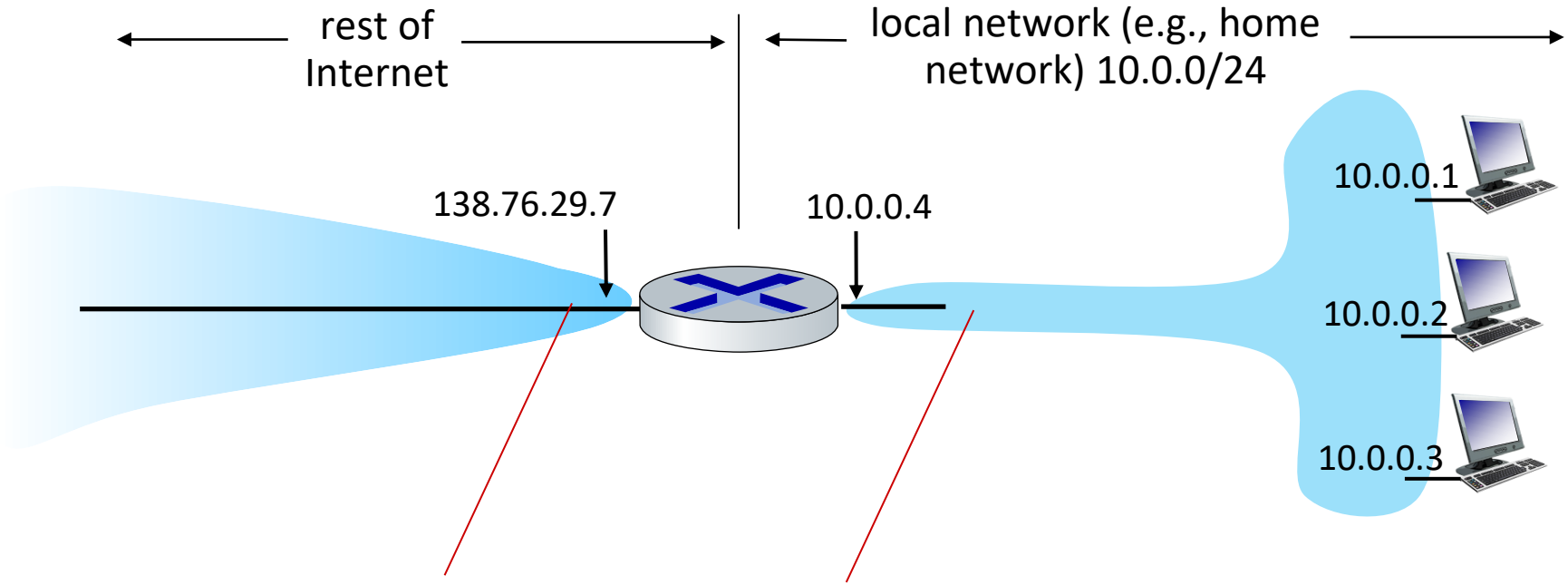
Network layer: “data plane” roadmap

- Network layer: overview
  - data plane
  - control plane
- What’s inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

- Generalized Forwarding, SDN
  - match+action
  - OpenFlow: match+action in action
- Middleboxes

NAT: network address translation

NAT: all devices in local network share just one IPv4 address as far as outside world is concerned



all datagrams *leaving* local network have *same* source NAT IP address: 138.76.29.7, but *different* source port numbers

datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: network address translation

- all devices in local network have 32-bit addresses in a “private” IP address space (10/8, 172.16/12, 192.168/16 prefixes) that can only be used in local network
- advantages:
  - just one IP address needed from provider ISP for *all* devices
  - can change addresses of host in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - security: devices inside local net not directly addressable, visible by outside world

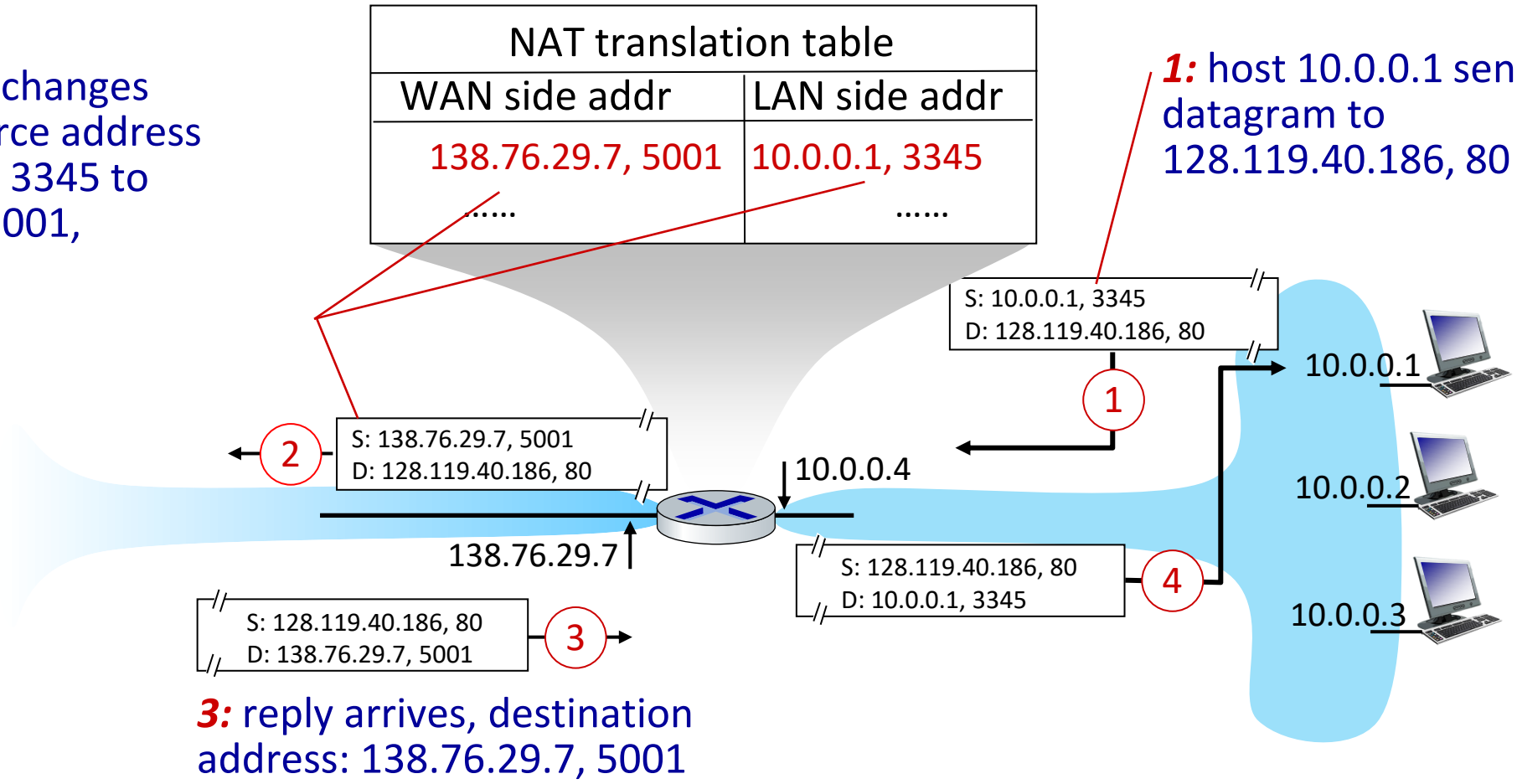
NAT: network address translation

implementation: NAT router must (transparently):

- outgoing datagrams: replace (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  - remote clients/servers will respond using (NAT IP address, new port #) as destination address
- remember (in NAT translation table) every (source IP address, port #) to (NAT IP address, new port #) translation pair
- incoming datagrams: replace (NAT IP address, new port #) in destination fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: network address translation

2: NAT router changes datagram source address from 10.0.0.1, 3345 to 138.76.29.7, 5001, updates table



3: reply arrives, destination address: 138.76.29.7, 5001

NAT: network address translation

- NAT has been controversial:
  - routers “should” only process up to layer 3
  - address “shortage” should be solved by IPv6
  - violates end-to-end argument (port # manipulation by network-layer device)
  - NAT traversal: what if client wants to connect to server behind NAT?
- but NAT is here to stay:
  - extensively used in home and institutional nets, 4G/5G cellular nets

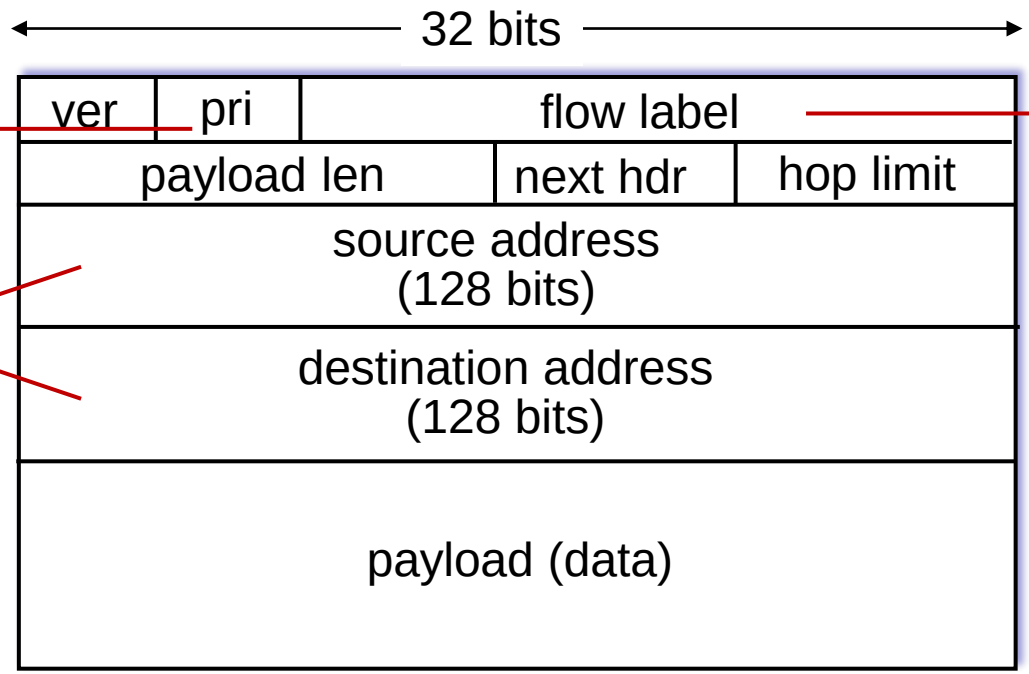
IPv6: motivation

- initial motivation: 32-bit IPv4 address space would be completely allocated
- additional motivation:
  - speed processing/forwarding: 40-byte fixed length header
  - enable different network-layer treatment of “flows”

IPv6 datagram format

priority: identify priority among datagrams in flow

128-bit IPv6 addresses



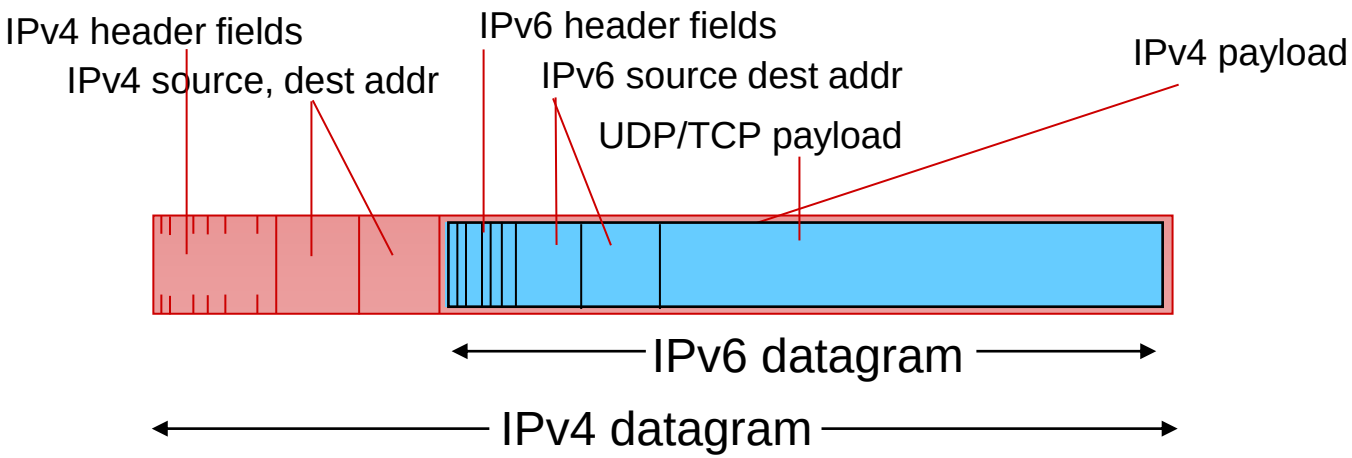
flow label: identify datagrams in same "flow." (concept of "flow" not well defined).

What's missing (compared with IPv4):

- no checksum (to speed processing at routers)
- no fragmentation/reassembly
- no options (available as upper-layer, next-header protocol at router)

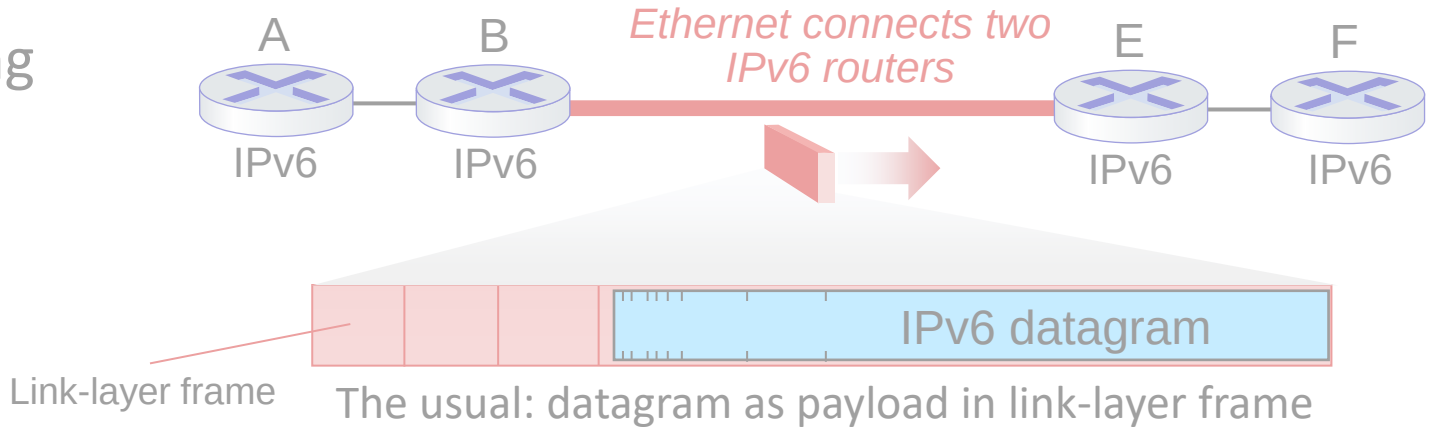
Transition from IPv4 to IPv6

- not all routers can be upgraded simultaneously
  - no “flag days”
  - how will network operate with mixed IPv4 and IPv6 routers?
- tunneling: IPv6 datagram carried as *payload* in IPv4 datagram among IPv4 routers (“packet within a packet”)
  - tunneling used extensively in other contexts (4G/5G)

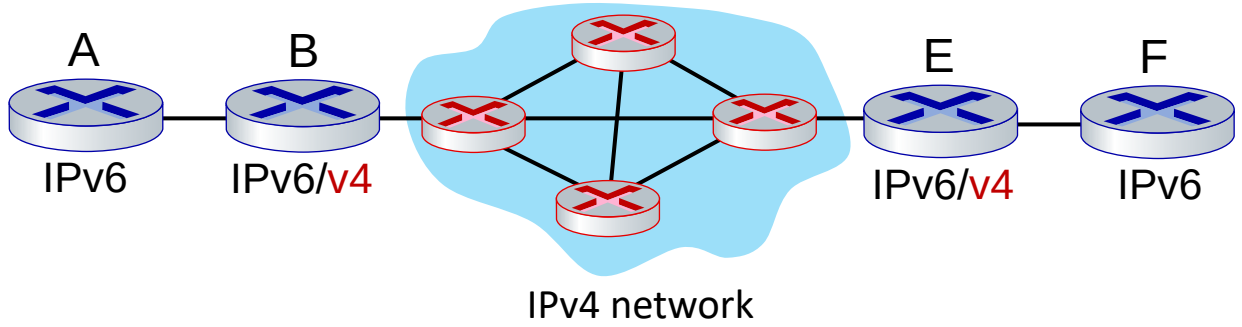


Tunneling and encapsulation

Ethernet connecting two IPv6 routers:



IPv4 network connecting two IPv6 routers



Tunneling and encapsulation

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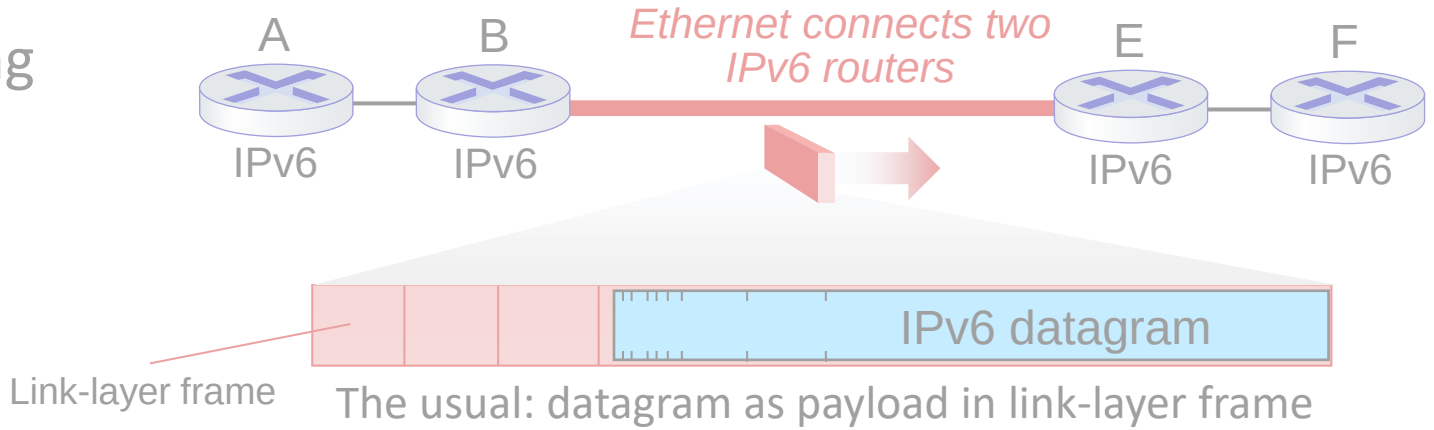
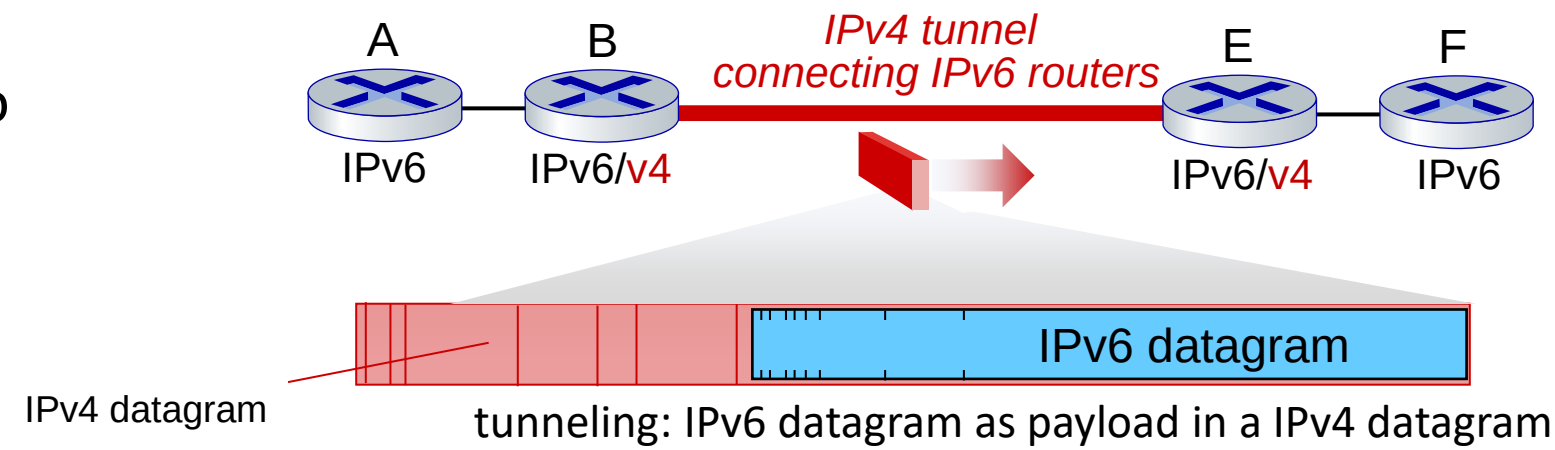
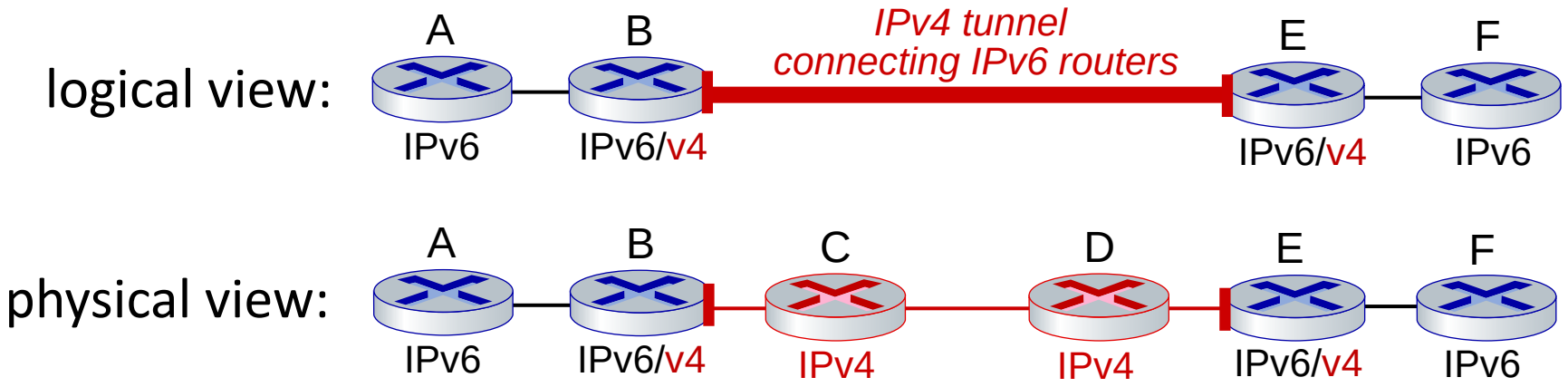


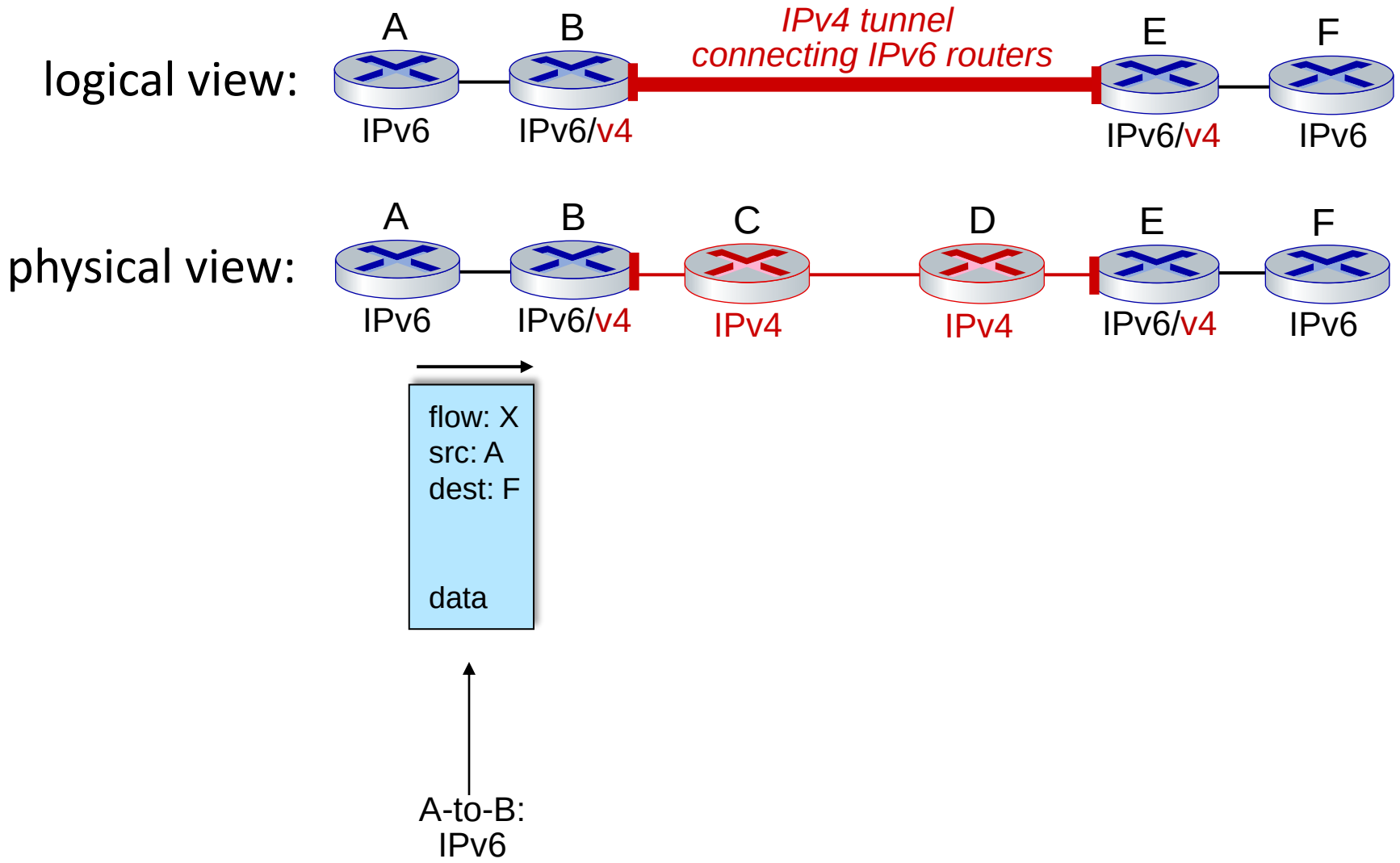
IPv4 tunnel connecting two IPv6 routers



Tunneling


logical view:
A
B
IPv4 tunnel
connecting IPv6 routers
E
F
IPv6
IPv6/v4
IPv6/v4
IPv6
physical view:
A
B
C
D
E
F
IPv6
IPv6/v4
IPv4
IPv4
IPv6/v4
IPv6

Tunneling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IPv6
IPv6/v4
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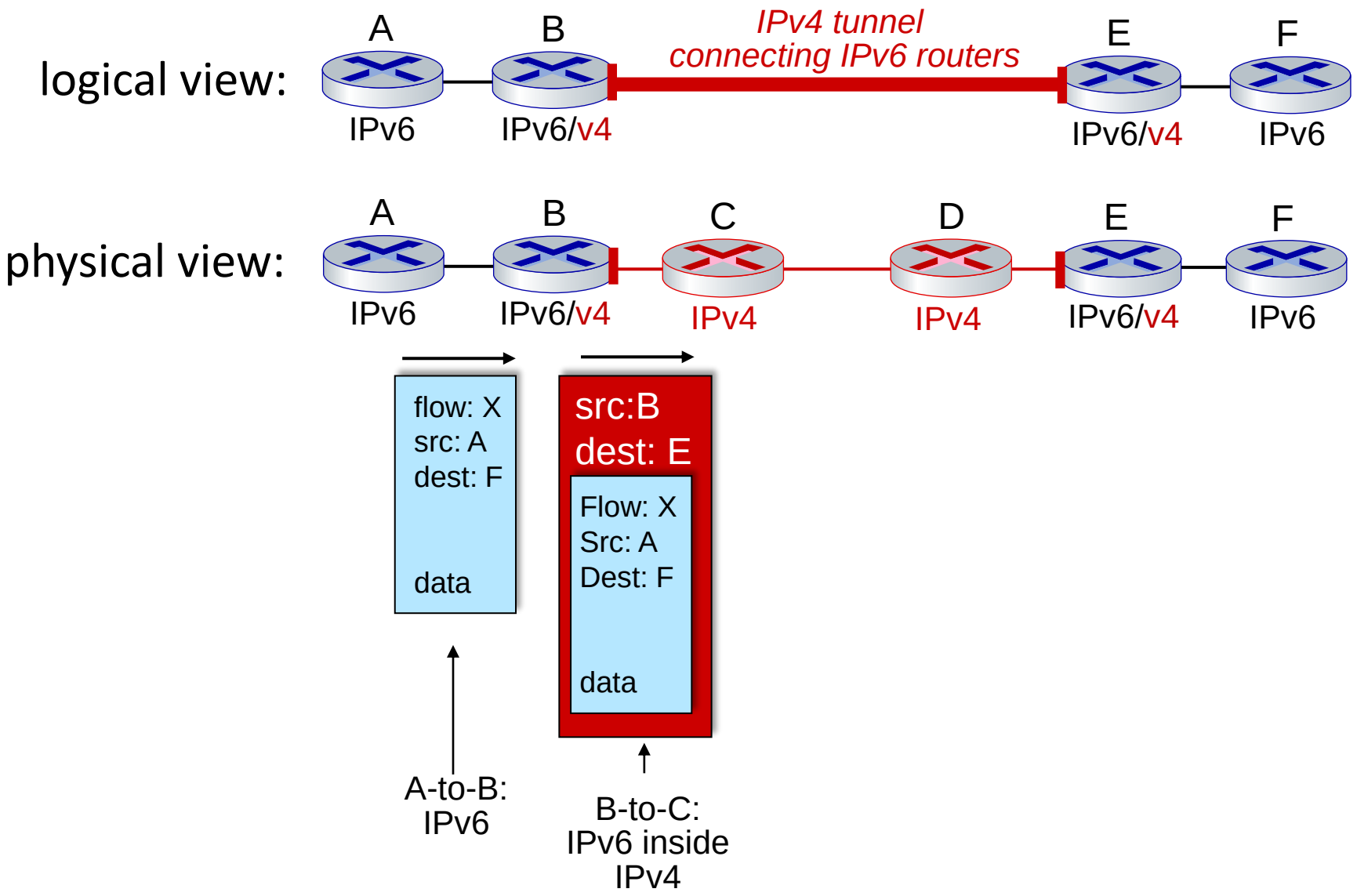
IPv6
physical view:
A
B
C
D
E
F
IPv6
IPv6/v4
IPv4
IPv4
IPv6/v4
IPv6
flow: X
src: A
dest: F
data
A-to-B:
IPv6

Tunneling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IPv6
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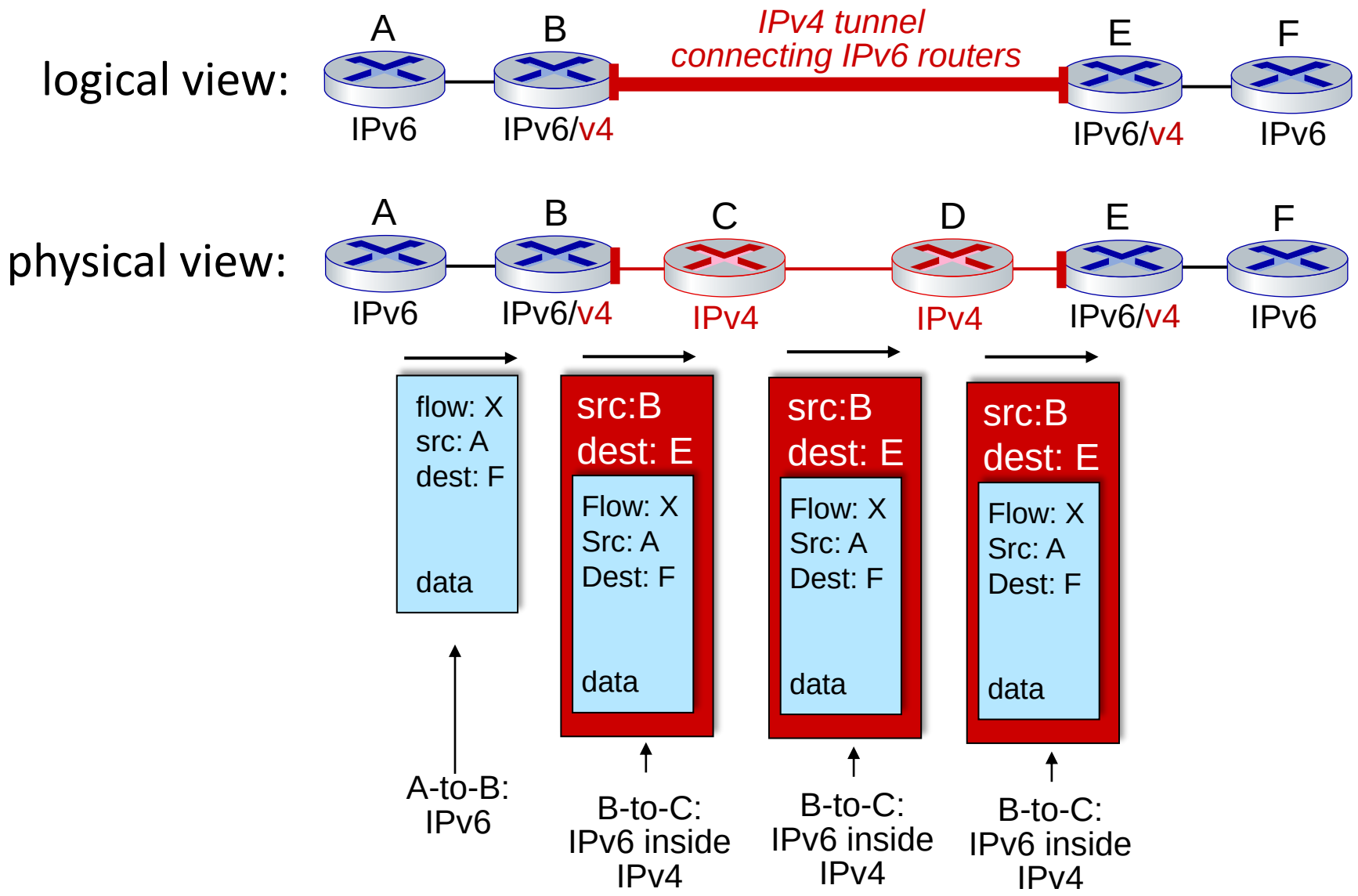
IPv6
physical view:
A
B
C
D
E
F
IPv6
IPv6/v4
IPv4
IPv4
IPv6/v4
IPv6
flow: X
src: A
dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
A-to-B:
IPv6
B-to-C:
IPv6 inside
IPv4

Tunneling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IPv6/v4
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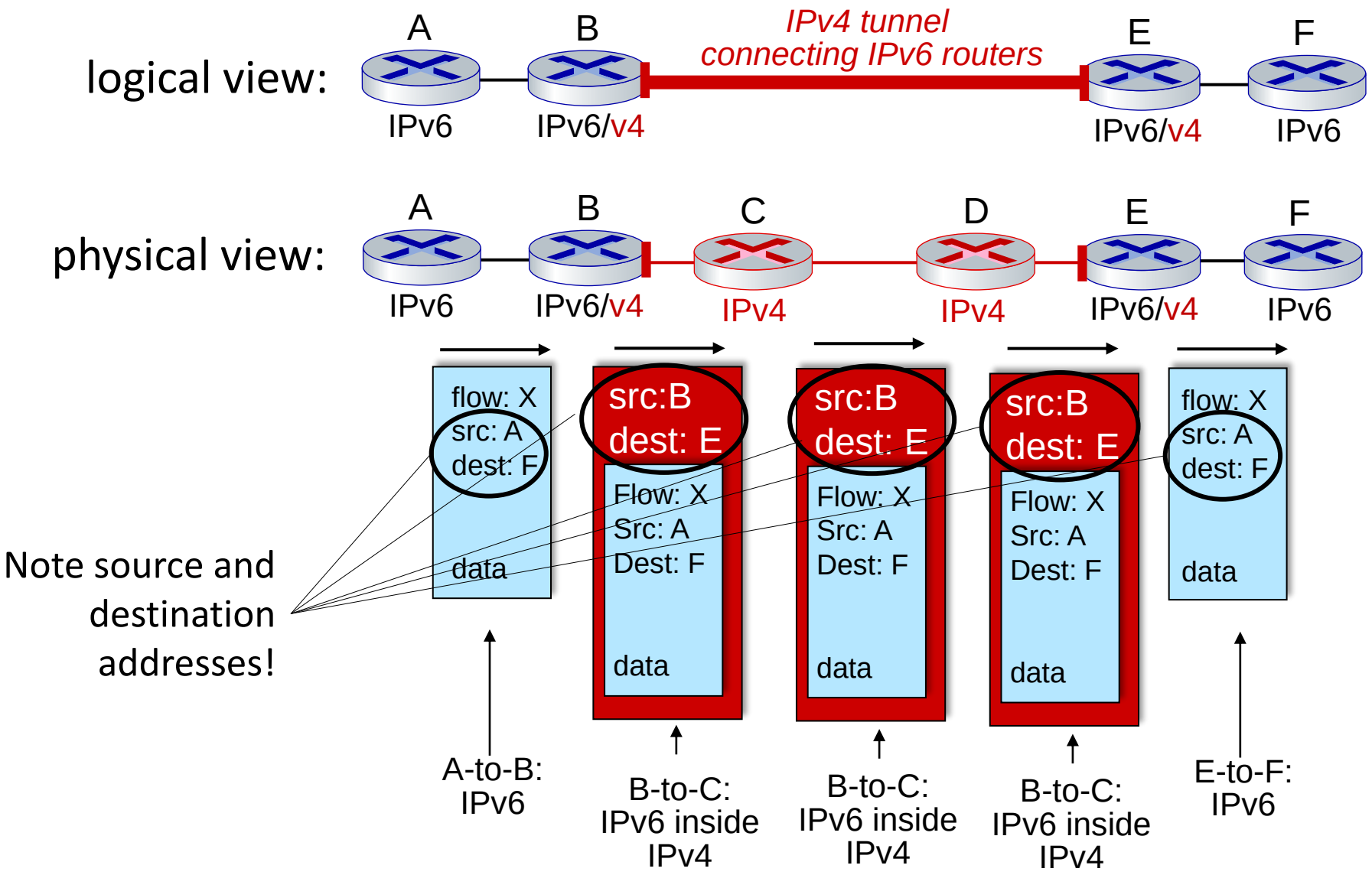
physical view:
A
B
C
D
E
F
IPv6
IPv6/v4
IPv4
IPv4
IPv6/v4
IPv6
flow: X
src: A
dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
A-to-B:
IPv6
B-to-C:
IPv6 inside
IPv4
B-to-C:
IPv6 inside
IPv4
B-to-C:
IPv6 inside
IPv4

Tunneling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IPv6
IPv6/v4
IPv6/v4
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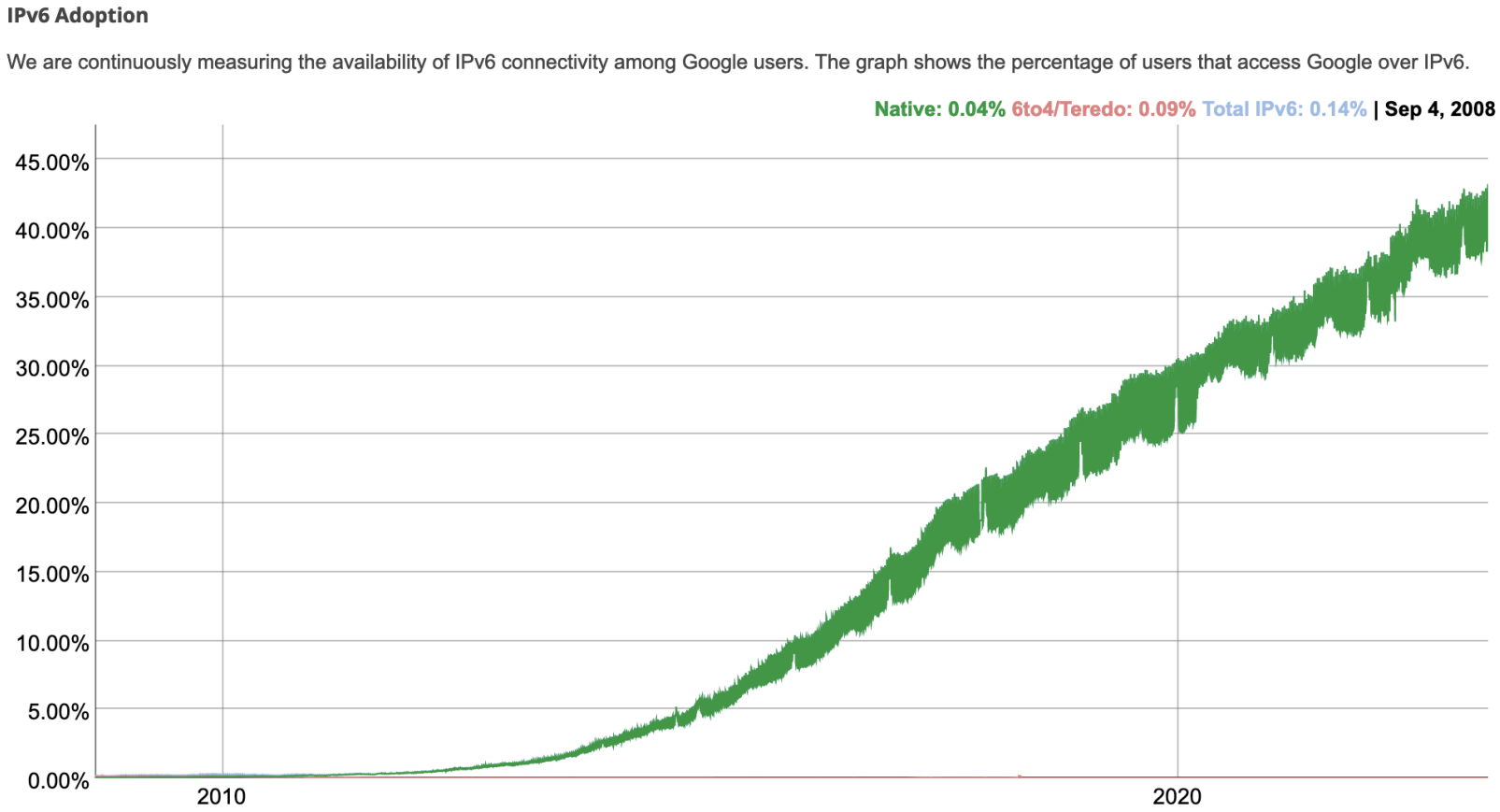
physical view:
A
B
C
D
E
F
IPv6
IPv6/v4
IPv4
IPv4
IPv6/v4
IPv6
Note source and
destination
addresses!
flow: X
src: A
dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
flow: X
src: A
dest: F
data
A-to-B:
IPv6
B-to-C:
IPv6 inside
IPv4
B-to-C:
IPv6 inside
IPv4
B-to-C:
IPv6 inside
IPv4
E-to-F:
IPv6

IPv6: adoption

- Google[1]: ~ 40% of clients access services via IPv6 (2023)
- NIST: 1/3 of all US government domains are IPv6 capable



IPv6: adoption

- Google[1]: ~ 40% of clients access services via IPv6 (2023)
- NIST: 1/3 of all US government domains are IPv6 capable
- Long (long!) time for deployment, use
  - 25 years and counting!
  - think of application-level changes in last 25 years: WWW, social media, streaming media, gaming, telepresence, …
  - *Why?*

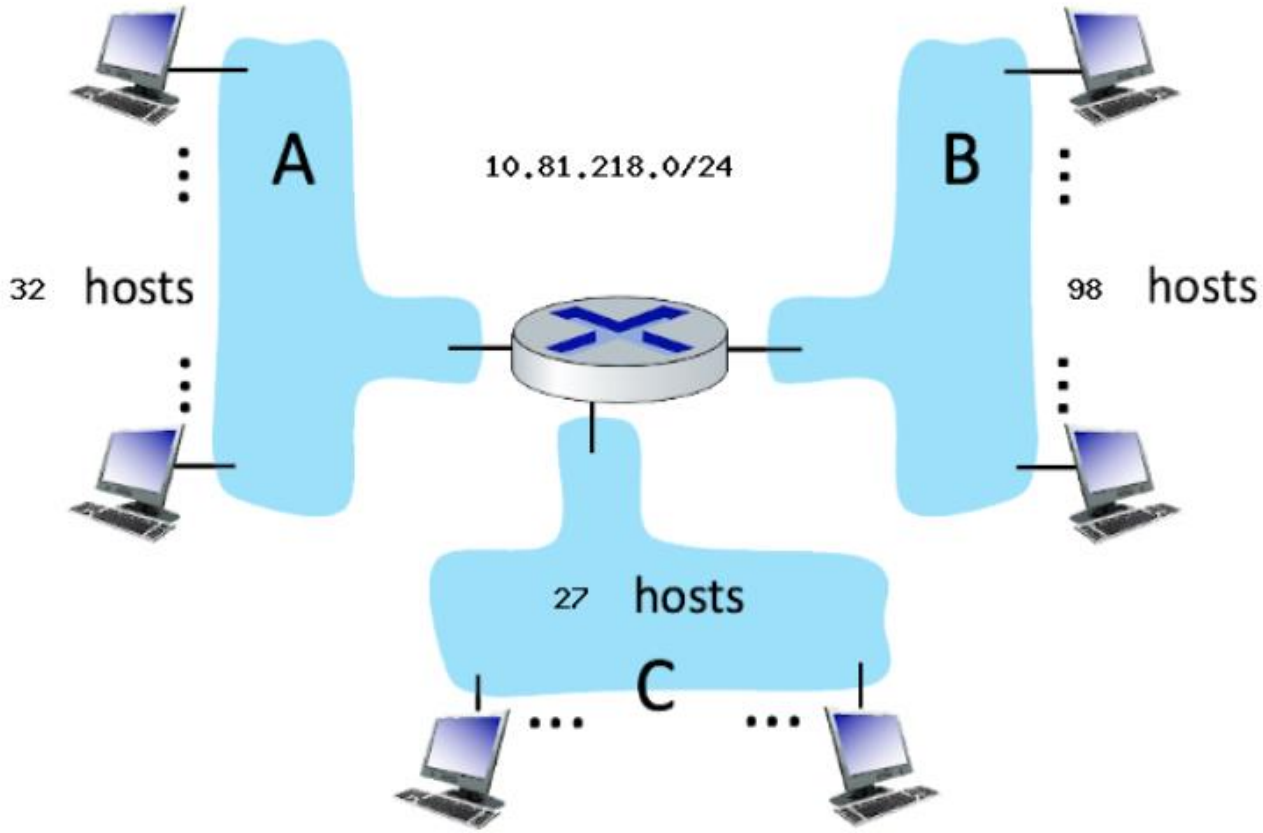
Network layer: "data plane" roadmap

- Network layer: overview
  - data plane
  - control plane
- What's inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

- Generalized Forwarding, SDN
  - Match+action
  - OpenFlow: match+action in action
- Middleboxes

Interactive Problem

- Consider the router and the three attached subnets below (A, B, and C). The number of hosts is also shown below. The subnets share the 24 high-order bits of the address space: 10.81.218.0/24



- Assign subnet addresses to each of the subnets (A, B, and C) so that the amount of address space assigned is minimal, and at the same time leaving the largest possible contiguous address space available for assignment if a new subnet were to be added. Then answer the questions below.

Interactive Problem

1. Is the address space public or private?

   The address 10.81.218.0/24 is private.

2. How many hosts can there be in this address space?

   Maximum number of hosts = 2^x - 2 = 2^8 - 2 = 254. The reason we have to subtract 2 from the final number is because there are always 2 addresses allocated for each address block: the subnet ID or network address (the first address) and the broadcast address (the last address)

Interactive Problem

3. What is the subnet address of subnet A? (CIDR notation)

Subnet A has 32 hosts, so it will need at least 34 addresses (for the subnet ID and broadcast address). The least number of bits that satisfy this is 6 bits. Knowing that, we take the prior subnet and add 64(2^6), the result of which is (2^7=128) 10.81.218.128/26

4. What is the broadcast address of subnet A?

The broadcast address of subnet A (10.81.218.128/26) is (128+63) 10.81.218.191, because it is the last address in the IP range.

Interactive Problem

5. What is the starting address of subnet A?

The first IP address of subnet A (10.81.218.128/26) is 10.81.218.129, found by adding 1 to the subnet address.

6. What is the ending address of subnet A?

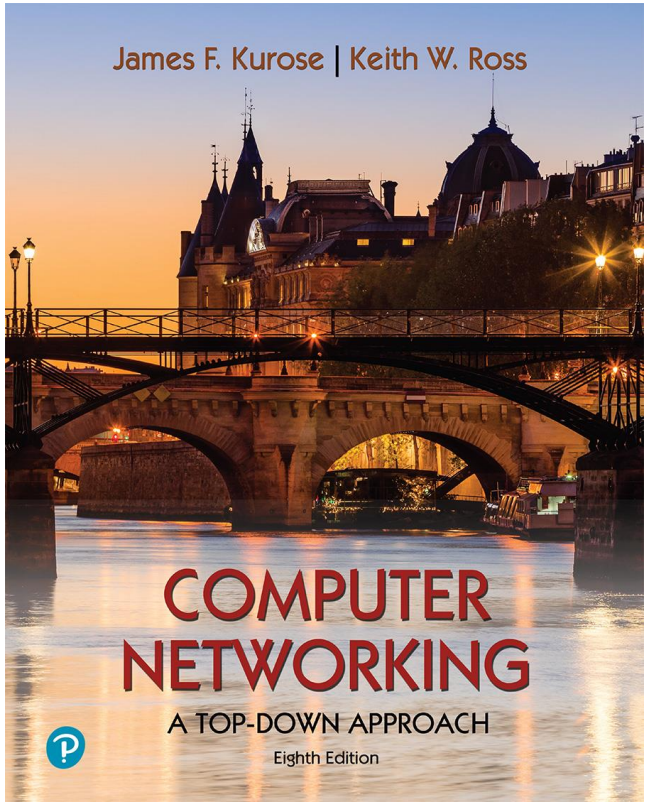
The last IP address of subnet A (10.81.218.128/26) is 10.81.218.190, found by subtracting 1 from the broadcast address (10.81.218.191).

Repeat these questions for subnet B and C for your practice!

Important Dates

07-12-2024(Friday), Midnight(11:59PM)–
Homework3 due date

Copyright Information



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

The Slides are adapted from,