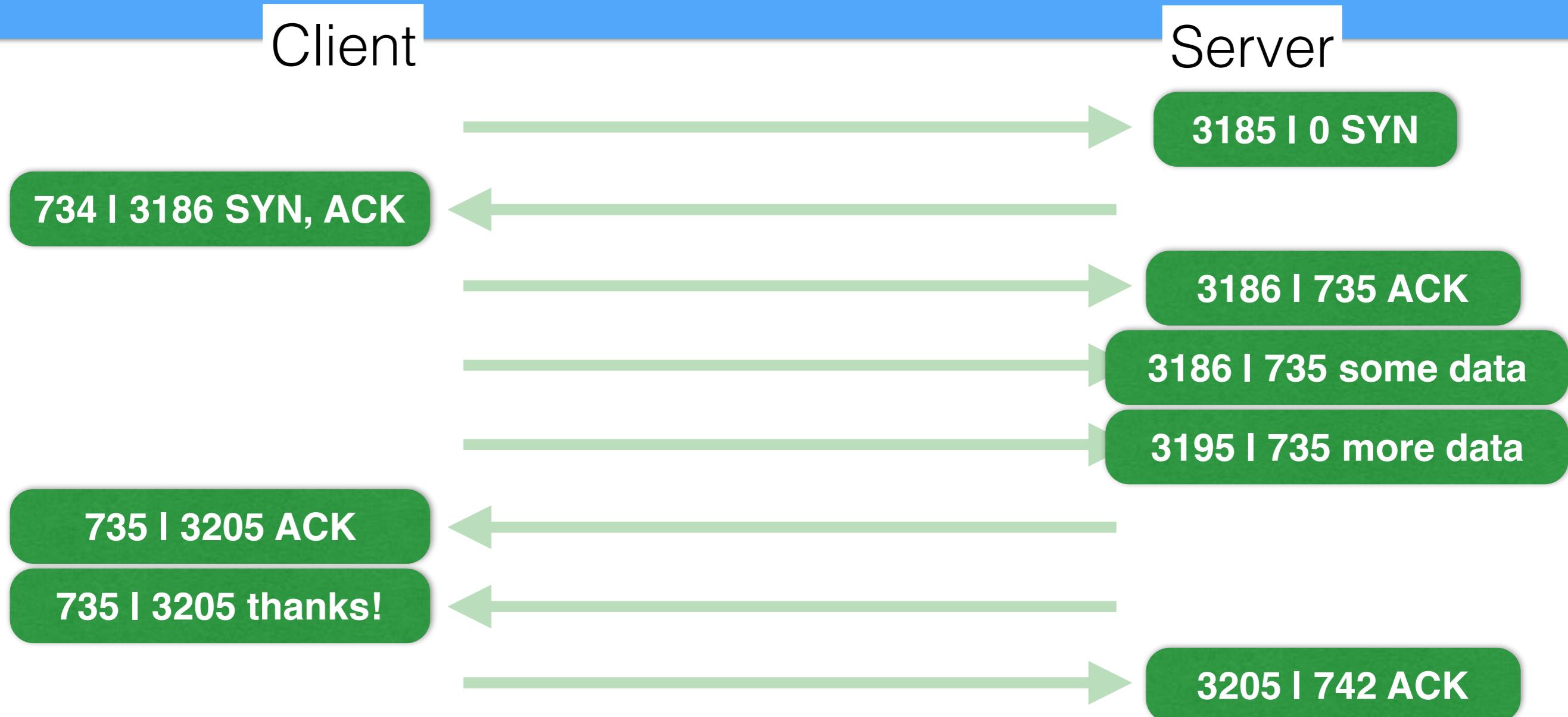
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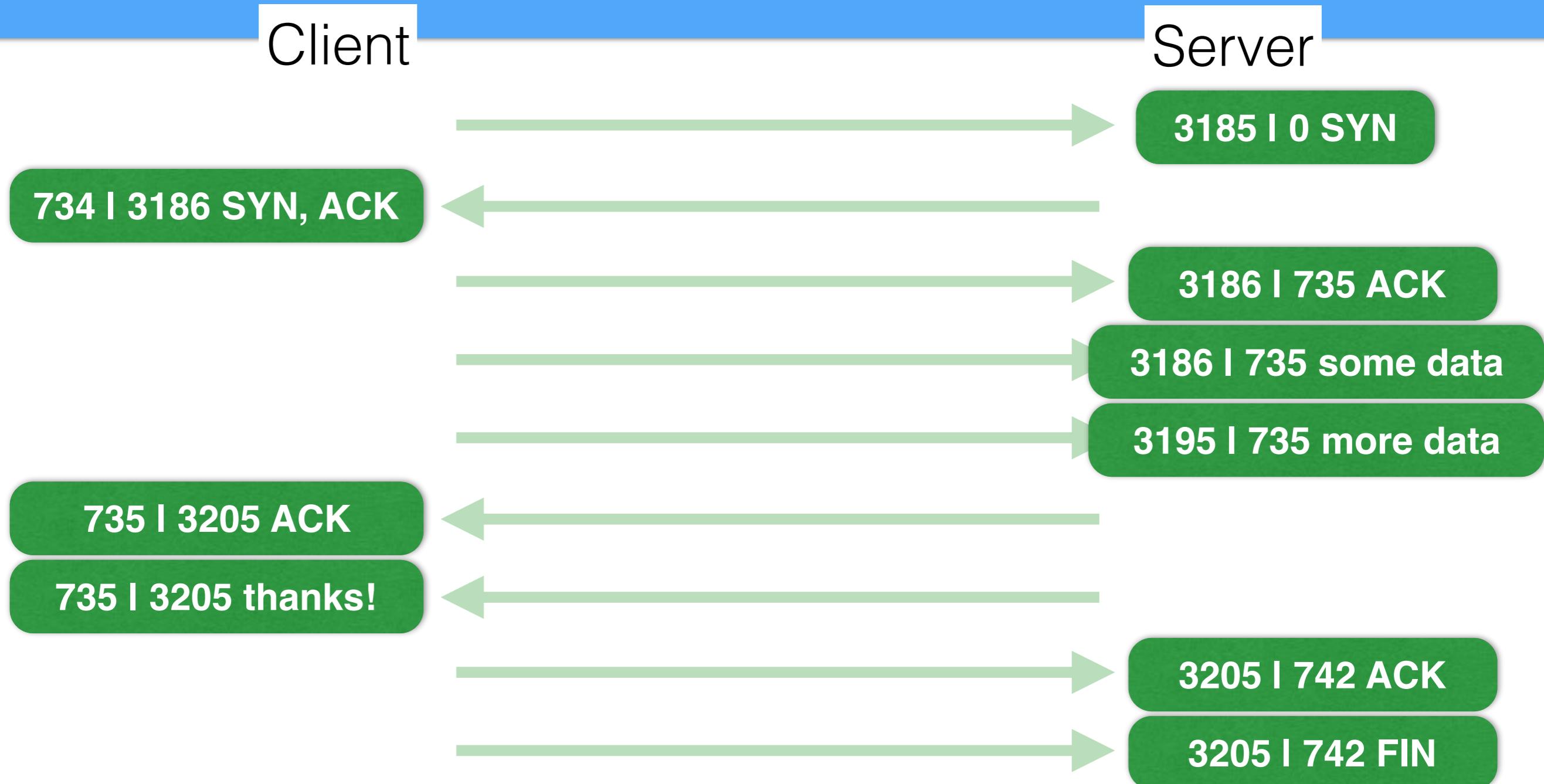
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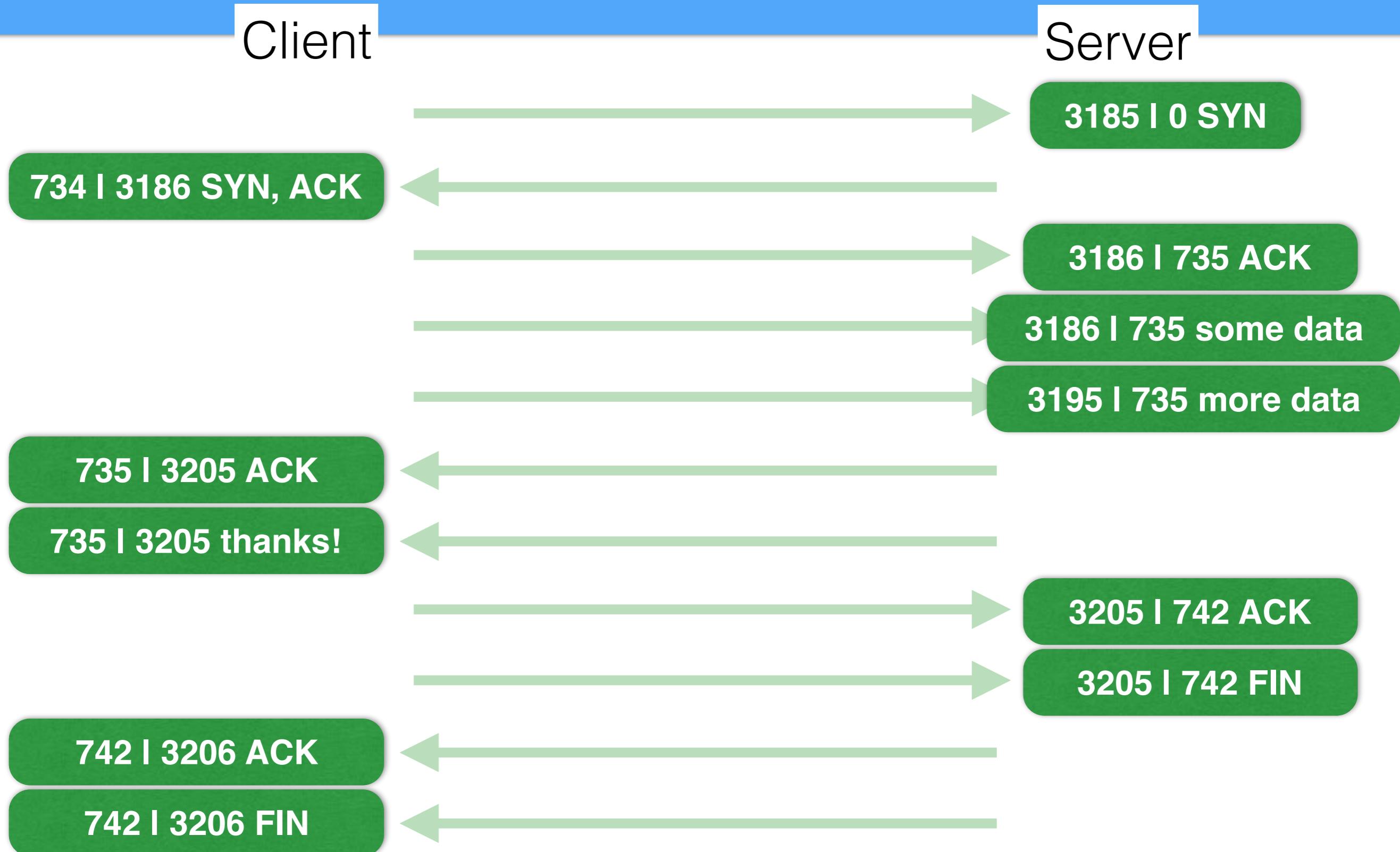
TCP session



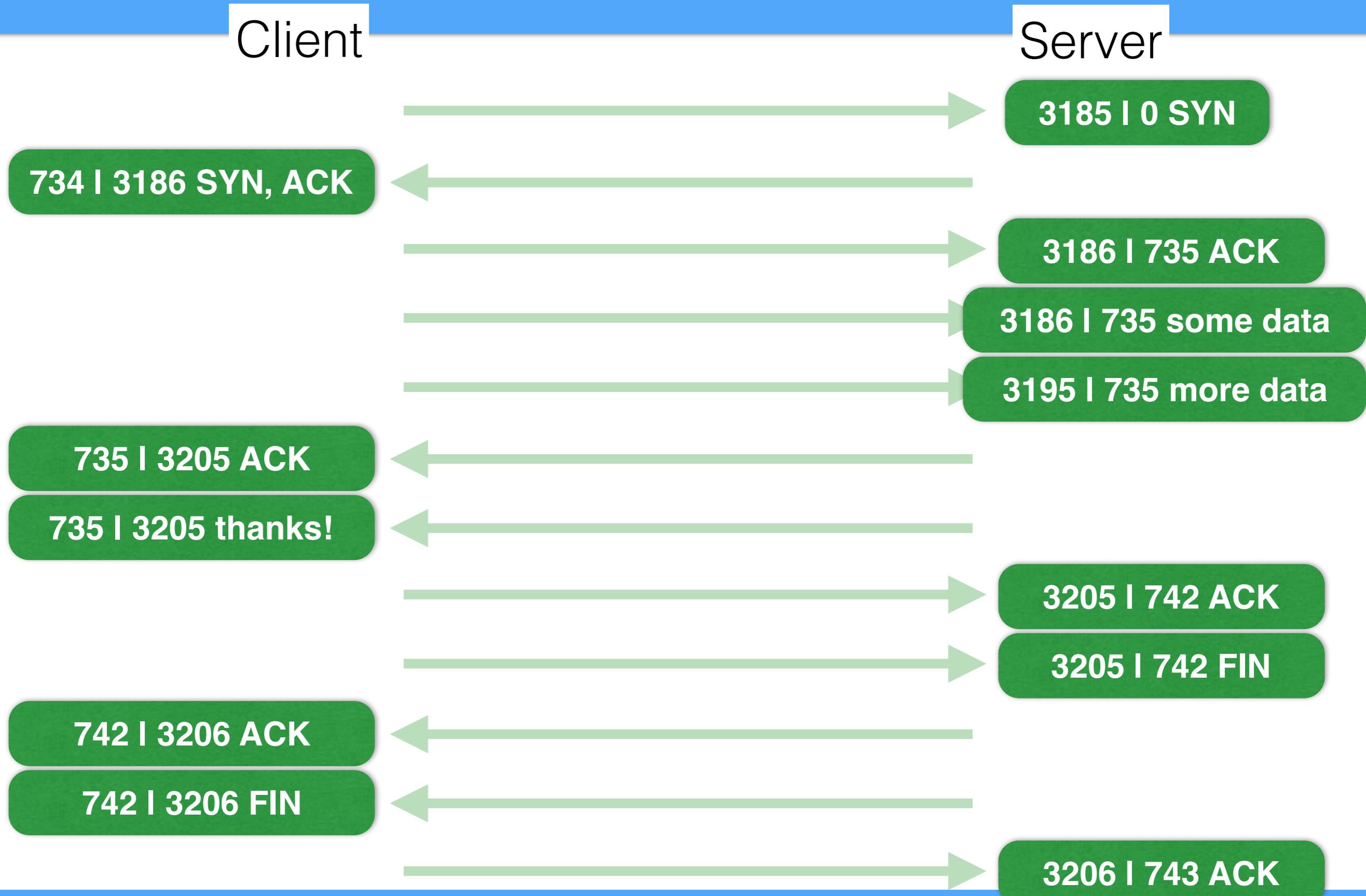
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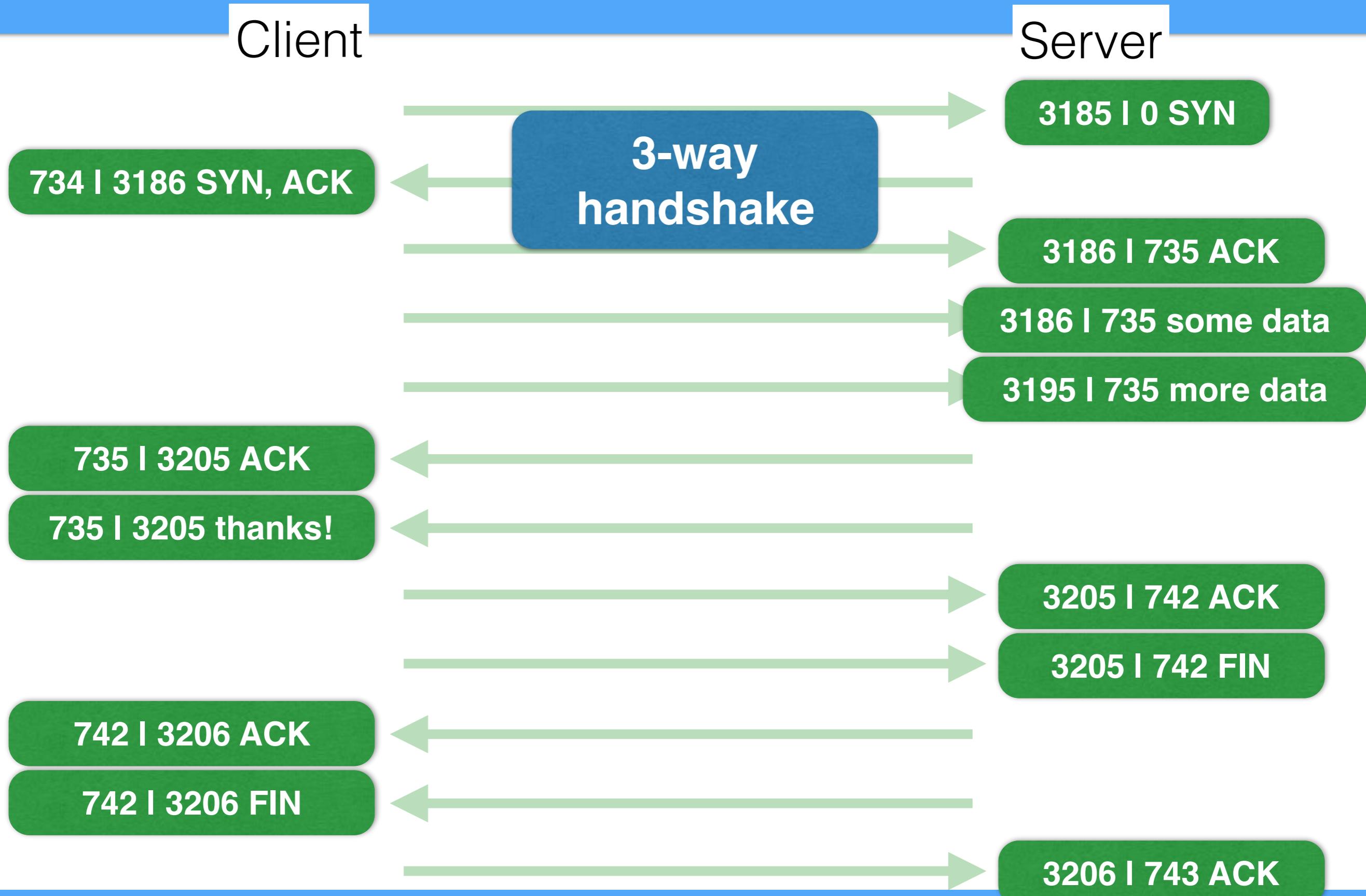
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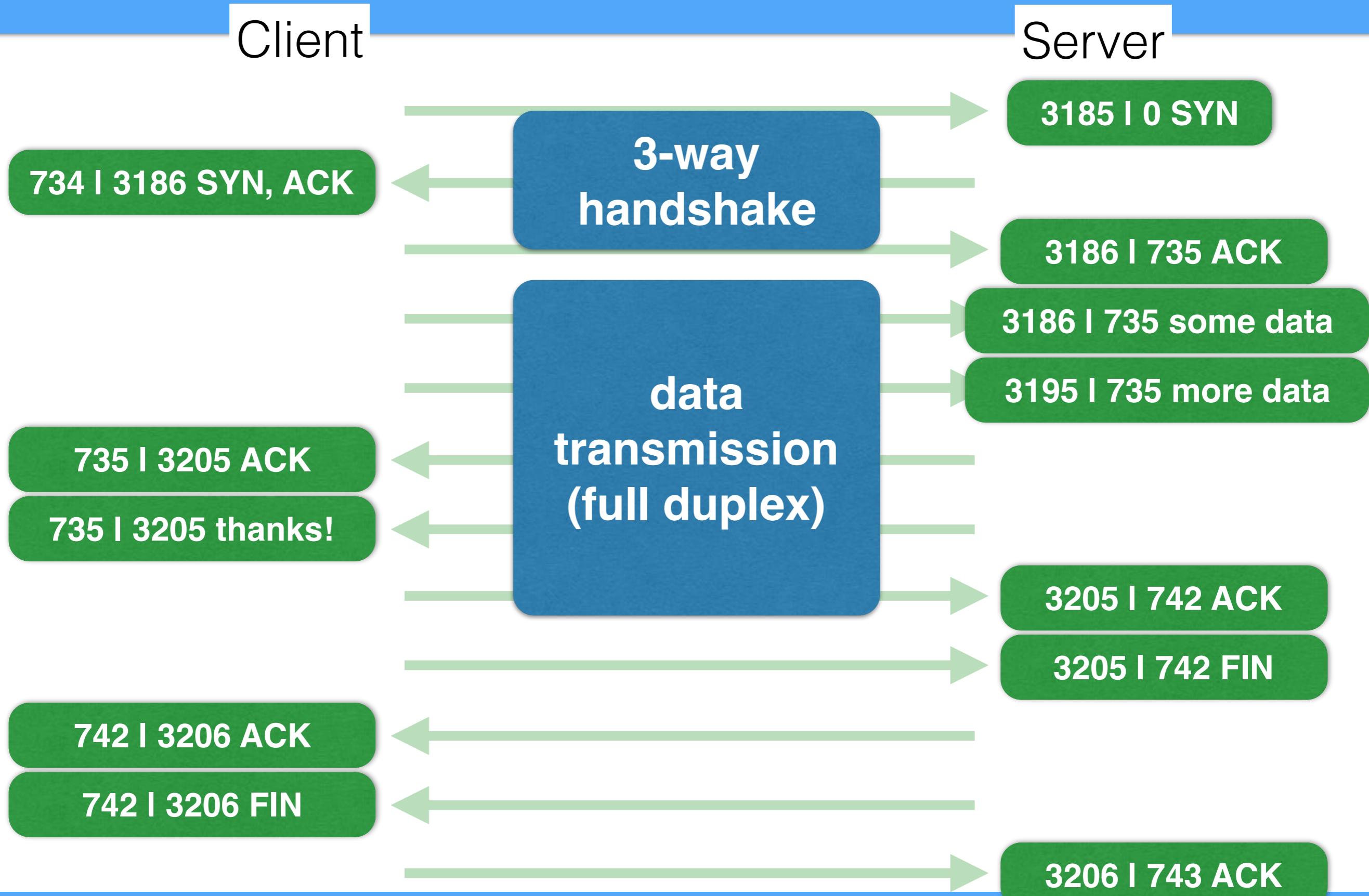
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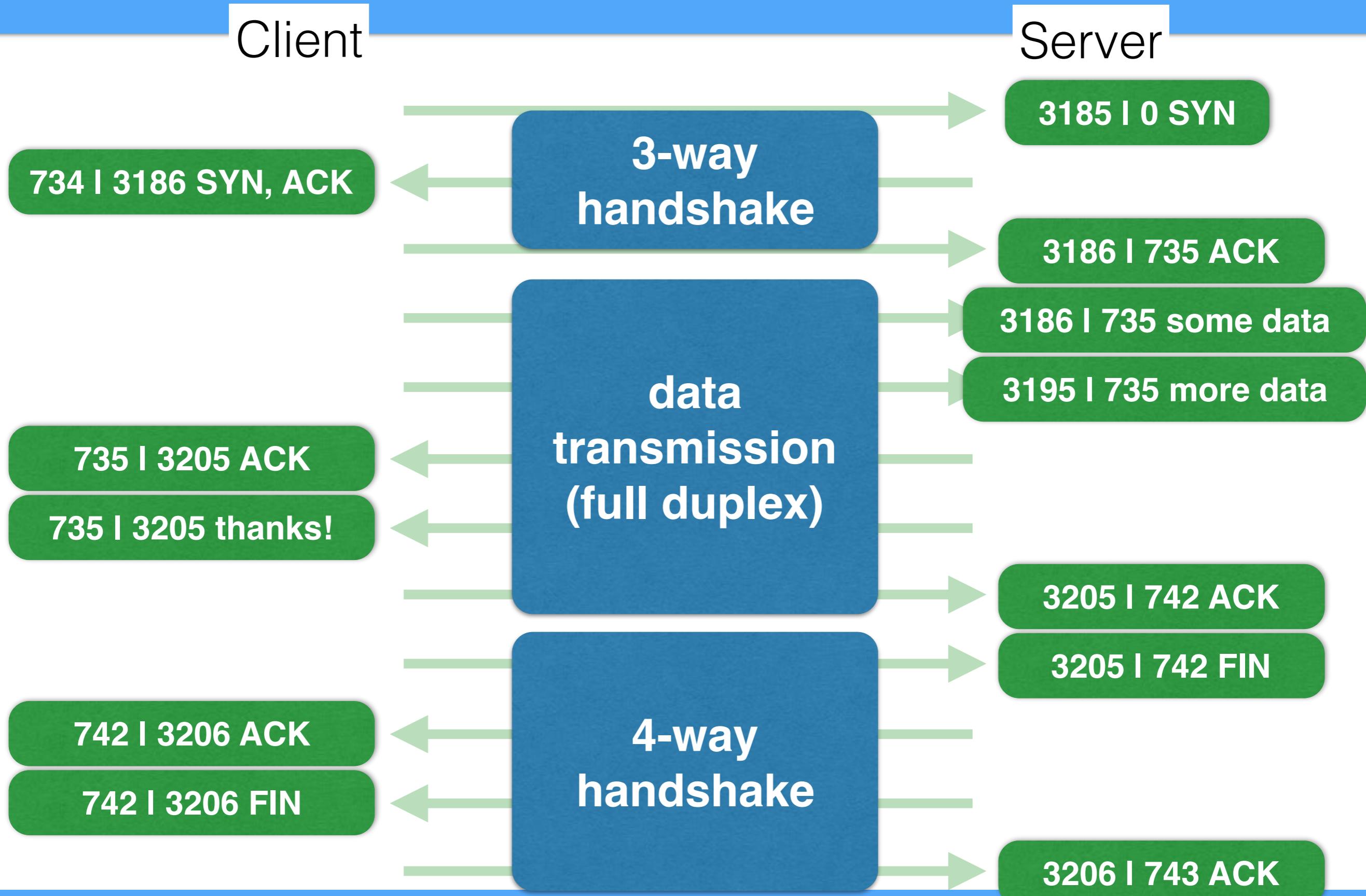
TCP session



TCP session



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TCP parameters

TCP implements segmentation

- large application layer messages are split into segments

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How fast to send segments?

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How fast to send segments?

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How to decide the segment size?

- Sending too large segments requires IP to **fragment**
- Large segments also increase errors

TCP segment size

Two approaches:

- use “reasonable” MTU, accept that IP sometimes needs to fragment

TCP segment size

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TCP segment size

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- use **Path MTU Discovery (PMTUD)**:
 - send IP packets to destination, asking routers to **never** fragment
 - if router would have to fragment, it sends back an error message
 - increase packet length until error occurs, then use last known error-free MTU

TCP congestion control

How fast to send?

- Receiver transmits its maximum buffer size
- Sender sends segments without waiting for ACK up to buffer size

TCP congestion control

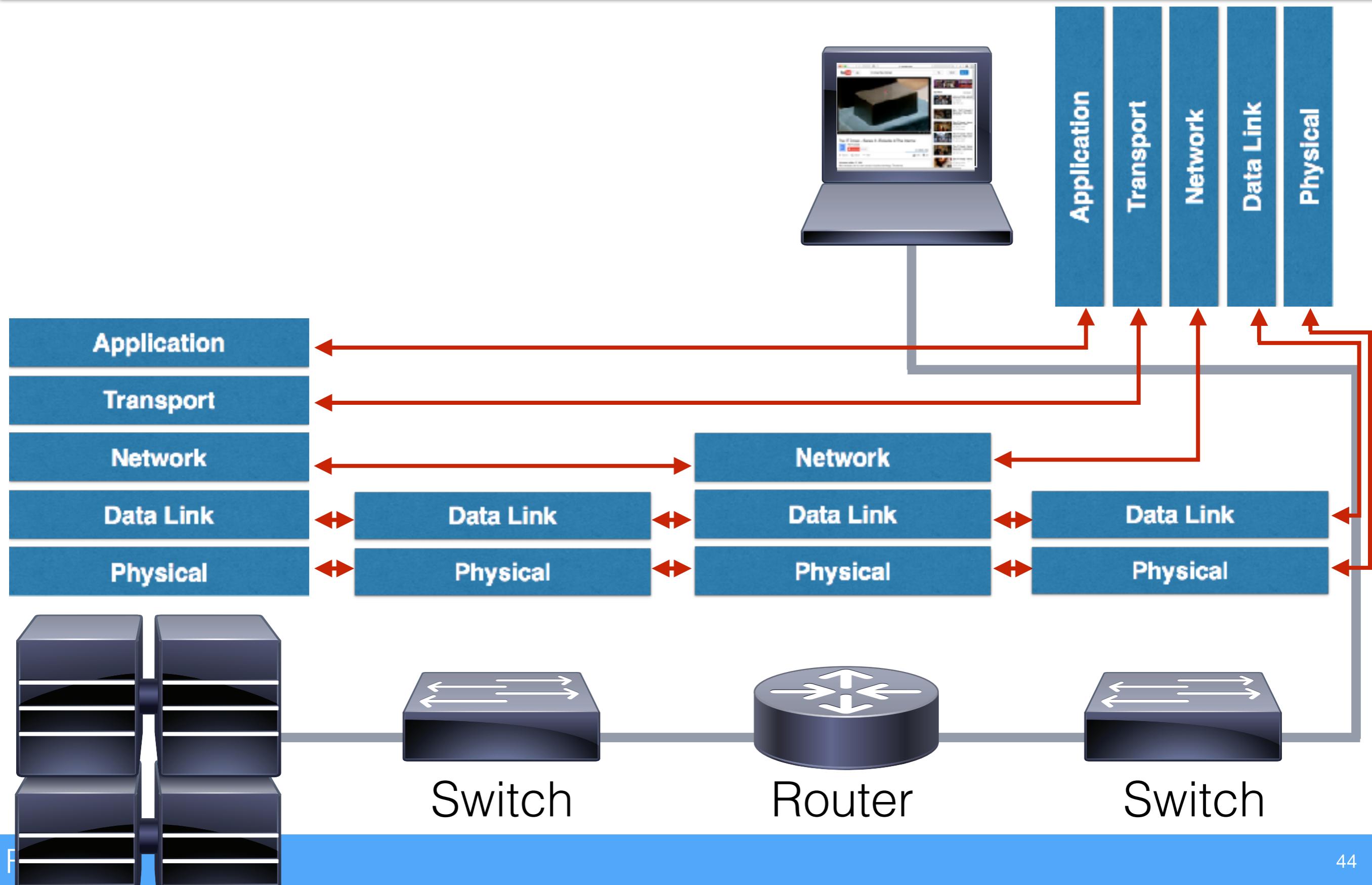
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What if network cannot cope?

- Start slow: wait for ACK after each segment
- Increase with every ACK: send two, four etc segments after each ACK
- Fall back to slower speed when no ACK arrives

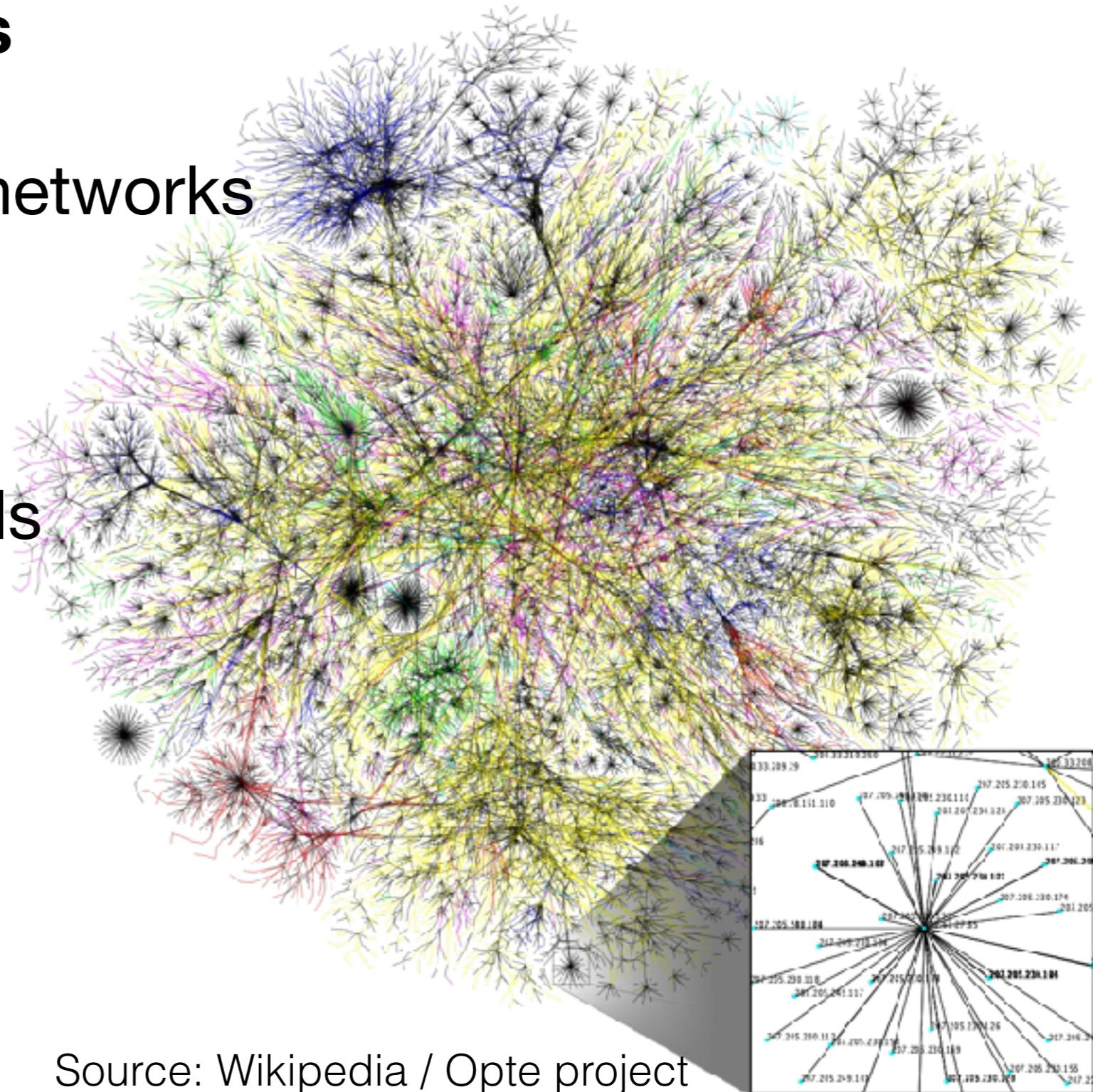
Layers of Abstraction



The Internet

The Internet

- A **network of networks**
- Connecting millions of networks and billions of devices
- Based on a common, standard set of protocols



Autonomous Systems

Networks operated by a single organisation

- e.g. Monash University's or your ISP's network

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Interior routing

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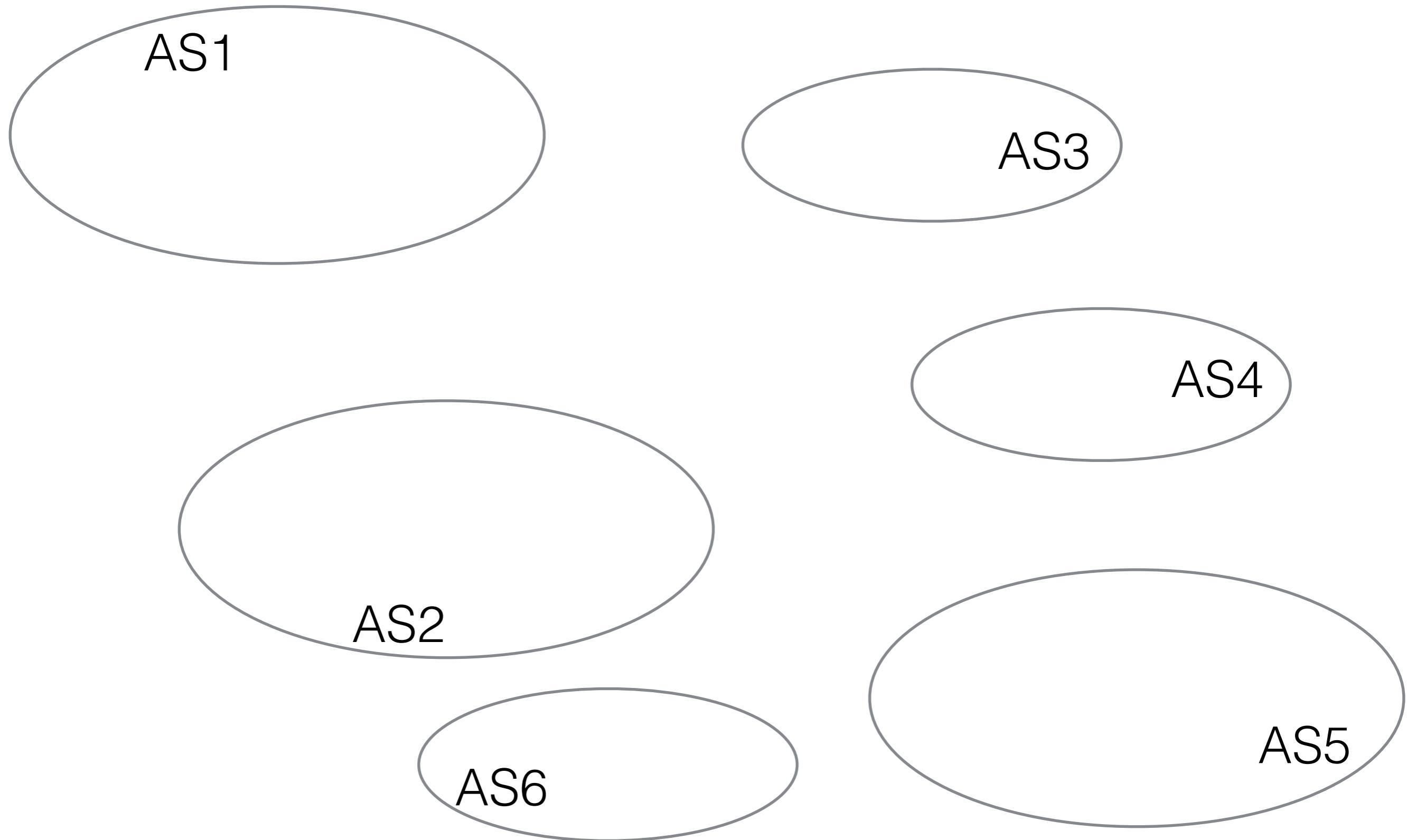
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Exterior routing

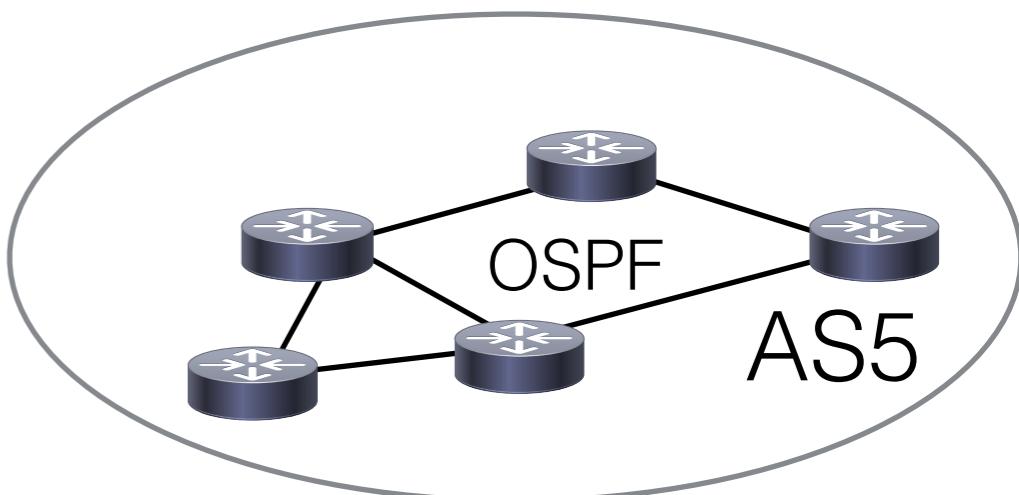
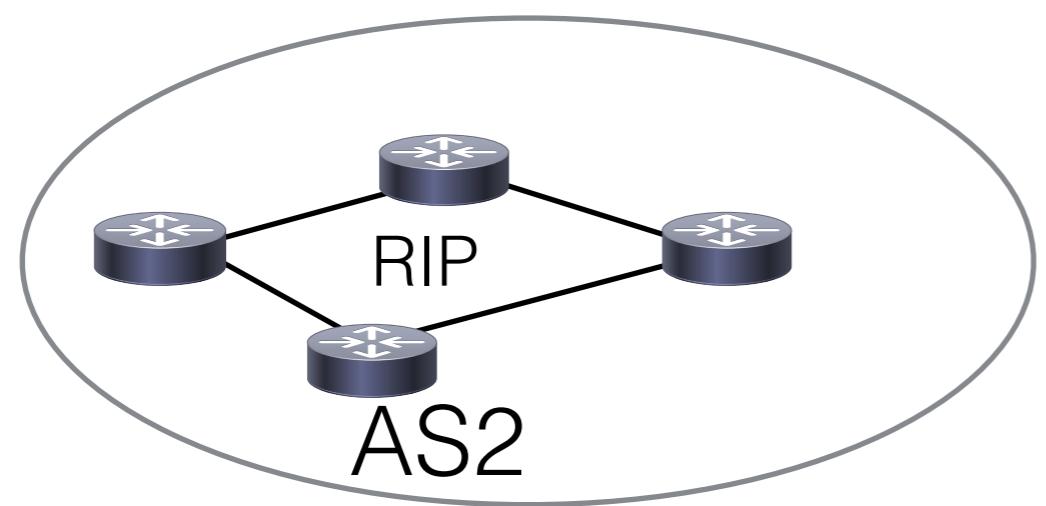
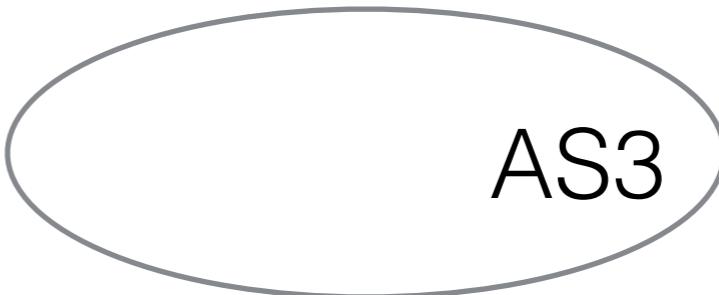
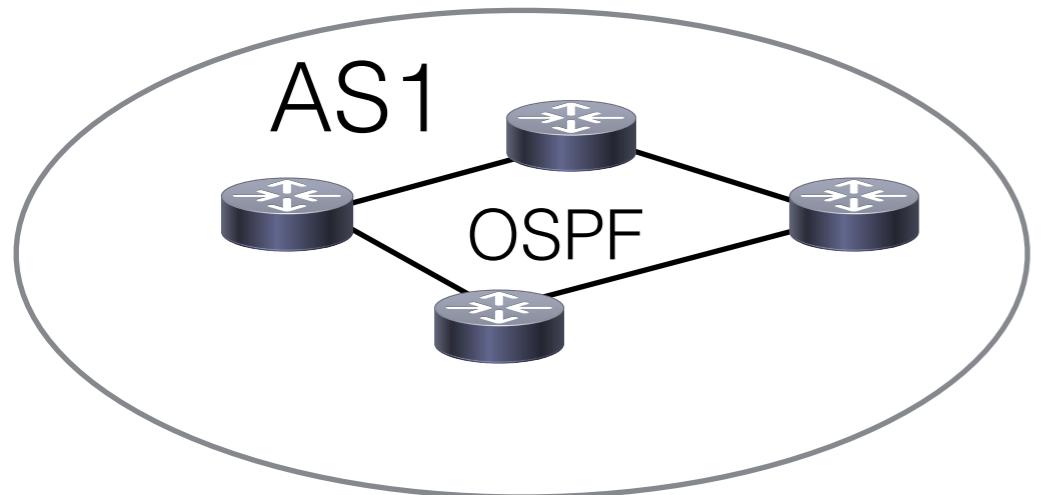
- for routing packets **between** different AS
- Internet uses BGP (Border Gateway Protocol)

Internet Architecture

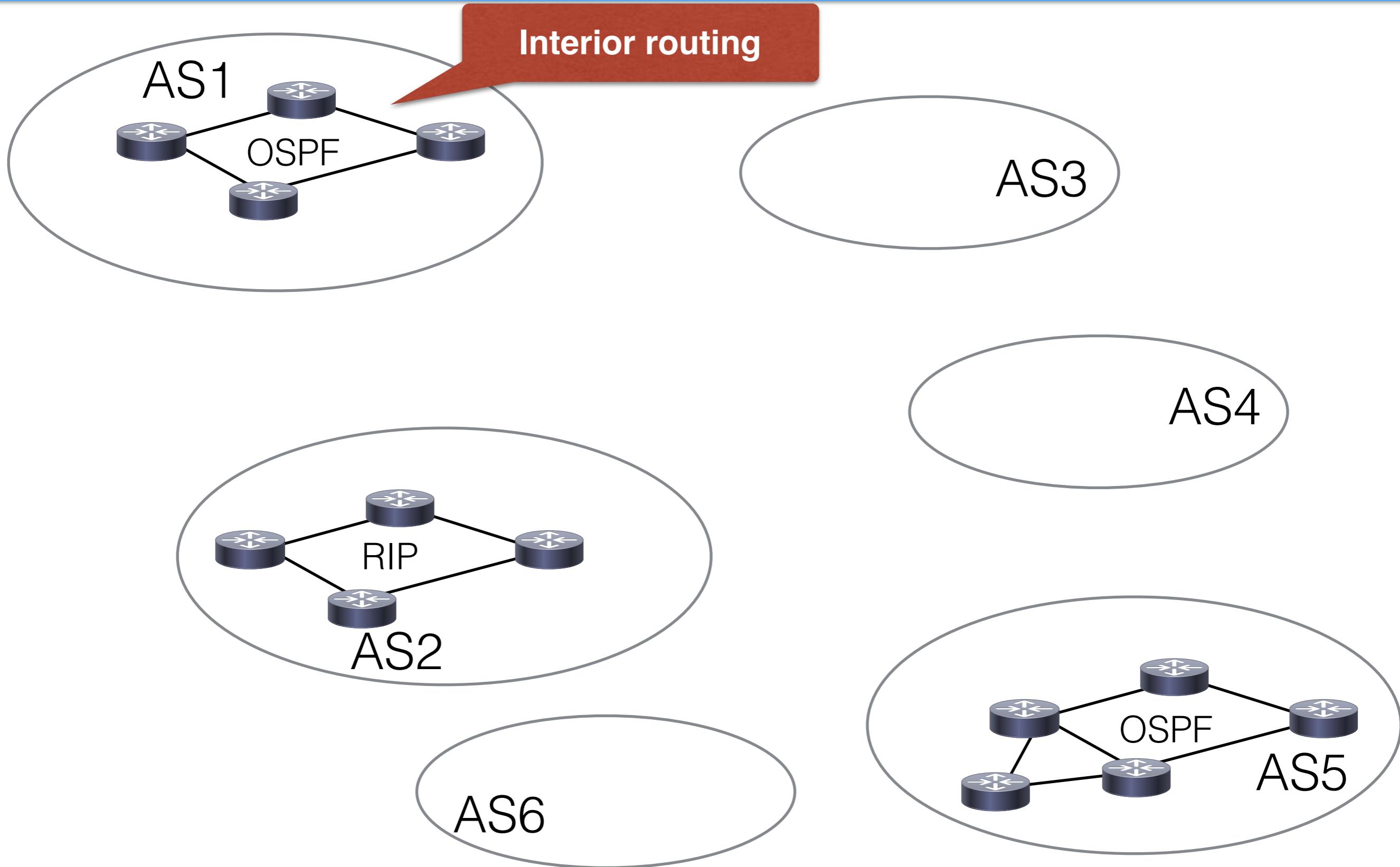
Internet Architecture



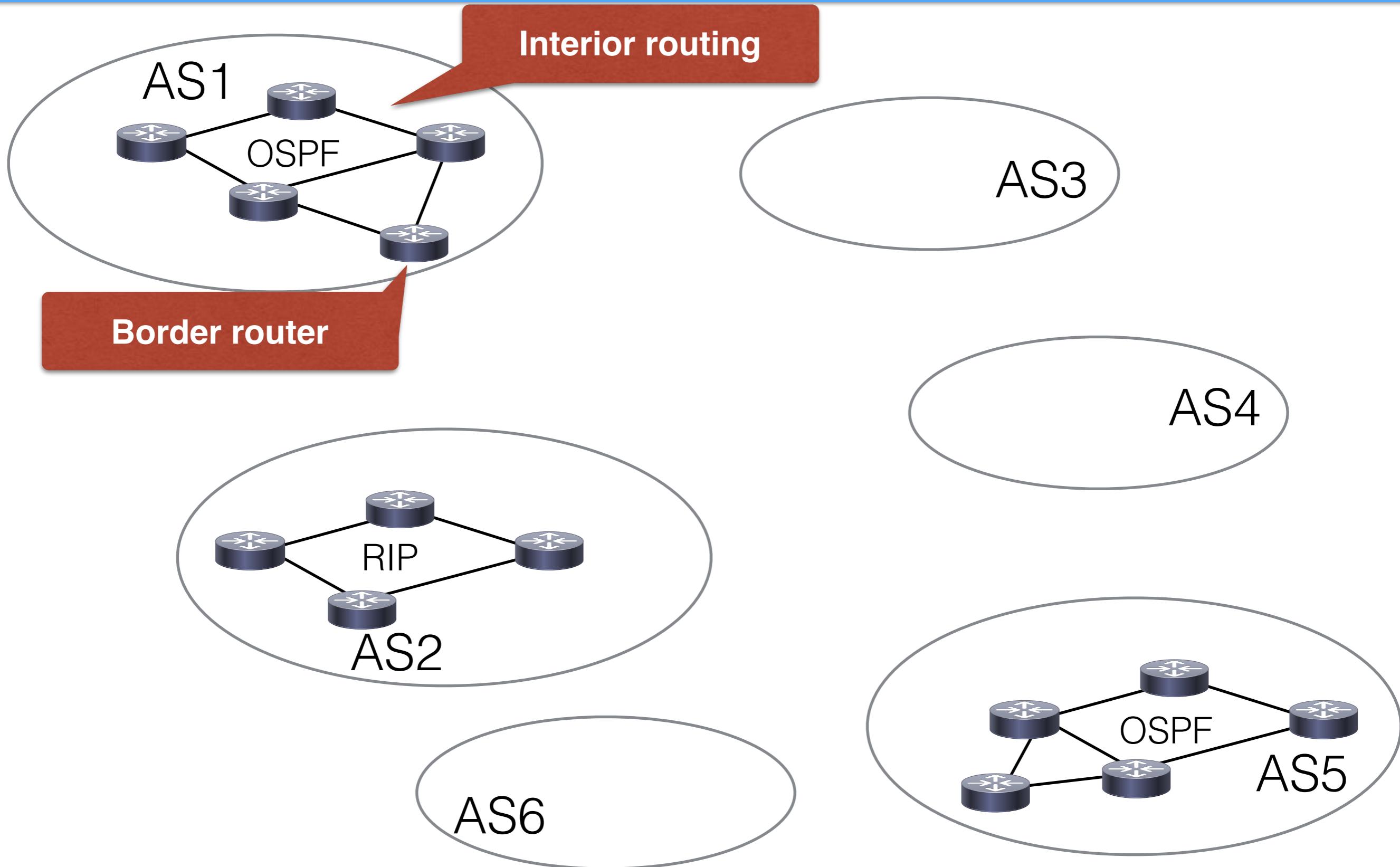
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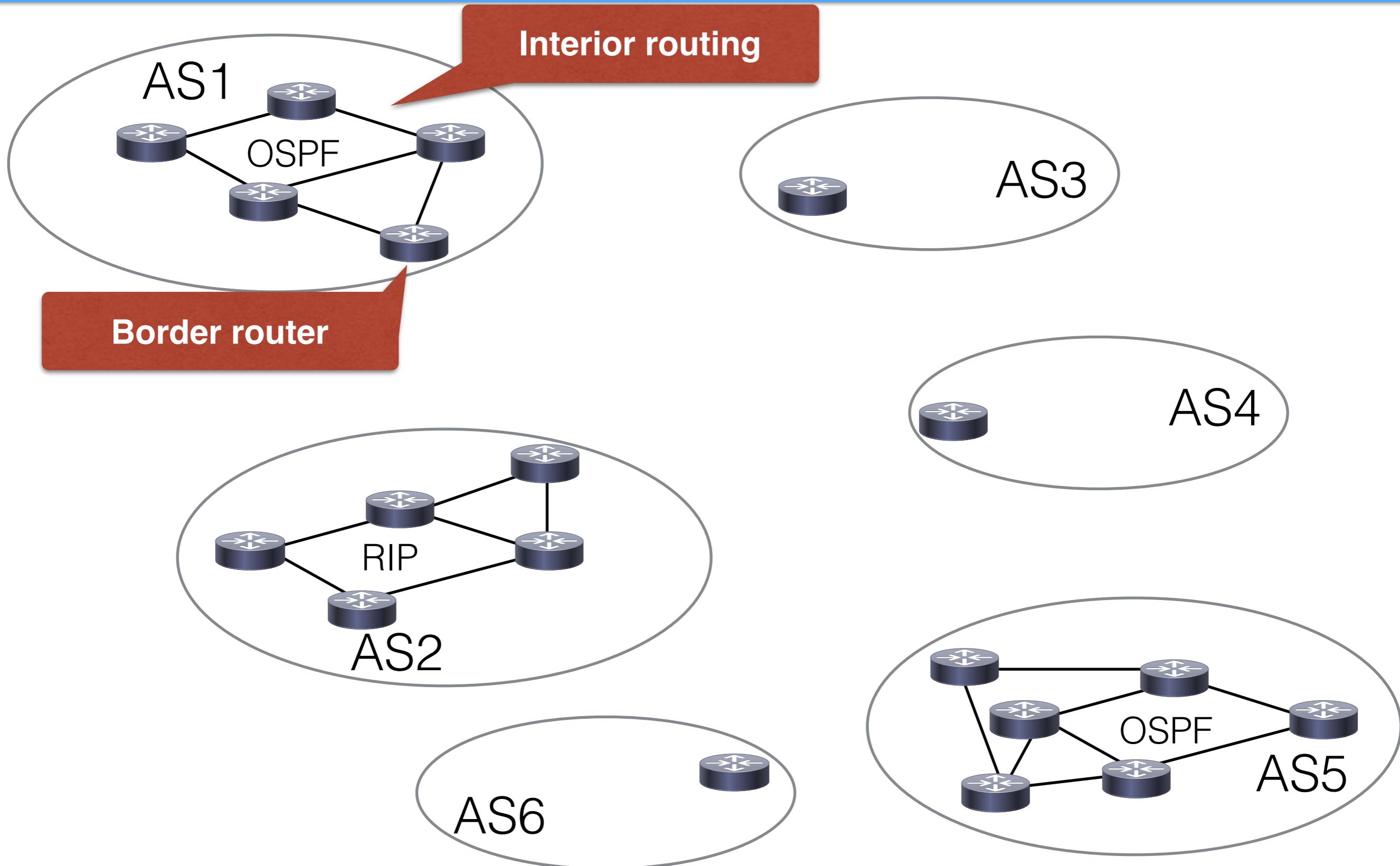
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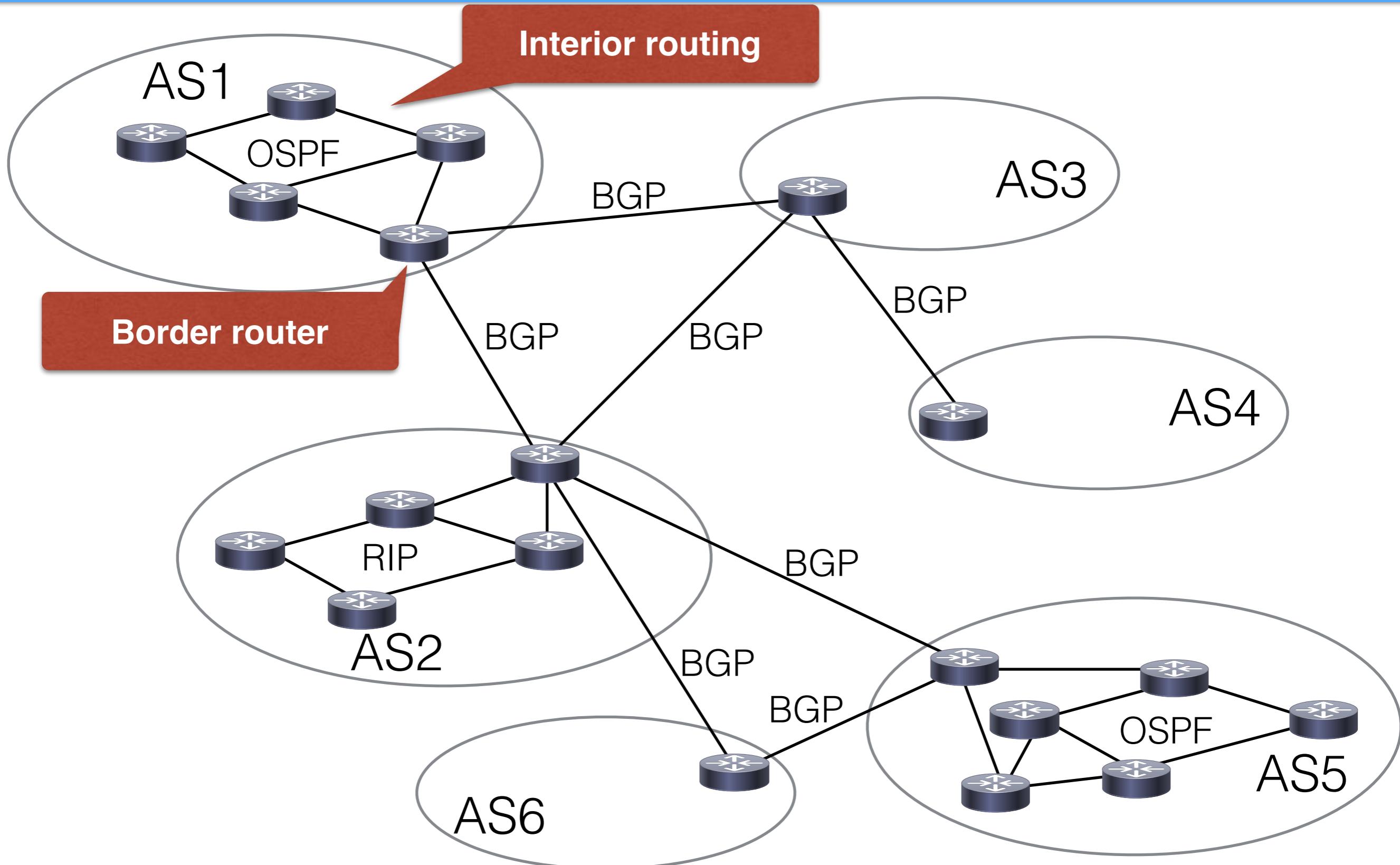
Internet Architecture



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Internet Architecture



Internet Structure

Internet Structure

Internet Service Providers

- Commercial companies
- You connect via ADSL, 4G, cable, NBN, ...
- How are they connected with each other?

Internet Structure

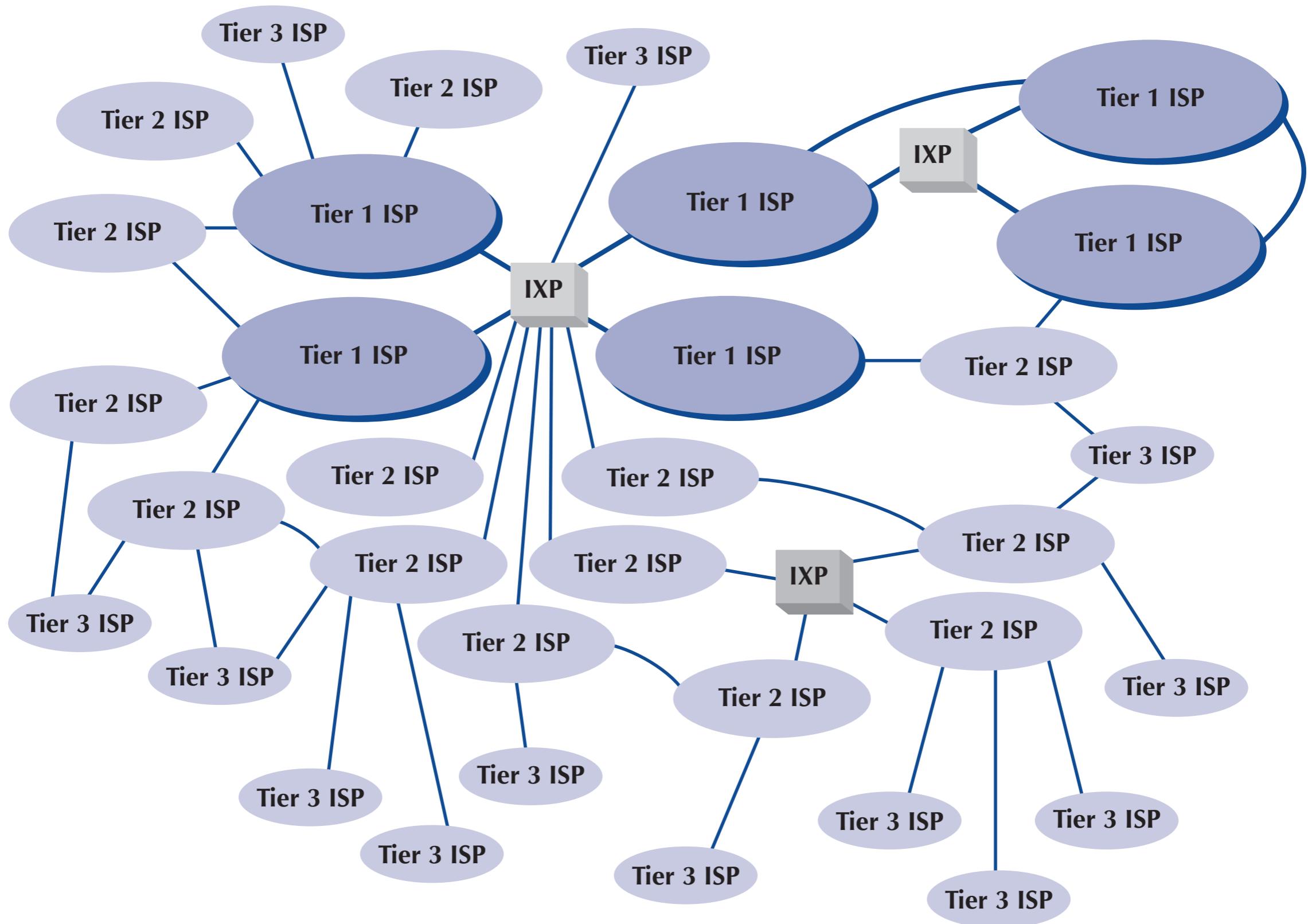
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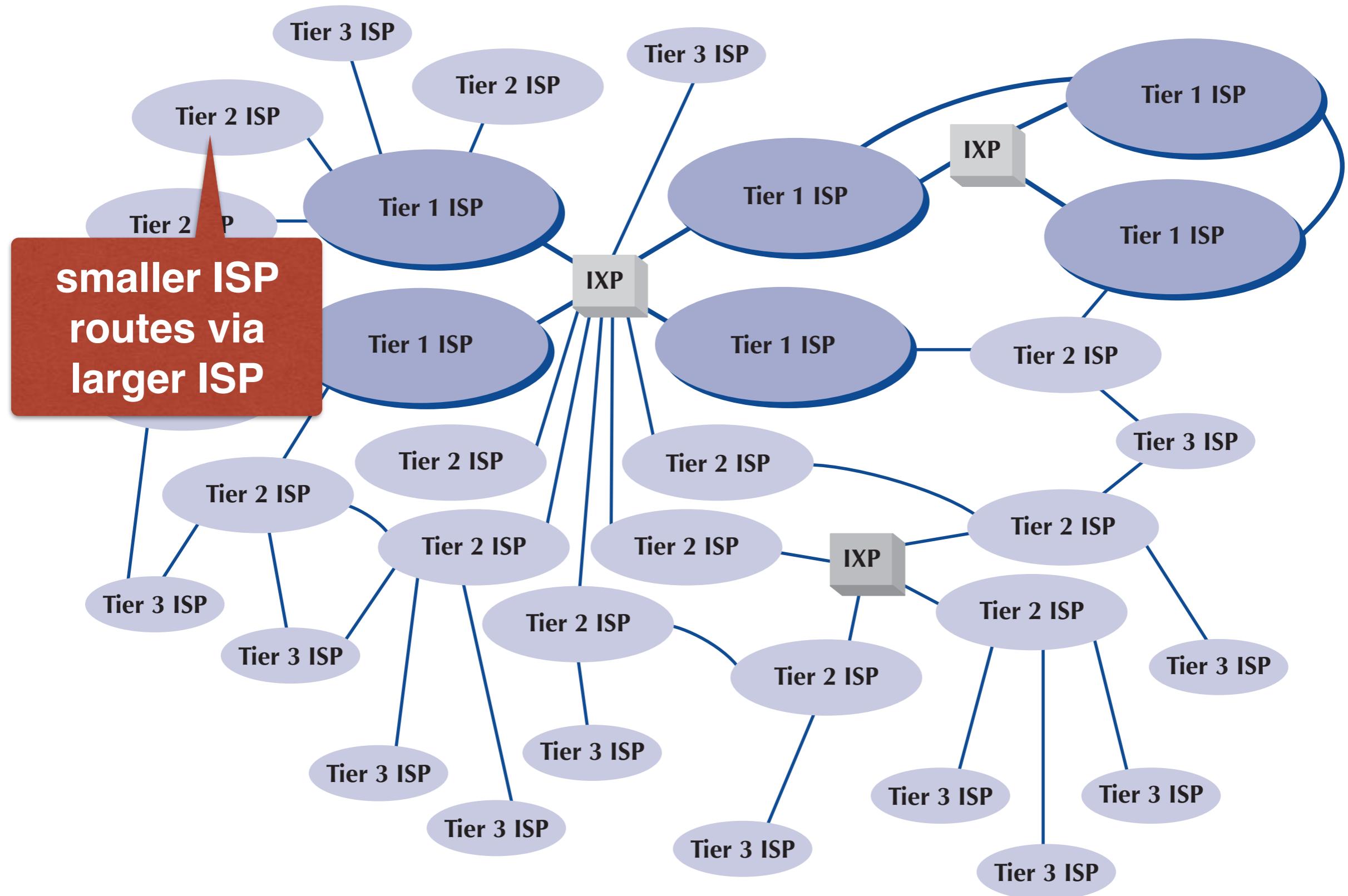
Hierarchy of ASs

- Each ISP operates an AS
- Routing information shared between ASs using BGP
- ISPs connect at **IXPs**

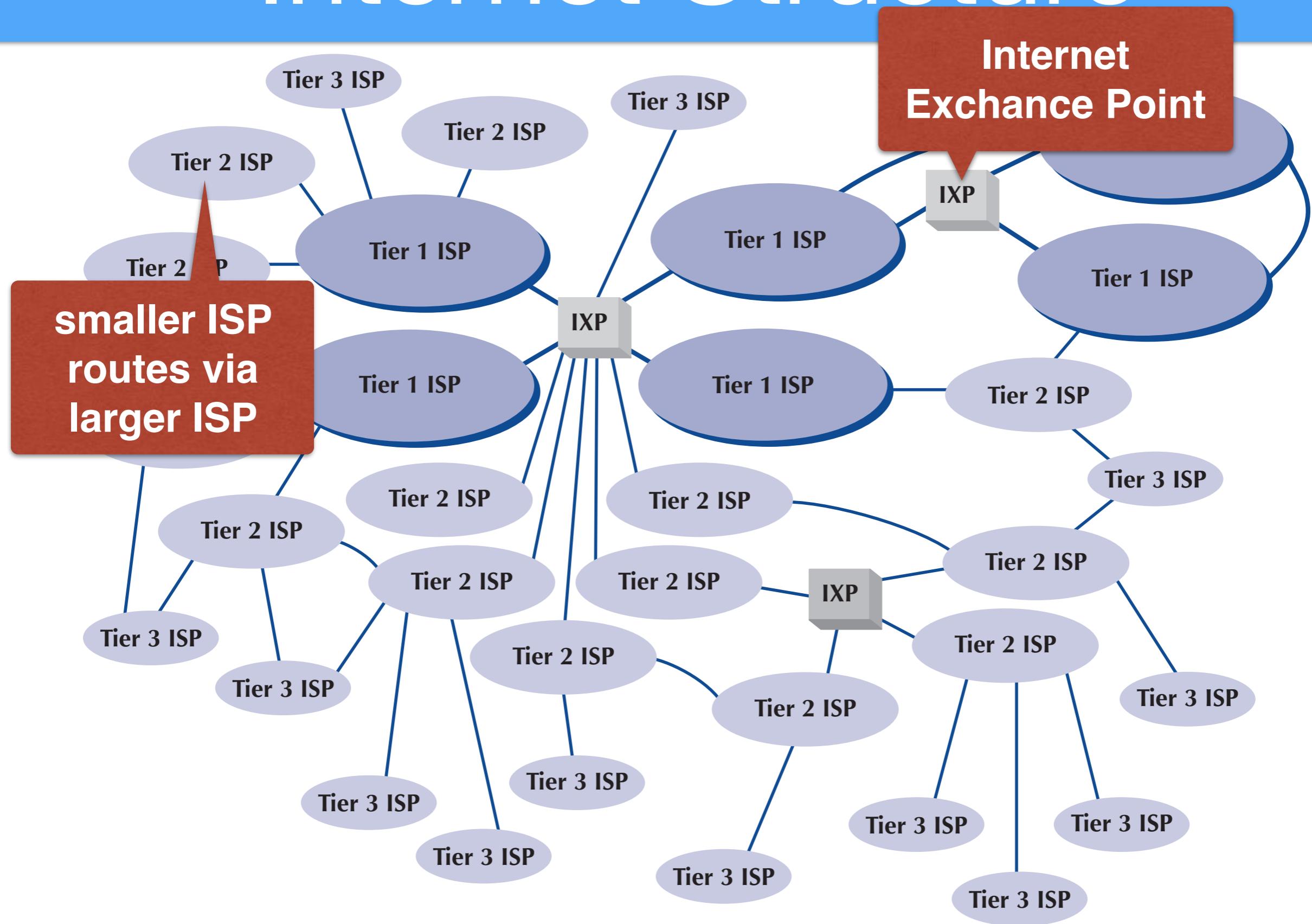
Internet Structure



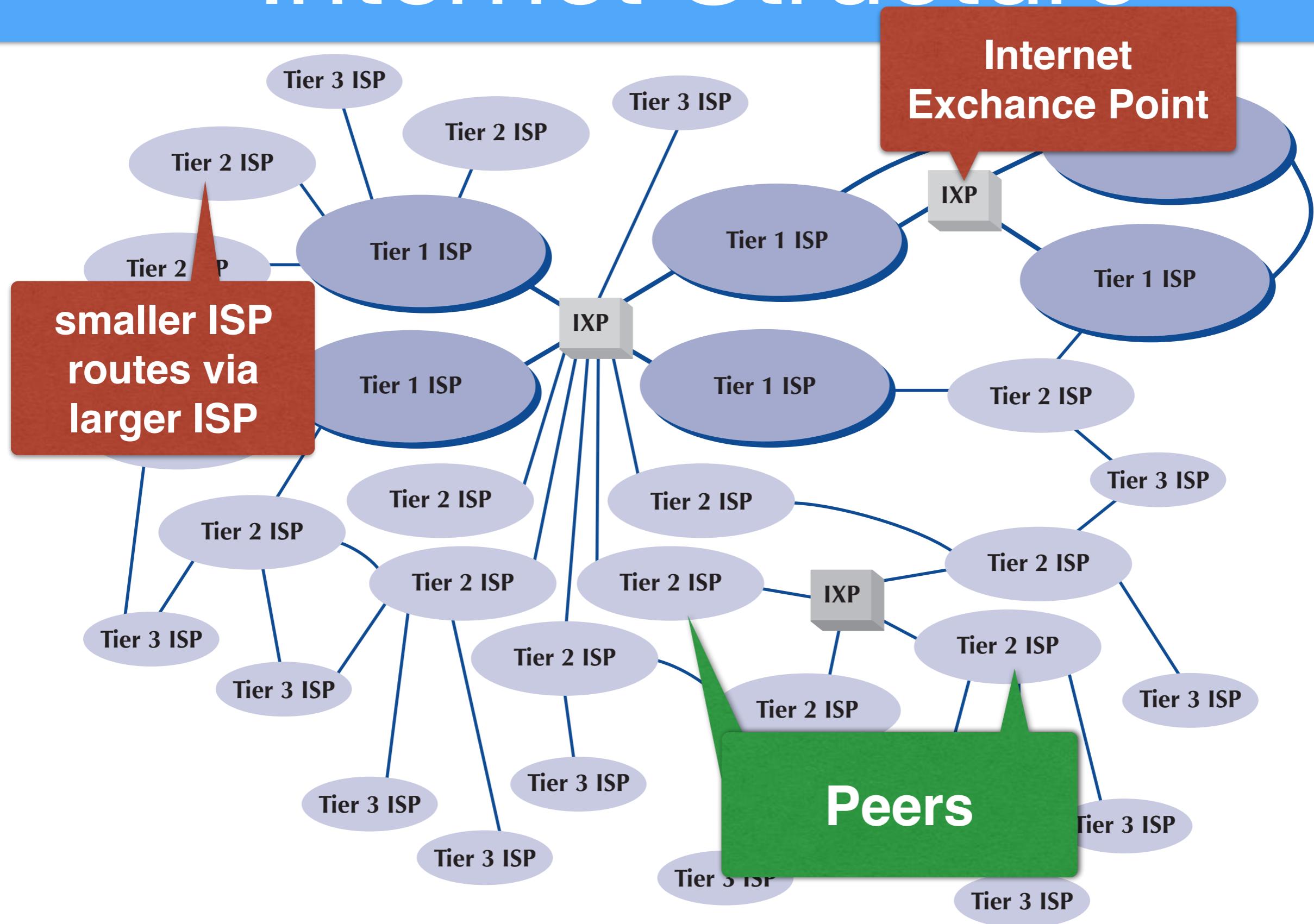
Internet Structure



Internet Structure



Internet Structure



Peering

Peering

Tier-1 ISPs

- Large ISPs with large WANs
- Charge smaller ISPs for routing their traffic

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Peering agreement between two ISPs

- accept each other's traffic without charge
- usually because both are similar size (similar amount of traffic)
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IXP

- provides the hardware for several ISPs to connect
- often owned by a consortium of ISPs

Inside an IXP



Delivering Content over the Internet

The problem

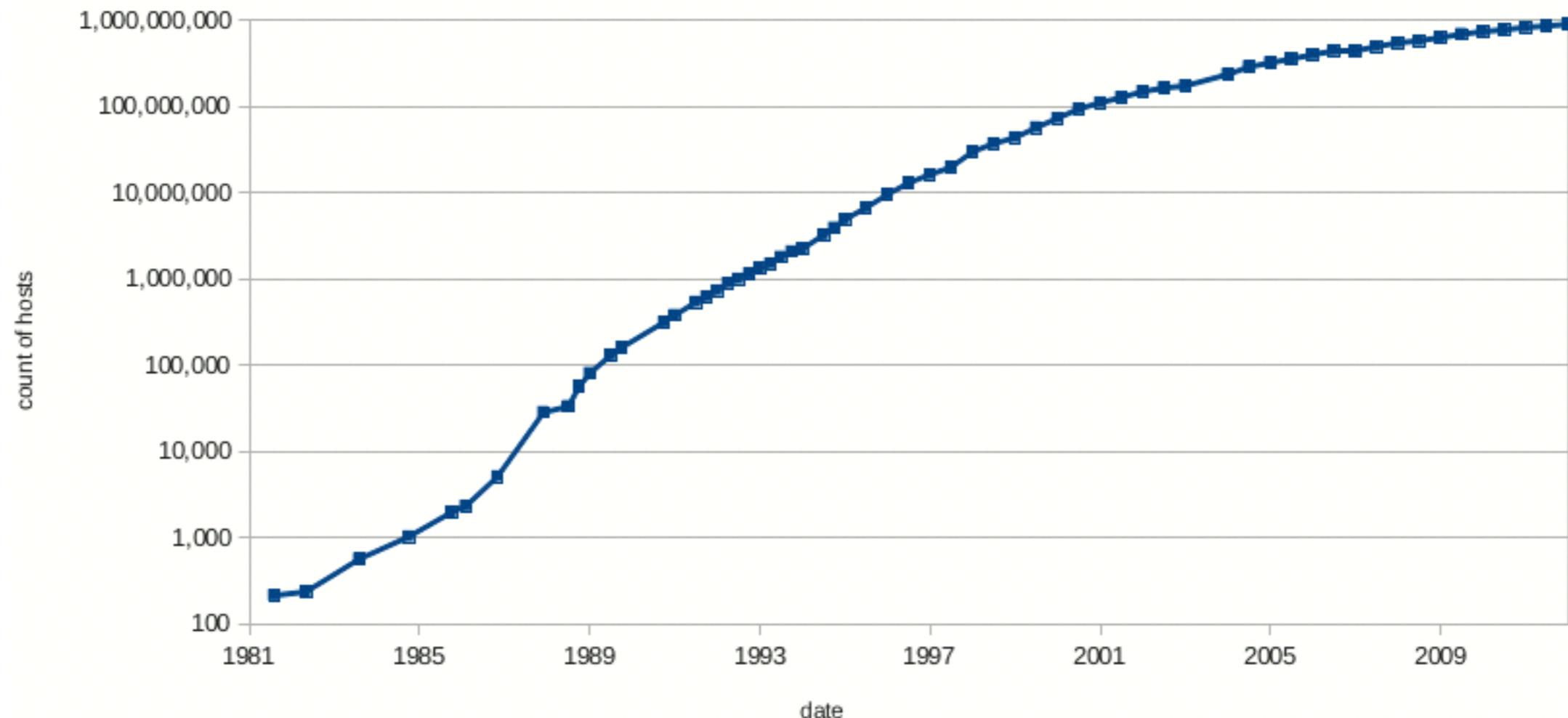
The Internet has grown

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Internet hosts 1981-2012

<https://www.isc.org/solutions/survey/history>



The problem

The Internet has grown

- not only the number of hosts, but also their **distance**
- many applications rely on **low latency** (video, streaming music, modern web sites)
- some services have millions of users
- the main protocols (HTTP, TCP/IP and BGP) were not designed for this growth

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So why does it still work?

- Load balancing
- Content Delivery Networks (CDNs)

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Many services impossible for single server

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Spread load over multiple servers

- DNS-based: host name maps to multiple IPs
- Special hardware: load balancer accepts requests, routes them to different servers

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From France:

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Content Caching

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Store web data closer to users

- replicate web pages etc. in *caches*
- can be implemented *transparently*:
 - user makes request
 - router on path to server queries *cache engine*
 - if content available, serve from local cache

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This is explicitly supported by HTTP

- GET requests can be cached
- HTTP headers can contain `Expires:` field
- Cache only serves GET requests that are not expired

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Load balancing only solves half the problem

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CDNs

- operate servers in multiple locations
- operate their own high-bandwidth network
- locate points of presence close to end users

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Get close to your customers

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CDNs are present at IXPs

- peer with anybody for free
- small ISPs avoid paying e.g. for YouTube content downloaded from the upstream ISP
- Example: Netflix peers with Australian ISPs, which can offer “unmetered” access

Summary (I)

Network layer

- subnet mask identifies other devices in same subnet
- routers use routing tables to determine next hop
- static vs dynamic routing
- IPv4 vs IPv6

Transport layer

- splits up long messages into segments
- uses ARQ for error control
- uses ports to identify applications

Summary (II)

The Internet

- consists of Autonomous Systems
- connected by routers that use BGP for sharing routes
- ISPs run autonomous systems, connect at IXP
- Load balancing and Content Delivery Networks enabled the massive growth