Network layer: "data plane" roadmap

- Network layer: overview
- What's inside a router
- IP: the Internet Protocol
- Generalized Forwarding

Middleboxes

- middlebox functions
- evolution, architectural principles of the Internet
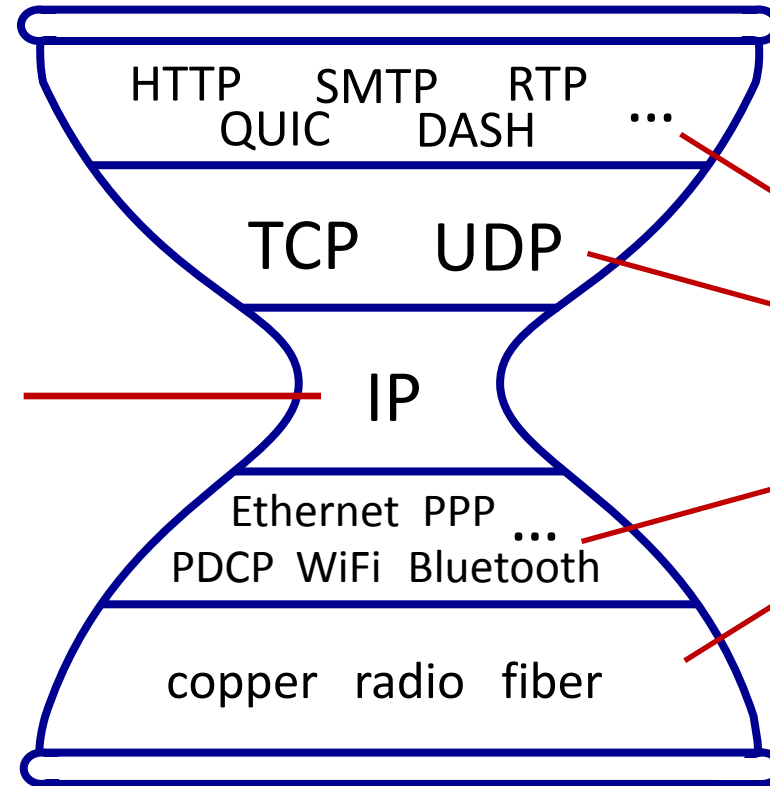
Middleboxes

Middlebox (RFC 3234)

"any intermediary box performing functions apart from normal, standard functions of an IP router on the data path between a source host and destination host"

Examples: NAT, Firewall, Cache, Load balancer, ….

The IP hourglass

Internet's "thin waist":
- *one* network layer protocol: IP
- *must* be implemented by every (billions) of Internet-connected devices

HTTP   SMTP   RTP
QUIC   DASH   ...

TCP   UDP

IP

Ethernet PPP ...
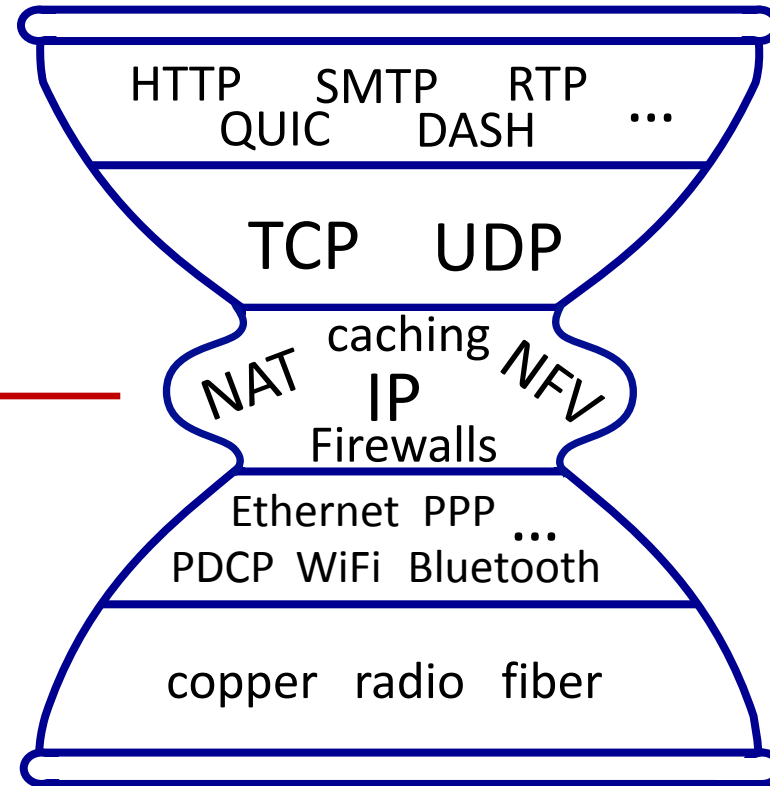PDCP WiFi Bluetooth

copper radio fiber

many protocols in physical, link, transport, and application layers

The IP hourglass, at middle age

Internet's middle age "love handles"?

■ middleboxes, operating inside the network

HTTP   SMTP   RTP
QUIC   DASH   ...

TCP   UDP

caching
NAT   IP   NFV
Firewalls

Ethernet PPP
...
PDCP WiFi Bluetooth

copper radio fiber

Architectural Principles of the Internet

RFC 1958

"Many members of the Internet community would argue that there is no architecture, but only a tradition, which was not written down for the first 25 years (or at least not by the IAB). However, in very general terms, the community believes that the goal is connectivity, the tool is the Internet Protocol, and the intelligence is end to end rather than hidden in the network."

Three cornerstone beliefs:
- simple connectivity
- IP protocol: that narrow waist
- intelligence, complexity at network edge

The end-end argument

- some network functionality (e.g., reliable data transfer, congestion) can be implemented in network, or at network edge
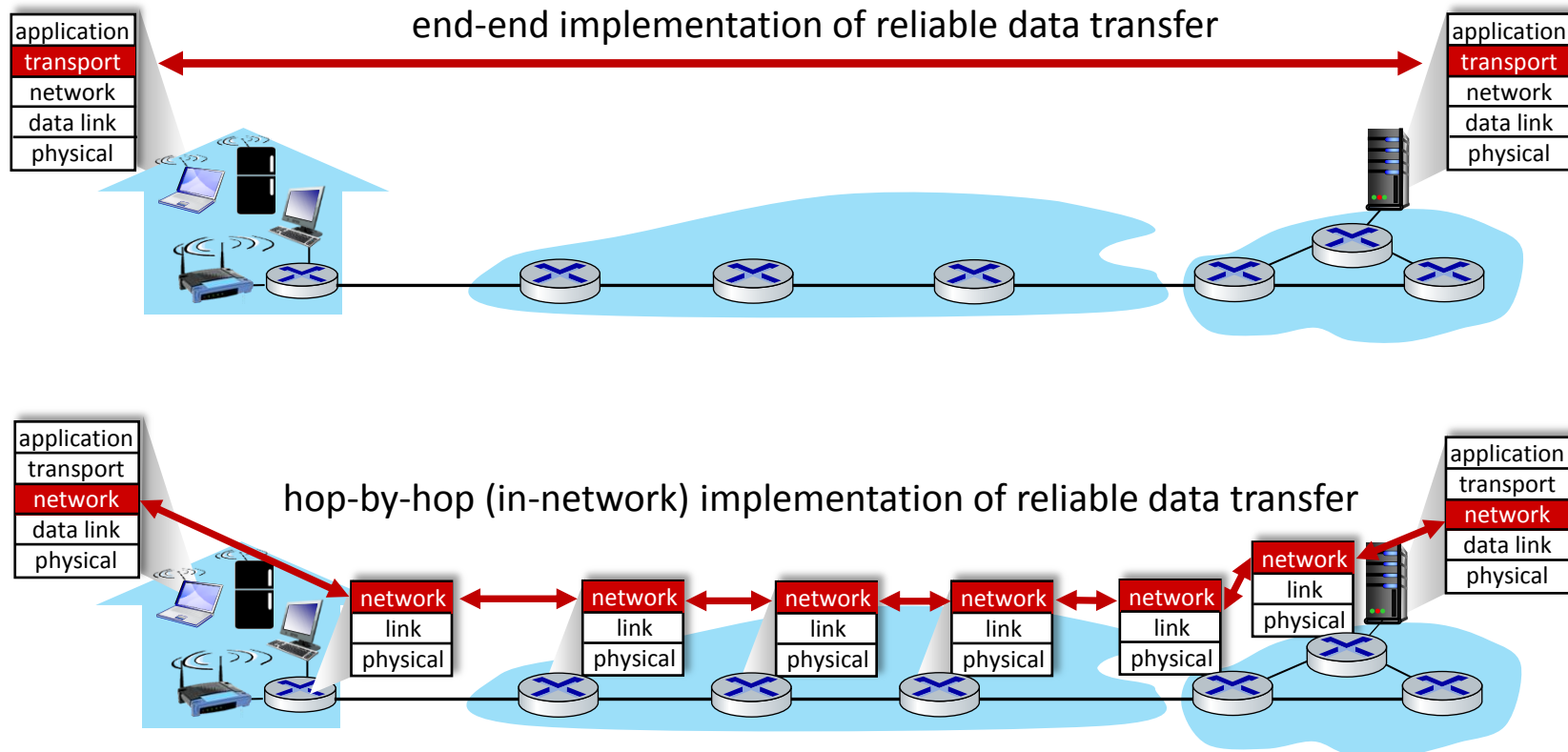
The end-end argument

- some network functionality (e.g., reliable data transfer, congestion) can be implemented in network, or at network edge

"The function in question can completely and correctly be implemented only with the knowledge and help of the application standing at the end points of the communication system. Therefore, providing that questioned function as a feature of the communication system itself is not possible. (Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.)
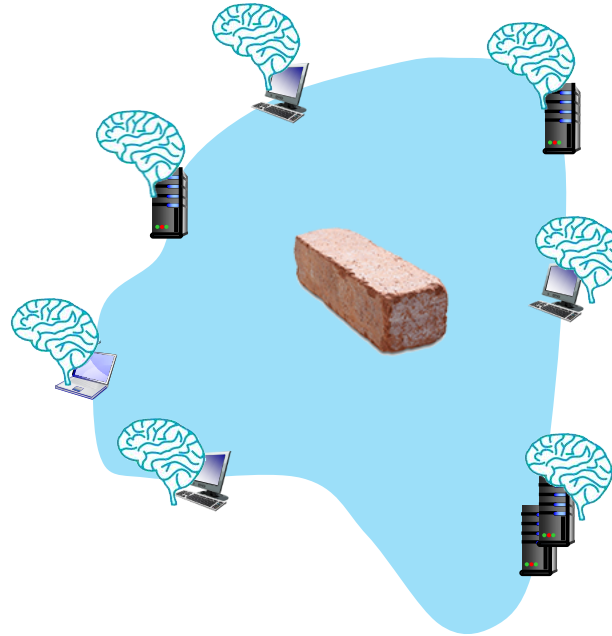
We call this line of reasoning against low-level function implementation the "end-to-end argument."

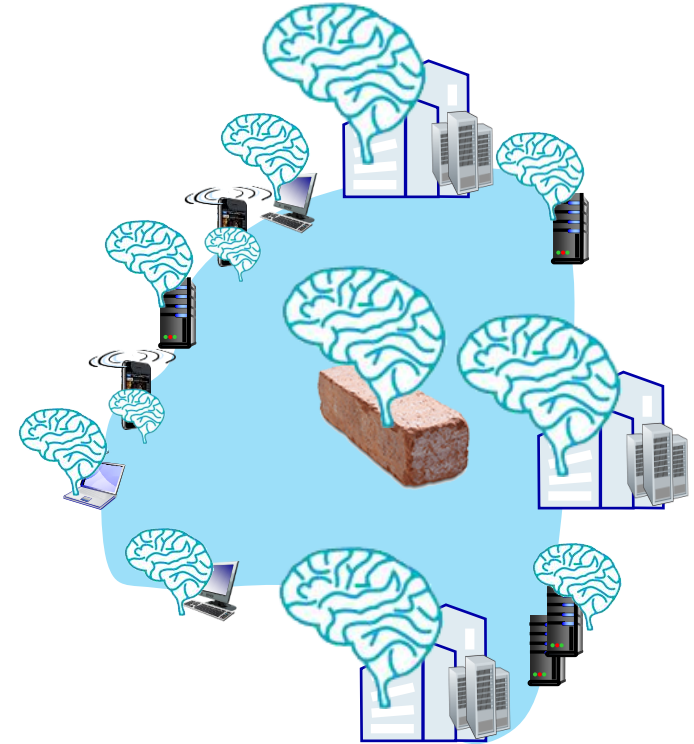Saltzer, Reed, Clark 1981

Where's the intelligence?
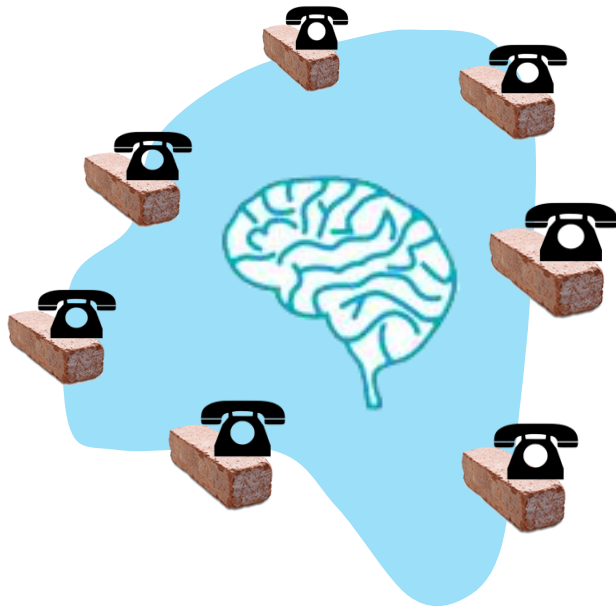
20th century phone net:
- intelligence/computing at network switches

Internet (pre-2005)
- intelligence, computing at edge

Internet (post-2005)
- programmable network devices
- intelligence, computing, massive application-level infrastructure at edge

Chapter 4: done!

- Network layer: overview
- What's inside a router
- IP: the Internet Protocol
- Generalized Forwarding, SDN
- Middleboxes

Question: how are forwarding tables (destination-based forwarding) or flow tables (generalized forwarding) computed?

Answer: by the control plane (next chapter)

Additional Chapter 4 slides

DHCP: Wireshark output (home LAN)

Message type: **<u>Boot Request (1)</u>**
Hardware type: Ethernet
Hardware address length: 6
Hops: 0   **request**
Transaction ID: 0x6b3a11b7
Seconds elapsed: 0
Bootp flags: 0x0000 (Unicast)
Client IP address: 0.0.0.0 (0.0.0.0)
Your (client) IP address: 0.0.0.0 (0.0.0.0)
Next server IP address: 0.0.0.0 (0.0.0.0)
Relay agent IP address: 0.0.0.0 (0.0.0.0)
Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Server host name not given
Boot file name not given
Magic cookie: (OK)
Option: (t=53,l=1) **DHCP Message Type = DHCP Request**
Option: (61) Client identifier
    Length: 7; Value: 010016D323688A;
    Hardware type: Ethernet
    Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Option: (t=50,l=4) Requested IP Address = 192.168.1.101
Option: (t=12,l=5) Host Name = "nomad"
Option: (55) Parameter Request List
    Length: 11; Value: 010F03062C2E2F1F21F92B
    1 = Subnet Mask; 15 = Domain Name
    3 = Router; 6 = Domain Name Server
    44 = NetBIOS over TCP/IP Name Server
    ……

Message type: **Boot Reply (2)**
Hardware type: Ethernet
Hardware address length: 6
Hops: 0   **reply**
Transaction ID: 0x6b3a11b7
Seconds elapsed: 0
Bootp flags: 0x0000 (Unicast)
Client IP address: 192.168.1.101 (192.168.1.101)
Your (client) IP address: 0.0.0.0 (0.0.0.0)
Next server IP address: 192.168.1.1 (192.168.1.1)
Relay agent IP address: 0.0.0.0 (0.0.0.0)
Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Server host name not given
Boot file name not given
Magic cookie: (OK)
Option: (t=53,l=1) DHCP Message Type = DHCP ACK
Option: (t=54,l=4) Server Identifier = 192.168.1.1
Option: (t=1,l=4) Subnet Mask = 255.255.255.0
Option: (t=3,l=4) Router = 192.168.1.1
Option: (6) Domain Name Server
    Length: 12; Value: 445747E2445749F244574092;
    IP Address: 68.87.71.226;
    IP Address: 68.87.73.242;
    IP Address: 68.87.64.146
Option: (t=15,l=20) Domain Name = "hsd1.ma.comcast.net."