CS 3700
Networks and Distributed Systems

Lecture 1: Logistics, Networking Programming, Overview

Outline

- Course Logistics
- Networking Overview
- Intro to Network Programming

Hello!

- Welcome to CS 3700
  - Are you in the right classroom?
  - Okay, good.

- Who am I?
  - Professor Alan Mislove
  - amislove@ccs.neu.edu
  - West Village H 250
  - Office Hours: 4:30-5:30pm Mondays

Why Take This Course?

- How many of you have checked your e-mail, FB, texts…

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  - In the past hour?
  - Since I started talking?

Networks and dist. systems are ubiquitous

- Touch every part of our daily life
  - Web search
  - Social networking
  - Watching movies
  - Ordering merchandise
  - Wasting time

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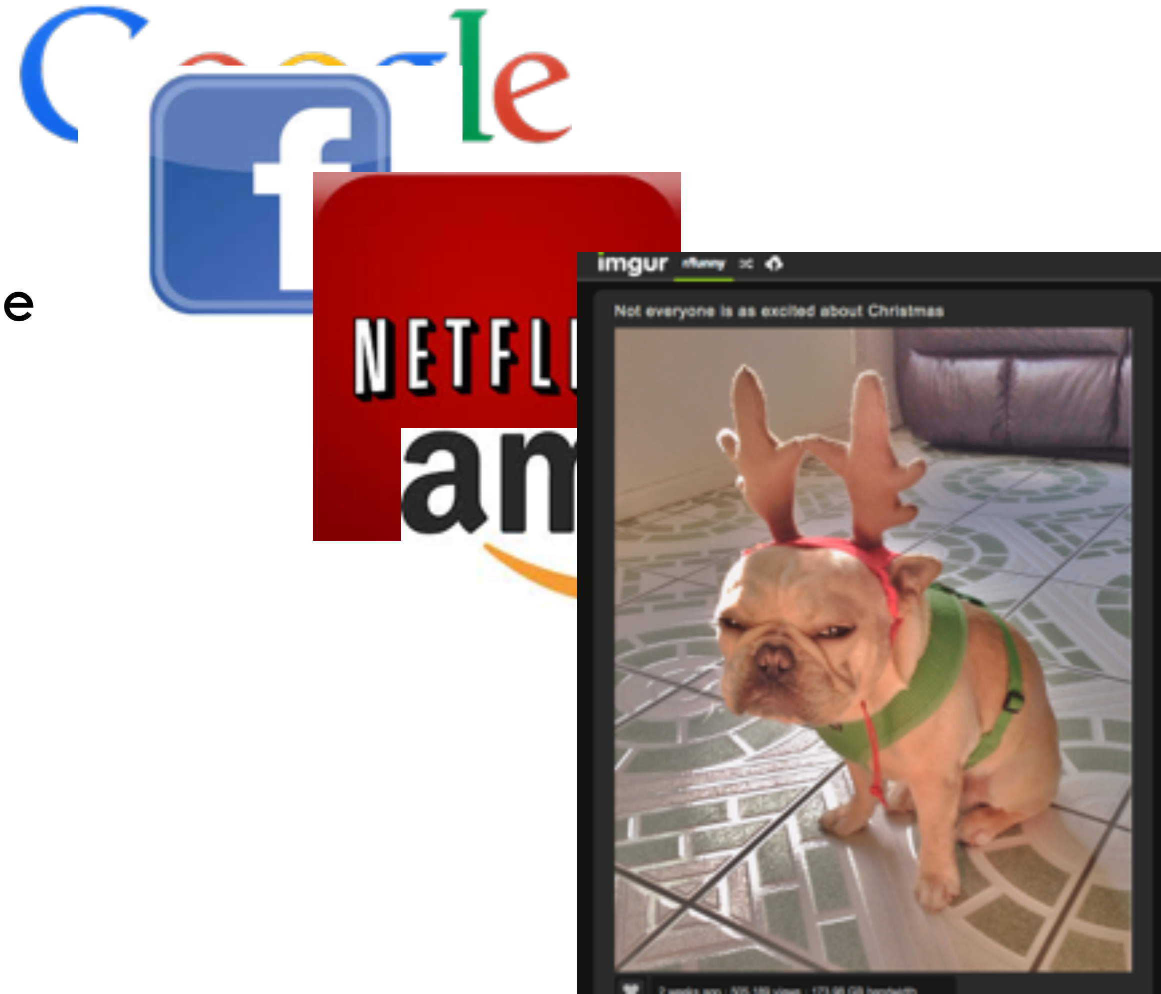


Networks and dist. systems are ubiquitous

- Networking is one of the most critical topics in CS
  - There would be no…
    - Big Data
    - Cloud
    - Apps or Mobile Computing
  - … without networks

Goals

- Fundamental understanding of networking and systems
  - All the way from bits on a wire…
  - … across the ever-evolving Internet…
  - … to a complex distributed application
- Focus on software and protocols
  - Not hardware
  - Minimal theory
- Project-centric, hands on experience
  - Real projects, protocols, etc

Online Resources

- http://www.ccs.neu.edu/~amislove/cs3700/spring15

- Class forum is on Piazza
  - Sign up today!
  - Install their iPhone/Android app

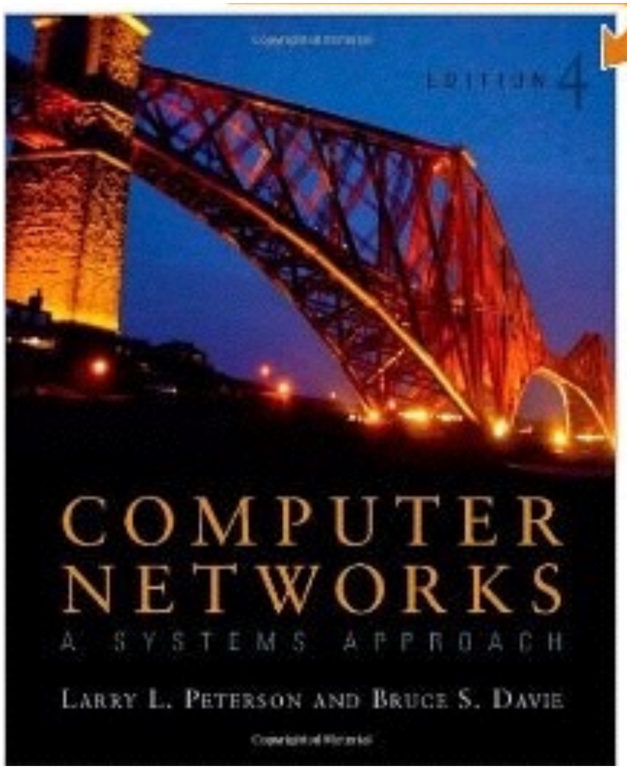
- When in doubt, post to Piazza
  - Piazza is preferable to email
  - Use #hashtags (#homework1, #lecture2, #project3, etc.)

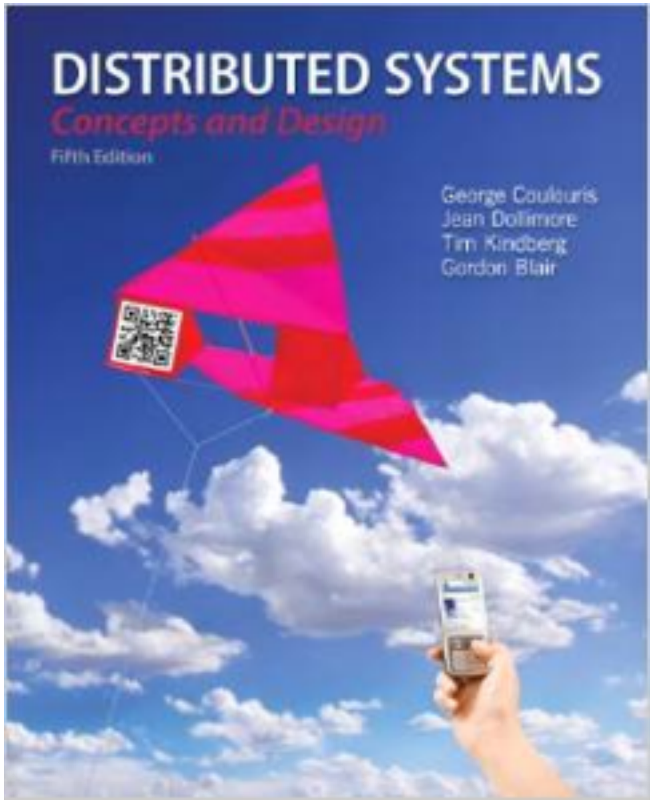
Teaching Style

- I am a networking and systems researcher
  - Things make sense to me that may not make sense to you
  - I talk fast if nobody stops me
- Solution: ask questions!
  - Seriously, ask questions
  - Standing up here in silence is very awkward
  - I will stand here until you answer my questions
- Help me learn your names
  - Say your name before each question

Textbook

- Two books, both optional
  - Computer Networks: A Systems Approach
  - Distributed Systems: Concepts and Design





Workload

Projects (5)	***1%, 12%, 15%, 12%, 15%***
Homeworks (10)	***1.5% each***
Midterm	***12.5%***
Final	***12.5%***
Participation	***5%***

Projects

- This course is project-centric
  - Designed to give you real networking experience
  - Start early!
  - Seriously, start early!

- 5 projects
  - Due at 11:59:59pm on specified date
  - Use turn-in scripts to submit your code, documentation, etc.
  - **Working code is paramount**

Project Logistics

- Languages
  - You may choose the language for (most of) the projects
    - Code must compile on the CCIS Linux machines
- Project 0 is released now, due next week
- Project questions?
  - Post them on Piazza!

Project Groups

- Projects will be completed in groups of two
  - Unless we have odd numbers…
- Partner selection
  - Pick whoever you want
  - You may switch partners between projects
  - Do not complain to me about your lazy partner
    - Hey, you picked them
- Can't find a partner?
  - Post a message on Piazza!

Late Policy

- Each student is given 4 slip days that they can use at any time to extend a deadline
  - You don't need to ask me, just turn-in stuff late
  - All group members must have unused slip days
    - i.e. if one member has zero slip days left, the whole group is late

- Assignments are due at 11:59:59, **no exceptions**
  - 1 second late = 1 hour late = 1 day late
  - 20% off per day late

Exams

- Midterm and Final
  - 1-2 hours, in class
  - Midterm on networking, final on distributed systems
  - The final will **not be cumulative**

- All exams are:
  - Closed book, closed notes, leave the laptop at home
  - You may have a 1-page double-sided “cheat sheet”
  - And use a calculator

Cheating

- Do not do it
  - Seriously, don't make me say it again
- Cheating is an automatic zero
  - Will be referred to the university for discipline and possible expulsion
- Project code must be original
  - You and your groupmates only
    - Unless we give you starter code, obviously
  - StackOverflow/Quora are not your friends
  - If you have questions about an online resource, ask me

Questions?

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What is a Comm. Network?

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  - People and roads
  - Telephones and switches
  - Computers and routers

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Networks are key for:

- Speed
- Distance

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- 2400 BC: courier networks in Egypt
- 550 BC: postal service invented in Persia

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Problems:
- Speed
- Reliability
- Security

Towards Electric Communication

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Higher compression = faster speeds

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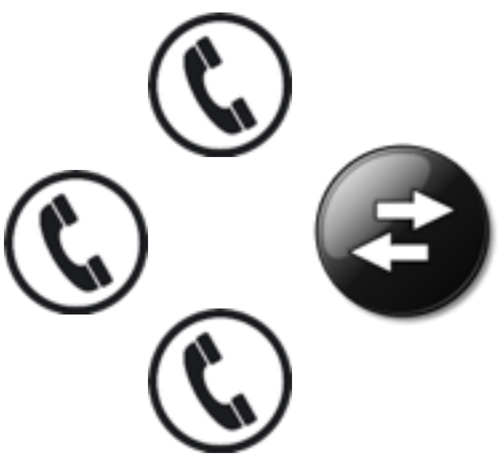

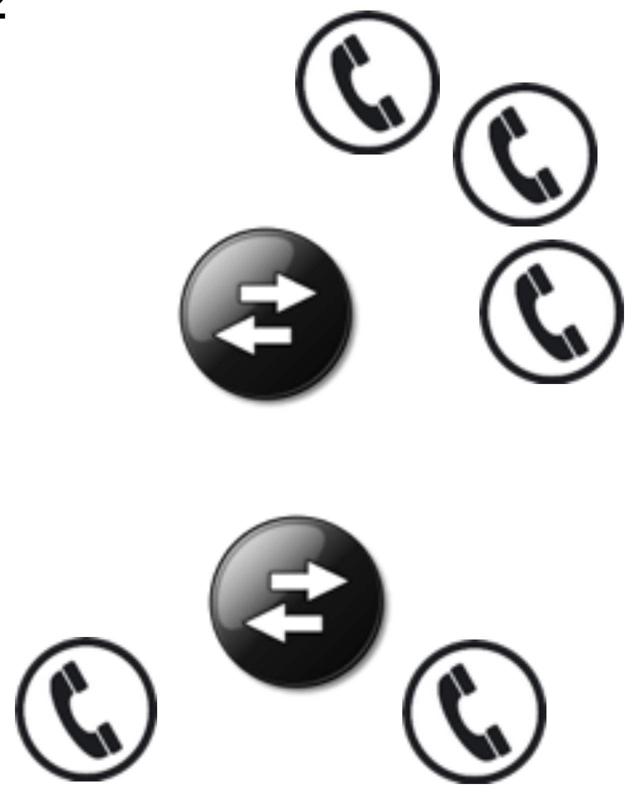

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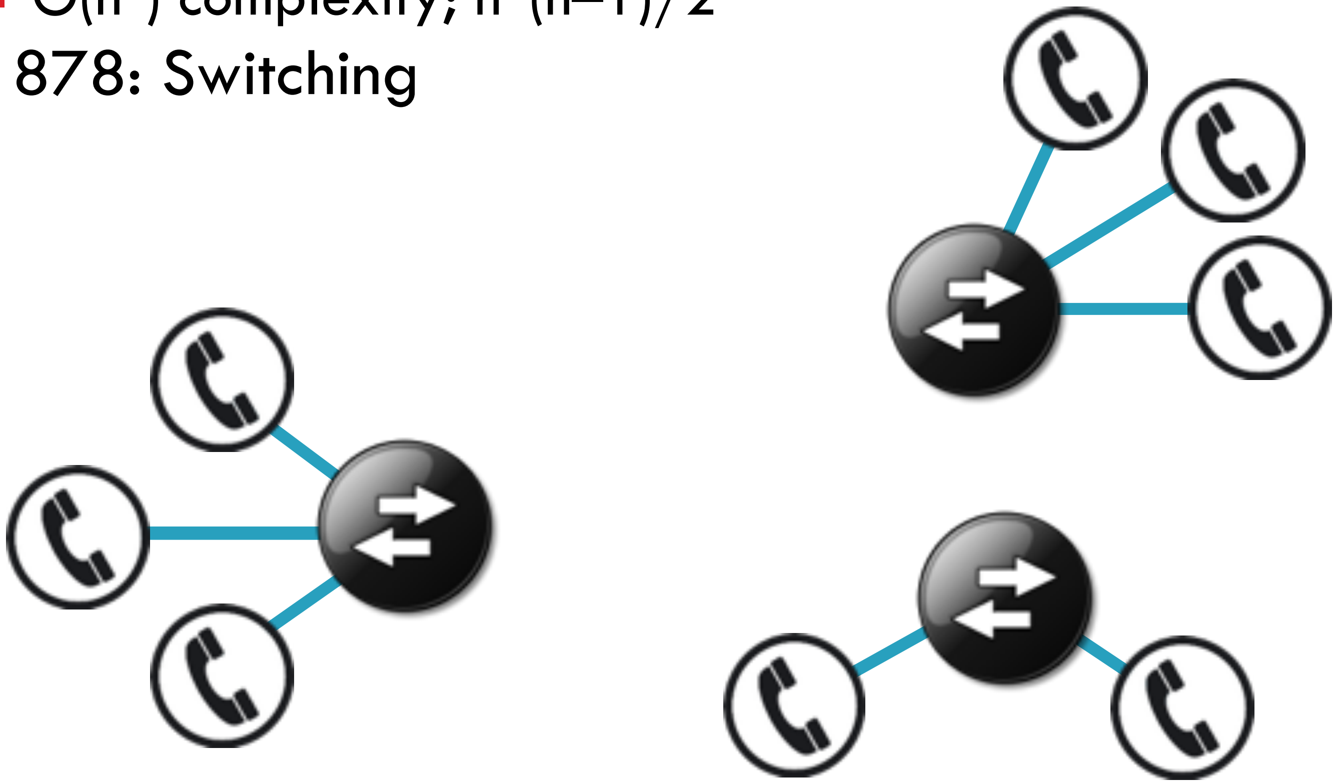

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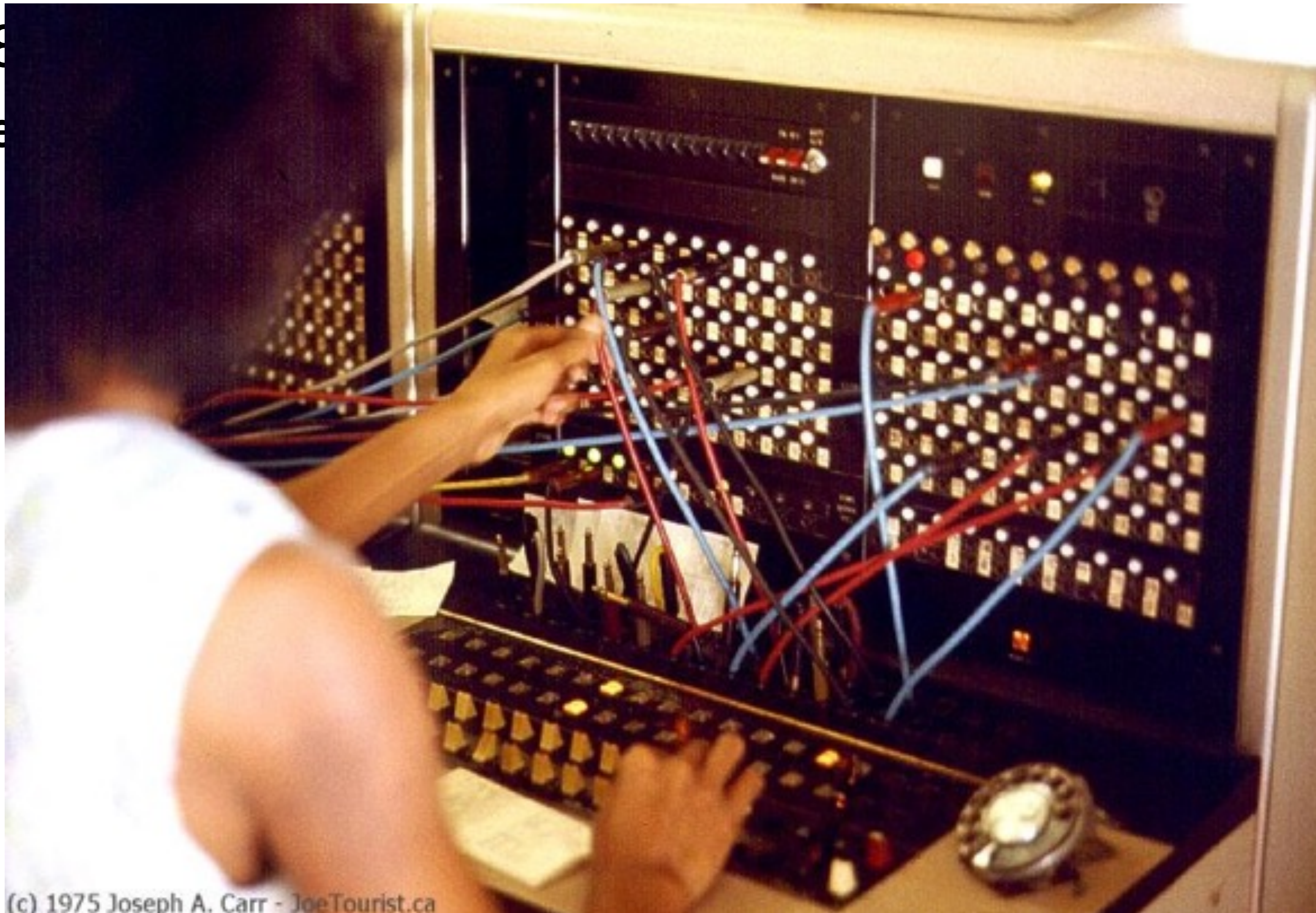

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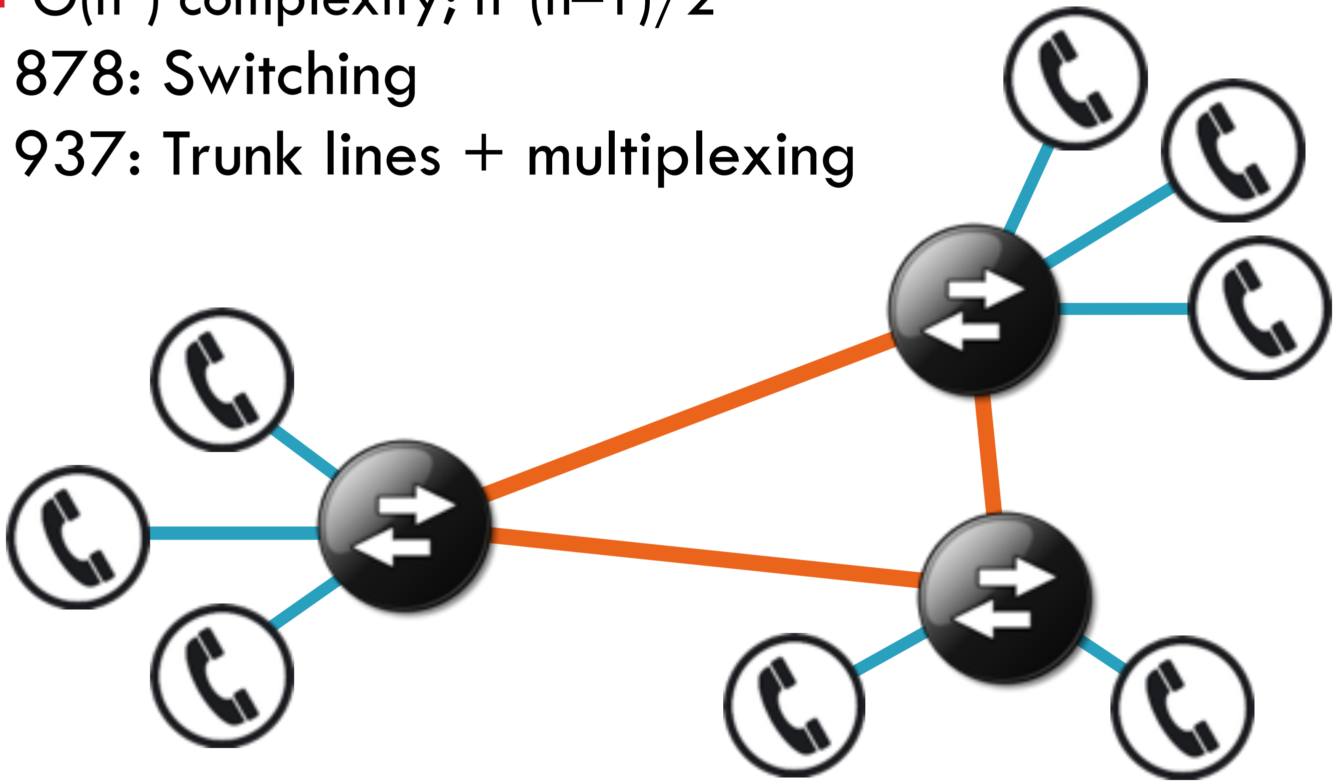
  - 1937: Trunk lines + multiplexing



Telephony

Advantages

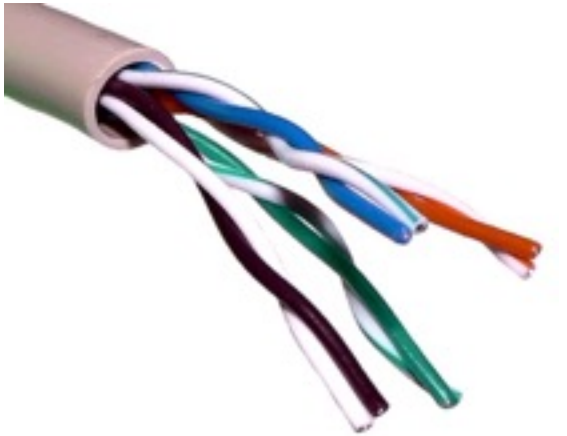
- Easy to use
- Switching mitigates complexity
- Makes cable management tractable

Problems

- Manual switching
- 1918: cross country call took 15 minutes to set up

Growth of the Telephone Network

- 1881: Twisted pair for local loops
- 1885: AT&T formed
- 1892: Automatic telephone switches
- 1903: 3 million telephones in the US
- 1915: First transcontinental cable
- 1927: First transatlantic cable
- 1937: first round-the-world call
- 1946: National numbering plan



at&t

Crazy idea: Packet switching

- Telephone networks are circuit switched
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  - Resource intense (what if the circuit is idle?)
  - Complex network components (per circuit state, security)
- Packet switching
  - No connection state, network is store-and-forward
  - Minimal network assumptions
  - Statistical multiplexing gives high overall utilization

The World's Most Successful Computer Science Research Project

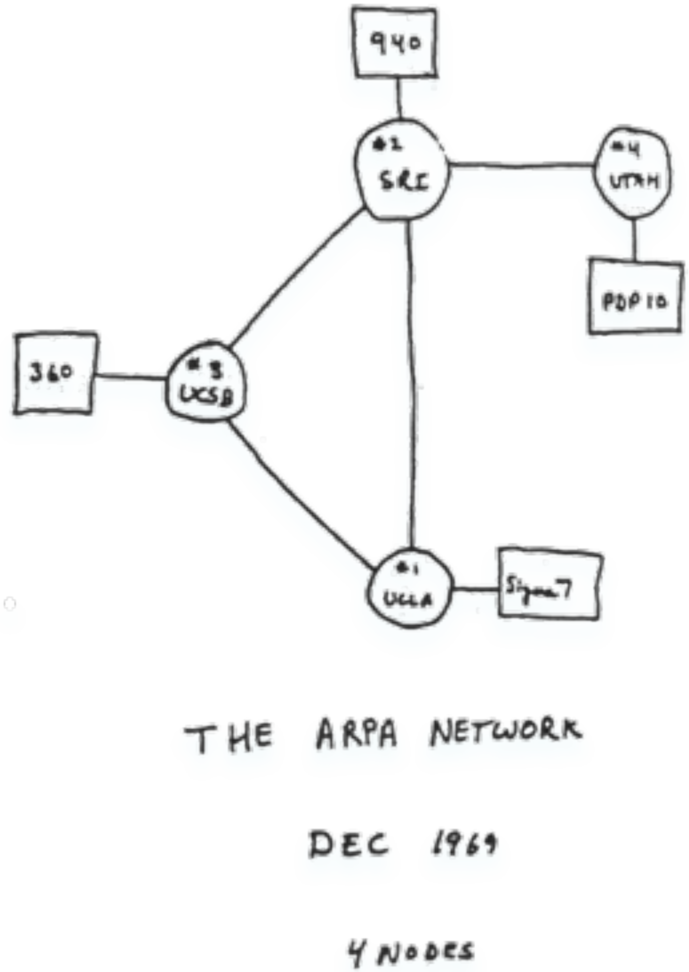
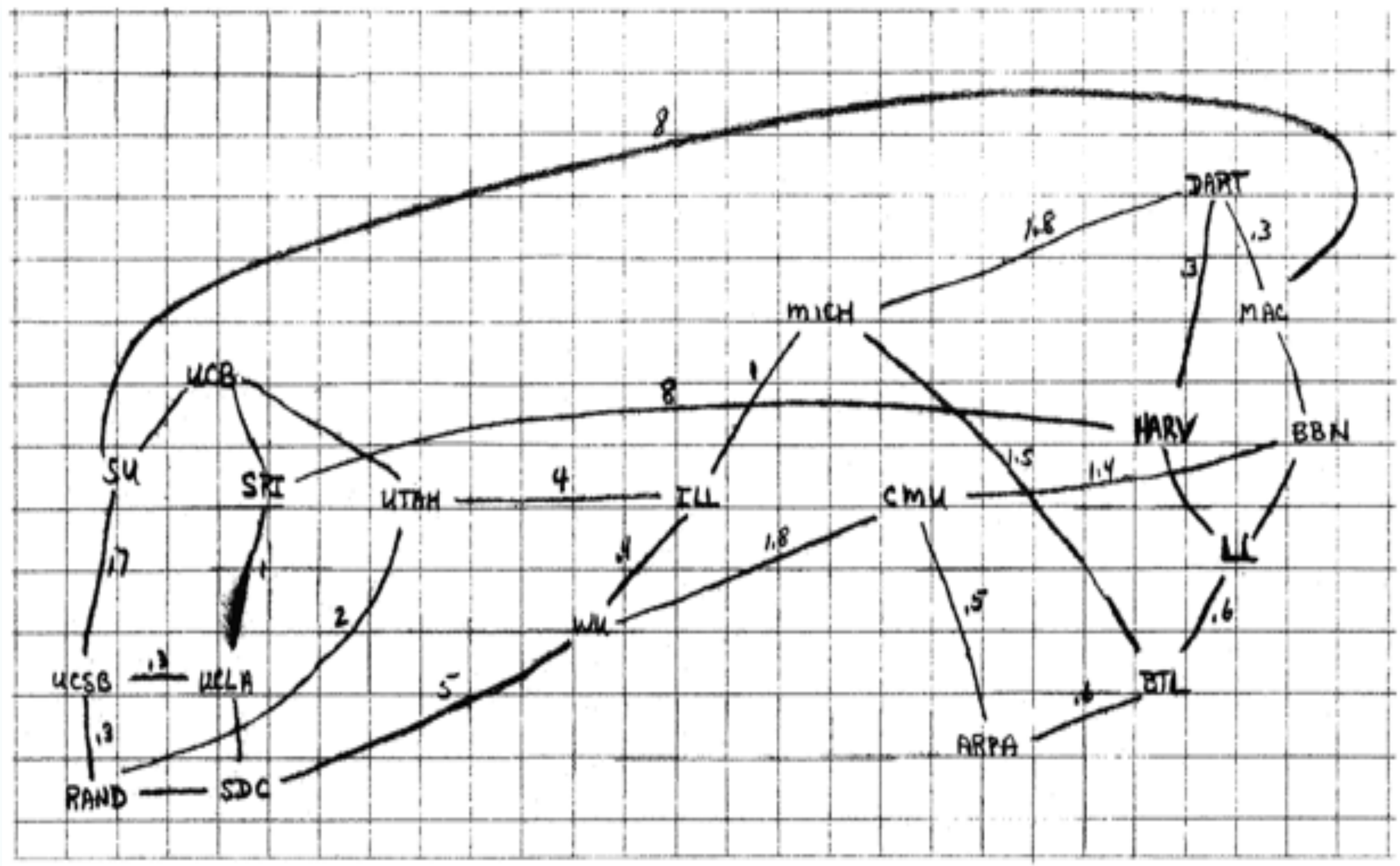


FIGURE 6.2 Drawing of 4 Node Network (Courtesy of Alex McKenzie)

History of the Internet

- 1961: Kleinrock @ MIT: packet-switched network
- 1962: Licklider's vision of Galactic Network
- 1965: Roberts connects computers over phone line
- 1967: Roberts publishes vision of ARPANET
- 1969: BBN installs first InterfaceMsgProcessor at UCLA
- 1970: Network Control Protocol (NCP)
- 1972: Public demonstration of ARPANET
- 1972: Kahn @ DARPA advocates Open Architecture
- 1972: Vint Cerf @ Stanford writes TCP

The 1960s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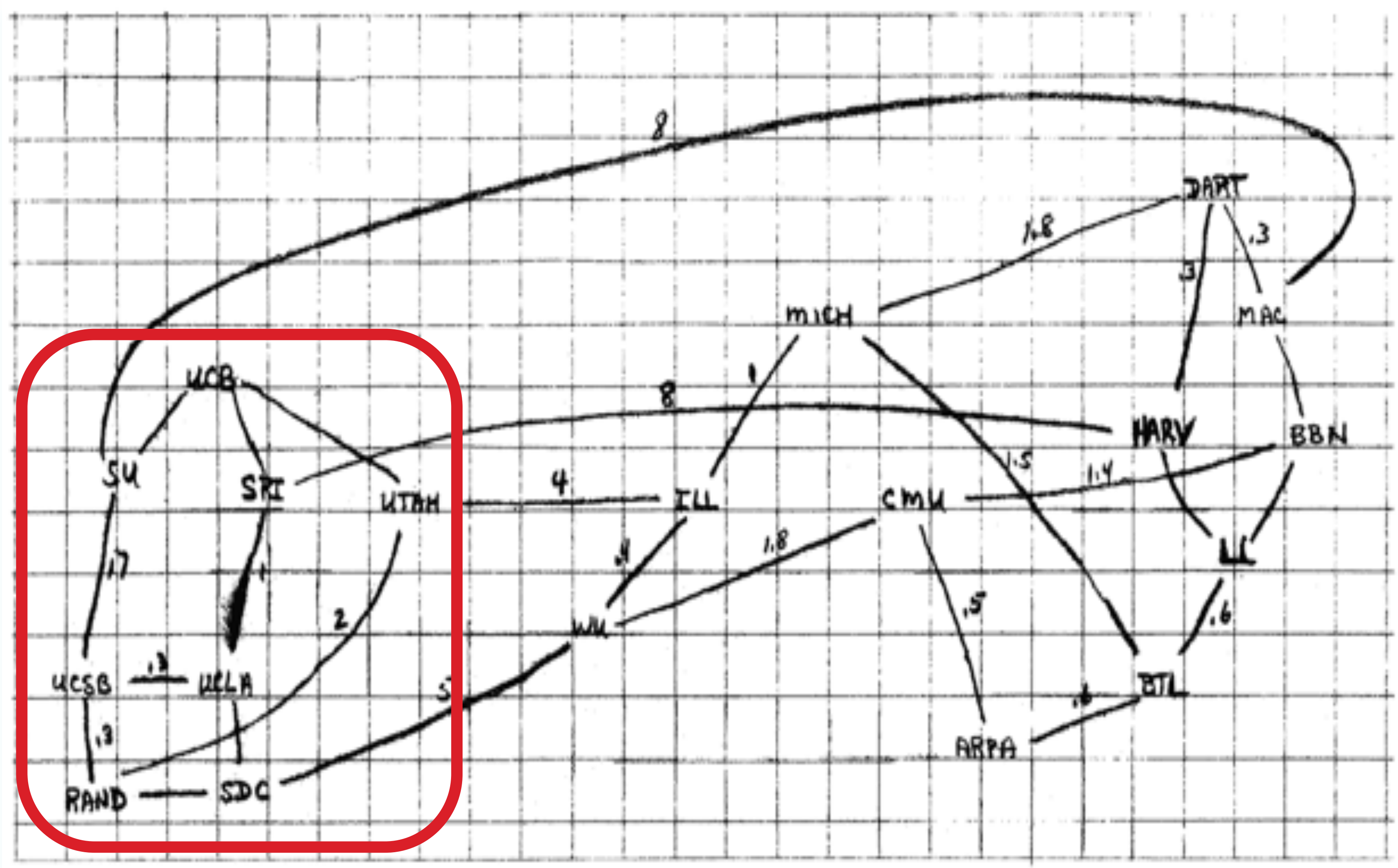
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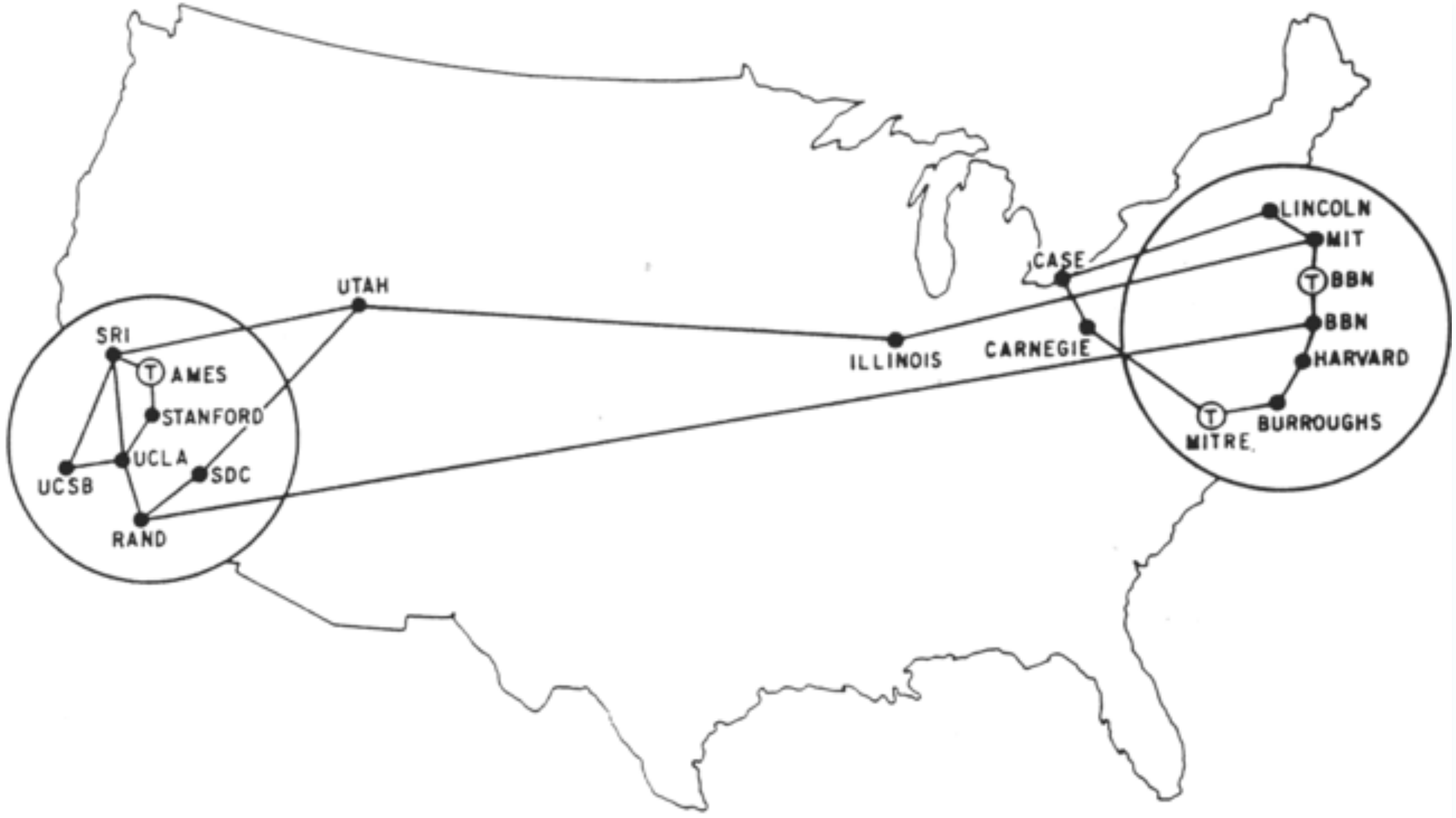
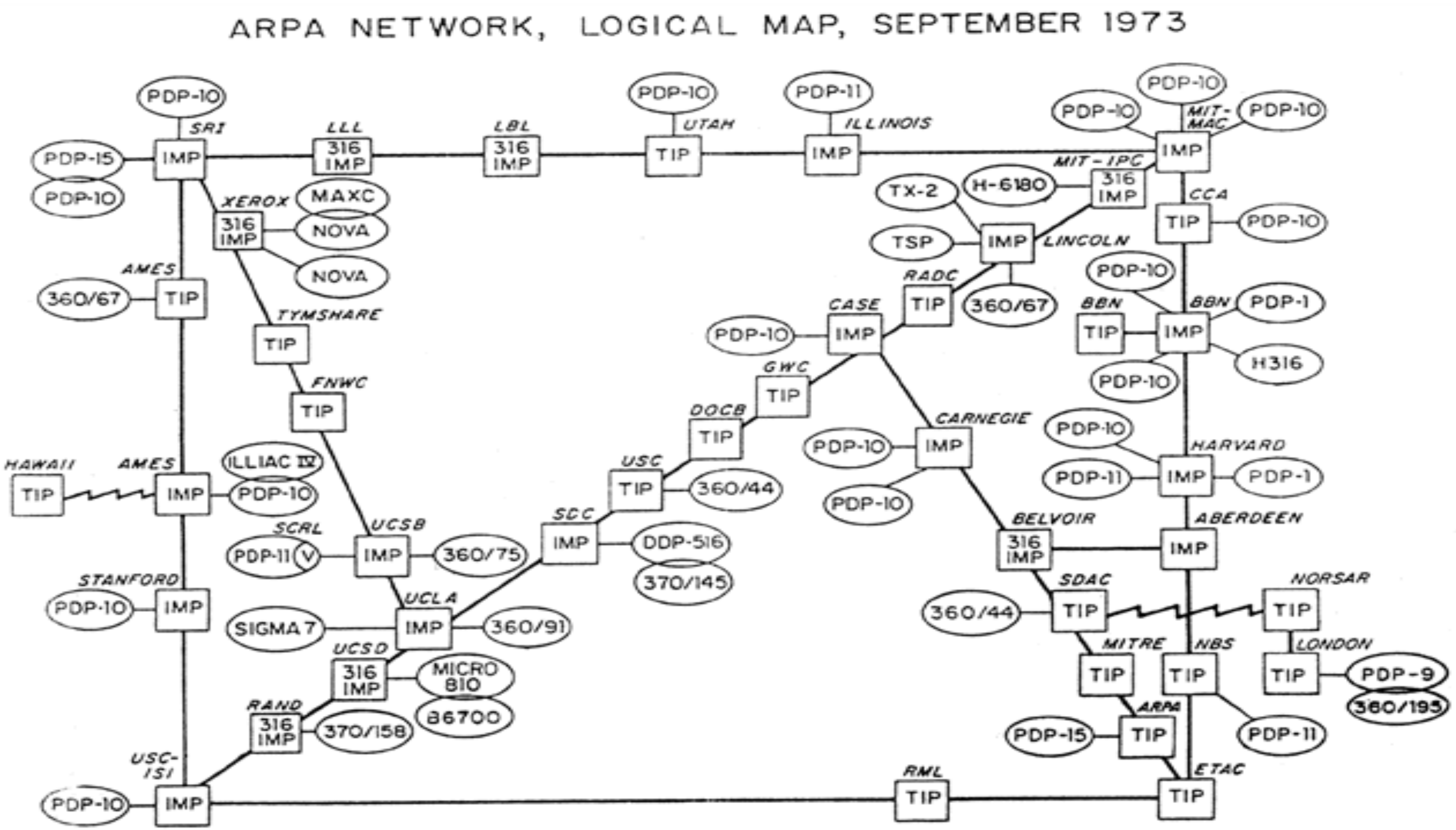


MAP 4 September 1971

1973


ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973
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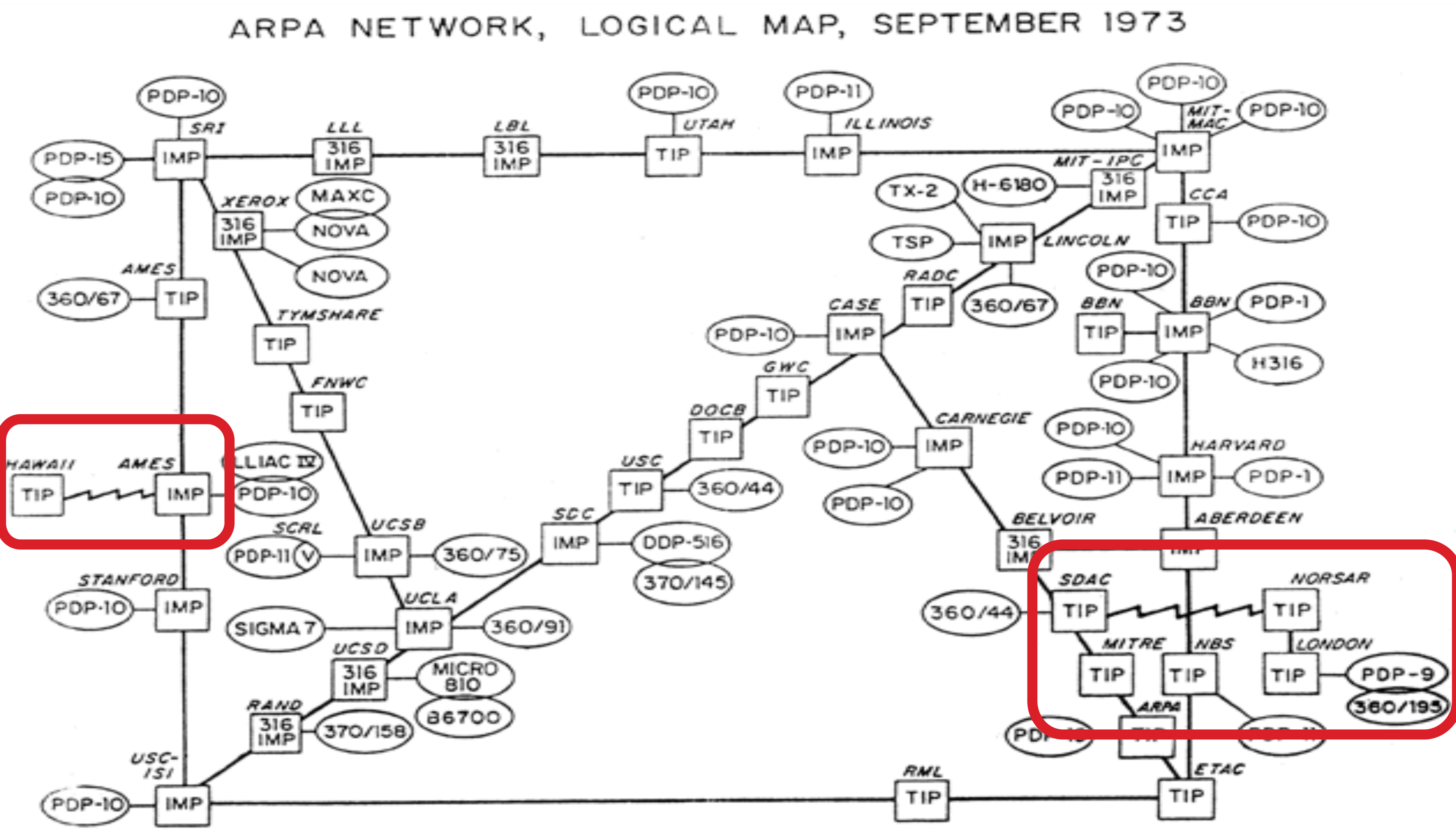
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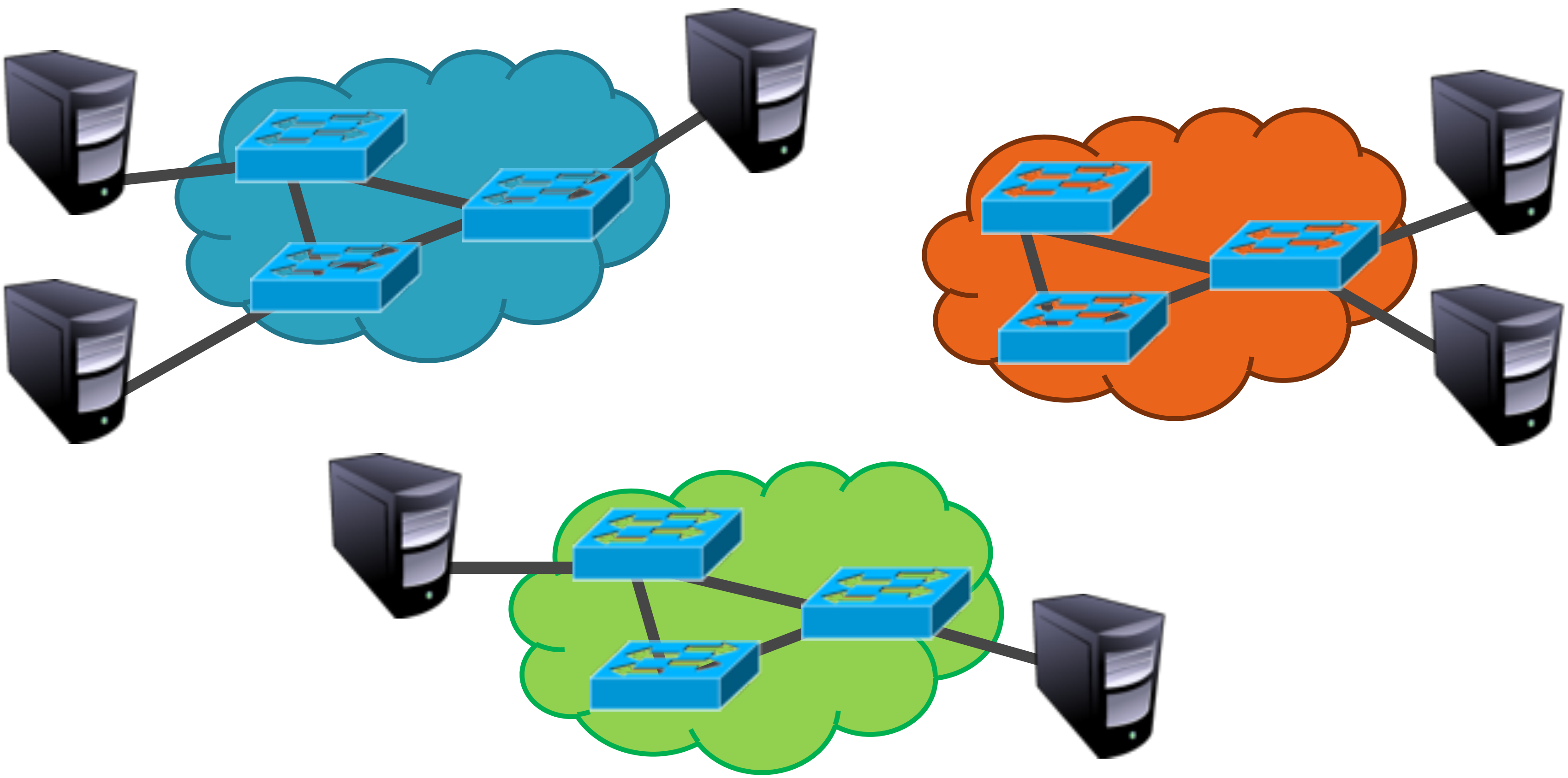
Growing Pains

- Problem: early networks used incompatible protocols



Kahn's Ground Rules

1. Each network is independent, cannot be forced to change
2. Best-effort communication (i.e. no guarantees)
3. Routers connect networks
4. No global control

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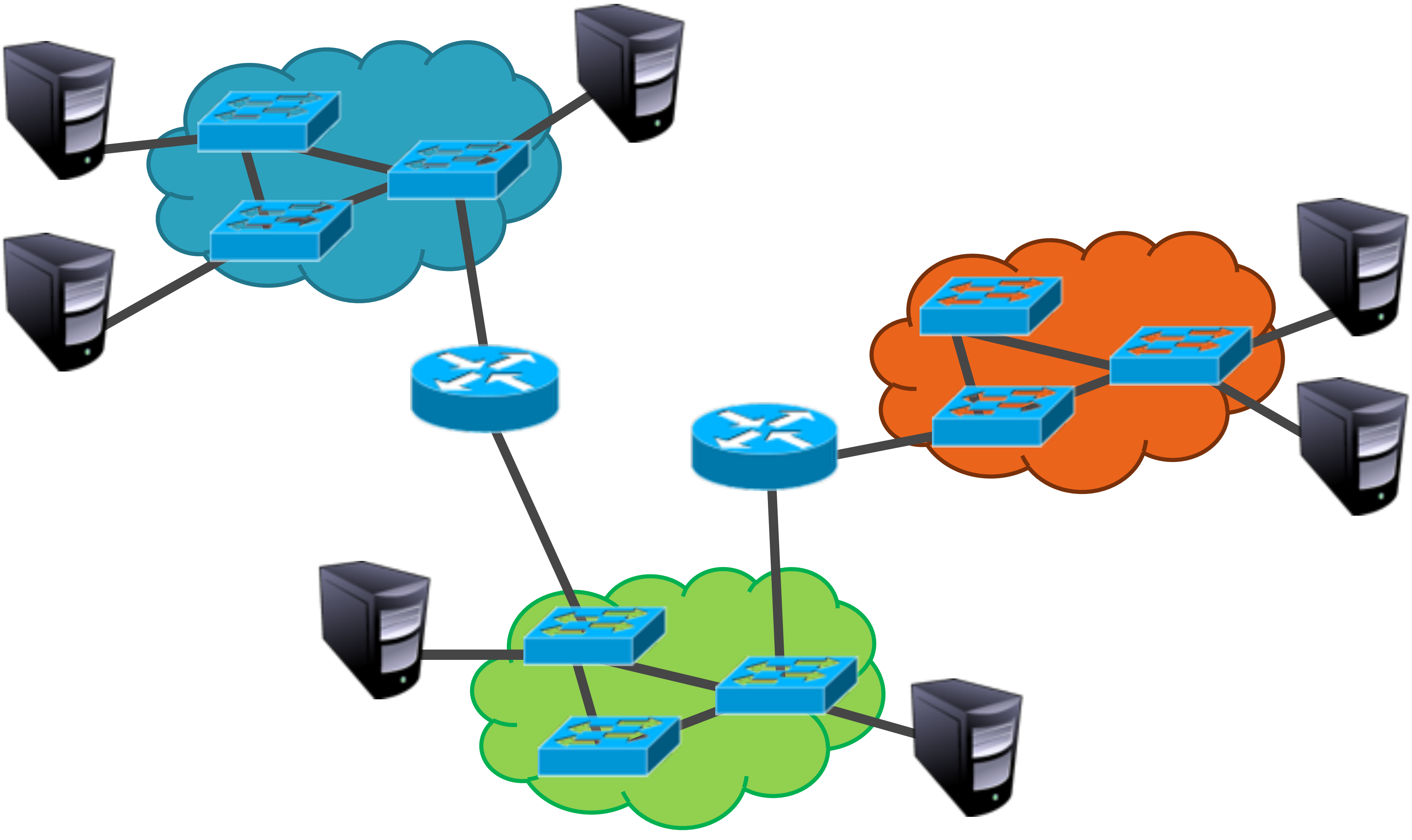
- Principles behind the development of IP
- Led to the Internet as we know it
- Internet is still structured as independent networks

The Birth of Routing



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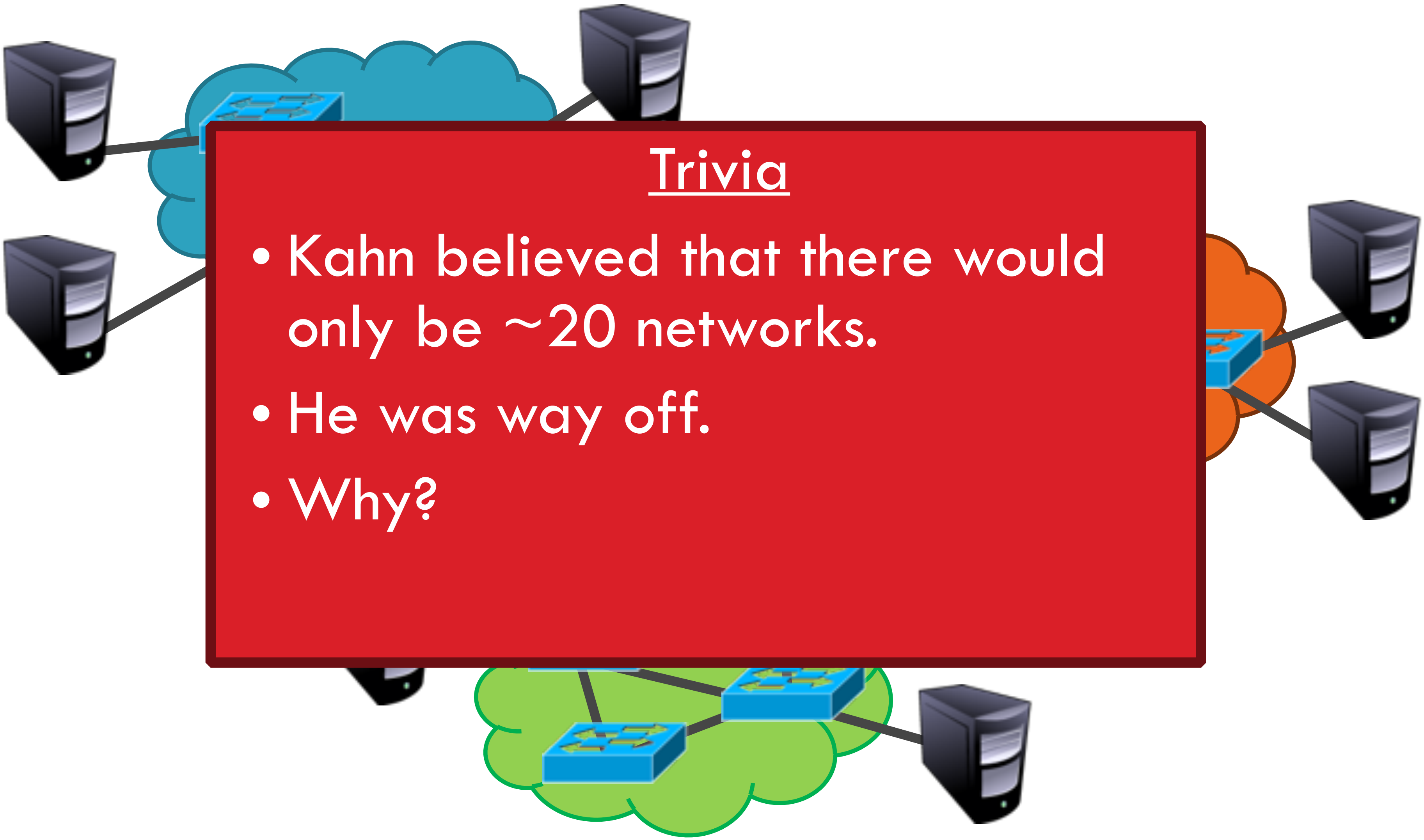
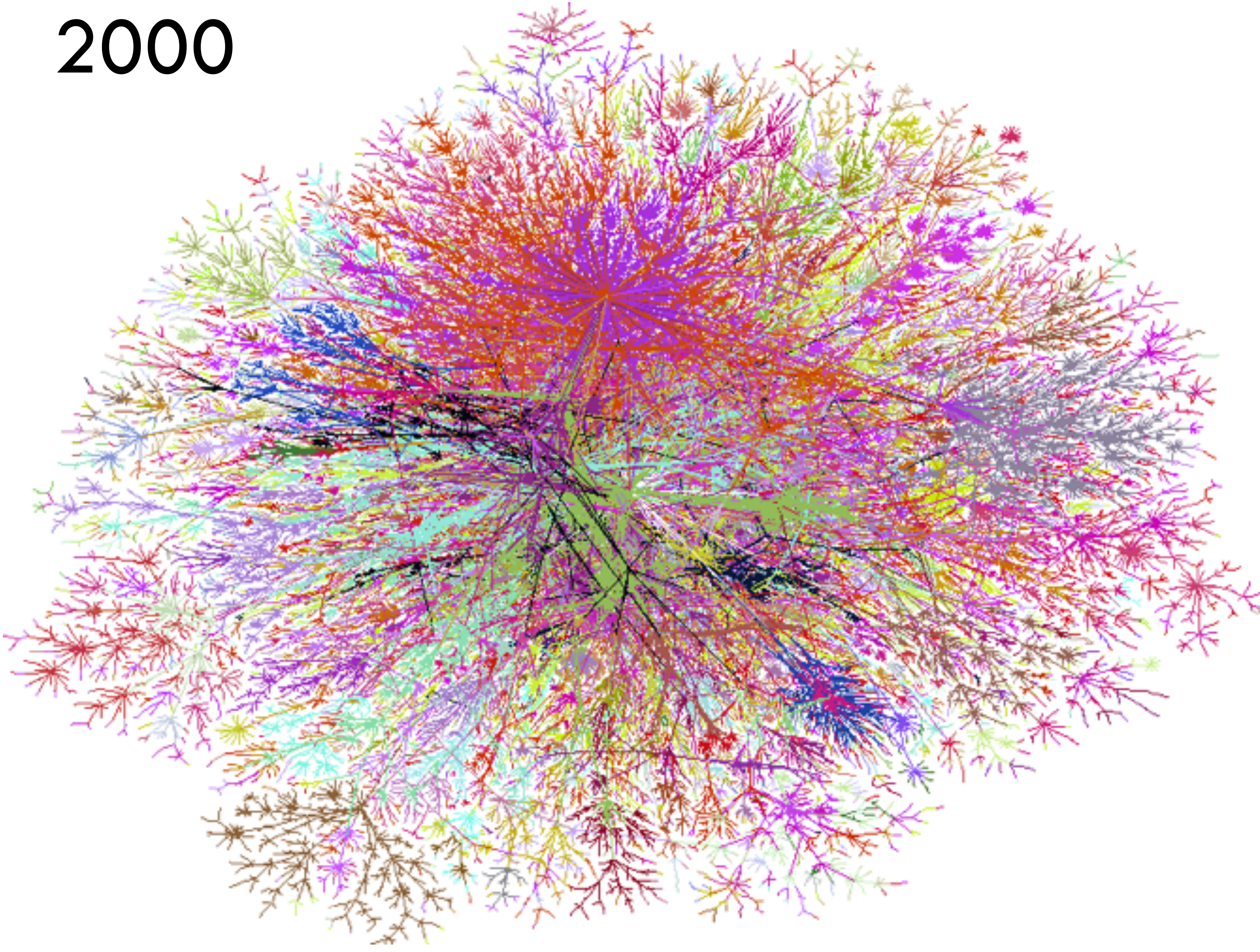


Trivia

- Kahn believed that there would only be ~20 networks.
- He was way off.
- Why?

2000



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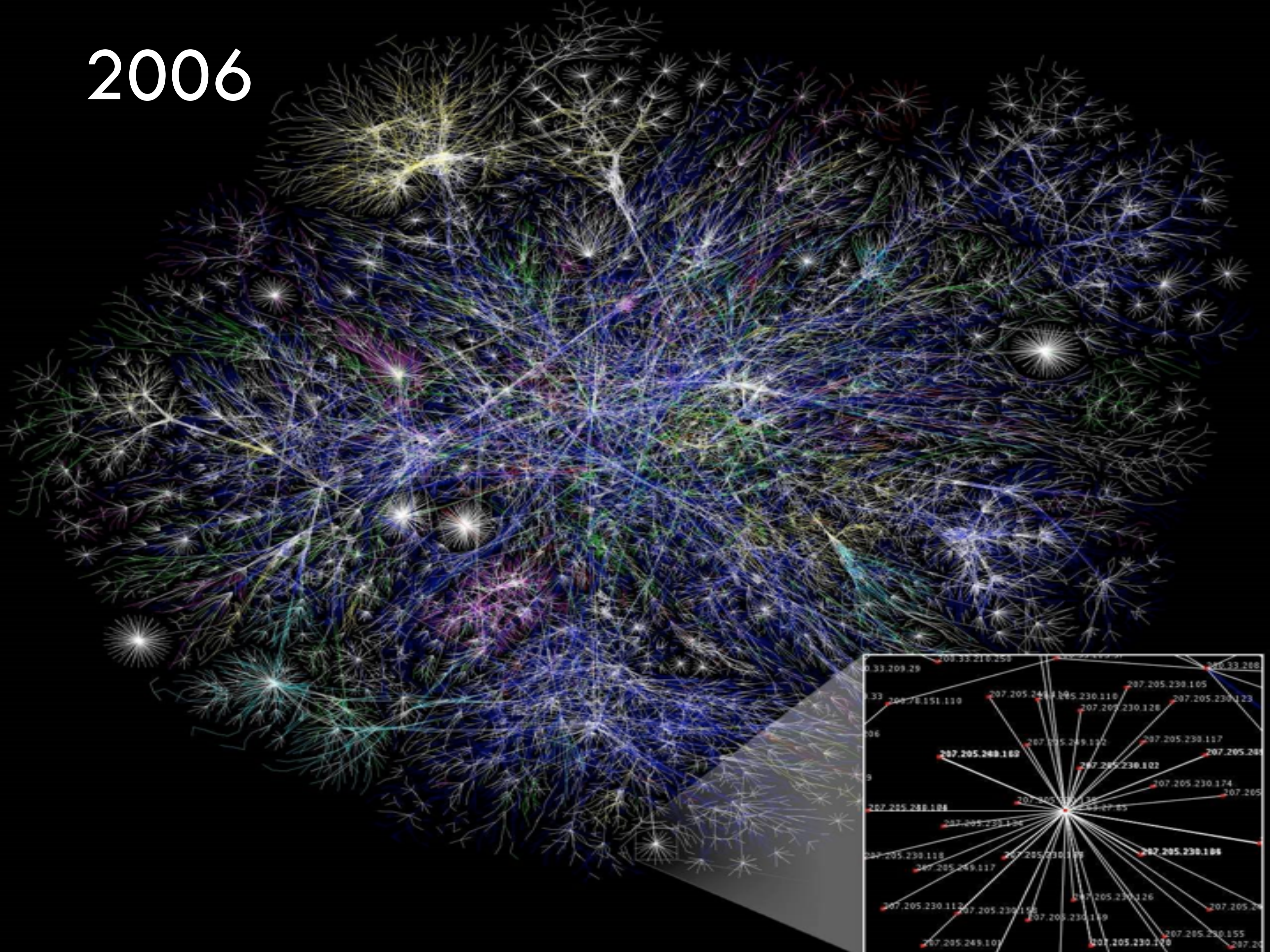

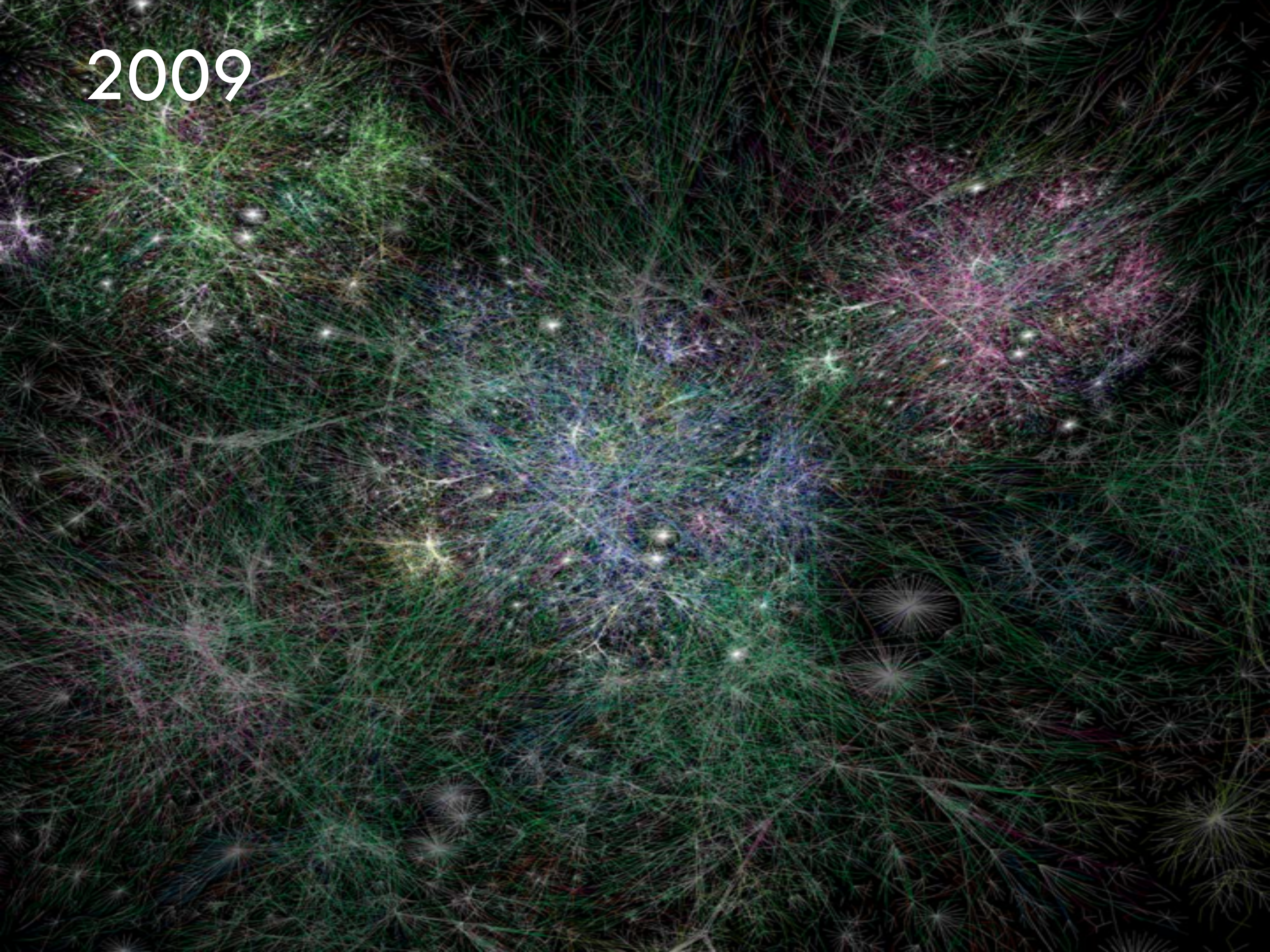
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More Internet History

- 1974: Cerf and Kahn paper on TCP (IP kept separate)
- 1980: TCP/IP adopted as defense standard
- 1983: ARPANET and MILNET split
- 1983: Global NCP to TCP/IP flag day
- 198x: Internet melts down due to congestion
- 1986: Van Jacobson saves the Internet (BSD TCP)
- 1987: NSFNET merges with other networks
- 1988: Deering and Cheriton propose multicast
- 199x: QoS rises and falls, ATM rises and falls
- 1994: NSF backbone dismantled, private backbone
- 1999-present: The Internet boom and bust … and boom
- 2007: Release of iPhone, rise of Mobile Internet

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What is next?

Internet Applications Over Time

- 1972: Email
- 1973: Telnet – remote access to computing
- 1982: DNS – “phonebook” of the Internet
- 1985: FTP – remote file access
- 1989: NFS – remote file systems
- 1991: The World Wide Web (WWW) goes public
- 1995: SSH – secure remote shell access
- 1995-1997: Instant messaging (ICQ, AIM)
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Invented by Shawn Fanning at NEU

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Takeaways

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- Key concepts have existed for a long time
  - Speed/bandwidth
  - Latency
  - Switching
  - Packets vs. circuits
  - Encoding
  - Cable management
  - Multiplexing
  - Routing

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  - Promise of free ($) and free (freedom) communication
  - Shrunk the world

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- What made the Internet so successful? Stay tuned!

Outline

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- Intro to Network Programming

Socket Programming

- Goal: familiarize yourself with socket programming
  - Why am I presenting C sockets?
  - Because C sockets are the de-facto standard for networking APIs

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- Goal: familiarize yourself with socket programming
  - Why am I presenting C sockets?
  - Because C sockets are the de-facto standard for networking APIs
- Project 0: Implement a semi-trivial protocol
  - We will have a server set up for you
  - There may be chances for extra credit ;)

C Sockets

- Socket API since 1983
  - Berkeley Sockets
  - BSD Sockets (debuted with BSD 4.2)
  - Unix Sockets (originally included with AT&T Unix)
  - Posix Sockets (slight modifications)
- Original interface of TCP/IP
  - All other socket APIs based on C sockets

Clients and Servers

- A fundamental problem: rendezvous
  - One or more parties want to provide a service
  - One or more parties want to use the service
  - How do you get them together?

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  - How do you get them together?
- Solution: client-server architecture
  - Client: initiator of communication
  - Server: responder
  - At least one side has to wait for the other
    - Service provider (server) sits and waits
    - Clients locates servers, initiates contact
    - Use well-known semantic names for location (DNS)

Key Differences

Clients

- Execute on-demand
- Unprivileged
- Simple
- (Usually) sequential
- Not performance sensitive

Servers

- Always-on
- Privileged
- Complex
- (Massively) concurrent
- High performance
- Scalable

Similarities

- Share common protocols
  - Application layer
  - Transport layer
  - Network layer
- Both rely on APIs for network access

Sockets

- Basic network abstraction: the socket

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 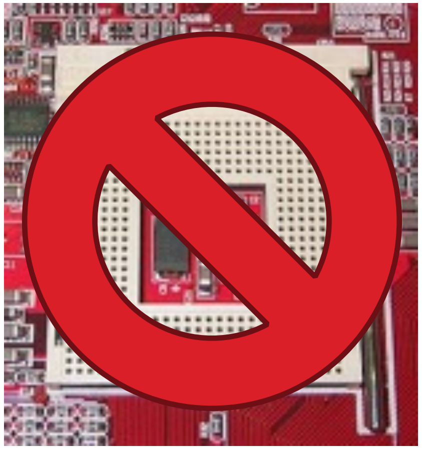

- Socket: an object that allows reading/writing from a network interface
- In Unix, sockets are just file descriptors
  - *read()* and *write()* both work on sockets
  - Caution: socket calls are blocking

C Socket API Overview

Clients

1. *gethostbyname()*
2. *socket()*
3. *connect()*
4. *write() / send()*
5. *read() / recv()*
6. *close()*

Servers

1. *socket()*
2. *bind()*
3. *listen()*
4. *while (whatever) {*
5.   *accept()*
6.   *read() / recv()*
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int socket(int, int, int)

- Most basic call, used by clients and servers
- Get a new socket
- Parameters
  - int *domain*: a constant, usually *PF_INET*
  - int *type*: a constant, usually *SOCK_STREAM* or *SOCK_DGRAM*
    - *SOCK_STREAM* means TCP
    - *SOCK_DGRAM* means UDP
  - int *protocol*: usually 0 (zero)
- Return: new file descriptor, -1 on error
- Many other constants are available
  - Why so many options?

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The C socket API is extensible.

- The Internet isn't the only network domain
- TCP/UDP aren't the only transport protocols
- In theory, transport protocols may have different dialects

- Many othe… available
  - Why so r…ons?

int bind(int, struct sockaddr *, int)

- Used by servers to associate a socket to a network interface and a port
  - Why is this necessary?
- Parameters:
  - int *sockfd*: an unbound socket
  - struct sockaddr * *my_addr*: the desired IP address and port
  - int *addrlen*: *sizeof(struct sockaddr)*
- Return: 0 on success, -1 on failure
  - Why might *bind()* fail?

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  - int soc   l socket

- Each machine may have ***multiple*** network interfaces
  - Example: Wifi and Ethernet in your laptop
  - Example: Cellular and Bluetooth in your phone
- Each network interface has its own IP address
- We'll talk about ports next…

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> TCP/UDP port field is 16-bits wide

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- Ports <1024 are reserved
  - Only privileged processes (e.g. superuser) may access
  - Why?
  - Does this cause security issues?

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- In olden times, all important apps used low port numbers
- Examples: IMAP, POP, HTTP, SSH, FTP
- This rule is no longer useful

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  - 65,535 ports available
  - Why?
- Ports <1024 are reserved
  - Only privileged processes (e.g. superuser) may access
  - Why?
  - Does this cause security issues?
- "I tried to open a port and got an error"
  - Port collision: only one app per port per host
  - Dangling sockets…

Dangling Sockets

- Common error: bind fails with “already in use” error
- OS kernel keeps sockets alive in memory after *close()*
  - Usually a one minute timeout
  - Why?

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- Closing a TCP socket is a multi-step process
- Involves contacting the remote machine
- "Hey, this connection is closing"
- Remote machine must acknowledge the closing
- All this book keeping takes time

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  - Usually a one minute timeout
  - Why?
- Allowing socket reuse

```
int yes=1;
if (setsockopt(listener, SOL_SOCKET, SO_REUSEADDR, &yes, sizeof(int))
        == -1) { perror("setsockopt"); exit(1); }
```

struct sockaddr

- Structure for storing naming information
  - But, different networks have different naming conventions
  - Example: IPv4 (32-bit addresses) vs. IPv6 (64-bit addresses)

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- Structure for storing naming information
  - But, different networks have different naming conventions
  - Example: IPv4 (32-bit addresses) vs. IPv6 (64-bit addresses)
- In practice, use more specific structure implementation

1. struct sockaddr_in my_addr;
2. memset(&my_addr, 0, sizeof(sockaddr_in));
3. my_addr.sin_family = htons(AF_INET);
4. my_addr.sin_port = htons(MyAwesomePort);
5. my_addr.sin_addr.s_addr = inet_addr("10.12.110.57");

htons(), htonl(), ntohs(), ntohl()

- Little Endian vs. Big Endian
  - Not a big deal as long as data stays local
  - What about when hosts communicate over networks?

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- Little Endian vs. Big Endian
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  - What about when hosts communicate over networks?
- Network byte order
  - Standardized to Big Endian
  - Be careful: x86 is Little Endian
- Functions for converting host order to network order
  - h to n s – host to network short (16 bits)
  - h to n l – host to network long (32 bits)
  - n to h * – the opposite

Binding Shortcuts

- If you don't care about the port
  - my_addr.sin_port = htons(0);
  - Chooses a free port at random
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- If you don't care about the port
  - my_addr.sin_port = htons(0);
  - Chooses a free port at random
  - This is rarely the behavior you want
- If you don't care about the IP address
  - my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
  - INADDR_ANY == 0
  - Meaning: don't bind to a specific IP
  - Traffic on any interface will reach the server
    - Assuming its on the right port
  - This is usually the behavior you want

int listen(int, int)

- Put a socket into listen mode
  - Used on the server side
  - Wait around for a client to *connect()*
- Parameters
  - int *sockfd*: the socket
  - int *backlog*: length of the pending connection queue
    - New connections wait around until you *accept()* them
    - Just set this to a semi-large number, e.g. 1000
- Return: 0 on success, -1 on error

int accept(int, void *, int *)

- Accept an incoming connection on a socket
- Parameters
  - int *sockfd*: the *listen()*ing socket
  - void * *addr*: pointer to an empty *struct sockaddr*
    - Clients IP address and port number go here
    - In practice, use a *struct sockaddr_in*
  - int * *addrlen*: length of the data in *addr*
    - In practice, *addrlen* == sizeof(*struct sockaddr_in*)
- Return: a new socket for the client, or -1 on error
  - Why?

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close(int sockfd)

- Close a socket
  - No more sending or receiving
- *shutdown(int sockfd, int how)*
  - Partially close a socket
    - how = 0; // no more receiving
    - how = 1; // no more sending
    - how = 2; // just like *close()*
  - Note: *shutdown()* does not free the file descriptor
  - Still need to *close()* to free the file descriptor

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struct * gethostbyname(char *)

- Returns information about a given host
- Parameters
  - const char * *name*: the domain name or IP address of a host
  - Examples: “www.google.com”, “10.137.4.61”
- Return: pointer to a *hostent* structure, 0 on failure
  - Various fields, most of which aren’t important

1. struct hostent * h = gethostname(“www.google.com”);
2. struct sockaddr_in my_addr;
3. memcpy(&my_addr.sin_addr.s_addr, h->h_addr,
      h->h_length);

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int connect(int, struct sockaddr *, int)

- Connect a client socket to a *listen()*ing server socket
- Parameters
  - int *sockfd*: the client socket
  - struct sockaddr * *serv_addr*: address and port of the server
  - int *addrlen*: length of the sockaddr structure
- Return: 0 on success, -1 on failure
- Notice that we don't *bind()* the client socket
  - Why?

write() and send()

- ssize_t write(int *fd*, const void **buf*, size_t *count*);
  - *fd*: file descriptor (ie. your socket)
  - *buf*: the buffer of data to send
  - *count*: number of bytes in *buf*
  - Return: number of bytes actually written
- int send(int sockfd, const void *msg, int len, int flags);
  - First three, same as above
  - *flags*: additional options, usually 0
  - Return: number of bytes actually written
- Do not assume that *count* / *len* == the return value!
  - Why might this happen?

read() and recv()

- ssize_t read(int fd, void *buf, size_t count);
  - Fairly obvious what this does
- int recv(int sockfd, void *buf, int len, unsigned int flags);
  - Seeing a pattern yet?
- Return values:
  - -1: there was an error reading from the socket
    - Usually unrecoverable. *close()* the socket and move on
  - >0: number of bytes received
    - May be less than *count* / *len*
  - 0: the sender has closed the socket

More Resources

- Beej's famous socket tutorial
  - http://beej.us/net2/html/syscalls.html