

CSCI-1680 - Computer Networks

John Jannotti (jj)

<http://www.cs.brown.edu/courses/cs168>



Based partly on lecture notes by Rodrigo Fonseca, David Mazières, Phil Levis, Peterson & Davie

Cast

- Instructor: John Jannotti (jj)
- HTAs: Nick Byman (nbyman) &
John Shen (shenjohn)
- **How to reach us: Piazza**
<https://piazza.com/brown/fall2015/cs168>



Overview

- **Goal: learn concepts underlying networks**
 - How do networks work? What can one do with them?
 - Gain a basic understanding of the Internet
 - Gain experience writing *protocols*
 - Tools to understand new protocols and applications

“From two communicating machines to the entire Internet”



Prerequisites

- **CSCI-0330 (or equivalent).**
 - We assume basic OS concepts (kernel/user, threads/processes, I/O, scheduling)
- **Low-level programming or be willing to learn quickly**
 - threads, locking, explicit memory management, ...
- **We allow any* language**
 - No high-level networking APIs, though (unless you write them yourself)
 - You will be bit twiddling and byte packing...



Administrivia

- **All assignments will be on the course page**
<http://www.cs.brown.edu/courses/cs168/f15>
- **Text: Peterson and Davie, Computer Networks - A Systems Approach, 4th or 5th Editions**
- **You are responsible to check the web page!**
 - All announcements will be there
 - Textbook chapters corresponding to lectures: read them before class
 - Handouts, due dates, programming resources, *etc...*
 - *Subject to change* (reload before checking assignments)



Grading

- **“Written” component**
 - Exams: Midterm (15%) and Final (25%)
 - Homework: 3 written assignments (15%)
 - Short answer and design questions
- **4 Programming Projects (45%)**
 - Snowcast: streaming music server
 - IP, as an overlay, on top of UDP
 - TCP, on top of *your* IP
 - Final (We’ll decide together)



Networks

- **What is a network?**
 - System of lines/channels that interconnect
 - *E.g.*, railroad, highway, plumbing, postal, telephone, social, **computer**
- **Computer Network**
 - Moves information
 - Nodes: general-purpose computers (most nodes)
 - Links: wires, fiber optics, EM spectrum, composite...

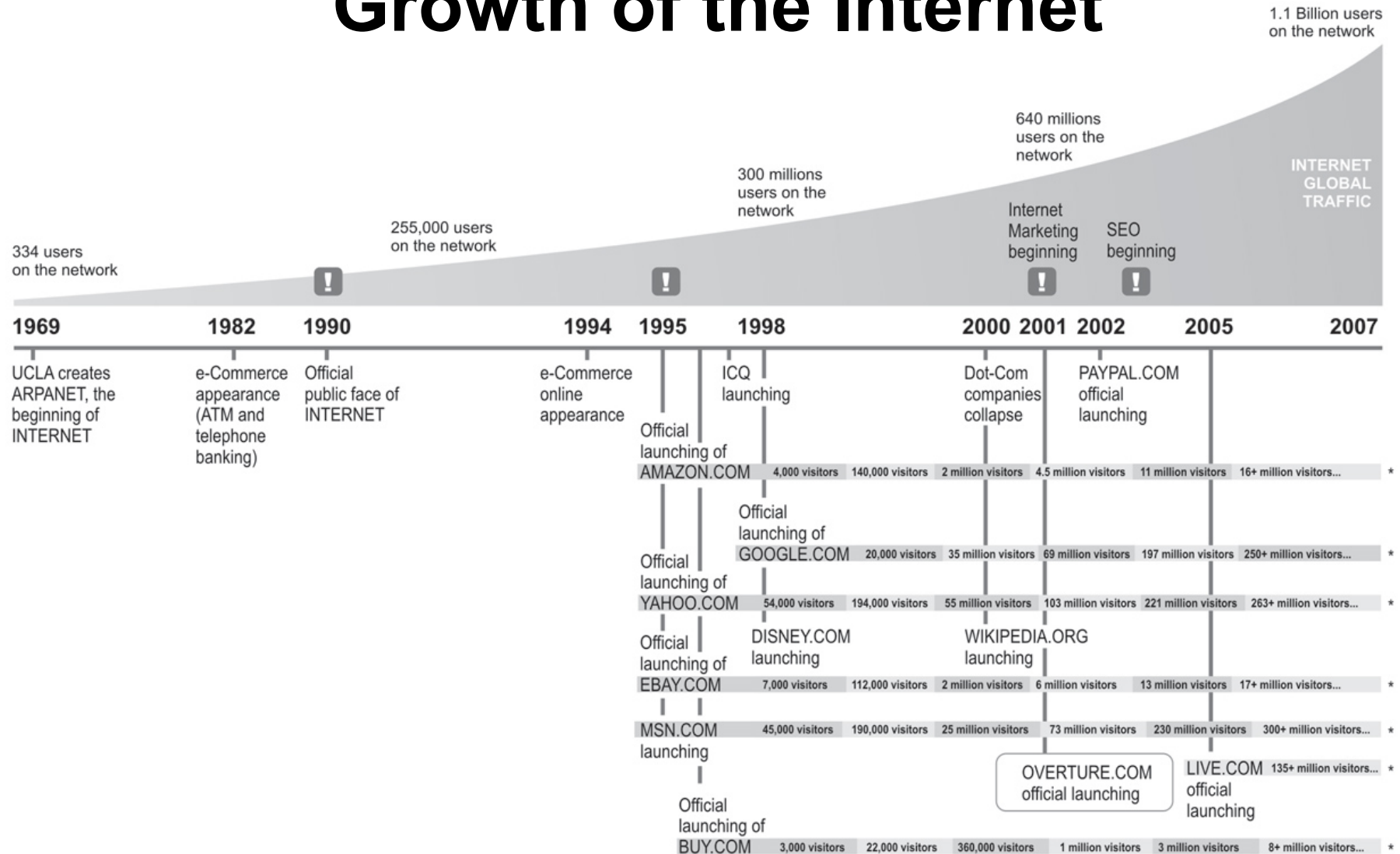


Why are computer networks cooler?

- Many nodes are general-purpose computers
- Very easy to innovate and develop new uses of the network: *you* can program the nodes
- Contrast with the ossified Telephone network:
 - Can't program most phones
 - Intelligence in the network, control by parties vested in the *status quo*, ...



Growth of the Internet



* User traffic calculation per day

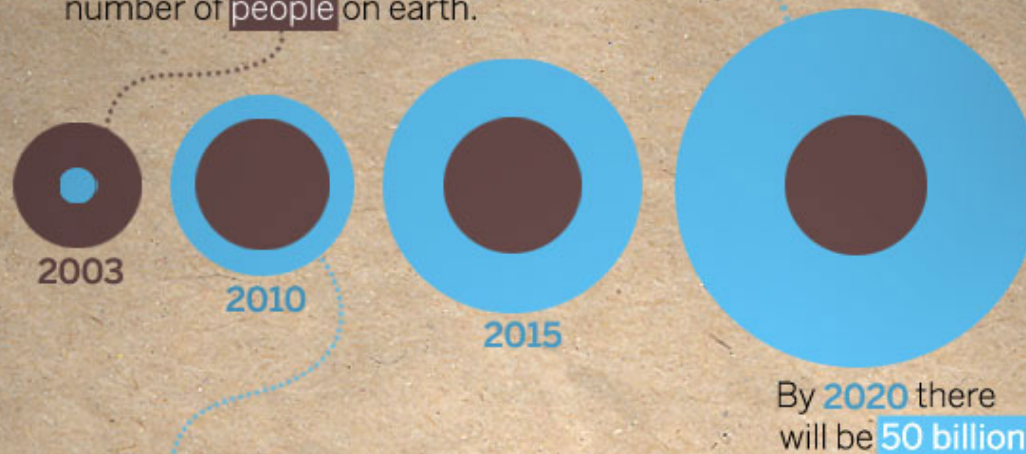


Source: Miguel Angel Todaro

INTERNET *of* THINGS



During 2008, the number of **things** connected to the Internet exceeded the number of **people** on earth.



These **things** are not just smartphones and tablets.

They're every **thing**.

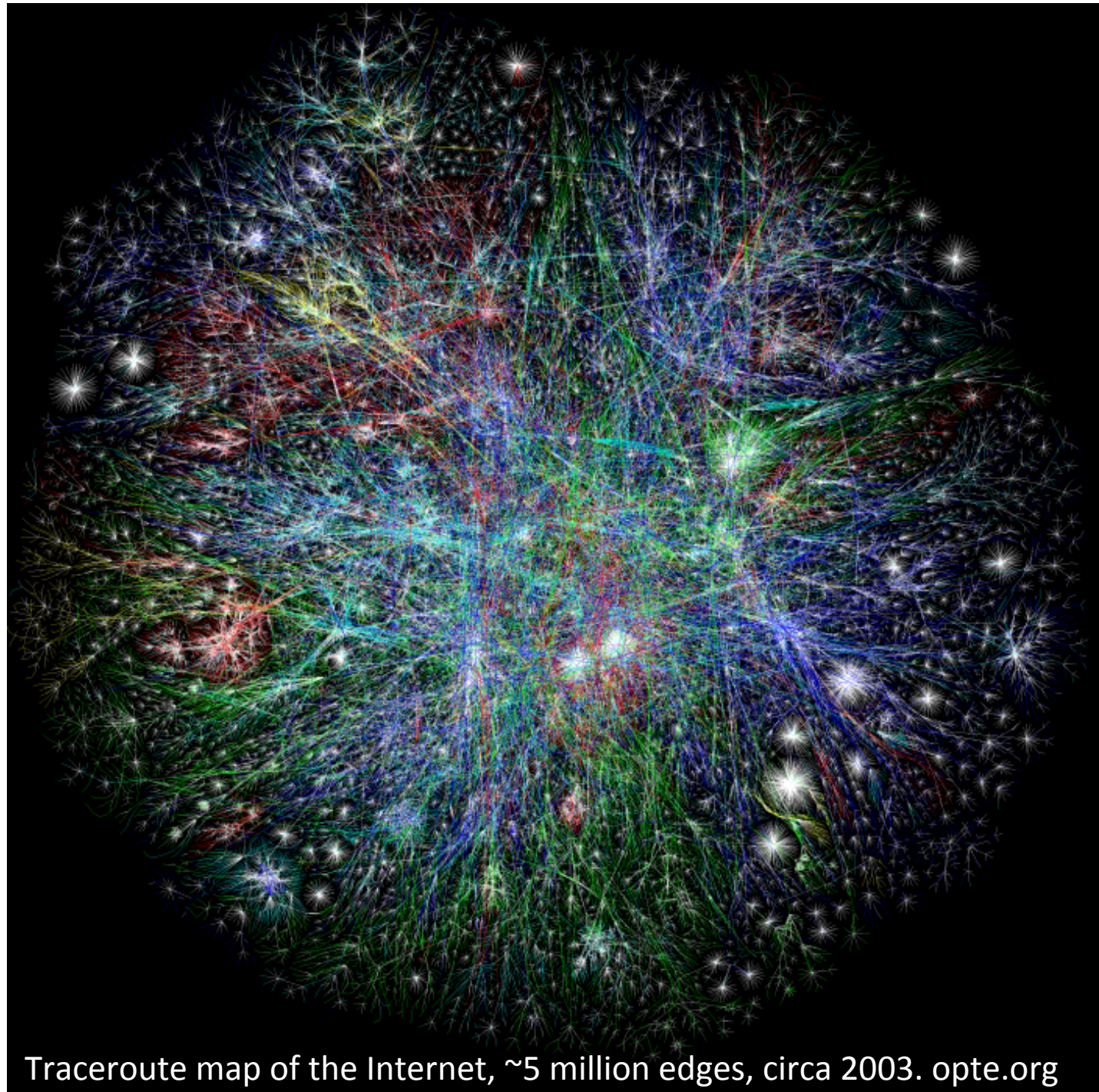
A Dutch startup, **Sparked**, is using wireless sensors on **cattle**.



Source: Cisco



Source: Facebook



Why should you take this course?

- **Impact**
 - Social, economic, political, educational, ...
 - Why would SOPA never work?
 - What does it mean to run out of IP addresses?
 - How could Egypt shut down the Internet internally
 - How could Pakistan shut down Youtube *globally*
- **Continuously changing and evolving**
 - Incredible complexity
 - Any fact you learn will be inevitably out of date
 - Learn general underlying *principles*
- **Learn to program the network**
- **Networks are cool!**



Roadmap

- **Assignments: learn by implementing**
 - Warm up: Snowcast, a networked music server
 - Get a feel for how applications use the network
- **Build knowledge from the ground up**
 - Link individual nodes
 - Local networks with multiple nodes
 - IP: Connect hosts across several networks
 - Transport: Connect processes on different hosts
 - Applications
- **A few cross-cutting issues**
 - Security, multimedia, overlay networks, P2P...



An aerial photograph of a tropical island. In the foreground, a small, sandy beach is covered with palm trees and a few small buildings. The water around the beach is a vibrant turquoise color, indicating shallow depths. In the background, a large, rugged mountain with a sharp peak rises from the water. The sky is blue with scattered white clouds. The text "Two-minutes for stretching..." is overlaid in the upper center of the image.

Two-minutes for stretching...

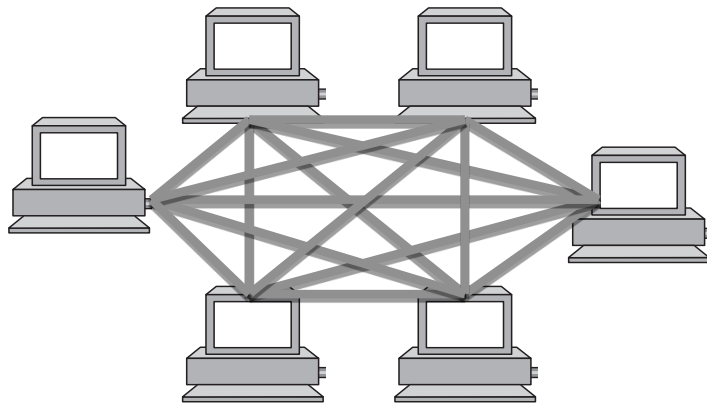
(and an opportunity to sneak out if you are shopping)

Building Blocks

- **Nodes: Computers (hosts), dedicated routers, ...**
- **Links: Coax, twisted pair, fiber, radio, ...**

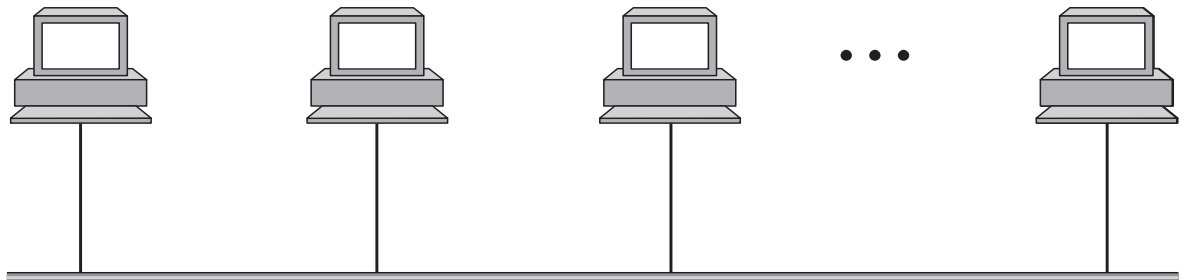


How to connect more nodes?

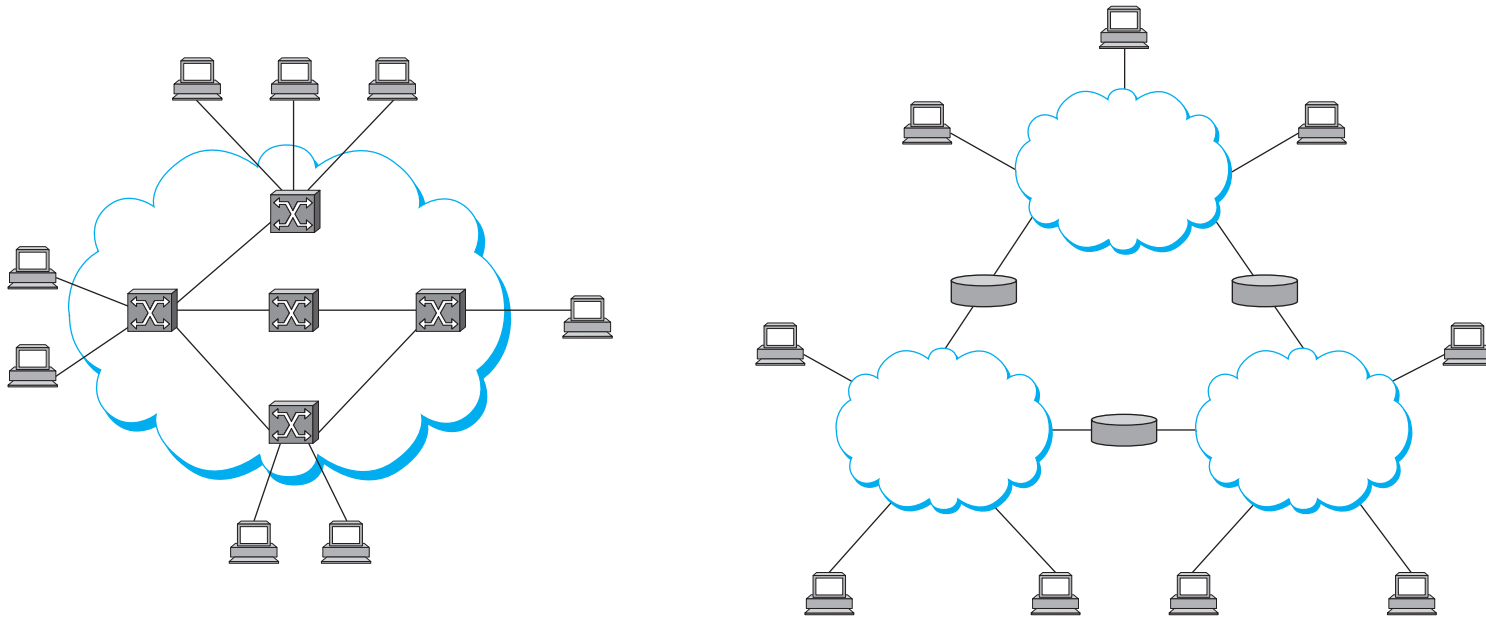


Multiple wires

Shared medium



From Links to Networks



- **To scale to more nodes, use *switching***
 - Nodes can connect to multiple other nodes
 - Recursively, one node can connect to multiple networks



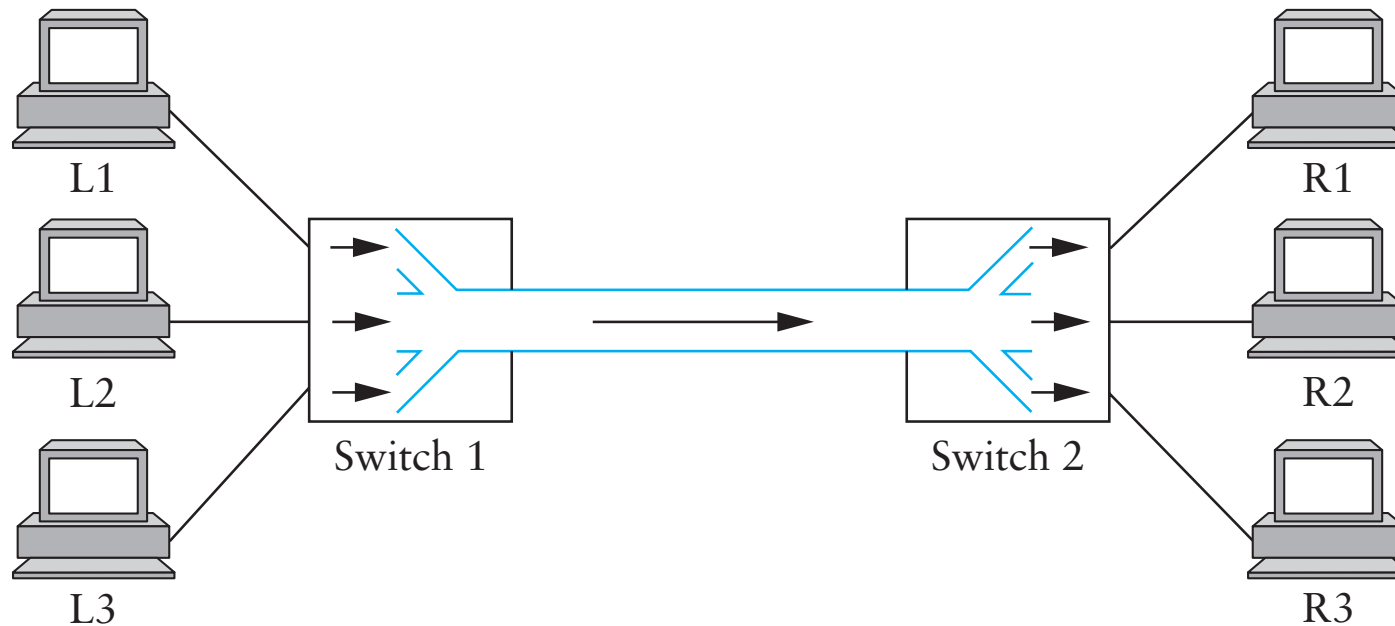
Switching Strategies

- **Circuit Switching – virtual link between two nodes**
 - Set up circuit (e.g. dialing, signaling) – may fail: busy
 - Transfer data at known rate
 - Tear down circuit
- **Packet Switching**
 - Forward bounded-size messages.
 - Each message can have different senders/receivers
 - Focus of this course

Analogy: circuit switching reserves the highway for a cross-country trip. Packet switching interleaves everyone's cars.



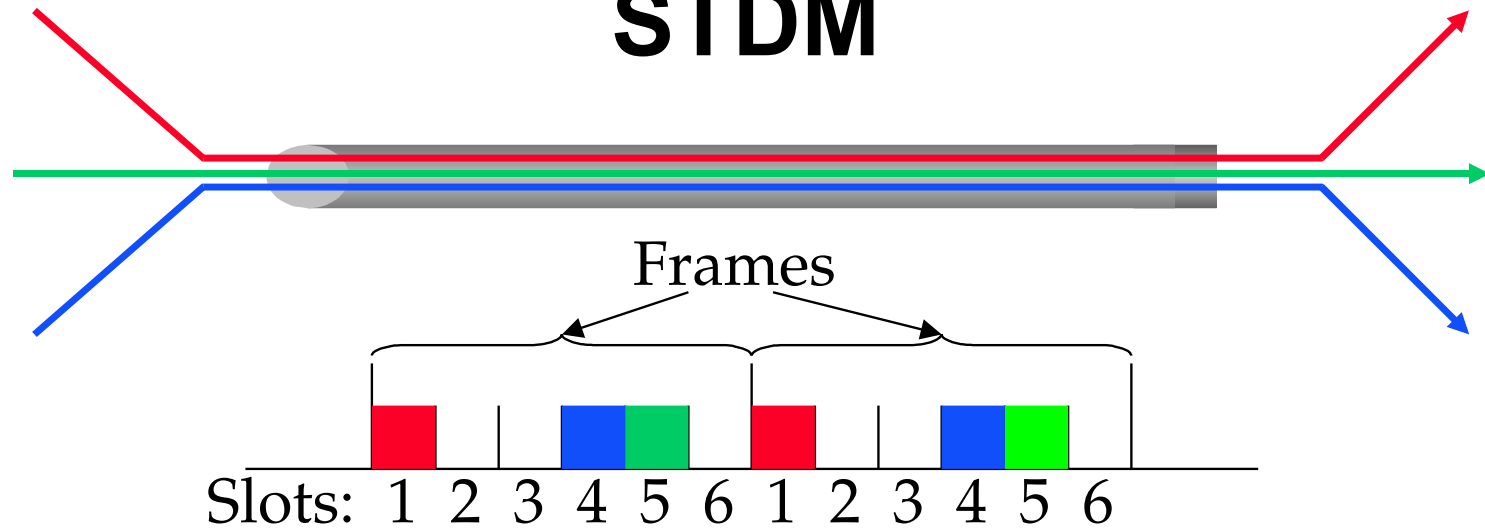
Multiplexing



- **What to do when multiple flows must share a link?**



STDM



- **Synchronous time-division multiplexing**
 - Divide time into equal-sized quanta, round robin
 - Illusion of direct link for switched circuit net
 - But wastes capacity if not enough flows
 - Also doesn't degrade gracefully when more flows than slots

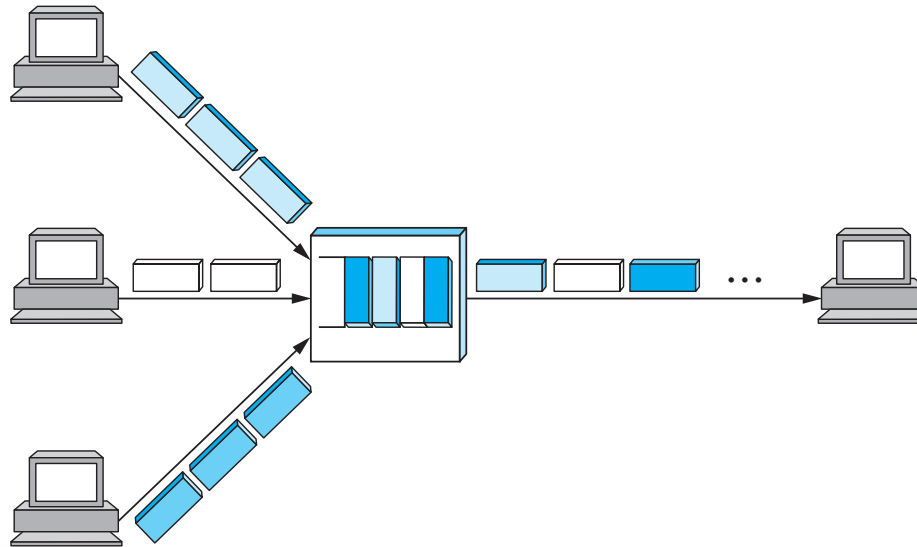


FDM

- **Frequency-division multiplexing:
allocates a frequency band for each flow**
 - Same TV channels and radio stations
- **Similar drawbacks to STDM**
 - Wastes bandwidth if someone not sending
 - Can run out of spectrum



Statistical Multiplexing



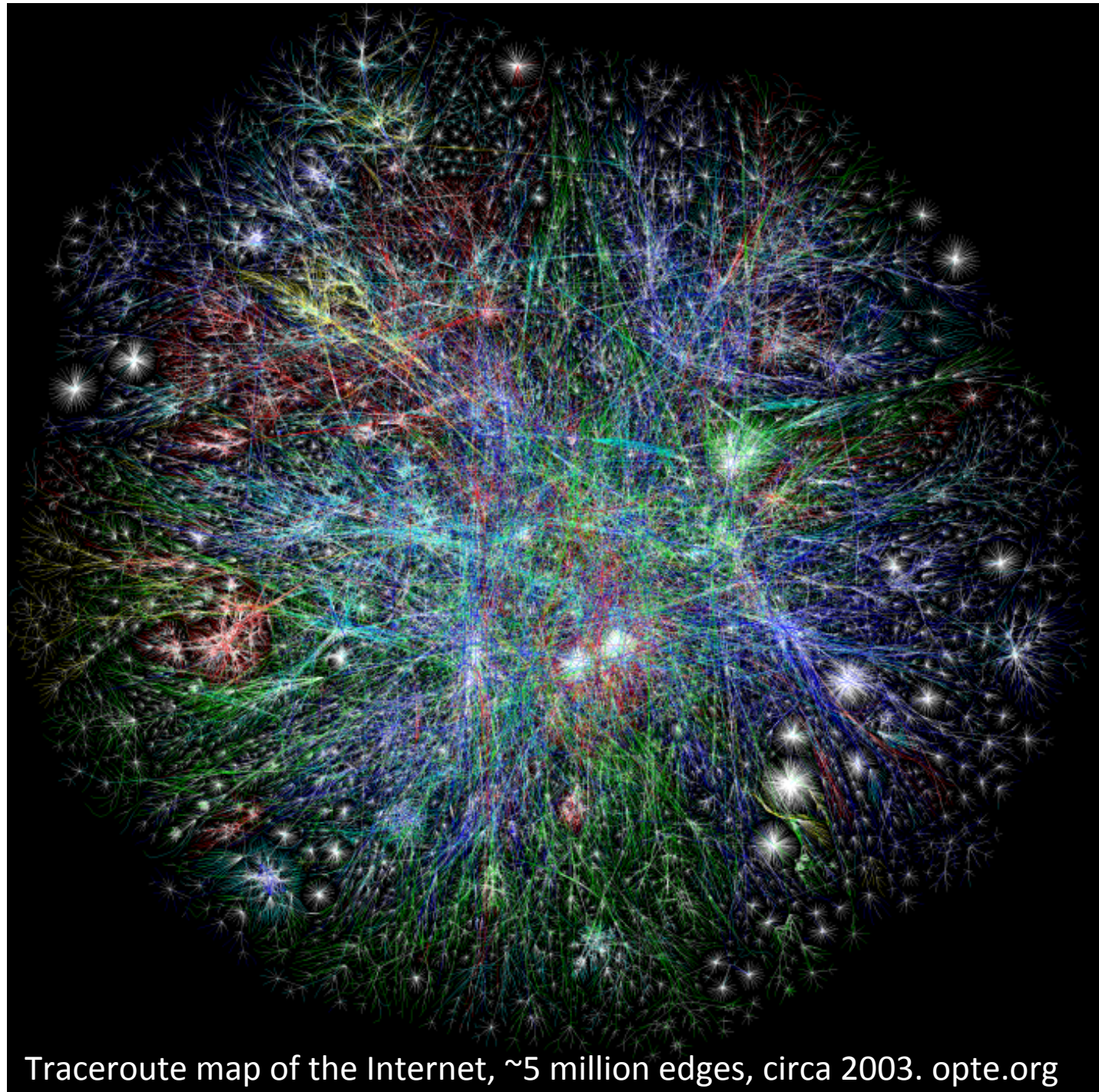
- **Idea: like STDM but with no pre-determined time slots (or order!)**
- **Maximizes link utilization**
 - Link is never idle if there are packets to send



Statistical Multiplexing

- **Cons:**
 - Hard to guarantee fairness
 - Unpredictable queuing delays
 - Packets may take different paths
- **Yet...**
 - This is the main model used on the Internet





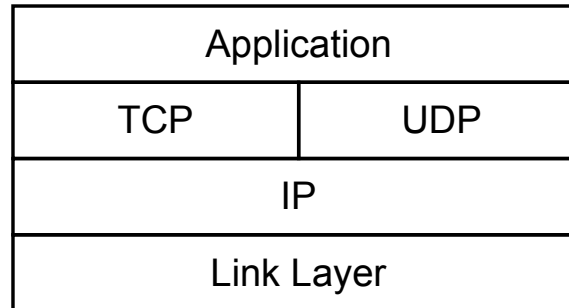
Traceroute map of the Internet, ~5 million edges, circa 2003. opte.org

Managing Complexity

- **Very large number of computers**
- **Incredible variety of technologies**
 - Each with very different constraints
- **No single administrative entity**
- **Evolving demands, protocols, applications**
 - Each with very different requirements!
- **How do we make sense of all this?**



Layering



- **Separation of concerns**
 - Break problem into separate parts
 - Solve each one independently
 - Tie together through common interfaces: abstraction
 - Encapsulate data from the layer above inside data from the layer below
 - Allow independent evolution
- **Example**
 - A *network layer* packet from A to D is put in *link layer* packets A to B, B to C, C to D



Single Link Communication

- **Physical Layer: Several questions:**
 - Encoding: voltage, frequency, phase,...
 - Medium: copper, fiber, radio, light,...
- **Link Layer: how to send data?**
 - When to talk
 - What to say (format, “language”)
- **Examples: Ethernet, USB**

Stay tuned for lectures 3 and 4...

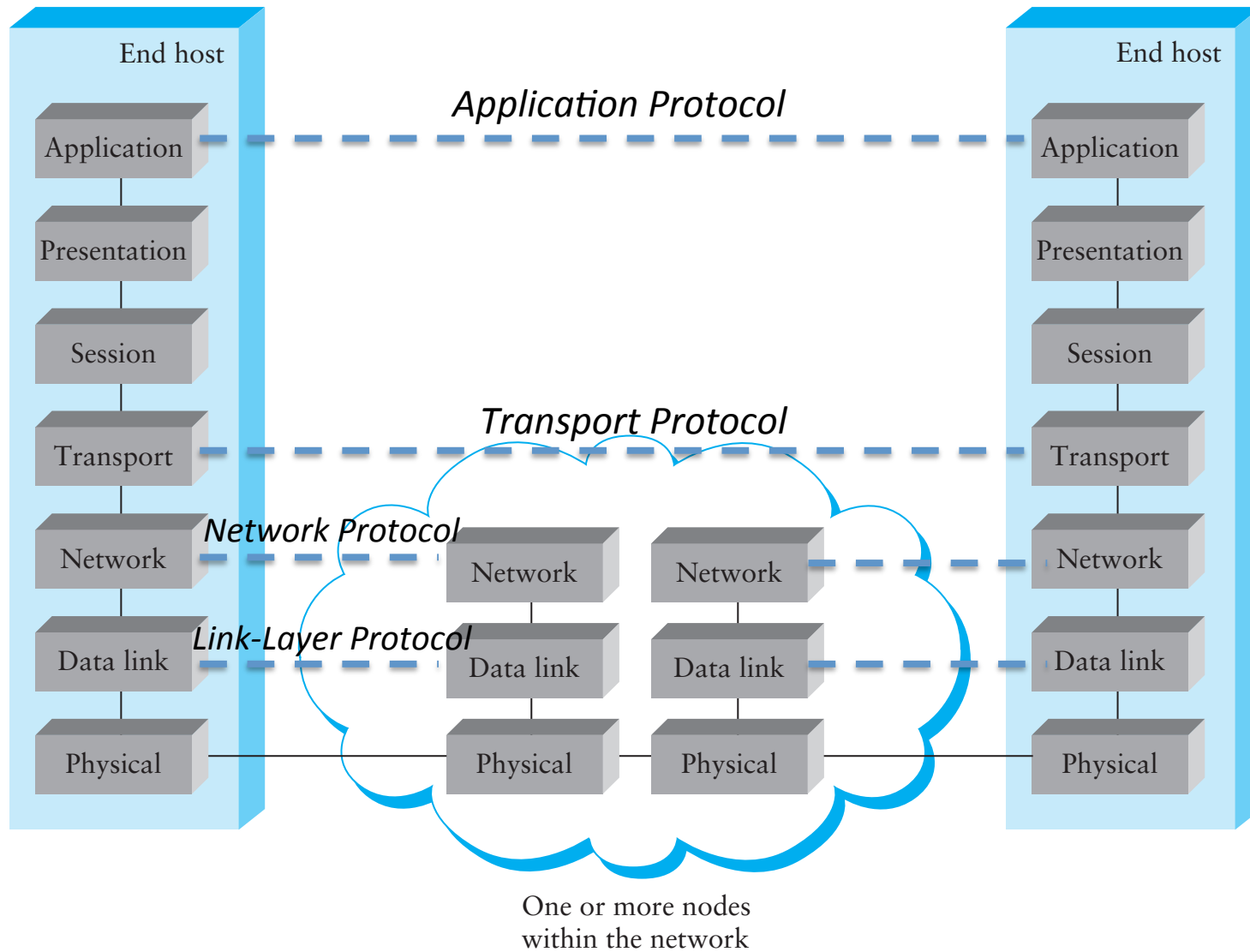


Layers

- **Application** – what the users sees, *e.g.*, HTTP
- **Presentation** – crypto, conversion between representations
- **Session** – can tie together multiple streams (*e.g.*, audio & video)
- **Transport** – demultiplexes, provides reliability, flow and congestion control
- **Network** – sends *packets*, using *routing*
- **Data Link** – sends *frames*, handles media access
- **Physical** – sends individual bits



OSI Reference Model



Protocols

- **What do you need to communicate?**
 - Definition of message formats
 - Definition of the semantics of messages
 - Definition of valid sequences of messages
 - Including valid timings



Addressing

- **Each node typically has a unique* name**
 - When that name also tells you how to get to the node, it is called an *address*
- **Each layer can have its own naming/addressing**
- ***Routing* is the process of finding a path to the destination**
 - In packet switched networks, each packet must have a destination address
 - For circuit switched, use address to set up circuit
- **Special addresses can exist for broadcast/multicast/anycast**



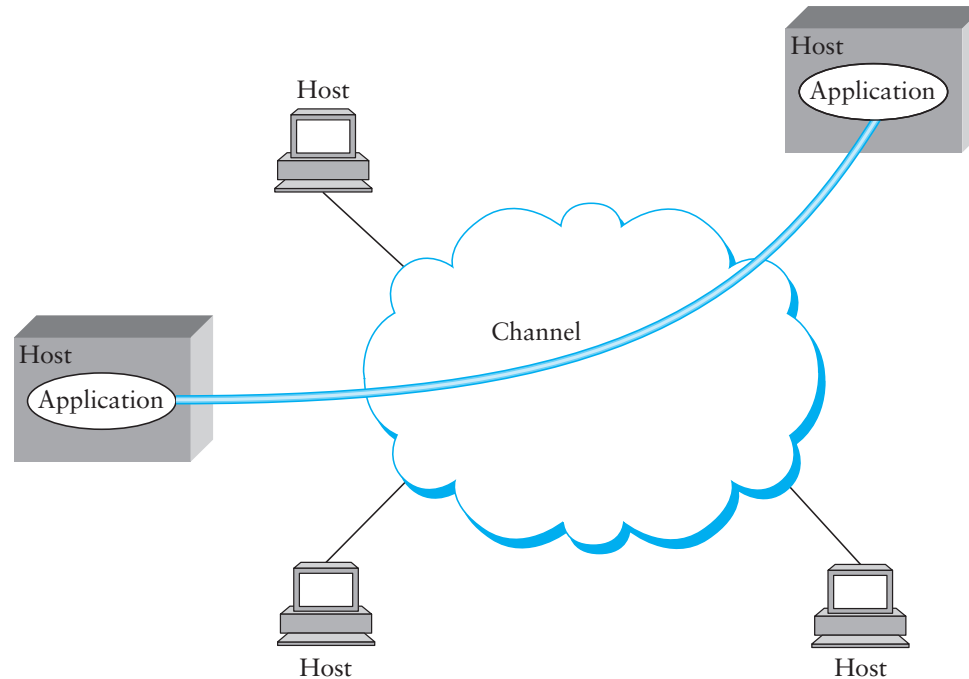
** or thinks it does, in case there is a shortage*

Network Layer: Internet Protocol (IP)

- **Used by most computer networks today**
 - Runs *over* a variety of physical networks, can connect Ethernet, wireless, modem lines, etc.
- **Every host has a unique 4-byte IP address (IPv4)**
 - *E.g.*, `www.cs.brown.edu` → 128.148.32.110
 - The *network* knows how to route a packet to any address
- **Need more to build something like the Web**
 - Need human-centric naming (DNS)
 - Interface for browser and server software (next lecture)
 - Need demultiplexing within a host: which network data is for the web browser, Skype, or the mail program?



Inter-process Communication



- Talking from host to host is great, but we want abstraction of inter-process communication
- Solution: *encapsulate* another protocol within IP



Transport: UDP and TCP

- **UDP and TCP most popular protocols on IP**
 - Both use 16-bit *port* number & 32-bit IP address
 - Applications *bind* a port & receive traffic on that port
- **UDP – User (unreliable) Datagram Protocol**
 - Exposes packet-switched nature of Internet
 - Sent packets may be dropped, reordered, even duplicated (but there is corruption protection)
- **TCP – Transmission Control Protocol**
 - Provides illusion of reliable ‘pipe’ or ‘stream’ between two processes anywhere on the network
 - Handles congestion and flow control

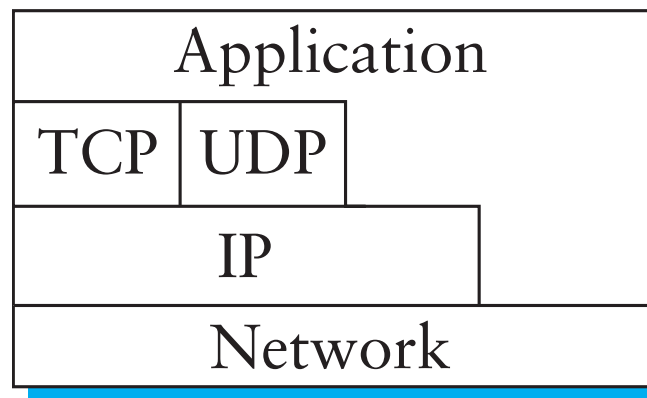


Uses of TCP

- **Most applications use TCP**
 - Easier to program (reliability is convenient)
 - Automatically avoids congestion (don't need to worry about taking down the network)
- **Servers typically listen on well-known ports:**
 - SSH: 22
 - SMTP (email): 25
 - Finger: 79
 - HTTP (web): 80



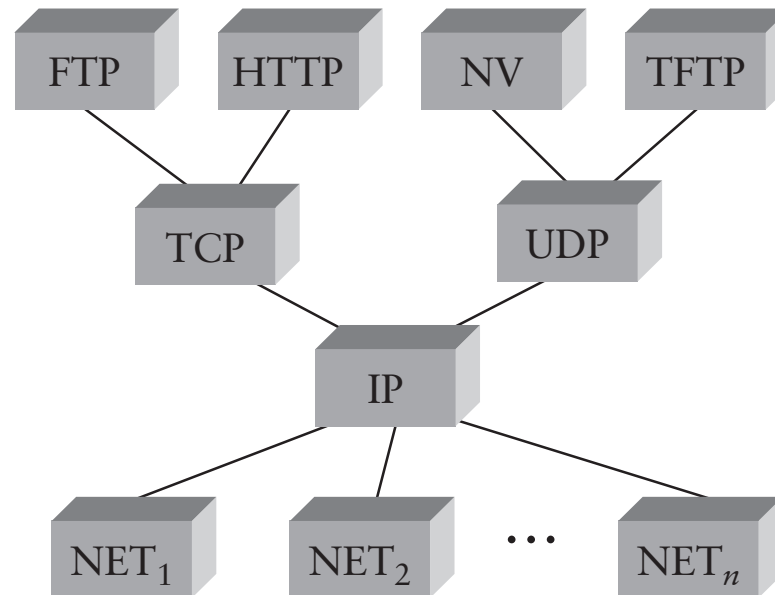
Internet Layering



- **Strict layering not *required***
 - TCP/UDP “cheat” to detect certain errors in IP-level information like address
 - Overall, allows evolution, experimentation



IP as the Narrow Waist



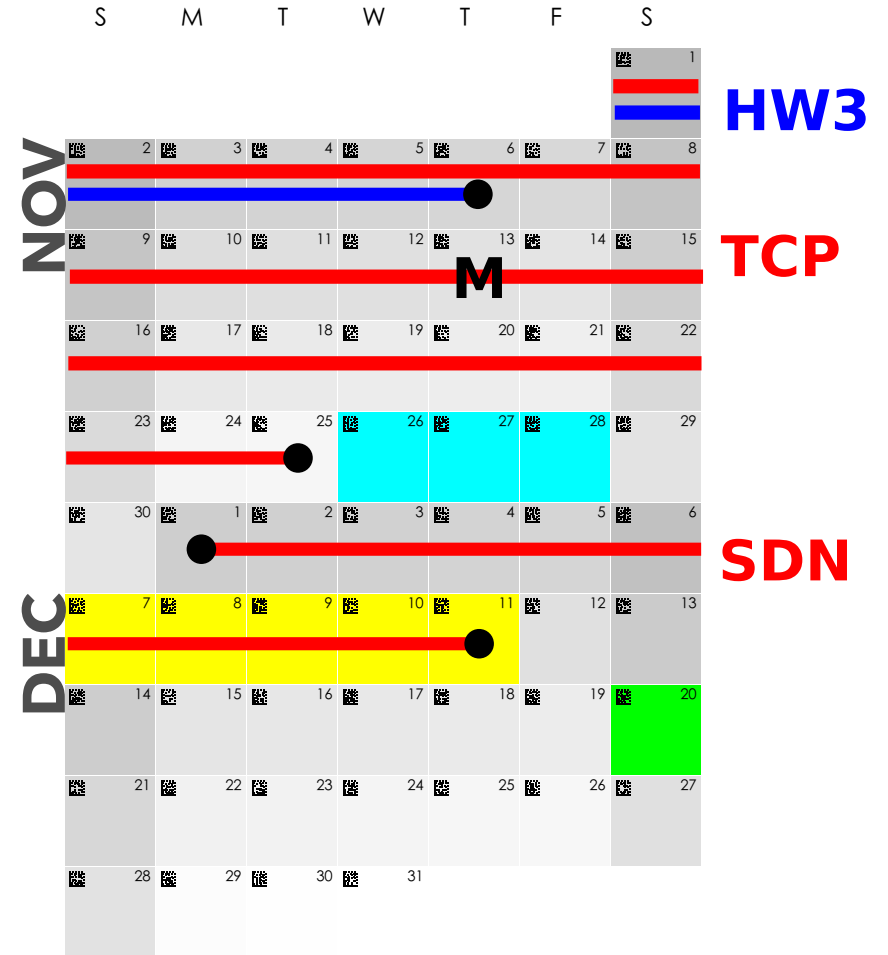
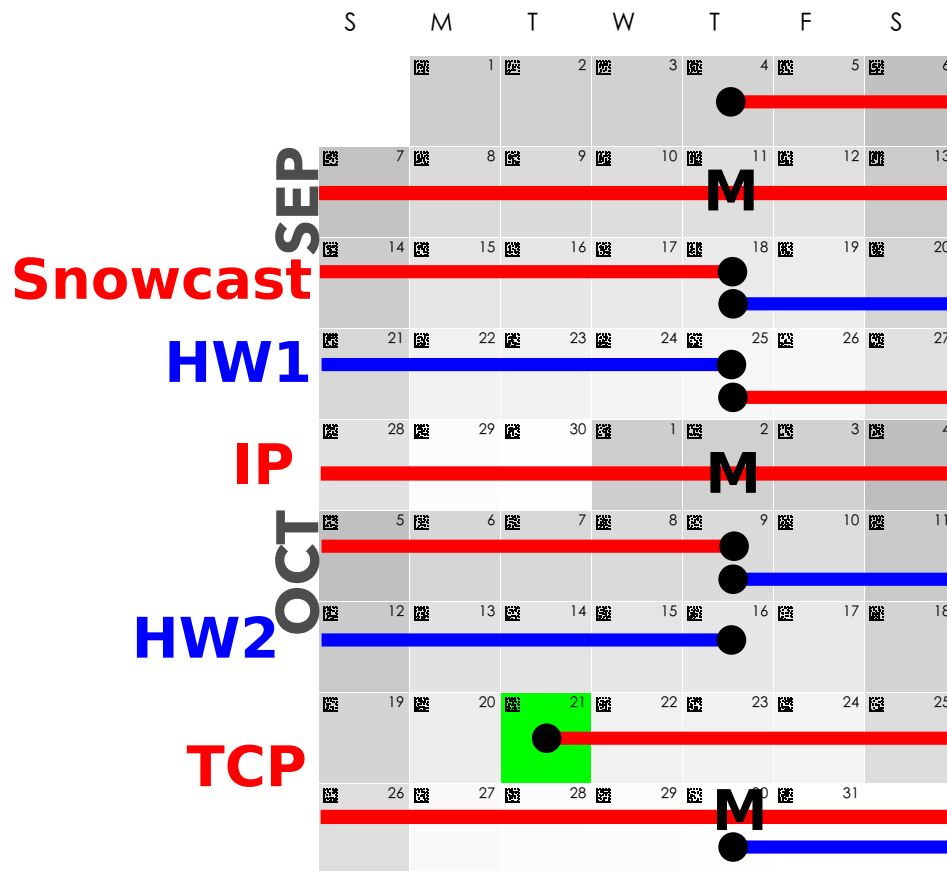
- **Many applications protocols on top of UDP & TCP**
- **IP works over many types of networks**
- **This is the “Hourglass” architecture of the Internet.**
 - If every network supports IP, applications run over many different networks (e.g., cellular network)



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Coming Up

- **Snowcast: start TODAY!**
- **Next class: how do applications use the network?**
 - Introduction to programming with Sockets
 - Peterson & Davie 1.4
 - Beej's Guide to Network Programming (link on the course website)
- **Then...**
 - We start moving up the network stack, starting from how two computers can talk to each other.

