ECPE / COMP 177
Fall 2013

Computer Networking

Some slides from Kurose and Ross, *Computer Networking*, 5th Edition

Logistics

- Instructor: Dr. Jeff Shafer
  - Email: jshafer at pacific dot edu
  - Office: Anderson 205
  - Office hours *(posted on my door)*
    - Wed: 1:00-3:00pm
    - Thur: 2:00-4:00pm
    - *… plus whenever my office door is open*

Logistics

- Lecture
  - When: Tuesday / Thursday, 10am-11:45am
  - Where: Chambers 115
- Lab
  - When: Tuesday, 2-4:50pm
  - Where: Baun 214
  - Lab start date: Tue Sept 3rd
    - **No lab today**

Logistics

- Course websites:
  - http://ecs-network.serv.pacific.edu/ecpe-177
    - Slides, syllabus, schedule, assignments, and more
  - http://pacific.rsmart.com/
    - Sakai for assignment submission and emails only
    - Should auto-signup if enrolled in course

Pre-Requisites

- COMP 53 – Data structures
  - Programming in high level language
  - Basic data structures, arrays, pointers, functions, system calls, …
- ECPE 170 – Computer Systems and Networks
  - Linux / command-line usage
  - C programming

Logistics

- Course revised for Fall 2013
- *Old* vision:
  - Broad overview of all areas of networking
- *New* vision:
  - *What do I, as an **application programmer**, need to understand about computer networks (including software and hardware both on your computer and elsewhere on the network) in order to write efficient, high-performing programs?*

Course Format for 2013

- In-class Presentations – 8%
  - Two presentations
- Labs – 12%
  - Ten labs in Baun 214
  - Applying theoretical concepts to real-world network equipment (Cisco routers and switches)
- Exams
  - Mid-term exam – 10%
  - Final exam – 10%
  - Lab practical exam – 10%

Hands-on programming problem during class time

Course Format for 2013

- Projects – 50%
  - 5 programming projects using network sockets
  - Individual
  - Implementation platform: Linux
  - Python (3.2+), C (C99)
- Current projects (subject to change):
  - Web server (basic) + web server (parallel)
  - Latency / bandwidth measurement tool
  - Instant messenger / file sharing client

Survey

- Will have in-class project work days throughout the semester
  (also, exams will involve programming)
  - A laptop to bring to class would be ideal
  - Must be able to run Linux (either in a virtual machine, or dual boot)
- Do you have a laptop?
- Do we need an alternate plan?
  (USB key booting…)

Project 1 Demo

Assignment description posted on website.

We'll start project soon!

Questions?

? ? ?

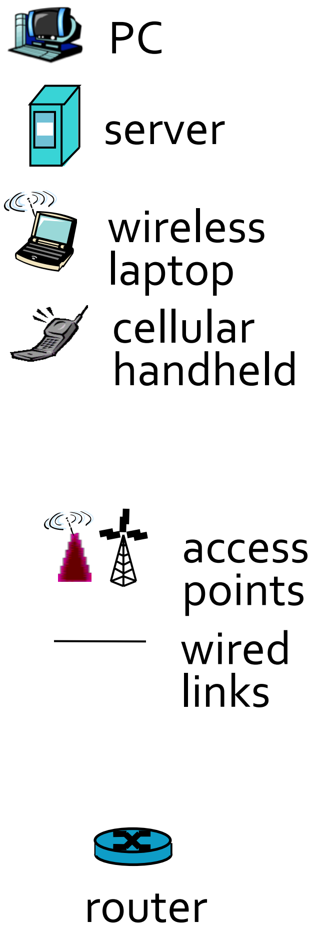
Intro to Networking

- What is the Internet?
- Network edge
  - End systems, access networks, links
- Network core
  - Packet switching, network structure
- Performance: Delay, loss and throughput in packet-switched networks
- Protocol layers, service models

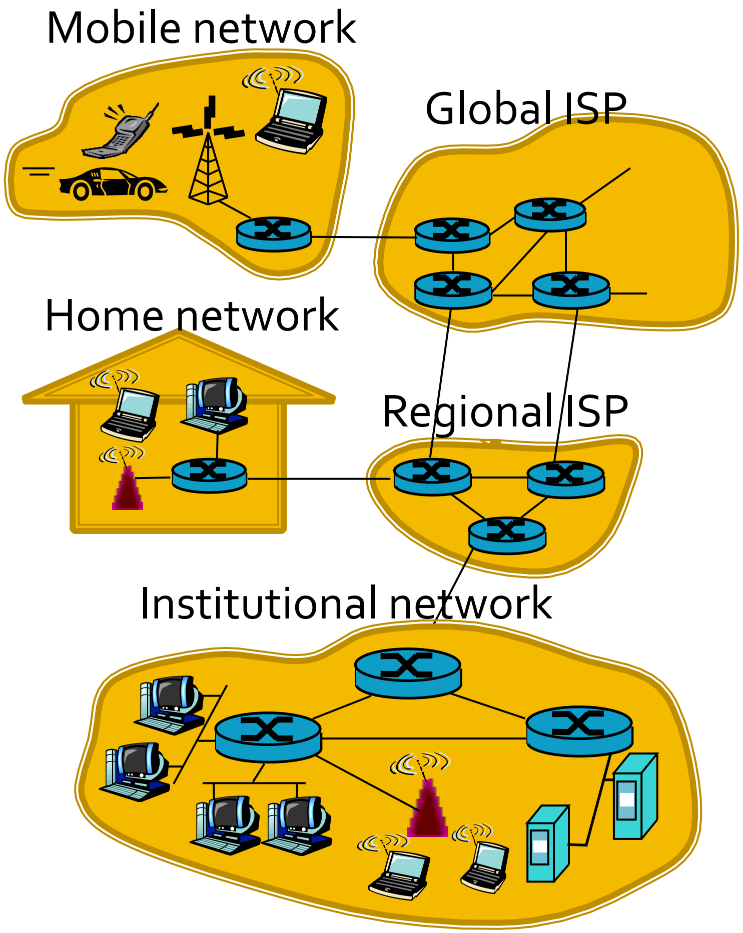
Networks are Ubiquitous

- What good is a computer when the network is down?
  - *I just keep hitting refresh on my web browser until something happens…*
- What good is my iPhone with no AT&T / Verizon service?
- What good is a TV without on-demand Netflix streaming?

What’s the Internet: High Level View

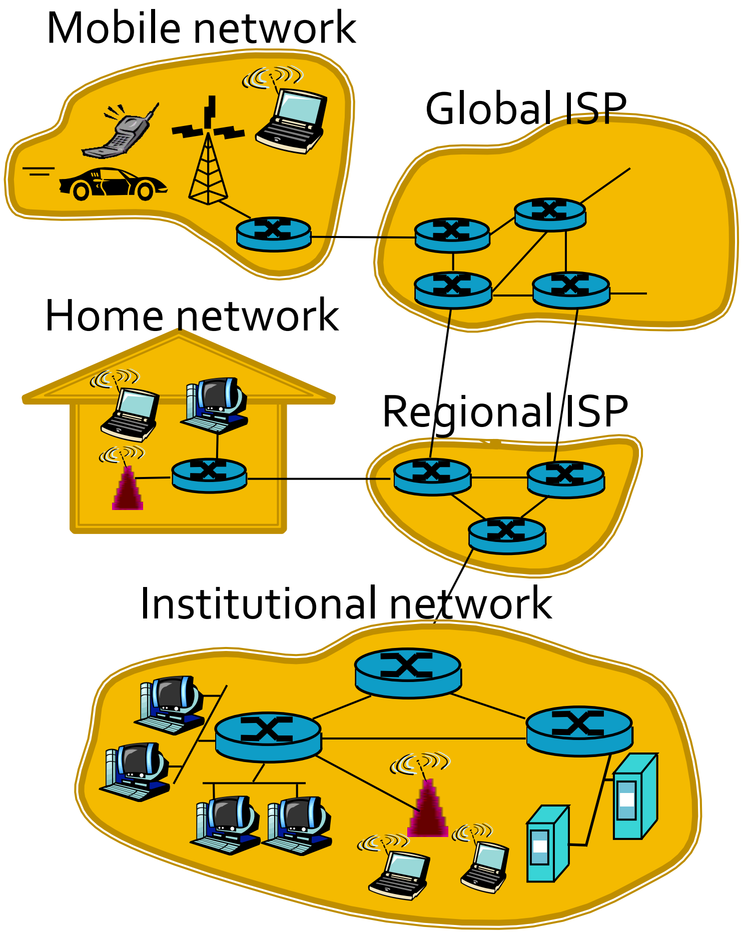


- **Hosts (end systems)**
  - Millions of connected computing devices
  - Running network apps
- **Communication links**
  - Fiber, copper, radio, satellite
  - Transmission rate = bandwidth
- **Routers**
  - Forward packets (chunks of data) between links



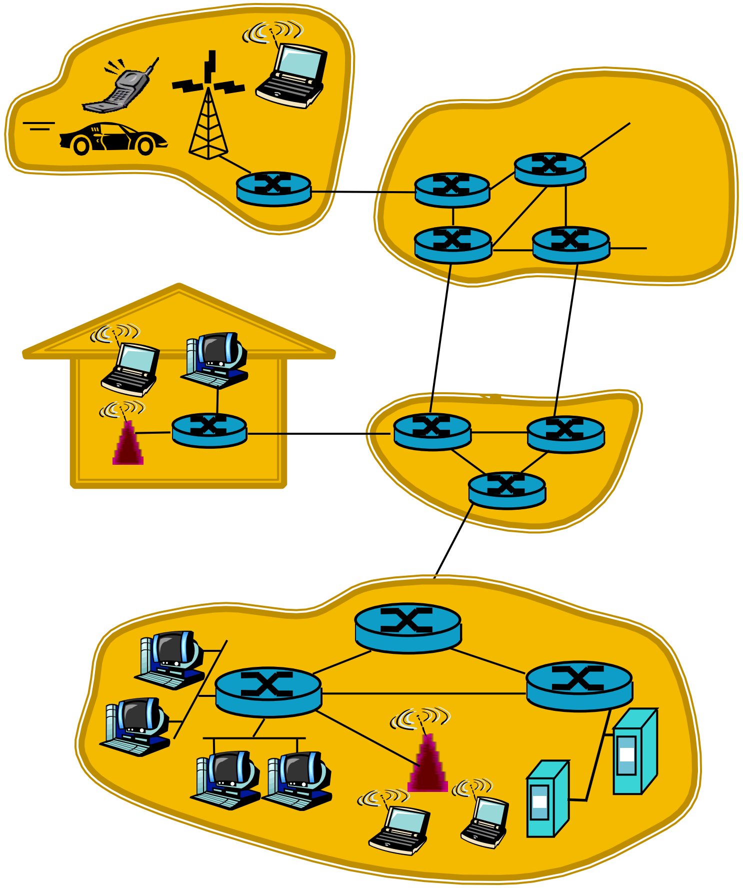
What's the Internet: High Level View

- **Protocols**
  - Control sending and receiving of messages
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- Internet standards
  - Who makes (some of) the protocols?
  - IETF: Internet Engineering Task Force
  - RFC: Request for comments
- **Internet**: "network of networks"
  - Loosely hierarchical
  - Public *Internet* versus private *intranet*



What’s the Internet: Service View

- **Communication infrastructure** enables distributed applications
  - Web, VoIP, email, games, e-commerce, file sharing
- **Communication services** provided to apps
  - Reliable data delivery from source to destination, *or*
  - “Best effort” (unreliable) data delivery



What’s a Protocol?

HUMAN PROTOCOLS

- “What’s the time?”
- “I have a question”
- Introductions

NETWORK PROTOCOLS

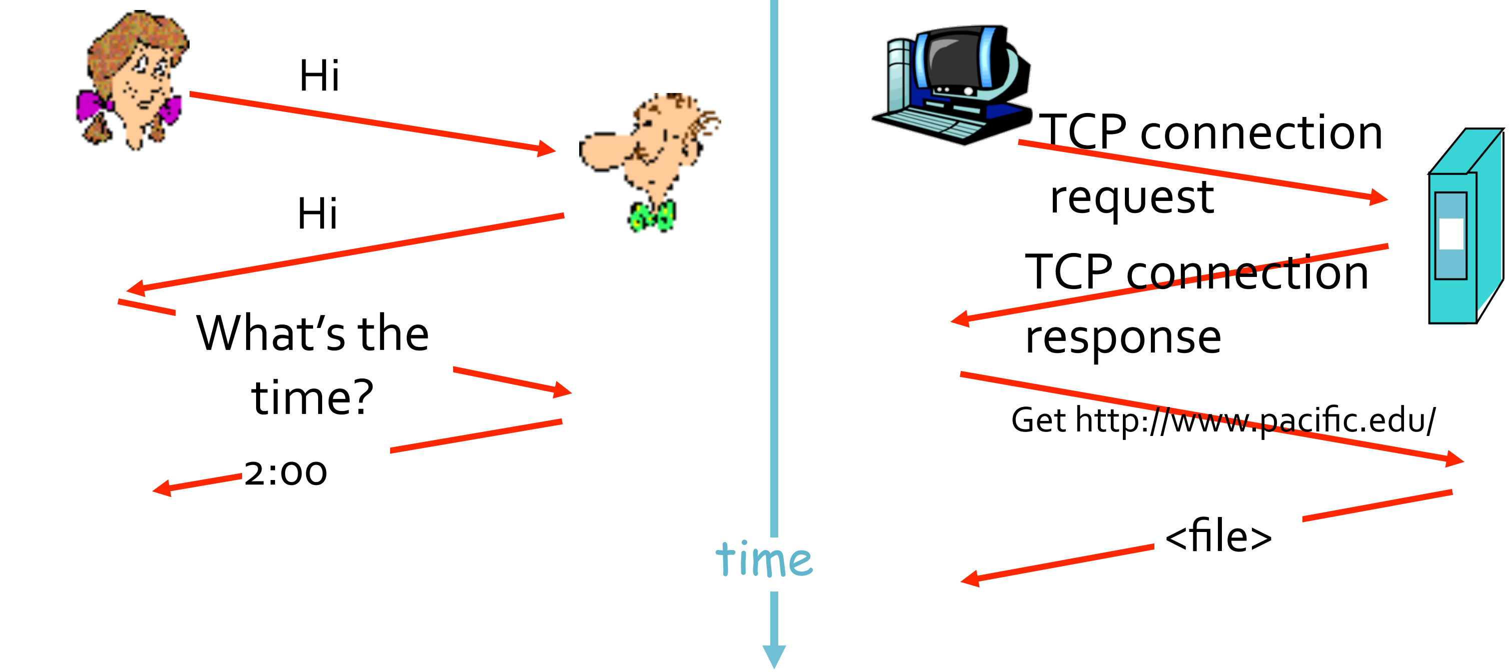
- Machines rather than humans
- All communication activity in Internet governed by protocols

- **Protocols (human and computer!) define**
  - Format of message
  - Order of messages sent/received on network
  - Actions taken after sending/receiving message

What’s a Protocol?

HUMAN PROTOCOL

COMPUTER NETWORK PROTOCOL



Hi

Hi

What’s the time?

2:00

time

TCP connection request

TCP connection response

Get http://www.pacific.edu/

<file>

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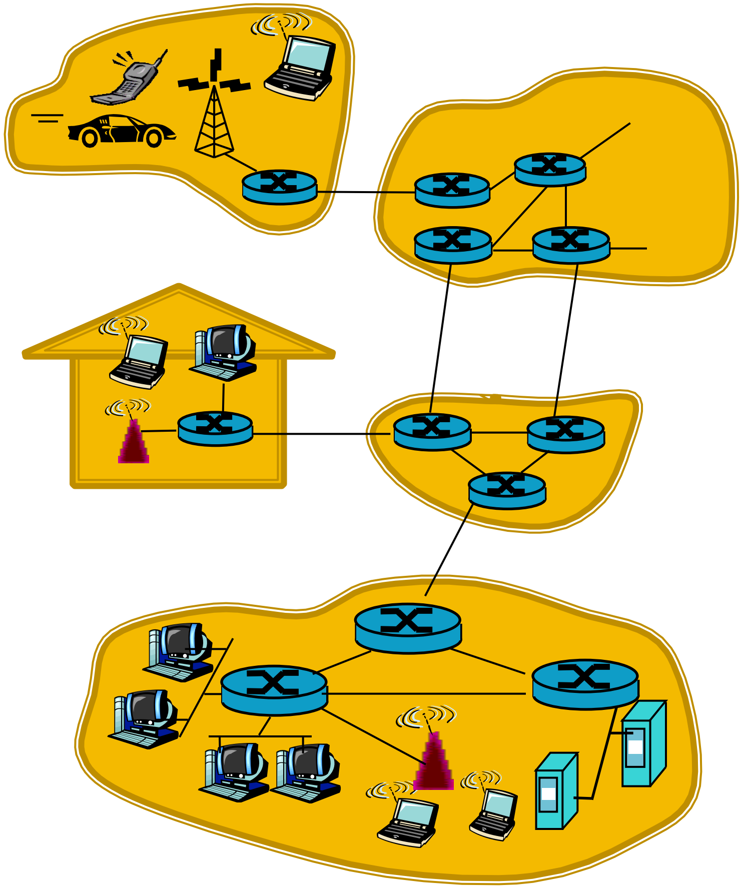
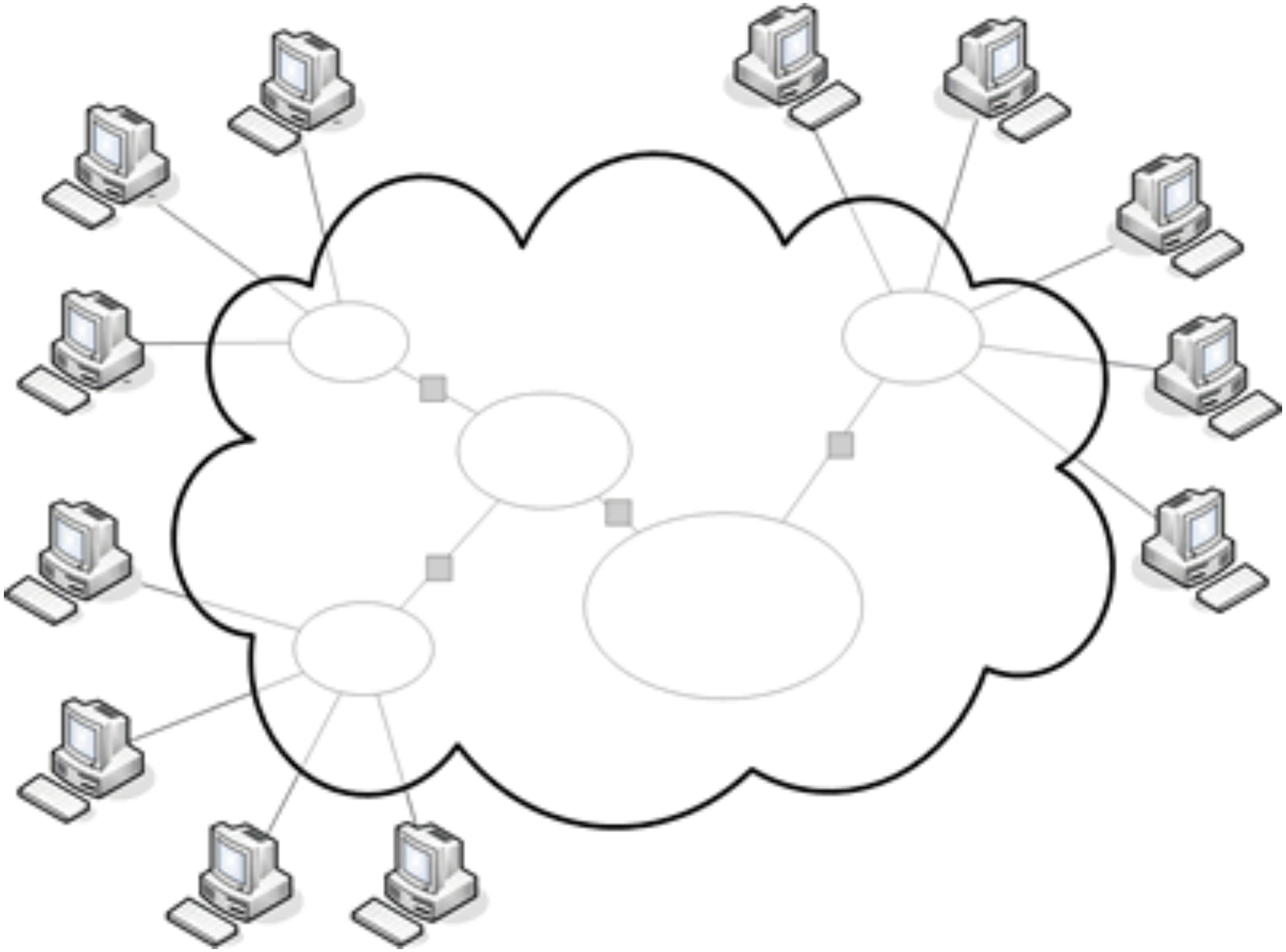
A Closer Look at Network Structure

- **Network edge**
  - Applications and hosts
- **Access networks and physical media**
  - Wired, wireless communication links
- **Network core**
  - Interconnected routers
  - Network of networks

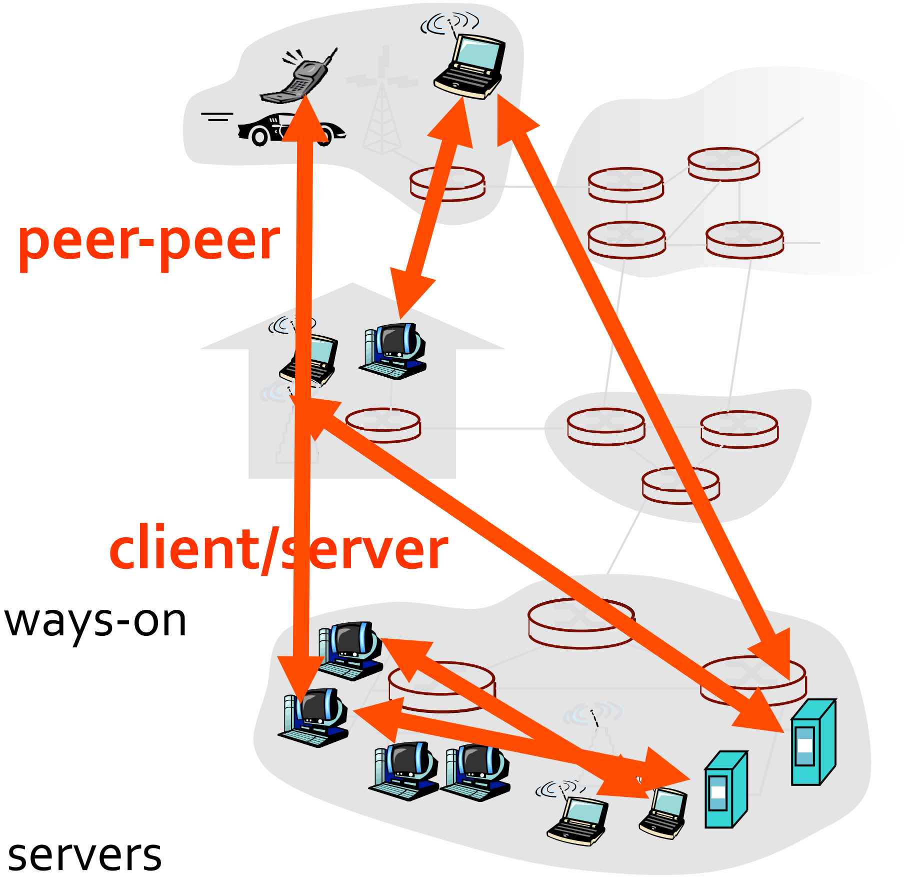


Why is it Called the Edge?



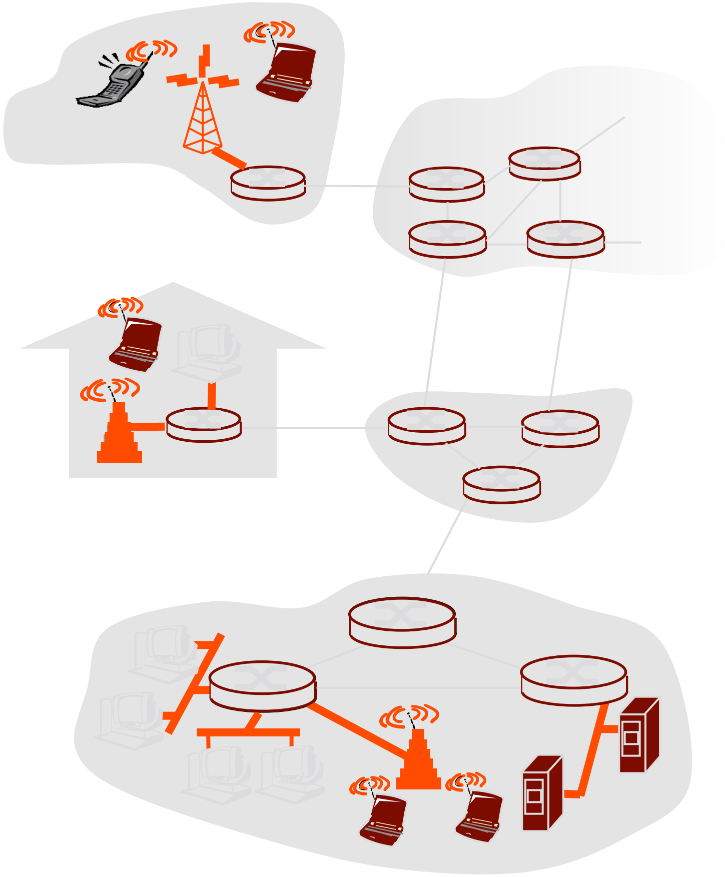
The Network Edge

- **End systems (hosts) at edge**
  - Run application programs
- Two models of applications
  - Client/server
  - Peer-to-Peer (P2P)
  - **What's the difference?**
- **Client/server model**
  - Client host requests data from always-on server (e.g. web, email, …)
- **Peer-to-peer model**
  - Minimal (or no) use of dedicated servers (e.g. Skype, BitTorrent)



Access Networks + Physical Links

- **How do you connect hosts to the nearest edge router?**
  - Residential access network
  - Institutional access networks (school, company)
  - Mobile access networks
- Concerns
  - Bandwidth (bits per second) of access network
  - Other concerns?
    - Shared or dedicated?
    - Cost?
    - Reliability?
    - Blocking / filtering?



Common Access Networks

- Digital Subscriber Line (DSL)
- Cable Modem
- Fiber to the home
- Ethernet
- Wireless LAN (WiFi)
- Wide-area wireless (3G, 4G, LTE, …)

- **What do you use?**

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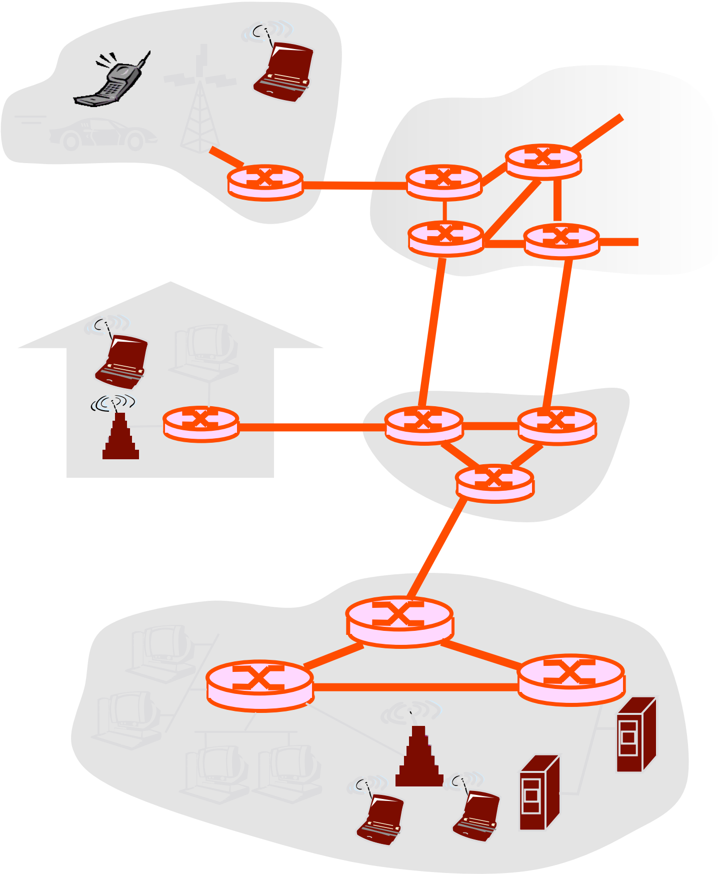
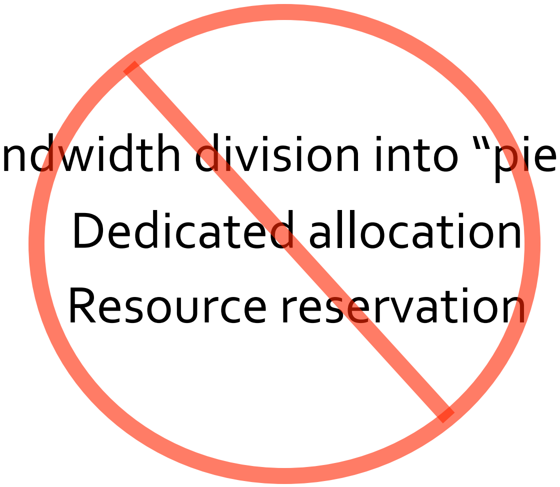
The Network Core

- Mesh of interconnected routers
- Fundamental question: **how is data transferred through mesh?**
  - **Circuit switching**
    - Dedicated circuit per call
    - "Classic" telephone network
  - **Packet-switching:**
    - Data sent thru mesh in discrete "chunks"



Network Core: Packet Switching

- Each end-end data stream divided into packets
  - User A, B packets share network resources
  - Each packet uses full link bandwidth
  - Resources used as needed



Bandwidth division into “pieces”

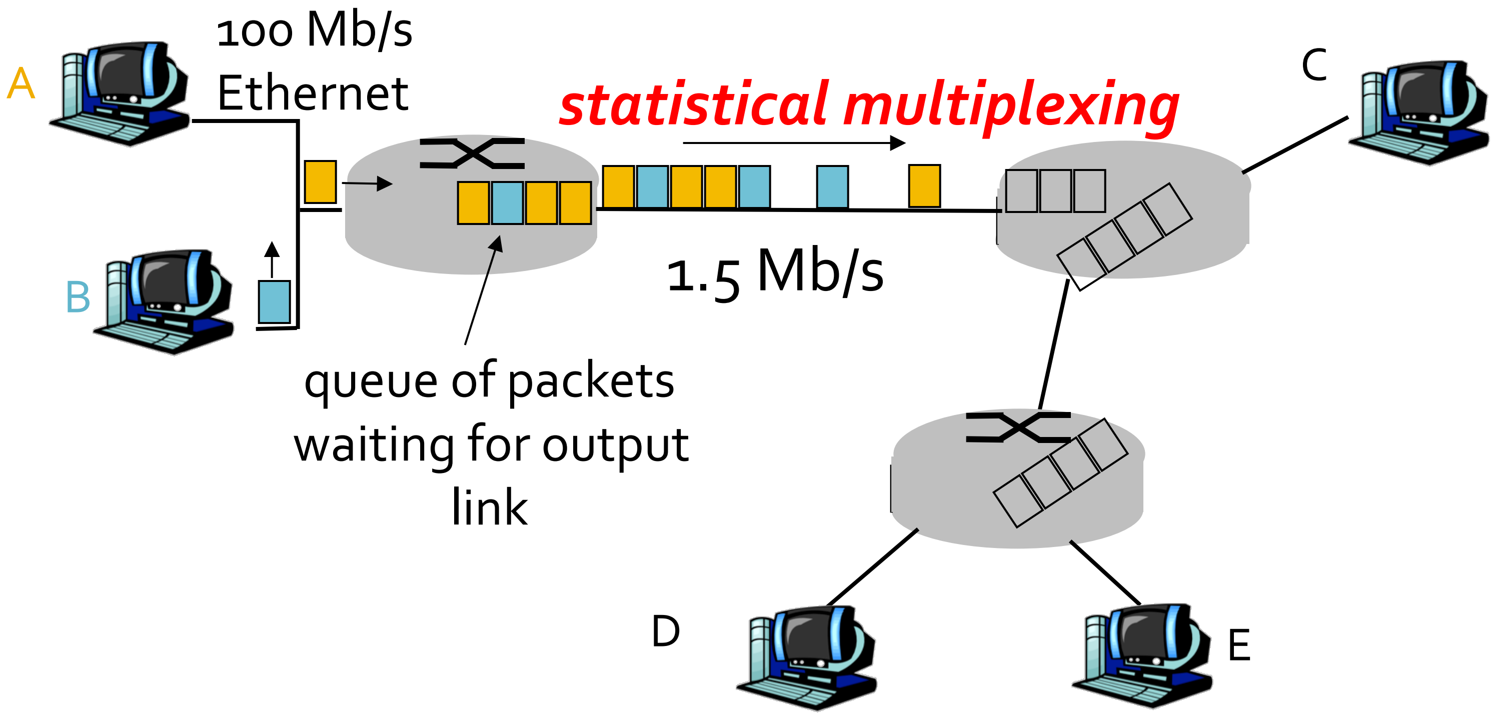
Dedicated allocation

Resource reservation

- Resource contention
  - Aggregate resource demand can exceed amount available
  - Congestion: packets must wait in queue

- Store and forward: packets move one hop at a time
  - Receive complete packet before forwarding

Packet Switching: Statistical Multiplexing

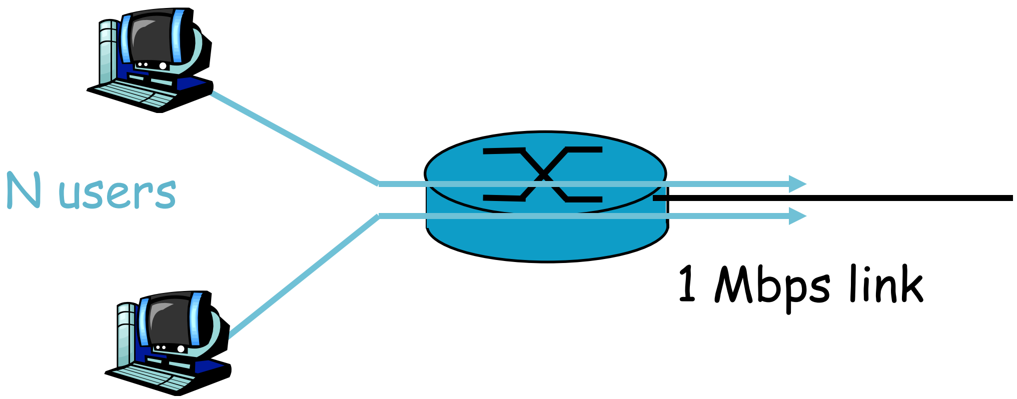


- Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➡ ***statistical multiplexing***.
- Contrast against circuit switching / time-division multiplexing
  - Each host gets same slot (fixed pattern)

Packet Switching vs Circuit Switching

Packet switching allows more users to use network!

- 1 Mb/s link
- Each user:
  - 100 kb/s when "active"
  - Active 10% of time
- **Circuit-switching:**
  - 10 users max
- **Packet switching:**
  - With 35 users, probability > 10 active at same time is less than .0004



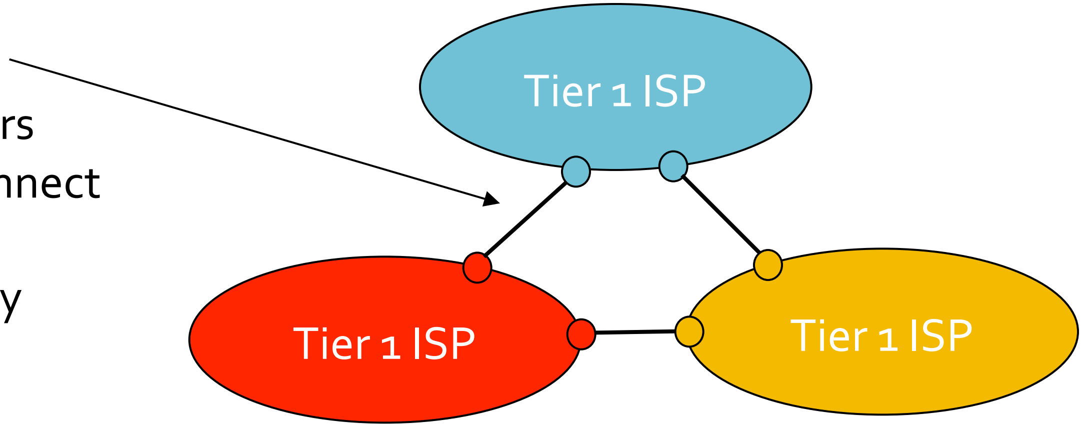
Packet Switching vs Circuit Switching

- **Is packet switching perfect in all situations?**
  - (Think about your own experiences)

- Great for bursty data
  - Resource sharing
  - Simpler, no call setup
- Less great during excessive congestion: packet delay / loss
  - Protocols needed for reliable data transfer and congestion control
- Some applications really want circuit-like behavior
  - Streaming video, streaming audio, interactive games, …
    - If streaming video data arrives late, it is useless
  - Bandwidth / latency (delay) guarantees needed
    - Still an unsolved problem!

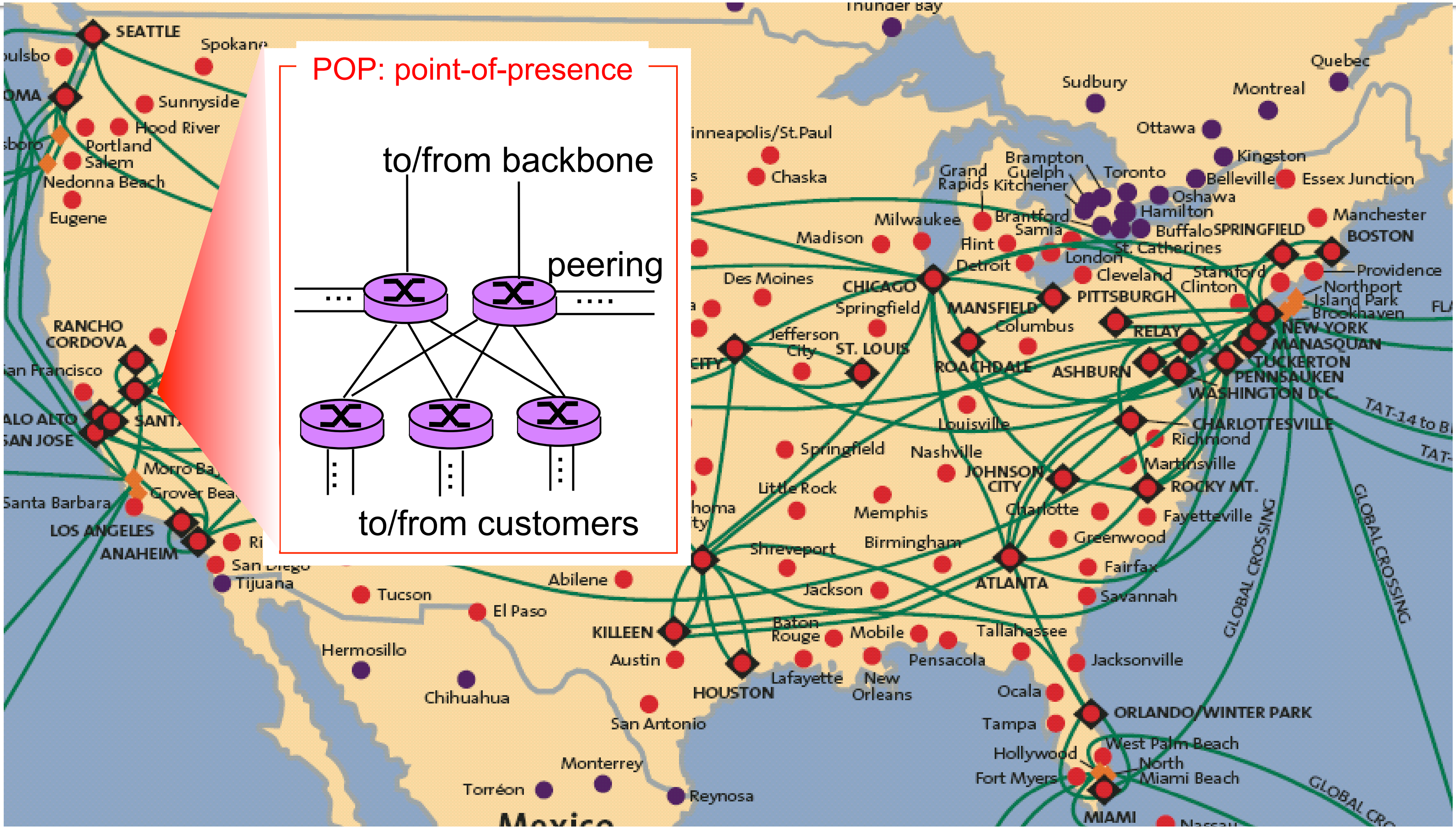
Internet Structure: Network of Networks

- Roughly hierarchical
- At center: **“tier-1” ISPs** with national/international coverage
  - Treat each other as equals
  - Examples: Qwest, Sprint, NTT, L3, AT&T…



Tier-1 providers interconnect (peer) privately

Tier-1 ISP: e.g., Sprint



POP: point-of-presence

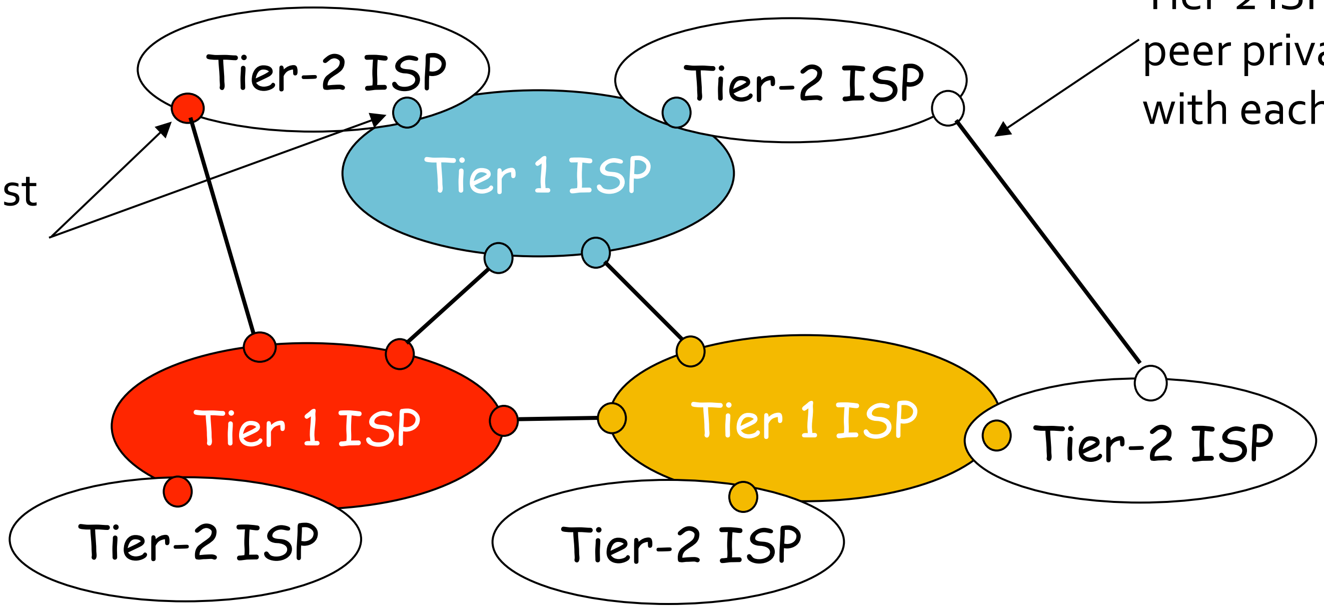
to/from backbone

peering

to/from customers

Internet Structure: Network of Networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



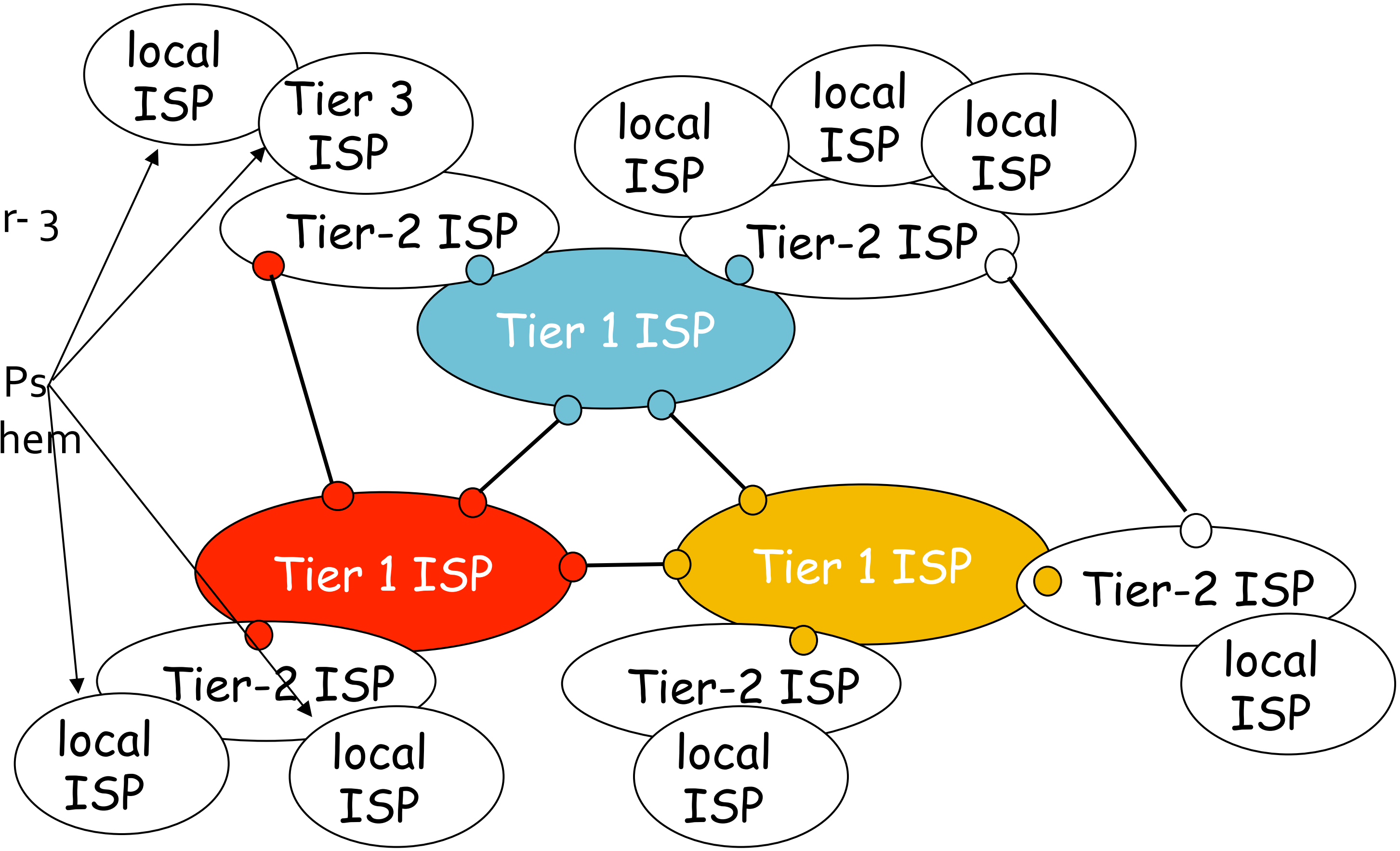
Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet (they are a *customer* of the Tier-1 provider)

Tier-2 ISPs also peer privately with each other.

Internet Structure: Network of Networks

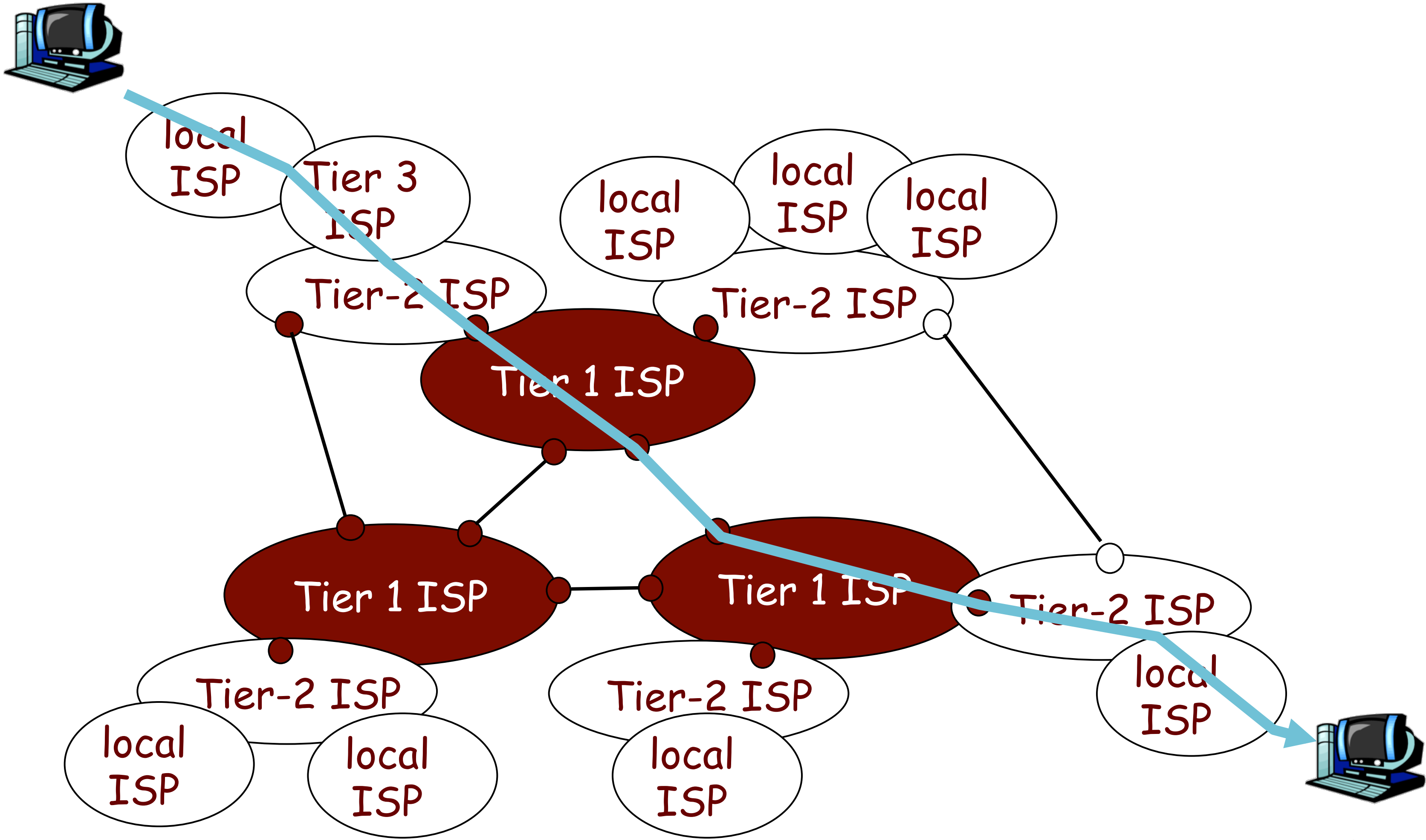
- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

Local and tier- 3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet



Internet Structure: Network of Networks

- A packet passes through many networks



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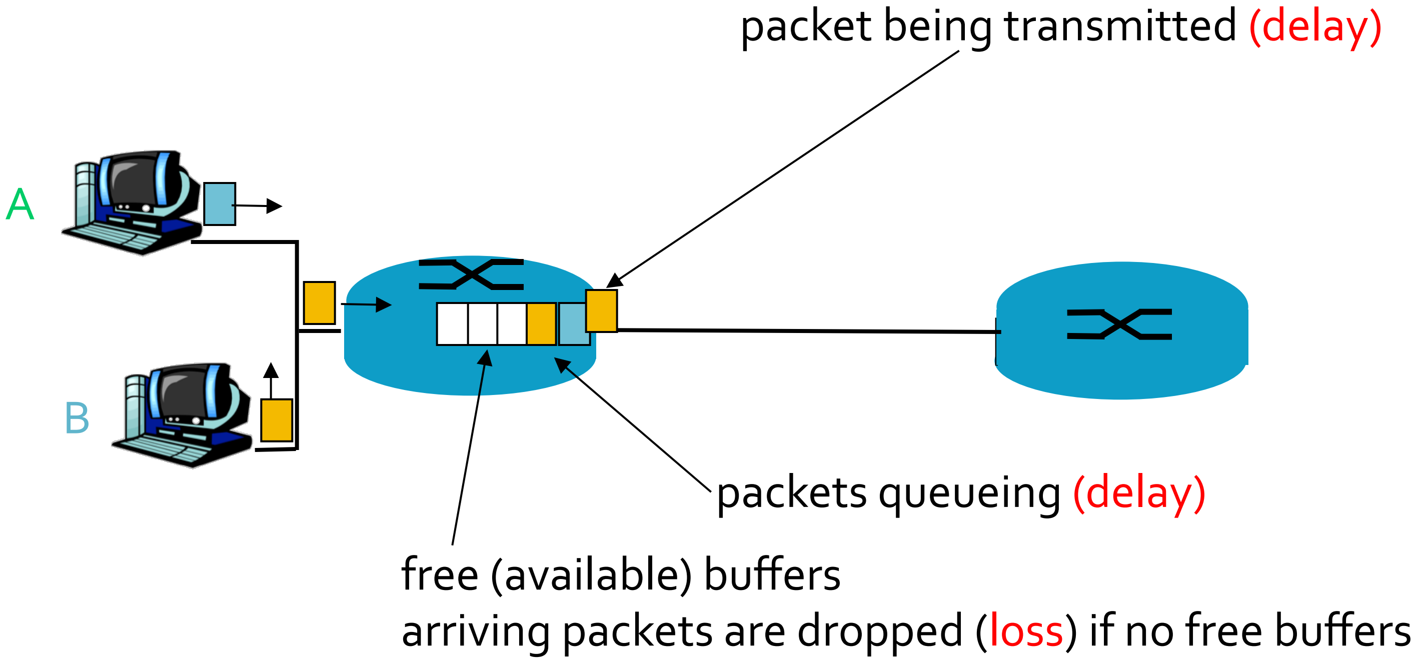
How do Loss and Delay occur?

Packets *queue* in router buffers

- Packet arrival rate to link exceeds output link capacity
- Packets queue and wait for turn



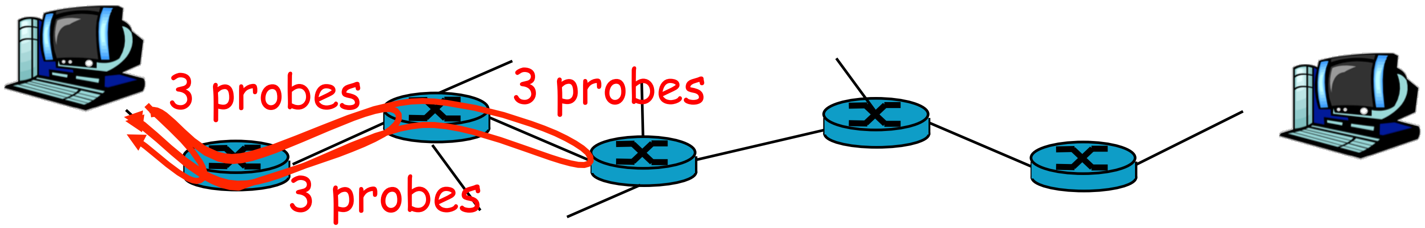
packet being transmitted (delay)

packets queueing (delay)

free (available) buffers
arriving packets are dropped (loss) if no free buffers

“Real” Internet Delays and Routes

- What do “real” Internet delay & loss look like?
- **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 measures time between transmission and reply.



"Real" Internet Delays and Routes

traceroute: my laptop @ pacific to www.msu.ru

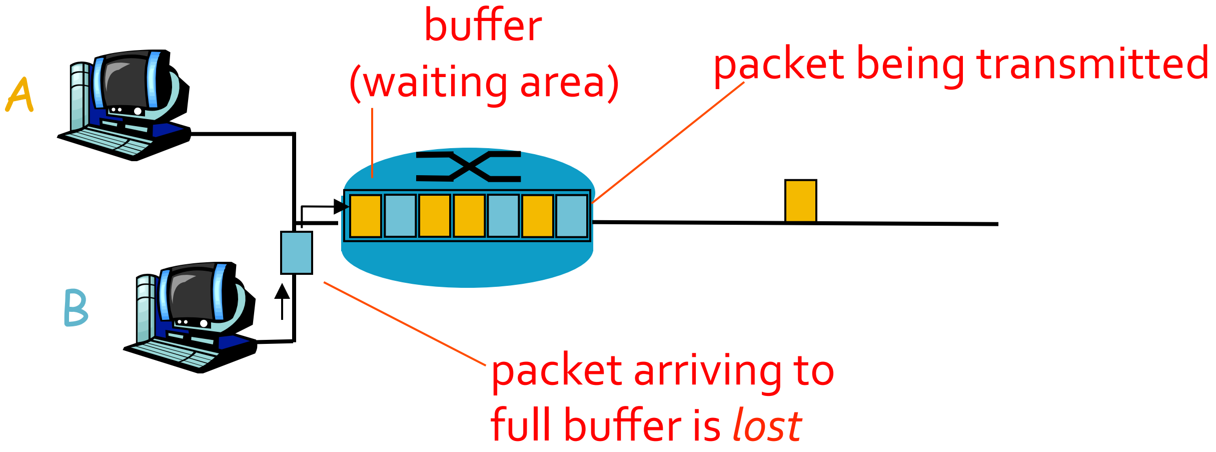
Three delay measurements

```
dhcp-10-10-207-20:~ shafer$ traceroute -a www.msu.ru
traceroute to www.msu.ru (193.232.113.151), 64 hops max, 52 byte packets
 1  [AS0] 138.9.253.252 (138.9.253.252)  0.740 ms  0.741 ms  1.290 ms
 2  [AS0] 74.202.6.5 (74.202.6.5)  5.245 ms  15.006 ms  5.142 ms
 3  [AS4323] sjc1-pr1-xe-0-0-0-0.us.twtelecom.net (66.192.251.170)  6.414 ms  6.640 ms  17.283 ms
 4  [AS6453] if-10-0-0-56.core3.sqn-sanjose.as6453.net (209.58.116.50)  6.628 ms *
    [AS6453] if-13-0-0-55.core3.sqn-sanjose.as6453.net (66.198.97.9)  7.056 ms
 5  [AS6453] if-9-0-0.mcore4.pdi-paloalto.as6453.net (216.6.33.6)  68.184 ms
    [AS6453] if-6-0-0-1145.mcore4.pdi-paloalto.as6453.net (216.6.86.45)  8.120 ms
    [AS6453] if-9-0-0.mcore4.pdi-paloalto.as6453.net (216.6.33.6)  491.007 ms
 6  [AS11029] if-0-0-0-892.mcore3.njy-newark.as6453.net (209.58.124.25)  78.807 ms  109.426 ms
78.890 ms
 7  [AS15706] if-4-0-0.core1.fv0-frankfurt.as6453.net (195.219.69.29)  167.206 ms  167.461 ms
167.002 ms
 8  [AS15706] if-0-0-0.core1.fr1-frankfurt.as6453.net (195.219.69.54)  171.256 ms  171.844 ms
174.118 ms
 9  [AS6453] if-7-1-0-1310.core1.stk-stockholm.as6453.net (195.219.131.45)  1180.587 ms  437.592 ms
586.125 ms
10  [AS6453] ix-4-0-1.core1.stk-stockholm.as6453.net (195.219.131.22)  200.475 ms  200.301 ms
201.106 ms
11  [AS3267] b57-1-gw.spb.runnet.ru (194.85.40.129)  216.199 ms  216.117 ms  214.311 ms
12  [AS3267] bl16-1-gw.spb.runnet.ru (194.85.40.78)  214.723 ms  214.463 ms  214.494 ms
13  [AS3267] bm18-1-gw.spb.runnet.ru (194.85.40.169)  214.608 ms  214.504 ms  214.493 ms
14  [AS3267] tv11-1-gw.msk.runnet.ru (194.85.40.137)  214.260 ms  214.360 ms  214.478 ms
15  [AS3267] m9-2-gw.msk.runnet.ru (194.85.40.53)  214.752 ms  214.496 ms  214.882 ms
16   [AS3267] msu.msk.runnet.ru (194.190.255.234)  214.197 ms  214.907 ms  214.656 ms
17  [AS2848] 193.232.127.12 (193.232.127.12)  214.501 ms  214.166 ms  214.531 ms
18  [AS2848] 193.232.113.151 (193.232.113.151)  214.864 ms !Z  214.666 ms !Z  214.522 ms !Z
```

trans-oceanic link

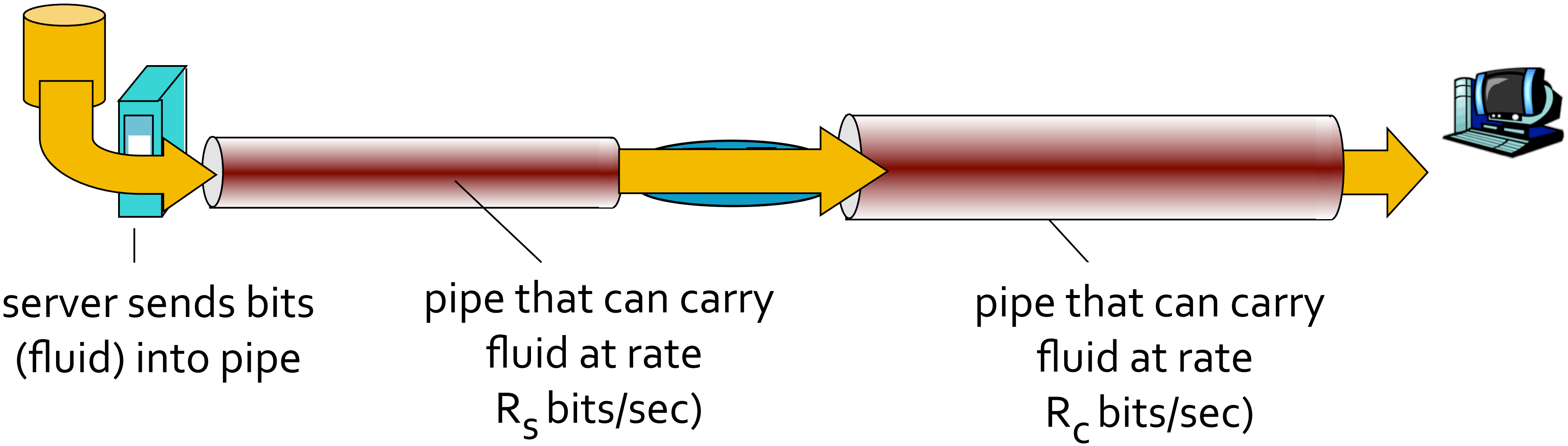
Packet Loss

- Queue (aka buffer) preceding link in buffer has finite capacity
- Packet arriving to full queue dropped (aka lost)
- Lost packet may be retransmitted by previous node, by source end system, or **not at all!**



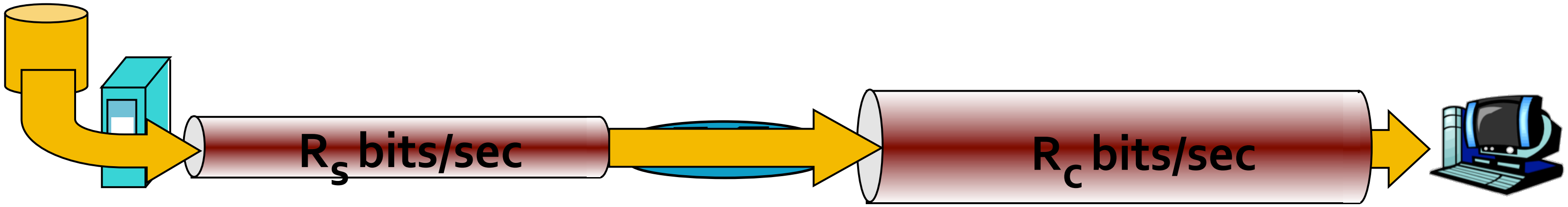
Throughput

- ***Throughput:*** rate (bits/time unit) at which bits transferred between sender/receiver
  - ***instantaneous:*** rate at given point in time
  - ***average:*** rate over longer period of time

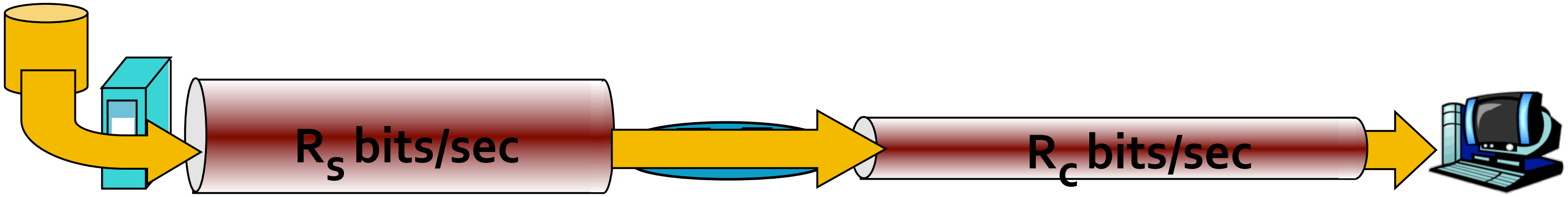

server sends bits (fluid) into pipe
pipe that can carry fluid at rate R_s bits/sec)
pipe that can carry fluid at rate R_c bits/sec)

Throughput (more)

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?

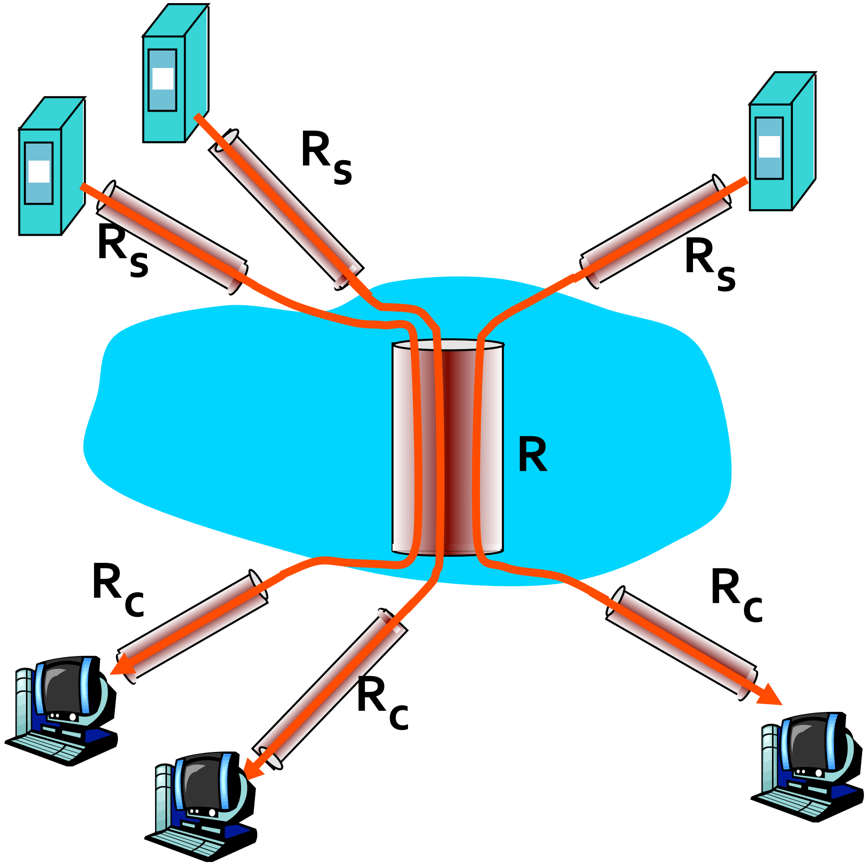


Bottleneck link

link on end-end path that constrains end-end throughput

Throughput: Internet Scenario

- 10 connections (fairly) share backbone bottleneck link at R bits/sec
- Per-connection end-end throughput: min(R_c,R_s,R/10)
- In practice: R_c or R_s is often bottleneck



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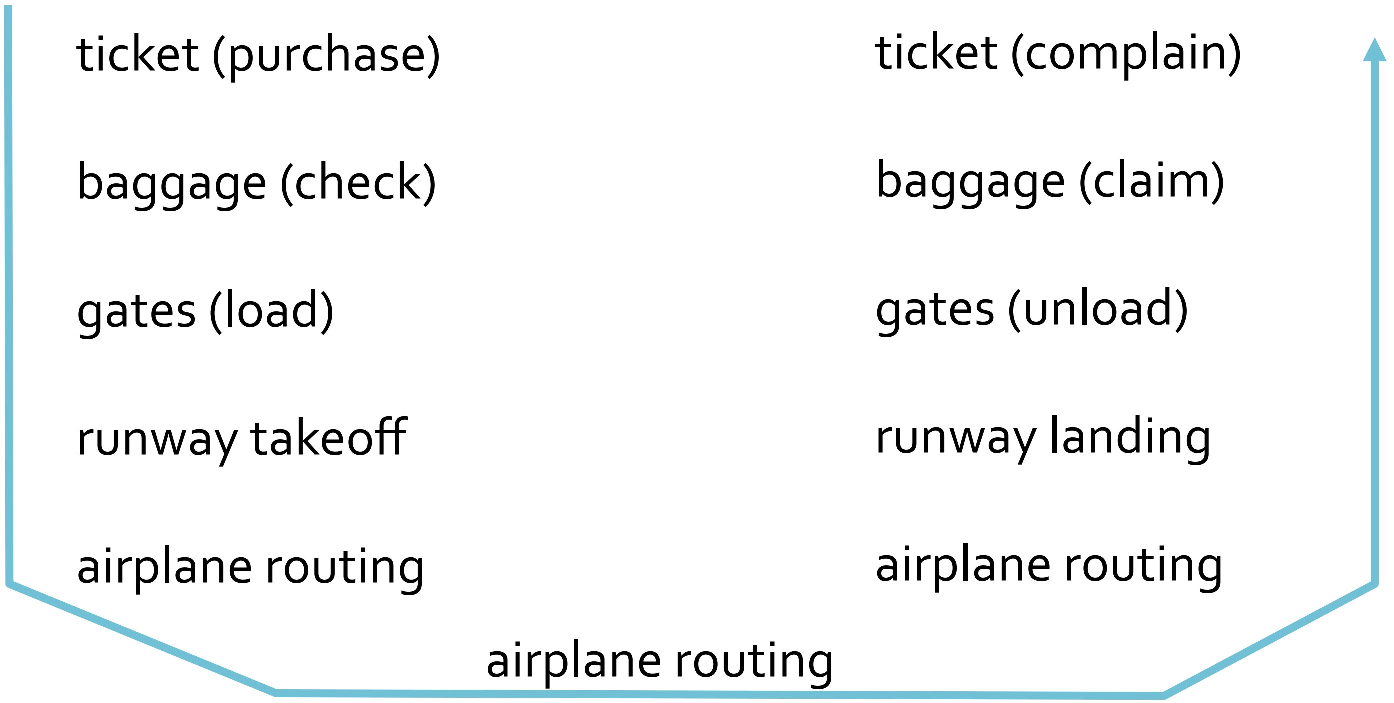
Layers of Protocols

- Networks are complex with many pieces
  - Hosts
  - Routers
  - Links of various media
  - Applications
  - Protocols
  - Hardware, software

- We divide network functions into “layers”
  - Easier to understand and discuss role of various devices

Organization of Air Travel



ticket (purchase)

baggage (check)

gates (load)

runway takeoff

airplane routing

ticket (complain)

baggage (claim)

gates (unload)

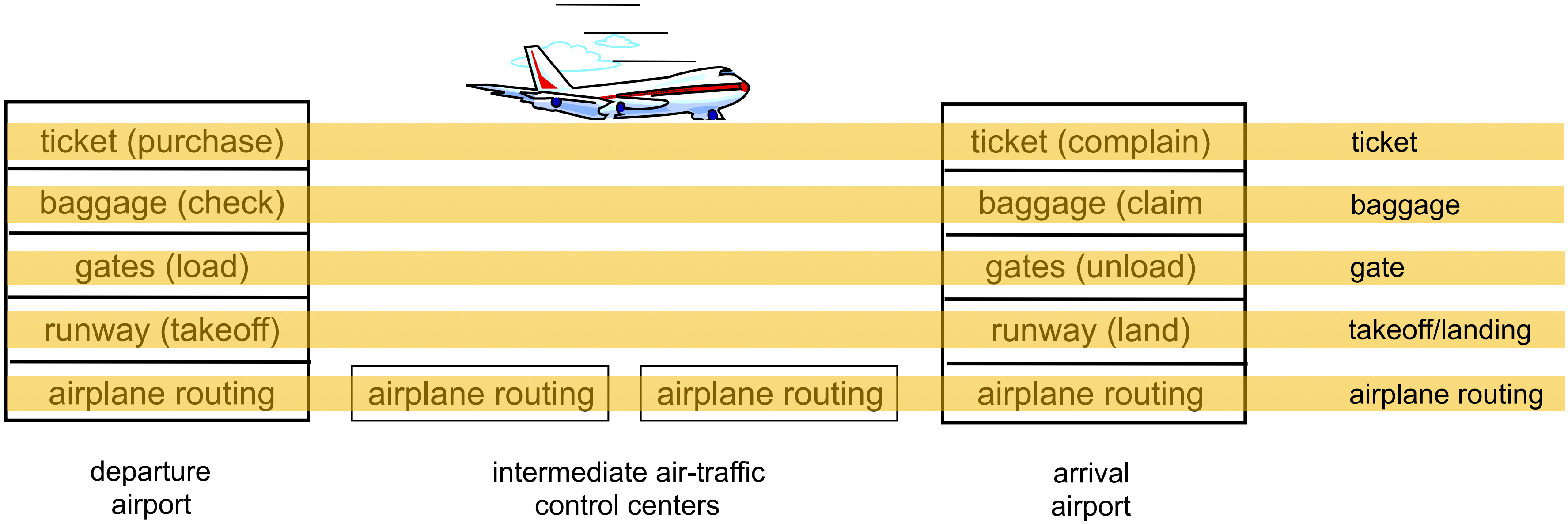
runway landing

airplane routing

airplane routing

- A series of steps

Layering of airline functionality



departure airport	intermediate air-traffic control centers		arrival airport	
ticket (purchase)			ticket (complain)	ticket
baggage (check)			baggage (claim	baggage
gates (load)			gates (unload)	gate
runway (takeoff)			runway (land)	takeoff/landing
airplane routing	airplane routing	airplane routing	airplane routing	airplane routing

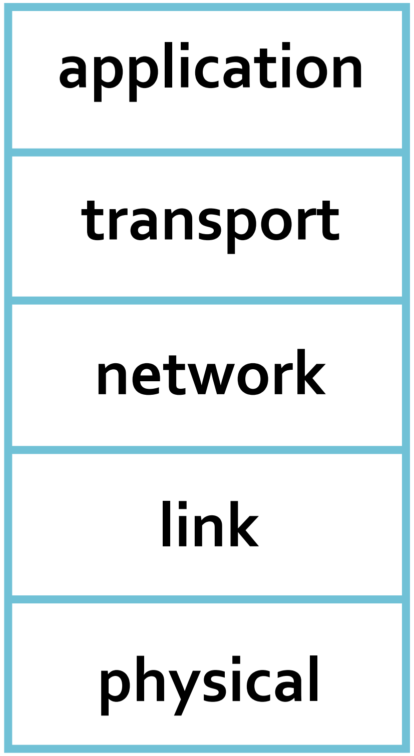
- Layers: Each layers implements a service
  - via its own internal-layer actions
  - relying on services provided by layer below

Why Layering?

- **Human Understanding / Discussion**
  - Dealing with complex systems
  - Explicit structure show relationship of between components
- Modularization eases **maintenance** and system **updates**
  - Can change how a layer is implemented without modifying other layers (change is transparent)
  - e.g., change in gate procedure doesn't affect rest of system

Internet Protocol Stack

- Application: supporting network applications
  - FTP, SMTP, HTTP
- Transport: process-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - Ethernet
- Physical: bits "on the wire"



application

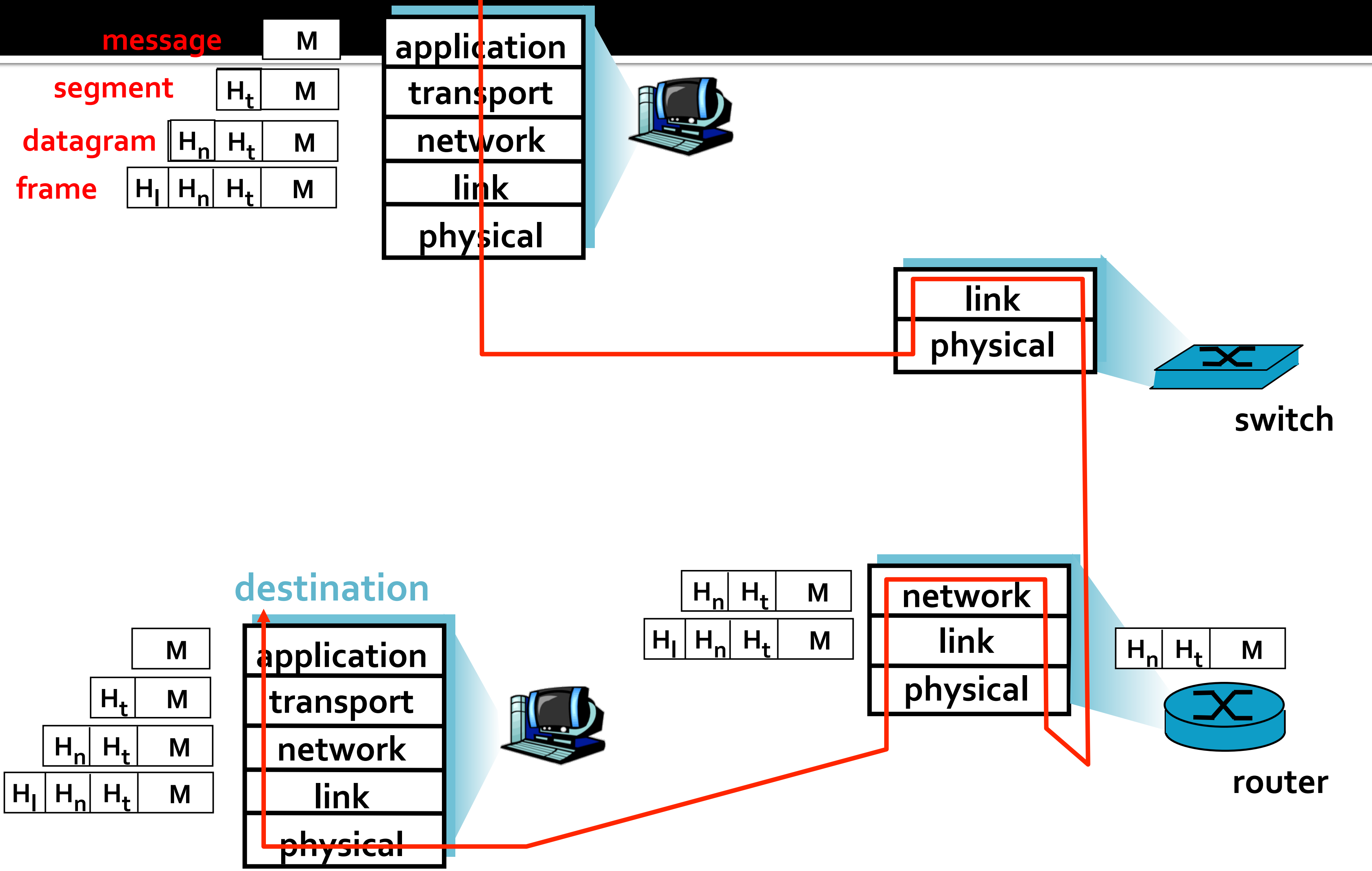
transport

network

link

physical

Encapsulation



source

message M

segment H_t M

datagram H_n H_t M

frame H_l H_n H_t M

application

transport

network

link

physical

link

physical

switch

destination

M

H_t M

H_n H_t M

H_l H_n H_t M

application

transport

network

link

physical

H_n H_t M

H_l H_n H_t M

network

link

physical

H_n H_t M

router

"Magic" of the Internet

- TCP: Reliable, in-order delivery
- IP: Un-reliable, order not guaranteed
- Magic
  - TCP is built on top of IP!

- Great clown analogy by Joel Spolsky
  http://www.joelonsoftware.com/articles/LeakyAbstractions.html

Clown Delivery

Need to move clowns from Broadway to Hollywood for a new job

Broadway, NYC

Clown Delivery – Problems?

Many cars, many clowns
Bad things are guaranteed to happen to at least *some* of them

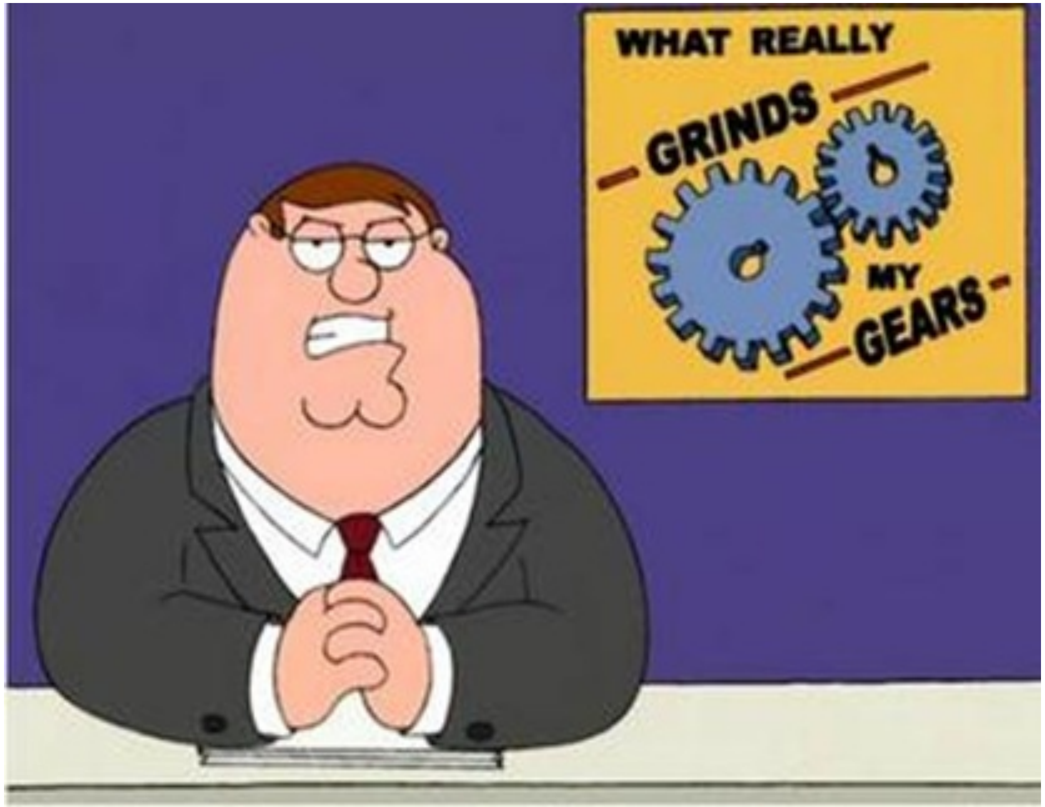
Car crash / lost

Shaved head / too ugly to work!

Different routes

Clown Delivery – Problems?

People in Hollywood get frustrated –
It's hard to make movies with clowns in this condition!



Clown Delivery - Solution

- New company
  - **Hollywood Express**
- Guarantees that all clowns
  - (1) Arrive
  - (2) In Order
  - (3) In Perfect Condition
- Mishap? Call and request clown's twin brother be sent immediately

- UFO crash in Nevada blocks highway?

- Clowns re-routed via Arizona
  - Director never even *hears* about the UFO crash
  - Clowns arrive a little more slowly

Networking Abstraction

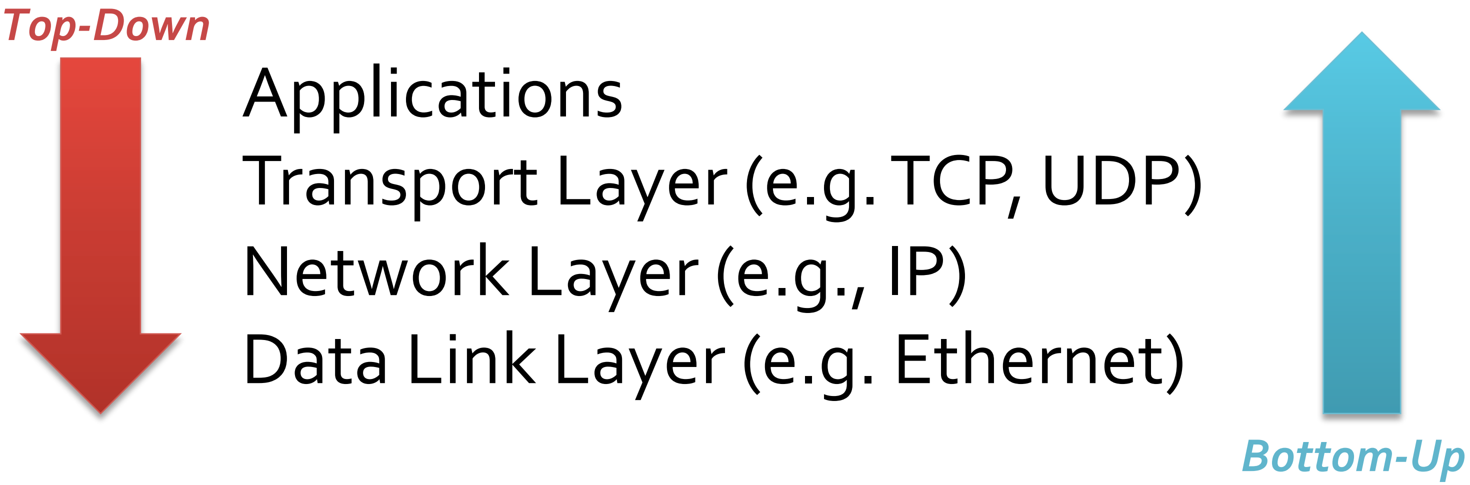
- TCP provides a similar reliable delivery service for IP
- Abstraction has its limits
  - Ethernet cable chewed through by cat?
  - No useful error message for that problem!
  - The abstraction is “leaky” – it couldn’t save the user from learning about the chewed cable

Introduction: Summary

- Today’s brief overview
  - Internet overview
  - What’s a protocol?
  - Network edge, core, access network
  - Performance: loss, delay, throughput
  - Layering, service models
- Rest of the semester: **more depth**!

Course Organization

- Two ways to organize course:



Top-Down

Applications
Transport Layer (e.g. TCP, UDP)
Network Layer (e.g., IP)
Data Link Layer (e.g. Ethernet)

Bottom-Up

- Chose top-down
  - Faster start to programming projects