Lecture 14: Communications and networking

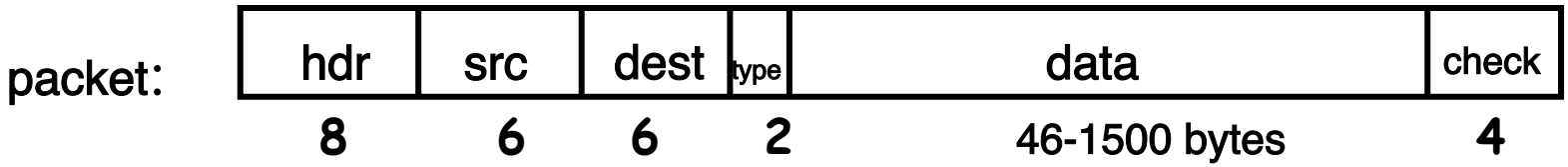
- history and background
  - telephone system
  - local area networks
- Internet
  - architecture: what the pieces are and how they fit together
  - names and addresses: what's your name and number?
    Domain Name System, IP addresses
  - routing: how to get from here to there
    traceroute, ping
  - fundamental protocols and layers: how pieces talk to each other
    IP, TCP
  - higher level protocols and services:
    HTTP, SSH, SMTP, IMAP, ...; web, email, instant messaging, peer to peer, ...
- Web
  - what makes it work: URL, HTTP, HTML, browser

Telephone system (Alexander Graham Bell, 1876)

- organizing principles, all based on voice traffic:
  - voice calls need only a narrow bandwidth channel
  - each call uses a dedicated circuit, with long setup and hold times
  - telephone number is a unique identifier
  - fixed routing for a specific call
  - parallel signaling network; data separated from control
  - simple user interface: all intelligence inside network
  - guarantees on quality of service; high reliability
- running out of some resources (area codes, 800/888/877/866/855/844, ...)
- traffic model changing rapidly (cell phones, data, ...)
- technology changing rapidly (wireless, Internet, ...)
- worldwide evolution from highly regulated and/or government-operated to deregulated / private
  - highly competitive
  - incumbent carriers threatened by Internet

Local Area Networks; Ethernet

- a LAN connects computers ("hosts") in a small geographical area
- Ethernet is the most widely used LAN technology
  - developed by Bob Metcalfe & David Boggs at Xerox PARC, 1973
  - each host has a unique 48-bit identification number
  - data sent from one host to another in "packets" of 100-1500 bytes
    including source and destination address and error checking bits
    typical data rate 10-1000 Mbits/sec; limits on cable length



- "broadcast" technology: data sent to all connected hosts
  - sender broadcasts, but if it detects someone else sending, stops, waits a random interval, tries again
- wireless Ethernet uses radio to carry signals
  - logical behavior is exactly like a wired Ethernet

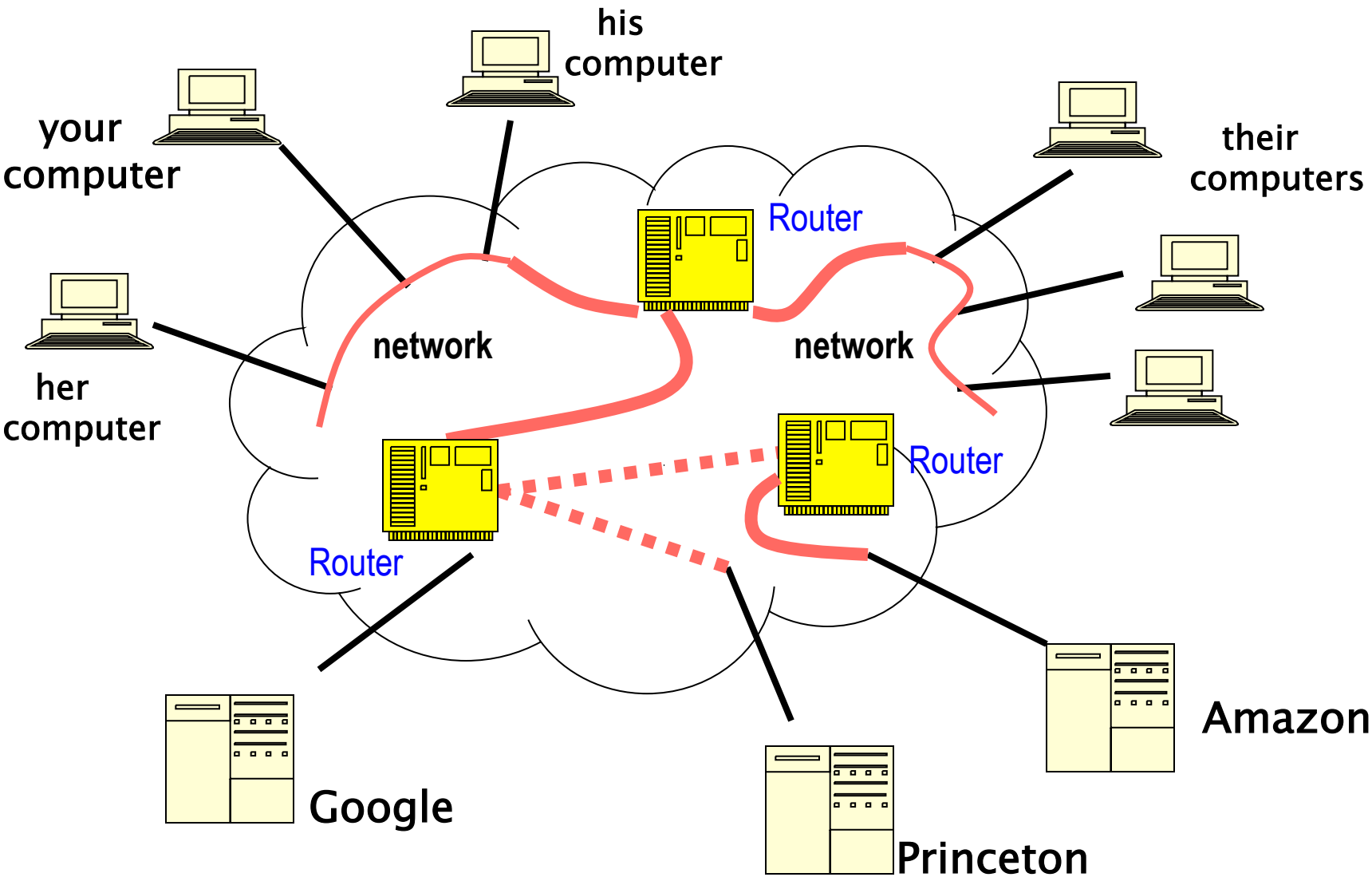
Connecting networks (wide area networks / WAN)

- how do we connect LANs to each other?
  - LANs may have different properties
  - may be far away

- names & addresses now needed to identify other networks and hosts
- routing needed to find a path if multiple networks are involved
  - can't have each network connected directly to all others
- protocols to agree on format of information and how it is exchanged
  - especially if networks are different kinds that use
    - different format for packets
    - different physical and electrical properties
    - different names and addresses themselves

- how do we handle errors, delays, overload, etc.?
- how does it scale as the number of networks gets really big?

Gateways and Routers



The Internet

- millions of independent networks that are connected
  - NOT a giant computer or a single network
  - each network may serve many host computers
- nearby computers are connected by a local area network
  - most often Ethernet (including wireless)
- information travels through networks in small "packets"
  - each packet independent of all others
    like individual envelopes through the mail
  - all packets have the same format
  - standard protocols for format of info and behavior
- networks connected by specialized gateway computers (routers)
  - route packets of information from one network to the next
  - gateways continuously exchange routing information
- each packet passes through multiple gateways
  - gateway passes packet to gateway that is closer to ultimate destination
  - gateways usually operated by different companies

Internet History

- 1961: packet switching concept (Leonard Kleinrock, MIT, UCLA)
- 1960's: ARPANET, funding from DARPA (Dept of Defense)
- 1969: first Internet communication
- 1972: first network email
- 1973: basic protocols: TCP/IP (Bob Kahn *64, Vint Cerf)
- 1980's: National Science Foundation funding, NSFNet (Al Gore)
- 1980's: Internet Engineering Task Force for technical decisions
- 1990's: commercialization, Web, dot-com boom
- 2000: dot-com bust
- 2010: universal availability
- 2020: increasing fragmentation, government controls

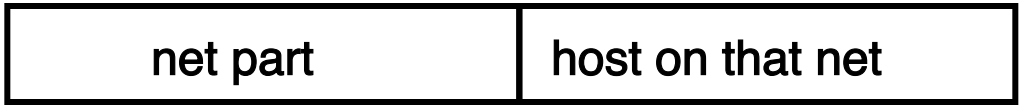
- for lots more, http://www.isoc.org/internet/history/

Basic mechanisms

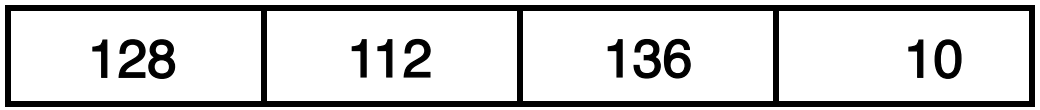
- names for computers
  - princeton.edu, finance.yahoo.com, www.whitehouse.gov, kernighan.net, ...
- addresses for identifying networks and computers
  - each has a unique number like 128.112.136.10 (IP address)
  - central authority assigns numbers to networks
  - each host computer has unique address (32 bit integer in IPv4, 128 in IPv6), assigned locally according to what network it's on
- Domain Name System to convert names to addresses
- routing for finding paths from network to network
- protocols (rules) for packaging and transporting information
  - IP, or "Internet Protocol": a uniform transport mechanism
    at IP level, all information is in a common format
  - below IP, different hardware uses different protocols
  - above IP, higher-level protocols for handling web pages, mail, login …

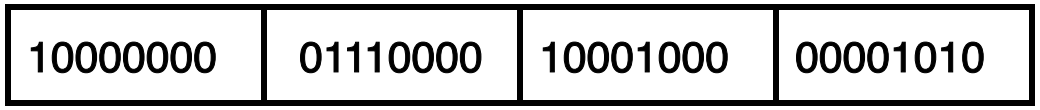
Internet (IP) addresses

- each network and each connected computer has an IP address
- IP address: a unique 32-bit number in IPv4 (IPv6 is 128 bits)
  - 1st part is network id, assigned centrally in blocks
    (Internet Assigned Numbers Authority -> Internet Service Provider -> you)
  - 2nd part is host id within that network
    assigned locally, often dynamically



- written in "dotted decimal" notation: each byte in decimal
  - e.g., 128.112.136.10 = www.princeton.edu





Domain names

- a hierarchical naming scheme
  - central authority (ICANN) manages top level of names
- top level domains include .com, .edu, .gov, .xx for country XX
  - and myriad newer domains like .biz, .info, .name, .xxx, …
- each domain delegates responsibilities to levels below
  - for administration and translation into addresses
- each level is responsible for names within it
  - princeton.edu handles all of princeton
  - delegates cs.princeton.edu to a CS computer
  - CS department manages names within, e.g., rinse.cs.princeton.edu

- names impose logical structure, not physical or geographical

Domain name system (DNS)

- DNS converts names to IP addresses and vice versa
  - www.princeton.edu == 140.180.223.42
  - carnegiehall.org == 45.60.73.146
  - kernighan.com == 23.111.140.49
- hierarchical searching for addresses
  - central authority controls top level domain names (.com, etc.)
  - delegates responsibilities for searching to levels below
  - each level responsible for names and addresses within it

    princeton.edu handles address lookup for all of princeton

    delegates cs.princeton.edu to a CS machine
- top level domains handled by 13 root servers
- lookup for a name asks a local name server first
  - if not known locally, asks a server higher up, …, to root server
  - recently-used names are cached to speed up access

Routing

- networks are connected by gateways or routers
- routing rules direct packets from gateway to gateway
  trying to get closer to ultimate destination
- routers exchange information frequently about routes
- bottom-up view:
  - gateways move packets from one network to another based on network id
  - if destination on the same network, use physical address
  - otherwise send to a gateway, which passes it to another network
- top-down view:
  - networks connected only through gateways
  - core has a small set of gateways that exchange complete routing info
    about which nets it knows about and number of hops to reach them
  - autonomous system: group of networks under single authority
  - passes reachability info to core for use by other autonomous systems
  - interior gateway protocols exchange routing info within a single AS
- ping: is there a path from here to there?
- traceroute: how do you get from here to there?