ACM Turing Award Winners (2004): Robert Kahn and Vinton Cerf

Presented by:

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Robert Kahn

- DoB: 23/Dec/1938
- Education
  - B.E.E. in Electrical Engg., City College of New York, 1960
  - M.A., Princeton Univ., 1962
  - Ph.D., Princeton Univ., 1964
- Experience
  - AT&T Labs, BBN, DARPA, MCI, CNRI, etc.
- https://amturing.acm.org/award_winners/kahn_4598637.cfm

Vinton Cerf

- DoB: 23/Jun/1943
- Education
  - B.S. in Mathematics, Stanford Univ., 1965
  - M.S., UCLA, 1970
  - Ph.D., UCLA, 1972
- Experience
  - IBM, Stanford, DARPA, MCI, CNRI, Google
- https://amturing.acm.org/award_winners/cerf_1083211.cfm

Citation details

- “for pioneering work on internetworking, including the design and implementation of the Internet's basic communications protocols, TCP/IP, and for inspired leadership in networking.”

- “They formulated fundamental design principles of networking, specified TCP/IP to meet these requirements, prototyped TCP/IP, and coordinated several early TCP/IP implementations.

- Since then, they have continued to provide leadership in the networking research community and in the emerging industries of the internet and telecommunications.”

- Source: https://amturing.acm.org/award_winners/cerf_1083211.cfm

Some key publications

- Kahn, Robert, Resource-Sharing Computer Communications Networks, *Proceedings of the IEEE,* November, 1972, pp. 1397-1407
  - ARPANET Description after Public Demo.

- Cerf, Vinton G. and Robert E. Kahn, A Protocol for Packet Network Intercommunication, IEEE Transactions on Communications (COM-22), May,1974, pp. 637-648.
  - Original Internet Architecture paper, describing TCP.

- Cerf, Vinton G., Protocols for Interconnected Packet Networks, ACM Computer Communication Review, Vol. 10, Num. 4, 1980, pp. 10-59.
  - Evolution of TCP into TCP/IP

- Kahn, Robert E., Steven A. Gronemeyer, Jerry Burchfiel and Ronald C. Kunzelman, Advances in Packet Radio Technology, *Proceedings of the IEEE,* Vol. 66, Num. 11, 1978, pp. 1468-1496.
  - Describes PRNET

- Source: https://amturing.acm.org/bib/cerf_1083211.cfm#linl_3

Misc.

- First ACM Turing award in “computer networking”
- Cerf and Kahn called “Fathers of the Internet”
- Other significant contributors to early Internet
  - Paul Baran (Packet switching)
  - Donald W. Davies (Packet switching)
  - Leonard Kleinrock, UCLA
  - Lawrence “Larry” G. Roberts (ARPANET)

TECHNICAL DETAILS

Packet Switching

- Circuit switching was dominant mode of communications for almost a century
- Packet switching was individually proposed by Baran and Davies
- Larry Roberts of ARPA plans ARPANET project based on Packet Sw. principles
  - **Objective: Interconnect powerful computers located across the USA**
  - BBN of Boston awarded the contract in 1968
  - UCLA: first node & Network Measurement Center

Initial ARPANET Sites

- UCLA: SDS SIGMA 7 Computer
- Stanford Research International (SRI): SDS 940
- University of California, Santa Barbara: IBM 360/75
- University of Utah: DEC PDP10
- First successful message: Oct. 29, 1969
  - "LO" part of a failed login attempt!

ARPANET

- BBN Team
  - Frank Heart
  - Bob Kahn
  - Will Crowther
  - Dave Walden
  - Bernie Cosell
  - Severo Ornstein
  - Ben Barker
- UCLA Software Team
  - Steve Crocker
  - Vint Cerf
  - Jon Postel
  - Charley Kline
  - Bill Naylor
  - Mike Wingfield

Source: Len Kleinrock's Brief History of Internet talk (Oct. 29, 2004)

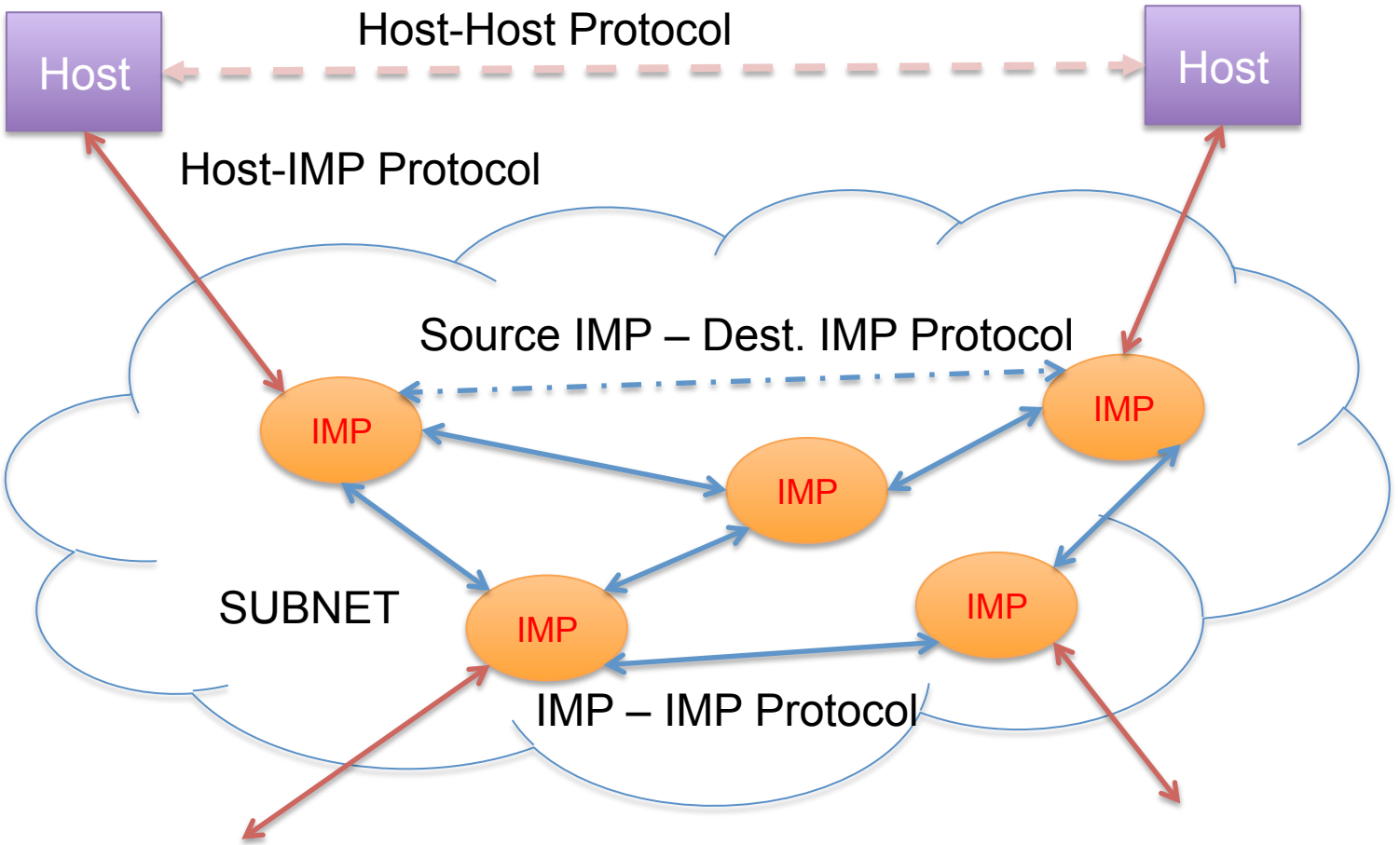
Kahn and Cerf

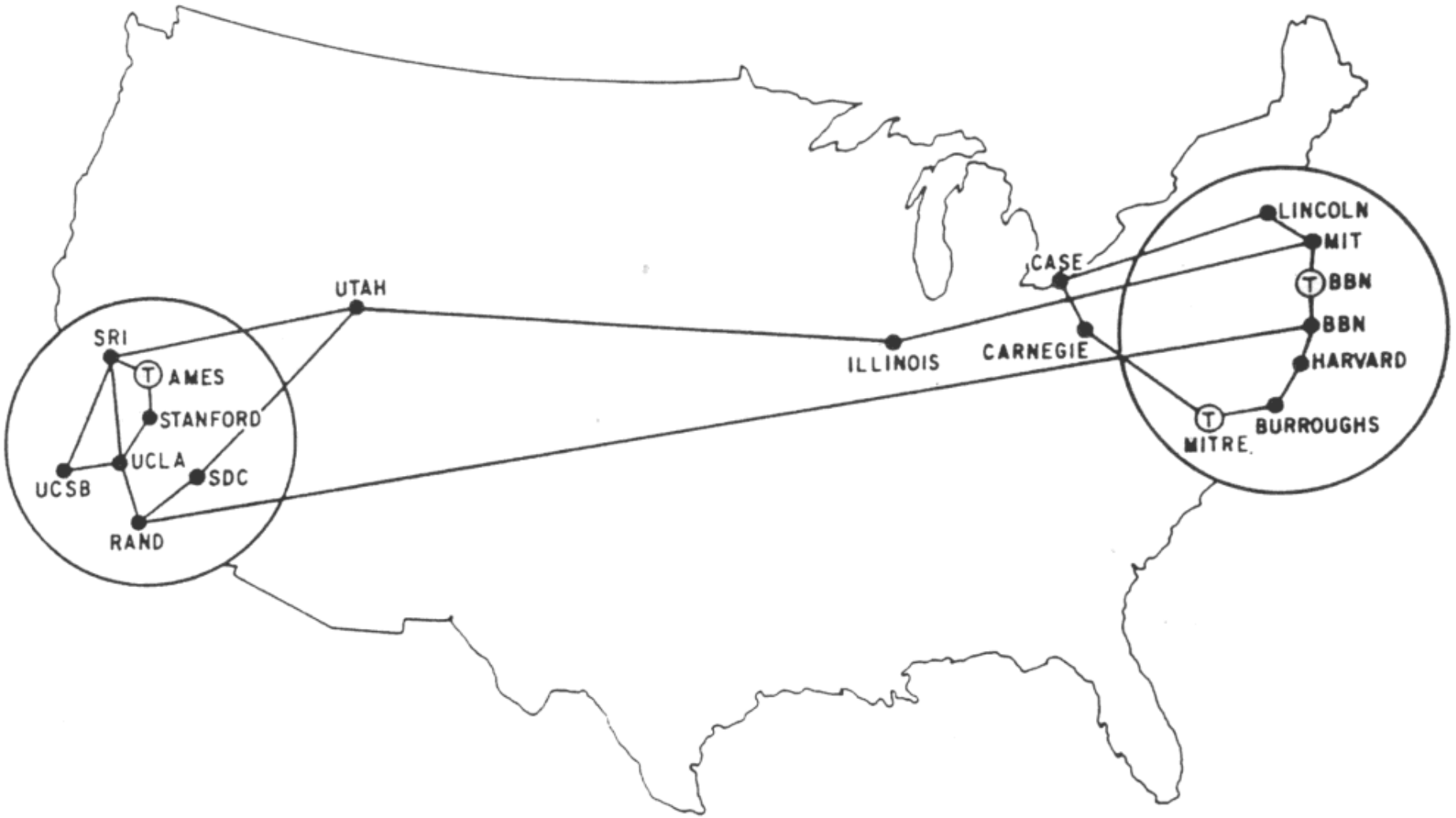
- Kahn and Cerf met in UCLA in 1969
  - Cerf was a PhD student under Prof. Estrin, spent time in Prof. Kleinrock's ARPANET Lab
  - Kahn visited UCLA (from BBN) for testing
  - Generated test data for failure detection and diagnosis

ARPANET Architecture, contd.

- Each site had a host computer
  - Running a different OS
  - Connected to BBN's Interface Message Processor (IMP)
  - Using serial communication lines and a newly defined protocol (named 1822; designed by BBN)
  - Later replaced by Network Control Program (NCP)
- Interface Message Processor (IMP)
  - Implemented on a minicomputer
  - IMPs performed store-and-forward packet switching functions
  - IMPs interconnected using 56 Kbps leased lines from the telecommunications company

ARPANET Architecture





MAP 4 September 1971

Source: https://personalpages.manchester.ac.uk/staff/m.dodge/cybergeography/atlas/historical.html

ARPANET Growth

- 1972: Public. Demo of ARPANET in Washington, D.C.
- 1973: 40 IMPs interconnected
- 1973: Norway and London IMPs connected to ARPANET
- 1975: ARPANET taken over by Defense Communications Agency
- 1984: Split into MILNET and Civilian net

Interconnected Network (Internet)

- SATNET: network based on satellite links
- PRNET: Packet radio network
- Goal: to interconnect ARPANET, SATNET, PRNET
  - Called Interconnected Network (or) Internet
  - The networks were technically incompatible

Interconnected Network (Internet)

- Designing protocols for a single network is complex
- Interconnecting dissimilar networks is even more complex
- A "complex" protocol: has no "real" but only "imaginary" existence

Differences in PS subnetworks

- Different end-point addressing mechanism
  - require a uniform addressing scheme
- Different maximum packet size
  - Either accept the smallest max. size (or) support fragmentation
- Different time delay in data handling
  - require “internetwork timing procedures”
- Data corruption inside a subnet
  - require “end-to-end restoration”

Industry's "Closed" protocols

- IBM Systems Network Architecture (SNA)
  - Released in 1974 to interconnect computer resources, terminals, etc.
  - Still used in Banks, Govt. agencies, etc.
- Digital Equipment Corporation DECnet
  - Released in 1975: Supported 255 nodes
  - Part of DEC's VMS Operating System
  - Later made "open" and ported to FreeBSD and Linux (then orphaned in 2010)
- Honeywell Bull: Distributed Systems Arch.
- Univac: Distributed Computing Arch.
- Burroughs: Burroughs Network Architecture
- International Computers Limited (ICL): Information Processing Architecture (IPA

“Open” Network Arch. principles

- Each network in an internet would be autonomous and independent
  - No changes needed for interconnection
- “Best-effort” delivery by the network
- Blackboxes (aka Gateways/Routers) used to interconnect the networks
- No centralized or global control

Interconnected Network (Internet)

- 1973: Kahn approached Cerf to design this “Internet”
- 1973: Work published in a Networking Conference in England
- **May 1974: Seminar paper by Cerf and Kahn titled “Protocol for Packet Network Intercommunication” in IEEE Trans. of Communications**
  - **Specified the TCP protocol**
  - **Initially a combined protocol; later split as TCP (host only) and IP (host and gateway)**
- 1977: Interconnection of PRNET, SATNET and ARPANET demonstrated

Abstract of 1974 paper

"A protocol that supports the sharing of resources that exist in different packet switching networks is presented.

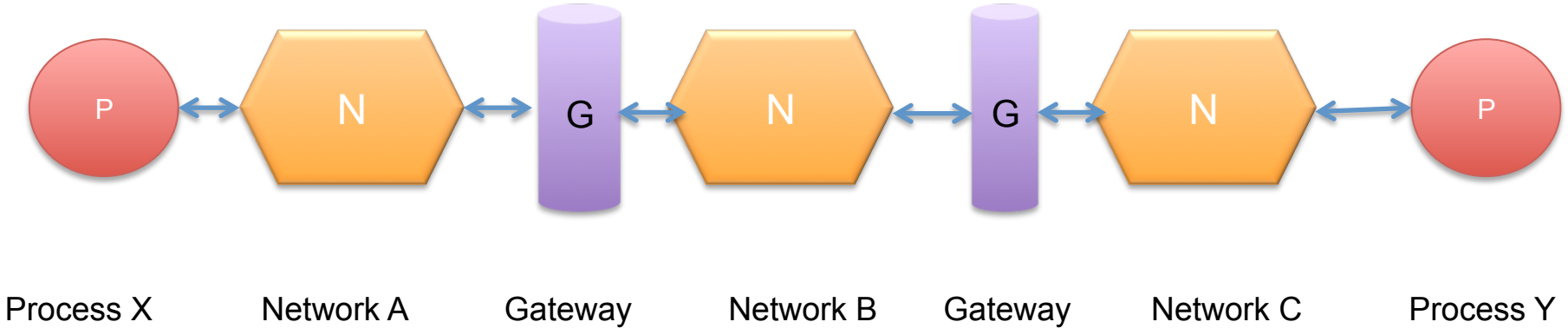
The protocol provides for variation in individual network packet sizes, transmission failures, sequencing, flow-control, end-to-end error checking,

and the creation and destruction of logical process-to-process connections…"

INTERNETWORK ARCHITECTURE

Main components of arch. (1974)

- **Gateway**
  - Interface node between two different networks



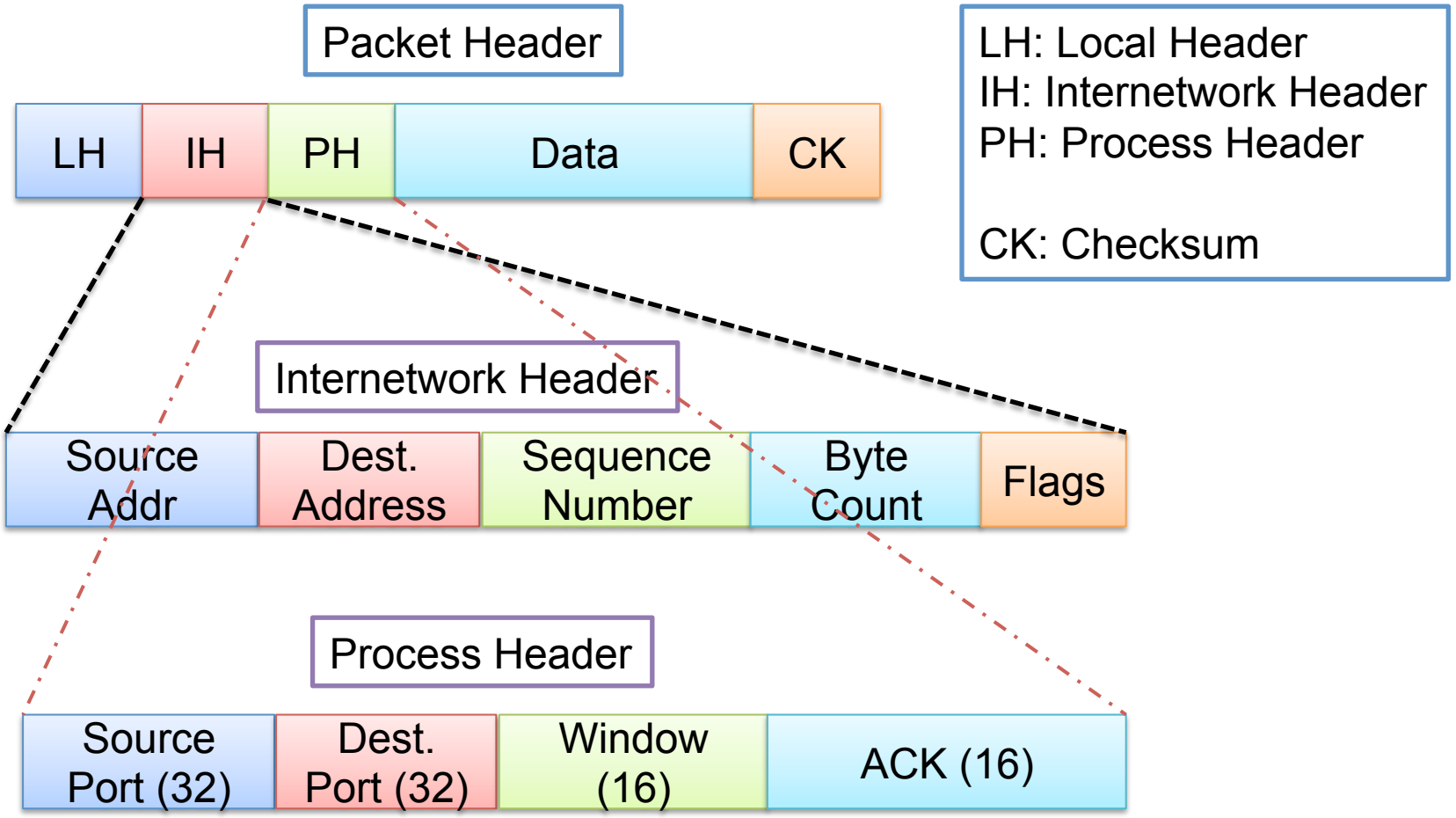
Main components, contd.

- **Fragmentation** of packets at intermediate gateways
  - Did not prescribe a single common packet-size for entire Internet
- **Transmission Control Program (TCP)**
  - Runs at each host
  - Handles messages from/to host processes
  - Multiplexing and de-multiplexing in host

Main components, contd.

- Uniform TCP **Address Space**
  - 8-bit network address (256 networks)
    - Used for routing
  - 16-bit TCP address (65536 distinct TCPs per network)
    - Part of this can also be used for routing
  - 16-bit port identifiers (suggested 16 bits)
    - For process demux at end hosts
    - Still in use today!

Packet Formats



Reliable transmission

- Per-byte sequence numbers
- Packets that are not acknowledged are transmitted
- Window-based retransmissions
  - Selective-Repeat
- Flow Control (Fast Sender; Slow Recr)
  - Receiver can send a small Window size to slow down sender
- Association between two ports on two different nodes
  - Briefly describes association establishment
  - Called Sessions today

Full TCP Spec. (1974)

- Cerf, Dalal and Sunshine wrote RFC 675
  - "SPECIFICATION OF INTERNET TRANSMISSION CONTROL PROGRAM"
- Some changes
  - 32-bit sequence number and ACK number
  - Defined SYN/ACK/FIN bits, in use today
  - Three-way handshake
  - TCB State Machine

Afterwards, …

- 1980: Transmission Control Program (TCP) split into:
  - Transmission Control **Protocol** (TCP): End-host only
  - Internet Protocol (IP): End-host and router
- 1981: RFC-791 defines TCP, in use today
- 1981: NSF creates CSNET for Academic Use
  - ARPANET was only allowed for those with Defense contracts
- 1983: TCP/IP replaced NCP in ARPANET
- 1985: NSFNET was created (56Kbps, 1.5Mbps in 1988, 45 Mbps in 1992, etc.)
- 1991: NSFNET was opened for Commercial Use
- 1993: Mosaic web browser; Netscape formed
- 1990s: ATM proposed by Telecom companies – lost to IP
- 1994: 25th Anniversary of UCLA "LO" message

And the rest is history that most of us know

THANK YOU…

QUESTIONS?