Computer Network & Security

Rong Zheng

Introduction

A little walk down the memory lane

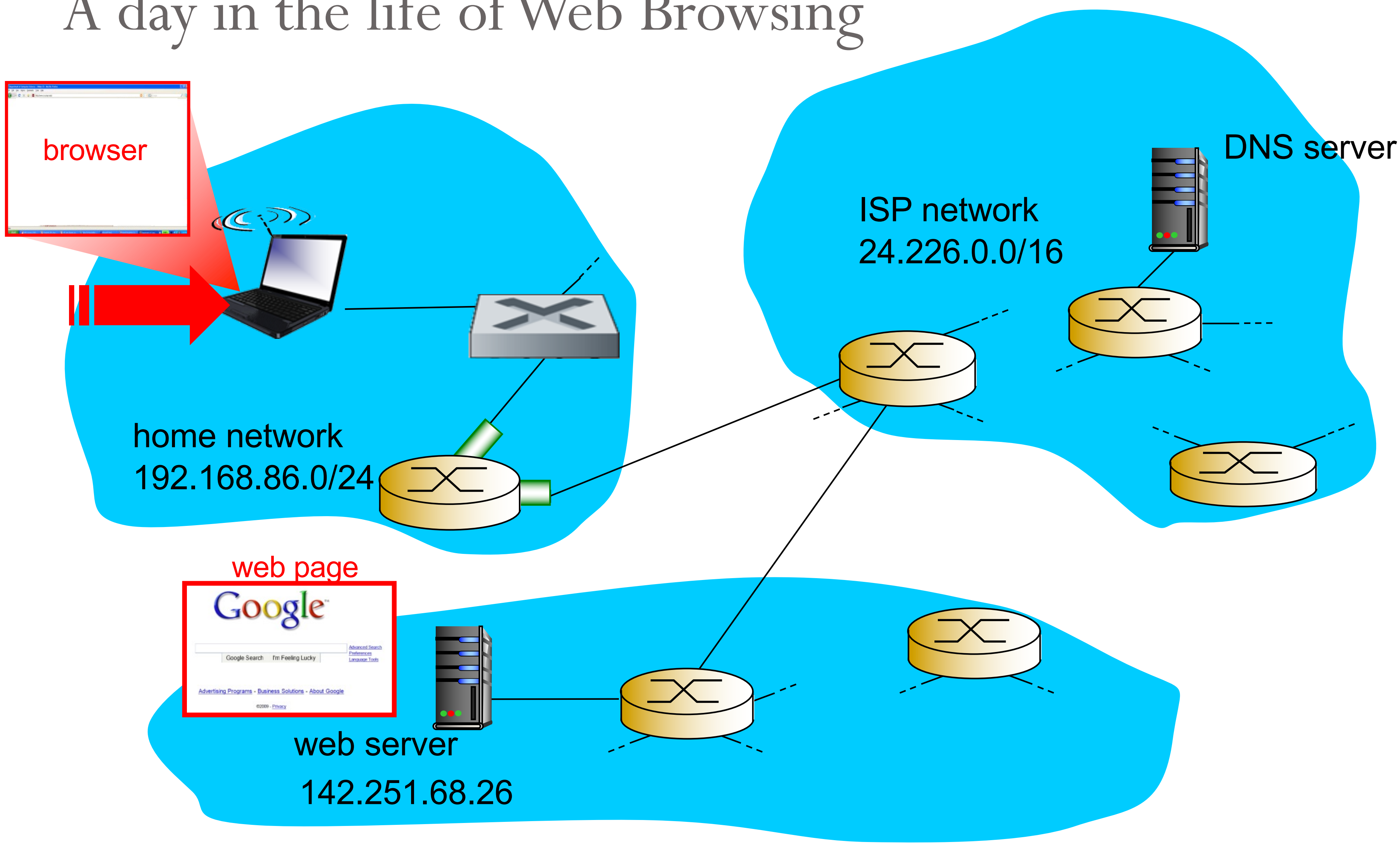
Nuts and bolts of the Internet

The Internet architecture and design principles

Readings:

- K & R Chapter 1
- J. H. Saltzer, D. P. Reed, and D. D. Clark. 1984. End-to-end arguments in system design. *ACM Trans. Comput. Syst.* 2, 4 (November 1984), 277-288 (optional)

A day in the life of Web Browsing



Computer Networks

- A computer network is a system for communication among two or more computers
  - System: both software & hardware
  - What amounts to "computers"?
  - What kind of communication? – "digital"

Our focus is on the Internet

Everyone Knows about Internet, Right?

- In 1971, a computer engineer named Ray Tomlinson sent the first __________
- In 1980, Tim Berners-Lee, a computer scientist, invented __________
- In 1994, __________ said "I took the initiative in creating the Internet"
- Instagram was launched in __________
- _________ blocked President Trump's account in Jan. 2021 and was reinstated by _________ in Nov. 2022

History of the Internet

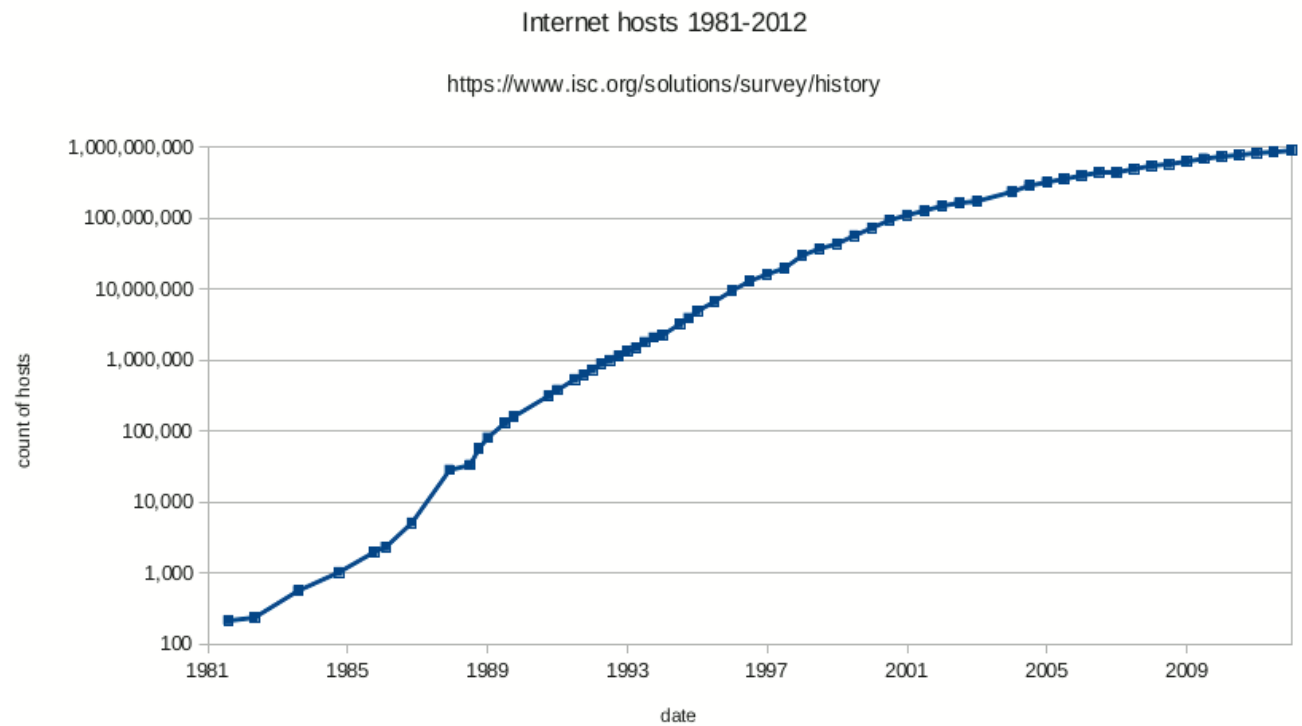
- 61-72: development of packet switching
- 72-80: Proprietary networks and internetworking
  - Multiple packet switching networks
  - "Networks of networks": earlier development of TCP, UDP, IP
  - ALOHA, Ethernet
- 80-90: proliferation of networks
  - Standardization of networking protocols TCP/IP, DNS etc
  - US National Science Foundation (NSF) builds NSFNET as backbone, links 6 Supercomputer centers, 1.5 Mbps, 10,000 computers
- 90's: Internet explosion
  - 94: NSF backbone dismantled, multiple private backbones
  - Emergence of World Wide Web (invented by Tim Berners-Lee)
- 2000 – present
  - More than 1 billion hosts including smartphones & tablets
  - 2001 – BitTorrent peer-to-peer file sharing
  - 2004 – Facebook social networking site
  - 2011 – Snapchat, photo sharing
  - 5G cellular data networks in deployment
  - 2022 -- Starlink satellite internet service available in North America

http://www.zakon.org/robert/internet/timeline/

Growth of the Internet

Number of Hosts on the Internet:

- Aug. 1981 213
- Oct. 1984 1,024
- Dec. 1987 28,174
- Oct. 1990 313,000
- Oct. 1993 2,056,000
- Apr. 1995 5,706,000
- Jan. 1997 16,146,000
- Jan. 1999 56,218,000
- Jan. 2001 109,374,000
- Jan 2003 171,638,297
- Jan. 2005 317,650,000
- Jan. 2010 732,740,000
- Jan. 2014 1,010,250,000
- July 2015 1,033,836,245
- 2019 1,012,700,000

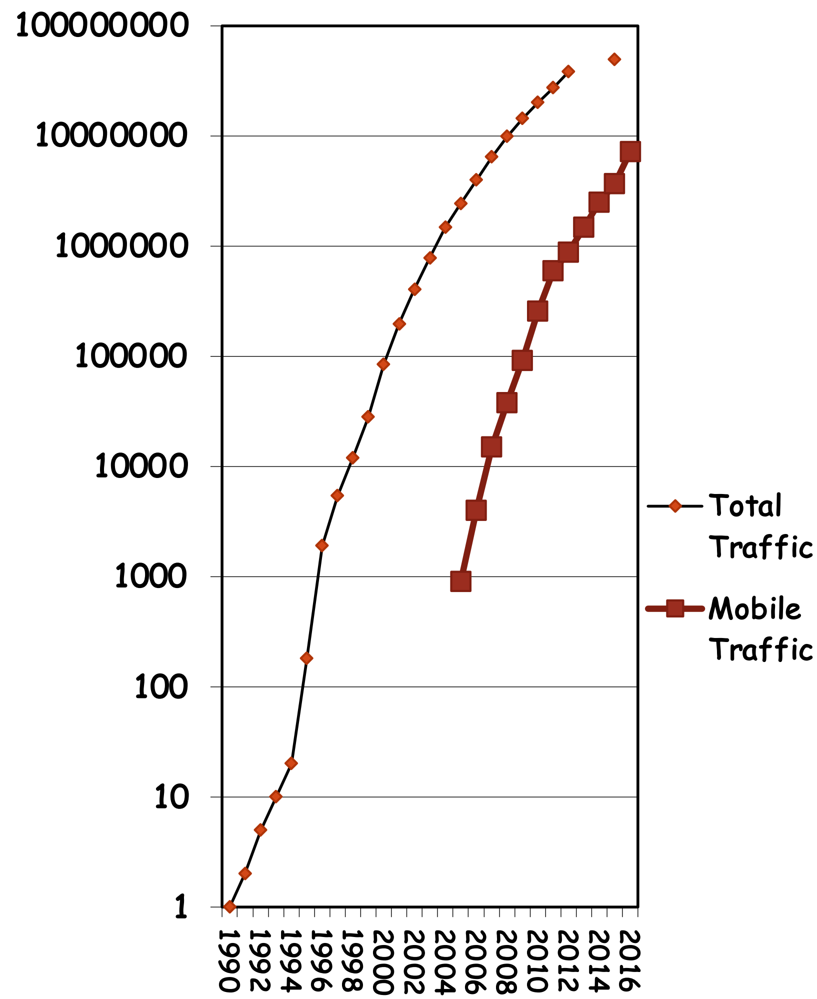


Source: Internet Systems Consortium

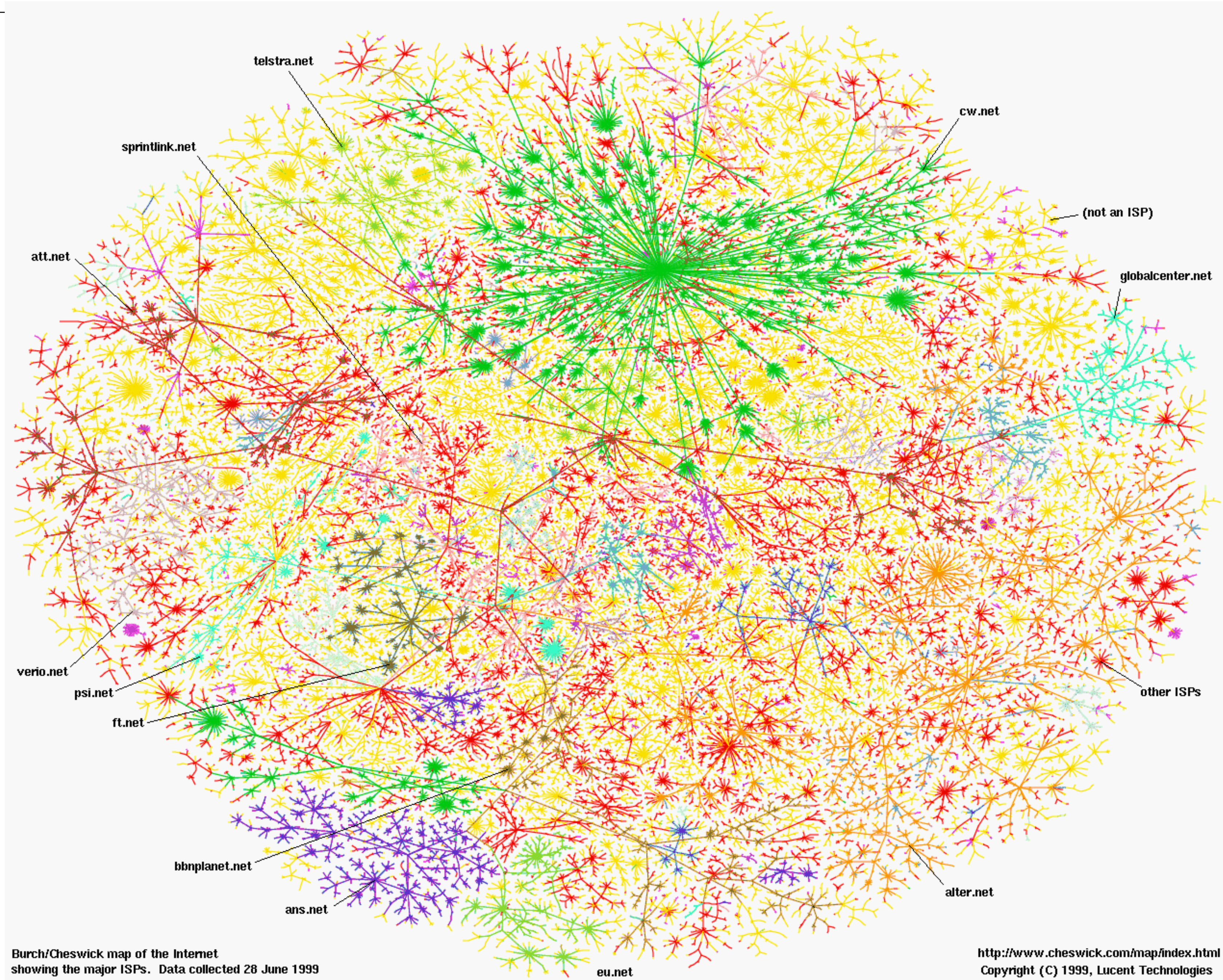
Growth of the Internet

Traffic on Internet (in TB/mo)

- 1990 1.0
- 1991 2.0
- 1992 4.4
- 1993 8.3
- 1994 16.3
- 1996 1,500
- 1997 2,500 - 4,000
- 1998 5,000 - 8,000
- 1999 10,000 - 16,000
- 2000 20,000 - 35,000
- 2001 40,000 - 70,000
- 2002 80,000 - 140,000
- 2005 2,426,000
- 2010 20,193,000
- 2012 32,000,000
- 2015 49,494,000
- 2016 65,942,000
- 2017 85,000,000



Source: http://en.wikipedia.org/wiki/Internet_traffic



A good source on Internet measurements can be found
http://www.caida.org/

Why Learn Computer Networks?

- To understand how things work
  - Help fixing day to day problems
- To develop distributed applications
- To configure and to operate (as a system administrator)

Network system administrator: salaries per region

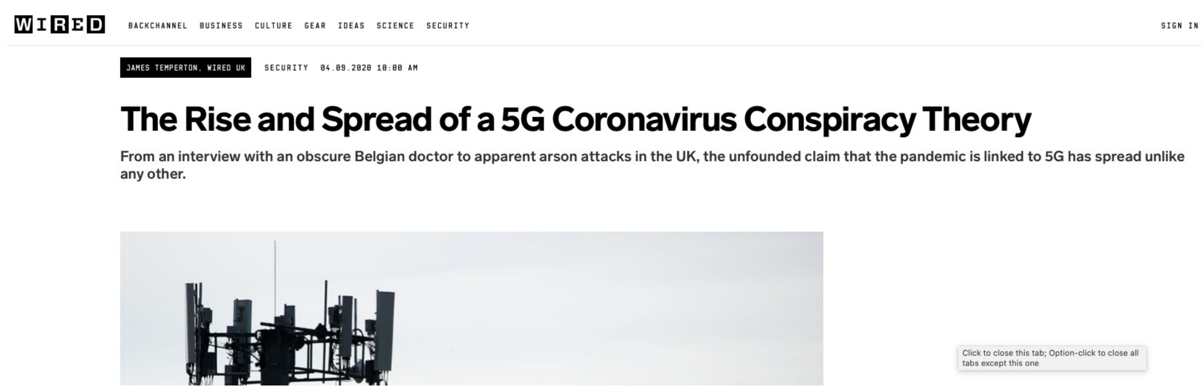
Quebec	$85,000
British Columbia	$82,595
Ontario	$77,500

Quick Facts: Network and Computer Systems Administrators	
2023 Median Pay	$95,360 per year $45.84 per hour
Typical Entry-Level Education	Bachelor's degree
Work Experience in a Related Occupation	None
On-the-job Training	None
Number of Jobs, 2023	335,400
Job Outlook, 2023-33	-3% (Decline)
Employment Change, 2023-33	-8,800

Source:
Talent.com
US Bureau of Labor Stats

Why Learn Computer Networks?

- To innovate and design
  - Emerging new network architecture and types of networks: Internet-of-Things, satellite networks, inter-stellar networks, software-defined networking, quantum networks…
- To defend
  - Cyber attacks are abundant
- To contribute to public discourse and policy making


WIRED BACKCHANNEL BUSINESS CULTURE GEAR IDEAS SCIENCE SECURITY SIGN IN

JAMES TEMPERTON, WIRED UK SECURITY 04.09.2020 10:00 AM

The Rise and Spread of a 5G Coronavirus Conspiracy Theory

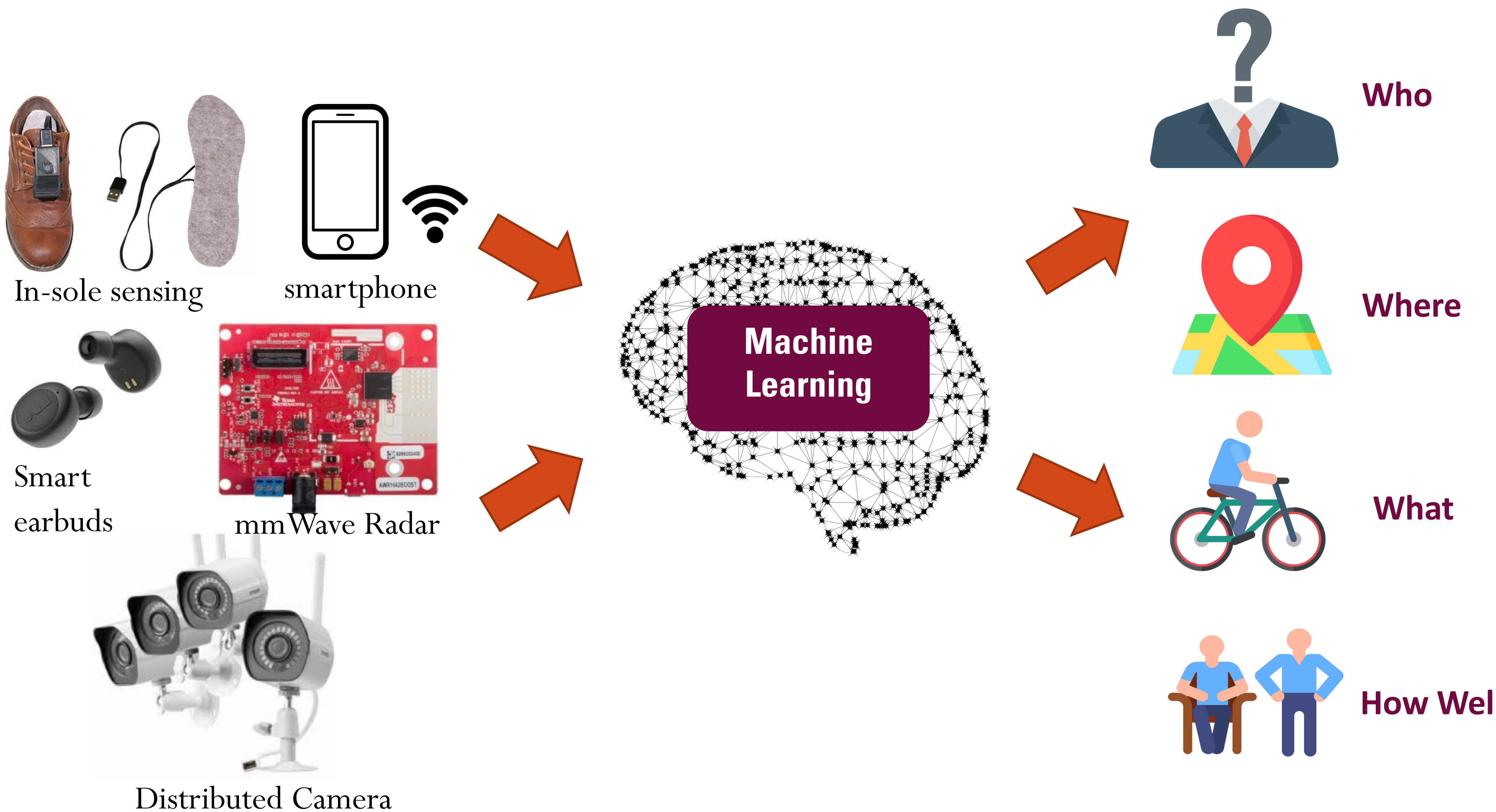
From an interview with an obscure Belgian doctor to apparent arson attacks in the UK, the unfounded claim that the pandemic is linked to 5G has spread unlike any other.

Click to close this tab; Option-click to close all tabs except this one

The Instructor

- Rong Zheng (rzheng)
- Tentative office hrs: Tue. 5 – 6pm

Wireless System Research (WiSeR)



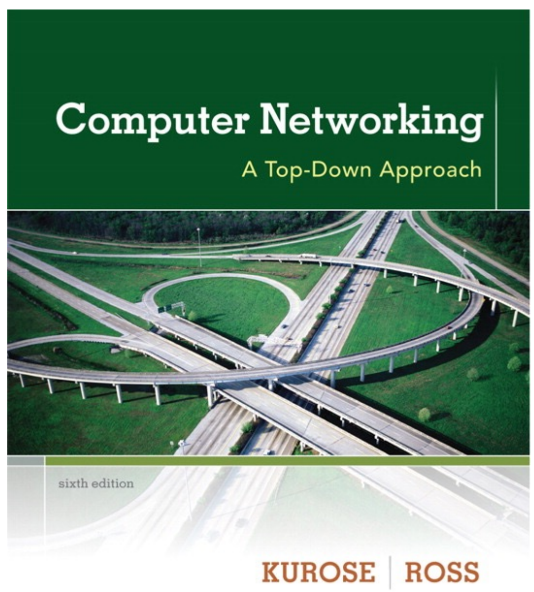
Vital sign sensing demo https://www.youtube.com/watch?v=milcmtQ8YUc

The TAs

- Yunkai Yu, Billy Chan, Kishor Pandya, Xinyu Ma
- Tutorials:
  - Demos & going over examples
  - Questions and answers

Textbook

- James F. Kurose, Keith W. Ross, "Computer Networking: A Top-Down Approach Featuring the Internet", 7th or 8th ed. Pearson Education
  - Earlier editions are fine but note changes in content



Organization of the Course

- Scope
  - Internet architecture: organizational, hardware, software/protocol
  - Applications & socket programming
  - Transport layer
  - Routing
  - Link layer
  - Network security
- Grading
  - Online exercises (~5): 25%
  - 5 assignments: 35%
  - Final: 40%
- 1 – 2 guest lectures

Easy to pass but hard to get an A+

Schedule

- Class time
  - MoTh 9:30AM - 10:20AM, Tu 10:30AM - 11:20AM
- Tutorials
  - Starts in Week 2
  - We 11:30AM - 12:20PM, ABB 163 (75) ~~JHE 326H~~
  - Mo 11:30AM - 12:20PM, ABB 164
  - Th 11:30AM - 12:20PM, JHE 326H

Online Quiz

- The quizzes are primarily designed to review the materials taught in classes
- Simple questions, usually takes 10 – 20 min to finish
- Typically due in 1 week
- Auto-graded and grades released within one week upon expiration of deadline
  - You can check the answers online afterwards
  - Remember to click the **SUBMIT** button!

Assignments

- Wireshark – a packet capture & analysis tool
  - First-hand understanding of Internet Protocols

    https://www.wireshark.org/download.html
  - Students are expected to capture packet traces themselves
  - Mainly of Question & Answer type – no programming involved
  - Typically due in one week
- Python Programming
  - Design & implement a miniature peer-to-peer (p2p) file sharing app
  - MOSS used for plagiarism check for codes
- Mininet -- an instant virtual networks on your laptop/PC

  http://mininet.org
  - Linux command lines
  - Use of basic network utilities (ifconfig, netstat, tcpdump, ping, traceroute, dig, netwox …)
  - Network security

Teaching Tools

- Avenue
  - All lecture contents, recording via echo 360
  - Quiz
  - Assignments
  - Grades
  - Announcements
  - Online discussions
    - Code of conducts:
      - Only course related discussions
      - Code snippets are allowed but DO NOT post complete solutions

Late Submission Policy

- a deduction of 10% of the maximum mark available from the actual mark achieved by the student shall be imposed upon expiry of the deadline;
- a further deduction of 5% of the maximum mark available from the actual mark achieved by the student shall then be imposed on each of the next subsequent days;

MSAF Policy

- Missed quizzes with MSAF approvals are permitted
- Subsequent missing assignments with MSAF approval need to be completed in 10 days; otherwise, starting from the 11th day, the late submission policy applies
- The list of approved MSAFs will be shared with students in the last week of class – no confirmation to individual ones will be provided during the term

Questions?

- Discussion on Avenue
  - Top students who answer most questions/ask Good questions will get 3% bonus
- 3% bonus of classroom participation: for top 15% students who ask meaningful questions or answer questions in class
- Email rzheng@mcmaster.ca with subject title "4C03"
  - I use email filters

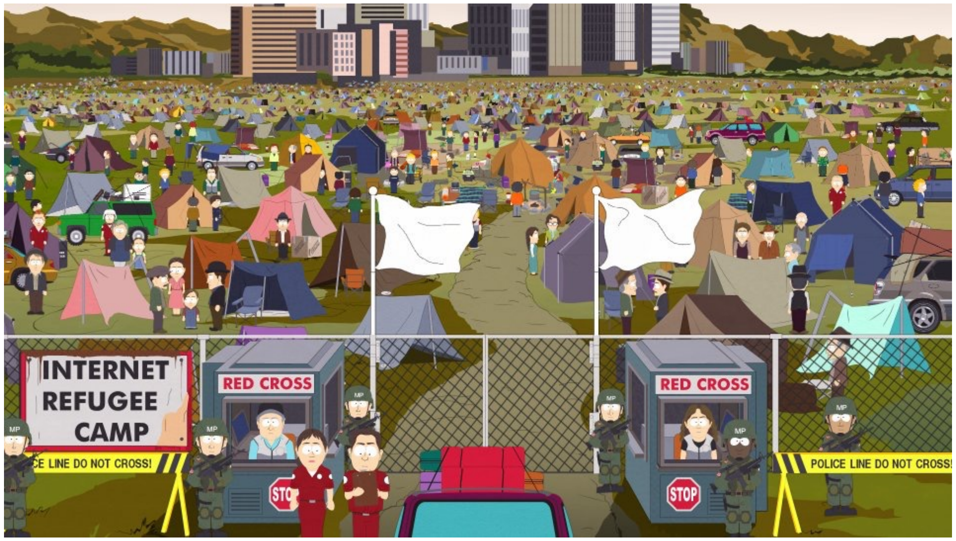
Outline

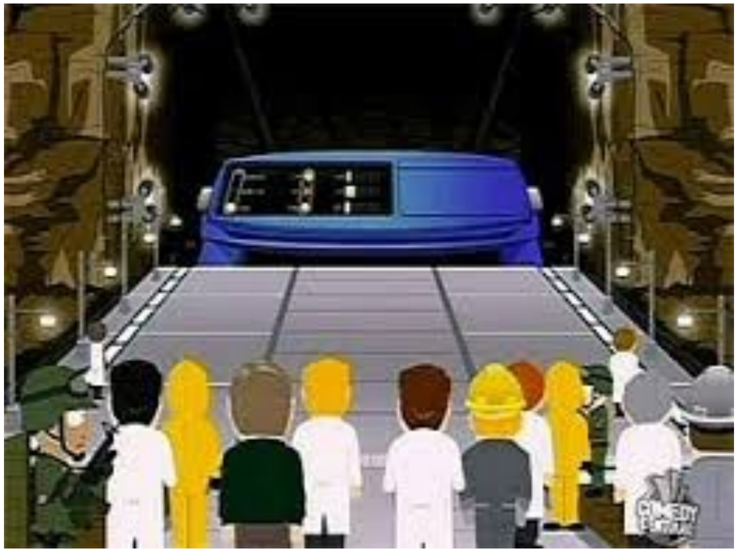
- A little walk down the memory lane
- Internet -- nuts & bolts
- Internet – a designer perspective

Readings:

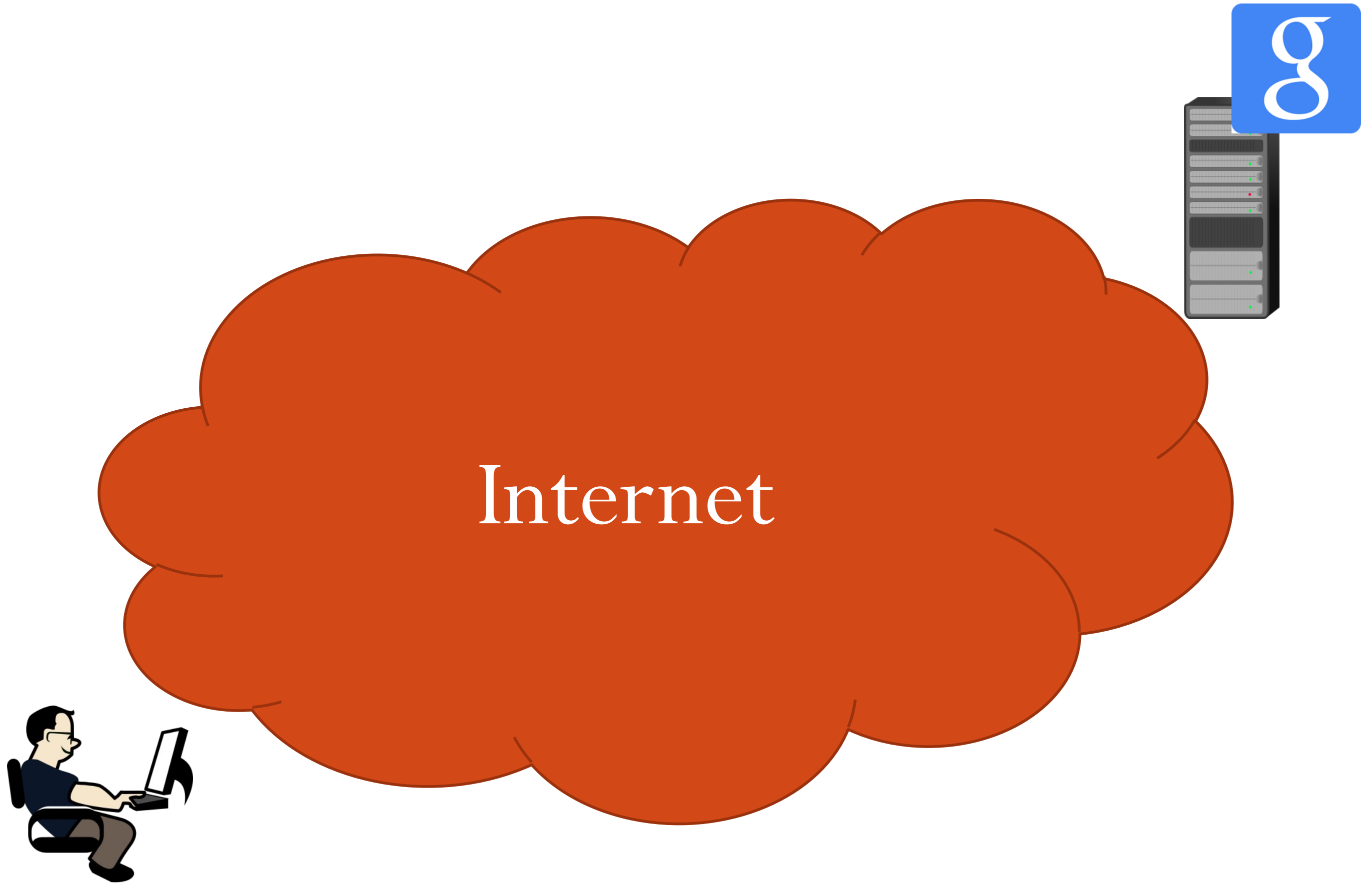
- K & R Chapter 1
- J. H. Saltzer, D. P. Reed, and D. D. Clark. 1984. End-to-end arguments in system design. *ACM Trans. Comput. Syst.* 2, 4 (November 1984), 277-288 (optional)

A World w/o Internet?

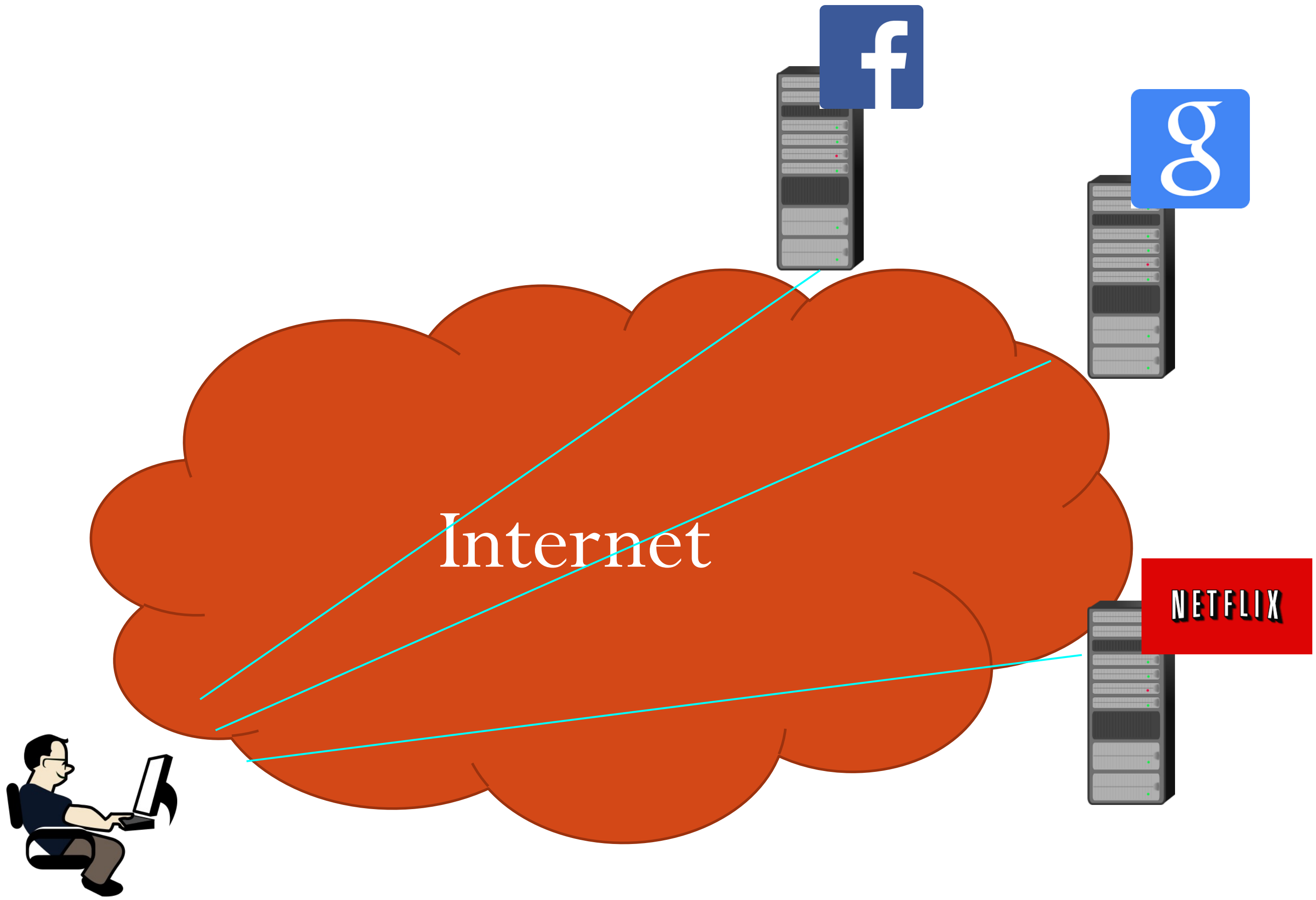




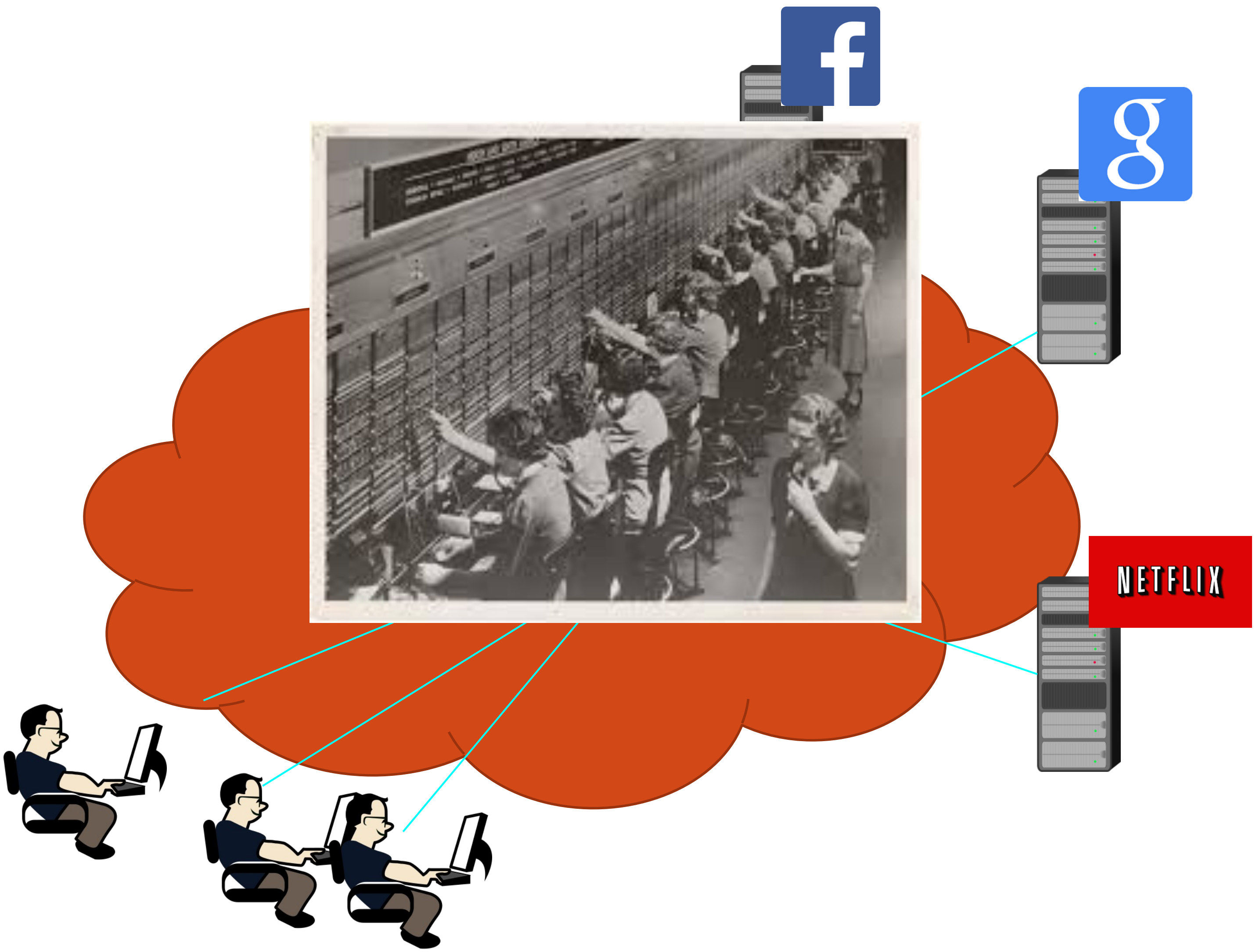
What's the Internet



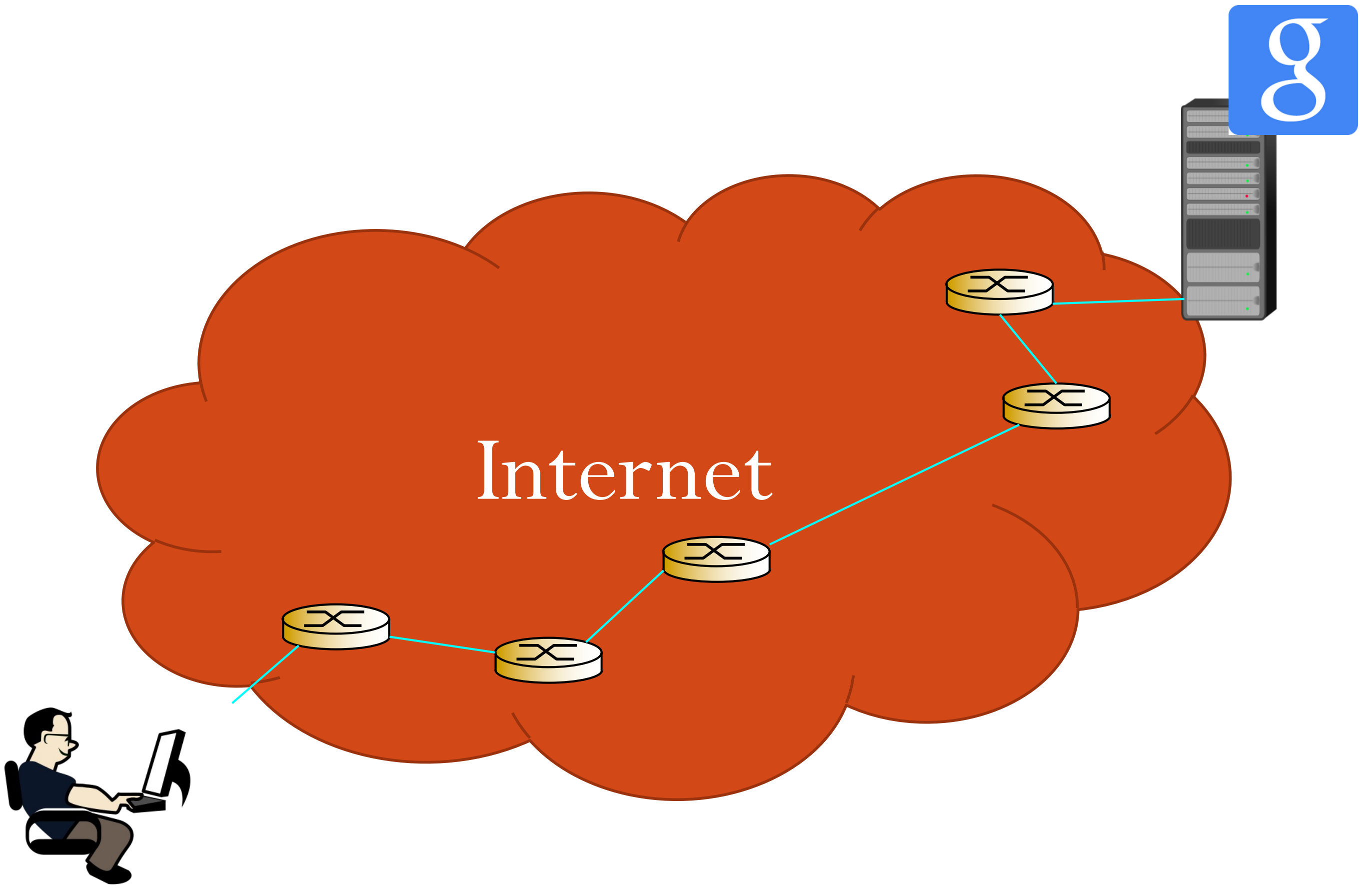
What's the Internet



What's the Internet

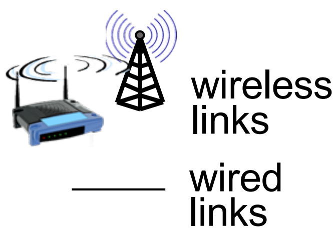


What's the Internet

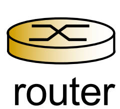


What's the Internet: "nuts and bolts" view

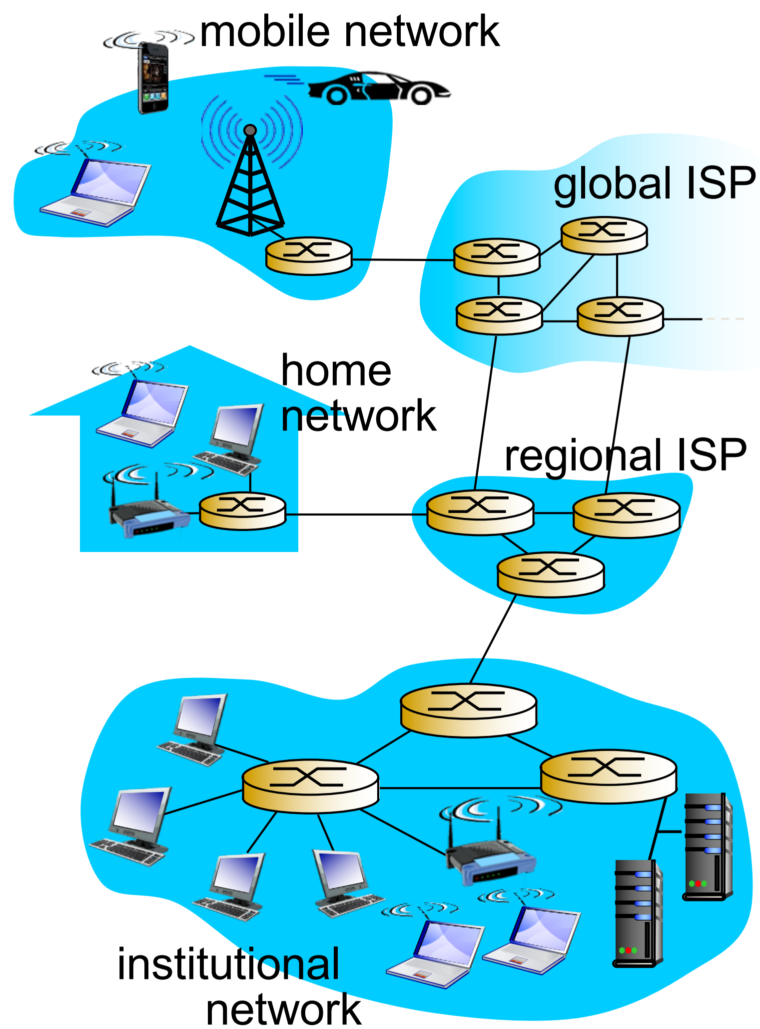
- A billion of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



- communication links
  - fiber, copper, radio, satellite
  - transmission rate: bandwidth



- Packet Switches: forward packets (chunks of data)
  - Routers and switches



Network Components (Examples)

Links

Fibers

Coaxial Cable

Interfaces

Ethernet card

Wireless card

Switches/routers

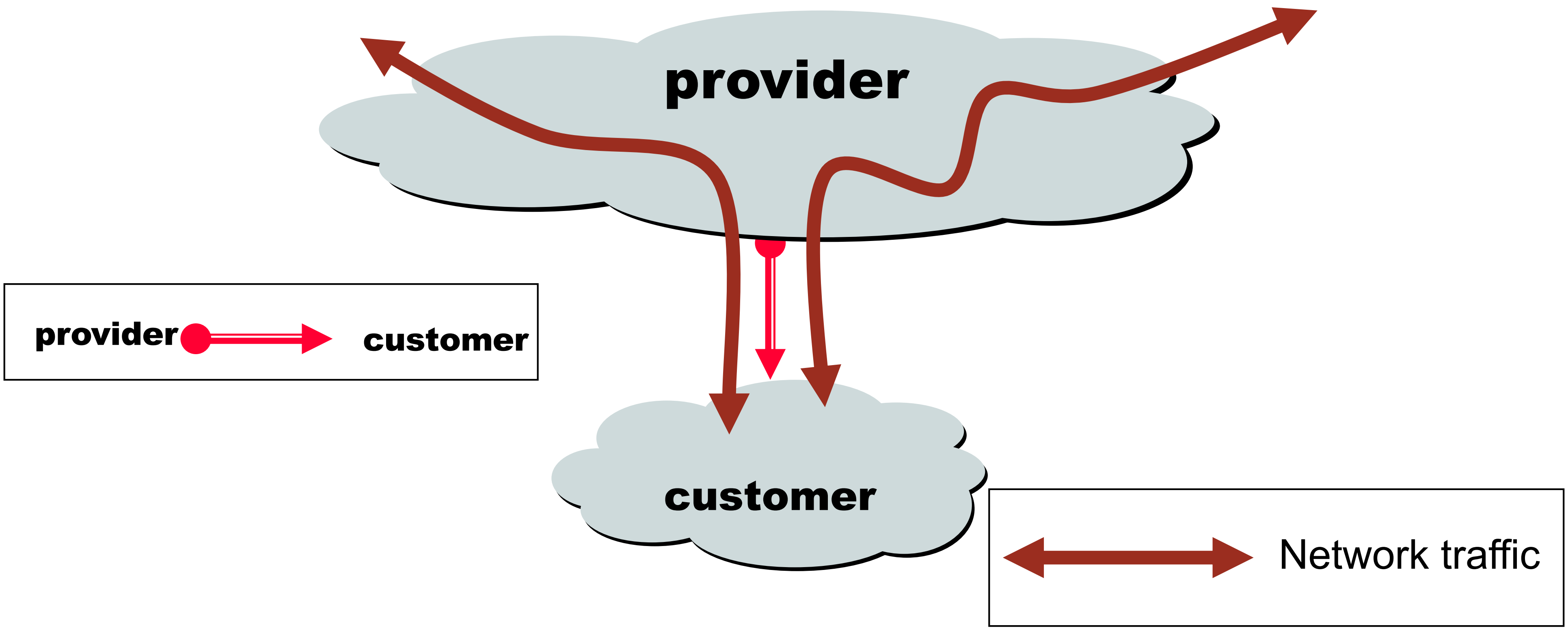
Large router

Switch

Internet structure: network of networks

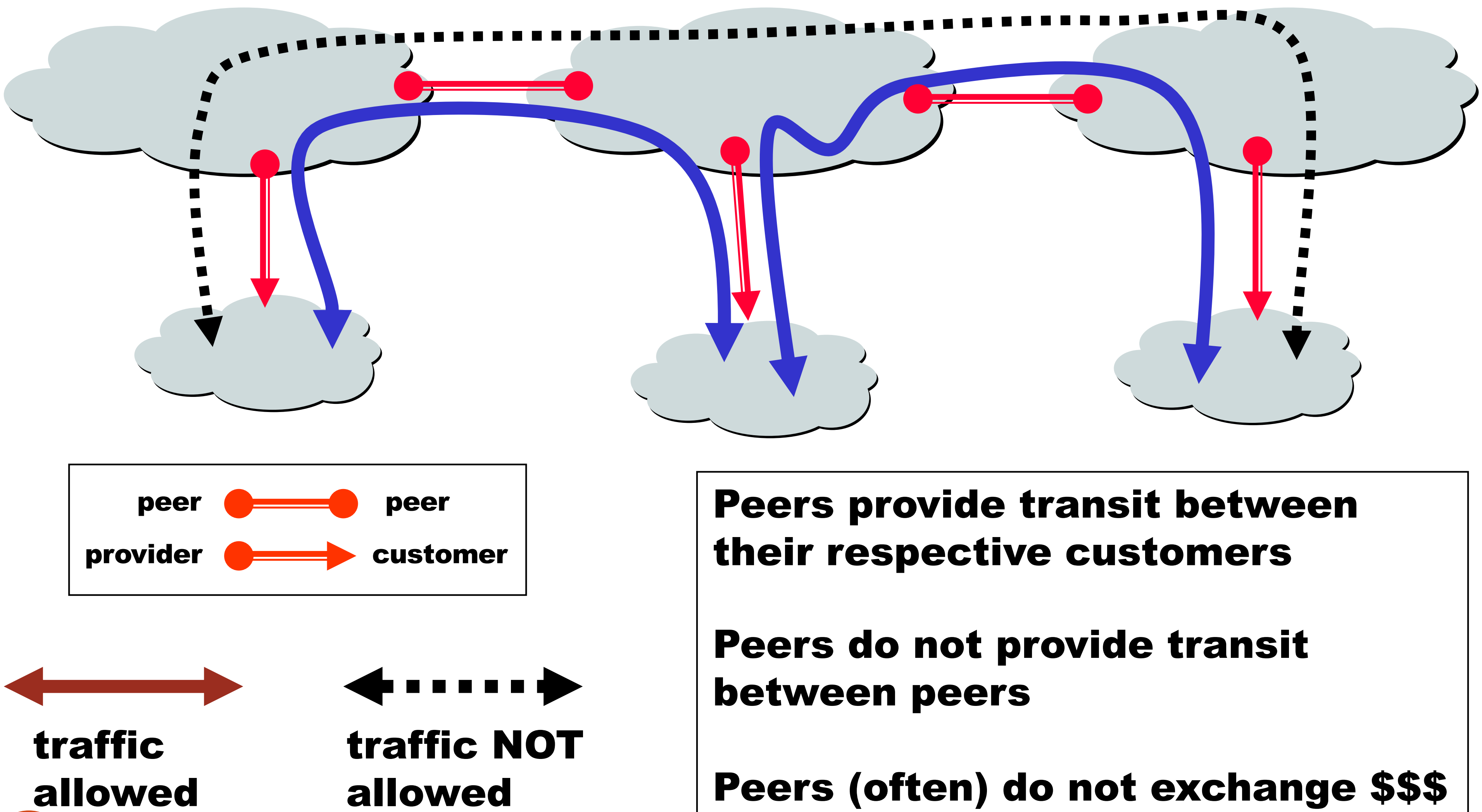
- ISP: End systems access the Internet through Internet Service Providers
  - Types: "Tier-1" ISPs, "Tier-2" ISPs, "Tier-3" ISPs, local ISP…
- Connection type:
  - Customers and Providers
  - Peering Relationship

Customers and Providers



Customer pays provider for access to the Internet

The Peering Relationship



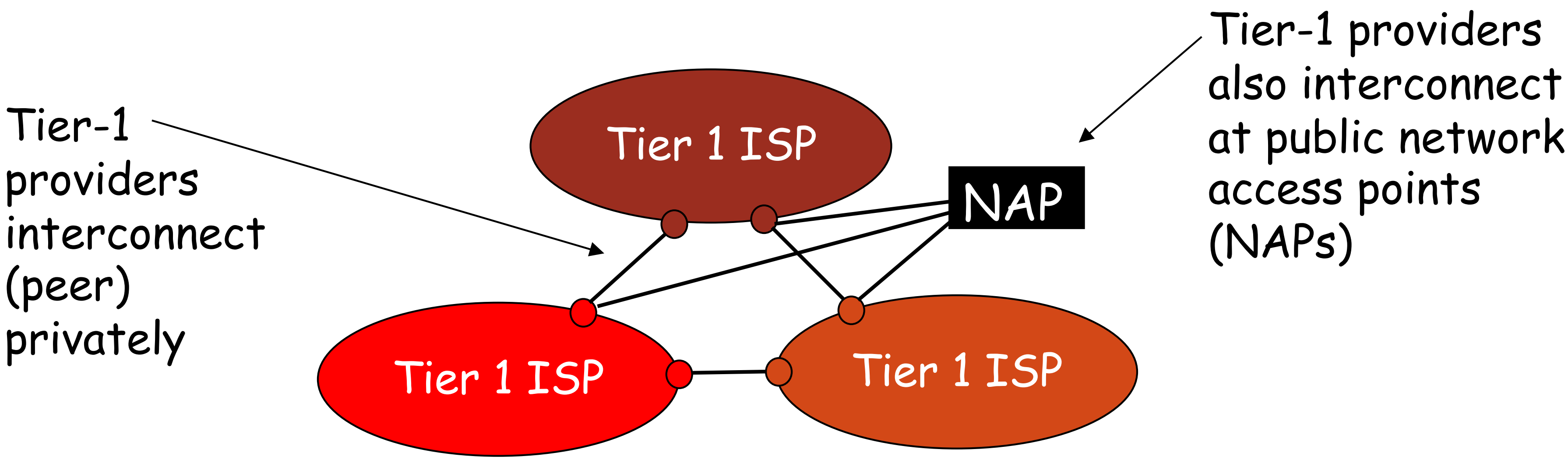
Peers provide transit between their respective customers

Peers do not provide transit between peers

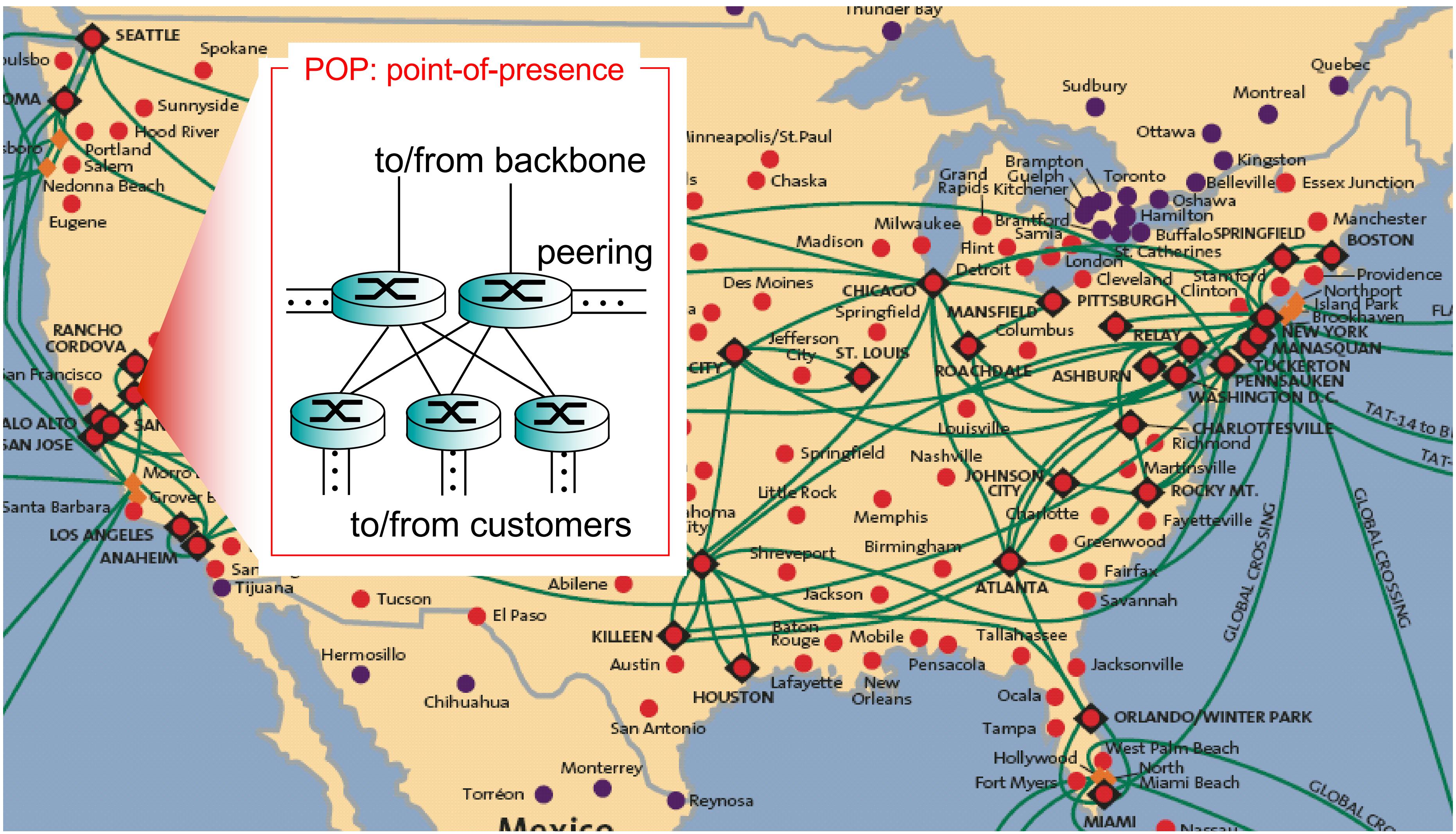
Peers (often) do not exchange $$$

Internet structure: network of networks

- Roughly hierarchical
- At center: "tier-1" ISPs (e.g., MCI, Sprint, AT&T, Cogent communication), national/multi-national coverage
  - Treat each other as equals

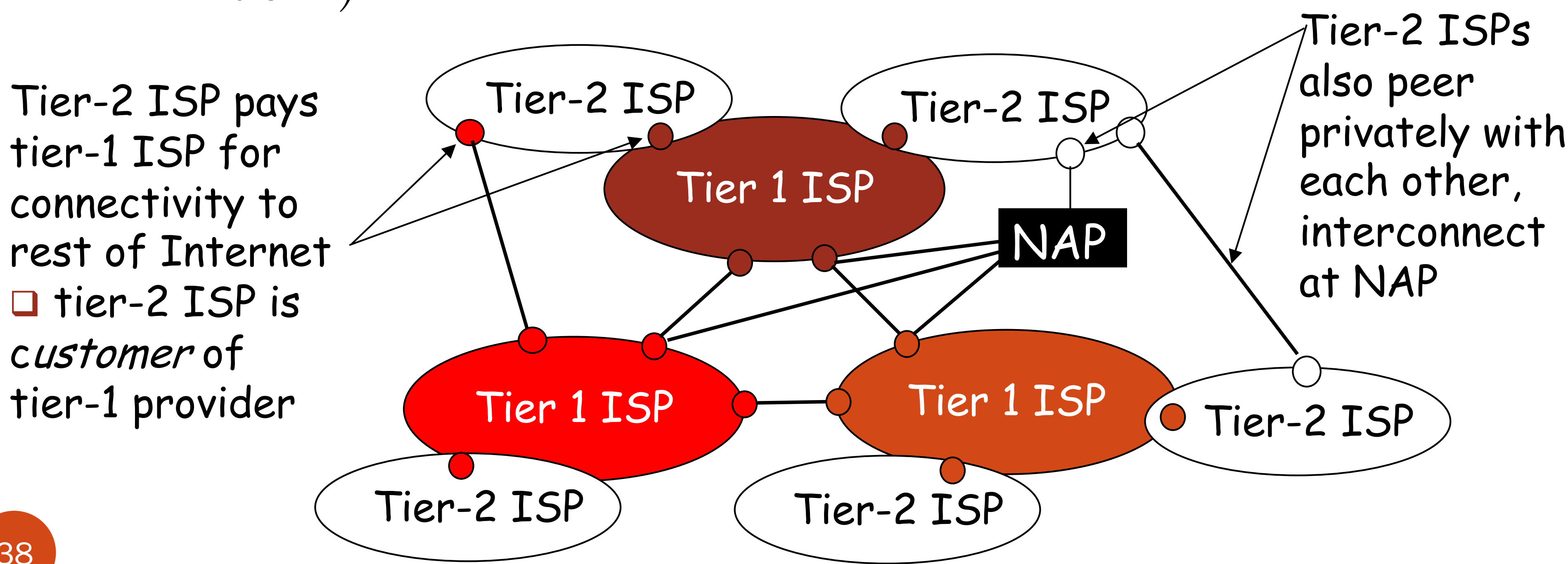


Tier-1 ISP: e.g., Sprint



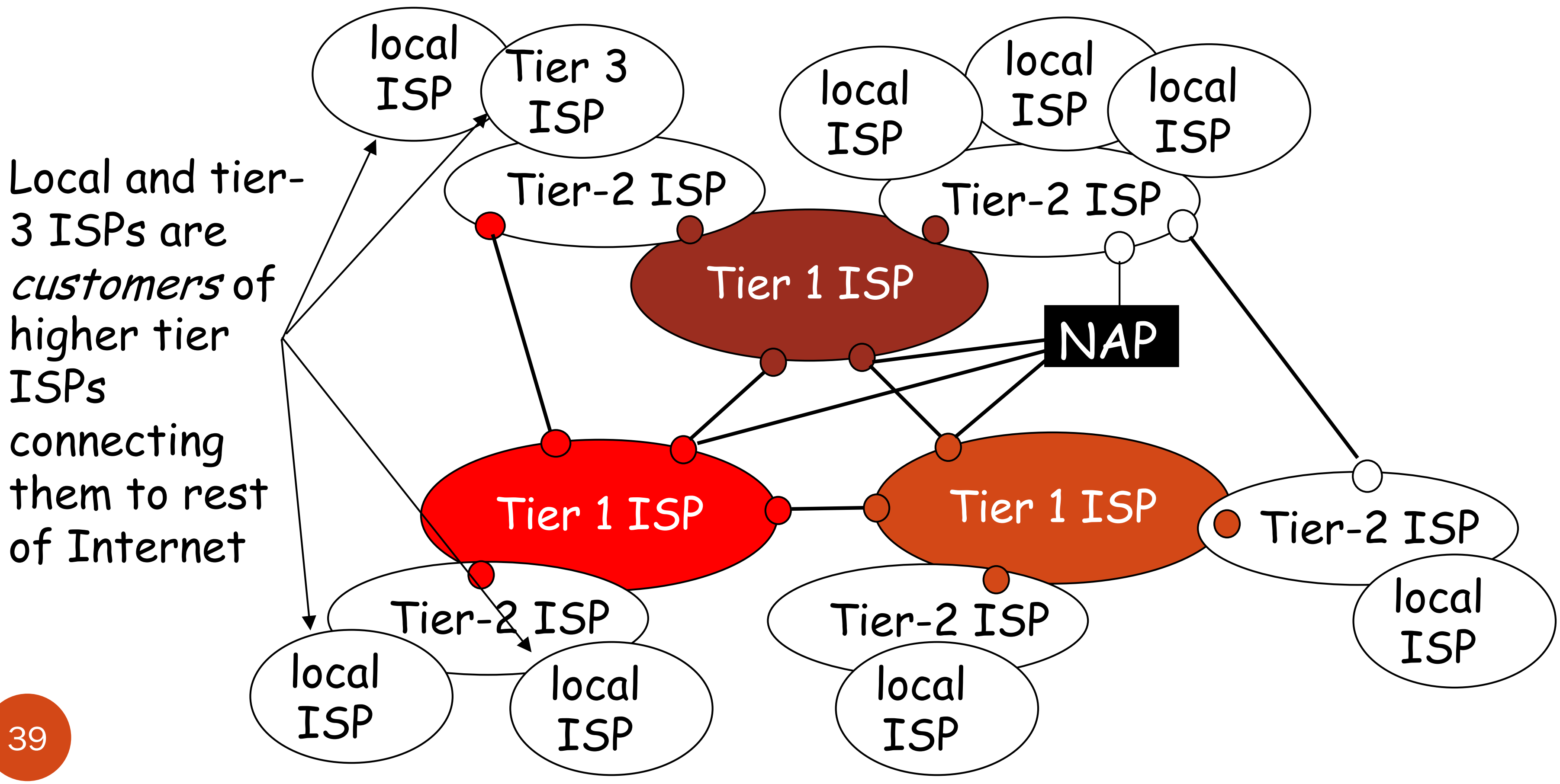
Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1(provider) ISPs
    - Each tier-1 has many tier-2 customers
  - tier-2 nets sometimes peer directly with each other (bypassing tier 1)



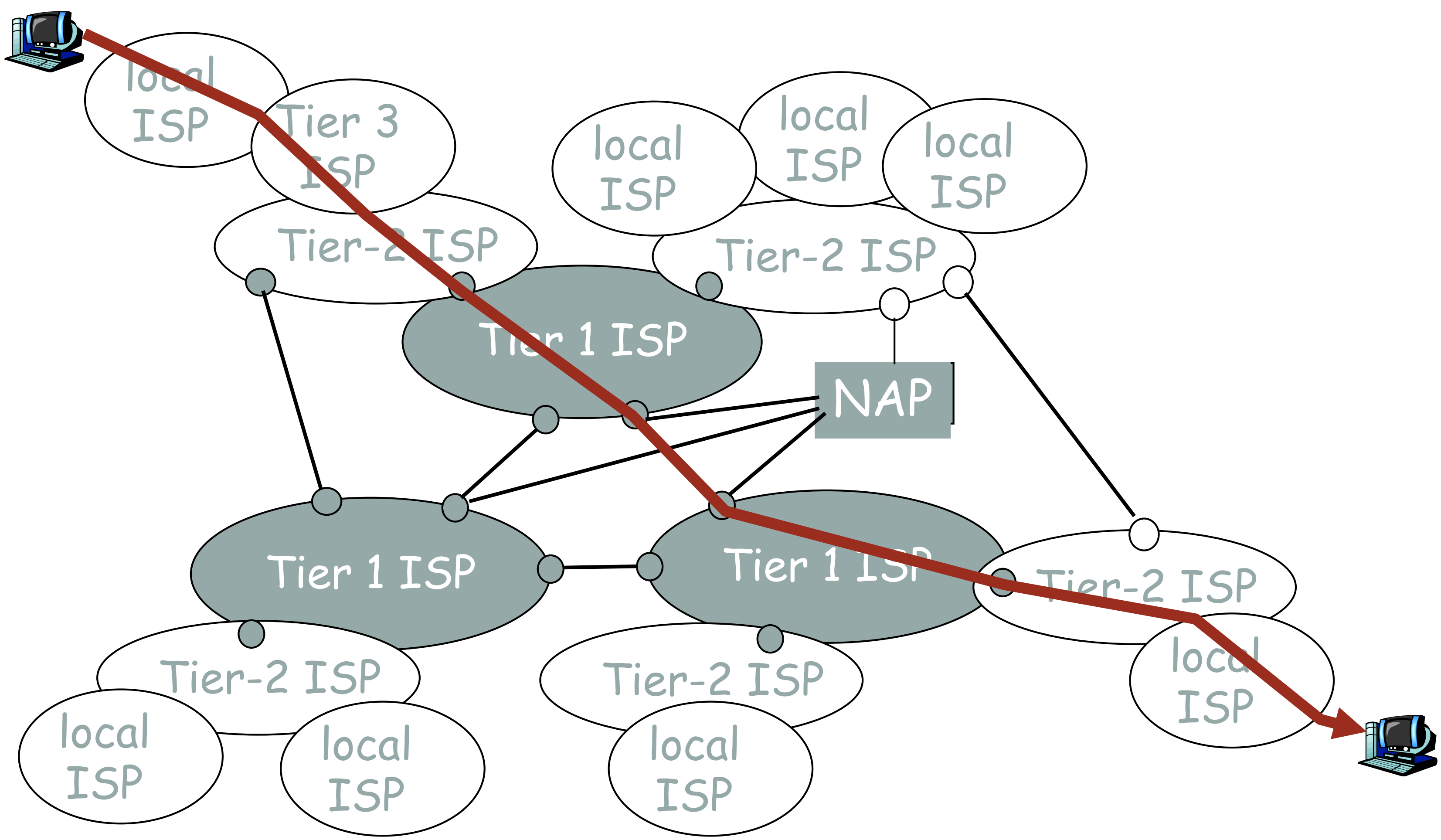
Internet structure: network of networks

- "Tier-3" ISPs and local ISPs
- Customer of higher tier ISPs
  - last hop ("access") network (closest to end systems)



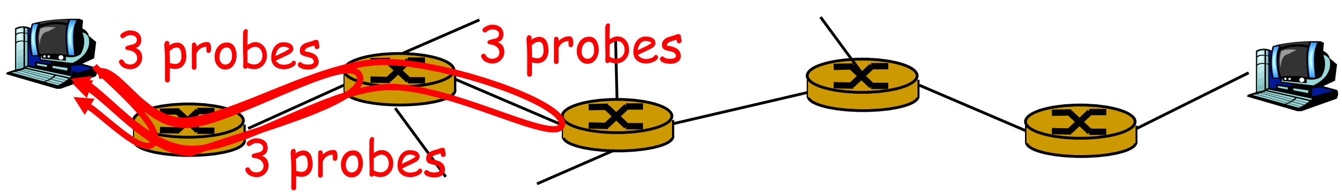
Internet structure: network of networks

- A message passes through many networks from source host to destination host !



Traceroute – a tool to look inside the “blackbox” of the Internet

- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination. For all i:
  - sends three packets that will reach router i on path towards destination
  - router i will return packets to sender
  - sender times interval between transmission and reply.



Traceroute from Campus

32 bit numbers in dot decimal representati

- Why 3 different values?

```
traceroute to www.uh.edu (129.7.97.54), 64 hops max, 52 byte packets
 1  172.17.48.1 (172.17.48.1)  7.514 ms  2.156 ms  2.658 ms
 2  core-vss-wifi.net.mcmaster.ca (172.26.20.10)  2.739 ms  2.954 ms  2.647 ms
 3  campus-border.net.mcmaster.ca (130.113.69.4)  3.138 ms  3.339 ms  4.886 ms
 4  66.97.23.21 (66.97.23.21)  2.706 ms  3.788 ms  5.572 ms
 5  66.97.16.141 (66.97.16.141)  6.776 ms  4.854 ms  5.098 ms
 6  toro1rtr1.network.canarie.ca (205.189.32.41)  4.357 ms  * 4.752 ms
 7  205.189.32.240 (205.189.32.240)  17.844 ms  16.367 ms  16.799 ms
 8  fourhundredge-0-0-0-2.4079.core1.chic.net.internet2.edu (163.253.2.20)  44.382 ms  42.879 ms  43.087 ms
 9  fourhundredge-0-0-0-1.4079.core2.kans.net.internet2.edu (163.253.2.29)  44.138 ms  42.722 ms  40.097 ms
10  fourhundredge-0-0-0-1.4079.core2.dall.net.internet2.edu (163.253.2.10)  42.359 ms  41.667 ms  43.598 ms
11  fourhundredge-0-0-0-1.4079.core1.hous.net.internet2.edu (163.253.1.15)  40.339 ms  38.901 ms  43.115 ms
12  fourhundredge-0-0-0-0.4079.core1.houh.net.internet2.edu (163.253.2.24)  41.770 ms  41.508 ms  40.482 ms
13  74.200.187.54 (74.200.187.54)  40.180 ms  93.106 ms  41.878 ms
14  74.200.187.46 (74.200.187.46)  39.694 ms  39.378 ms  38.919 ms
15  hou3-edge1.r.setg.net (198.32.229.152)  40.789 ms  39.427 ms  38.878 ms
16  uh-1.r.setg.net (198.32.229.153)  40.515 ms  41.673 ms  40.352 ms
17  * * *
18  * * *
19  * * *
20  uh.edu (129.7.97.54)  39.478 ms  38.561 ms  38.839 ms
```

- Who decides the route?
- How does the program know which hop?

Did we cross the ocean somewhere?

traceroute to www.nhs.uk (104.127.41.46), 64 hops max, 52 byte packets

1 172.17.48.1 (172.17.48.1) 7.200 ms 4.877 ms 1.552 ms

2 core-vss-wifi.net.mcmaster.ca (172.26.20.10) 2.018 ms 1.753 ms 1.554 ms

3 campus-border.net.mcmaster.ca (130.113.69.4) 2.255 ms 2.259 ms 2.018 ms

4 66.97.23.21 (66.97.23.21) 2.268 ms 2.490 ms 2.369 ms

5 66.97.16.141 (66.97.16.141) 5.306 ms

66.97.16.145 (66.97.16.145) 8.301 ms 8.275 ms

6 66.97.16.2 (66.97.16.2) 5.459 ms

66.97.16.9 (66.97.16.9) 8.535 ms 8.248 ms

7 ca-1-1-c8.ter1.ord7.us.zip.zayo.com (128.177.76.41) 19.851 ms 18.127 ms *

8 * * *

9 * * *

10 * * *

11 ae12.mcs1.lhr11.uk.eth.zayo.com (64.125.28.225) 123.760 ms 102.718 ms 103.423 ms

12 94.31.33.246.ipyx-264640-zyo.zip.zayo.com (94.31.33.246) 425.828 ms 107.063 ms 108.087 ms

13 a104-127-41-46.deploy.static.akamaitechnologies.com (104.127.41.46) 108.747 ms 108.554 ms 110.884 ms

Who is McMaster’s ISP?

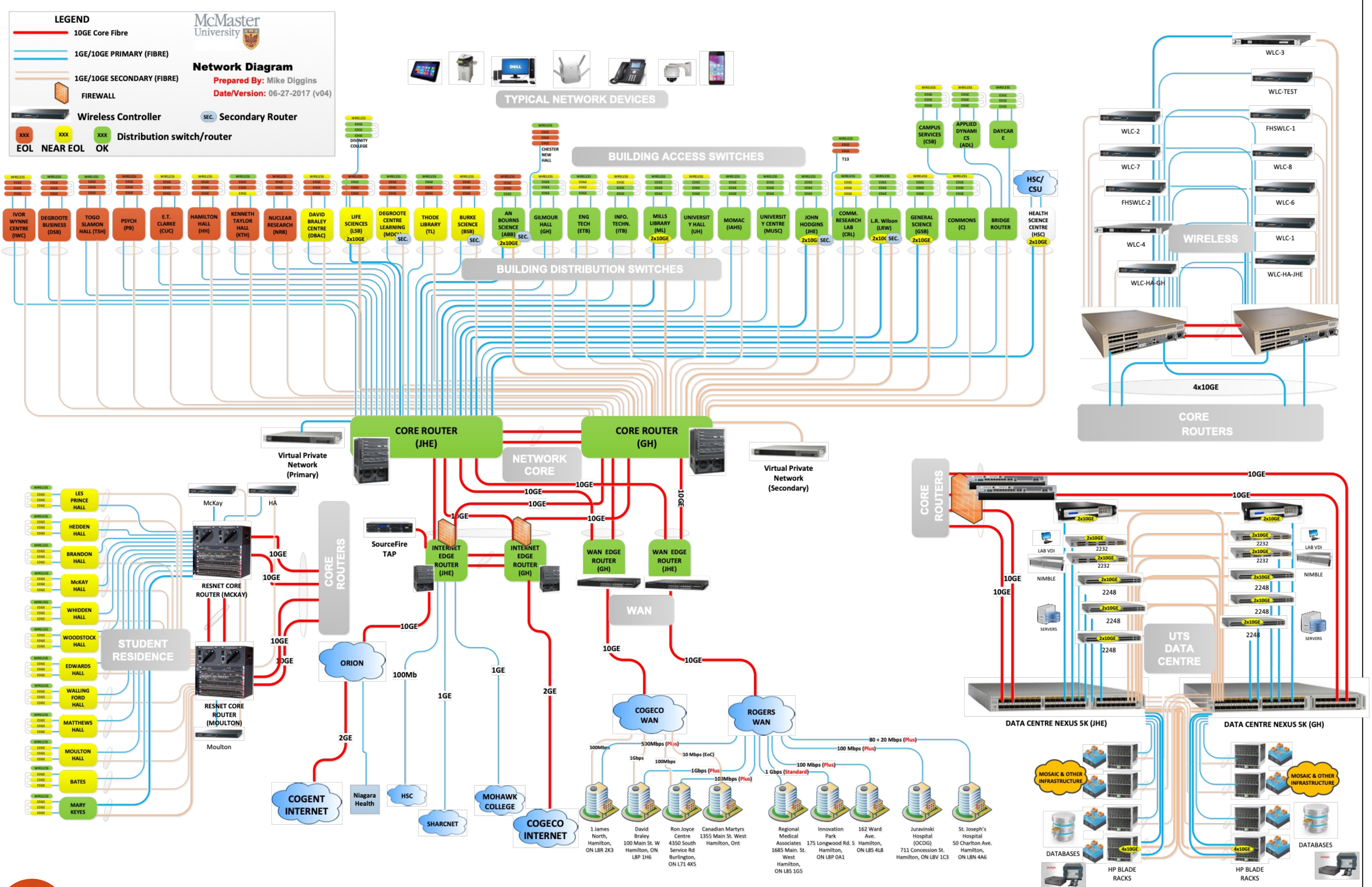
IP range details

66.97.23.0/24

AS26677 · ORION

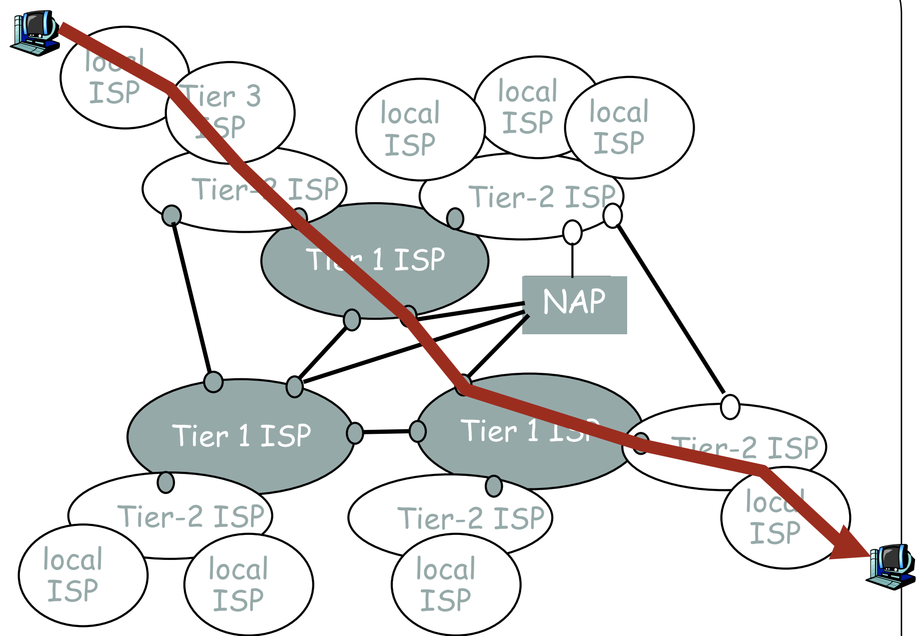
Summary

Country	Canada
Domain	orion.on.ca
ASN	AS26677
Registry	arin
Hosted IPs	256
ID	ORION


LEGEND
10GE Core Fibre
1GE/10GE PRIMARY (FIBRE)
1GE/10GE SECONDARY (FIBRE)
FIREWALL
Wireless Controller
Secondary Router
EOL
NEAR EOL
OK
Distribution switch/router
McMaster University
Network Diagram
Prepared By: Mike Diggins
Date/Version: 06-27-2017 (v04)
TYPICAL NETWORK DEVICES
BUILDING ACCESS SWITCHES
BUILDING DISTRIBUTION SWITCHES
WIRELESS
CORE ROUTERS
CORE ROUTER (JHE)
CORE ROUTER (GH)
NETWORK CORE
Virtual Private Network (Primary)
Virtual Private Network (Secondary)
STUDENT RESIDENCE
RESNET CORE ROUTER (MCKAY)
RESNET CORE ROUTER (MOULTON)
SourceFire TAP
INTERNET EDGE ROUTER (JHE)
INTERNET EDGE ROUTER (GH)
WAN EDGE ROUTER (GH)
WAN EDGE ROUTER (JHE)
WAN
ORION
COGENT INTERNET
Niagara Health
HSC
SHARCNET
MOHAWK COLLEGE
COGECO INTERNET
COGECO WAN
ROGERS WAN
UTS DATA CENTRE
DATA CENTRE NEXUS 5K (JHE)
DATA CENTRE NEXUS 5K (GH)
MOSAIC & OTHER INFRASTRUCTURE
DATABASES
HP BLADE RACKS
4x10GE

Review

- Internet is a network of networks consisting of ISPs at different tiers
  - Resilience
  - “multihoming”
- Traceroute allows end hosts to “probe” the paths that packets follows to specified destination



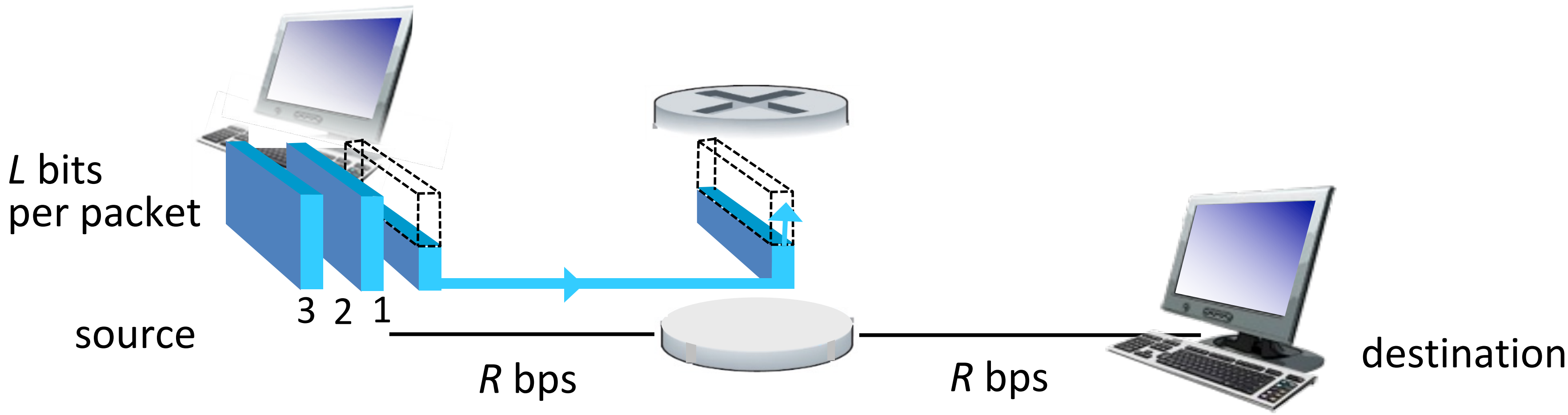
```
 3  campus-border.net.mcmaster.ca (130.113.69.4)  3.138
ms  3.339 ms  4.886 ms
 4  66.97.23.21 (66.97.23.21)  2.706 ms  3.788 ms  5.572 ms
 5  66.97.16.141 (66.97.16.141)  6.776 ms  4.854 ms  5.098
ms
 6  toro1rtr1.network.canarie.ca (205.189.32.41)  4.357
ms  *  4.752 ms
```

Why do packet losses occur?

Why are there variable delays? -- what causes the delay?

And, what to do about them?

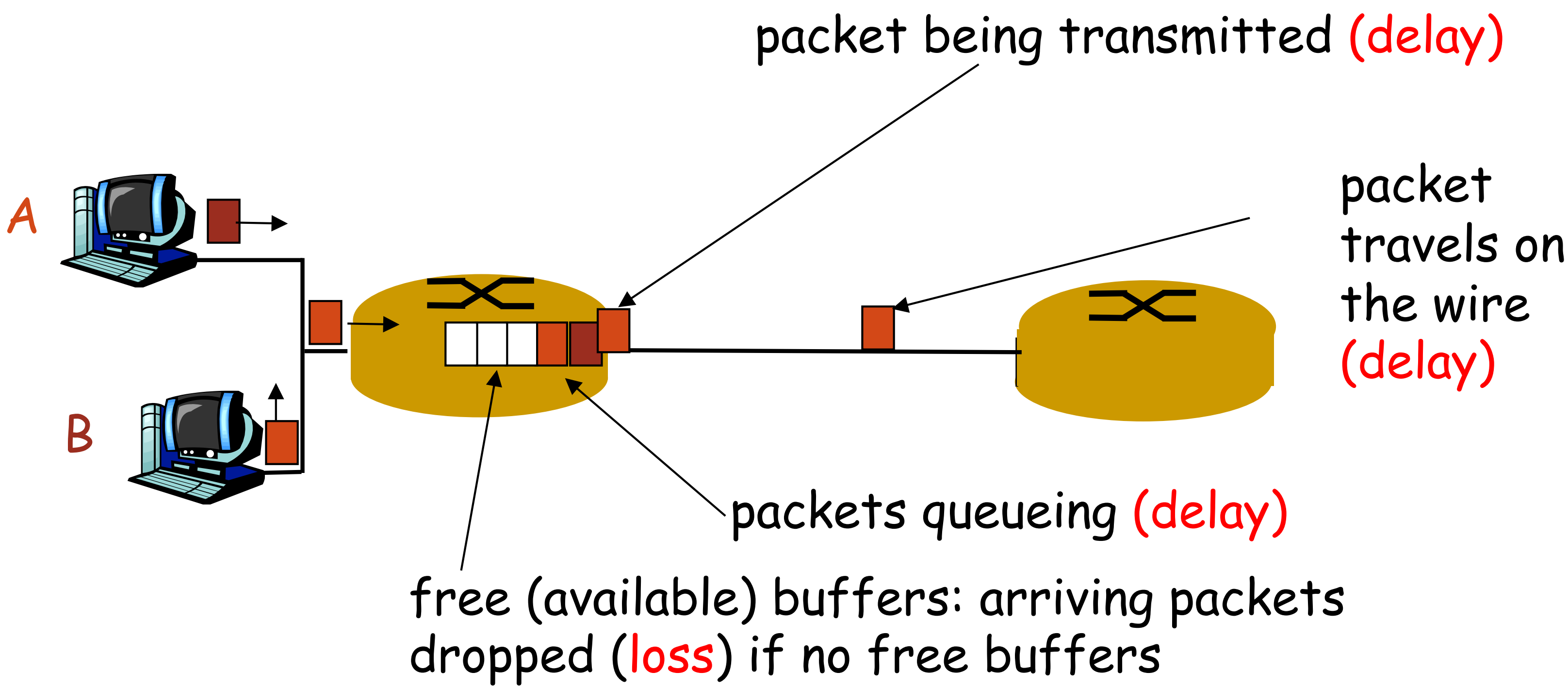
Packet-switching: store-and-forward



- Application message is broken down into packets, typically ~1000 bytes
- store and forward:
  - entire packet must arrive at a router before it can be transmitted on next link
  - forward packets from one router to the next, across links on path from source to destination
- Individual packets can be forwarded along different network paths

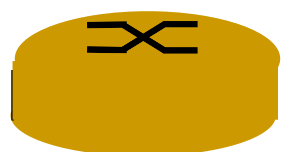
How do loss and delay occur?

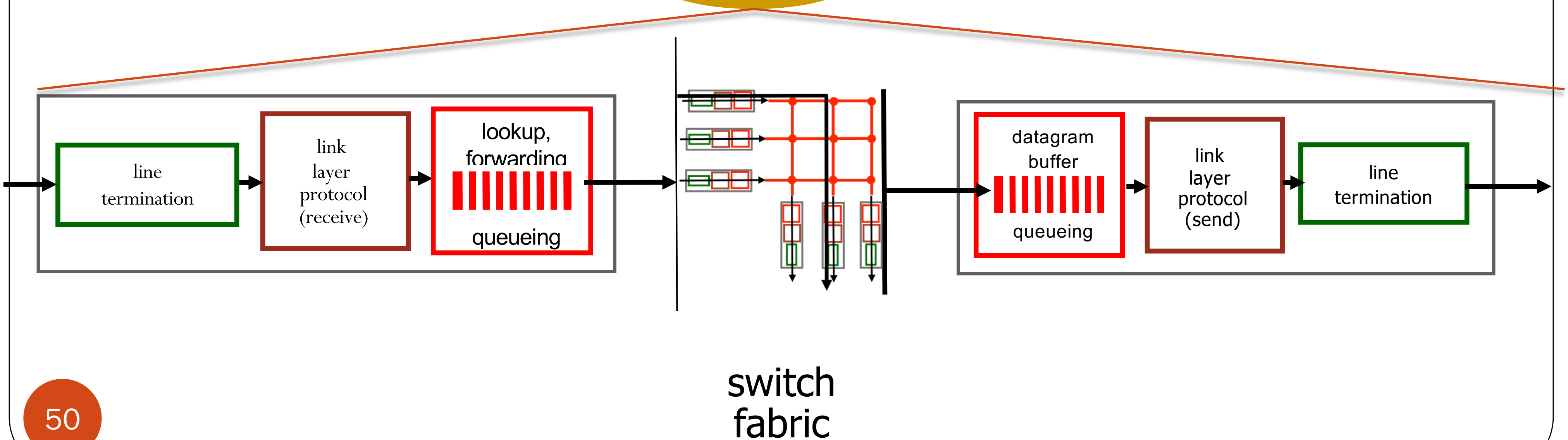
- packets stored in router buffers
- When packet arrival rate to link exceeds output link capacity
  - packets queue, wait for turn



How do loss and delay occur?

- packets stored in router buffers
- When packet arrival rate to link exceeds output link capacity
  - packets queue, wait for turn





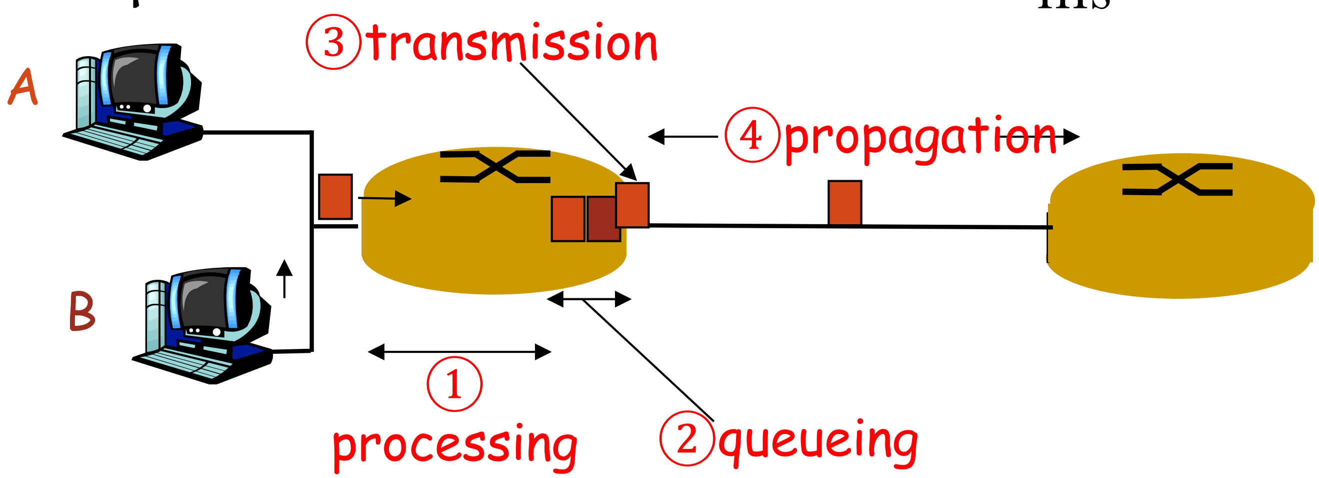
Four sources of packet delay

1. Processing delay (computational):

- check bit errors
- determine output link
- Deep packet inspection
- μs

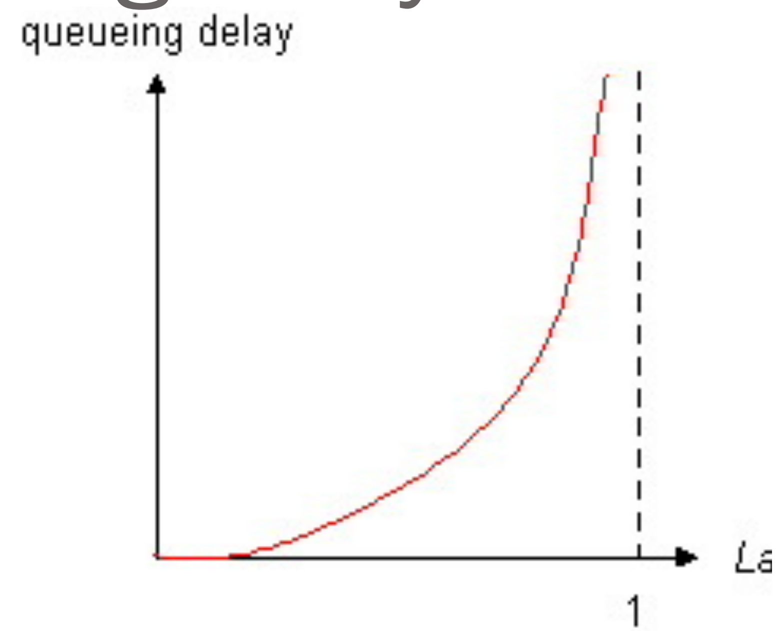
2. Queueing delay

- time waiting at output link for transmission
- depends on congestion level of router
- ms



② More on queueing delay

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate (packet/s)



traffic intensity = L*a/R

- L*a/R ~ 0: average queueing delay small
- L*a/R -> 1: delays become large
- L*a/R > 1: more "work" arriving than can be serviced, average delay infinite!
  - True if the buffer is infinite large
  - What about finite buffer?

Delay in packet-switched networks

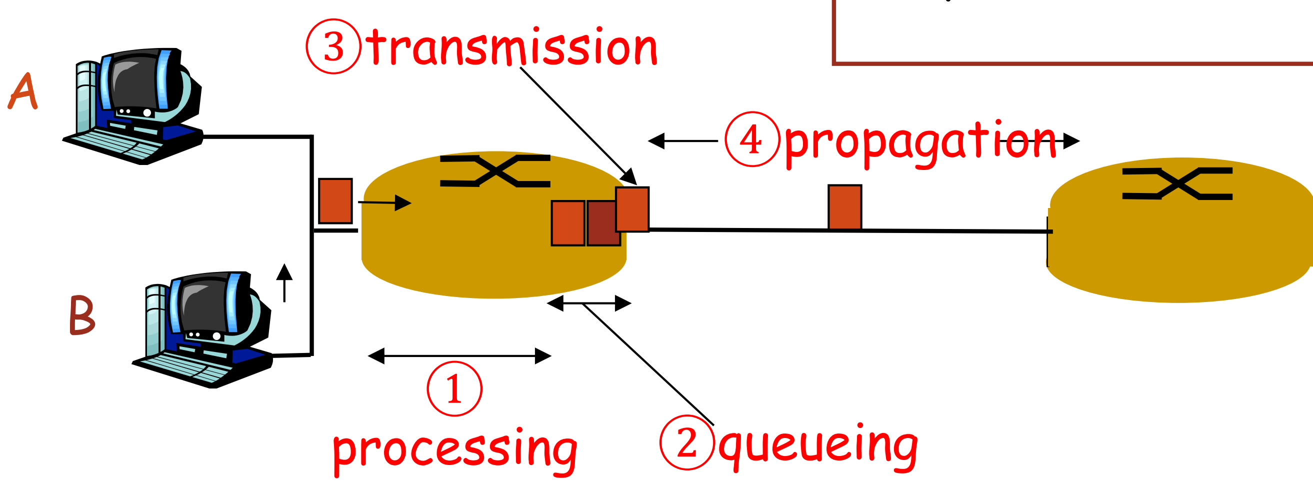
3. Transmission delay (outgoing):

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~$3x10^8$ m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!



Nodal delay

$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on the level of network loads
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Transmission vs propagation delay applet

Examples

- In the movie "The Martian", Houston sends a message of 50000 bytes to Mark on Mars over a radio link at speed 1Kbps
- Mars & Earth are at the orbital closet distance of 56 million km apart

Question: How long does it take for the message to reach Mark from Houston? (hint: 1. ignore the processing & queueing delay. 2. speed of EM waves = $3x10^8$)

Answer:

1. Transmission delay: 50000*8/1000 = 400 sec
2. Propagation delay: $56*10^9/3x10^8$ = 186 sec
3. Total delay = 586 sec

Examples

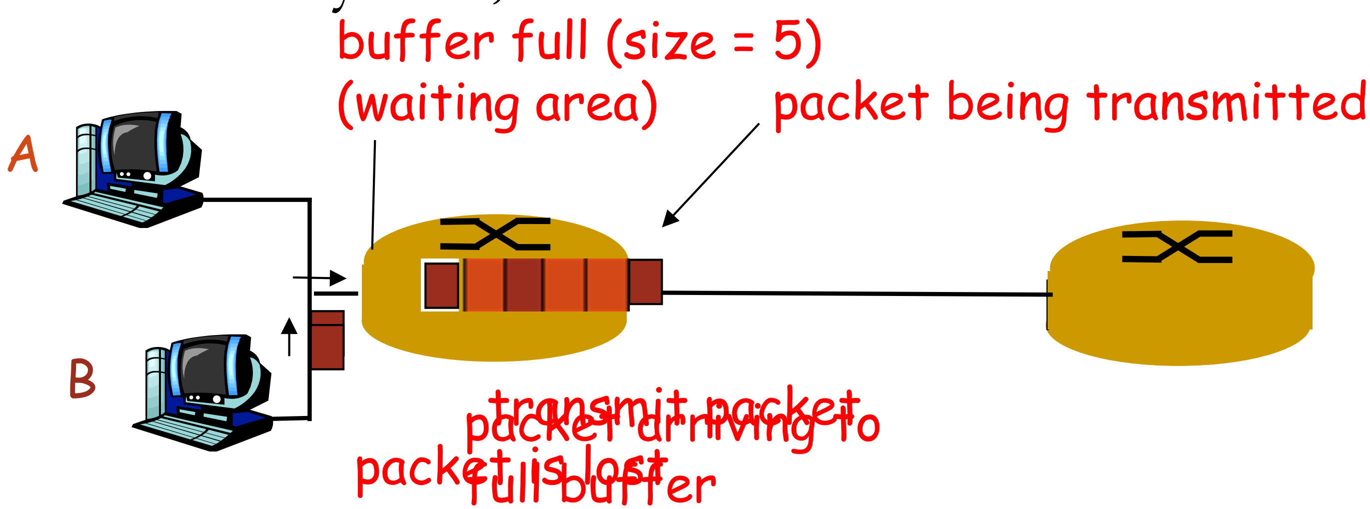
- Houston to send a message of 50000 bytes to Mark on Mars over a radio link at speed 1Kbps
- Mars & Earth are at the orbital furthest distance of 140 million km apart

Question:

- what changed?
- How long does it take for the message to reach Mark from Houston? (hint: 1. ignore the processing & queueing delay. 2. speed of light = 3×10^8)

Packet losses

- Transmission links can be unreliable
  - Bit error rate of ~10^{-6} in radios and 10^{-15} over optical
- queue (aka buffer) has finite capacity
  - when packet arrives to full queue, packet is dropped (aka lost) -- Which one gets dropped?
- lost packet may be retransmitted by the previous node, by the source end system, or not retransmitted at all

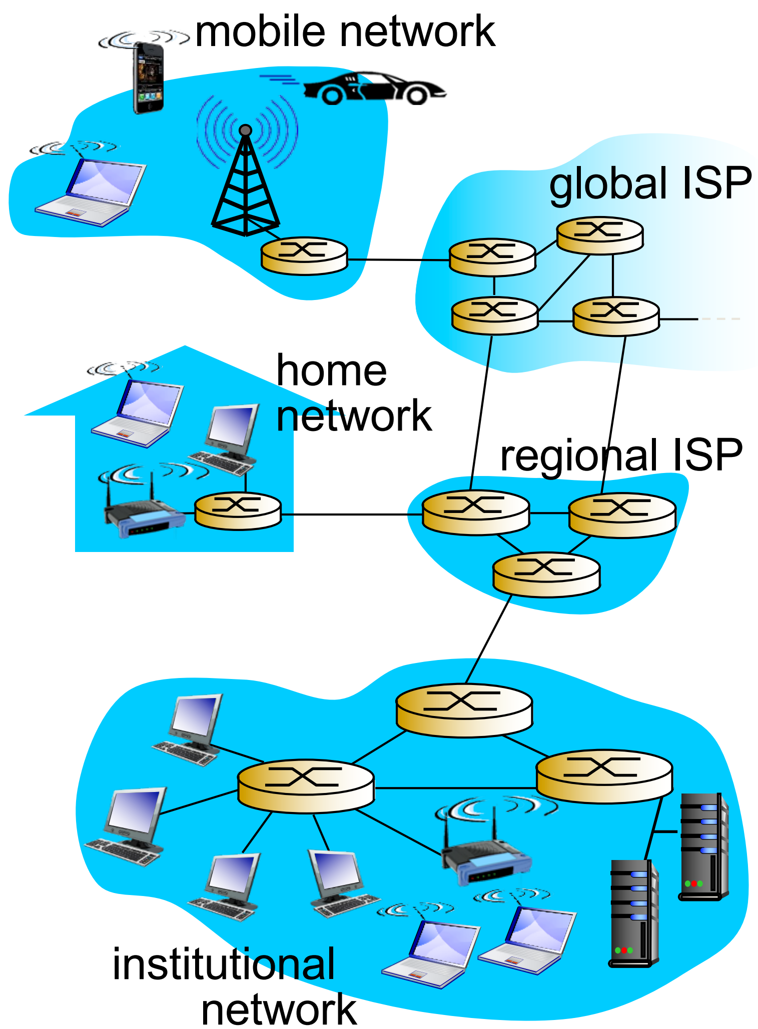


Outline

- A little walk down the memory lane
- Nuts and bolts of the Internet
- The Internet architecture and design principles

Internet Protocols

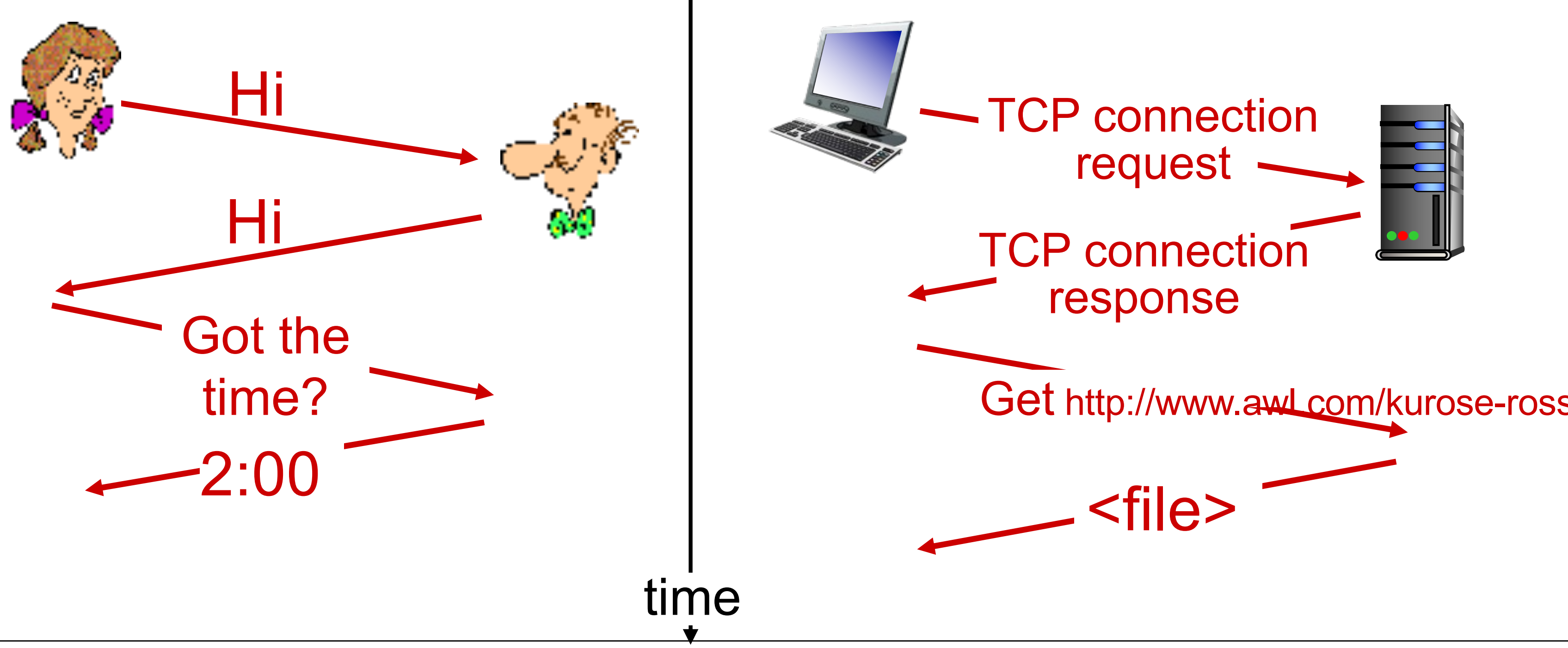
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What’s a protocol?

- Protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt
  - e.g., TCP, IP, HTTP, FTP, PPP, ICMP

human protocol | computer network protocol



Protocol "Layers"

Networks are complex!

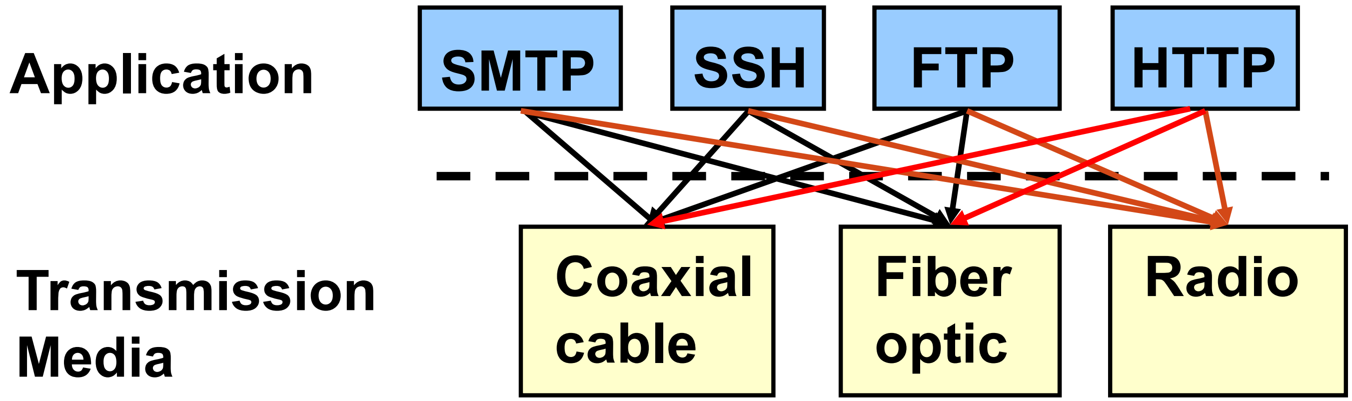
with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

- Is there any hope of organizing structure of network?
- Or at least our discussion of networks?

Why layering? An Imaginary 2-tier



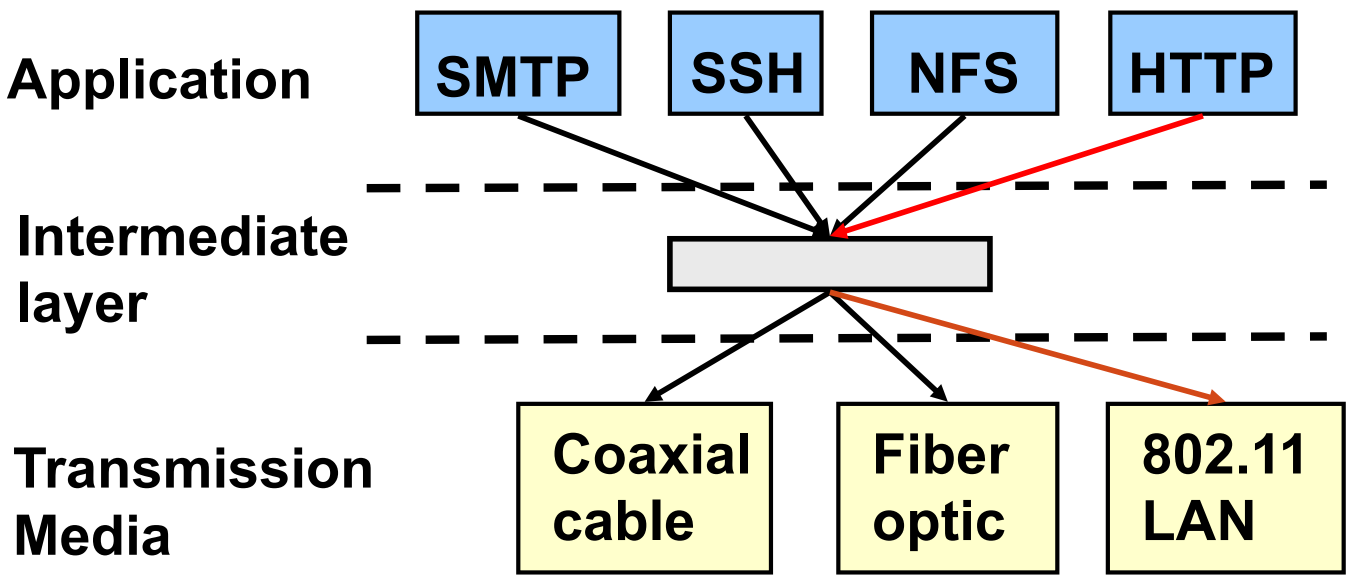
- New application has to interface to all existing media
  - adding new application requires O(m) work, m = number of media
- New media requires all existing applications be modified
  - adding new media requires O(a) work, a = number of applications
- Total work in system O(ma) → eventually too much work to add apps/media
- Application end points may not be on the same media!

"All problems in computer science can be solved by another level of indirection"

- David Wheeler

Solution: Indirection

- Solution: introduce an intermediate layer that provides a single abstraction for various network technologies
  - O(1) work to add app/media
  - Indirection is an often used technique in computer science



Network Architecture

- Architecture is not the implementation itself
- Architecture is how to "organize" implementations
  - what interfaces are supported
  - where functionality is implemented
- Architecture is the modular design of the network

Software Modularity

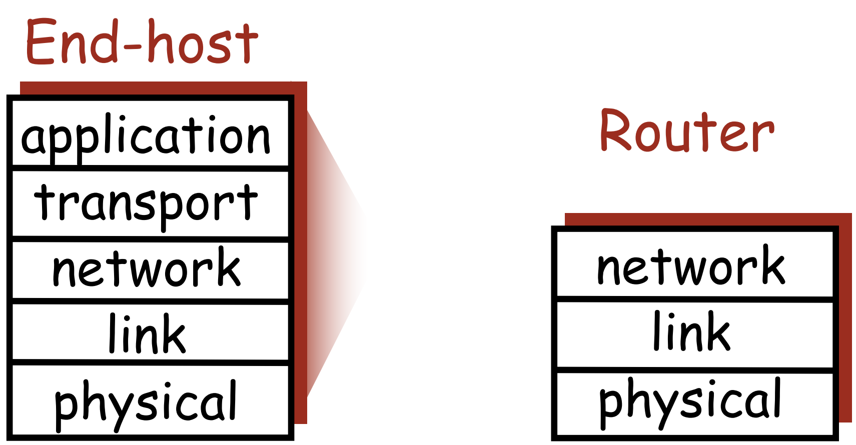
- Decompose system into modules
- Well-defined interfaces gives flexibility
  - can change implementation of modules
  - can extend functionality of system by adding new modules
- Interfaces hide information
  - Separation of concerns
  - allows for flexibility
  - but may hurt performance

Network Modularity

- Like software modularity, but with a twist:
- Implementation distributed across routers and hosts
- Must decide both:
  - **how to decompose system into modules**
  - **where modules are implemented**

Layering

- Layering is a particular form of modularization
- The system is broken into a vertical hierarchy of logically distinct entities (layers)
- Rigid structure: easy reuse, performance may suffer

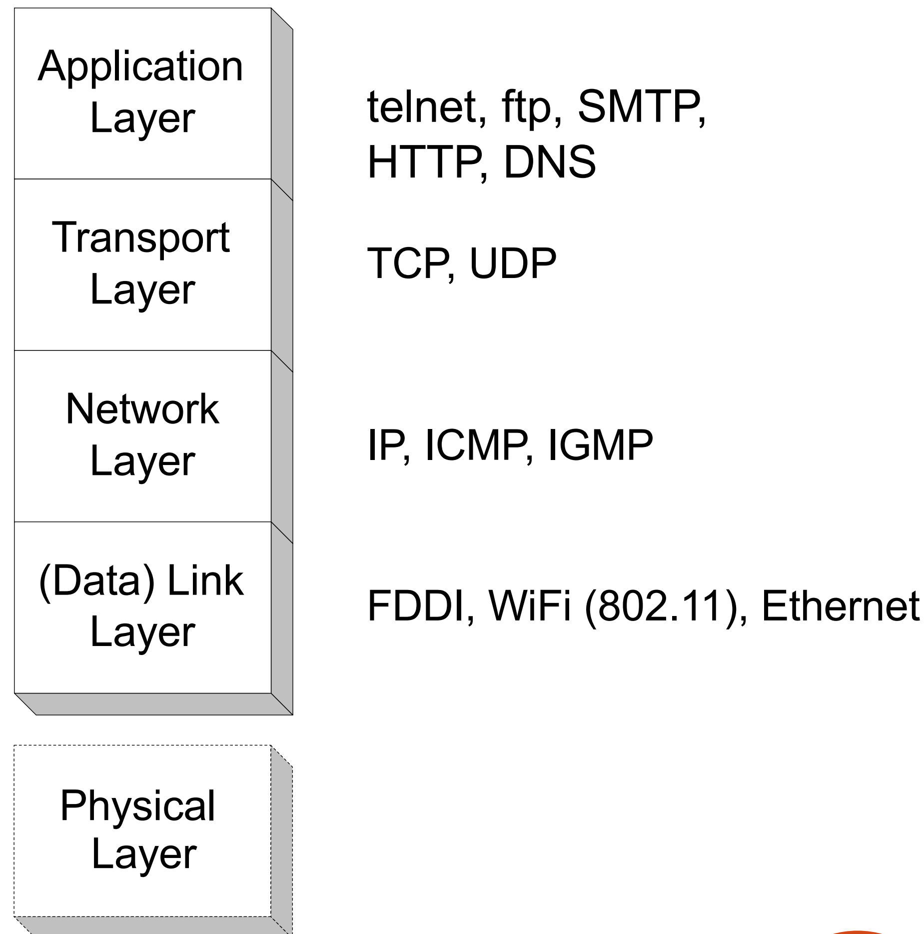


Key Concepts

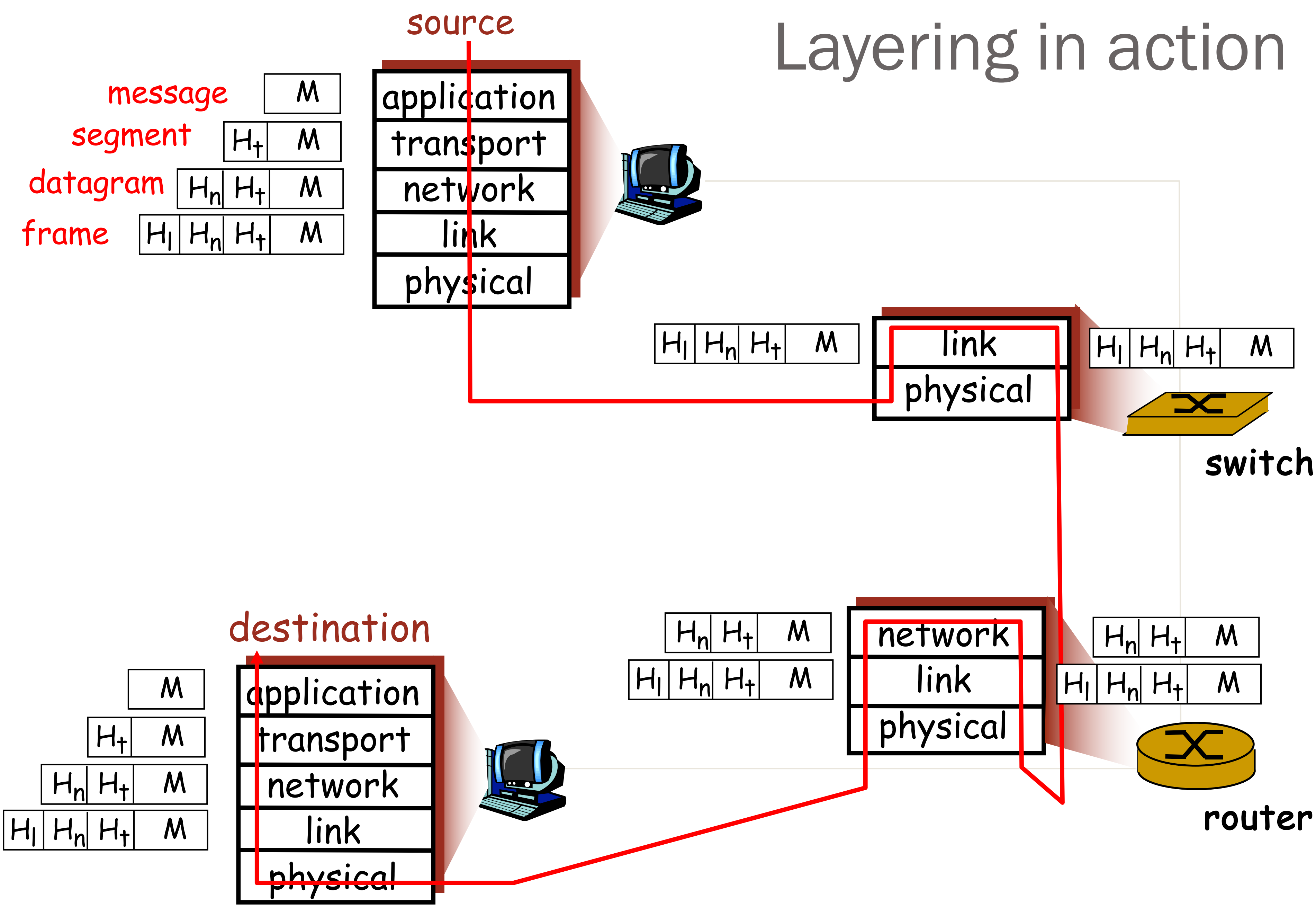
- Service – says what a layer does
  - Ethernet: unreliable subnet unicast/multicast/broadcast datagram service
  - IP: unreliable end-to-end unicast datagram service
  - TCP: reliable end-to-end bi-directional byte stream service
- Service Interface – says how to access the service
  - E.g. socket interface
- Protocol – says how is the service implemented
  - a set of rules and message formats that govern the communication between two peers

Internet Protocol Architecture

- The TCP/IP protocol suite is the basis for the networks that we call the Internet.
- The TCP/IP suite has four layers: Application, Transport, Network, and (Data) Link Layer.
- Computers (hosts) implement all four layers. Routers (gateways) only have the bottom two layers and some network devices only have implemented the bottom layer



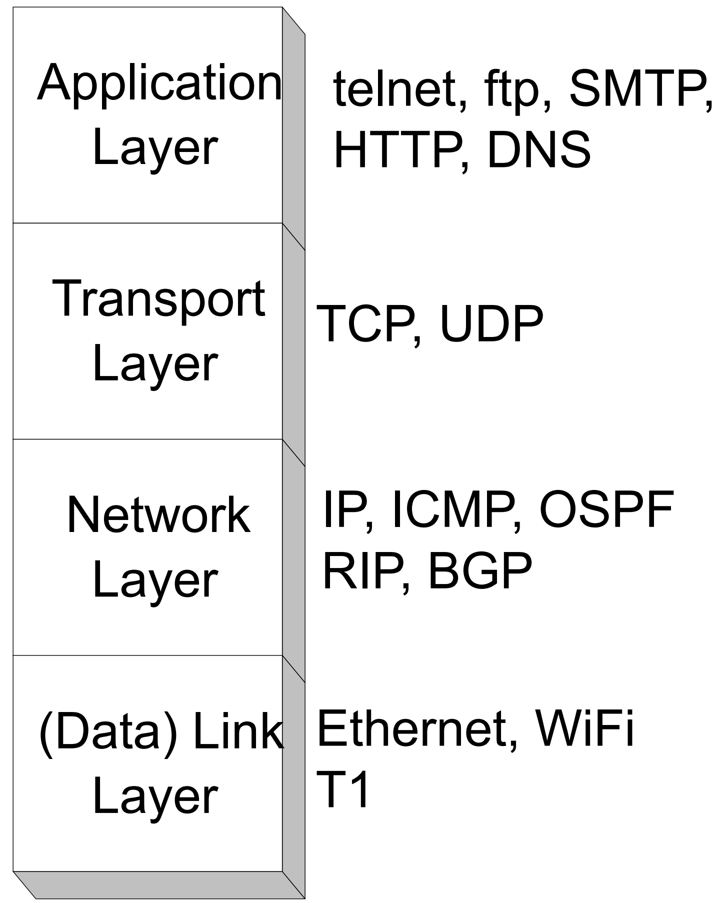
Layering in action



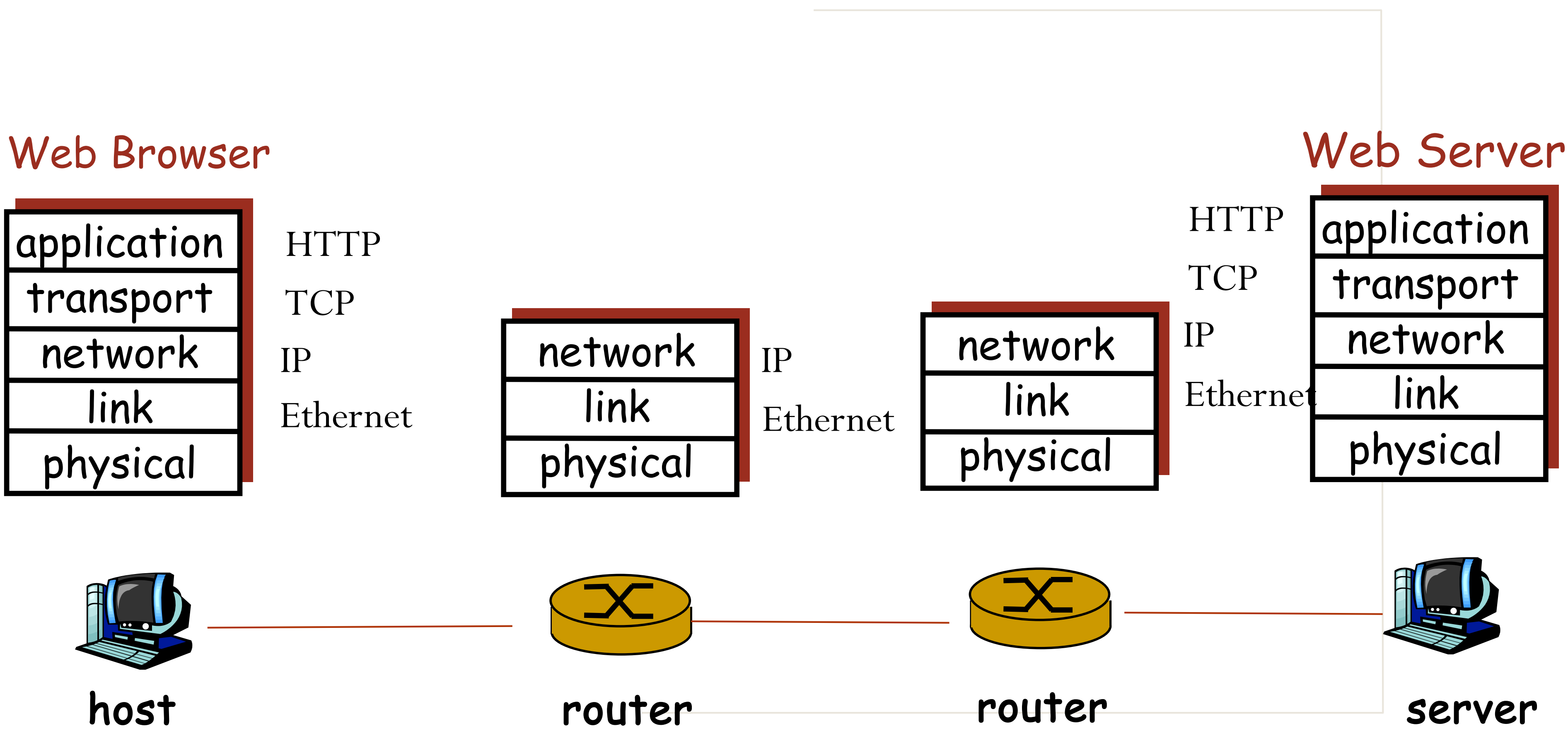
Encapsulation

Services of the Layers

- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: process-to-process data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination hosts
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP



Layering in an Example



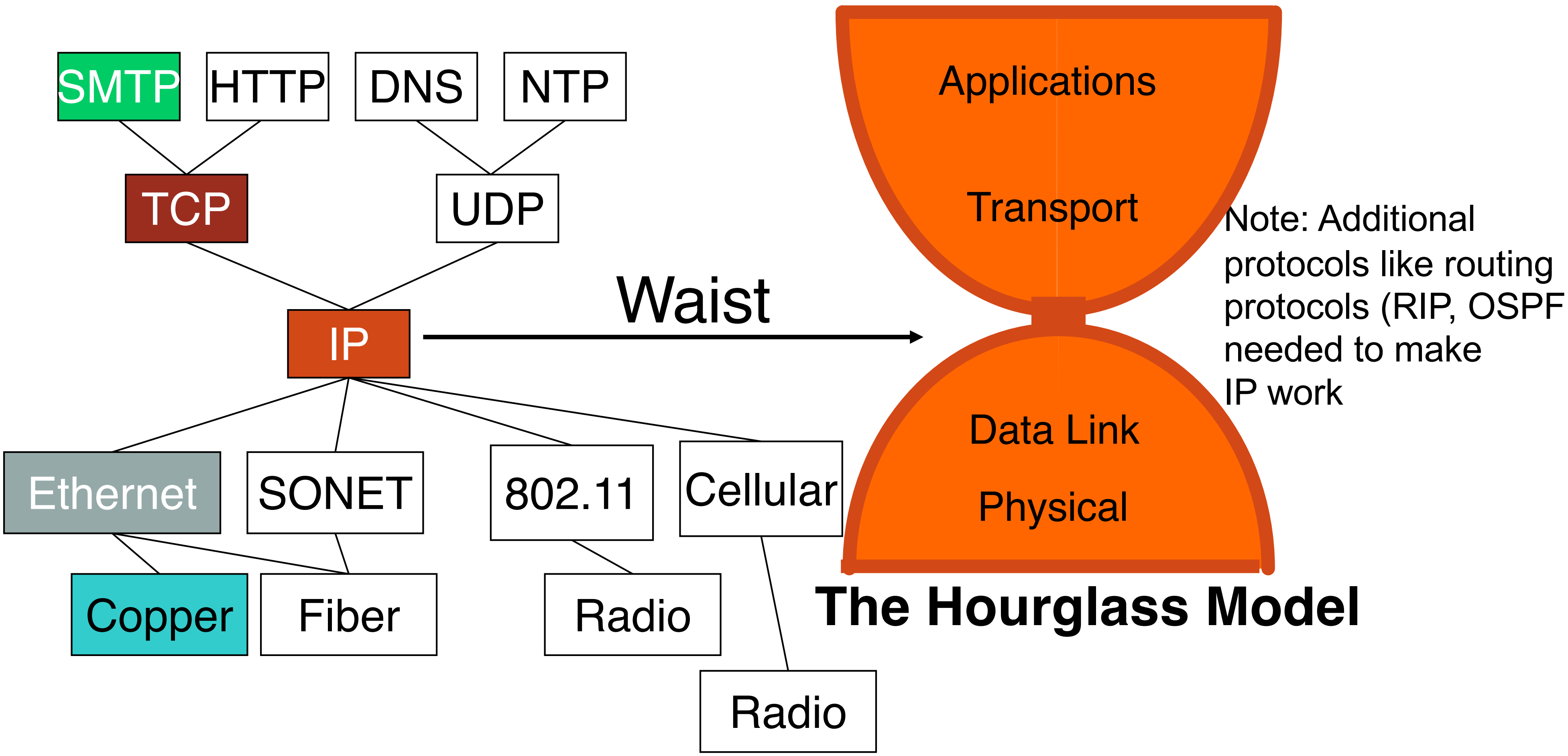
Reality

- Layering is a convenient way to think about networks
- But layering is not always followed rigorously
  - Middle-boxes: Firewalls, network address translation
  - Cross layer optimization

The Internet Design Question

- Support for common services (for diverse applications)
  - Reliability? In-order delivery? Guaranteed bandwidth? Low latency? Accountability? Security?
- What functionalities should be supported?
- Where should the functionality be placed?
  - inside the network? At the end systems? Or both?

The Hourglass Model



The Hourglass Model

IP core is unreliable, non-realtime, insecure

Implications of Hourglass

- A single Internet layer module
- Allows all networks to interoperate
  - all network technologies that support IP can exchange packets
- Allows all applications to function on all networks
  - all applications that can run on IP can use any network
- Simultaneous developments above and below IP
- Router implementation simplified

Chapter 1: Summary

- What's the Computer Network?
- network components
- Internet Structure: ISPs
- traceroute
- Packet-switching
- Performance: loss, (4 types of) delays
- What's a protocol?
- Layering: structure, services, protocols
- Wireshark

Take Home Messages