CSE 224: NETWORKING FUNDAMENTALS

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UC San Diego

ATTRIBUTION

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AGENDA

Today:

- Chapters 1 and 2 of "Network Programming with Go" (not including DNS)

Thursday:

- DNS, DHCP, Naming, and Go's "net" package

TODO THIS WEEK

1. Read Network Programming with Go chapters 1, 2, and 3
2. Project 1 due a week from today (Tue Jan 11)

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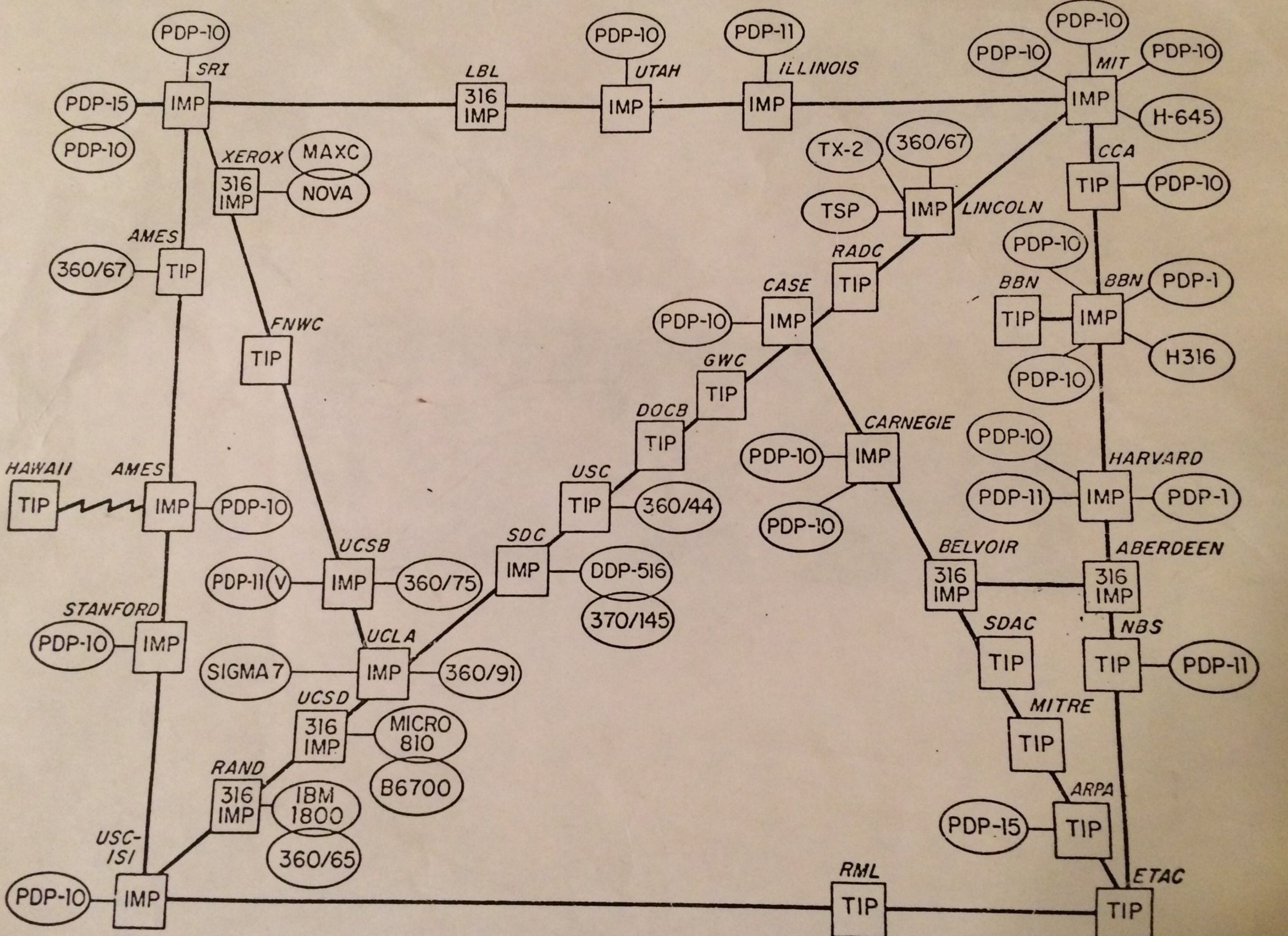
BRIEF HISTORY OF THE INTERNET

- 1968 - DARPA (Defense Advanced Research Projects Agency) contracts with BBN (Bolt, Beranek & Newman) to create ARPAnet
- 1970 - First five nodes:
  - UCLA
  - Stanford
  - UC Santa Barbara
  - U of Utah, and
  - BBN
- 1974 - TCP specification by Vint Cerf
- 1984 – On January 1, the Internet with its 1000 hosts converts en masse to using TCP/IP for its messaging

Data from the Internet Society

ARPA NETWORK, LOGICAL MAP, MAY 1973



Outline

1. Performance
2. Layering
3. Addressing

PERFORMANCE METRICS

- Bandwidth: number of bits transmitted per unit of time
- Latency = Propagation + Transmit + Queue
  - Propagation = Distance/SpeedOfLight(*)
  - Transmit = 1 bit/Bandwidth
  - Queue = Time waiting in switches/routers behind other traffic (traffic jam)
- Overhead
  - # secs for CPU to put message on wire
- Error rate
  - Probability P that message will not arrive intact

* In that particular medium

BANDWIDTH VS. LATENCY

1 Byte Object

	Latency: 1 ms	Latency: 100 ms
Bandwidth: 1 Mbps	1,008 µs	100,008 µs
Bandwidth: 100 Mbps	1,000 µs	100,000 µs

10 MB Object

	Latency: 1 ms	Latency: 100 ms
Bandwidth: 1 Mbps	80.001 s	80.1 s
Bandwidth: 100 Mbps	.801 s	.9 s

NETWORK PERFORMANCE MEASUREMENT UNITS

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000,000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

TERMINOLOGY STYLE

- Mega versus Mega, Kilo versus Kilo
  - Computer architecture: Mega → 2^20, Kilo → 2^10
  - Computer networks: Mega → 10^6, Kilo → 10^3
- Mbps versus MBps
  - Networks: typically megabits per second
  - Architecture: typically megabytes per second
- Bandwidth versus throughput
  - Bandwidth: available over link
  - Throughput: available to application
    - E.g. subtract protocol headers, etc.

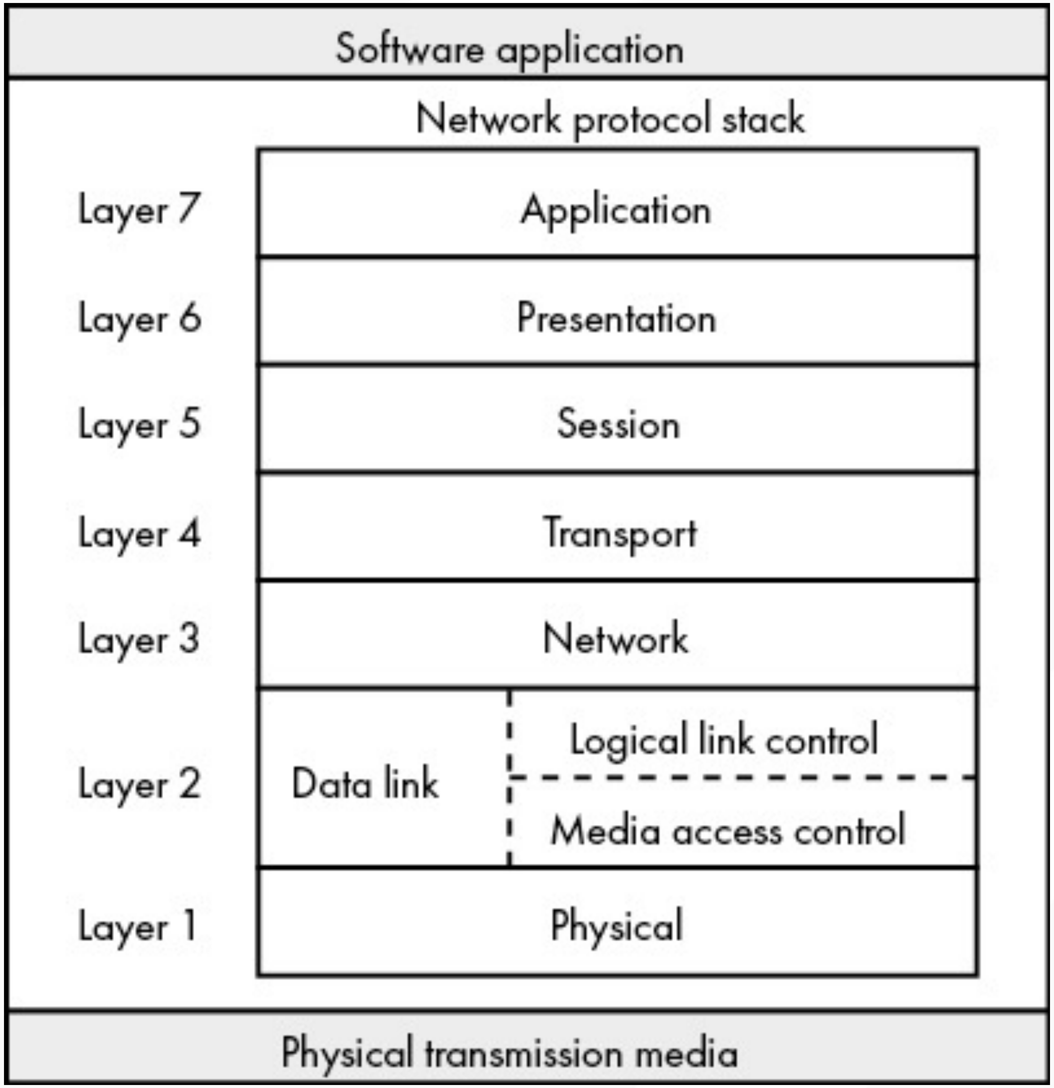
PERFORMANCE TOOLS

- Ping
  - Test if other side is “alive”
  - Measures round-trip latency
- Netperf/iperf3
  - Times how long it takes to send N bytes to the other endpoint
  - Used to calculcate bandwidth

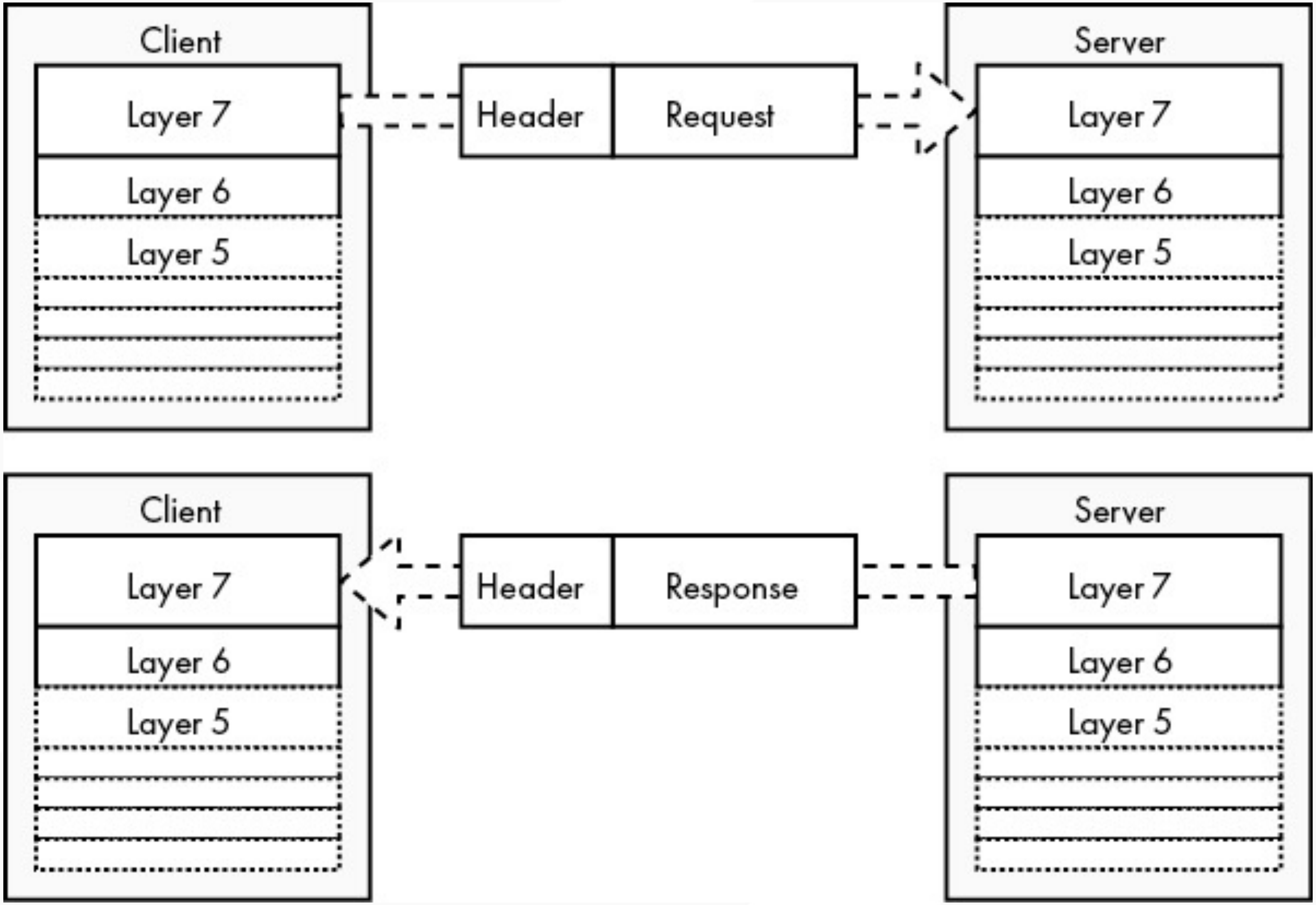
Outline

1. ~~Performance~~
2. Layering
3. Addressing

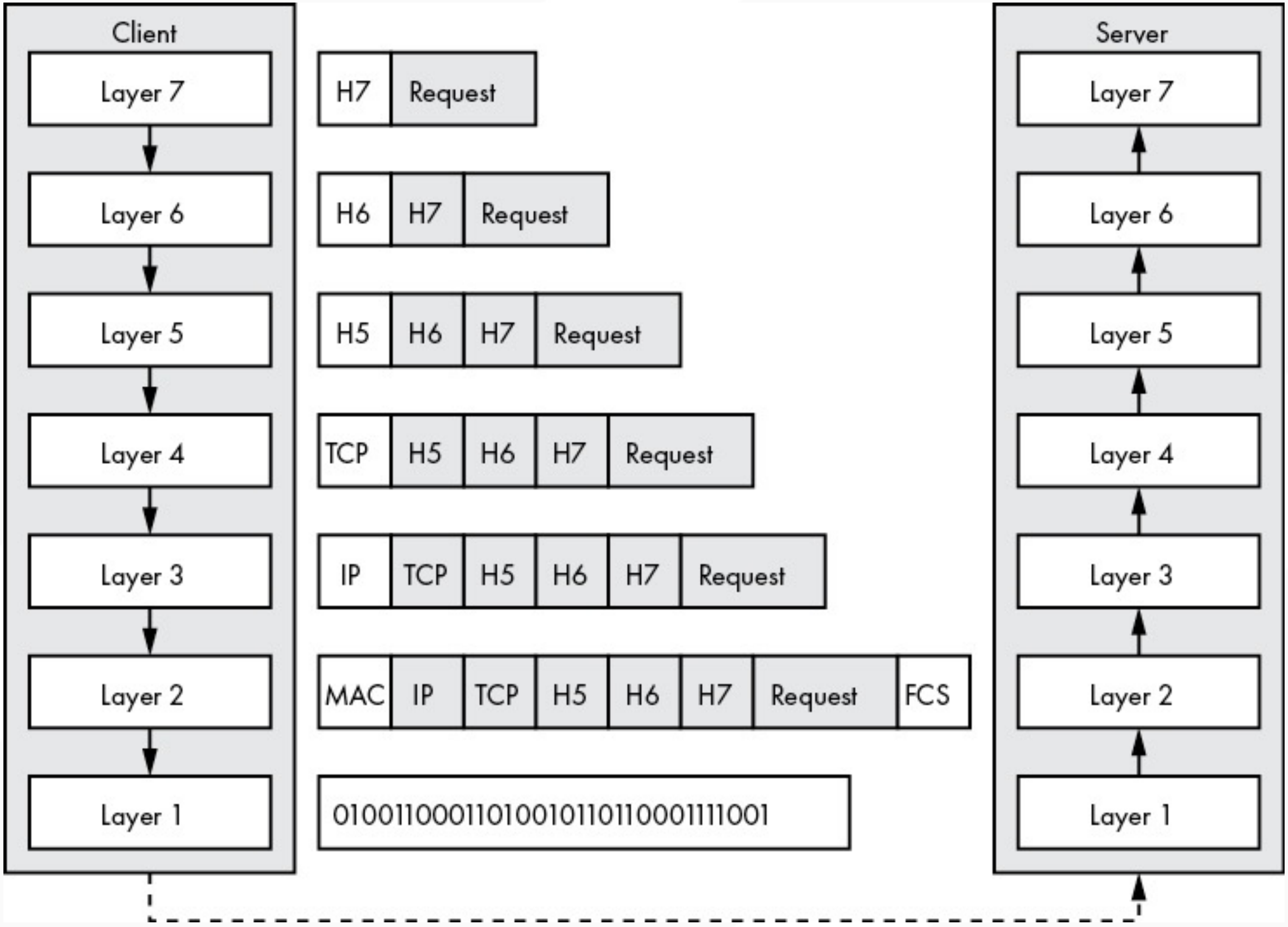
OSI NETWORK STACK



PROTOCOLS GOVERN MESSAGES EXCHANGED WITHIN A SINGLE LAYER



LAYERING AND ENCAPSULATION



TCP/IP MODEL (VS OSI MODEL)

Software application	
TCP/IP	**OSI**
Application	Application
	Presentation
	Session
Transport	Transport
Internet/network	Network
Link	Data link
	Physical
Physical transmission media	

Outline

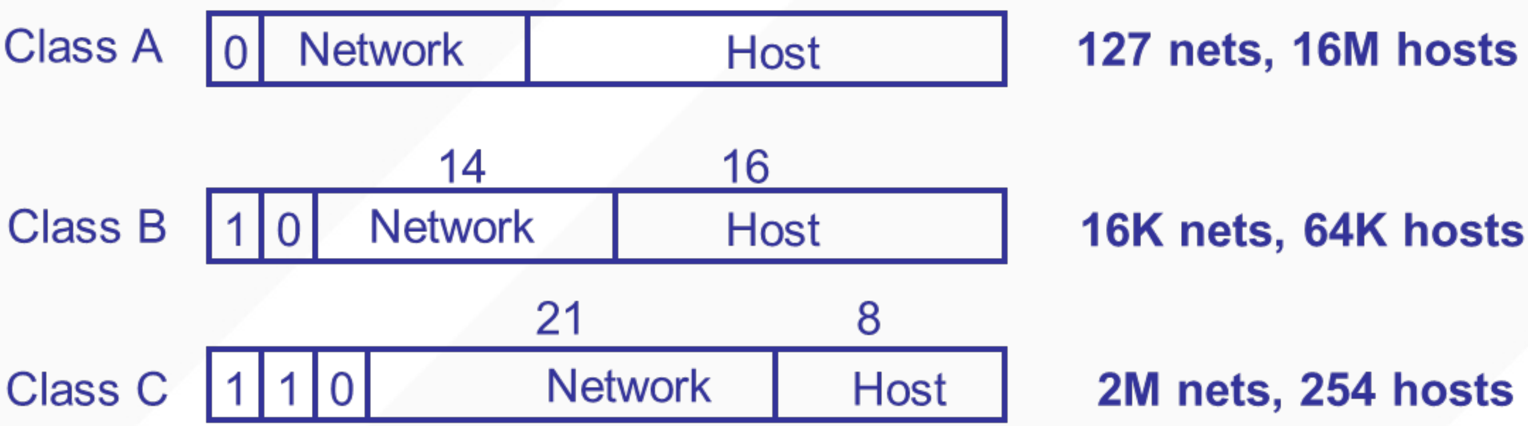
1. ~~Performance~~
2. ~~Layering~~
3. Addressing

IP VERSION 4 (IPV4)

11000000	.	10101000	.	00000001	.	00001010		(Binary)
192	.	168	.	1	.	10		(Decimal)

CLASS-BASED ADDRESSING (NOT REALLY USED ANYMORE)

- Most significant bits determines "class" of address

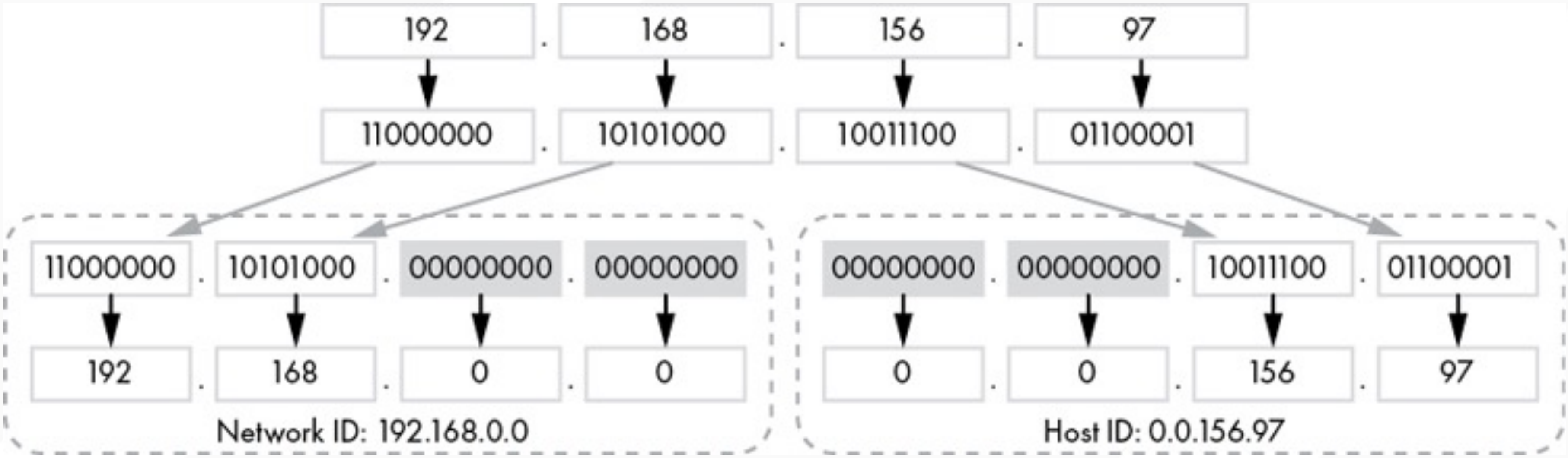


- Special addresses
  - Class D (1110) for multicast, Class E (1111) experimental
  - 127.0.0.1: local host (a.k.a. the loopback address)
  - Host bits all set to 0: network address
  - Host bits all set to 1: broadcast address

CLASS-BASED ADDRESSING EXAMPLES

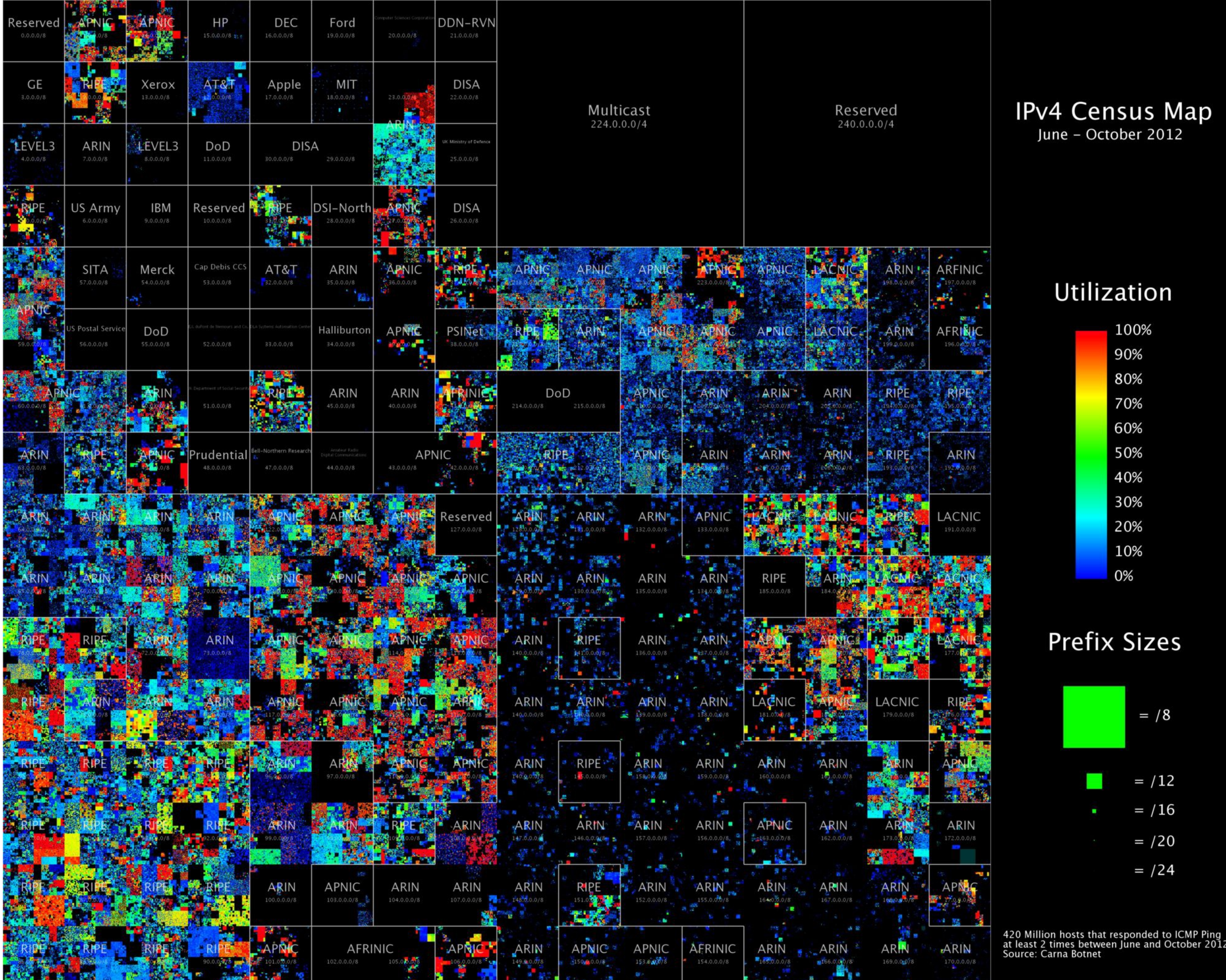
Network ID	First octet	Second octet	Third octet	Fourth octet	Host ID
8 bits	Network 10	Host 1	Host 2	Host 3	24 bits
16 bits	Network 172	Network 16	Host 1	Host 2	16 bits
24 bits	Network 192	Network 168	Network 1	Host 2	8 bits

ADDRESSING EXAMPLE



IP ADDRESS PROBLEM (1991)

- Address space depletion
  - In danger of running out of classes A and B
- Why?
  - Class C too small for most organizations (only ~250 addresses)
  - Very few class A – very careful about giving them out (who has 16M hosts anyway?)
  - Class B – greatest problem

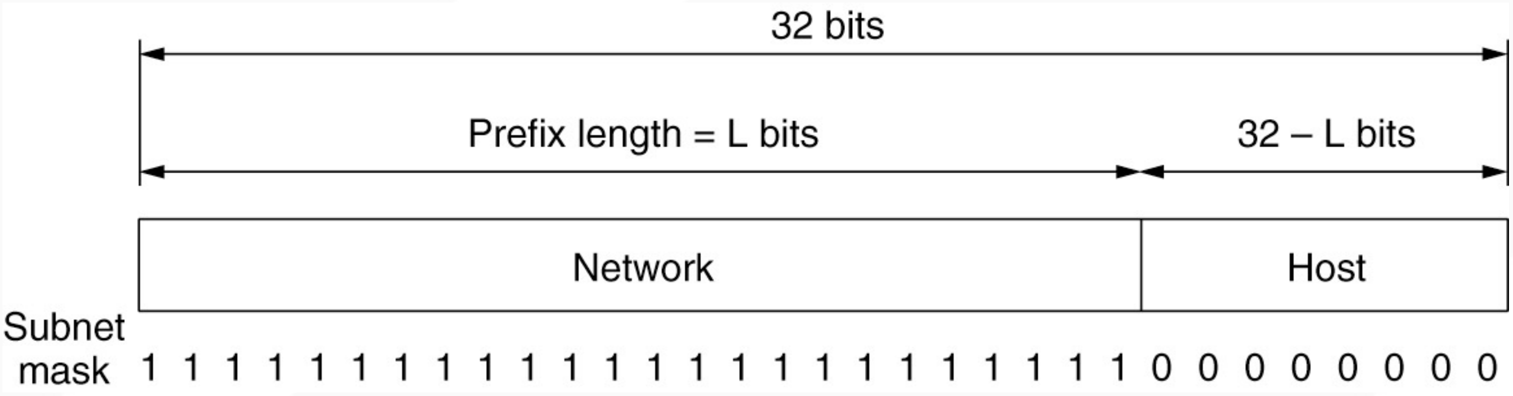

IPv4 Census Map
June - October 2012
Utilization
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Prefix Sizes
= /8
= /12
= /16
= /20
= /24
Multicast
224.0.0.0/4
Reserved
240.0.0.0/4
420 Million hosts that responded to ICMP Ping at least 2 times between June and October 2012
Source: Carna Botnet

CIDR

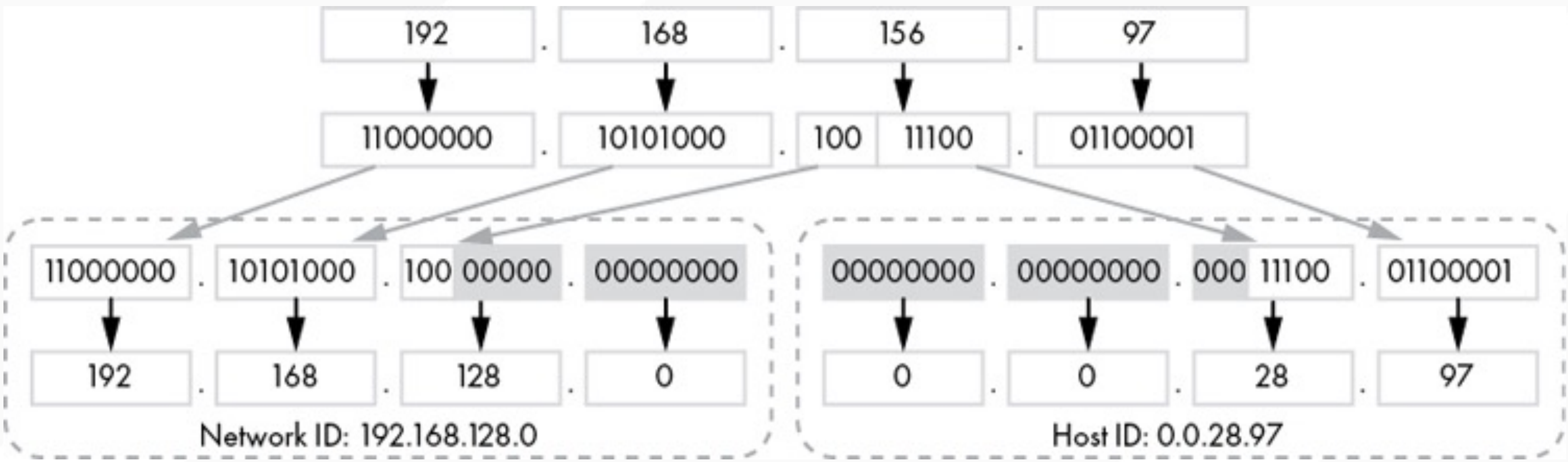
- Classless Inter-Domain Routing (1993)
  - Networks described by variable-length prefix and length
  - Allows arbitrary allocation between network and host address

  - e.g. 10.95.1.2 contained within 10.0.0.0/8:
    - 10.0.0.0 is network and remainder (95.1.2) is host
- Pro: Finer grained allocation; aggregation
- Con: More expensive lookup: longest prefix match

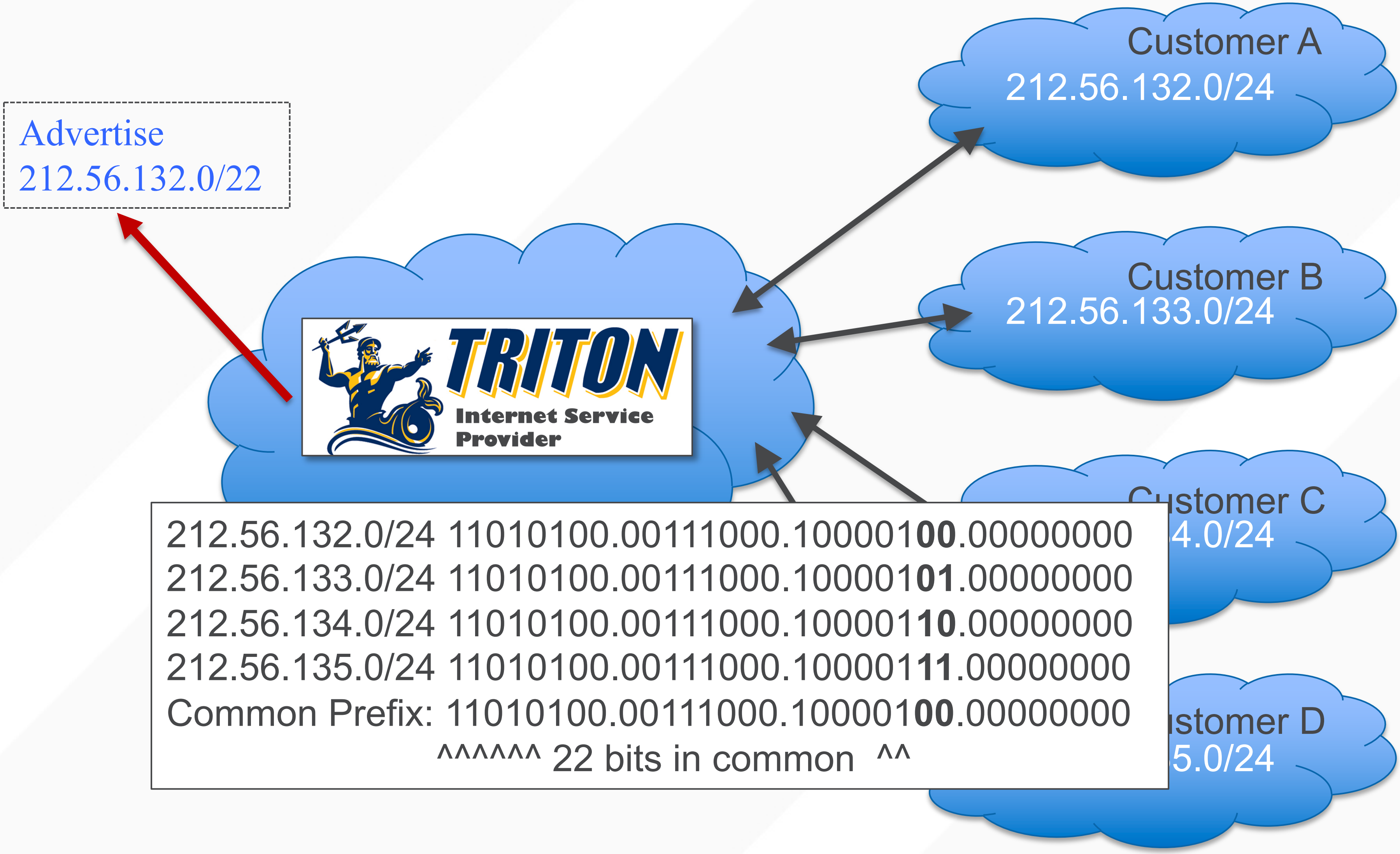
SUBNETS AND NETMASKS



192.168.156.97/19

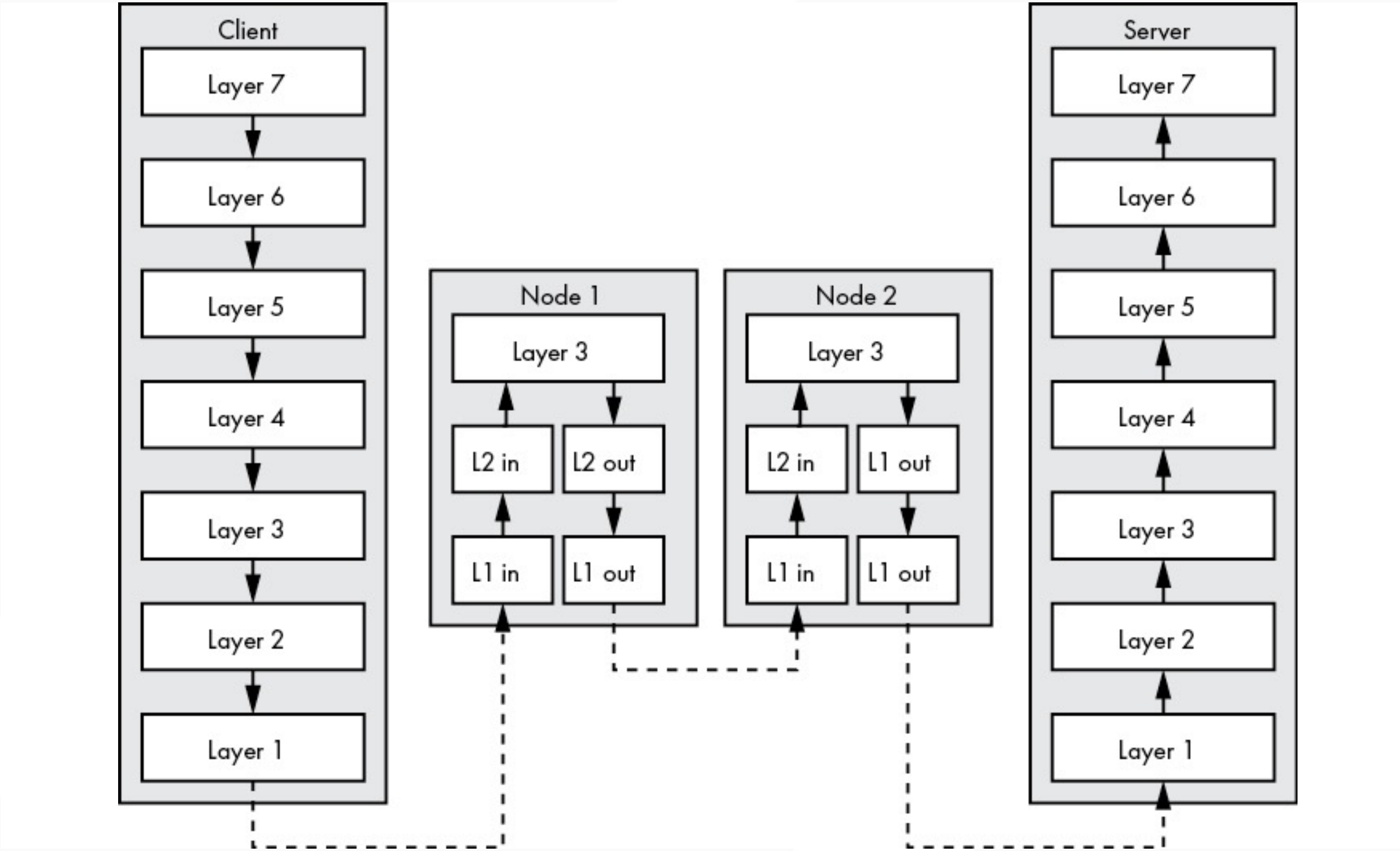


ADDRESS AGGREGATION EXAMPLE



212.56.132.0/24 11010100.00111000.100001**00**.00000000
212.56.133.0/24 11010100.00111000.100001**01**.00000000
212.56.134.0/24 11010100.00111000.100001**10**.00000000
212.56.135.0/24 11010100.00111000.100001**11**.00000000
Common Prefix: 11010100.00111000.100001**00**.00000000
^^^^^^ 22 bits in common ^^

ROUTING

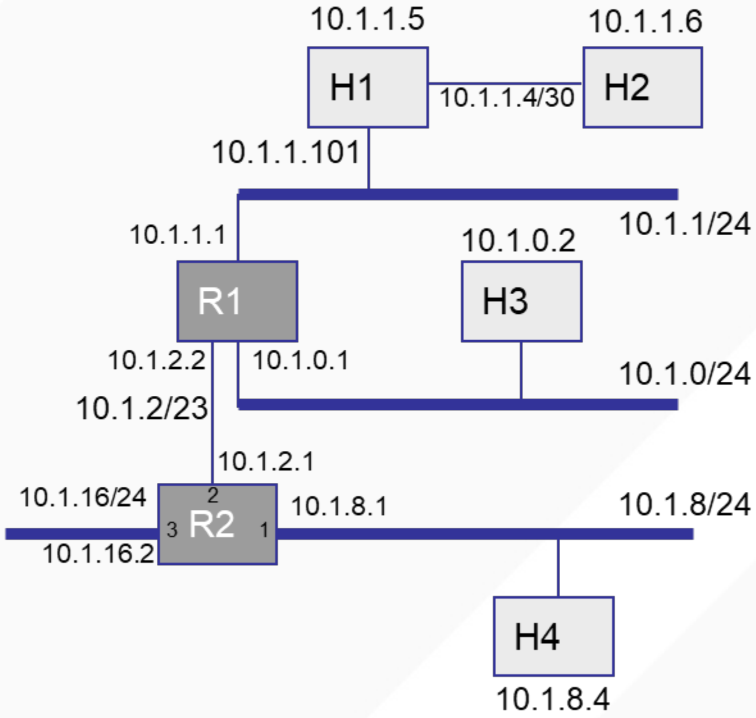


Client
Layer 7
Layer 6
Layer 5
Layer 4
Layer 3
Layer 2
Layer 1
Node 1
Layer 3
L2 in
L2 out
L1 in
L1 out
Node 2
Layer 3
L2 in
L1 out
L1 in
L1 out
Server
Layer 7
Layer 6
Layer 5
Layer 4
Layer 3
Layer 2
Layer 1

ROUTING TABLE EXAMPLE (R2)

- Packet to 10.1.1.6
- Matches 10.1.0.0/23

Destination	Next Hop
127.0.0.1	loopback
Default or 0/0	10.1.16.1
10.1.8.0/24	interface1
10.1.2.0/23	interface2
10.1.0.0/23	10.1.2.2
10.1.16.0/24	interface3

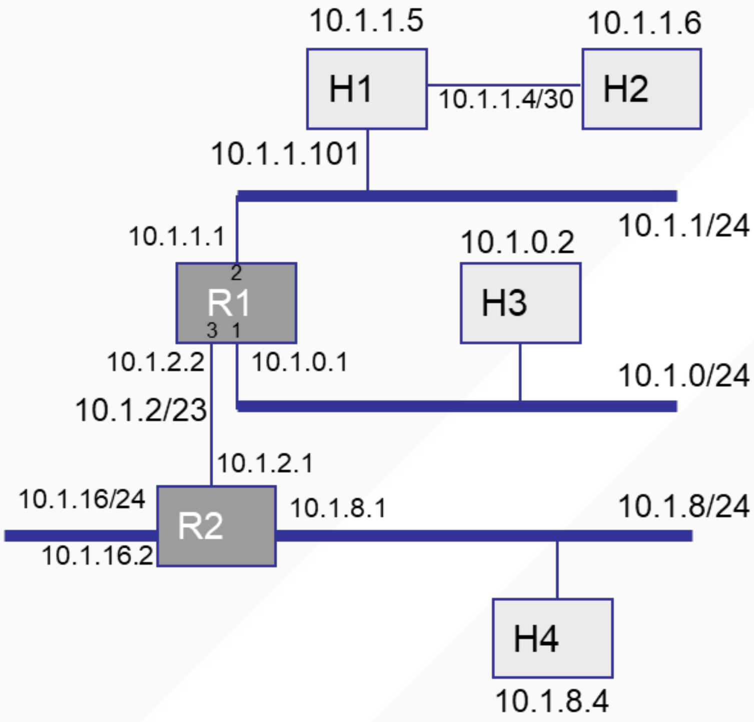


ROUTING TABLE EXAMPLE 2 (R1)

- Packet to 10.1.1.6
- Matches 10.1.1.4/30
  - Longest prefix match

Routing table at R1

Destination	Next Hop
127.0.0.1	loopback
Default or 0/0	10.1.2.1
10.1.0.0/24	interface1
10.1.1.0/24	interface2
10.1.2.0/23	interface3
10.1.1.4/30	10.1.1.101

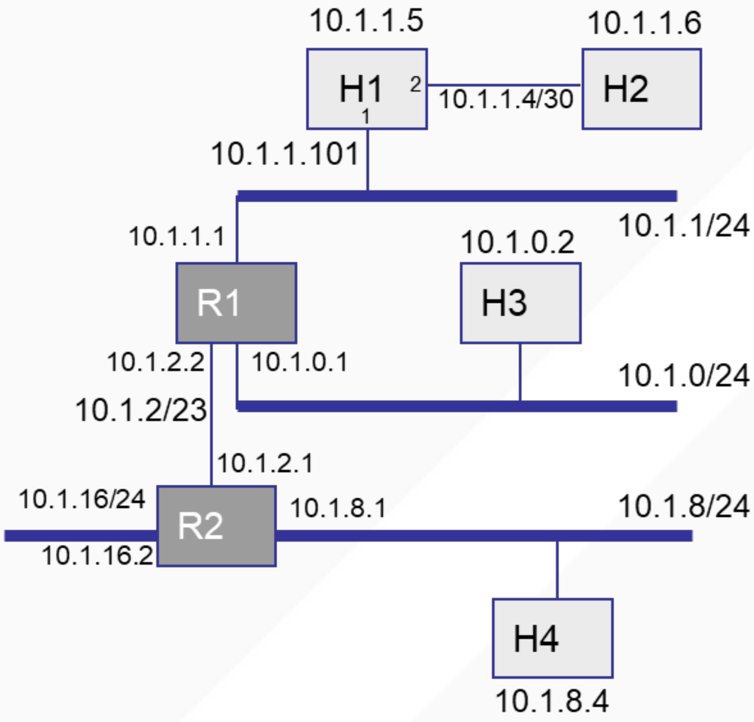


ROUTING TABLE EXAMPLE 3 (H1)

- Packet to 10.1.1.6
- Direct route
    - Longest prefix match

Routing table at H1

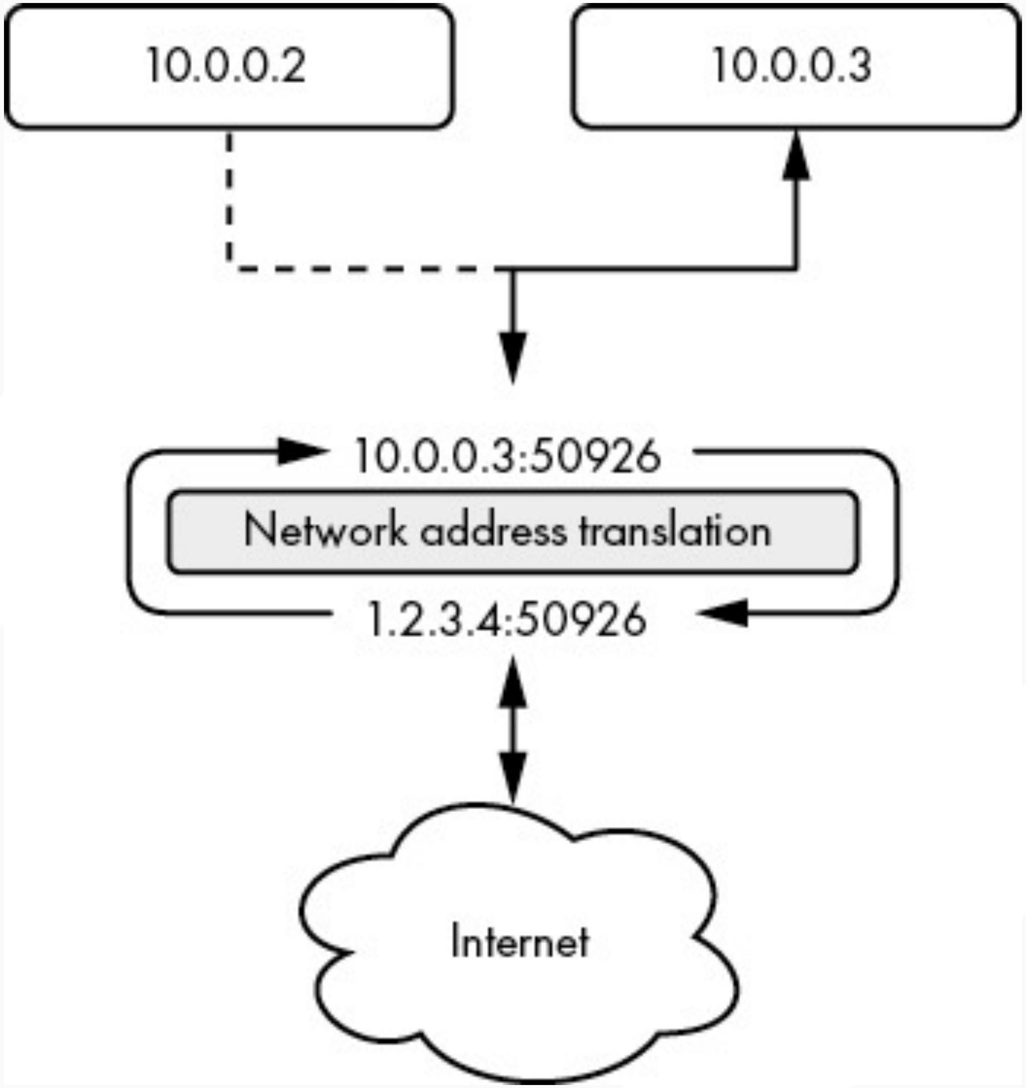
Destination	Next Hop
127.0.0.1	loopback
Default or 0/0	10.1.1.1
10.1.1.0/24	interface1
10.1.1.4/30	interface2



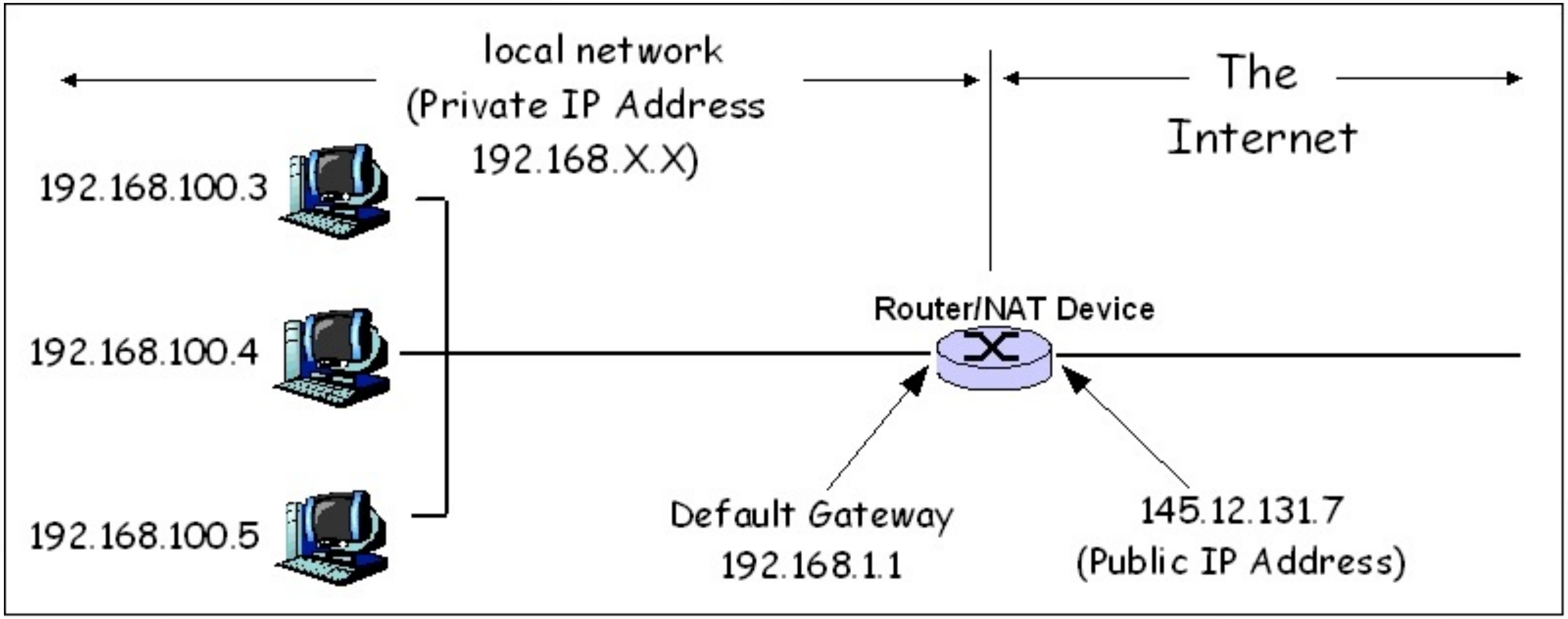
PORTS

- IP addresses identify a *machine*
  - Actually they identify a network interface on a machine
- How to identify different programs on the machine?
  - Process ID/PID? (no… why not?)
  - Instead we use a port (which is a 16-bit number)
  - 0-1024 reserved for the OS, you can use 1025-65535

NETWORK ADDRESS TRANSLATION



LOAD BALANCING VIA NETWORK ADDRESS TRANSLATION



Courtesy of: https://en.wikibooks.org/wiki/Communication_Networks/NAT_and_PAT_Protocols

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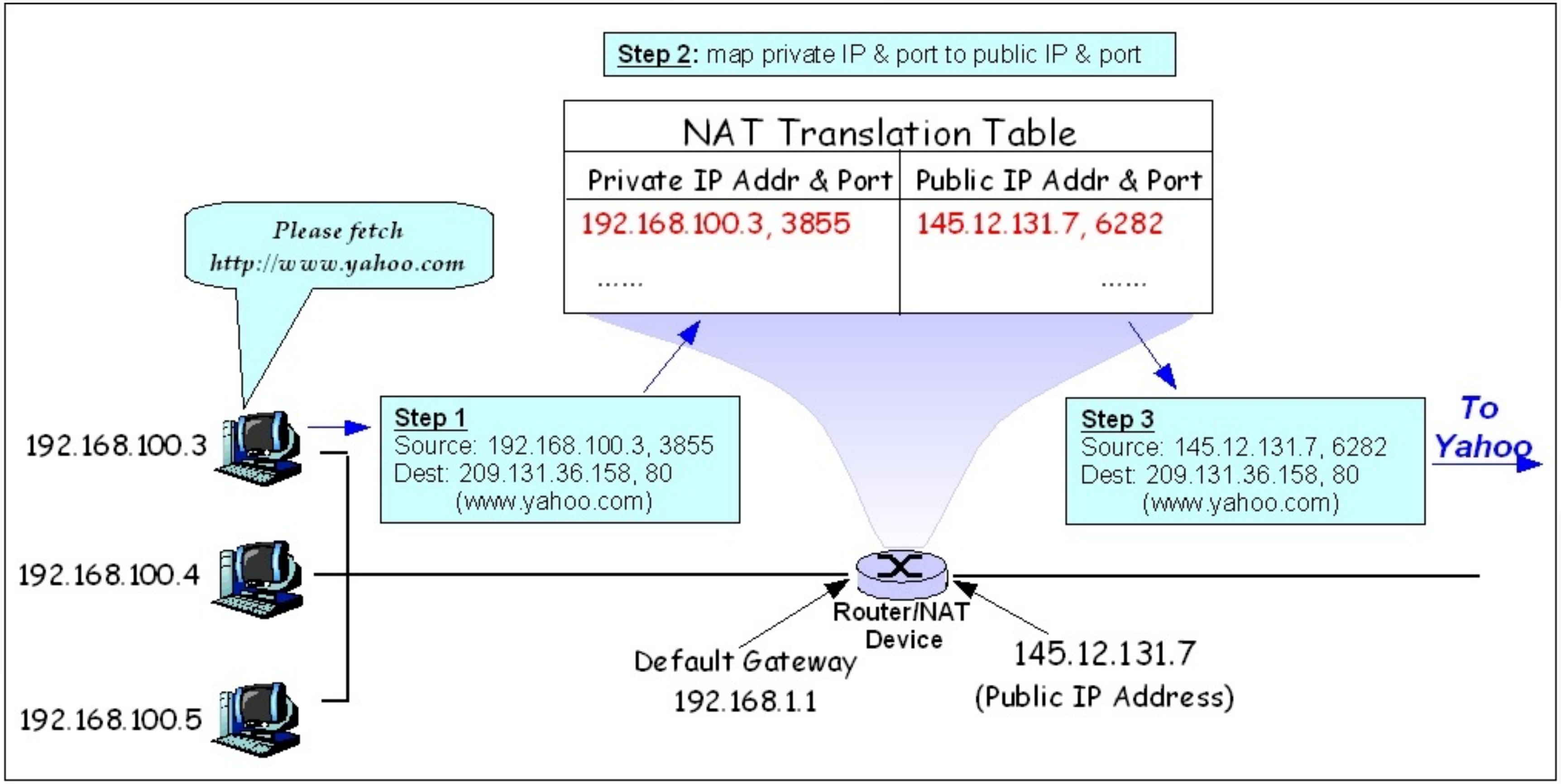

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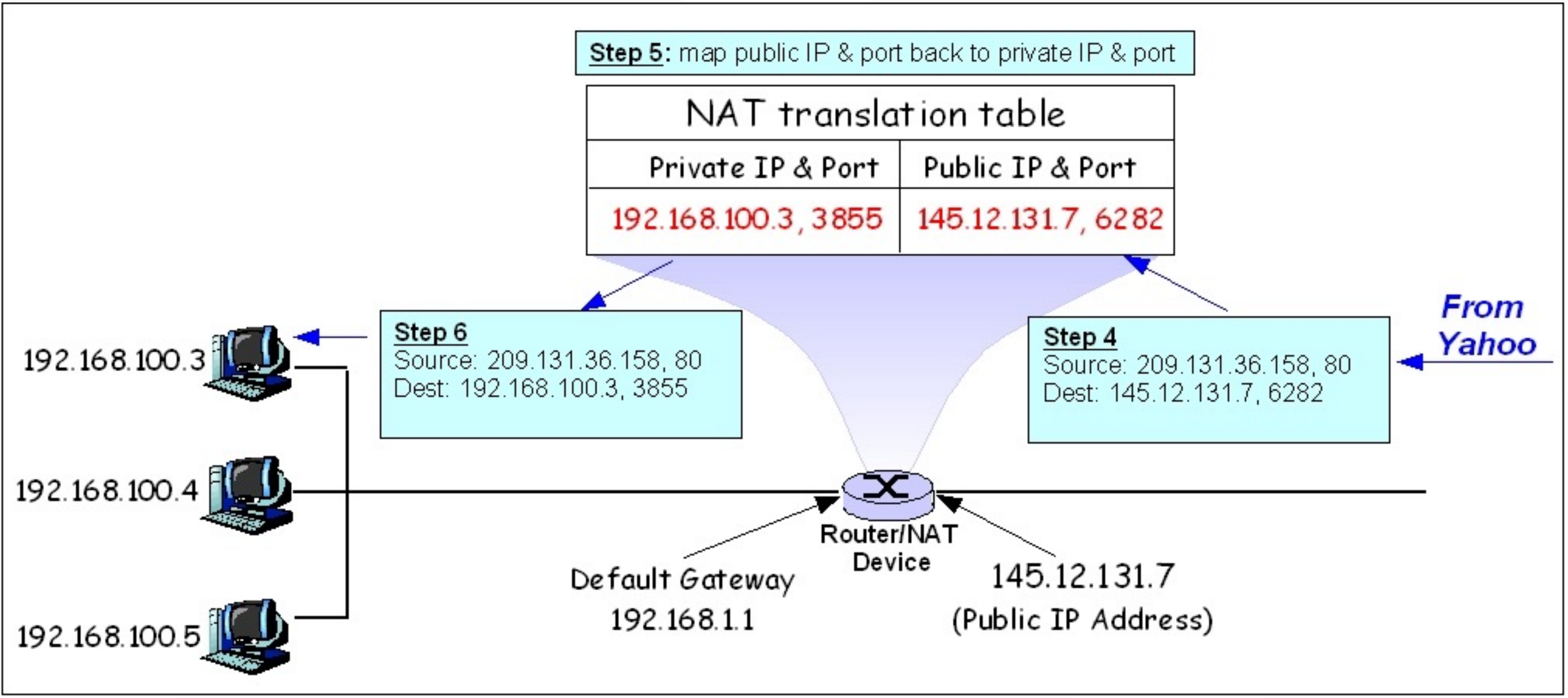

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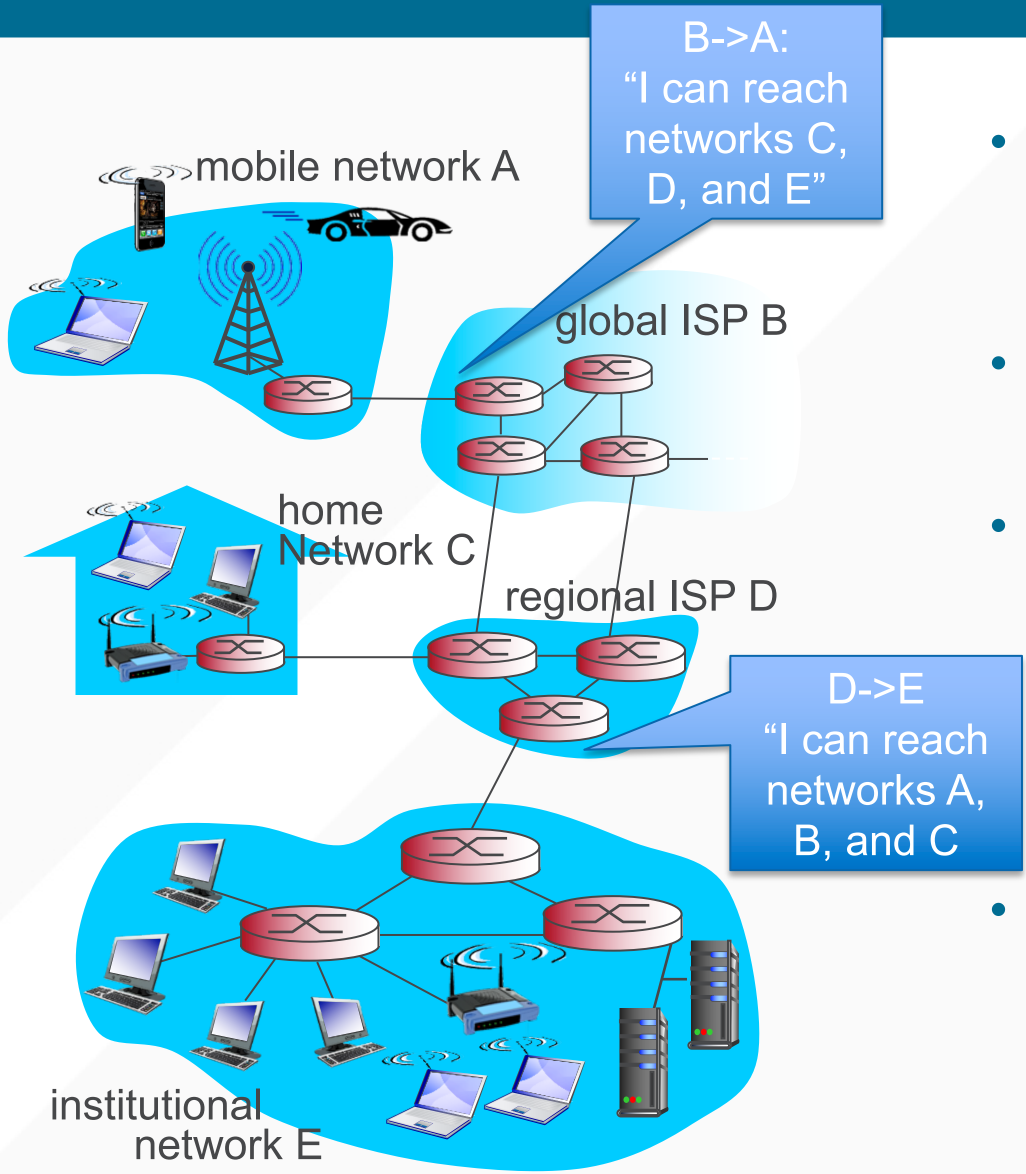
ROUTING PACKETS BETWEEN NETWORKS



- Networks use *Border Gateway Protocol (BGP)* to announce reachability
- Each network talks just with its neighbors
- Goal is to get a packet to the destination network
  - It is up to that destination network to get individual packets to their ultimate destination
- Back-to-back packets from the same "connection" might take different paths!
  - Might arrive out of order too

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