

Networks

It's not a network, it's a notwork.

Communicating Computers

- Protocols define specific ways to communicate
- Standards ensure that devices made by different people can still communicate
 - Voluntary bodies: IEEE, IETF, ...
 - Government bodies: ISO, CCITT, ANSI, ...
 - Companies: IBM, Apple, Google, AT&T, Microsoft,...

ISO Reference Model

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Physical Layer

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Bits – what's a 1?
What's a 0?

Electrical, Optical,
Wireless,
Mechanical

RS-232, V.35,
10Base-T, DSL,
SONET

IETF RFC 1149: Standard for the transmission of IP datagrams on avian carriers



Data Link Layer

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Provide error-free communications of "frames"; share a physical link

Physical addresses (bridges, switches)

IEEE 802.3 (Ethernet), 802.11 (WiFi), ATM, PPP, ...

Data Link Layer



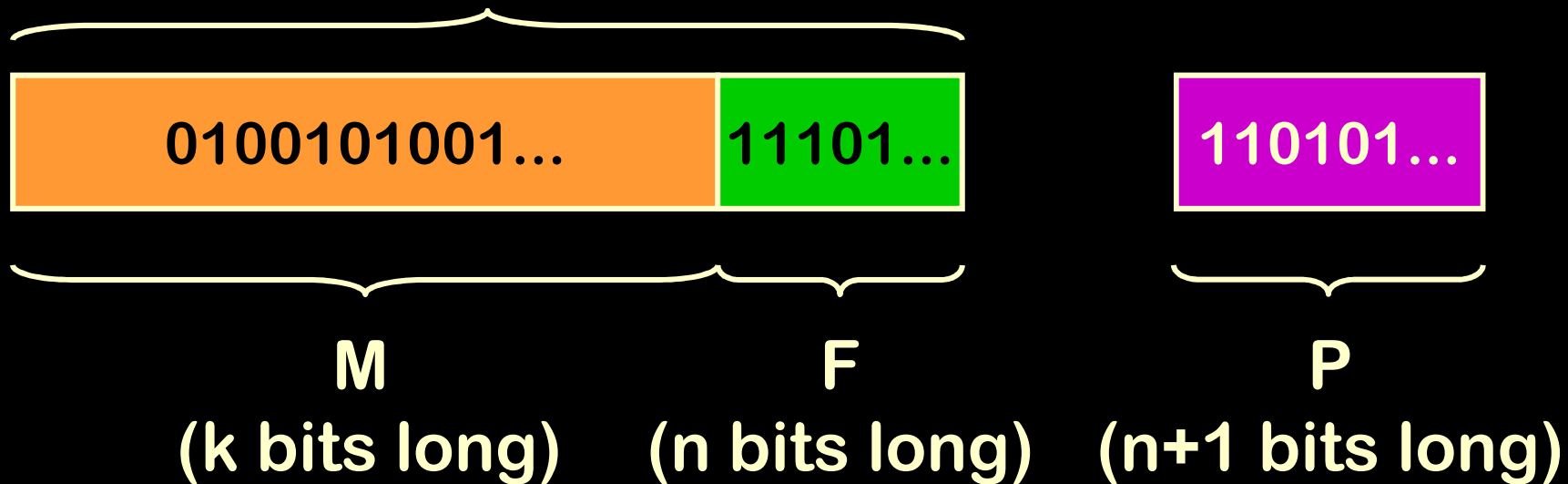
Data Link Layer



Odd Parity

Cyclical Redundancy Check

T (k+n bits long)



Detects all n-bit or less "burst" errors,
and $1-2^{-n}$ of longer errors

Cyclical Redundancy Check



Create F such that $T / P = 0$

F = remainder of M / P

Even Parity: $x + 1$

Bluetooth: $x^{16} + x^{12} + x^5 + 1$ (aka CRC-CCITT)

USB: $x^{16} + x^{15} + x^2 + 1$ (aka CRC-16)

V.42: $x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$

Network Layer

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

**Transfer error-free
data between
endpoints**

**Network addresses
(routers)**

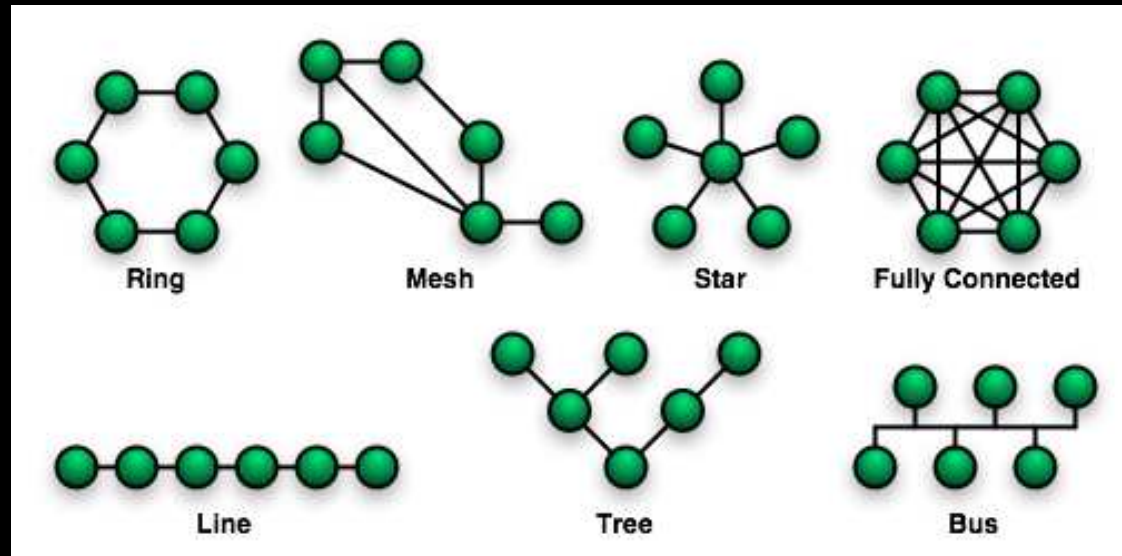
**IP, IPsec, ICMP, ARP,
Q.931, SCCP, ...**

Network Topologies

Token Ring
FDDI

“the”
Internet

Switched
Ethernet

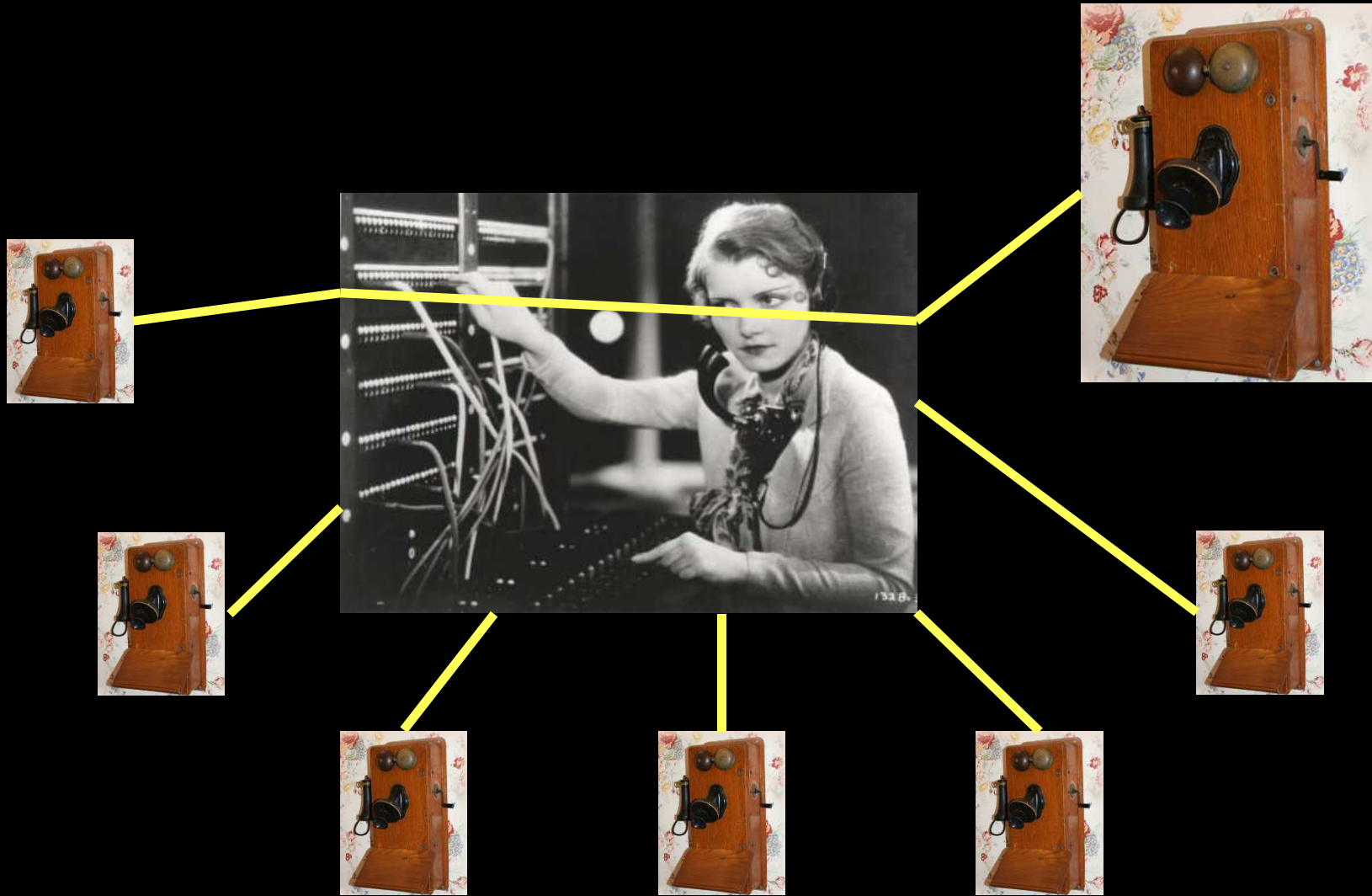


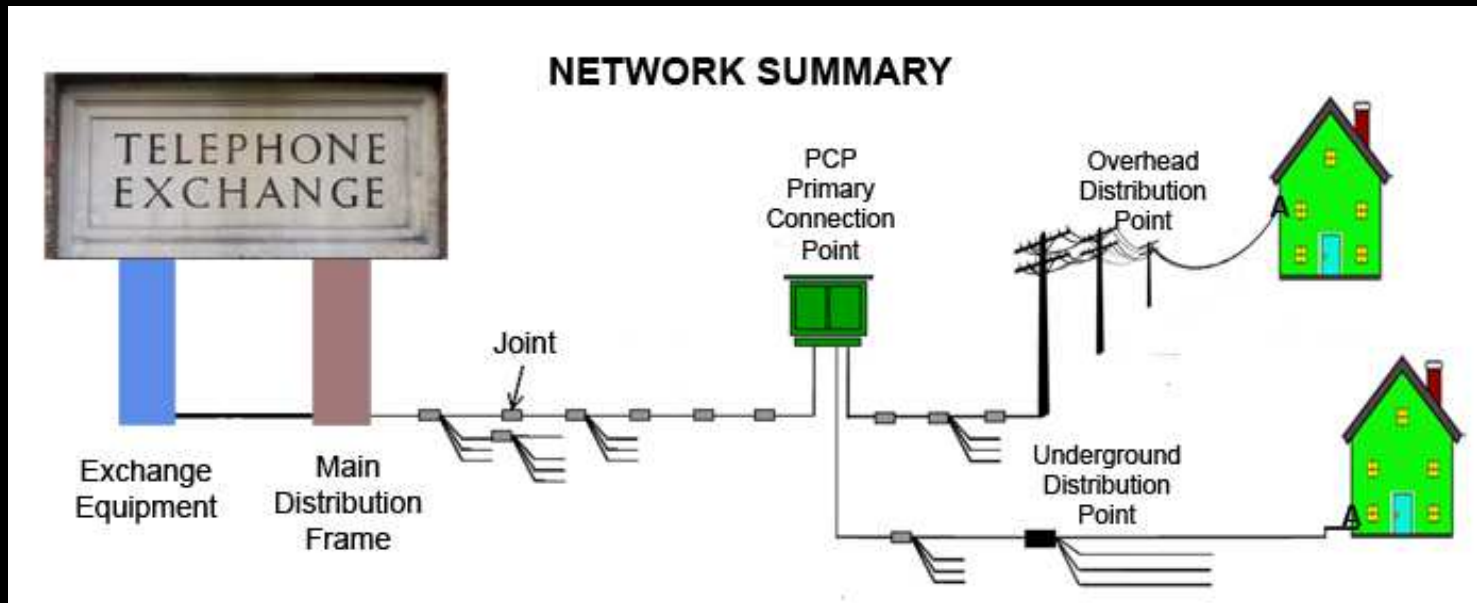
Daisy Chain

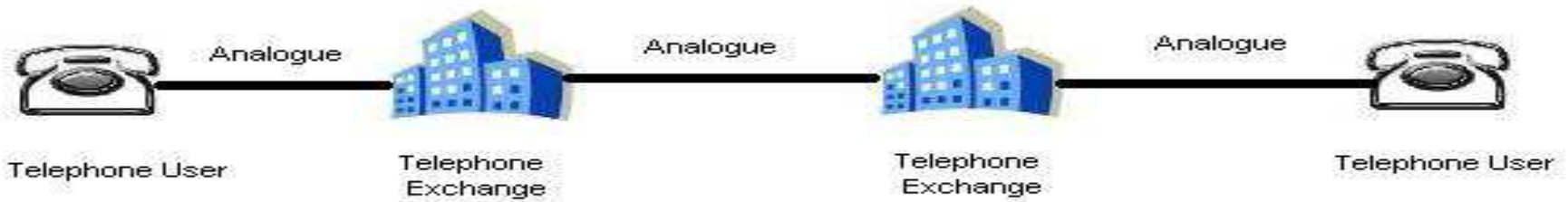
Wired Phones
USB

Original
“Shared”
Ethernet

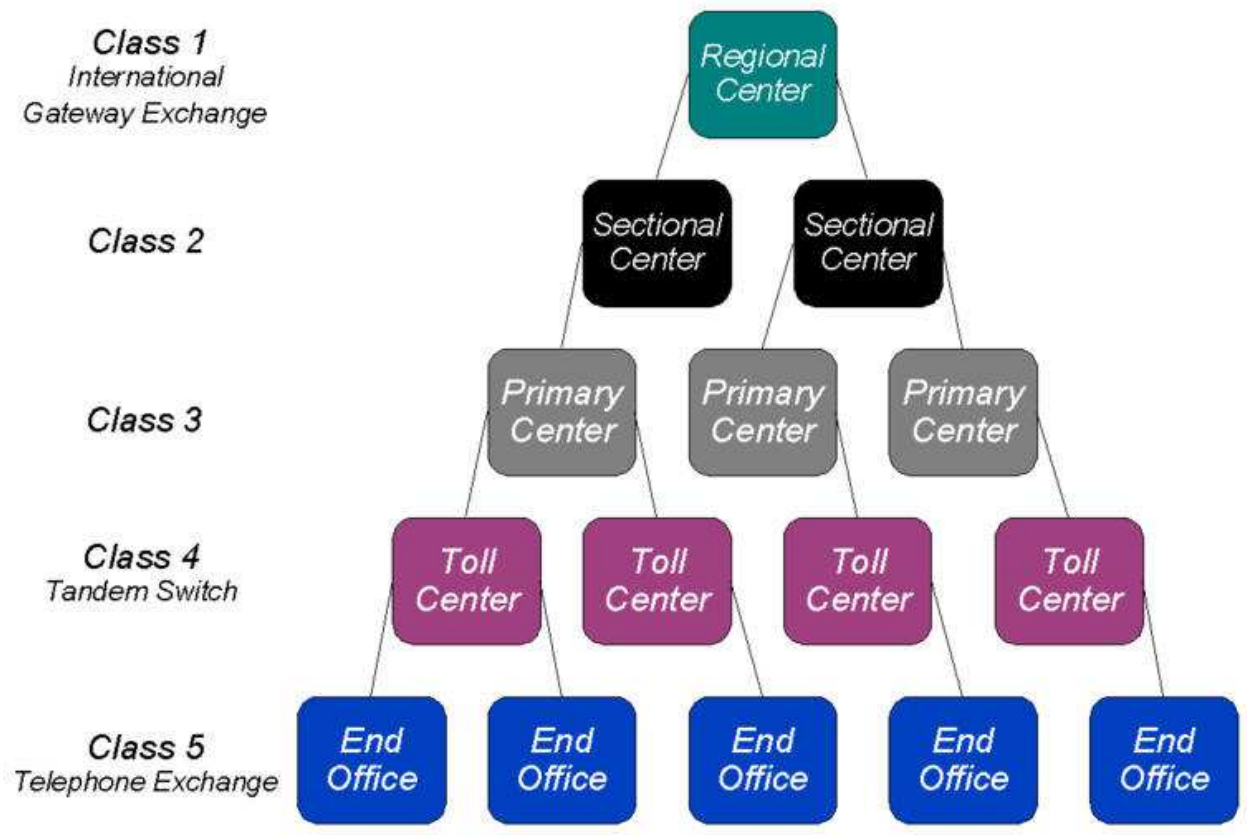
Circuit-Switched Networks







NerdCrunch - All Rights Reserved



Packet-switched Networks

<http://courses.iddl.vt.edu/CS1604/media/packets.html>

http://www.pbs.org/opb/nerds2.0.1/geek_glossary/packet_switching_flash.html

Finding your conversational partner

- Name
- Postal Address
- Telephone Number
- Internet Address

Telephone Numbers

- ITU assigns Country Codes
- Countries assign numbers
 - AT&T handled North America
 - Assigned Area Codes
 - Phone companies assigned numbers
 - Now done by FCC
 - North American Numbering Plan Administration
 - www.nanpa.com
 - Contracted to NeuStar (spin-out from Lockheed)

ITU Country Codes

1 US (and Canada, and some islands)

7 Russia (and Kazakhstan)

2n – 9n, ex 7 Lesser countries

2nn – 9nn, ex 7 Barely countries

Internet Addresses

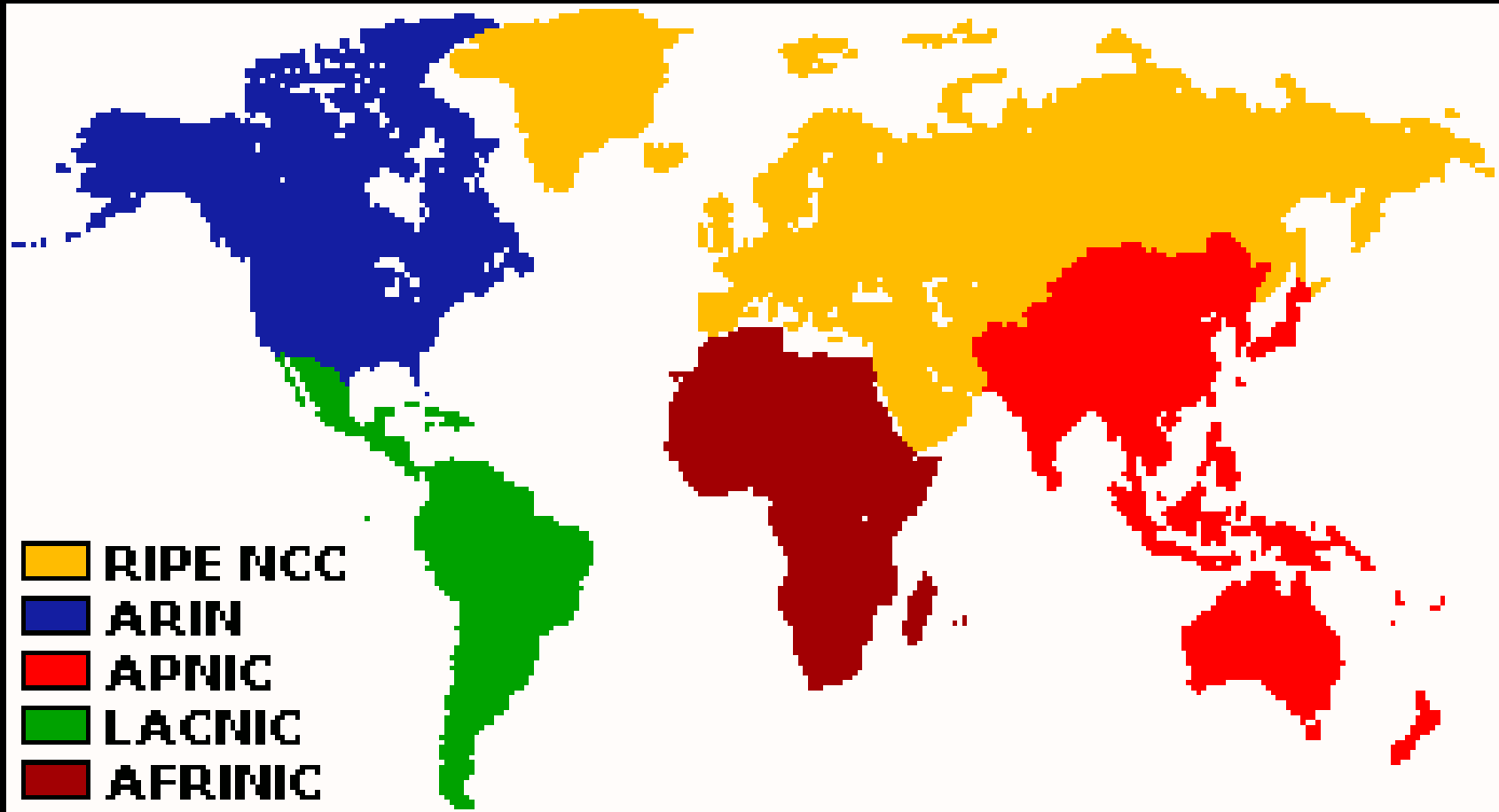
71

254

232

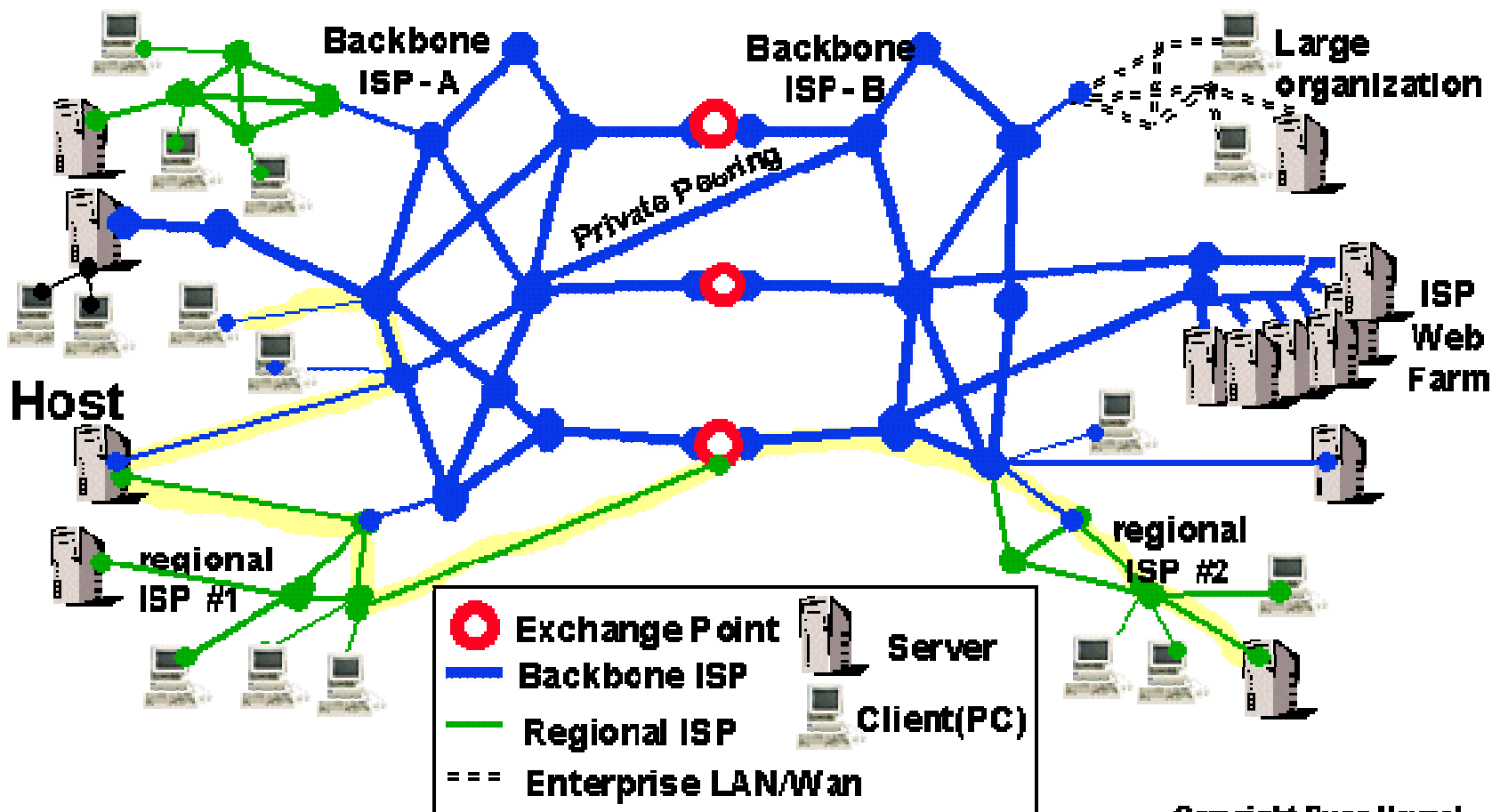
36

- 4 Bytes
 - 4 Billion addresses
- 5 Regional Internet Registries
 - NA, Europe, Latin America, Africa, Asia Pacific
 - Cooperate(?) as the Numbers Resource Organization
- Private IP Addresses
 - 10.0.0.0 → 10.255.255.255, some others



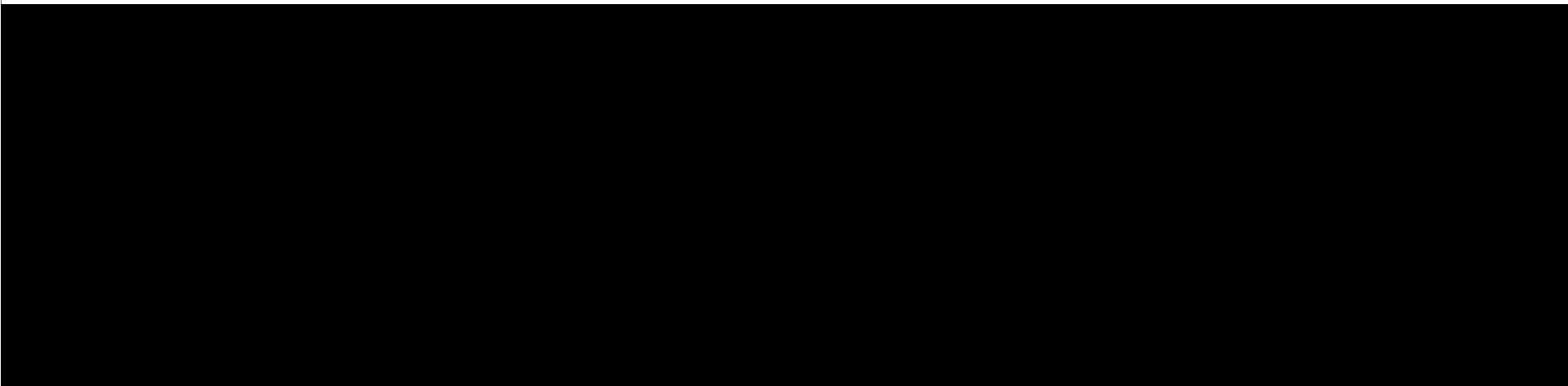
3	General Electric Company	32	AT&T Global Network Services
4	Level 3 Communications, Inc.	33	DLA Systems Automation Center
6	Army Information Systems Center	34	Halliburton Company
8	Level 3 Communications, Inc.	35	MERIT Computer Network
9	IBM	38	Performance Systems International
11	DoD Intel Information Systems	40	Eli Lilly & Company
12	AT&T Bell Laboratories	45	Interop Show Network
13	Xerox Corporation	47	Bell-Northern Research
15	Hewlett-Packard Company	48	Prudential Securities Inc.
16	Digital Equipment Corporation	52	E.I. duPont de Nemours and Co., Inc.
17	Apple Computer Inc.	53	Cap Debis CCS
18	MIT	54	Merck and Co., Inc.
19	Ford Motor Company	55	DoD Network Information Center
20	Computer Sciences Corporation	56	US Postal Service
22	Defense Information Systems Agency	...	
26	Defense Information Systems Agency		
29	Defense Information Systems Agency		
30	Defense Information Systems Agency		

Millions of Computers → > 100,000 Networks → <10,000 ISP's → Dozens of backbones & Exchange Points



Information Flows over MANY Paths

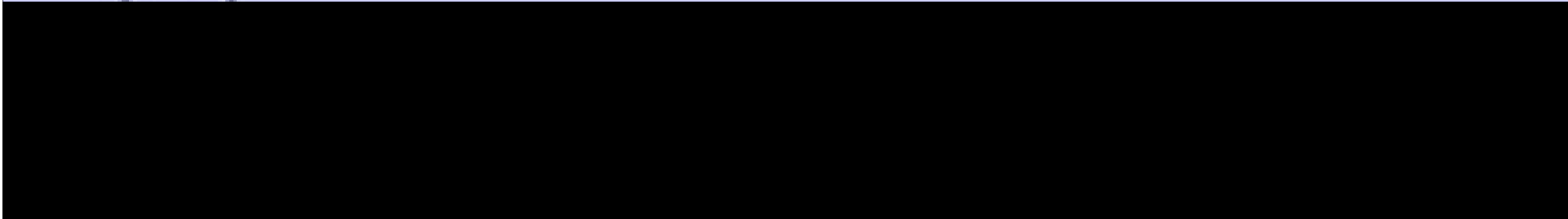
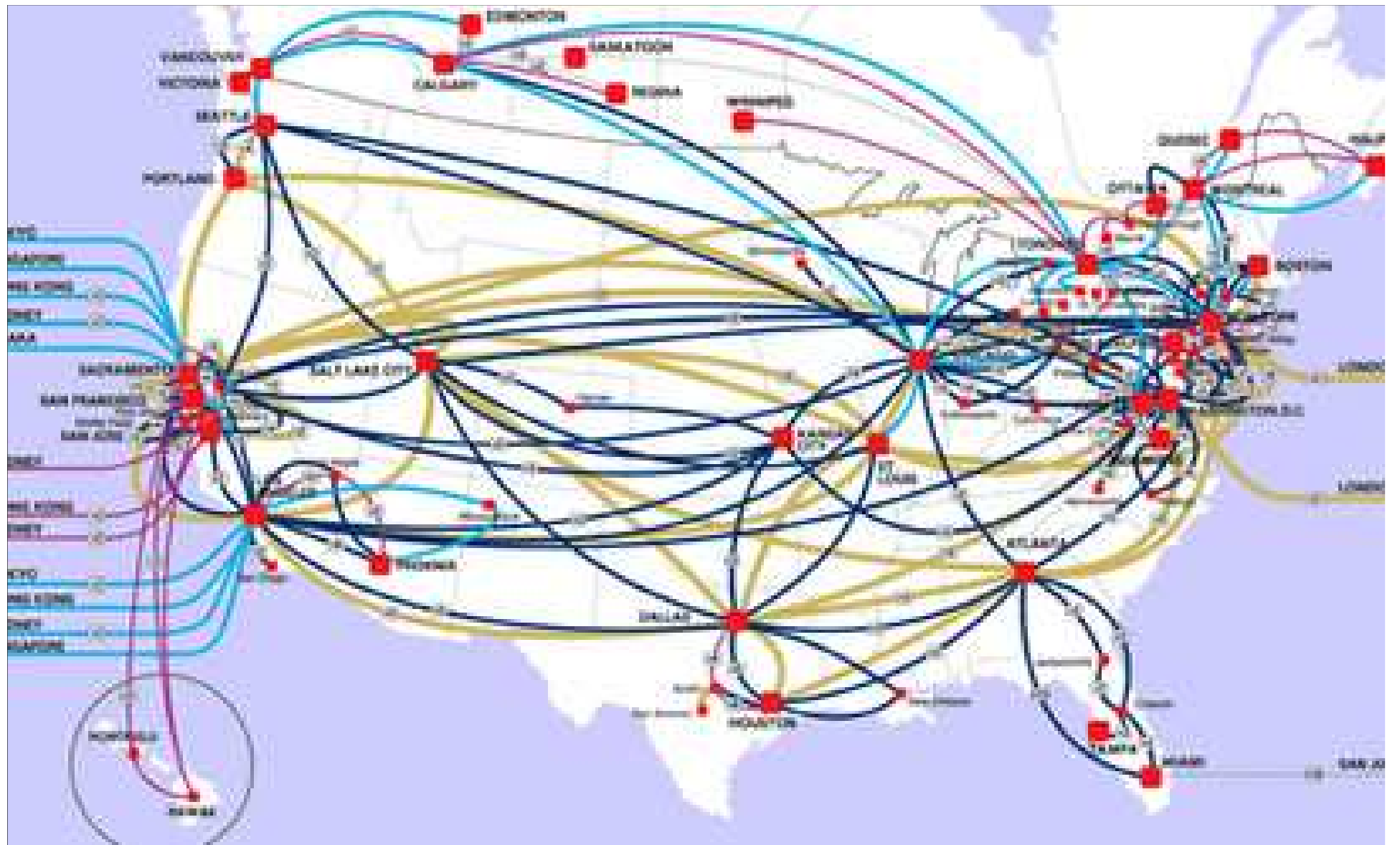
Copyright Russ Haynal
<http://navigators.com>



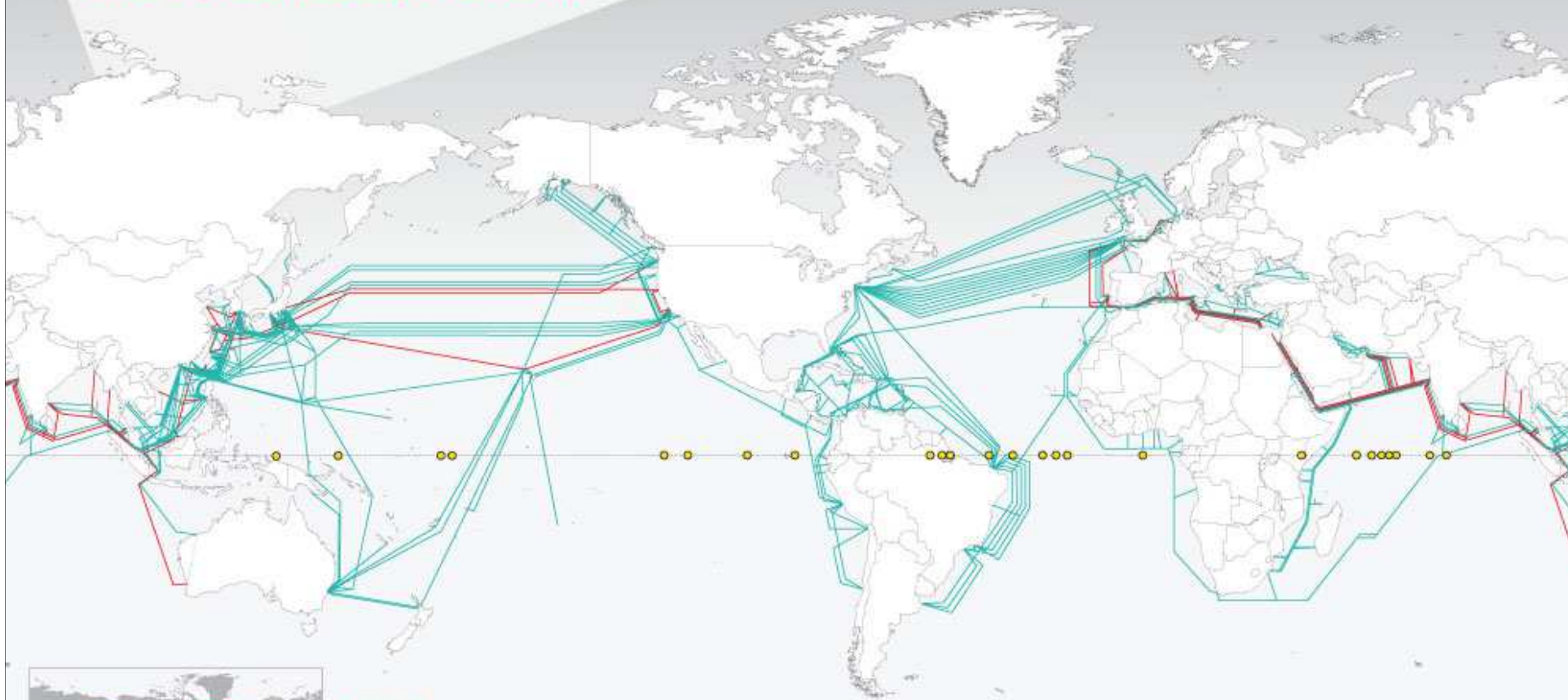


- OC192
- OC48
- OC12
- DS3





The Verizon Global Network

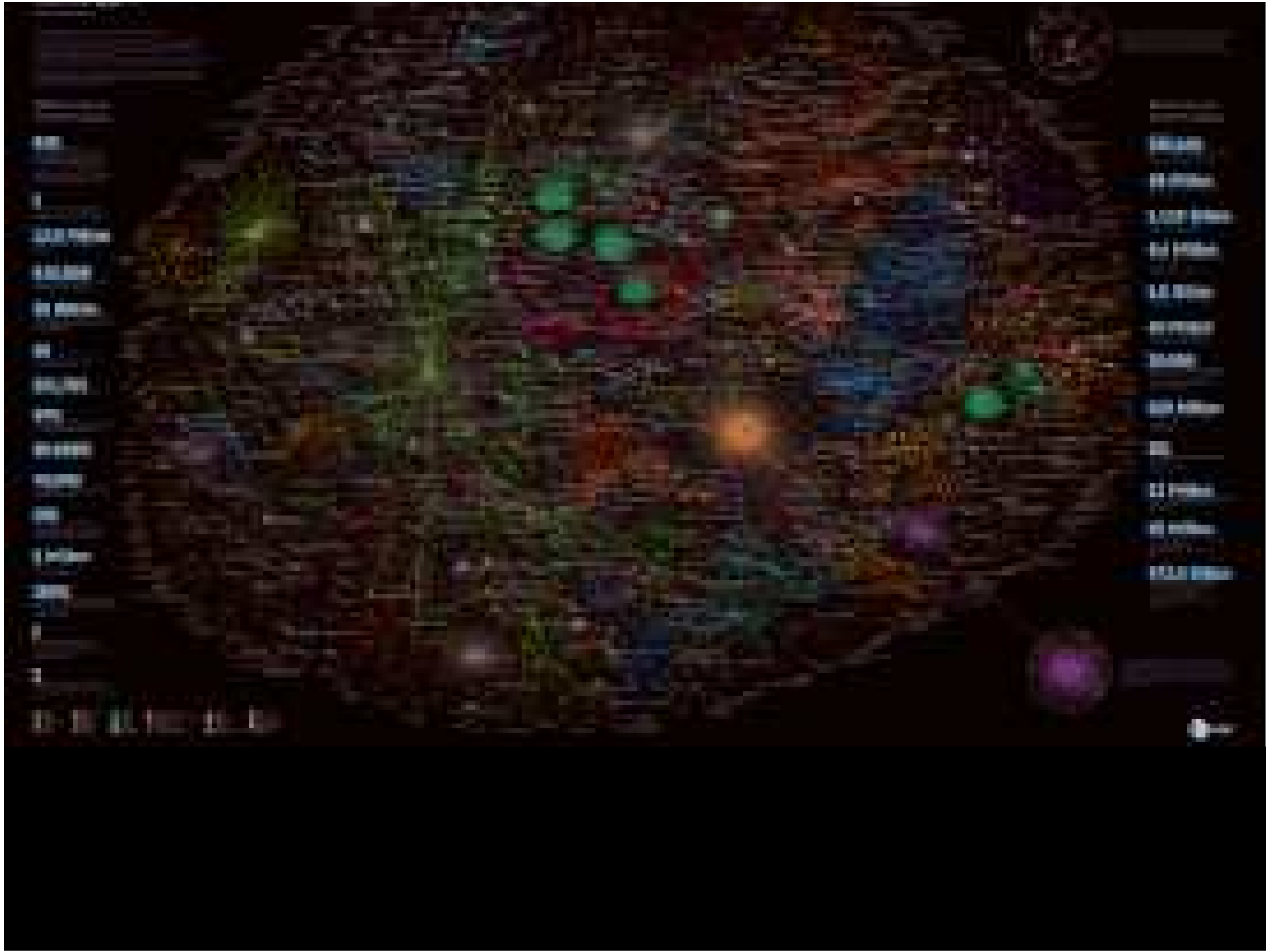


Legend

- Other Submarine Cables
- Next Generation Submarine Cables
- Satellites
- Verizon Global MESH



- G block



```
Y:\>tracert westwood.k12.ma.us
```

```
Tracing route to westwood.k12.ma.us [71.245.232.36]  
over a maximum of 30 hops:
```

1	12 ms	12 ms	11 ms	bd11.nwt-ubr3.sbo-nwt.ma.cable.rcn.net [10.20.216.1]
2	123 ms	54 ms	34 ms	vl200.aggr1.sbo.ma.rcn.net [209.6.160.100]
3	12 ms	14 ms	16 ms	vl131.border1.sbo.ma.rcn.net [207.172.15.132]
4	12 ms	14 ms	17 ms	xe-10-3-0.bar2.Boston1.Level3.net [4.53.50.13]
5	17 ms	20 ms	21 ms	ae-8-8.ebr1.NewYork1.Level3.net [4.69.140.98]
6	33 ms	31 ms	35 ms	ae-71-71.csw2.NewYork1.Level3.net [4.69.134.70]
7	23 ms	18 ms	17 ms	ae-2-79.edge2.NewYork2.Level3.net [4.68.16.76]
8	18 ms	18 ms	17 ms	mci-level3-xe.newyork2.Level3.net [4.68.110.234]
9	16 ms	18 ms	17 ms	0.xe-5-0-1.XL4.NYC4.ALTER.NET [152.63.3.121]
10	25 ms	28 ms	26 ms	0.so-7-0-0.XL2.BOS4.ALTER.NET [152.63.0.221]
11	26 ms	27 ms	25 ms	0.so-7-3-0.BOS-BB-RTR2.verizon-gni.net [152.63.16.142]
12	27 ms	27 ms	28 ms	P12-0-0.LCR-04.BSTNMA.verizon-gni.net [130.81.29.171]
13	31 ms	30 ms	32 ms	mail.westwood.k12.ma.us [71.245.232.36]

```
Trace complete.
```



```
Y:\>tracert www.harvard.edu
```

```
Tracing route to hno-webprod.harvard.edu [128.103.60.28]  
over a maximum of 30 hops:
```

1	10 ms	9 ms	10 ms	bd11.nwt-ubr3.sbo-nwt.ma.cable.rcn.net [10.20.216.1]
2	19 ms	14 ms	24 ms	vl200.aggr1.sbo.ma.rcn.net [209.6.160.100]
3	12 ms	13 ms	11 ms	vl133.border1.sbo.ma.rcn.net [207.172.15.116]
4	19 ms	12 ms	12 ms	AS174.sbo.ma.rcn.net [207.172.9.14]
5	12 ms	12 ms	14 ms	te4-1.ccr01.bos05.atlas.cogentco.com [154.54.25.254]
6	220 ms	18 ms	18 ms	ospraie-management-llc.demarc.cogentco.com [38.104.7.
7	86 ms	26 ms	19 ms	coregw2-te-4-1-rcore.net.harvard.edu [128.103.0.145]
8	18 ms	19 ms	18 ms	oxgw2-te-2-3-rcore.net.harvard.edu [128.103.0.158]
9	19 ms	20 ms	28 ms	hno-webprod.harvard.edu [128.103.60.28]

```
Trace complete.
```

```
Y:\>tracert berkeley.edu
```

```
Tracing route to berkeley.edu [169.229.131.81]  
over a maximum of 30 hops:
```

1	9 ms	10 ms	9 ms	bd11.nwt-ubr3.sbo-nwt.ma.cable.rcn.net [10.20.216.1]
2	13 ms	12 ms	12 ms	vl200.aggr1.sbo.ma.rcn.net [209.6.160.100]
3	12 ms	10 ms	12 ms	vl130.core4.sbo.ma.rcn.net [207.172.15.156]
4	41 ms	41 ms	41 ms	ge1-0-0.core2.chsl.il.rcn.net [207.172.19.154]
5	130 ms	128 ms	128 ms	ge2-0.core4.sfrn.ca.rcn.net [207.172.19.125]
6	99 ms	104 ms	99 ms	ge6-2.border3.sfrn.ca.rcn.net [208.59.255.27]
7	99 ms	98 ms	98 ms	calren-cenic.paix.net [198.32.176.33]
8	102 ms	108 ms	108 ms	dc-oak-core1--paix-px1-ge.cenic.net [137.164.47.19]
9	*	110 ms	112 ms	dc-oak-aggr2--oak-core1-ge-2.cenic.net [137.164.46.64]
10	105 ms	107 ms	106 ms	ucb--oak-dc2-ge.cenic.net [137.164.23.30]
11	101 ms	101 ms	107 ms	t2-3.inr-202-reccev.Berkeley.EDU [128.32.0.39]
12	104 ms	119 ms	100 ms	t1-1.inr-211-srb.Berkeley.EDU [128.32.255.43]
13	106 ms	109 ms	106 ms	webfarm.Berkeley.EDU [169.229.131.81]

```
Trace complete.
```

```
Y:\>tracert bbc.co.uk
```

```
Tracing route to bbc.co.uk [212.58.224.138]  
over a maximum of 30 hops:
```

1	15 ms	11 ms	9 ms	bd11.nwt-ubr3.sbo-nwt.ma.cable.rcn.net [10.20.216.1]
2	13 ms	14 ms	14 ms	vl200.aggr1.sbo.ma.rcn.net [209.6.160.100]
3	25 ms	14 ms	12 ms	ge3-1.core2.sbo.ma.rcn.net [207.172.15.98]
4	31 ms	31 ms	19 ms	pos5-0.core2.nyw.ny.rcn.net [207.172.19.37]
5	26 ms	20 ms	18 ms	ge5-1.core4.nyw.ny.rcn.net [207.172.19.112]
6	35 ms	*	18 ms	tge2-1.border1.nyw.ny.rcn.net [207.172.19.109]
7	91 ms	90 ms	90 ms	83.245.126.93
8	136 ms	96 ms	101 ms	212.58.238.129
9	90 ms	87 ms	91 ms	virtual-vip.thdo.bbc.co.uk [212.58.224.138]

```
Trace complete.
```

```
Y:\>tracert www.unsw.edu.au
```

```
Tracing route to cws2-7.admin.unsw.edu.au [149.171.96.158]  
over a maximum of 30 hops:
```

1	9 ms	9 ms	9 ms	bd11.nwt-ubr3.sbo-nwt.ma.cable.rcn.net [10.20.216.1]
2	429 ms	27 ms	399 ms	vl200.aggr1.sbo.ma.rcn.net [209.6.160.100]
3	19 ms	12 ms	12 ms	ge4-0.core3.sbo.ma.rcn.net [207.172.15.147]
4	22 ms	*	17 ms	pos5-0.core3.nyw.ny.rcn.net [207.172.19.5]
5	*	19 ms	20 ms	pos5-0.core2.phd1.pa.rcn.net [207.172.19.10]
6	25 ms	30 ms	37 ms	pos5-0.core3.lnh.md.rcn.net [207.172.19.21]
7	25 ms	23 ms	25 ms	ge6-1.core4.lnh.md.rcn.net [207.172.19.194]
8	27 ms	25 ms	25 ms	tge2-4.border1.eqnx.va.rcn.net [207.172.19.205]
9	24 ms	24 ms	25 ms	207.172.9.66
10	26 ms	26 ms	25 ms	64.125.31.209
11	27 ms	34 ms	27 ms	ge-3-3-0.mpr2.dca2.us.above.net [64.125.27.30]
12	70 ms	71 ms	67 ms	so-1-0-0.mpr4.iah1.us.above.net [64.125.28.50]
13	87 ms	90 ms	89 ms	so-1-1-0.mpr4.lax9.us.above.net [64.125.25.18]
14	96 ms	103 ms	100 ms	64.124.200.234
15	257 ms	247 ms	246 ms	so-4-0-0.bb1.b.syd.aarnet.net.au [202.158.194.157]
16	256 ms	250 ms	250 ms	ge-1-1-3.bb1.a.syd.aarnet.net.au [202.158.202.161]
17	269 ms	255 ms	249 ms	gigabitethernet0.er1.unsw.cpe.aarnet.net.au [202.158.
18	279 ms	246 ms	244 ms	gw1.er1.unsw.cpe.aarnet.net.au [202.158.202.234]
19	248 ms	250 ms	259 ms	te-1-1.ombcr1.gw.unsw.edu.au [149.171.255.106]
20	251 ms	246 ms	245 ms	te-1-2.libdcdr1.gw.unsw.edu.au [149.171.255.122]
21	*	*	*	Request timed out.
22	*	*	*	Request timed out.
23	^C			

- D,H block

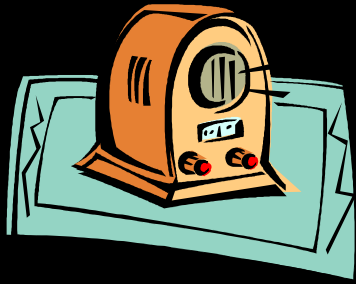
Transport Layer

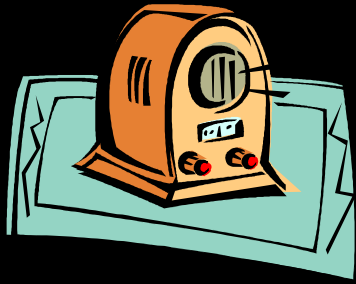
7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

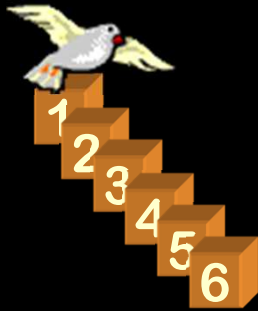
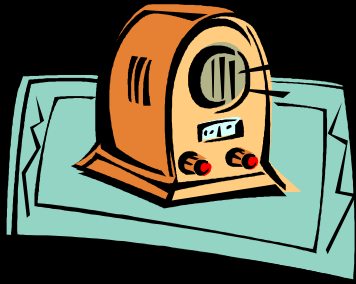
Transfer data
efficiently and error-
free between logical
endpoints

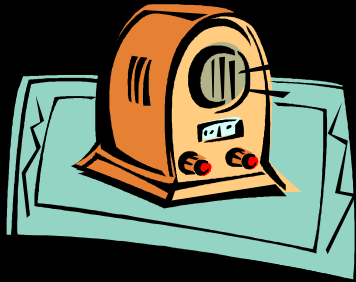
IP Address + Port

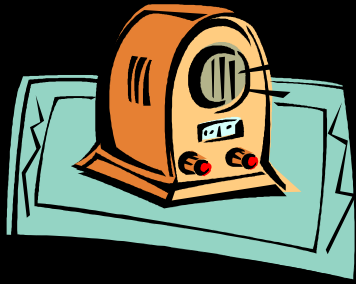
TCP, UDP, RTP,
SCMP, ...

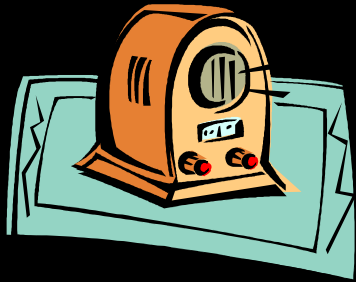


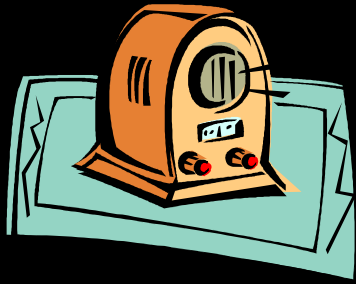


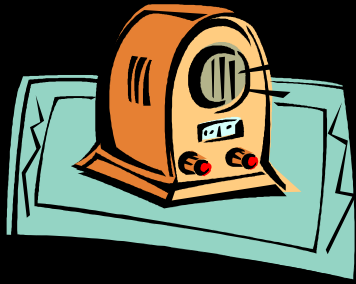


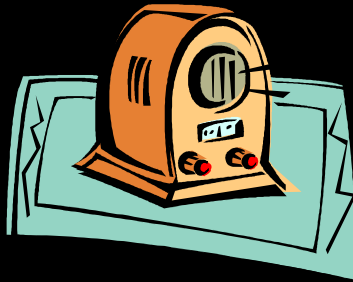












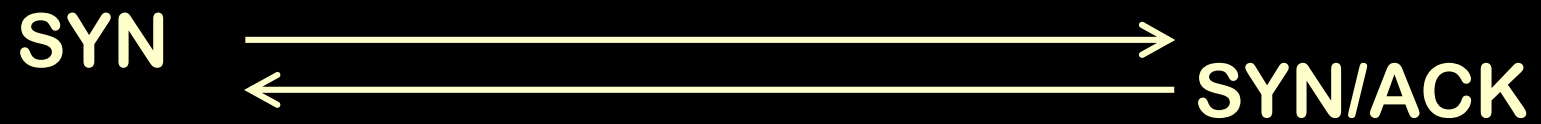
Got #6, missing #3

TCP Transmission

TCP Transmission

SYN →

TCP Transmission



TCP Transmission



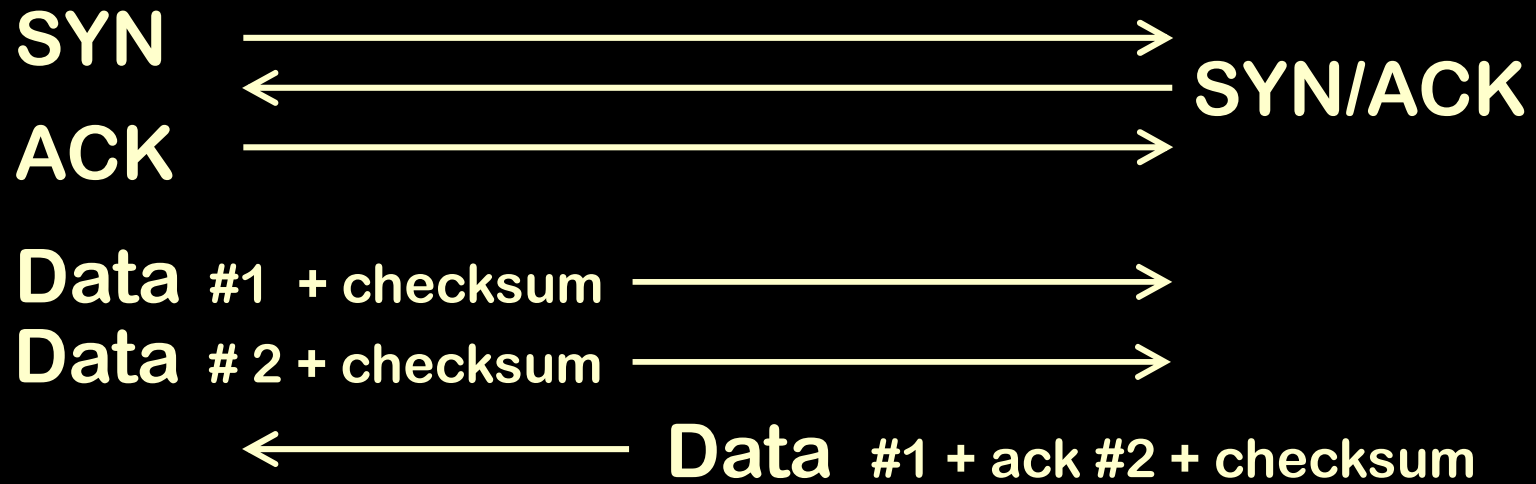
TCP Transmission



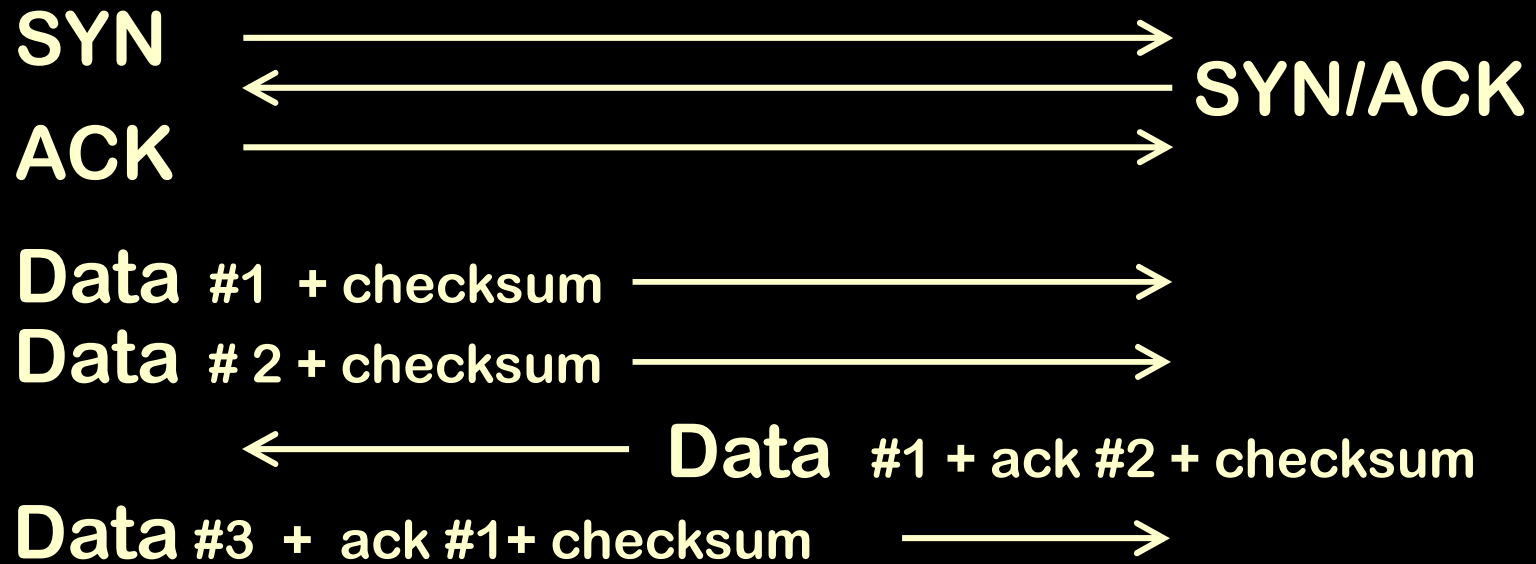
TCP Transmission



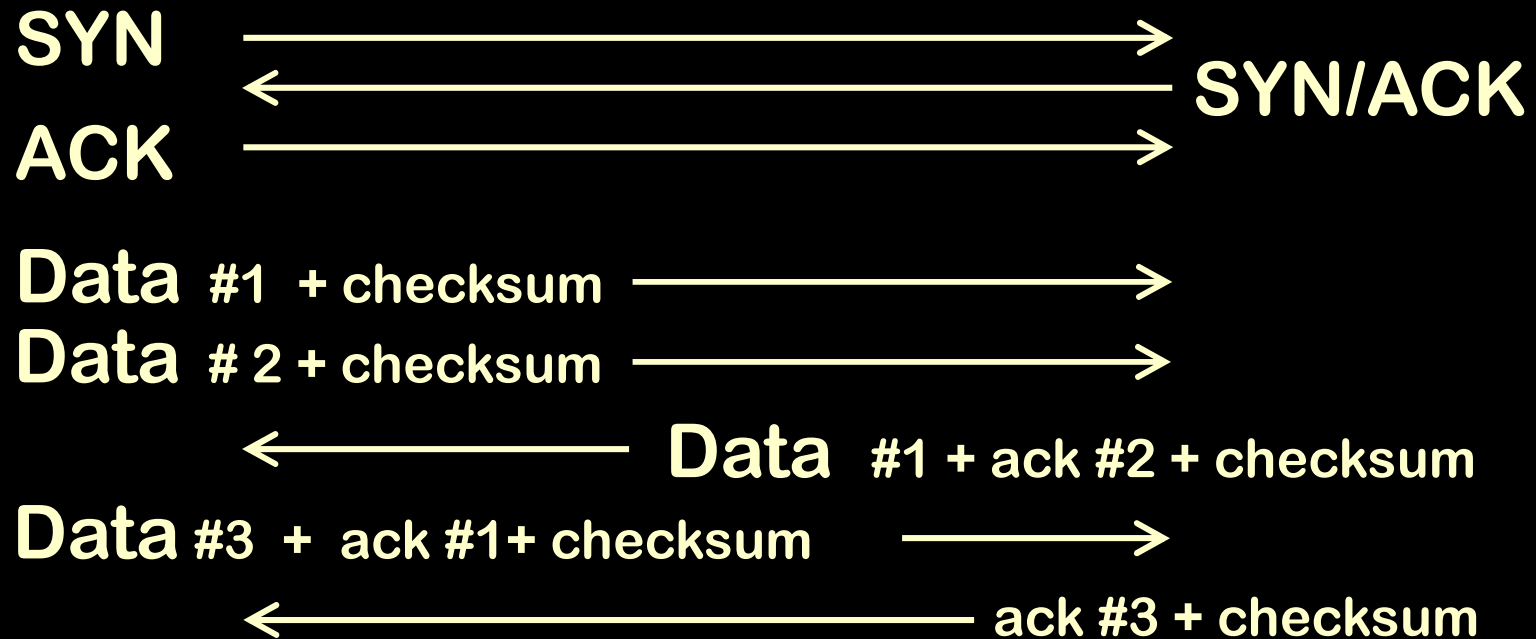
TCP Transmission



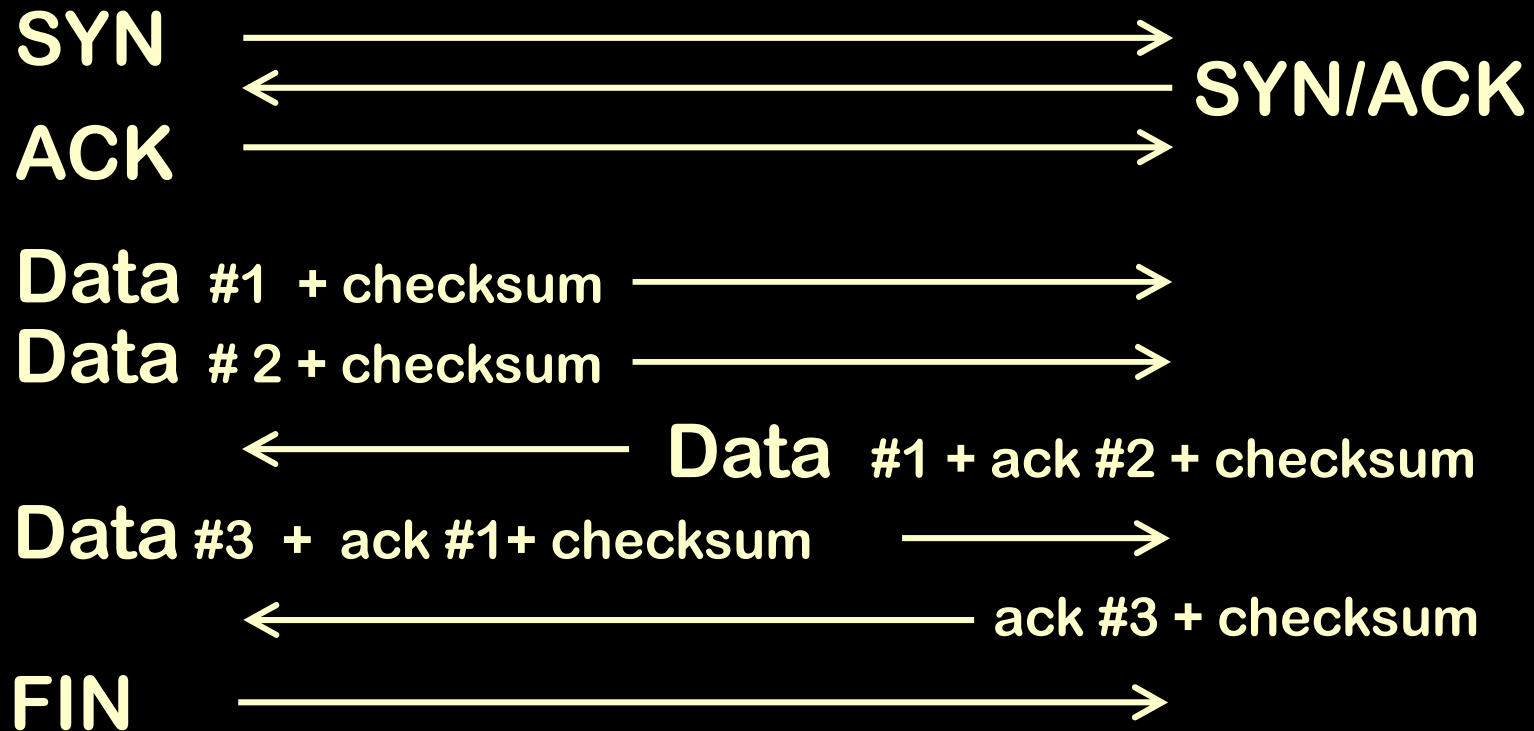
TCP Transmission



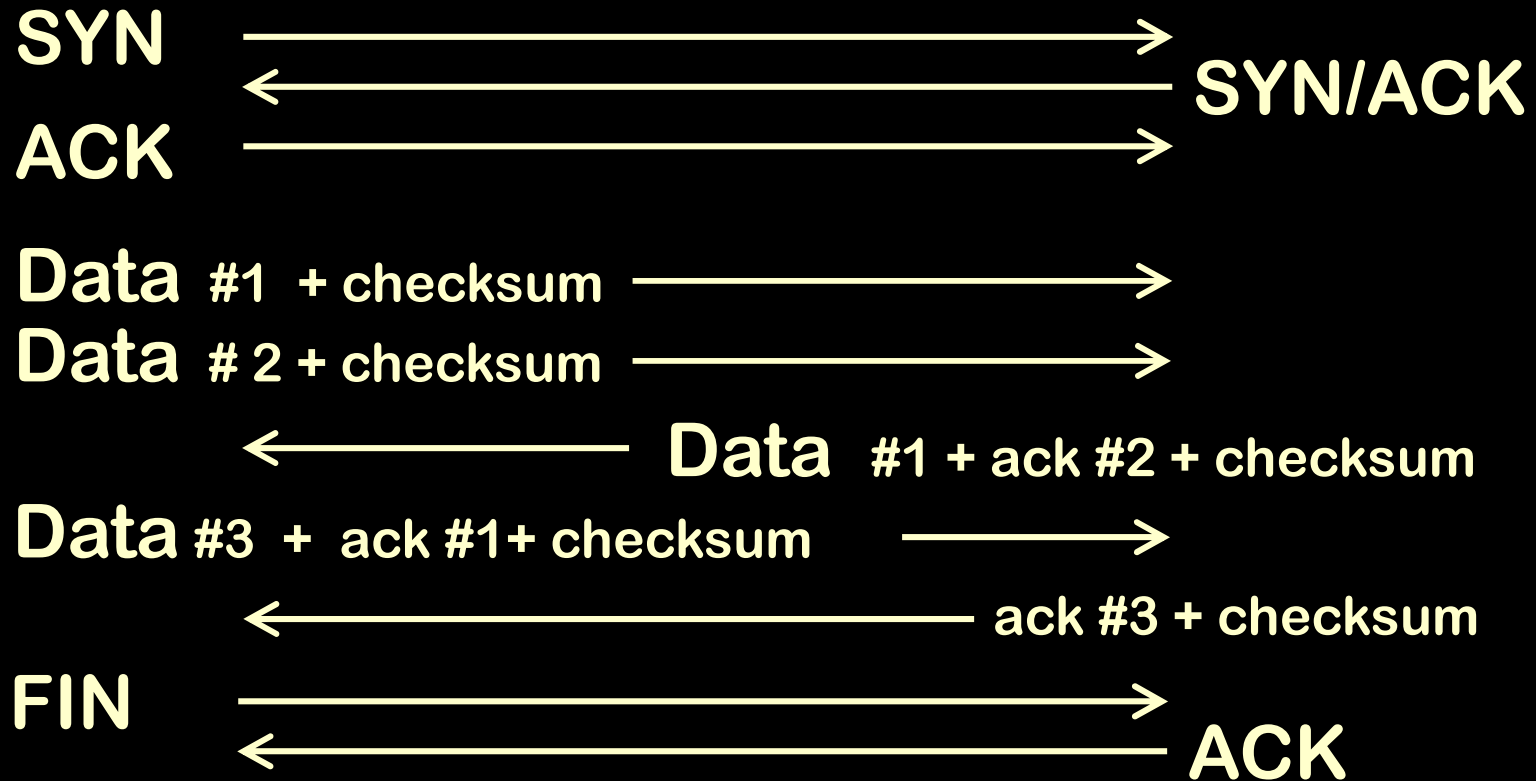
TCP Transmission



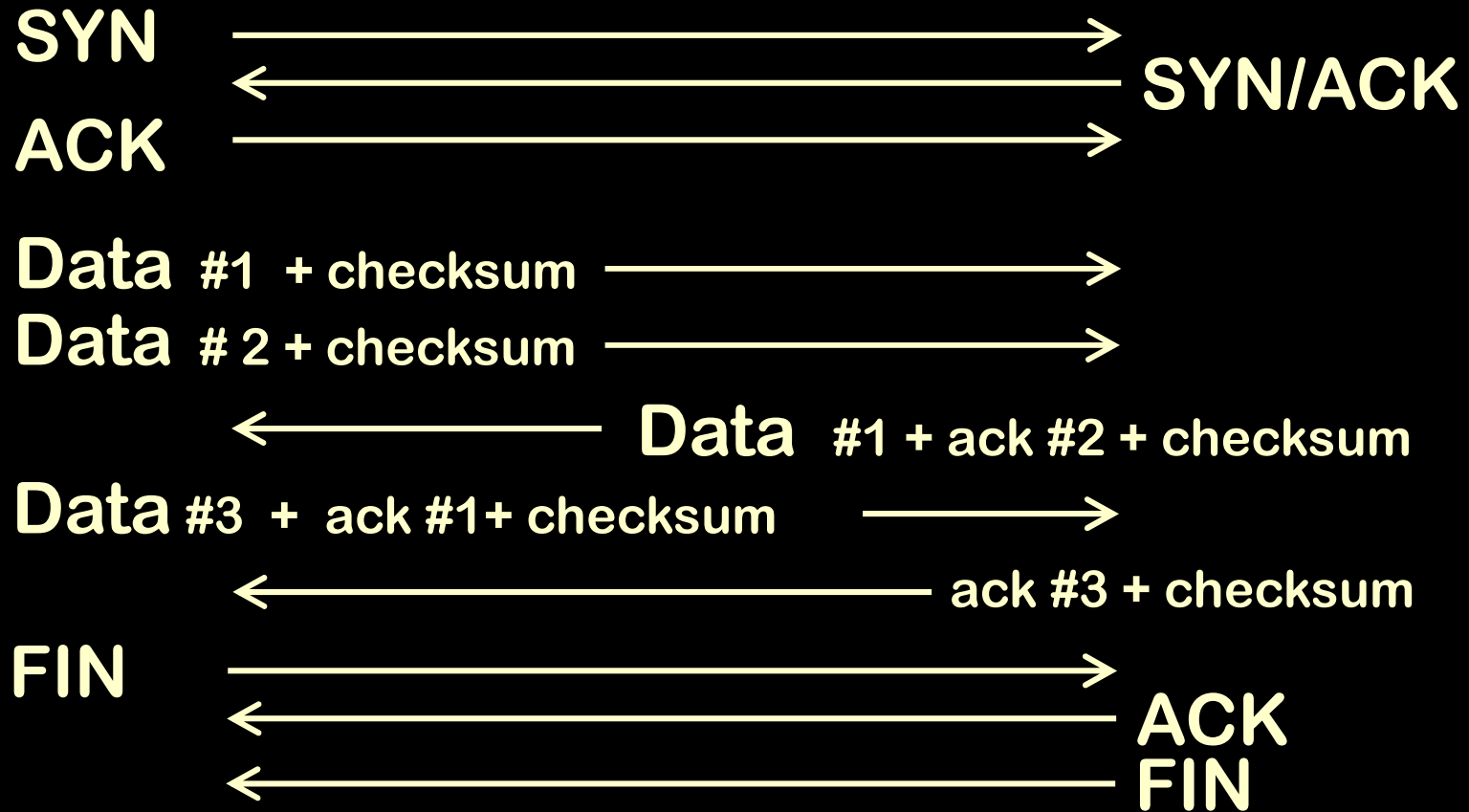
TCP Transmission



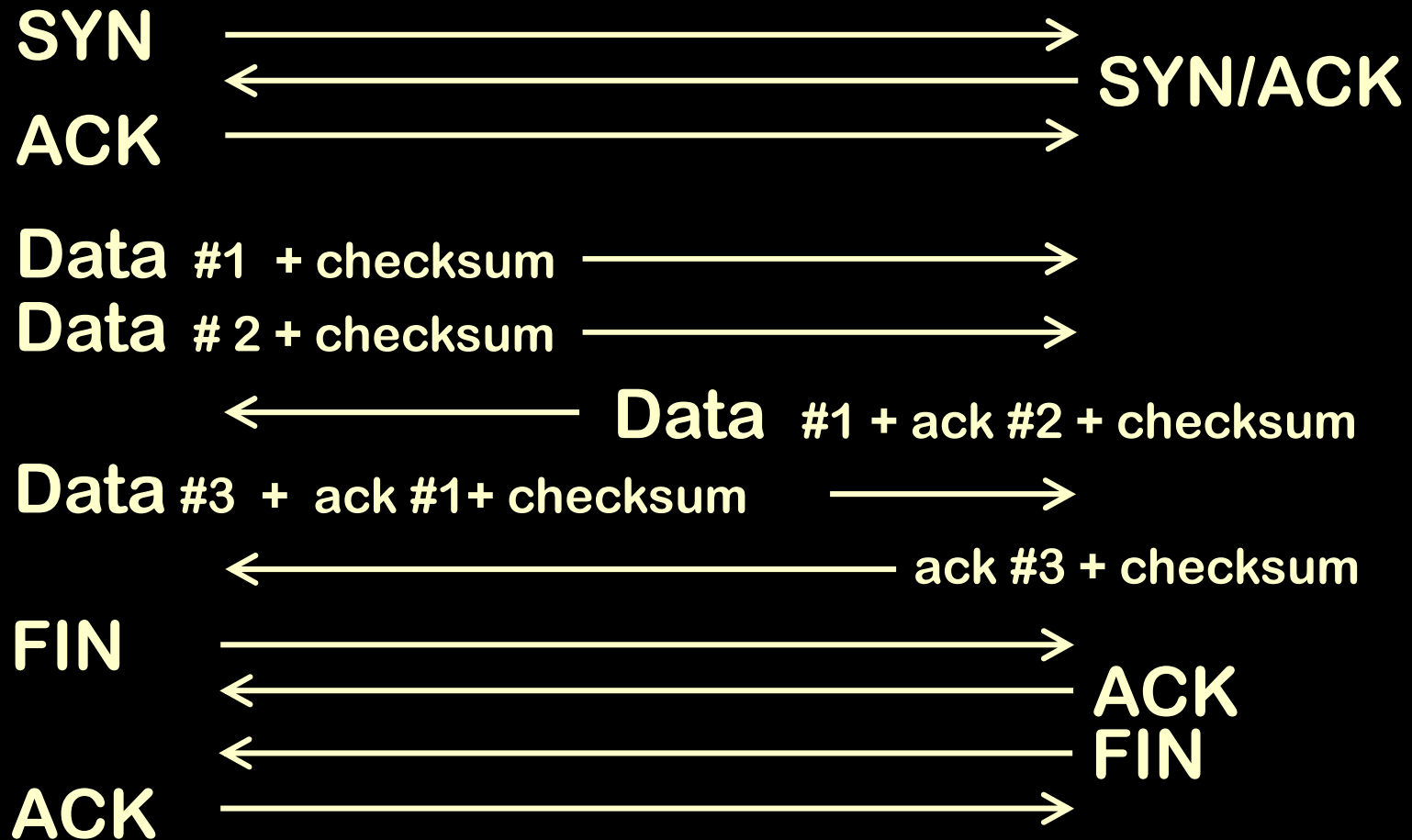
TCP Transmission



TCP Transmission



TCP Transmission



Session Layer

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Manage time two users are logically connected

TCP, SIP, SAP, NetBIOS, Named Pipes

Presentation Layer

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Defines how data is presented to user

Conversion between types may be possible

ASCII, HTML, MPEG, MIME, GIF, JPEG ...

Application Layer

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Applications (IE, Outlook, ...) talk to this layer

HTTP, FTP, SMTP, SMS, DNS, NFS, ISUP, TCAP, DNS, POP, IMAP ...

7

Application

<http://www.google.com>

7	Application
6	Presentation

GET/HTTP/1.1 www.google.com

7	Application
6	Presentation
5	Session
4	Transport

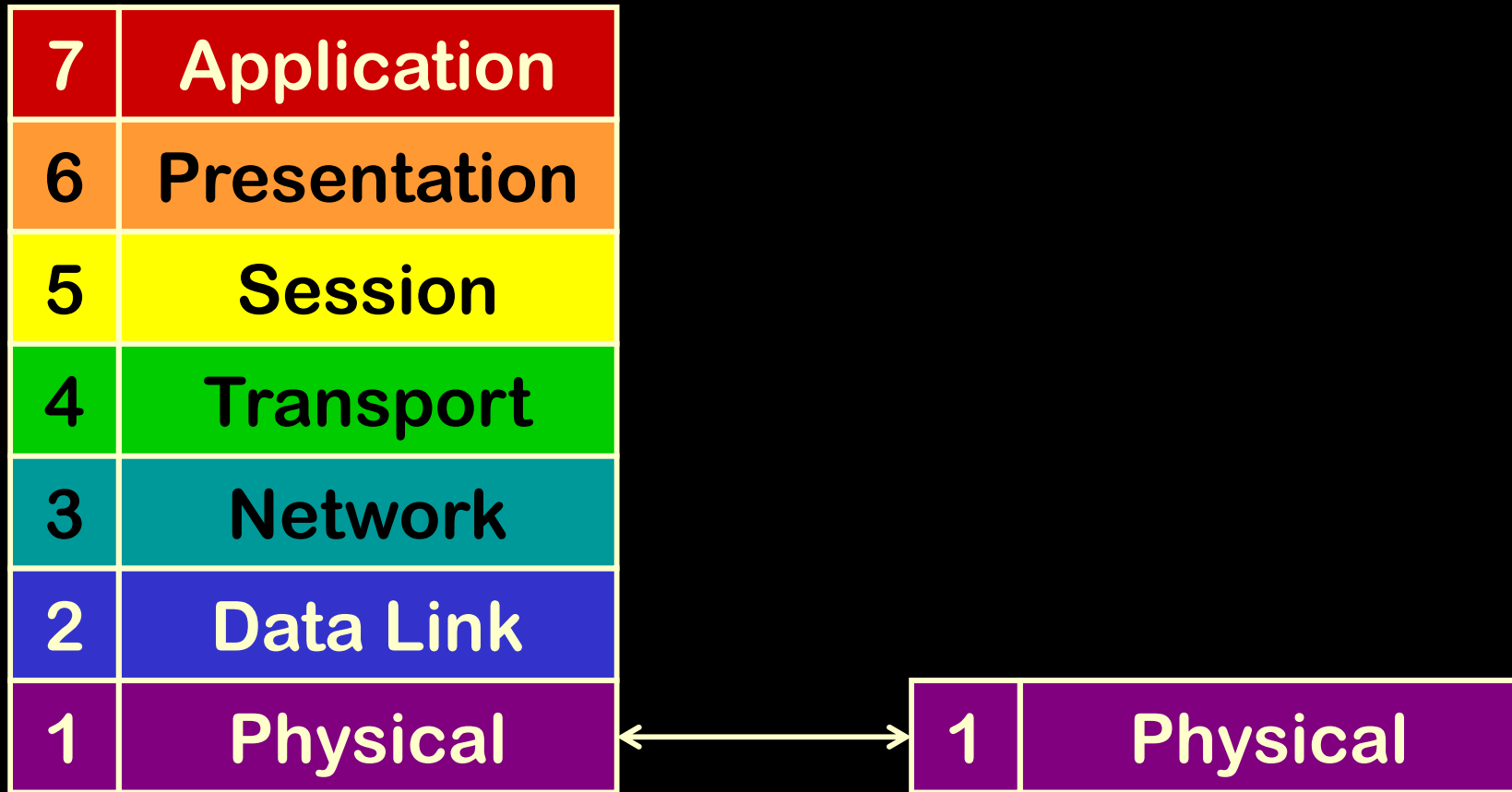
GET/HTTP/1.1 www.google.com

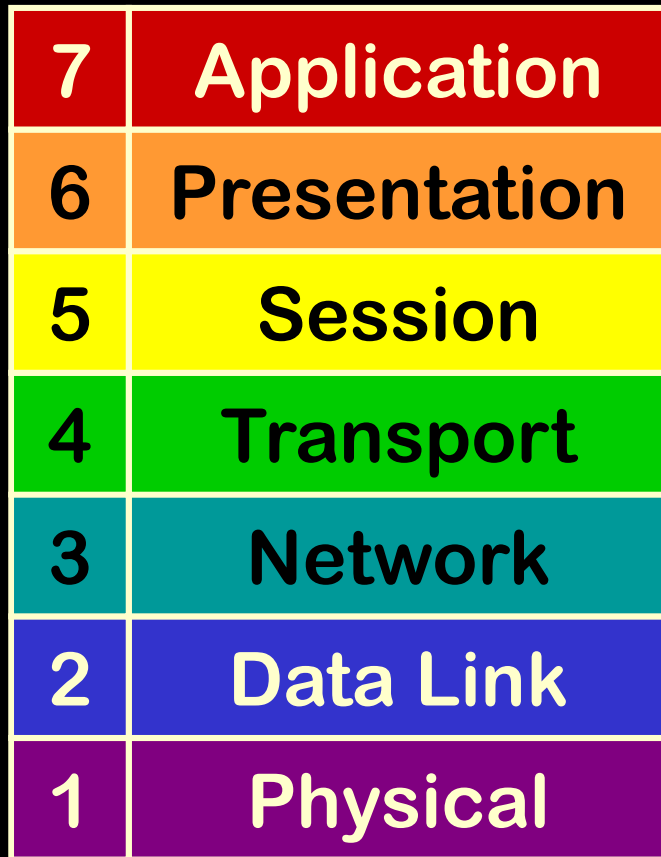
7	Application
6	Presentation
5	Session
4	Transport
3	Network

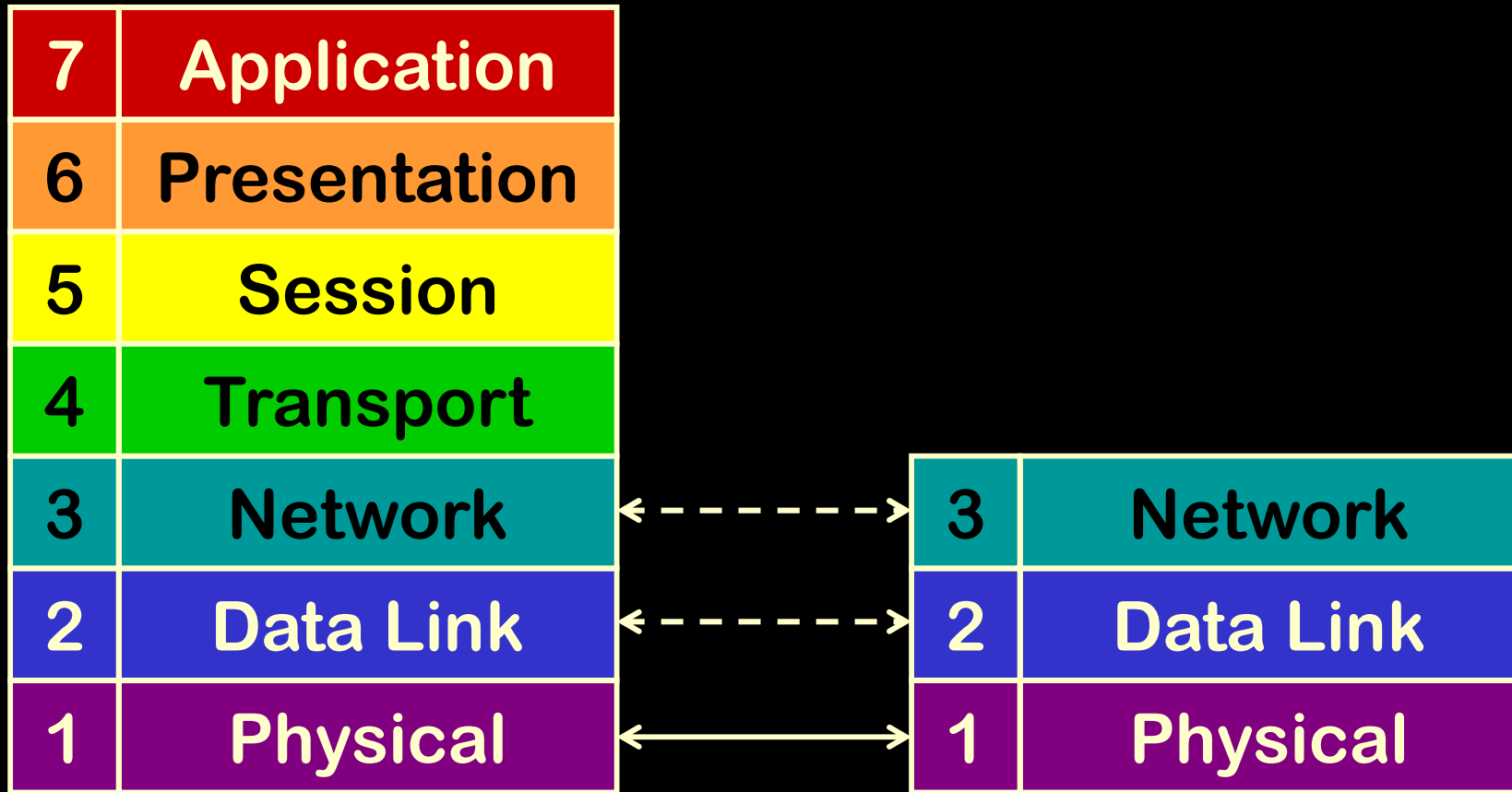
GET/HTTP/1.1 www.google.com

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link

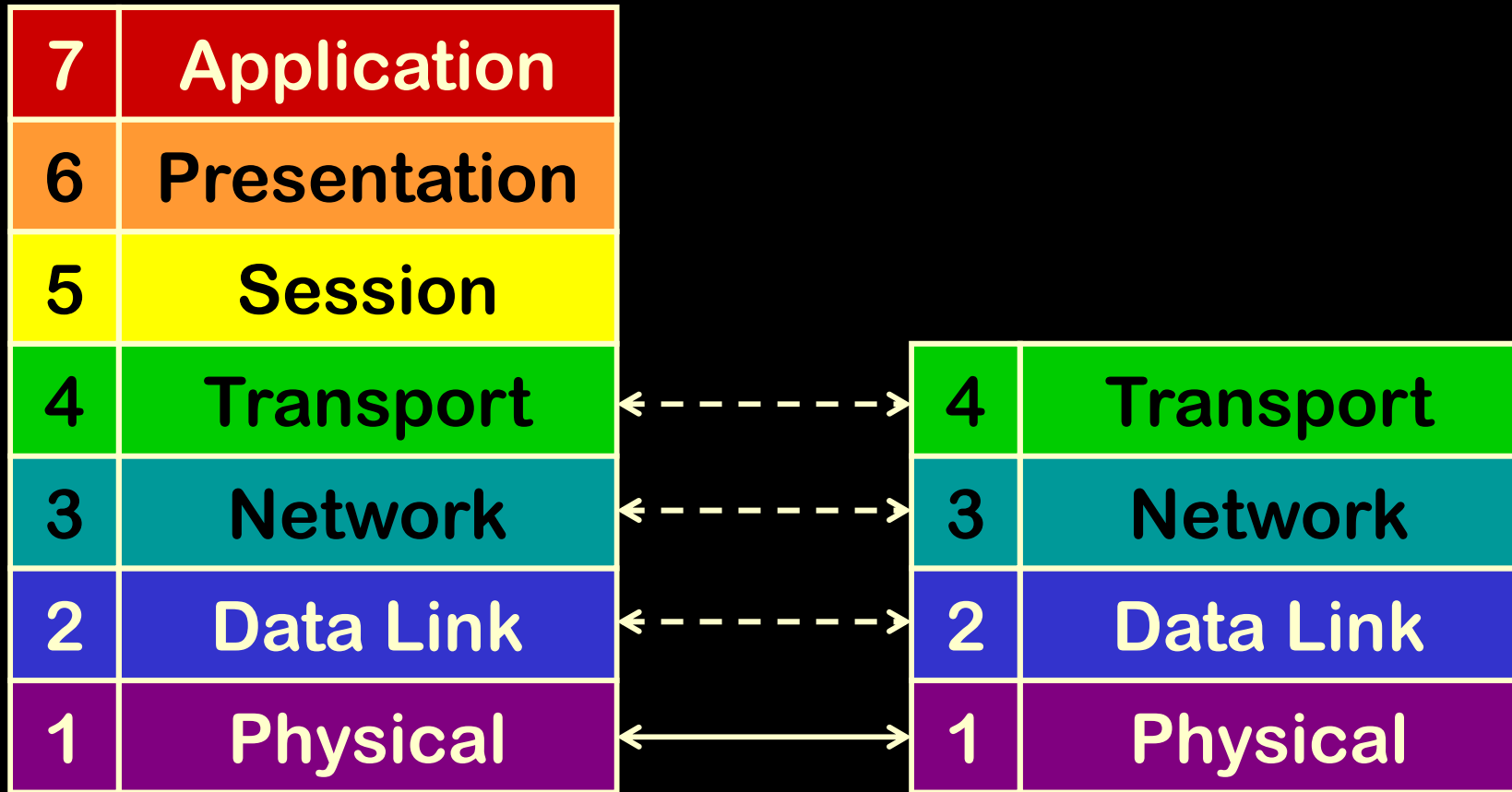




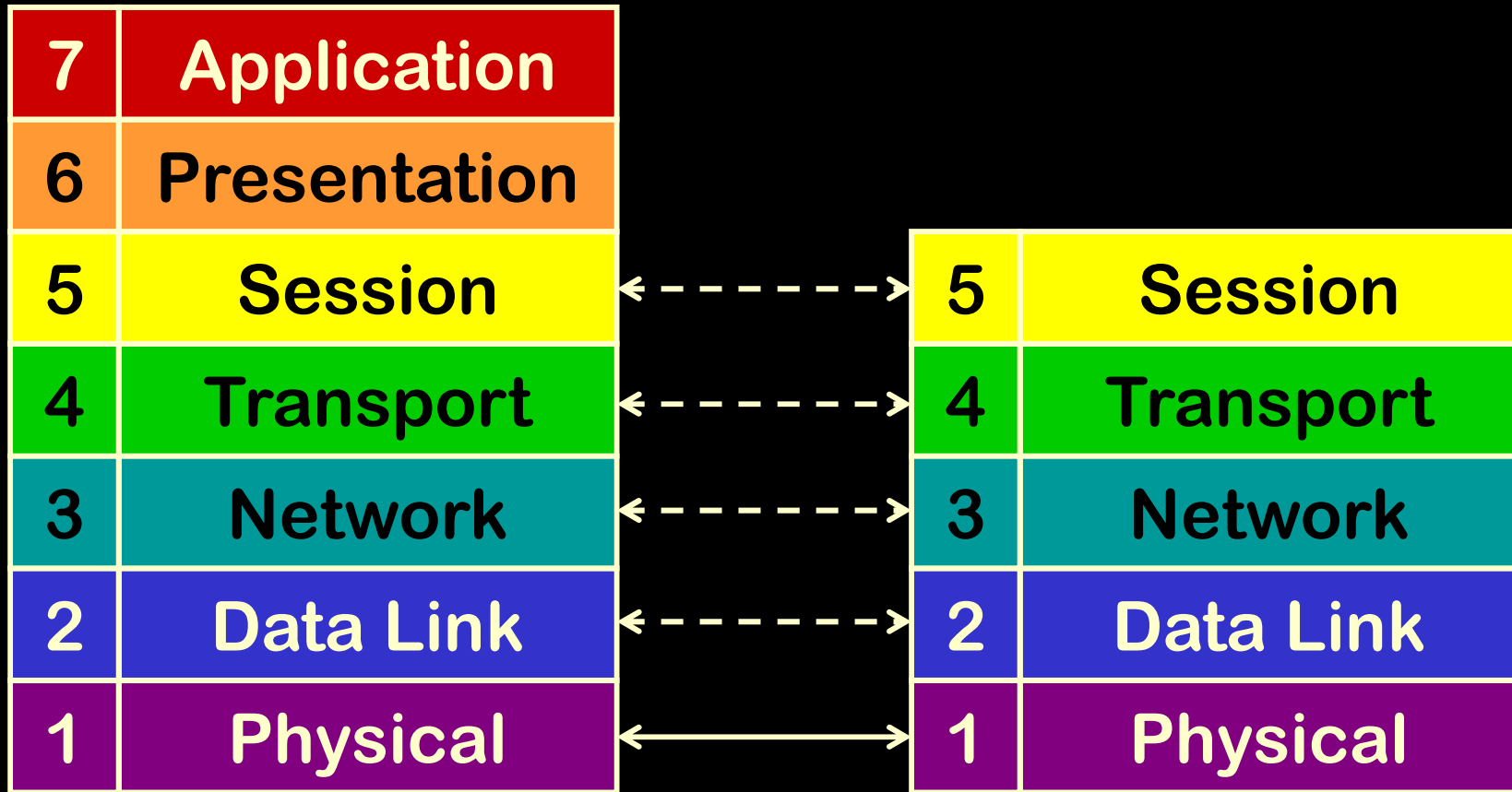




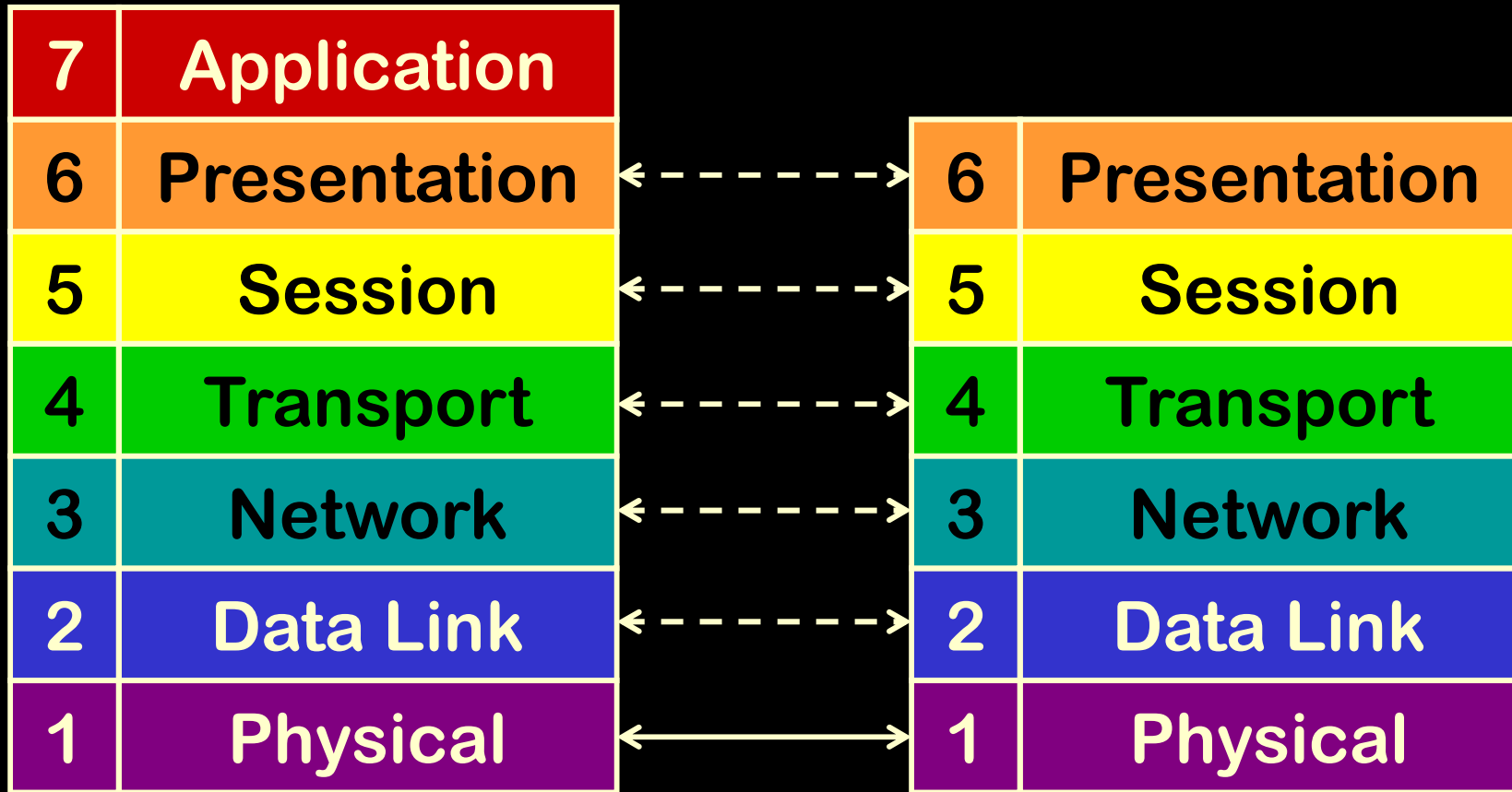
GET/HTTP/1.1 www.google.com



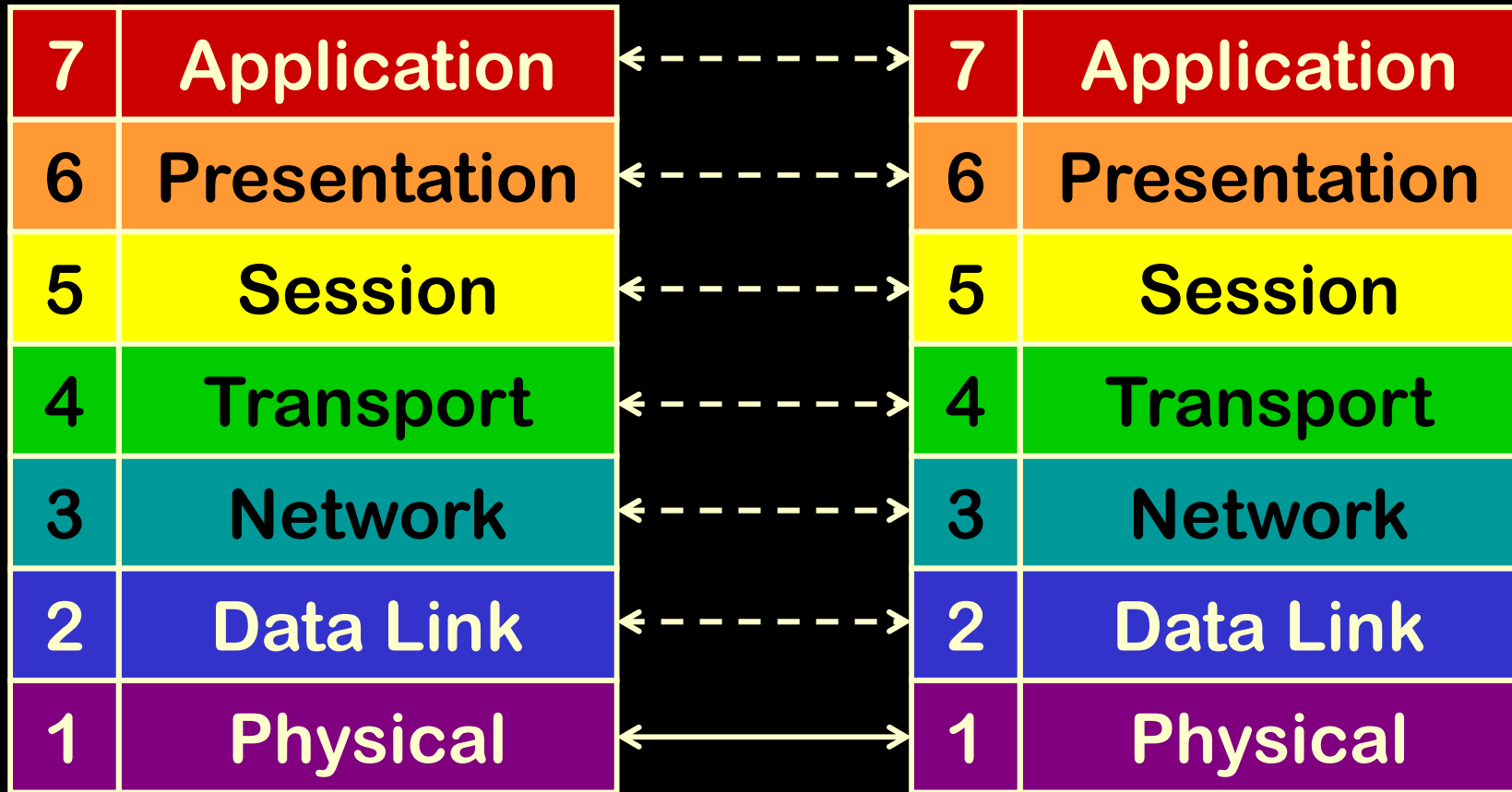
GET/HTTP/1.1 www.google.com



GET/HTTP/1.1 www.google.com



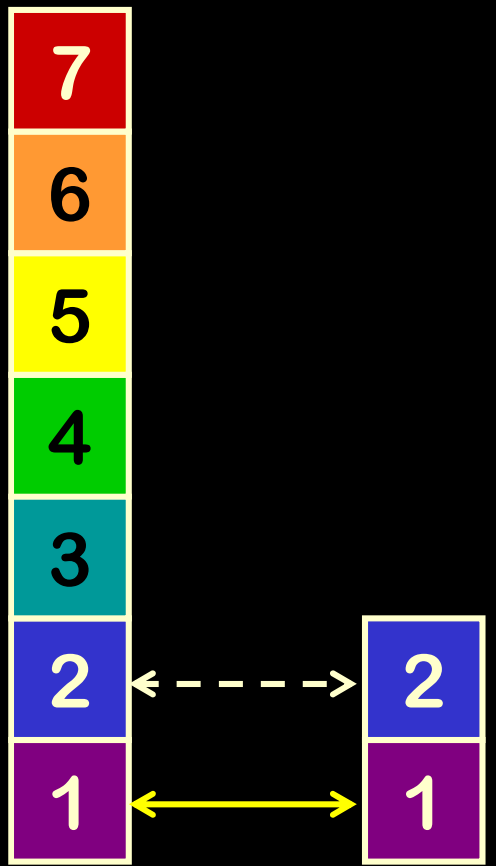
GET/HTTP/1.1 www.google.com



GET/HTTP/1.1 www.google.com

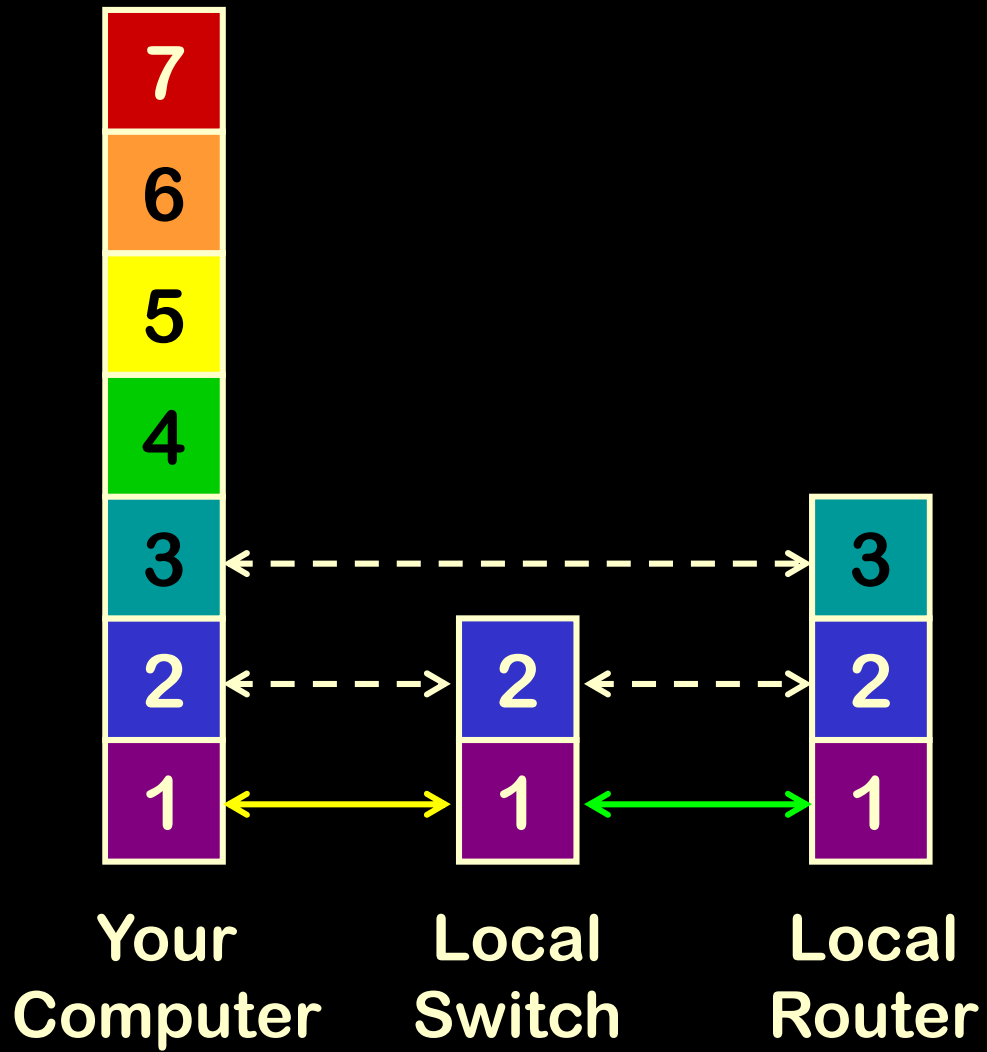


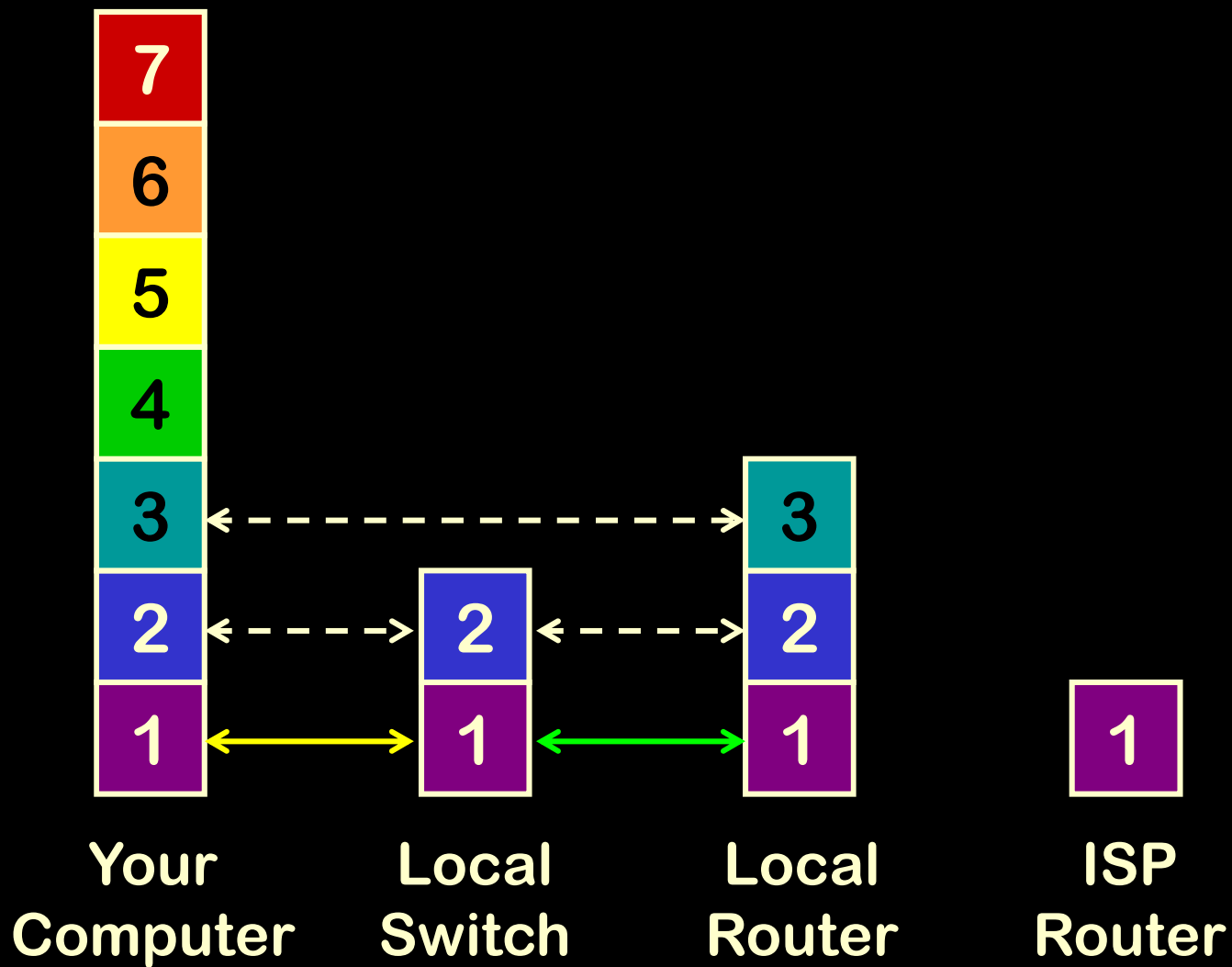
Your
Computer

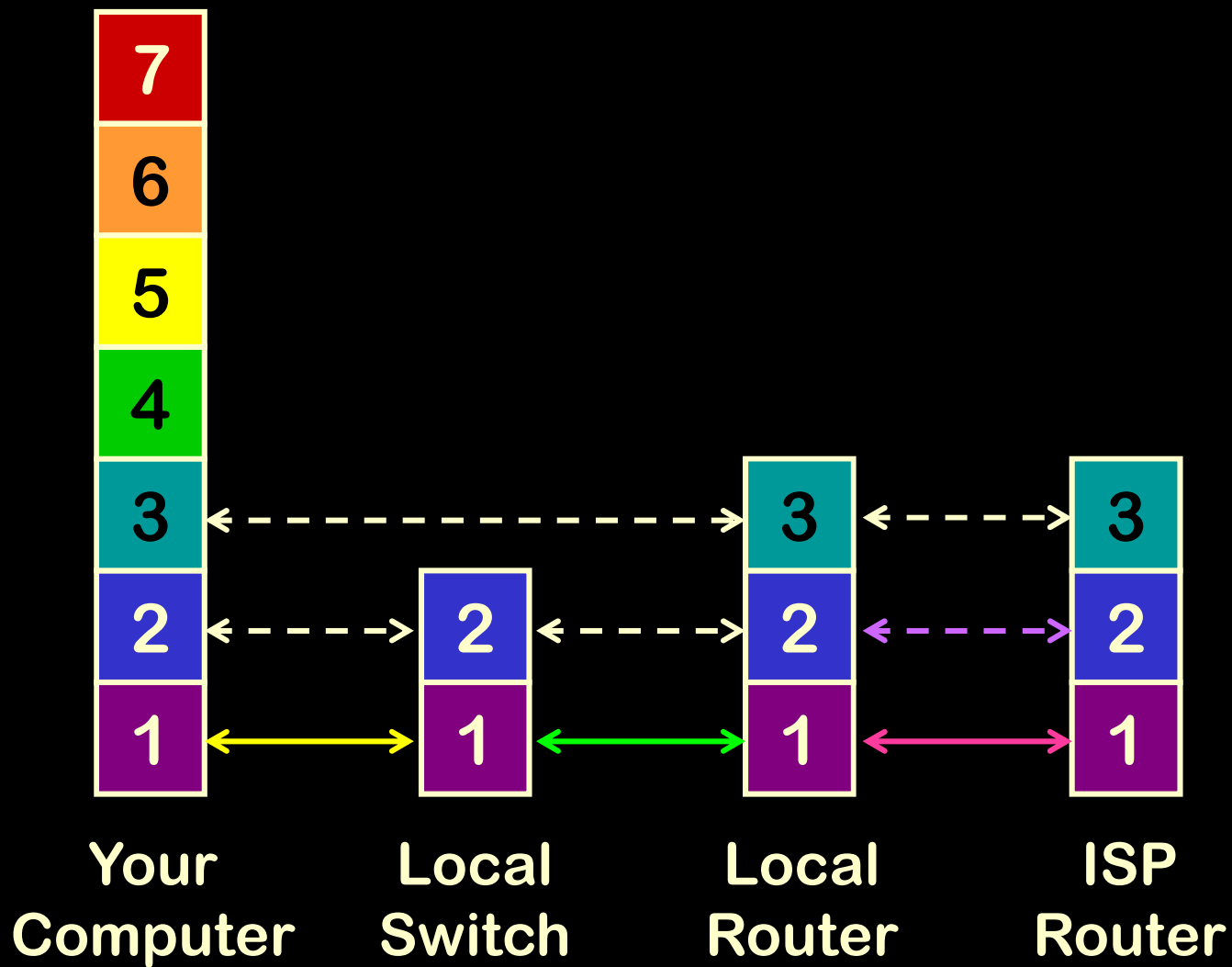


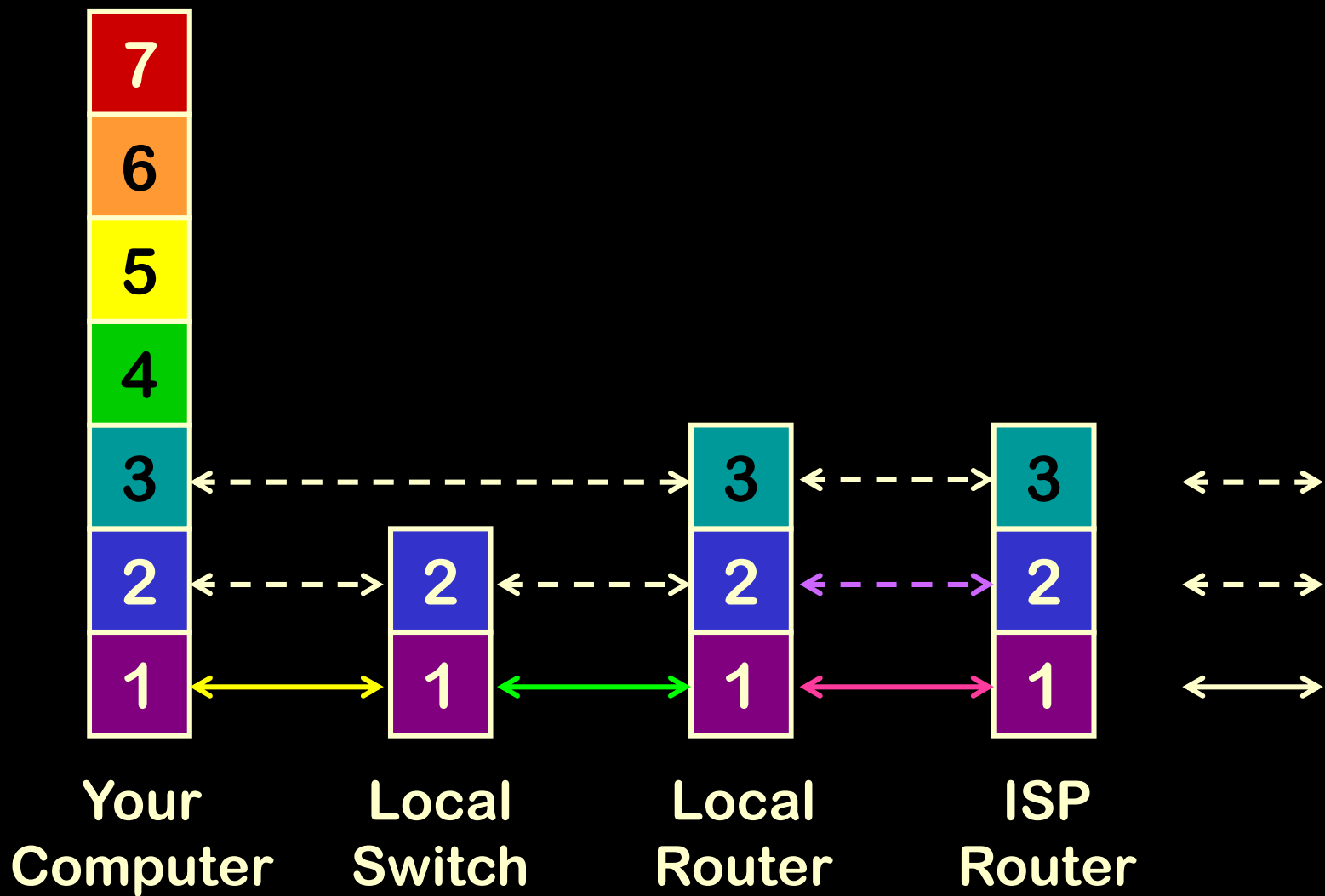
Your
Computer

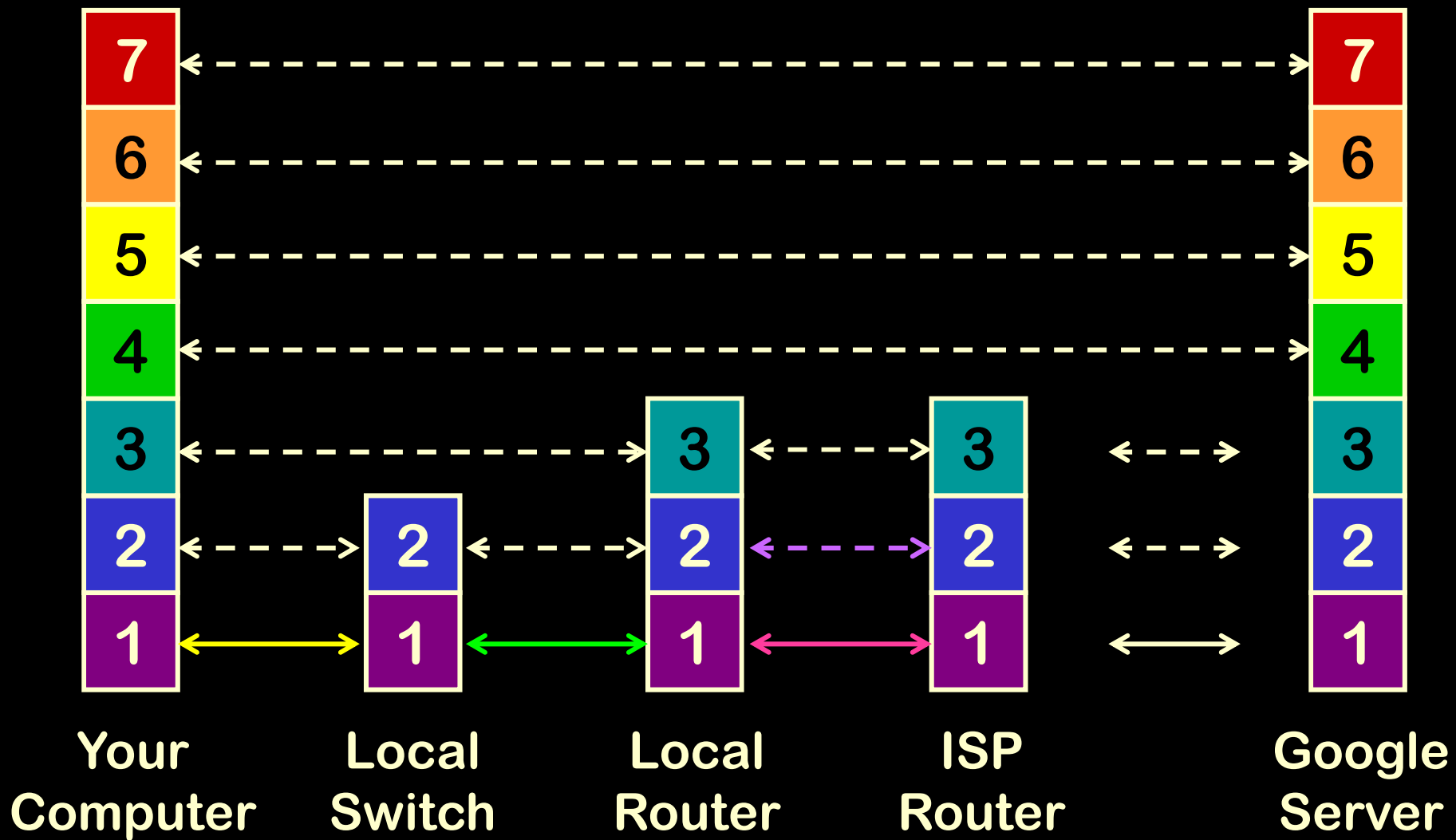
Local
Switch

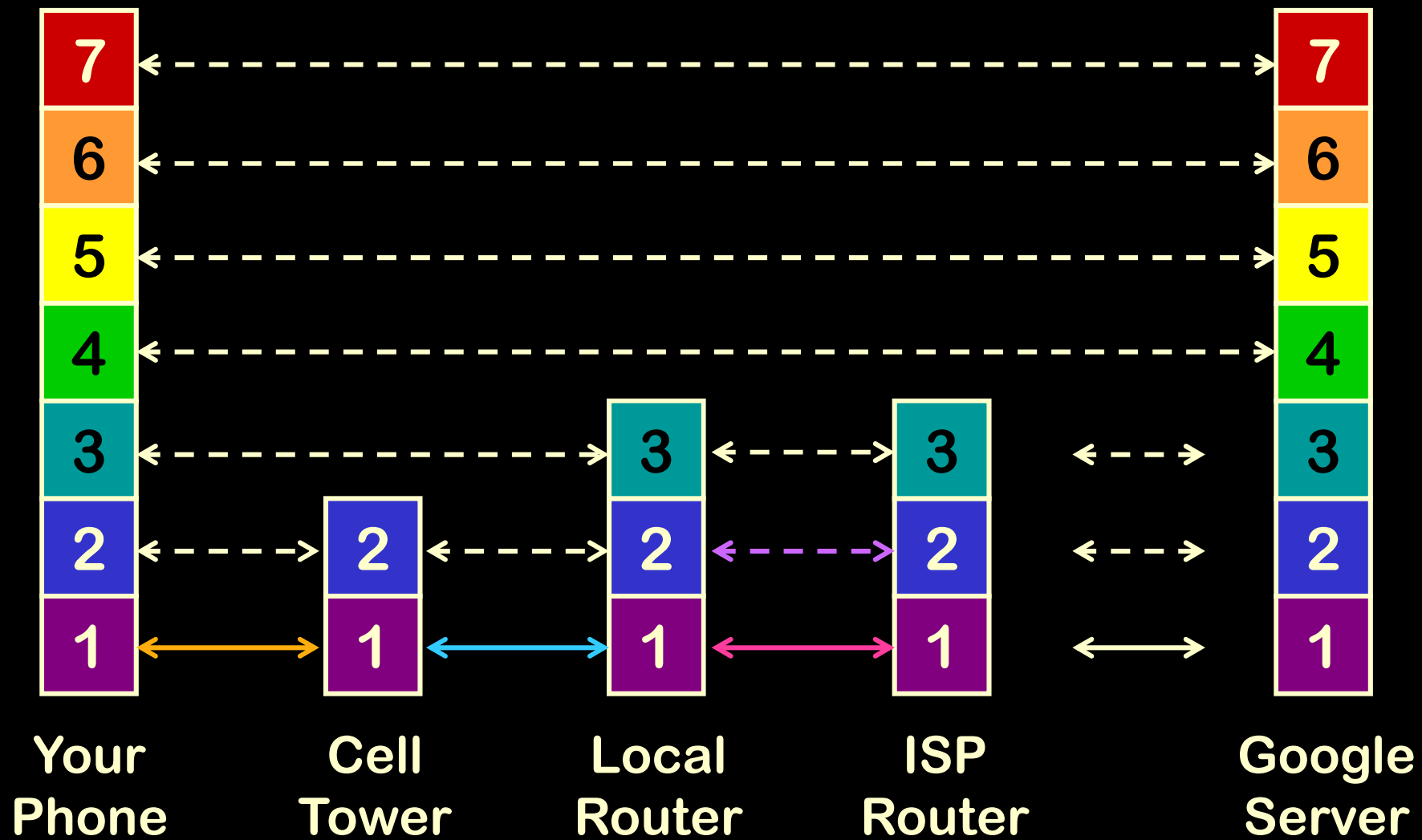




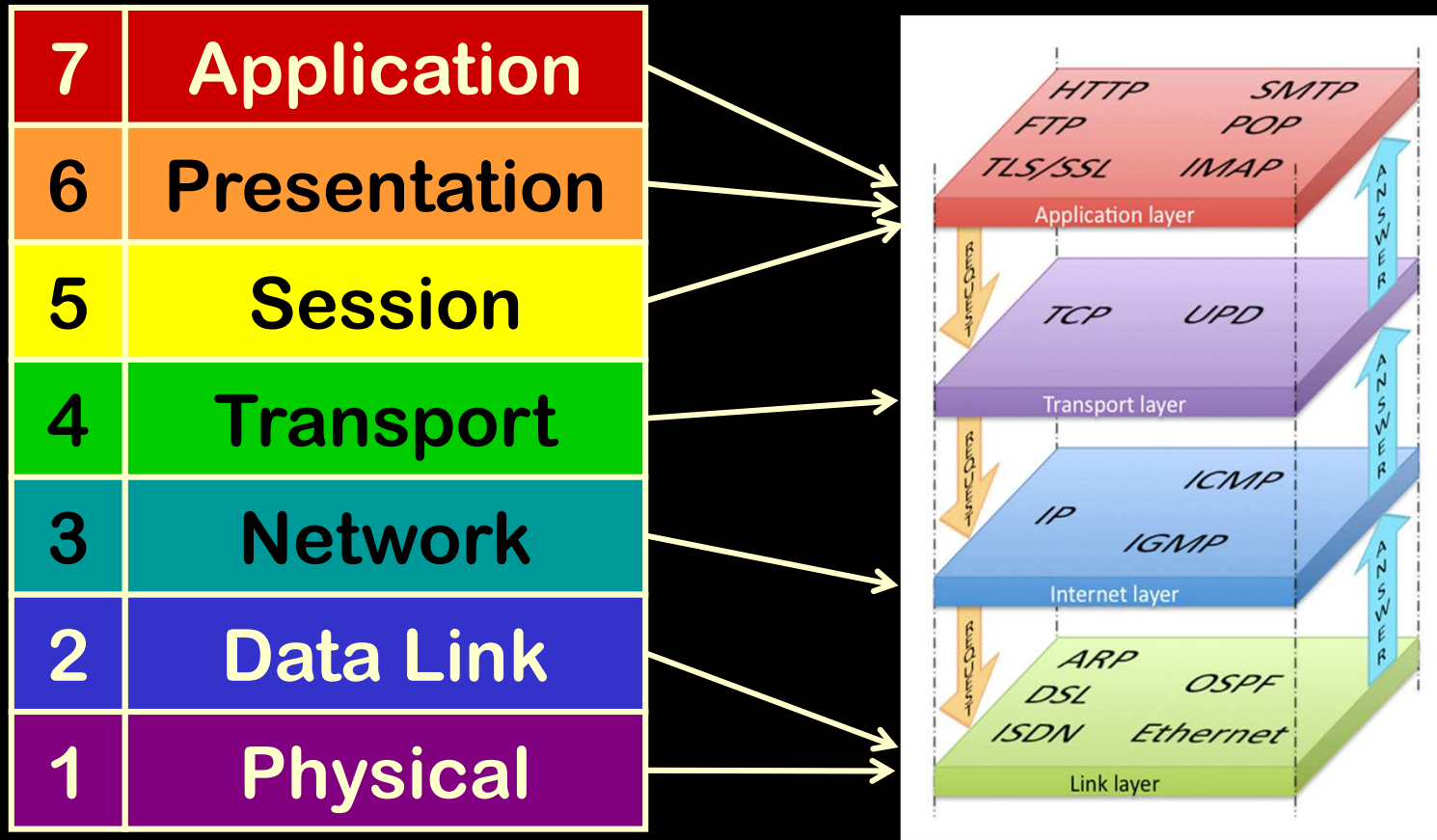








ISO and the Internet

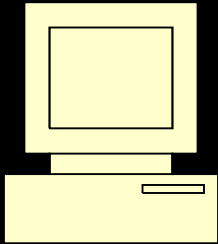


Domain Name System (DNS)

westwood.k12.ma.us → 71.254.232.36

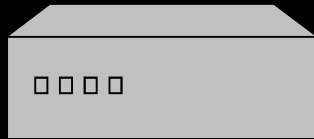
- **Top Level Domain (TLD)**
 - Allocated by Internet Corporation for Assigned Names and Numbers (ICANN)
 - Includes ISO-3166 country codes
 - us, ca, uk, de, jp, ...
- **Hierarchical right to left**
 - opposite of internet address (left to right)

Domain Name System

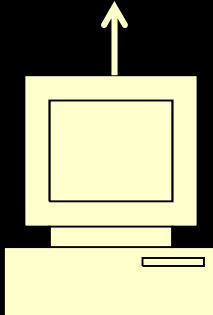


westwood.k12.ma.us

Domain Name System

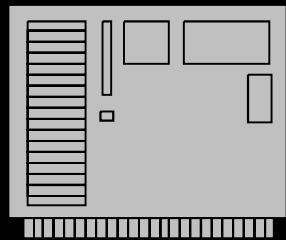


**local Domain
Name Server**

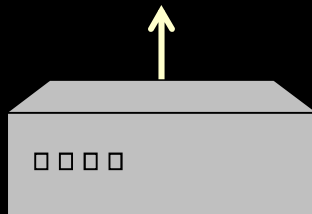


westwood.k12.ma.us

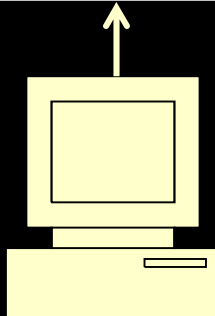
Domain Name System



**Internet Service
Provider Domain
Name Server**

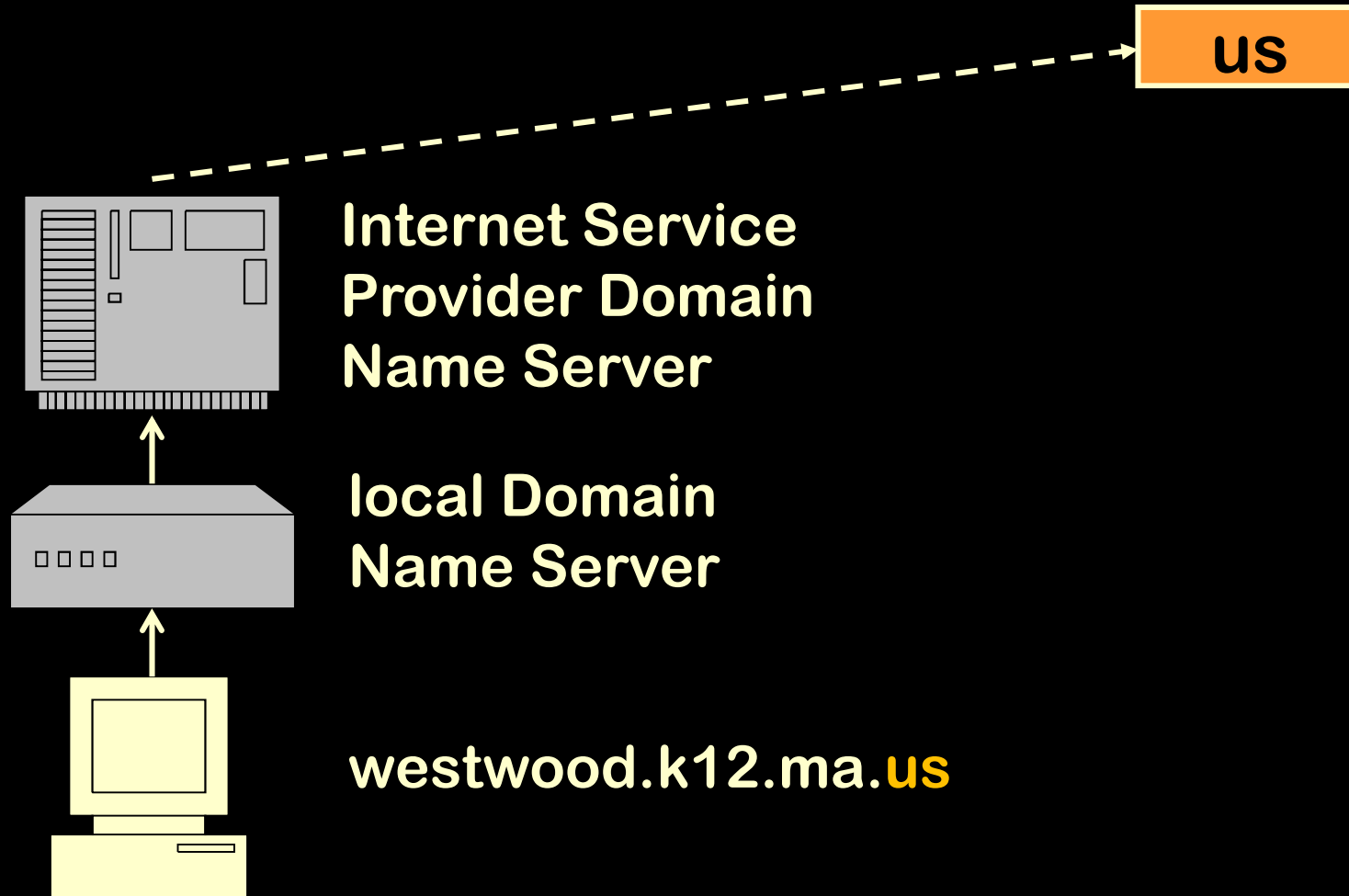


**local Domain
Name Server**

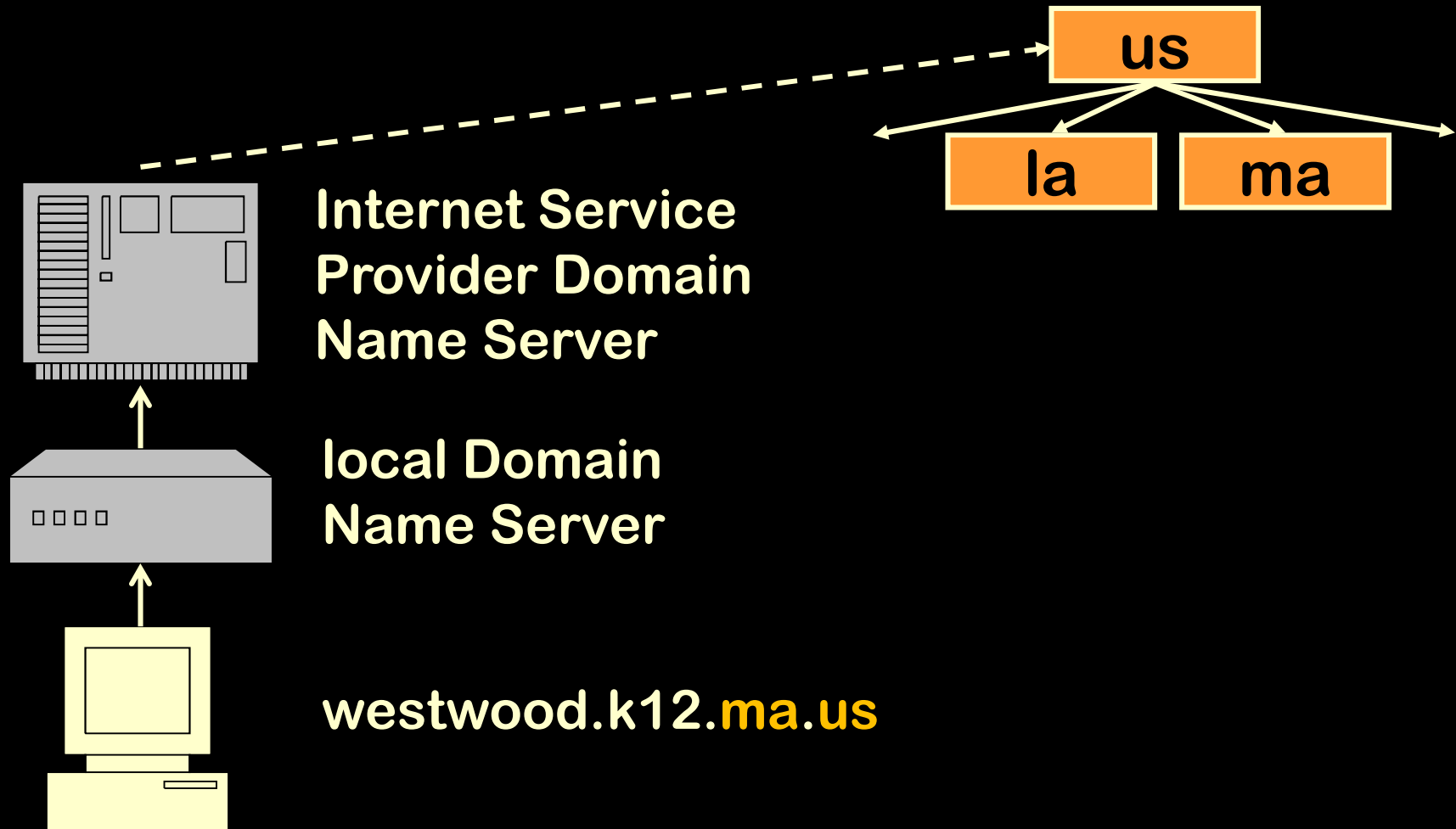


westwood.k12.ma.us

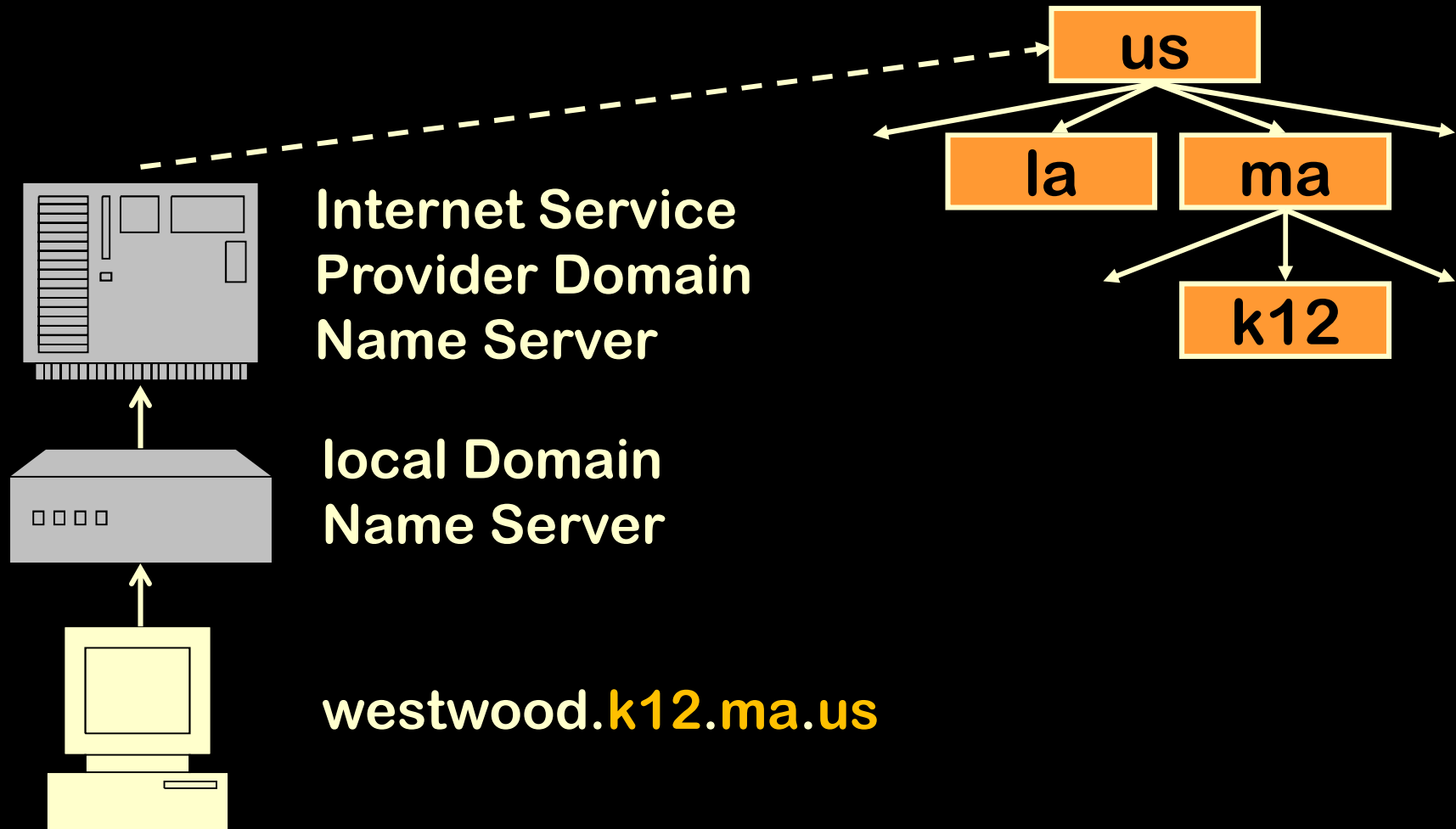
Domain Name System



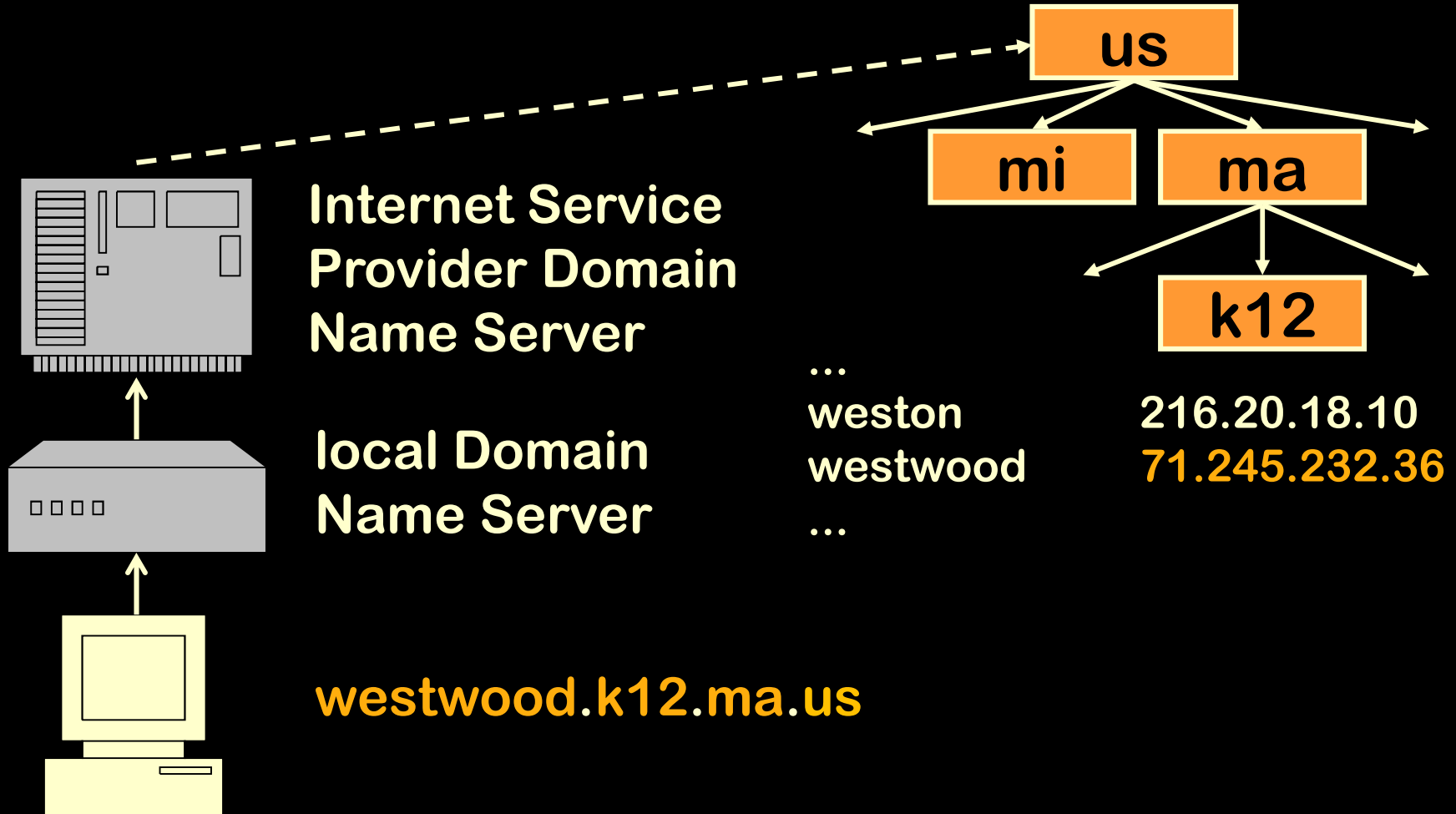
Domain Name System



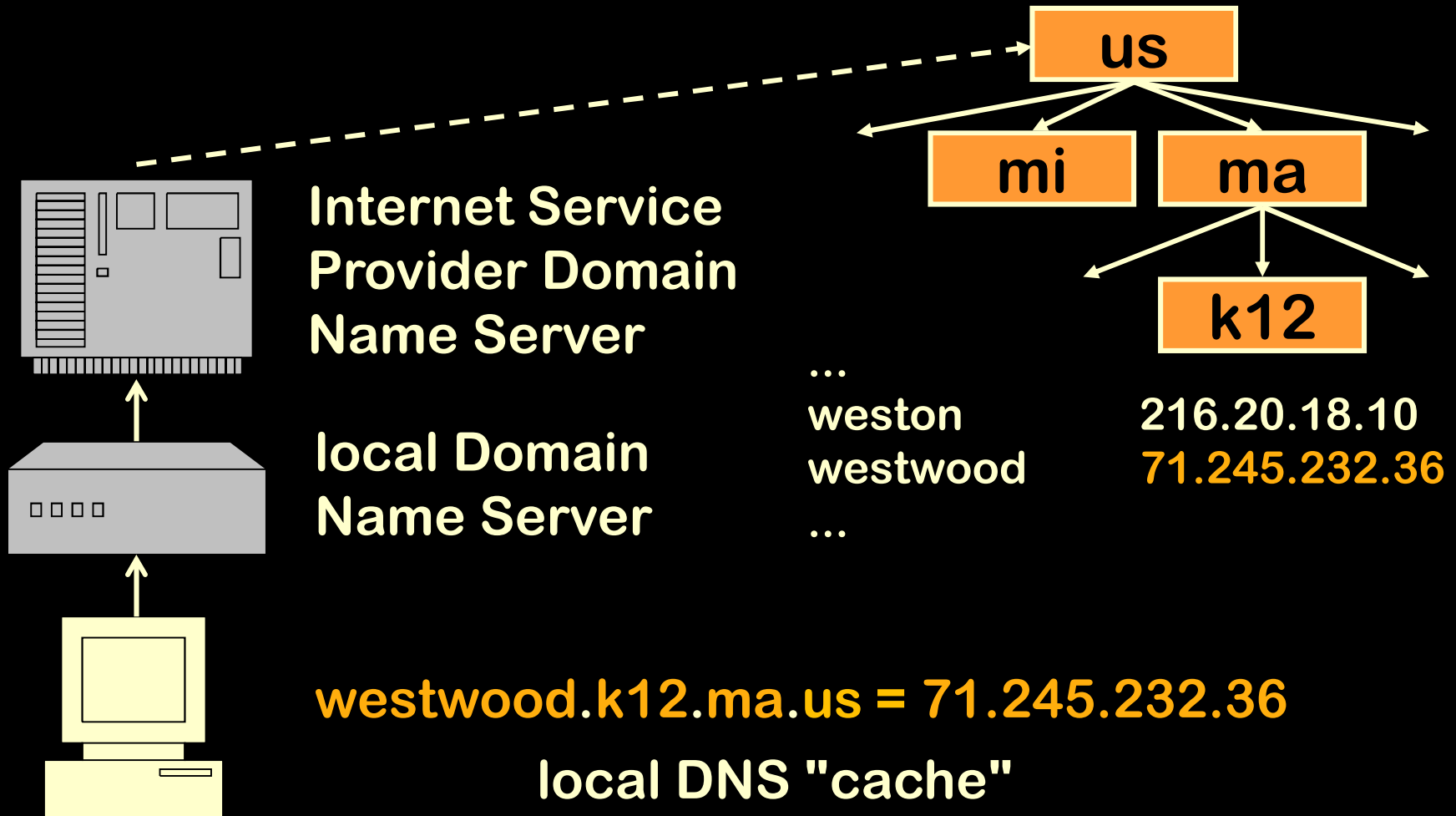
Domain Name System



Domain Name System



Domain Name System



Y:\>ipconfig /all

Windows IP Configuration

Host Name : HS88GMLH1
Primary Dns Suffix : WPSS.org
Node Type : Hybrid
IP Routing Enabled. : No
WINS Proxy Enabled. : No
DNS Suffix Search List. : WPSS.org
sbo.ma.cable.rcn.com

Ethernet adapter Wireless Network Connection:

Connection-specific DNS Suffix . : sbo.ma.cable.rcn.com
Description : Intel(R) PRO/Wireless 3945ABG Network Connection #2
Physical Address. : 00-1F-3C-C7-8B-37
Dhcp Enabled. : Yes
Autoconfiguration Enabled : Yes
IP Address. : 192.168.1.101
Subnet Mask : 255.255.255.0
Default Gateway : 192.168.1.1
DHCP Server : 192.168.1.1
DNS Servers : 207.172.3.8
207.172.3.9
208.59.247.45
Lease Obtained. : Thursday, August 26, 2010 7:53:56 AM
Lease Expires : Friday, August 27, 2010 7:53:56 AM

Y:\>

```
Y:\>tracert mit.edu
```

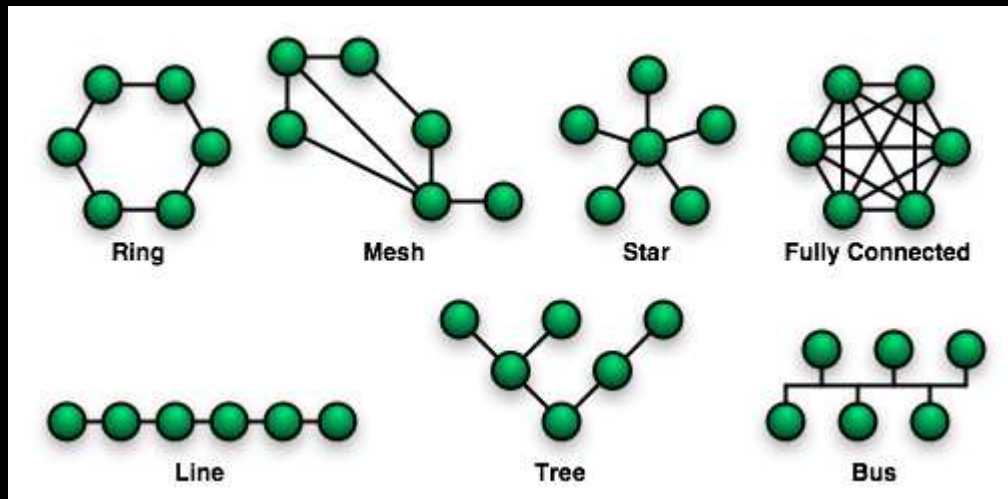
```
Tracing route to mit.edu [18.7.22.69]  
over a maximum of 30 hops:
```

1	19 ms	12 ms	11 ms	bd11.nwt-ubr3.sbo-nwt.ma.cable.rcn.net [10.20.216.1]
2	22 ms	27 ms	21 ms	vl200.aggr1.sbo.ma.rcn.net [209.6.160.100]
3	29 ms	18 ms	22 ms	vl130.border1.sbo.ma.rcn.net [207.172.15.148]
4	17 ms	13 ms	26 ms	207.210.143.29
5	13 ms	13 ms	19 ms	207.210.143.110
6	19 ms	13 ms	12 ms	W92-RTR-1-BACKBONE-2.MIT.EDU [18.168.1.25]
7	*	17 ms	12 ms	WEB.MIT.EDU [18.7.22.69]

```
Trace complete.
```

<http://tools.whois.net/whoisbyip/>





http://en.wikibooks.org/wiki/Communication_Networks/Network_Topologies