

Lecture 15
Communications
and Networking

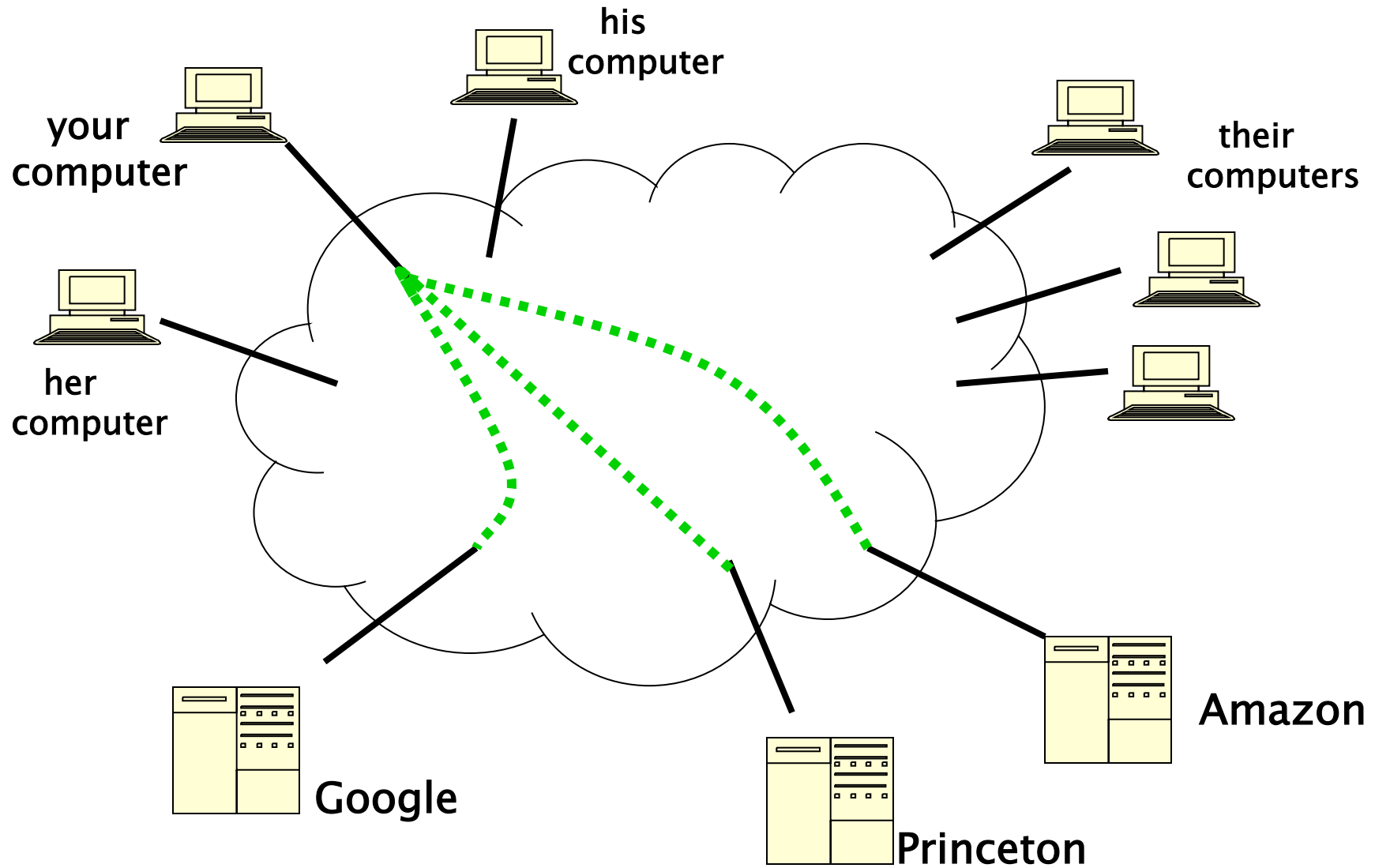
Communications and networking

- **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
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

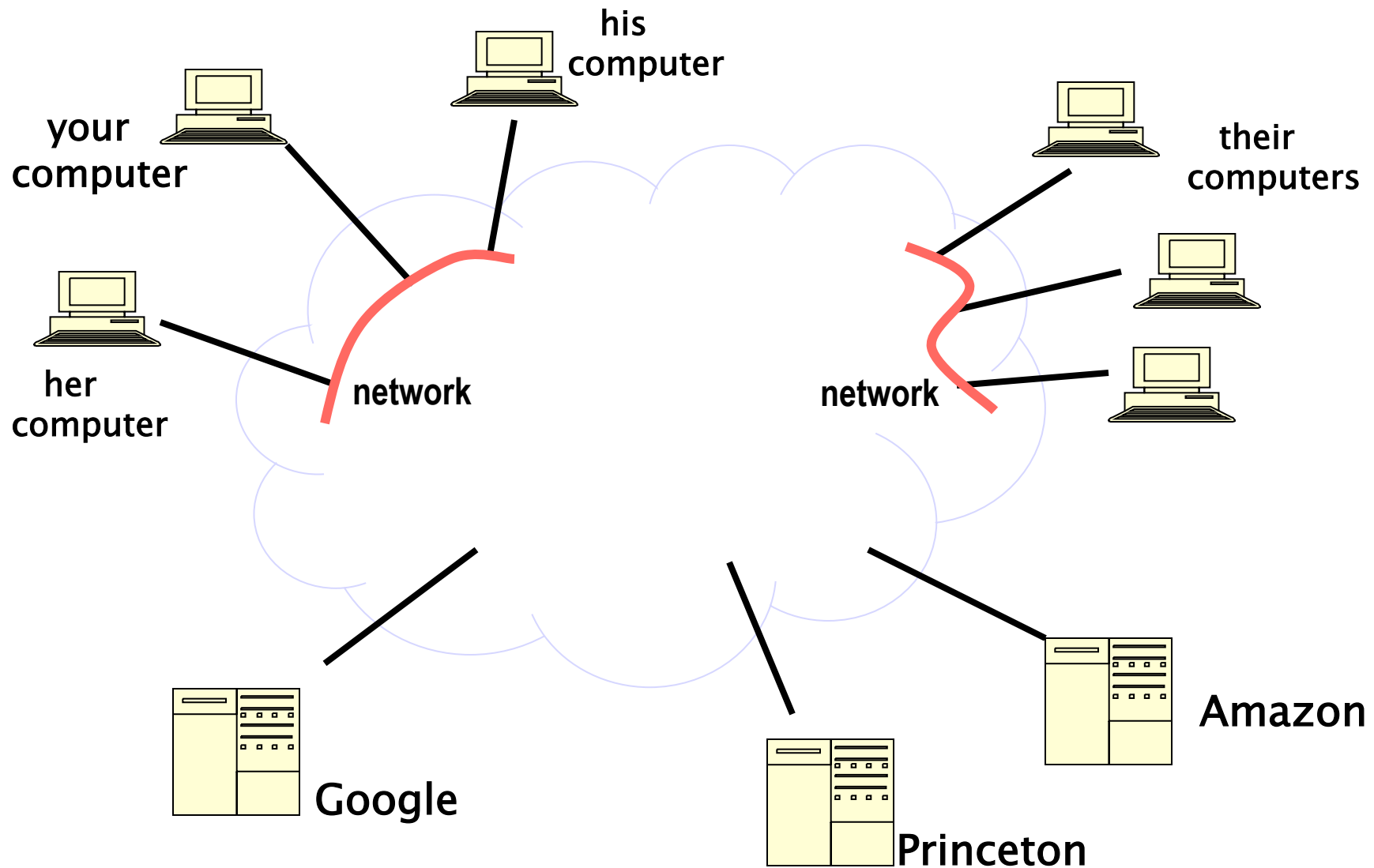
Telephone system (Alexander Graham Bell, 1876)

- **organizing principles, all based on voice traffic:**
 - voice calls need only a narrow bandwidth channel
 - a 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, ...)**
- **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

The Internet

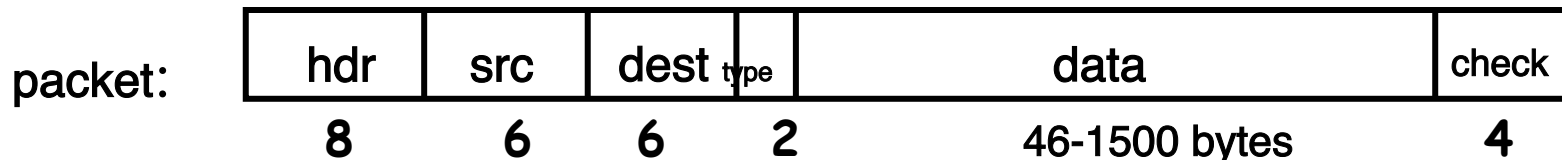


Local Area Networks ("LAN")



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 bitstypical data rate 10-1000 Mbits/sec; limits on cable length

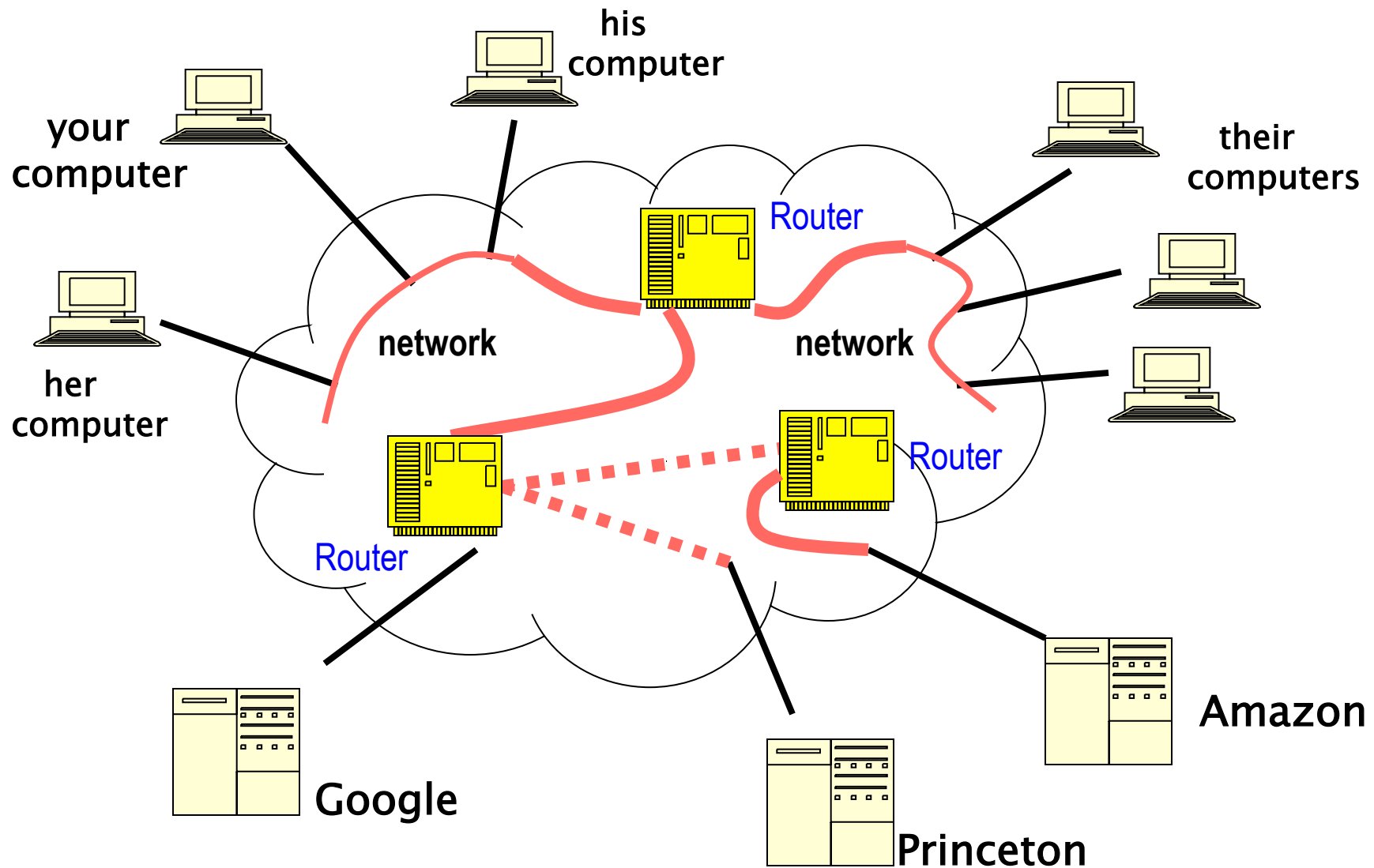


- "broadcast" technology: data sent to all connected hosts
 - sender **broadcasts**, but if it detects someone else sending, stops, waits a random interval, tries again
- wireless Ethernet uses radio to carry signals
 - logical behavior is exactly like a wired Ethernet

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 find 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: fragmentation?

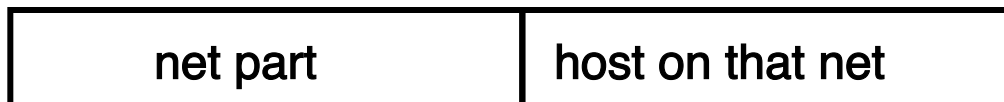
- for lots more, <http://www.isoc.org/internet/history/>

Basic mechanisms

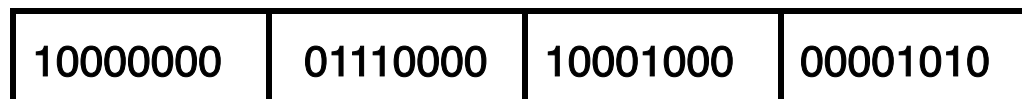
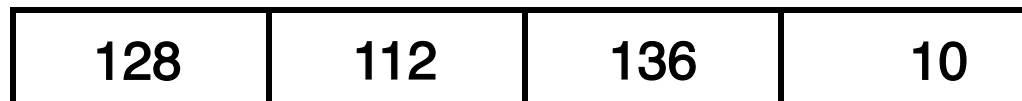
- **names** for computers
 - princeton.edu, finance.yahoo.com, www.whitehouse.gov, kernighan.net, ...
- **addresses** for identifying networks and computers
 - each has a unique number like 128.112.136.10 (IP address)
 - central authority assigns numbers to networks
 - each host computer has unique address (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**

ICANN

- **Internet Corporation for Assigned Names and Numbers**
 - non-profit corporation, established 1998 by Dept of Commerce
 - technical coordination of the Internet
 - www.icann.org
- **"coordinates the assignment of the following identifiers that must be globally unique for the Internet to function:**
 - Internet domain names
 - IP address numbers
 - protocol parameter and port numbers
- **"coordinates the stable operation of the Internet's root server system"**

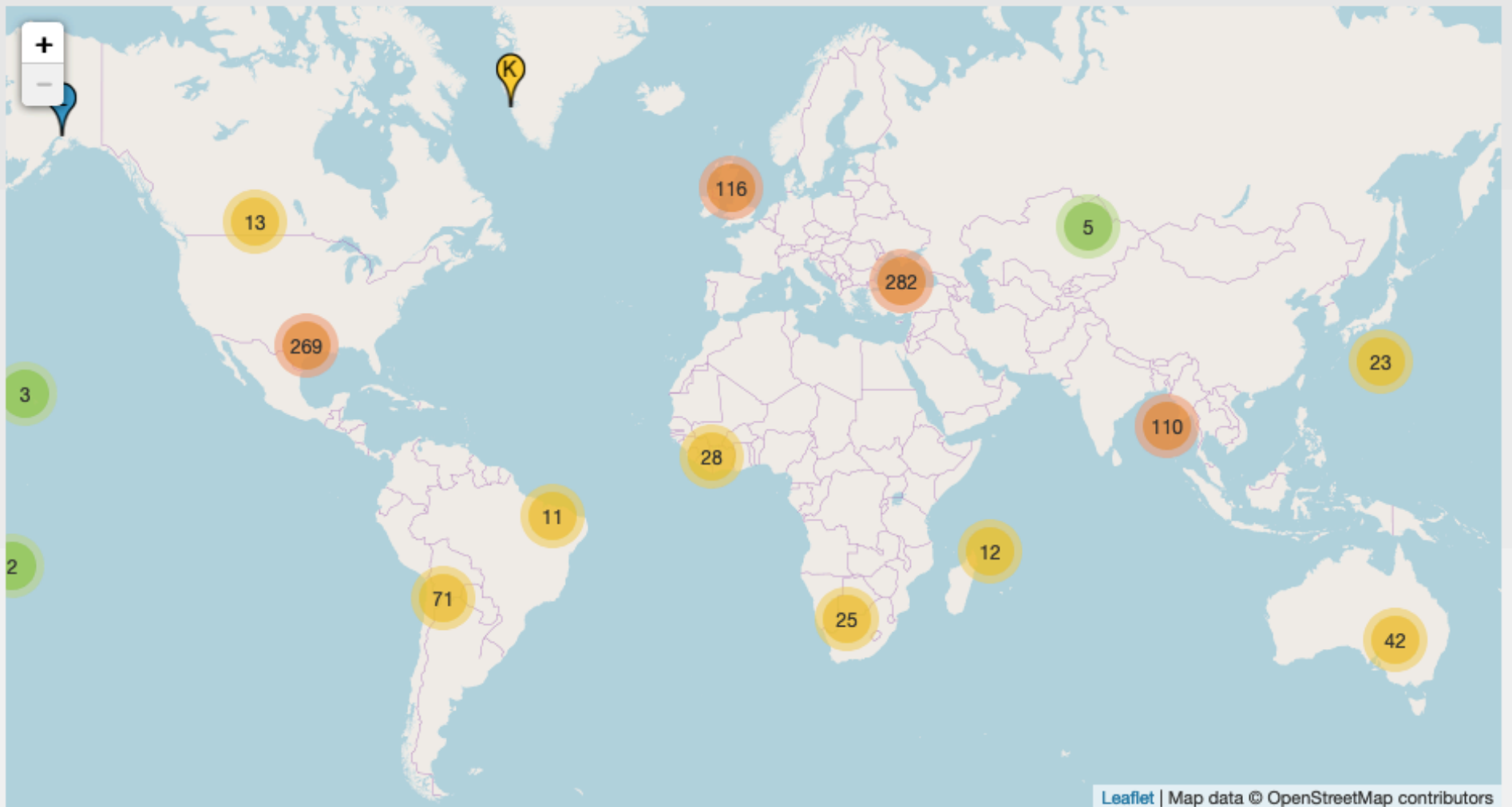


Domain name system (DNS)

- **DNS converts names to IP addresses and vice versa**
 - www.princeton.edu == 140.180.223.42
 - carnegiehall.org == 45.60.73.146
 - kernighan.com == 69.46.29.42
- **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
- **names impose logical structure, not physical or geographical**

Root servers (www.root-servers.org)

Root Server System



As of 2019-11-10, the root server system consists of 1015 instances operated by the 12 independent root server operators.

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
- **traceroute: how do you get from here to there?**