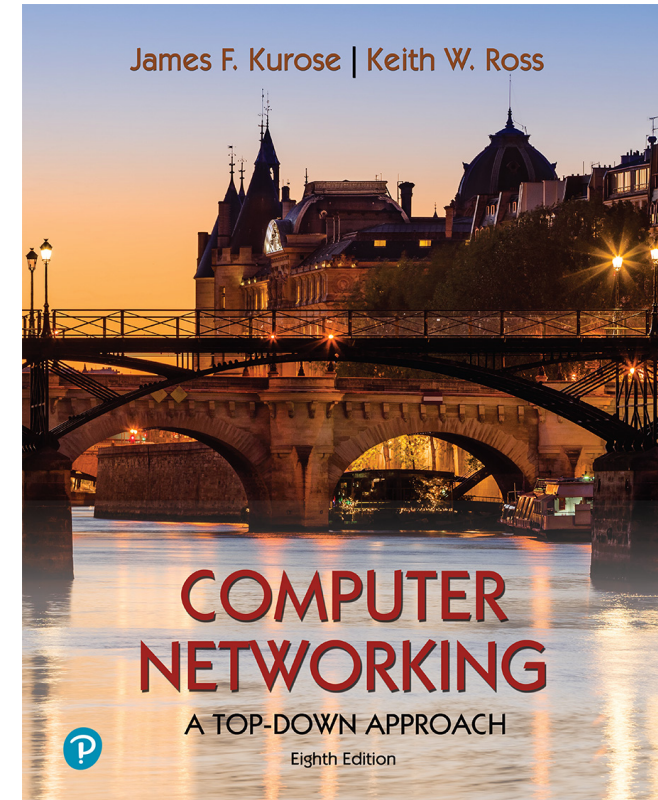


# Chapter 4

## Network Layer: Data Plane



### *Computer Networking: A Top-Down Approach*

8<sup>th</sup> edition

Jim Kurose, Keith Ross  
Pearson, 2020

Acknowledgement: Based on the textbook's website:  
[https://gaia.cs.umass.edu/kurose\\_ross/index.php](https://gaia.cs.umass.edu/kurose_ross/index.php)

# 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

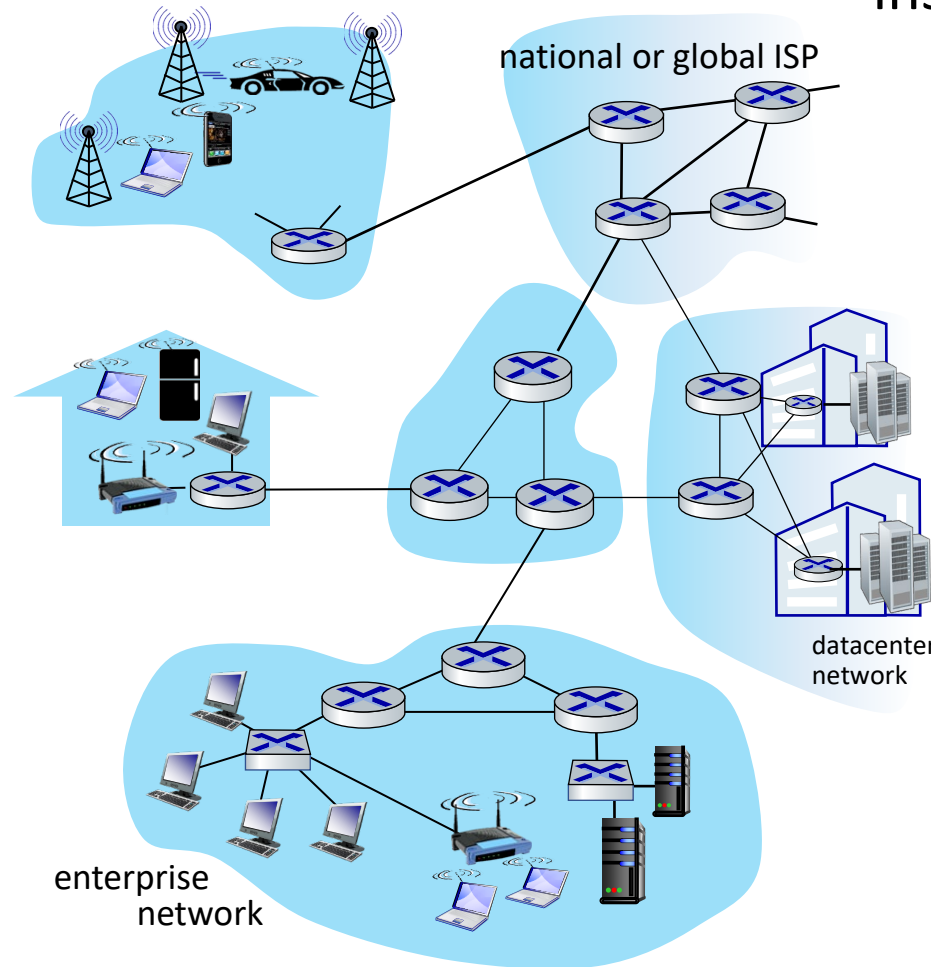
Middlebox (RFC 3234)

“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”

# Middleboxes everywhere!

**NAT:** home, cellular, institutional

**Application-specific:** service providers, institutional, CDN



**Firewalls, IDS:** corporate, institutional, service providers, ISPs

**Load balancers:** corporate, service provider, data center, mobile nets

**Caches:** service provider, mobile, CDNs

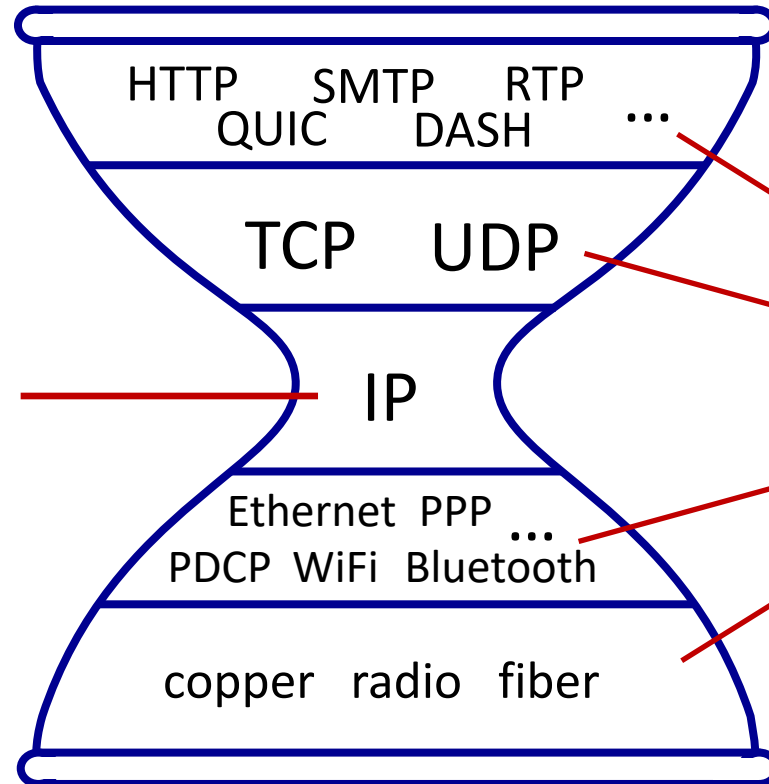
# Middleboxes

- initially: proprietary (closed) hardware solutions
- move towards “whitebox” hardware implementing open API
  - move away from proprietary hardware solutions
  - programmable local actions via match+action
  - move towards innovation/differentiation in software
- SDN: (logically) centralized control and configuration management often in private/public cloud
- network functions virtualization (NFV): programmable services over white box networking, computation, storage

# The IP hourglass

## Internet's "thin waist":

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

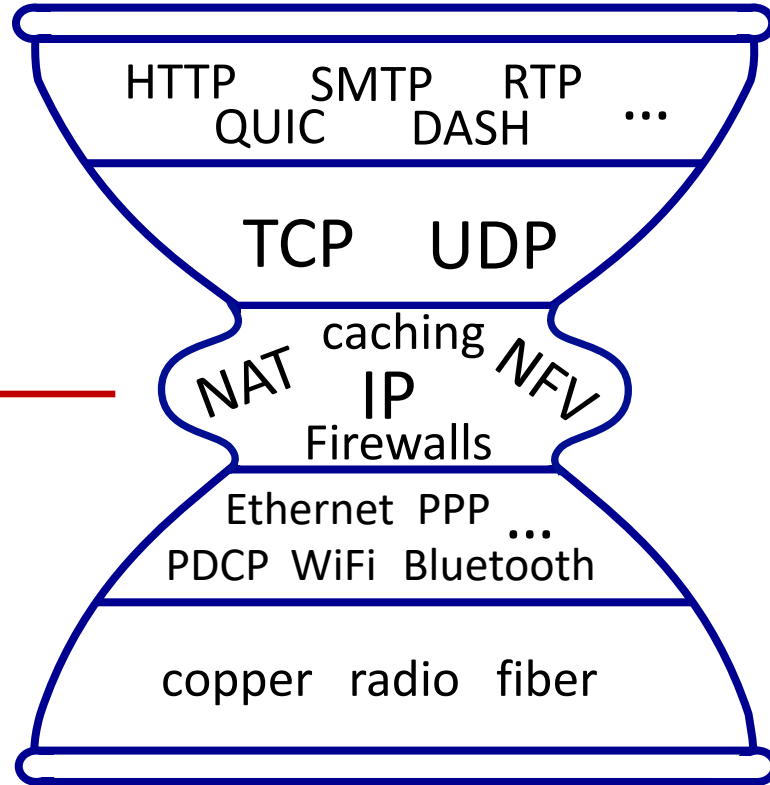


*many* protocols in physical, link, transport, and application layers

# The IP hourglass, at middle age

Internet's middle age  
"love handles"?

- middleboxes, — operating inside the network



# 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.**”

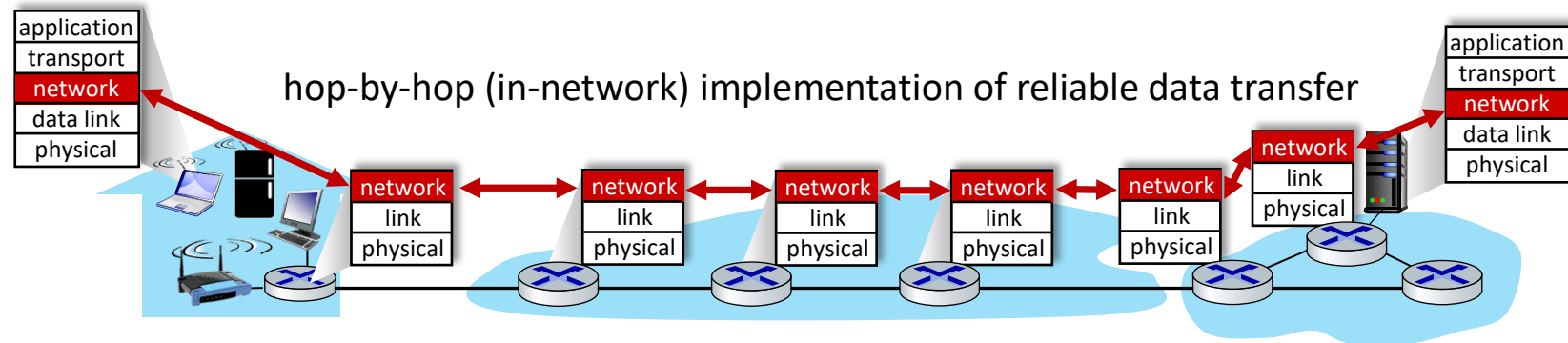
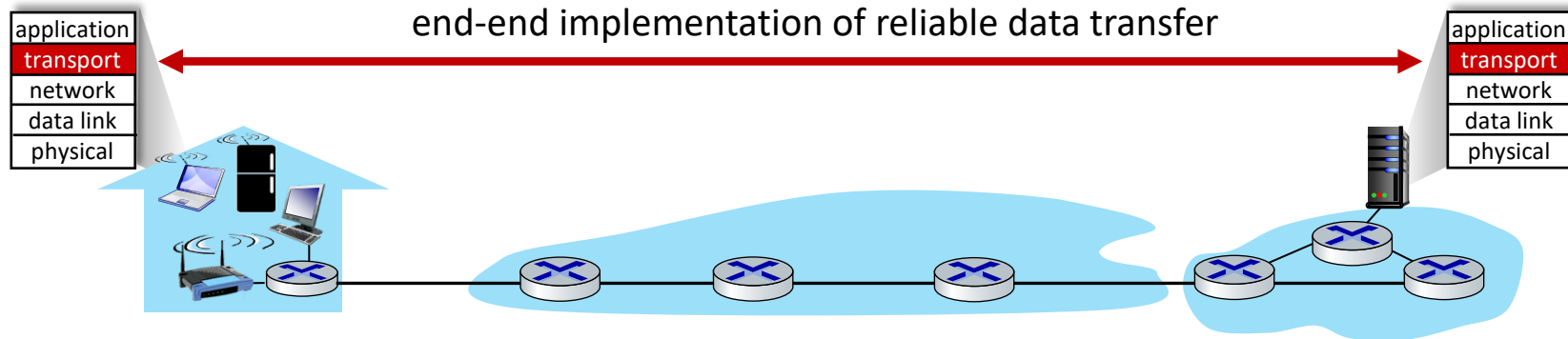
Three cornerstone beliefs:

- 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

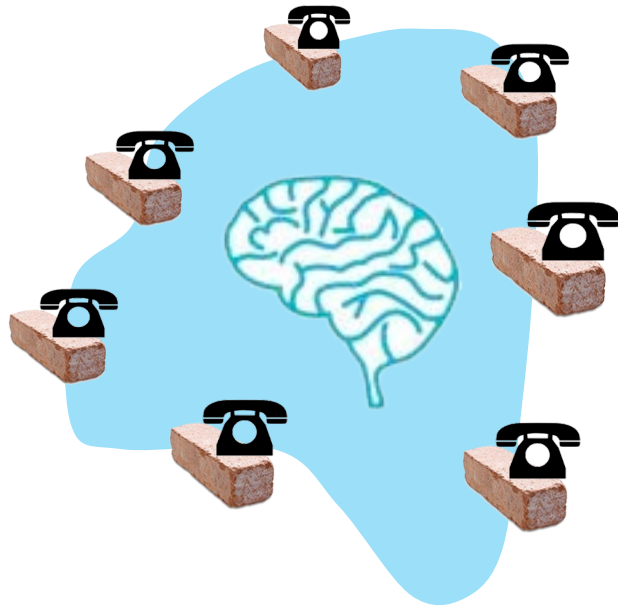
- some network functionality (e.g., reliable data transfer, congestion) can be implemented **in network**, or at **network edge**

“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.”

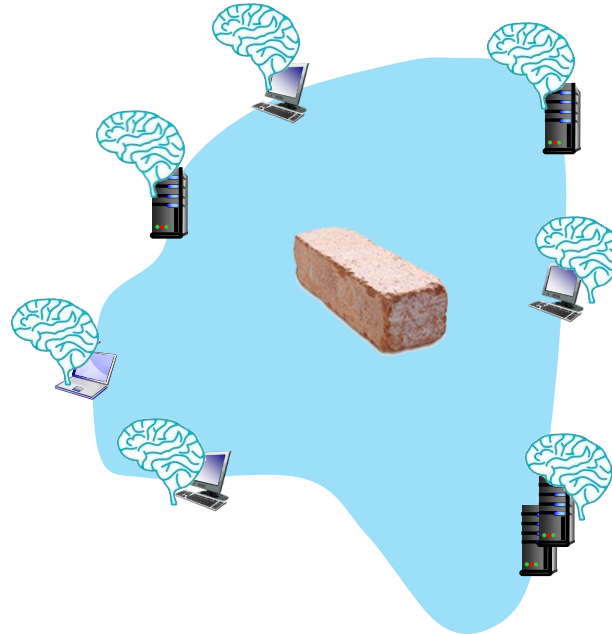
Saltzer, Reed, Clark 1981

# Where's the intelligence?



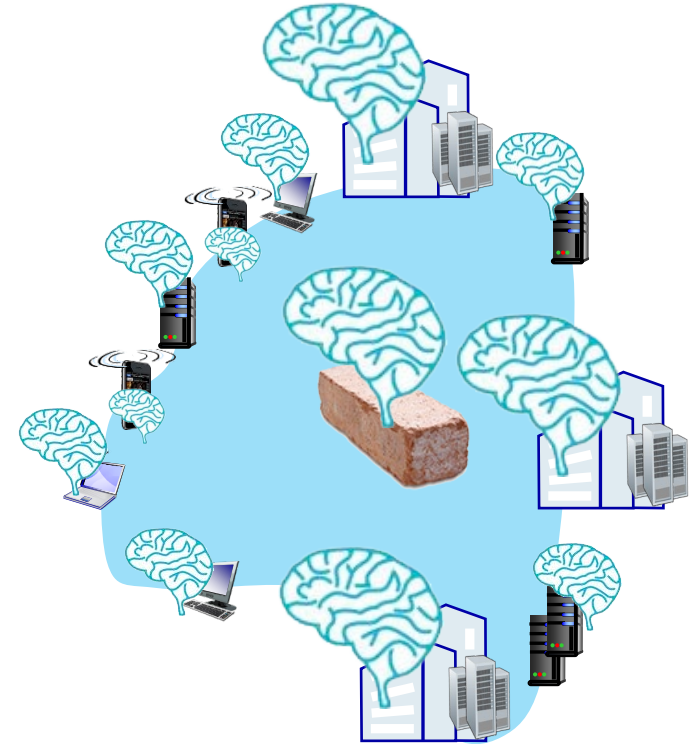
## 20<sup>th</sup> century phone net:

- 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)