Lecture 8.

Internet Network Layer:

IP Fundamentals

G.Bianchi, G.Neglia, V.Mancuso

Università degli Studi di Palermo

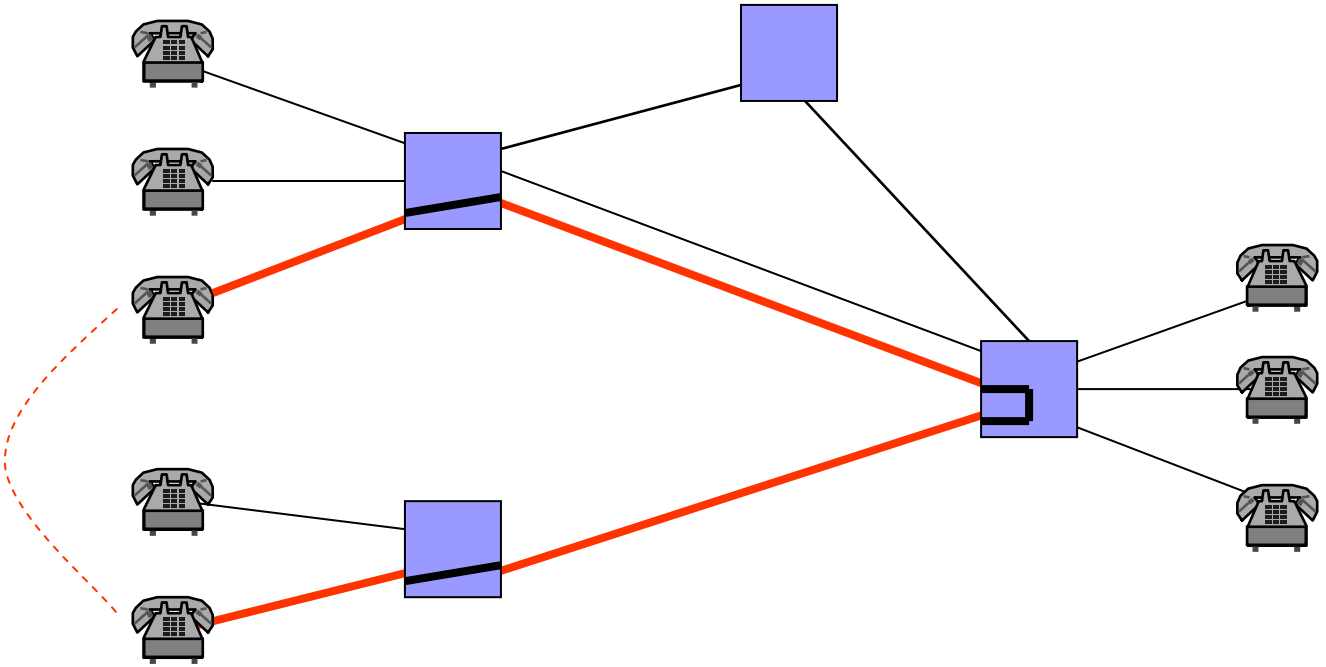
Outline

- Layer 3 functionalities
- Internet Protocol (IP) characteristics
- IP packet (first look)
- IP addresses
- Routing tables: how to use
- ARP

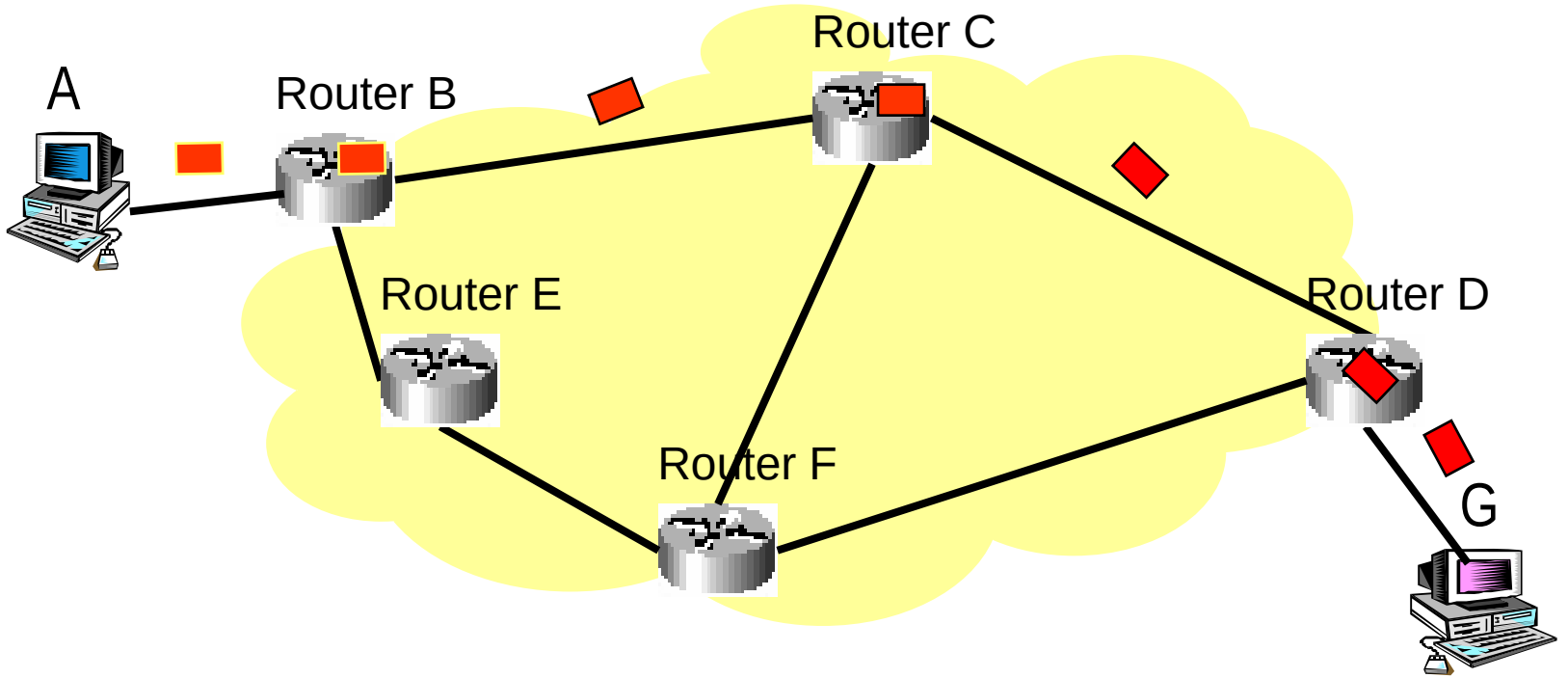
Layer 3 functionalities

- **This layer handles the routing of the data: i.e. delivery data to the correct destination**
- **Layer 3 functionalities are spread all over the network**
  - ⇨in ad hoc apparatus (*routers)*
  - ⇨in your PC (as routing software)

Circuit Switched Network



Packet Switched Network



Internet routing

Internet Protocol (IP)
RFC 791 (1981)

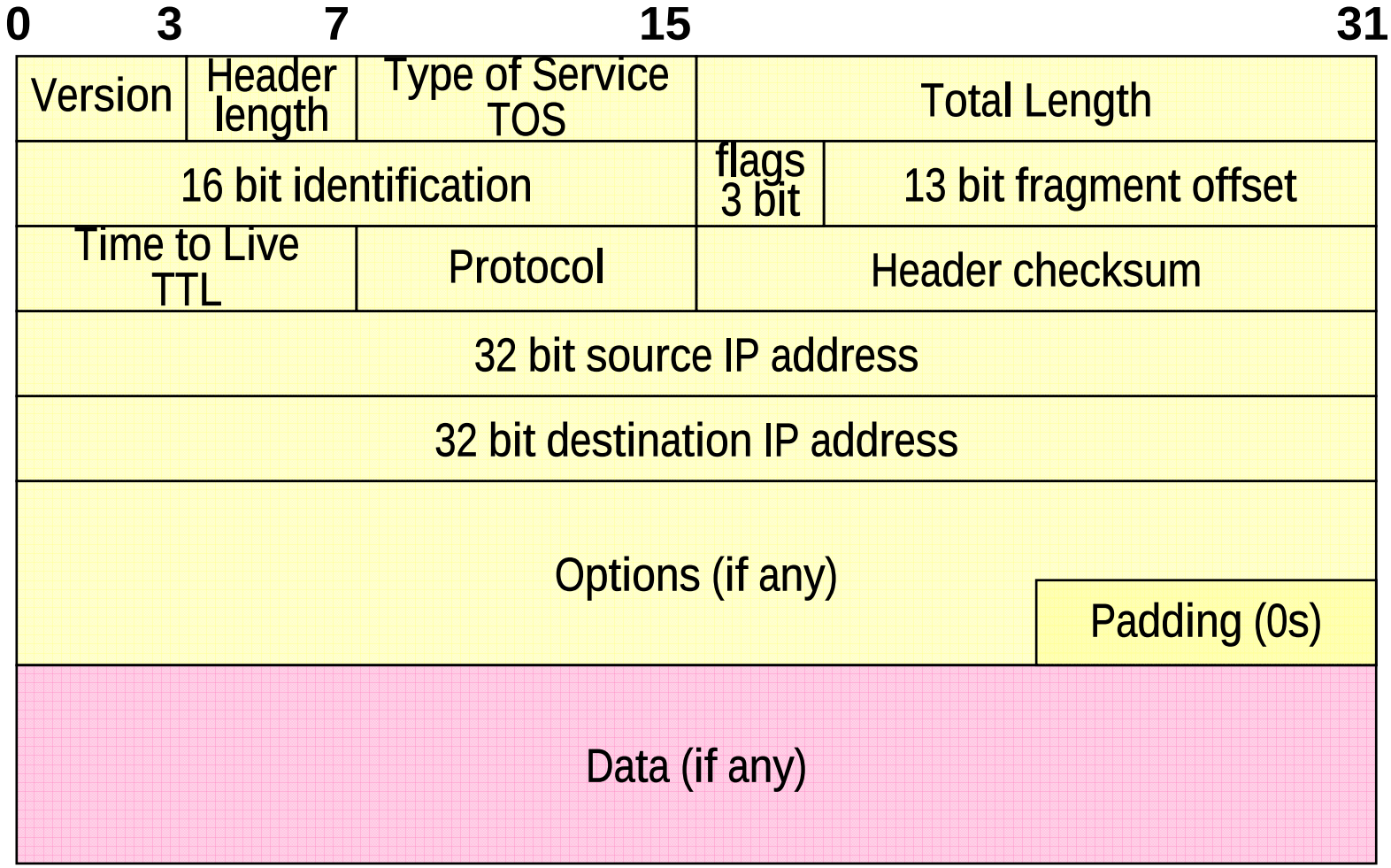
- **Connectionless**
  - ⇨ datagram delivery service
- **Best-effort**
- **Unreliable**
  - ⇨ no guarantees of reception & packet order
  - ⇨ error-handling algorithm: throw away packet!
    - → Upon buffer congestion
    - → Upon error check failed

IP functions in your PC

- **in trasmission:**
  - Encapsulates data from transport layer into datagrams
  - prepare header (src & dest addresses, etc)
  - apply routing algorithm
  - send datagram to network interface
- **in reception:**
  - check validity of incoming datagrams
  - read header
  - verify whether datagram is to be forwarded
  - if datagram has reached destination, deliver payload to higher layer protocol

IP datagram format

20 bytes header (minimum)



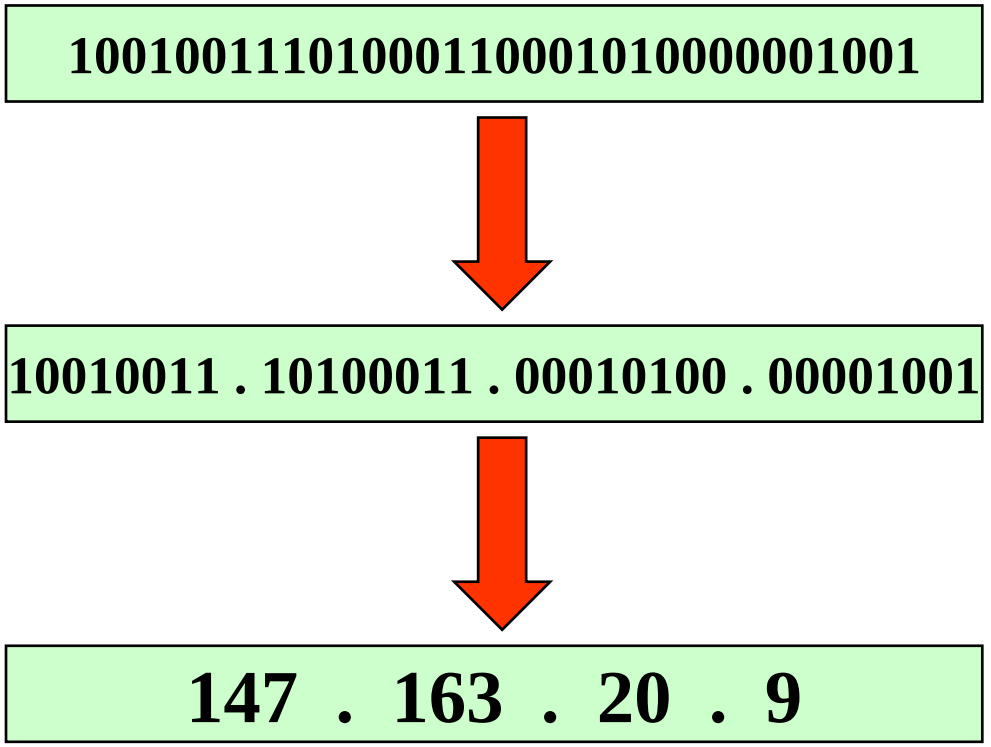
IP address

➔**32 bit string**

- ⇨Bit-wise notation
- ⇨*the natural notation*

➔**dotted notation:**

- ⇨4 x 8 bits
- ⇨each 8 bit = 0:255 integer
- ⇨*intended for humans*



Dotted Notation is often misleading, as it may hide address properties

Notation conversion
bin -> dotted

10010011.10100011.00010100.00001001

binary	128	64	32	16	8	4	2	1	decimal
10010011	1	0	0	1	0	0	1	1	128+16+2+1=147
10100011	1	0	1	0	0	0	1	1	128+32+2+1 = 163
00010100	0	0	0	1	0	1	0	0	16+4 = 20
00001001	0	0	0	0	1	0	0	1	8+1 = 9

➔ 147.163.20.9 (www.diepa.unipa.it)

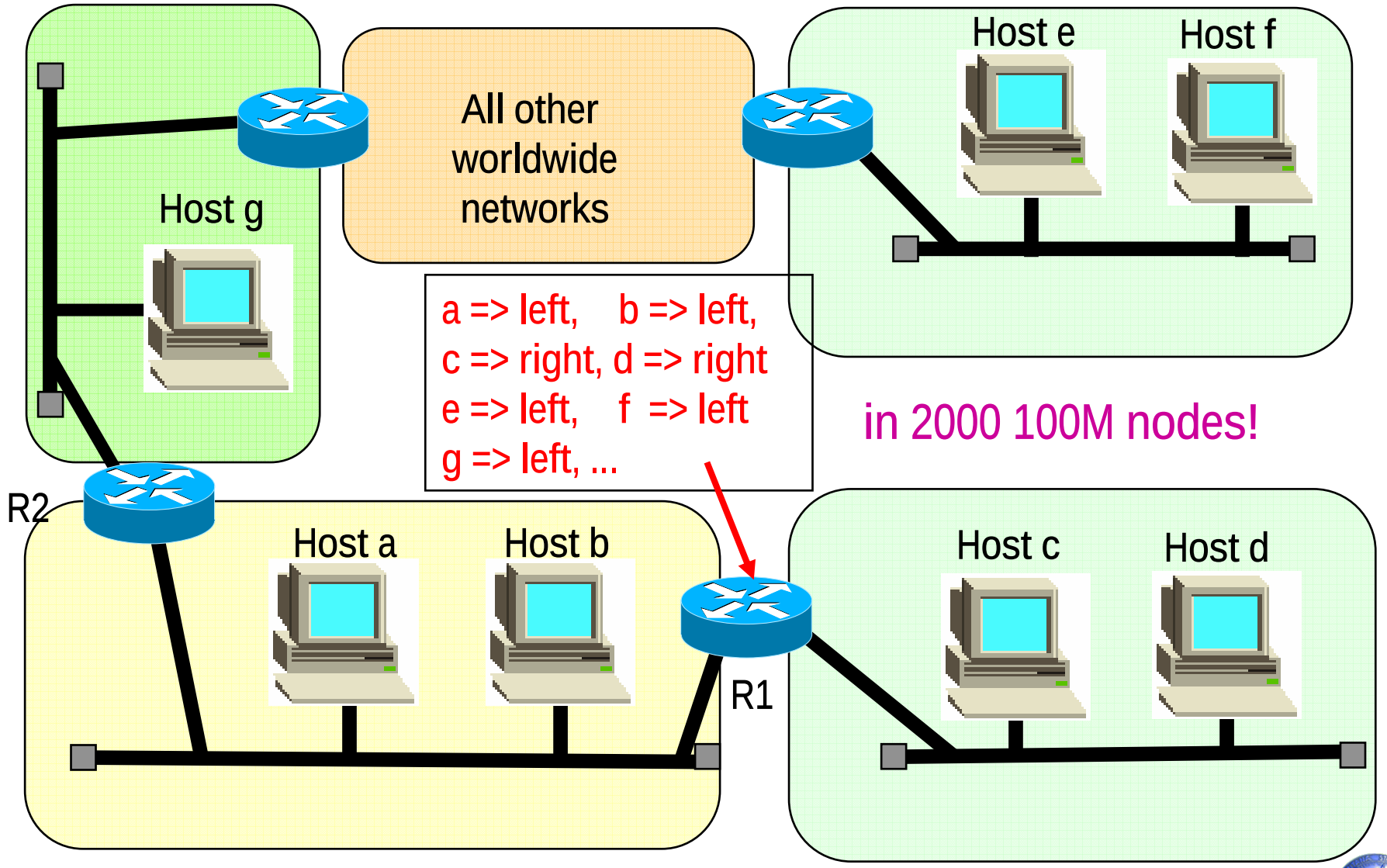
Notation conversion dotted -> bin

➔ **131.175.21.1** **(morgana.elet.polimi.it)**

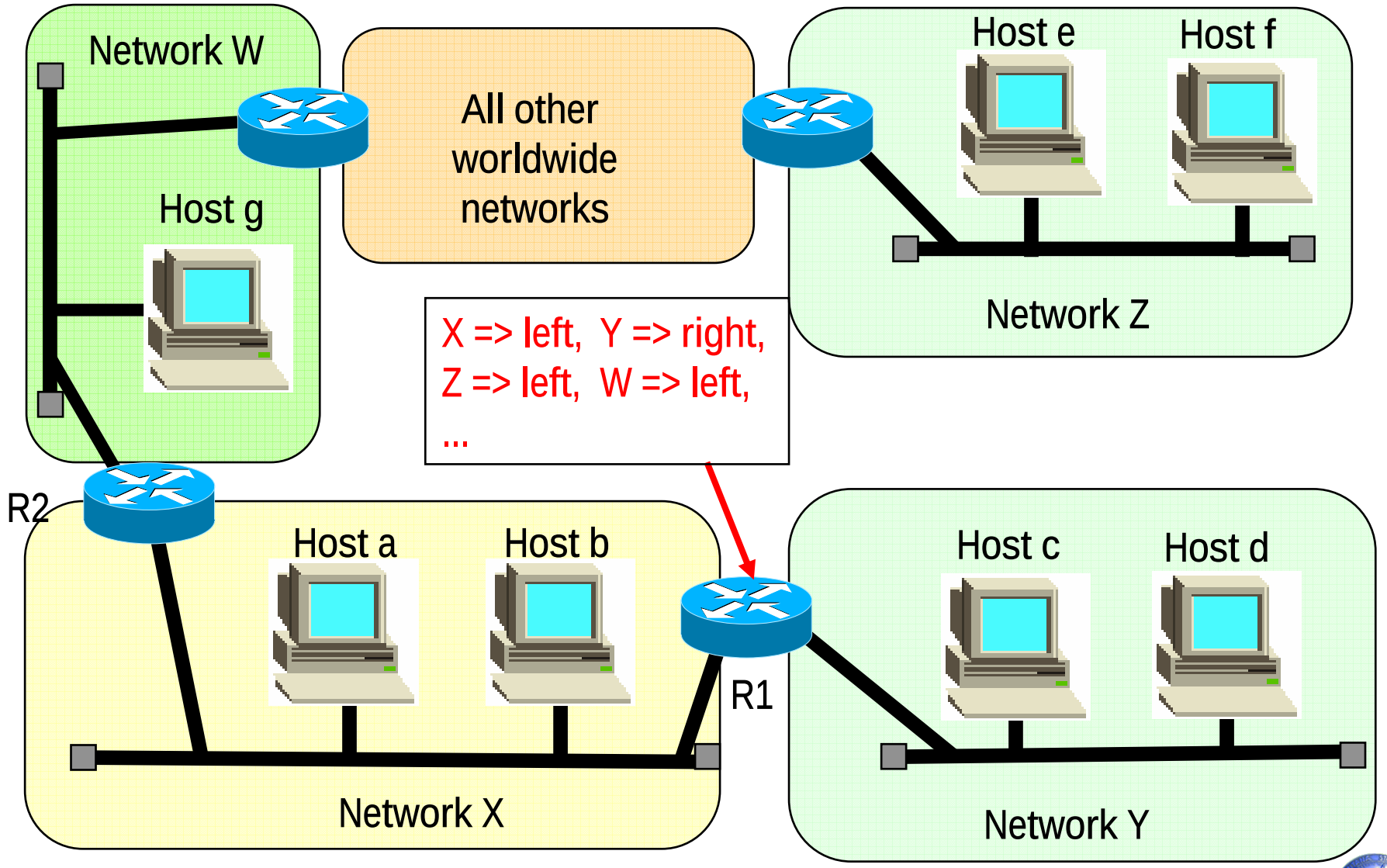
decimal	128	64	32	16	8	4	2	1	binary
131	1	0	0	0	0	0	1	1	128+2+1=10000011
175	1	0	1	0	1	1	1	1	128+32+8+4+2+1 = 10101111
21	0	0	0	1	0	1	0	1	16+4+1 = 00010101
1	0	0	0	0	0	0	0	1	1 = 00000001

10000011.10101111.00010101.00000001

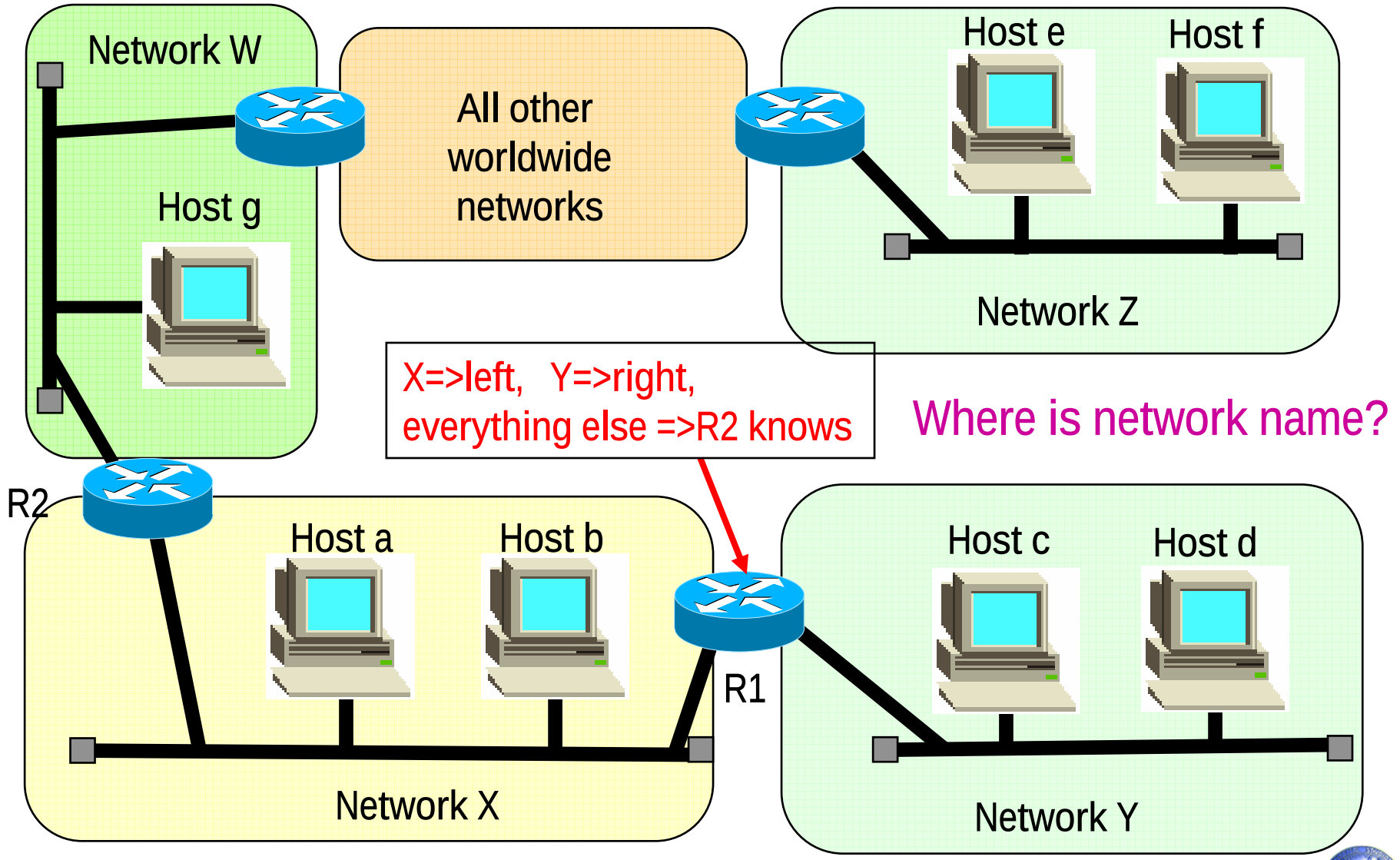
Need for network name



Need for network name

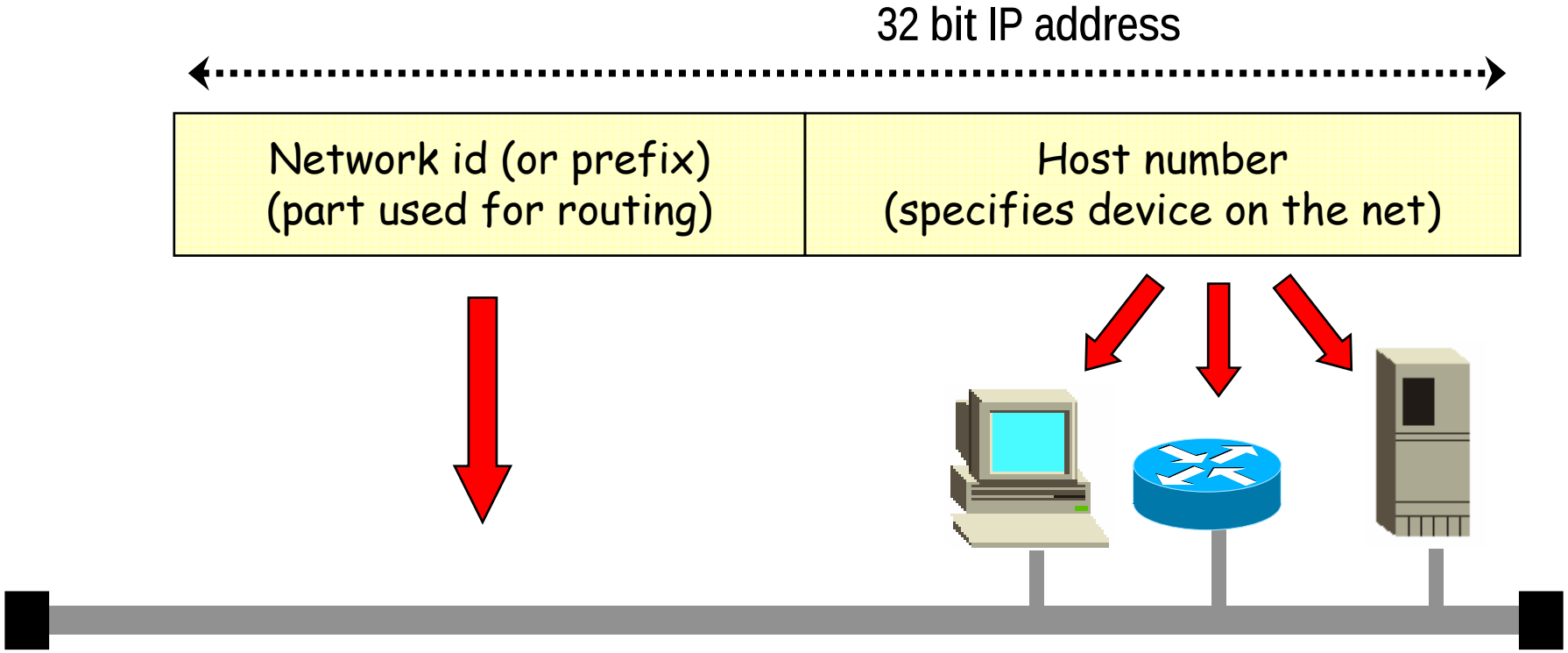


Need for network name



IP Address Structure

partitioned into two fields

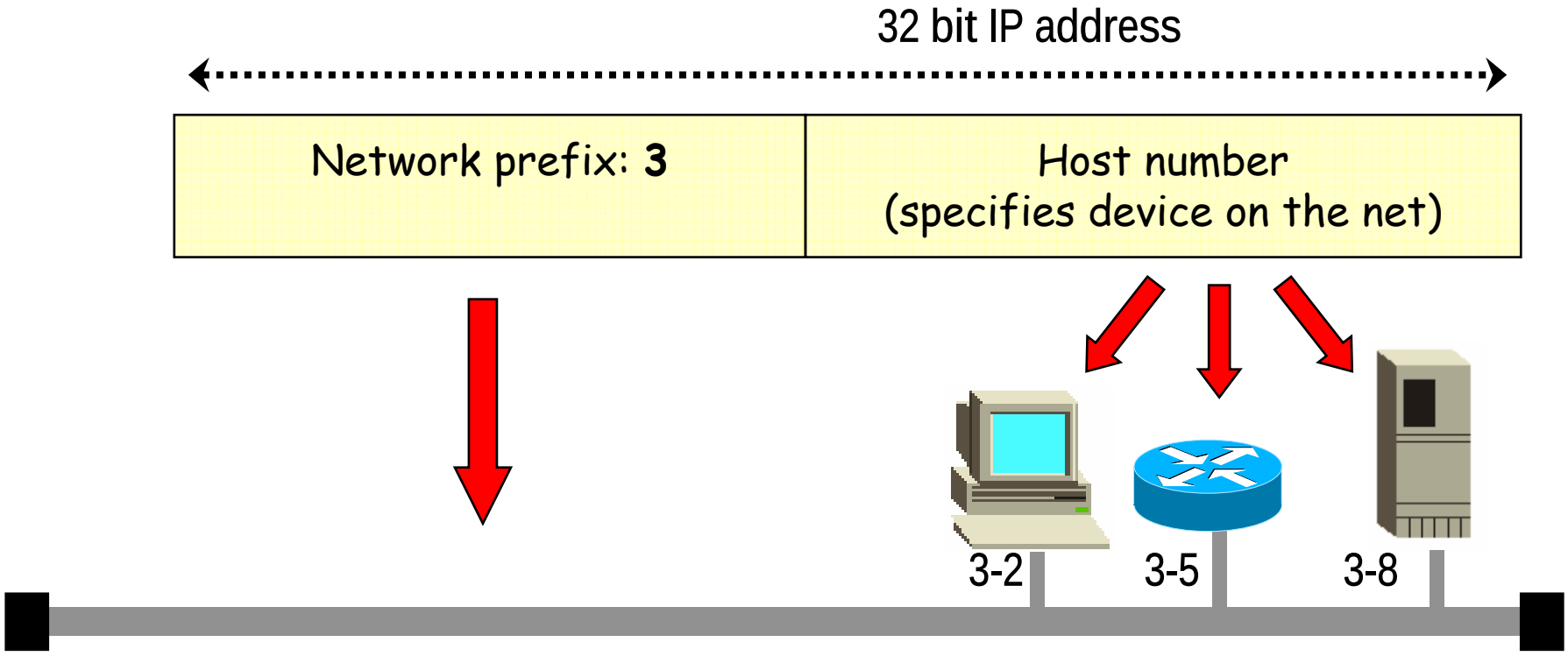


Dotted notation: ***AAA.BBB.CCC.DDD*** *- no physical meaning!*

A more correct notation should be: ***NNNNN-HHHHH***

IP Address Structure

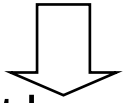
partitioned into two fields



Host Addresses
3-8 means: host 8 on network 3

Dotted notation vs IP address structure

- **Dotted Notation**
  - AAA.BBB.CCC.DDD
    - no physical meaning!
    - often misleading!
      - it may hide address properties
- **More correct notation:**
  - NNNNN-HHHHH
    - Physical meaning (network prefix, host #)
  - Prefix size is variable,
  - Not implicit in the IP address (from 1993)



Separator must be provided externally

Example

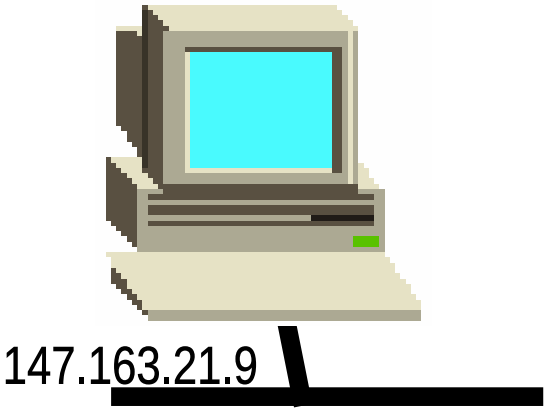
- **IP address 147.163.22.130**
  - Bitwise notation:

    10010011.10100011.00010110.10000010
- **Network prefix:**
  - Externally provided
  - Example: first 22 bits network ID, last 10 bits host ID

    10010011.10100011.00010110.10000010
  - Network prefix notation:
    - /22 (modern notation)
    - Netmask (traditional notation)

      11111111.11111111.11111100.00000000
    - Netmask → dotted decimal: 255.255.252.0

Network Address



Local Host Interface:
147.163.21.9/22

10010011.10100011.00010101.00001001

Network prefix Hostid

Network Address

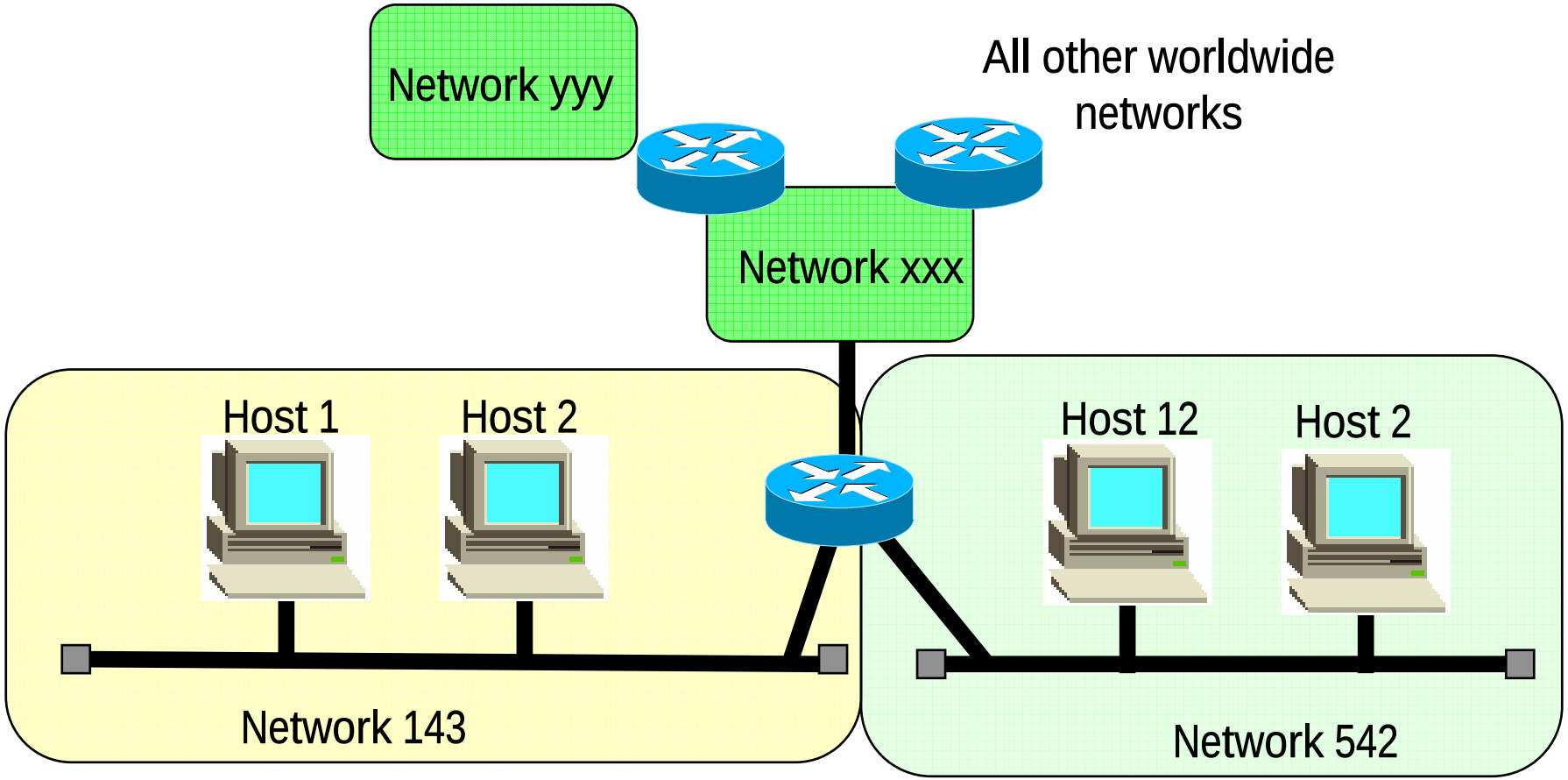
10010011.10100011.00010100.00000000

➔ **Dotted notation for the network address**

⇨147.163.20.0

Pure Convenience (not only for men)!

Naming in IP: networks



Network name:	Network prefix	000000000000

Special IP addresses, with all 0's in host part
All existing (physical) networks have different names!

Naming in IP: hosts

Netid	Hostid
3	0

Host Addresses
3-8 means: host 8 on network 3

Network address: 3-0
Host-id field set to 0 means this address
is a name for an entire network
(this is network 3, unique name in all the world)

- ➔ **Worldwide Unique Network address Assignment**
- ➔ **Within a network, unique IP address assignment to each host (better: interface)**
  - ⇨ CONCLUSION: ALL EXISTING HOSTS HAVE DIFFERENT IP ADDRESSES

Example

➔ **IP address 147.163.22.130**

10010011.10100011.00010110.10000010

➔ **Network prefix:**

⇨ /22 (equivalently: 255.255.252.0)

➔ **It is an IP address for a HOST**

⇨ Simple: not all 0's in host part

10010011.10100011.00010110.10000010

➔ **Which belongs to network 147.163.20.0/22**

⇨ Simple: just set 0's in host part

10010011.10100011.00010100.00000000

Naming in IP: broadcast

Netaddr	Hostid
3	All 1's

Means: all the hosts on the considered network!
Used to send a "broadcast" information (to all the Attached hosts)

➔ **Example: network 147.163.20.0/22**

- ⇨ What is the IP address to use for broadcasting?
- ⇨ Simple: just set all 1's in host part

10010011.10100011.00010111.11111111

➔ **Broadcast address: 147.163.23.255**

Test

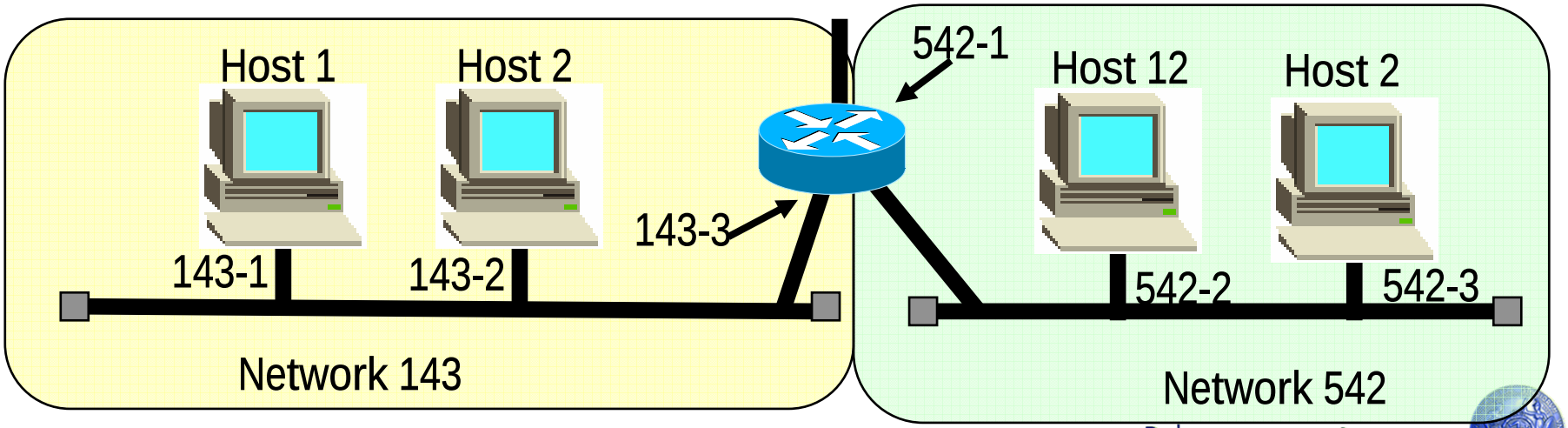
- **147.163.0.128 (prefix: /26)**
  - ⇨Network? Host? Broadcast?
- **147.163.0.128 (prefix: /24)**
  - ⇨Network? Host? Broadcast?
- **147.163.14.3 (prefix: /30)**
  - ⇨Network? Host? Broadcast?
- **174.163.20.255 (prefix: /22)**
  - ⇨Network? Host? Broadcast?

Think in binary! And everything becomes trivial….

Second role of an IP address: routing

Routing = ability to forward packets to destination

- **Routing: based on network addresses**
  - Key idea: first find the physical network where the host resides, and then find specific host
  - routing tables addressing each of 100M+ hosts would be unfeasible
- **A Router (2nd definition): computer with 2+ interfaces**
  - Connects different networks (hence the name inter-net), eventually with different technologies
  - An IP address per each interface
  - Task: collect datagrams on one interface and forward on other(s)



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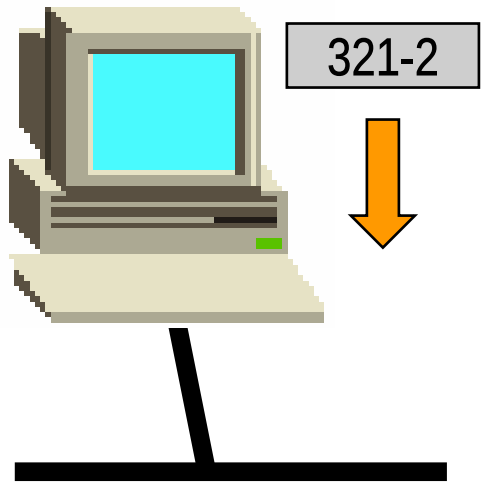
Packet Routing (at local host)



Application running at local computer generates a datagram destined to IP address 321-2 [host 2 on network 321]

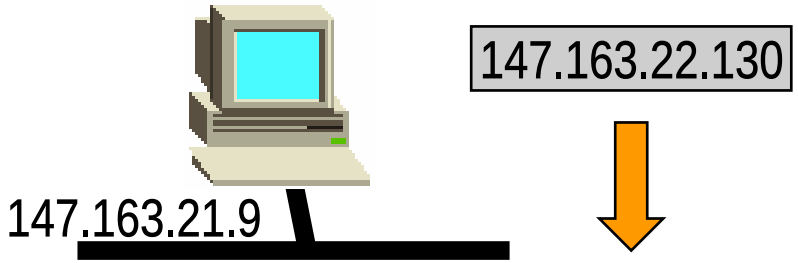
➔**Local host operation:**

- ⇨ Knows its IP address NNN-XXX
- ⇨ Thus knows on which network NNN the computer is attached
- ⇨ Hence, knows whether packet 321-2 needs to be forwarded to
  - ⇨A. an host on this same network
  - ⇨B. an host on a different network

Local host runs IP routing SW
(some people thinks Routing sw confined At routers…)

NetAddress computation (Masking)

➔ **Is on the same network?**



Local Host Interface:
147.163.21.9

10010011.10100011.00010101.00001001

Destination IPaddr:
147.163.22.130

10010011.10100011.00010110.10000010

Netaddresses are equal!

⇩

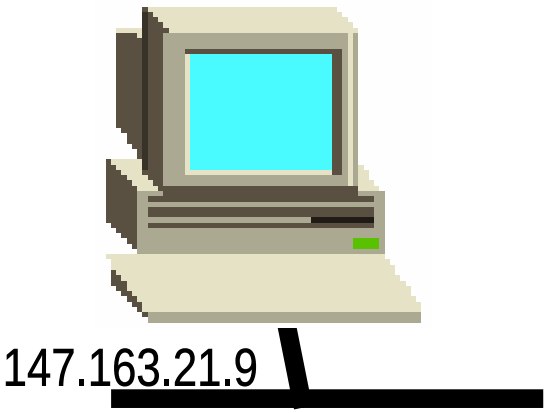
They are on the same network!

How does IP software really work?

NetAddress computation (Masking)

➔ **Network mask**

- ⇨ associated to the network address
- ⇨ string of 1s in network address, 0s in host address



Local Host Interface:
147.163.21.9

10010011.10100011.00010101.00001001

Netaddress Hostid

Netmask

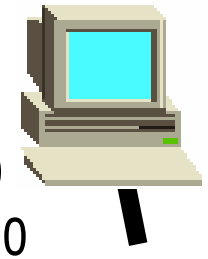
11111111.11111111.11111100.00000000

➔ **Dotted notation for the netmask**

- ⇨ 255.255.252.0

NetAddress computation (Masking)

➔ **Is on the same network?**



147.163.21.9
255.255.252.0

147.163.22.130

Destination IPaddr:
147.163.22.130

10010011.10100011.00010110.10000010

Bitwise AND

Netmask:
255.255.252.0

11111111.11111111.11111100.00000000

=

10010011.10100011.00010100.00000000

=?

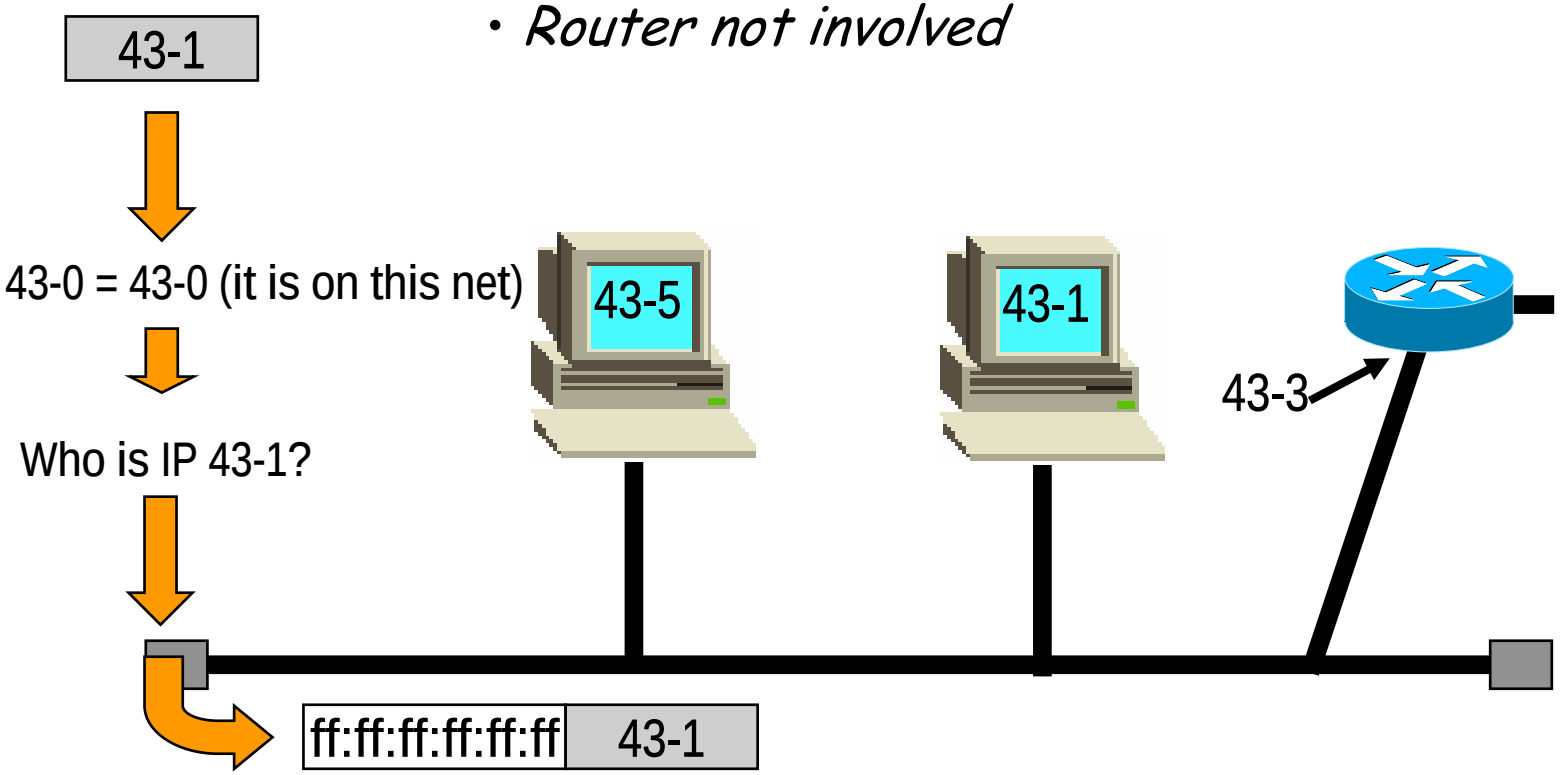
Network Address:
147.163.20.0

10010011.10100011.00010100.00000000

They are on the same network!

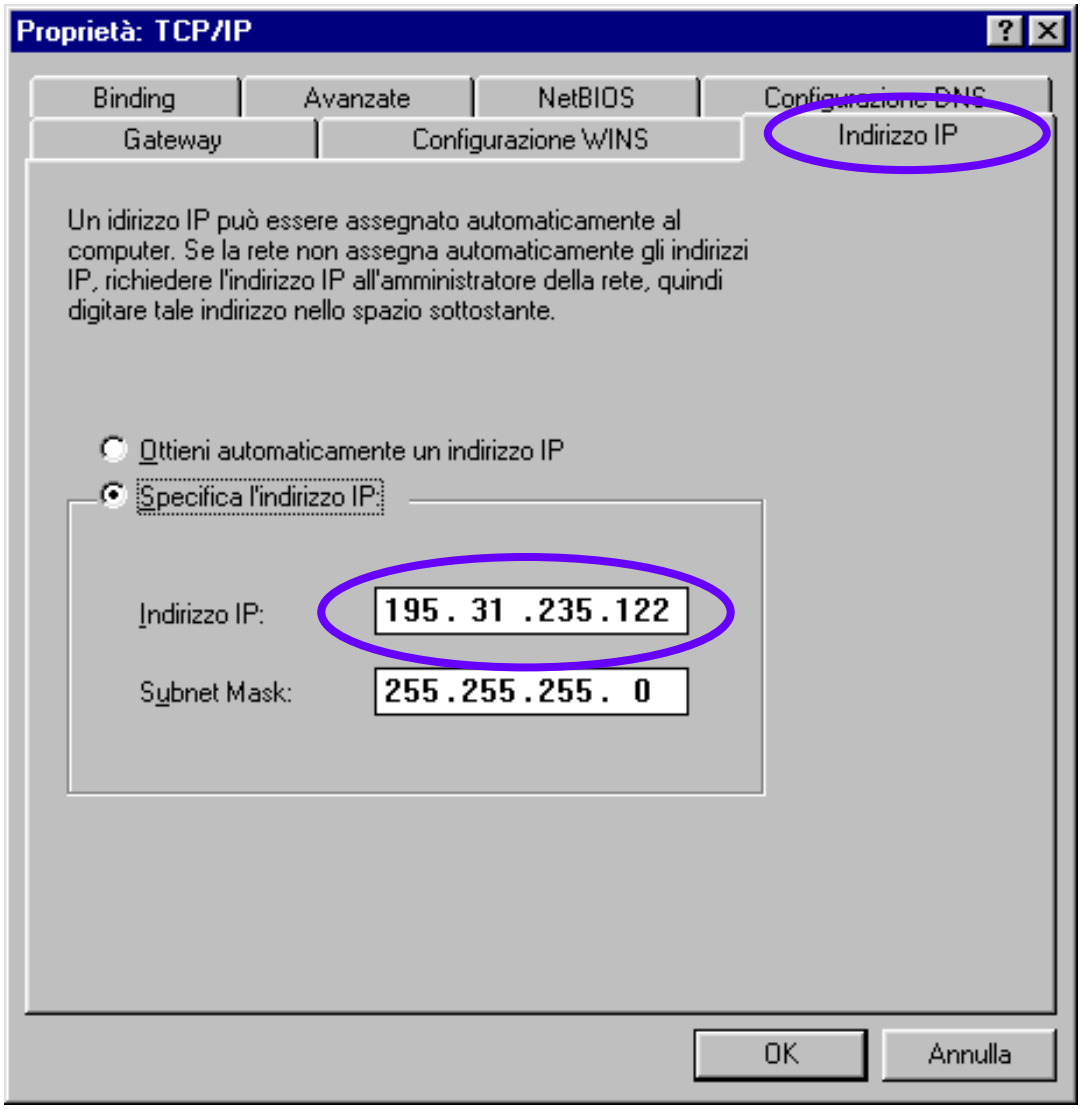
Inside the LAN

- *Router not involved*



Physical transmission: a) resolve IP address in physical network address, b) encapsulate packet in datalink frame, and c) deliver according to local networking technology

Host configuration (Windows)



Possible netmask values

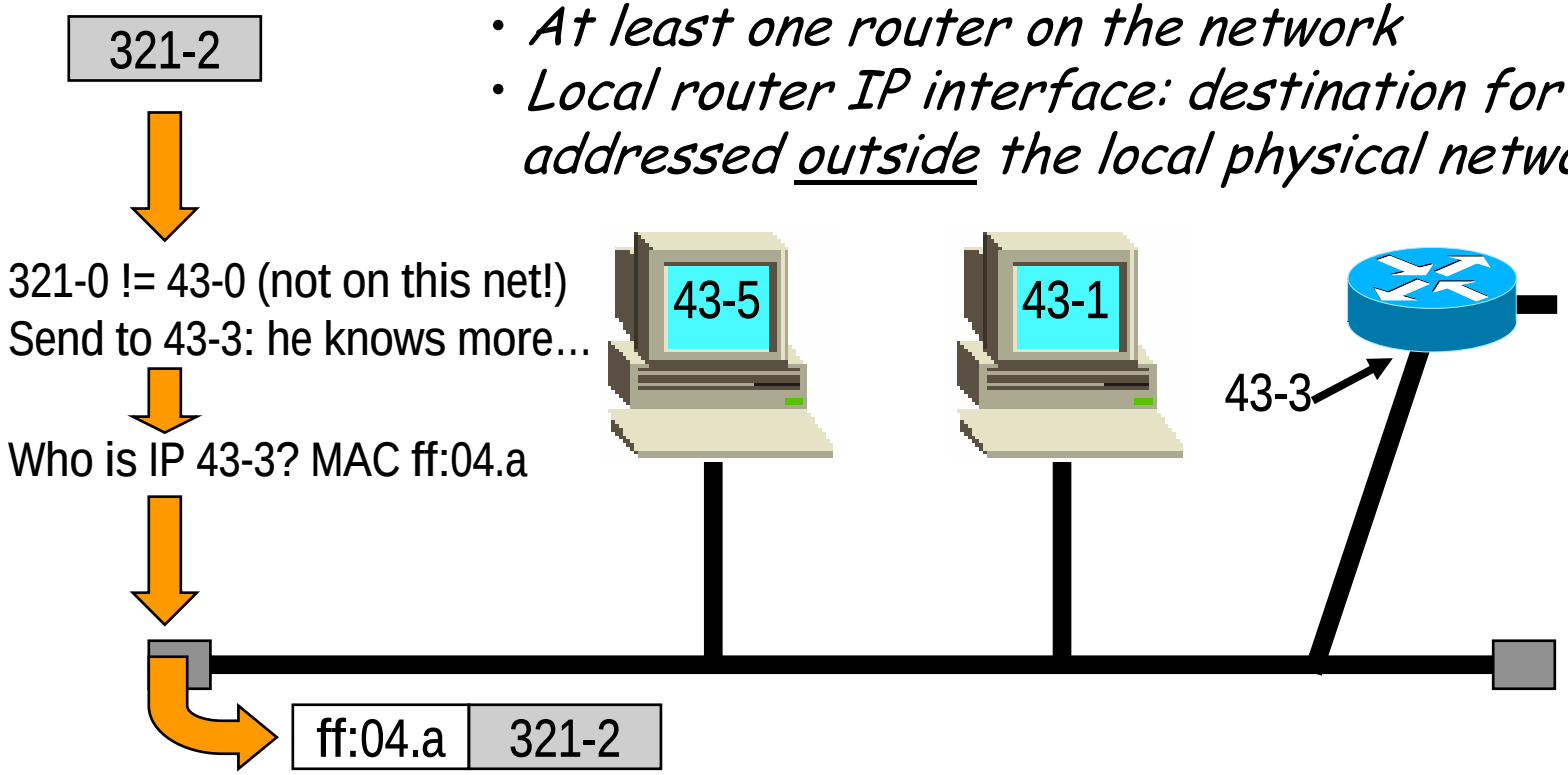
"magic netmask numbers"

128	64	32	16	8	4	2	1	
1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**= 128**
1	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**= 192**
1	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**= 224**
1	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**= 240**
1	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**= 248**
1	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**= 252**
1	*1*	*1*	*1*	*1*	*1*	*1*	*0*	*= 254*
1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*= 255*

Examples: /21 → 255.255.248.0
/29 → 255.255.255.248

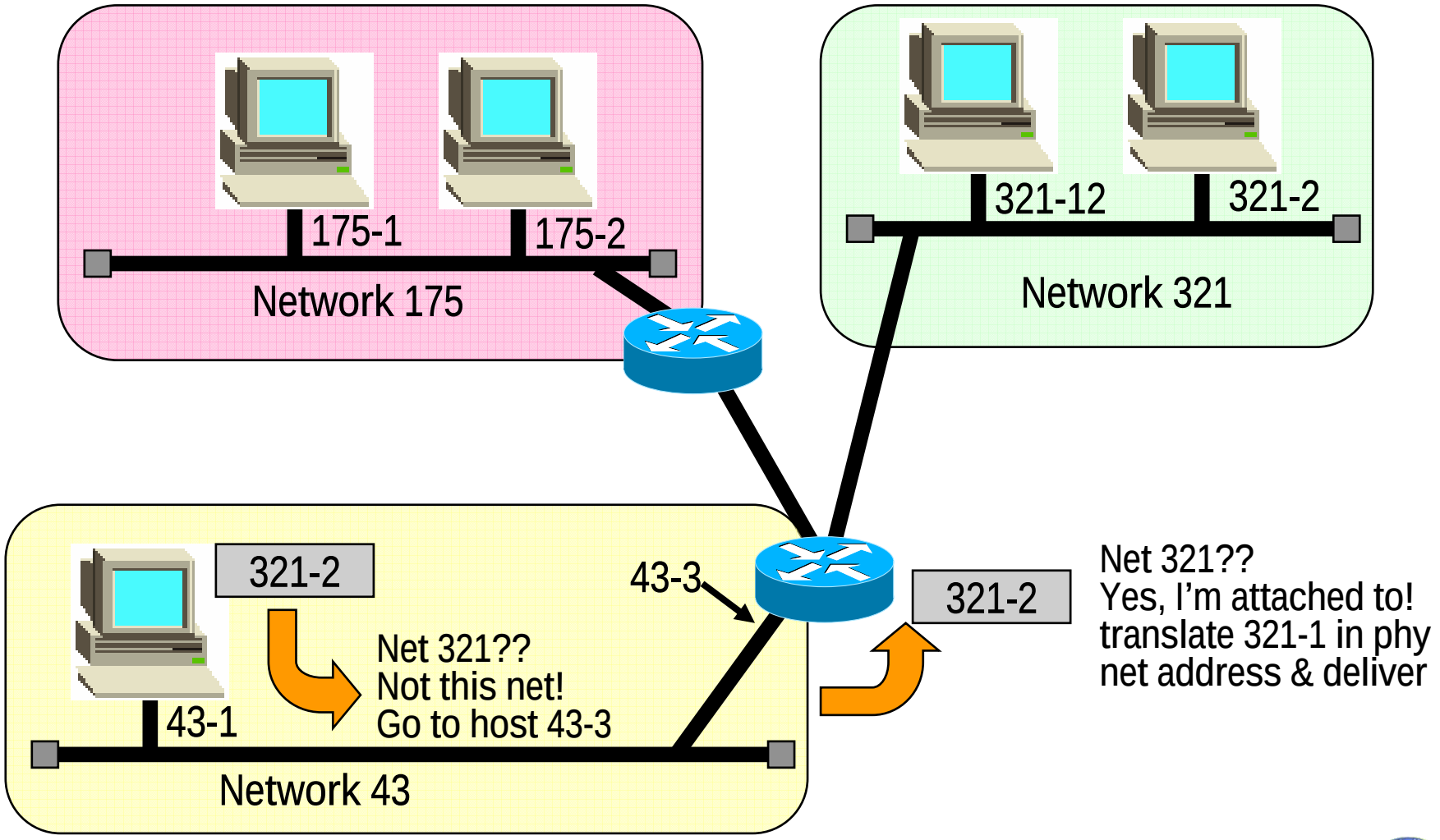
Going through a Router

- *At least one router on the network*
- *Local router IP interface: destination for all packets addressed outside the local physical network*

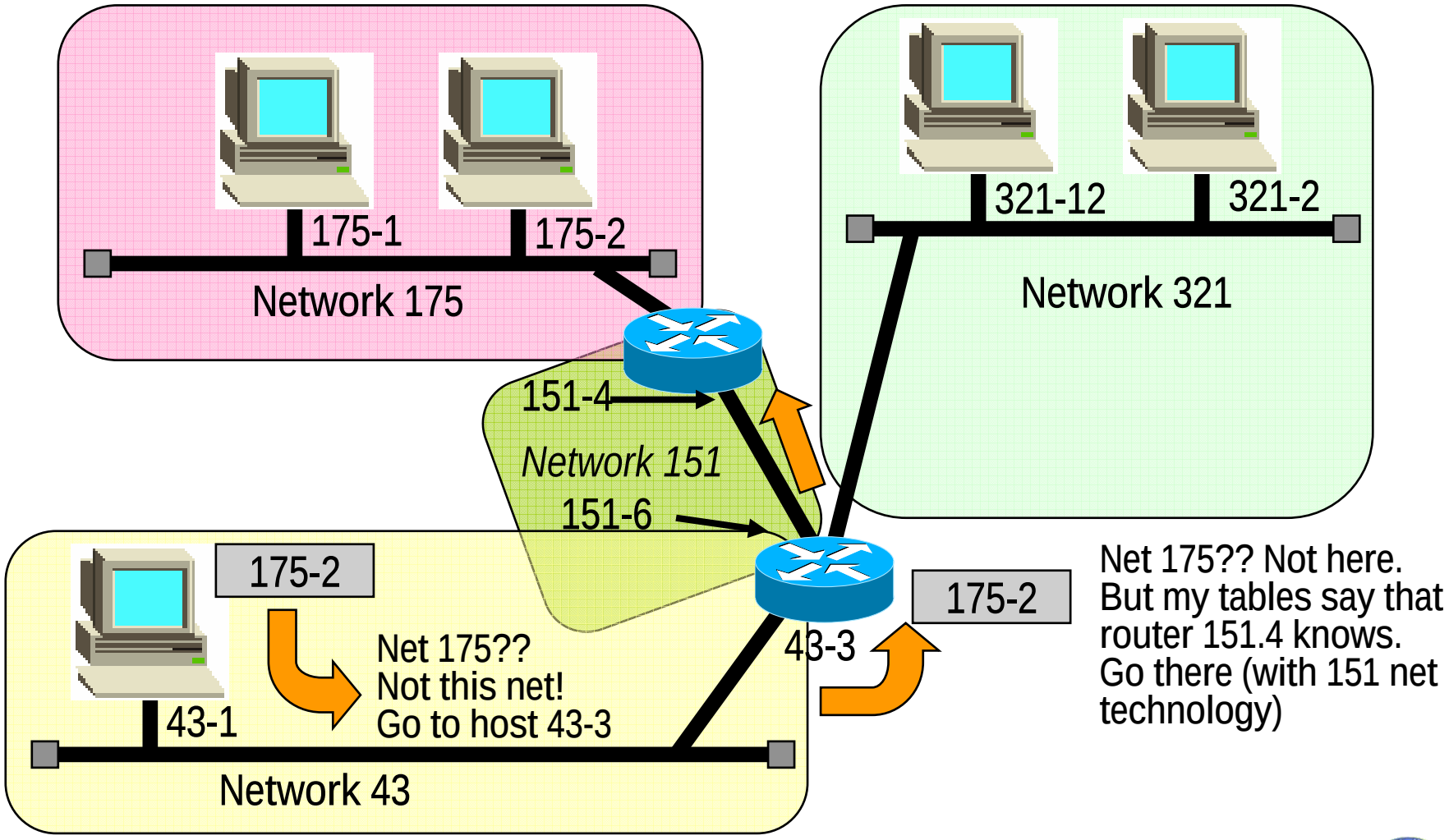


Physical transmission: a) resolve IP address in physical network address, b) encapsulate packet in datalink frame, and c) deliver according to local networking technology

Router operation: Direct Forwarding

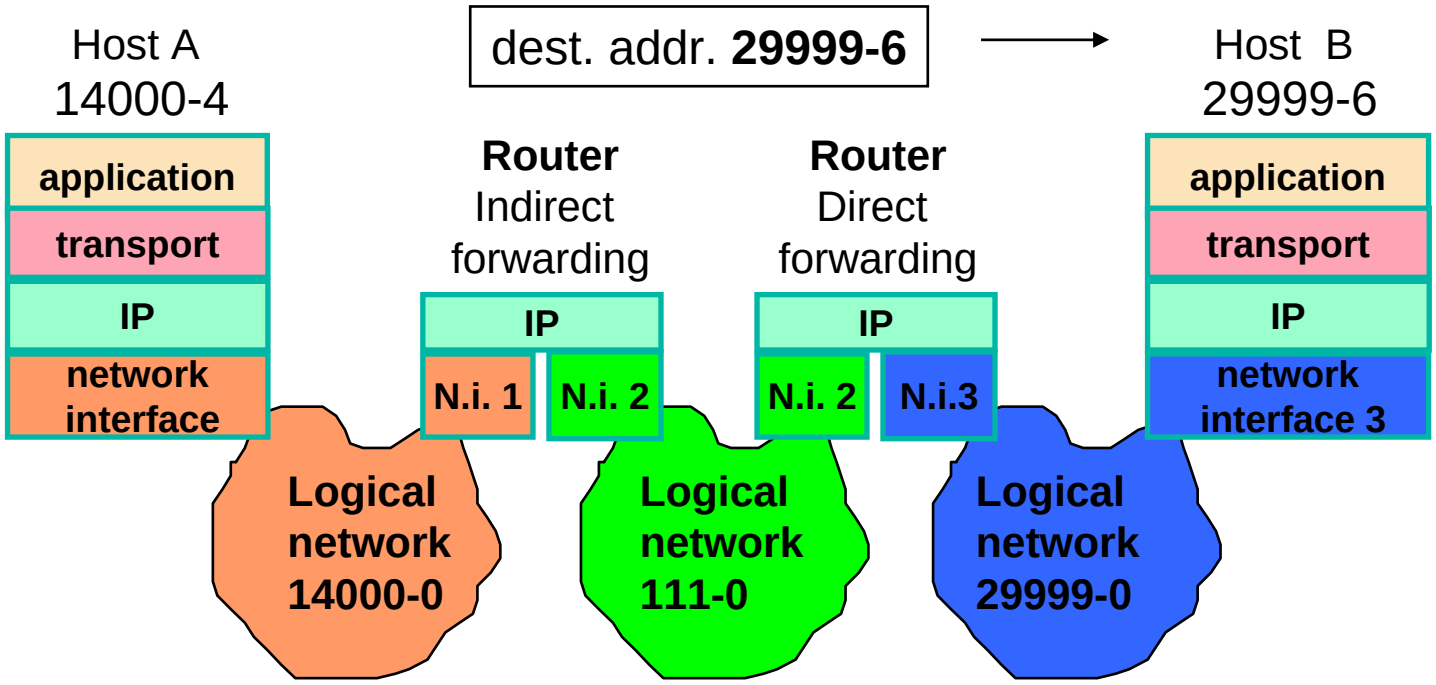


Router operation: Indirect Forwarding



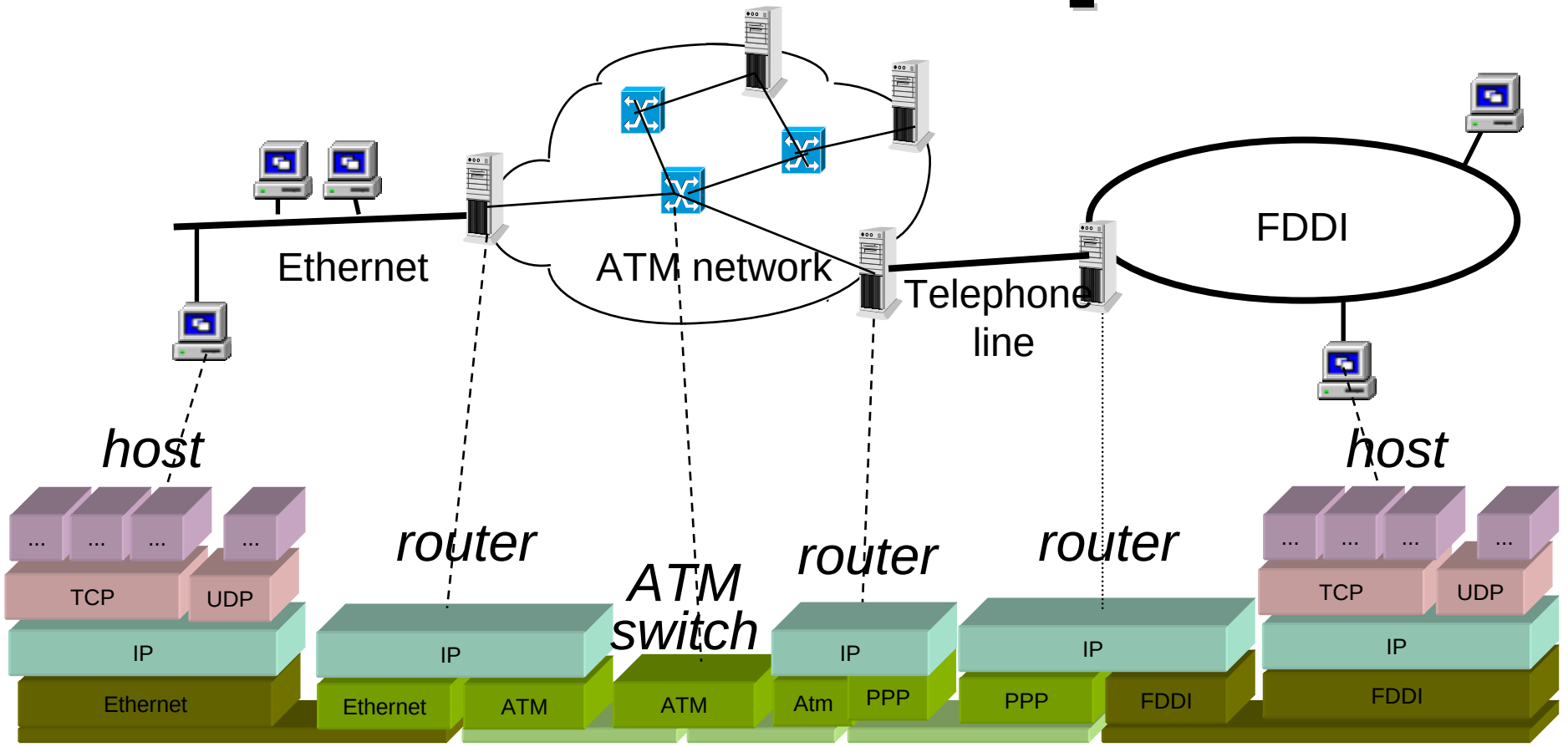
INTERNET = arbitrary networks interconnected via routers

Layered view



Datagrams travel from router to router (indirect forwarding)
until a router is on the same network of dest host (direct forwarding)

Inter - Net example

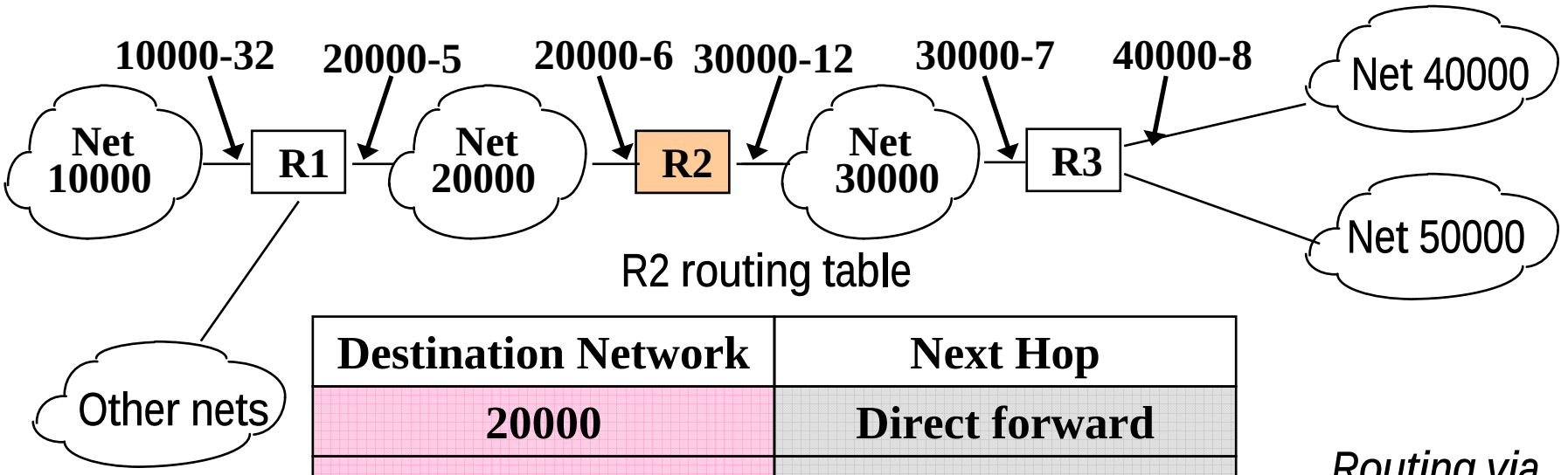


1 hop = ATM network and switch crossing!

Internet vs specific physical networking technology

- **IP: an overlay networking protocol**
  - interconnection of widely heterogeneous networks
    - seen by TCP/IP as sub networks
    - Routers do not care about specific network technology (LAN, WAN, circuit switching, packet switching, …)
    - but they NEED to have a specific network interface (Routers with Ethernet interfaces cheap; with FDDI or ATM very expensive…)
- **Router duties:**
  - just select destination (end or intermediate router)!
  - then map IPaddr in physical network address
  - IP datagrams tunneled into underlying network data units
  - specific physical network routing may be extremely complex (router sees this as single hop)

Routing table



R2 routing table

Destination Network	Next Hop
20000	Direct forward
30000	Direct forward
10000	20000-5
40000	30000-7
50000	30000-7
default	20000-5

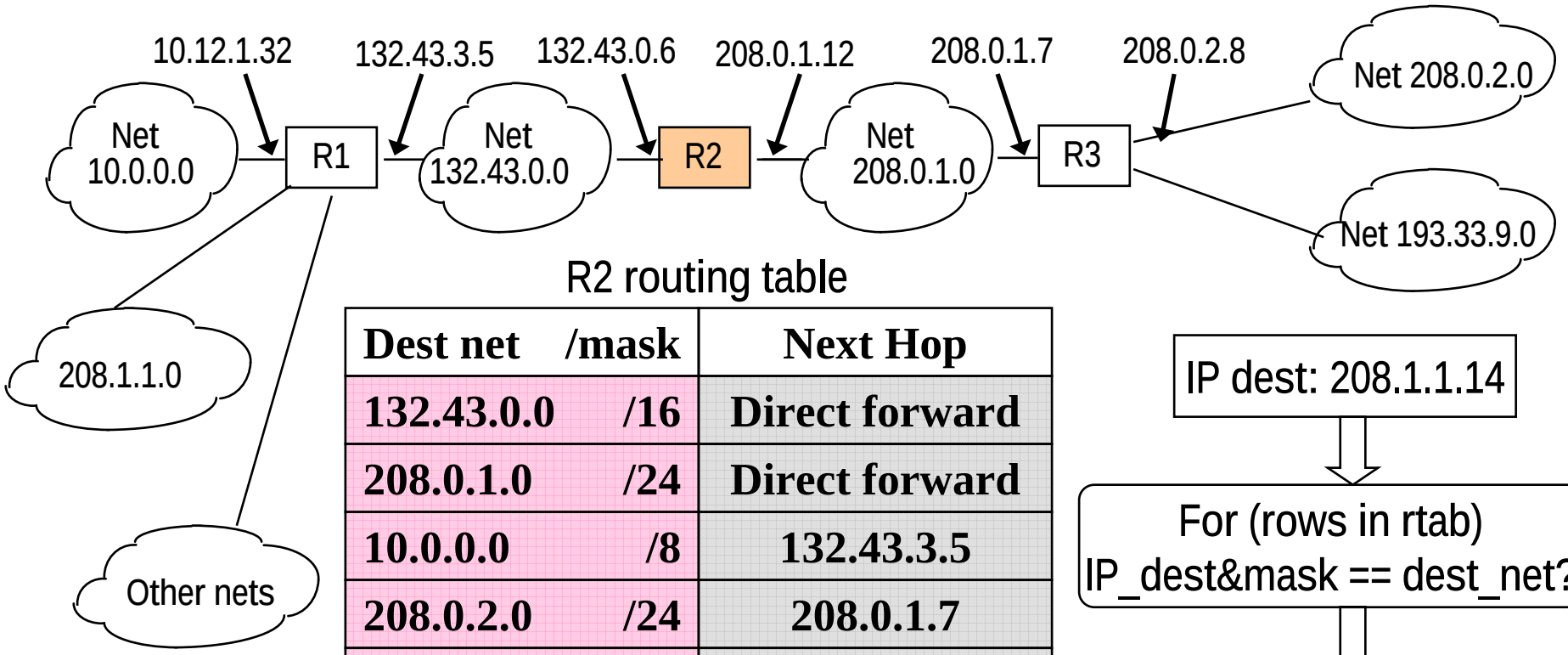
Routing via network Id, not host Id!

Otherwise too large tables

Three cases:

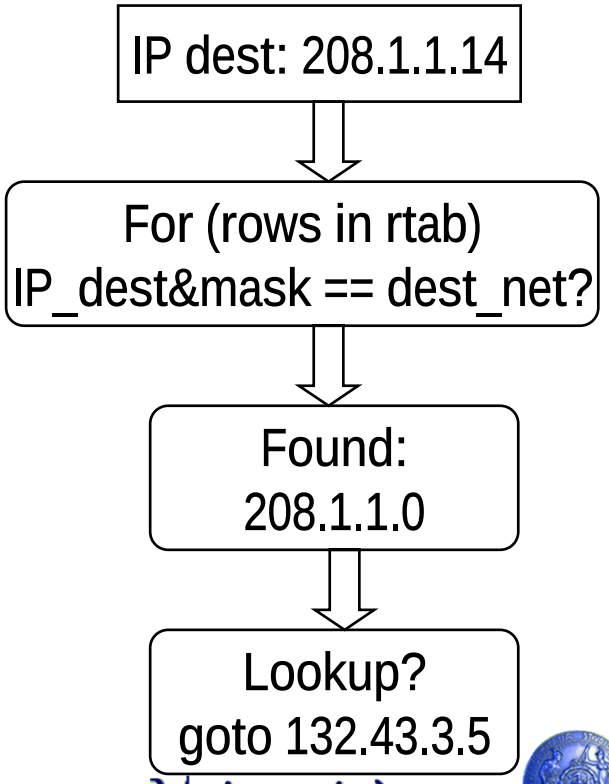
1) direct forwarding
2) Indirect forwarding (explicit)
3) Indirect forwarding via default router (when available)

Routing table lookup



R2 routing table

Dest net	/mask	Next Hop
132.43.0.0	/16	Direct forward
208.0.1.0	/24	Direct forward
10.0.0.0	/8	132.43.3.5
208.0.2.0	/24	208.0.1.7
193.33.9.0	/24	208.0.1.7
208.1.1.0	/24	132.43.3.5
default		132.43.3.5



Route print (DOS,unix)

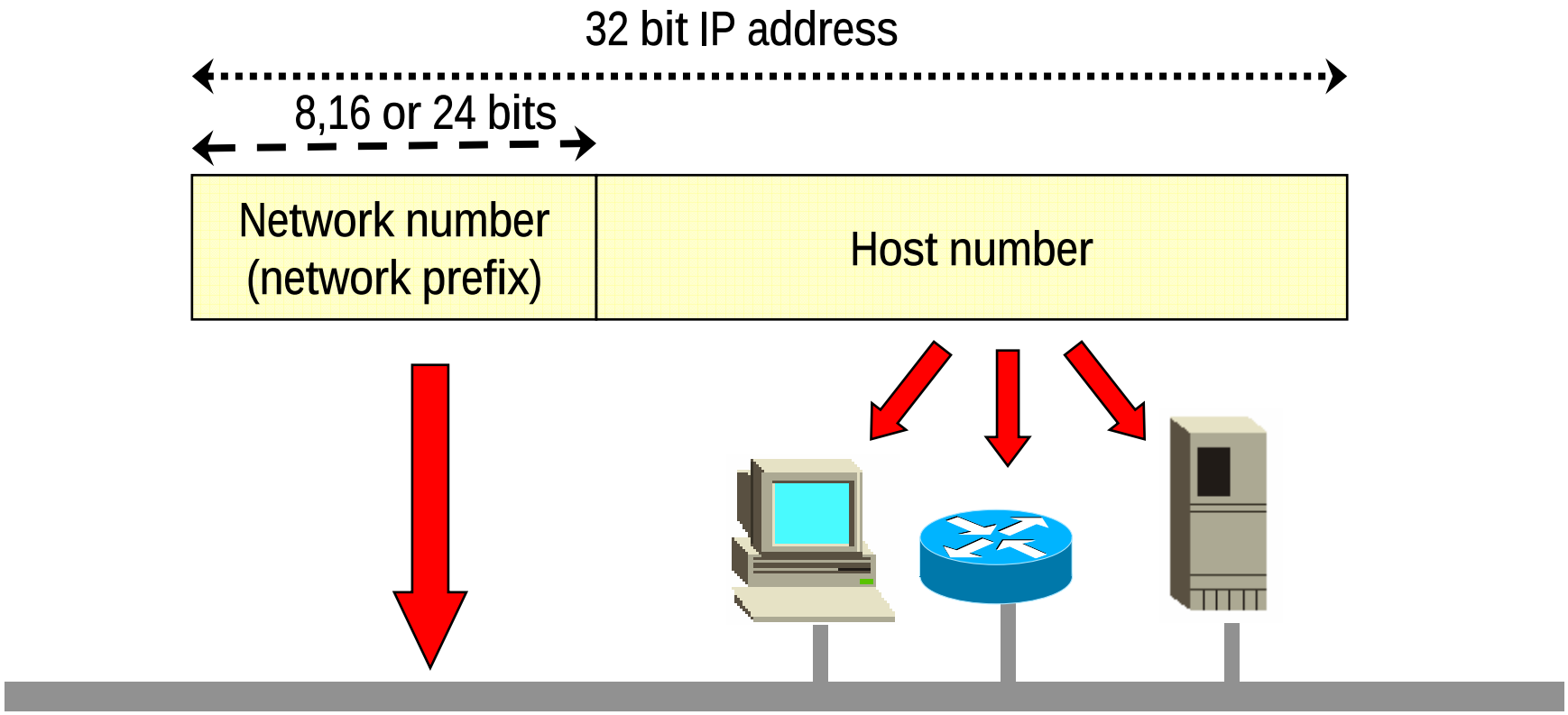
shows routing table of your PC

(remember: your PC is a simple IP router)

```
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0      10.163.57.1    10.163.57.77    1
      10.163.57.0    255.255.255.0     10.163.57.77    10.163.57.77    1
     10.163.57.77  255.255.255.255        127.0.0.1       127.0.0.1    1
   10.255.255.255  255.255.255.255     10.163.57.77    10.163.57.77    1
        127.0.0.0        255.0.0.0        127.0.0.1       127.0.0.1    1
        224.0.0.0        224.0.0.0     10.163.57.77    10.163.57.77    1
  255.255.255.255  255.255.255.255     10.163.57.77    10.163.57.77    1
Default Gateway:       10.163.57.1
===========================================================================
```

Classful IP Addressing

Originally (from 1981) a rigid two-level address structure

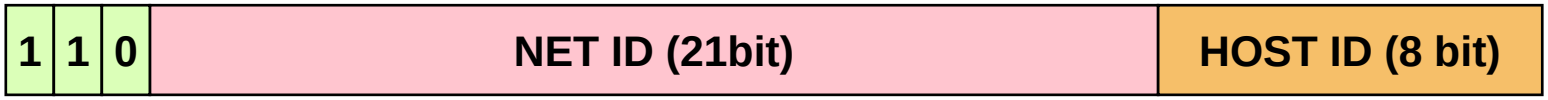


Primary Address Classes
3 standardized classes

Class A - /8 network prefix

Class B - /16 network prefix

Class C - /24 network prefix



/xx notation: modern notation
in principle not necessary for classful IP addressing

Additional classes

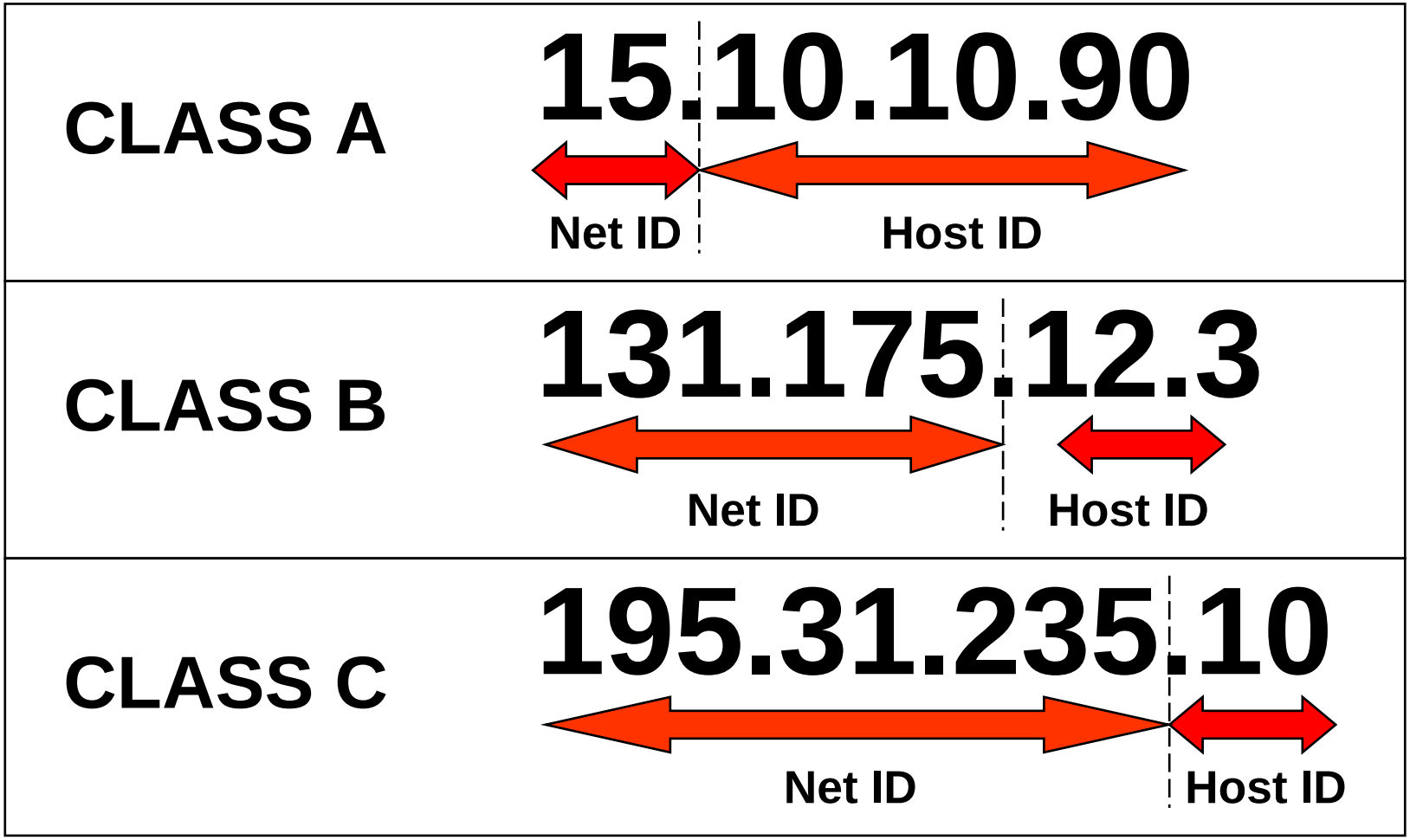
Class D: IP multicasting

Class E: reserved for experimental use

Dotted Decimal Ranges

Address Class	Dotted Decimal ranges
Class A	1.xxx.xxx.xxx through 126.xxx.xxx.xxx
Class B	128.0.xxx.xxx through 191.255.xxx.xxx
Class C	192.0.0.xxx through 223.255.255.xxx
Class D (mcast)	224.xxx.xxx.xxx through 239.xxx.xxx.xxx
Class E (exper)	240.xxx.xxx.xxx through 255.xxx.xxx.xxx

Examples


CLASS A
15.10.10.90
Net ID
Host ID
CLASS B
131.175.12.3
Net ID
Host ID
CLASS C
195.31.235.10
Net ID
Host ID

Addressing networks

- **All 0s host ID = reserved for network name.**
- **Examples:**
  - CLASS A network: 13.0.0.0
  - CLASS B network: 131.175.0.0
  - CLASS C network: 193.32.43.0
- **Test:**
  - 188.66.32.0 = ???
  - 122.0.0.0 = ???

Special Addresses

- **all 1s host id: broadcast address (all hosts in the network)**
  - es. 131.175.255.255 =all hosts attached to the 131.175 net
- **0.0.0.0 = *THIS* host on *THIS* network (0.x.x.x also reserved)**
  - e.g. to boot diskless WS (BOOTP)
- **127.x.x.x used for loopback (es. 127.0.0.1=localhost)**
- **all 1s = 255.255.255.255 = limited broadcast**
  - all nodes on *THIS* local network

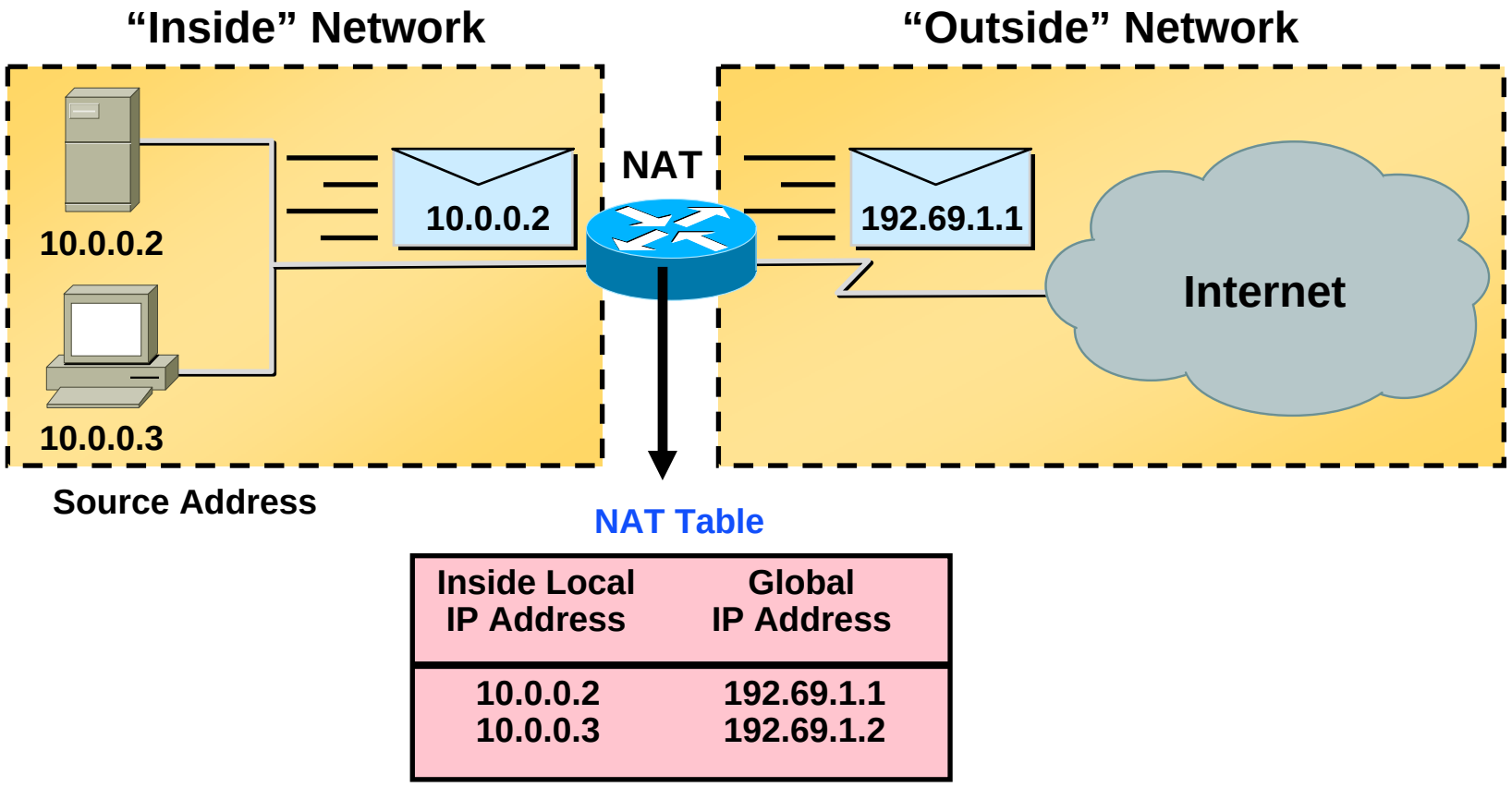
Address blocks for private Internets (RFC 1918)

IANA-Allocated, Non-Internet Routable, IP Address Schemes

Class	Network Address Range
A	10.0.0.0 - 10.255.255.255
B	172.16.0.0 - 172.31.255.255
C	192.168.0.0 - 192.168.255.255

To be used by private organizations not connected to the Internet
No need to ask to IANA or InterNIC for these addresses.
Use Network Address Translator (NAT) when external connectivity needed

Network Address Translator

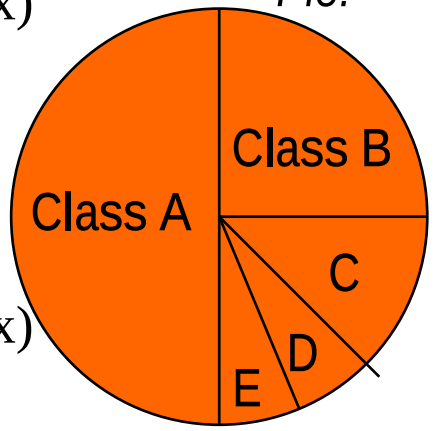


➔**Map external address with Internal ones (may be a subset)**

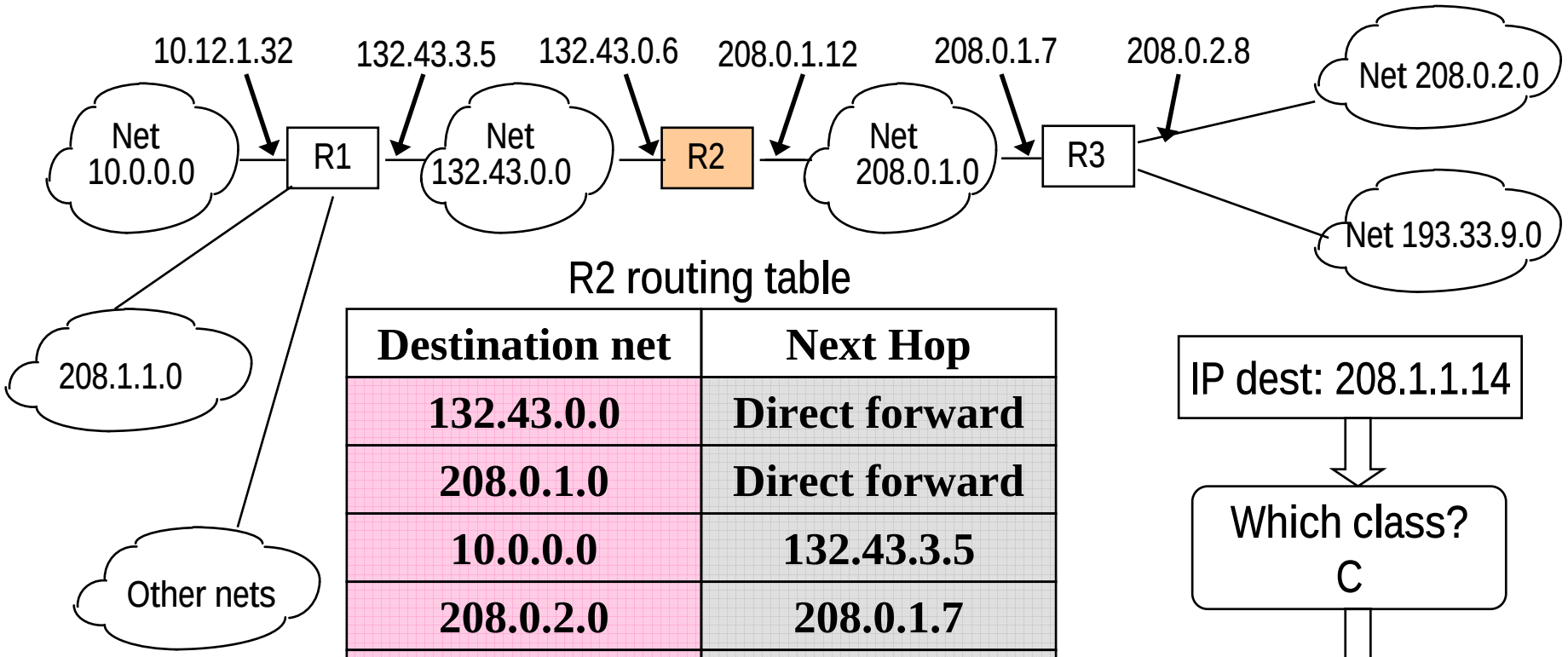
Counting up

- **32 bit IP address:**
  - 2^{32} = 4.294.967.296 theoretical IP addresses
- **class A:**
  - 2^{7}-2 =126 networks [0.0.0.0 and 127.0.0.0 reserved]
  - 2^{24}-2 = 16.777.214 maximum hosts
    - **2.113.928.964** addressable hosts (49,22% of max)
- **class B**
  - 2^{14}=16.384 networks
  - 2^{16}-2 = 65.534 maximum hosts
    - **1.073.709.056** addressable hosts (24,99% of max)
- **class C**
  - 2^{21}=2.097.152 networks
  - 2^{8}-2 = 254 maximum hosts
    - **532.676.608** addressable hosts (12,40% of max)

The IP address Pie!

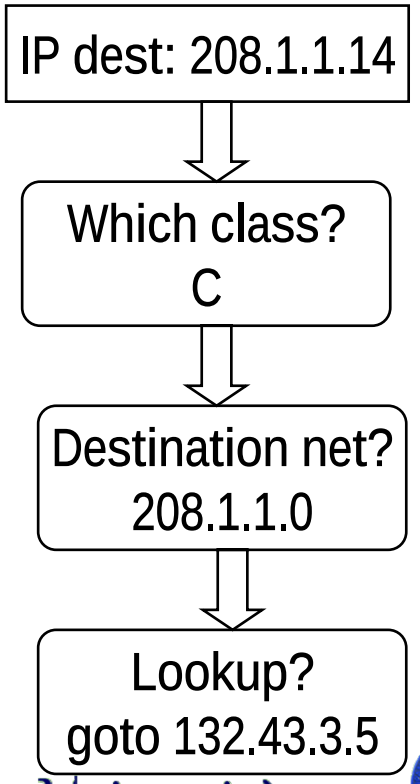


Routing table lookup



R2 routing table

Destination net	Next Hop
132.43.0.0	Direct forward
208.0.1.0	Direct forward
10.0.0.0	132.43.3.5
208.0.2.0	208.0.1.7
193.33.9.0	208.0.1.7
208.1.1.0	132.43.3.5
default	132.43.3.5



Net Address computation (Masking)

- class mask:
  - Depends on first bits of address (which specify class)
    - Class A mask: 255.0.0.0
    - Class B mask: 255.255.0.0
    - Class C mask: 255.255.255.0

DEST IP address: 159.100.9.18 class B	**10**011111	01100100	00001001	00010010
	Bitwise AND			
Class B Mask: 255.255.0.0	11111111	11111111	00000000	00000000
	⬇			
Net address 159.100.0.0	10011111	01100100	00000000	00000000