ECE 356/COMPSI 356
Computer Network Architecture

Lecture 3:
Internet Architecture and History

Wednesday August 28th

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Recap

- Last lecture: network architectures
- Readings for this lecture: **PD 1.3**

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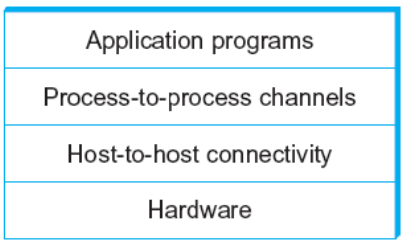
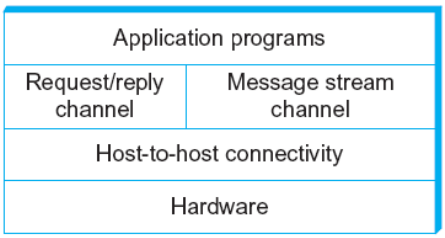
Lecture Outline

- Internet and OSI protocol stacks
- Internet history
- Selected frontiers of networking

Recap: Layering

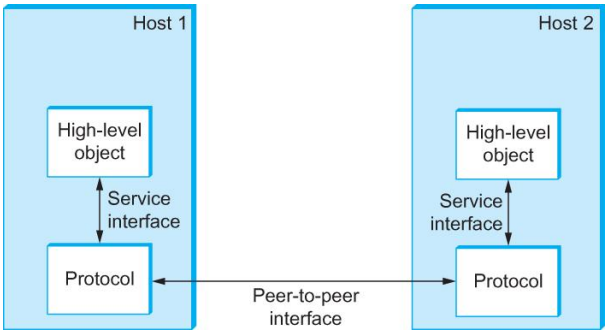




- An abstraction to handle complexity
  - A unifying model that capture important aspect of a system
  - Encapsulate the model in an object that has an interface for others to interact with
  - Hide the details from the users of the object

Recap: Protocols

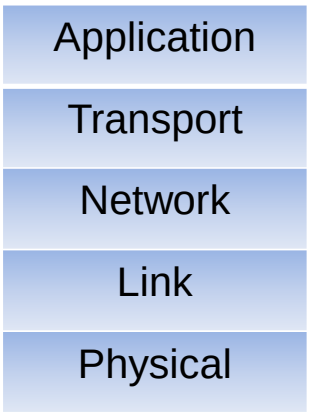
- The abstract objects that make up the layers of a network system are called **protocols**
- Each protocol defines two different interfaces
  - Service interface
  - Peer interface



- Protocol belongs to a layer
- There can be multiple protocols on each layer

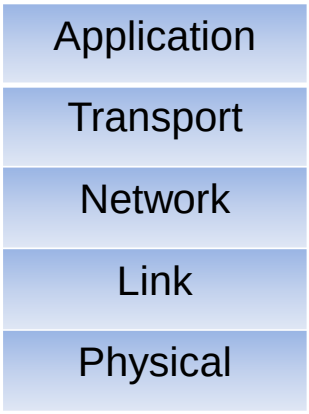
Internet Protocol Stack (1/3)

- ***Application:*** supporting network applications
  - FTP, SMTP, HTTP
- ***Transport:*** process-process data transfer
  - TCP, UDP
- ***Network:*** routing of datagrams from source to destination
  - IP, routing protocols



Internet Protocol Stack (2/3)

- ***Link:*** data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- ***Physical:*** bits "on the wire"



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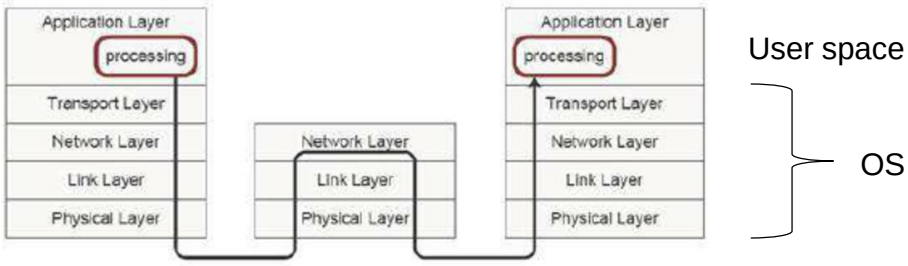
Internet Protocol Stack (3/3)



- Sending or receiving a packet from end systems (hosts) may involve actions of all five layers
- Packet forwarding (by routers) only involves the bottom three layers

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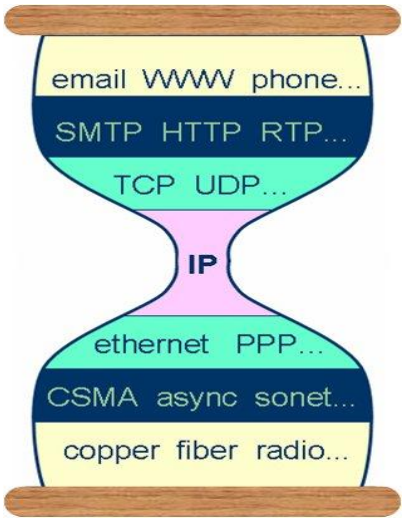
The Hourglass Model



Application
Transport
Network
Link
Physical

- "Thin waist" of the hourglass
- Why do you think this is useful?

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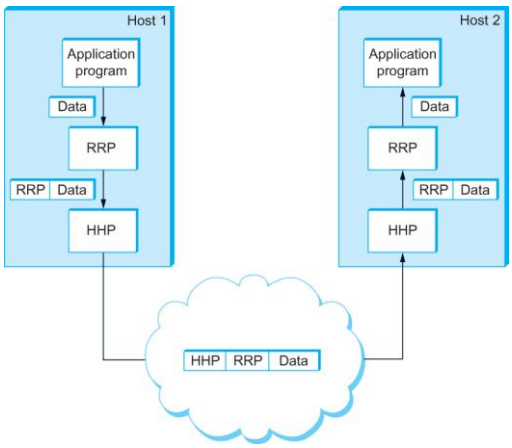
Recap: Encapsulation

- Encapsulation: As data is moving down the protocol stack, each protocol is adding layer-specific control information
- Decapsulation is the reverse process



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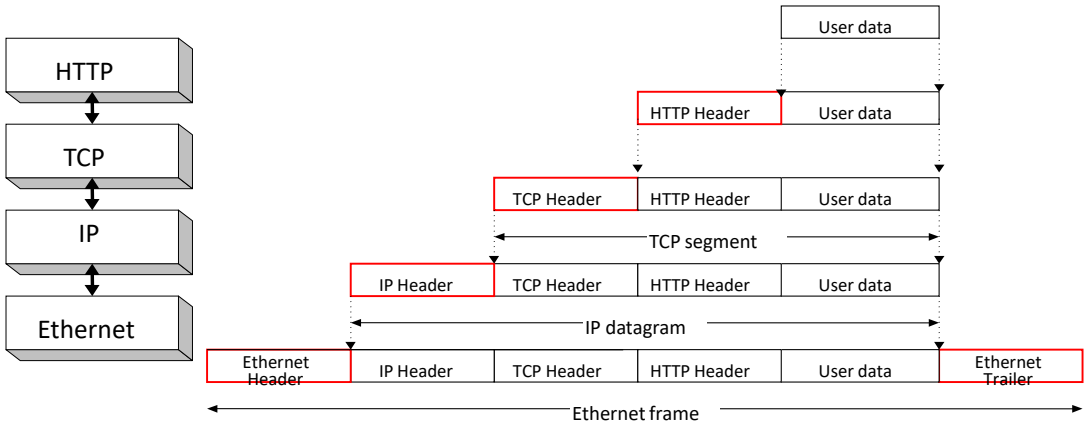
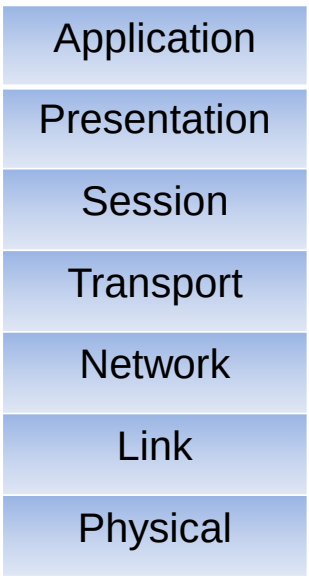
Encapsulation and Decapsulation on the Internet



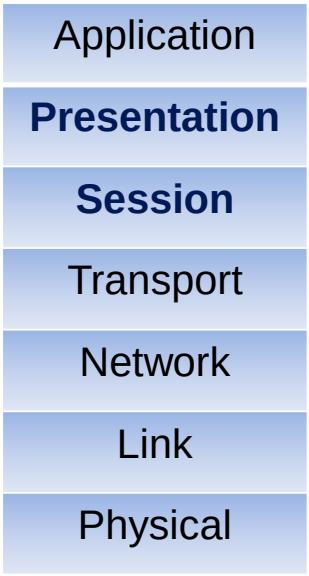
ISO OSI Reference Model (1/2)

- International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Model
- Created when Internet protocols were in their infancy



ISO OSI Reference Model (2/2)

- ***Presentation:*** allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- ***Session:*** synchronization, checkpointing, recovery of data exchange
- Implemented in application when needed



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Protocol Standardization

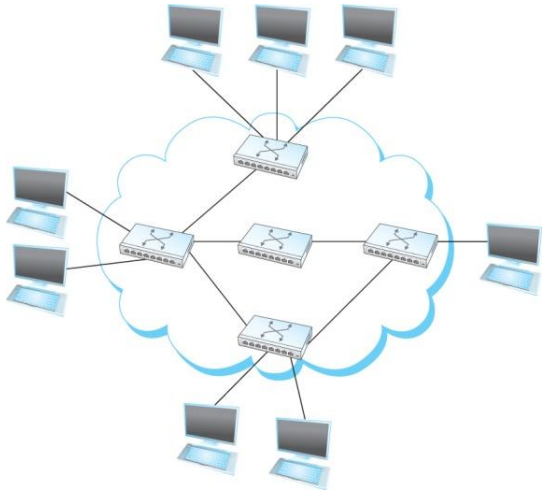
- Standard bodies such as Internet Engineering Task Force (IETF) govern procedures for introducing, validating, and approving protocols
  - The Internet protocol suite uses open standard
- New IETF protocol requires a specification and *working implementations*
  - Places value on working software

Lecture Outline

- Internet and OSI protocol stacks
- **Internet history**
- Selected frontiers of networking

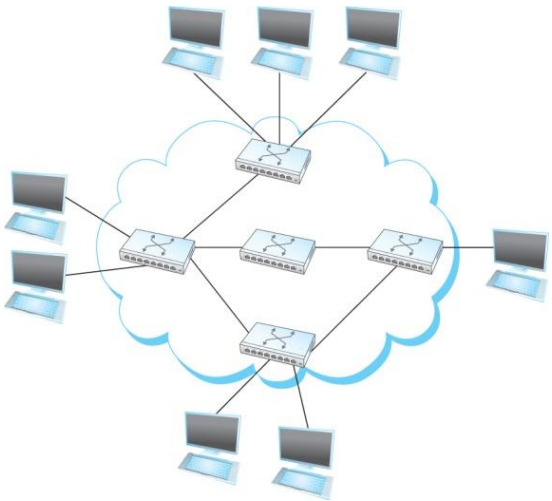
Recap: Circuit Switching

- Sets up a circuit before nodes can communicate
- Switches connect circuits on different links
- Telephone network, the precursor to the Internet, uses circuit switching



Recap: Packet Switching

- Data are split into discrete blocks of data called **packets**
- Store and forward
- Nodes send packets and switches forward them



Internet History: 1961-1972

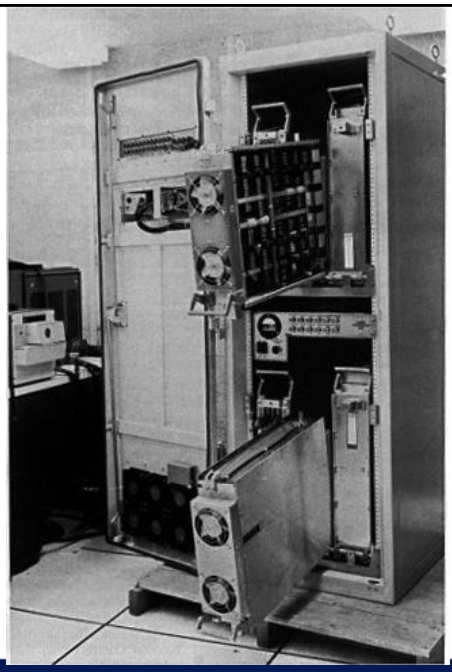
Early packet-switching principles

- 1961: Leonard Kleinrock - queuing theory shows effectiveness of packet-switching
- 1964: Paul Baran - packet-switching in military nets
- 1967: **ARPAnet** conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
    - No TCP/IP yet
  - First e-mail program
  - ARPAnet has 15 nodes

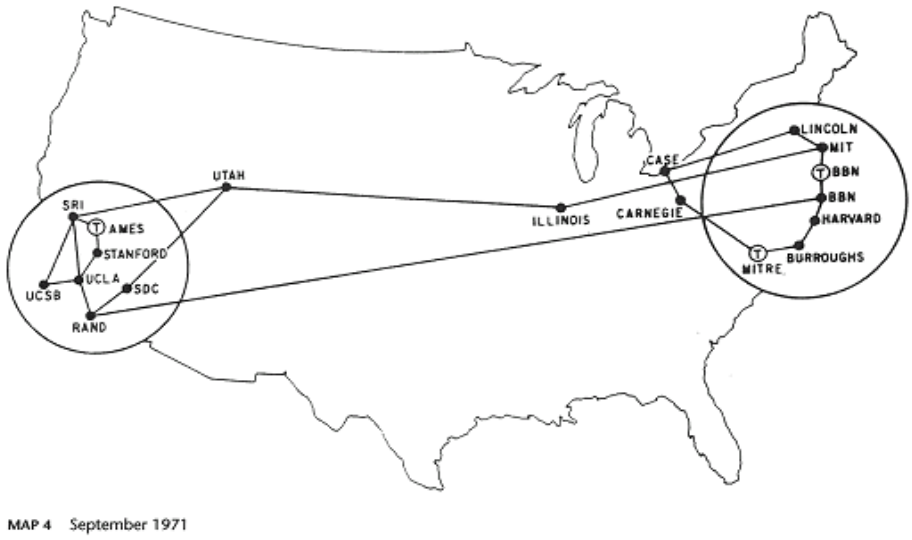
Early Packet Switch

- A switch back then



- A switch now

Internet in 1971



MAP 4 September 1971

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Internet History: 1972 – 1980

Internetworking, new and proprietary nets

- 1970: ALOHAnet microwave network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks (Turing award work)
- Late70's: proprietary architectures: DECnet, SNA, XNA
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- Minimalism, autonomy - no internal changes required to interconnect networks
- Best effort service model
- Stateless routers
- Decentralized control

Define today's Internet architecture

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Internet History: Early 1990's

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned 1995)
- Internet backbone traffic carried by commercial Internet Service Providers (ISPs)
- Early 1990s: Web
  - Hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP, web server, browser: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

Internet History: Late 1990's – 2000's

1990, 2000's: commercialization, the Web, new apps

Late 1990's – 2000's:

- More killer apps: instant messaging, P2P file sharing
- Network security to forefront
- Est. 50 million host, 100 million+ users
- Backbone links running at Gbps

amazon

Est. 1994

Internet History: 2000 – now (1/2)

- Broadband Internet to homes → wealth of video applications
  - YouTube, Netflix, Google Hangouts

Internet History: 2000 – now (2/2)

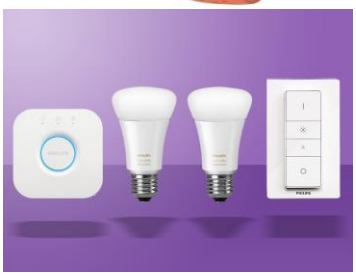
- Mobile computing
  - 2011: Number of wireless devices connected to the Internet surpassed the number of wired ones
- Online social networks
  - Facebook, Twitter, WeChat
  - Networks on top of the Internet
- Dedicated customized networks of online service providers and cloud computing

Frontiers of Networking

- The Internet of Things (IoT)
- Cloud computing
- Edge computing

The Internet of Things

- *Everything* is wirelessly connected to the Internet
  - ➢Wearables
  - ➢Smart homes



The Internet of Things: Enablers and Challenges

- Enablers:
  - Moore's law
  - Low-power transceivers
- Challenges:
  - Security
  - Privacy

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Cloud Computing: Applications and Providers

- Amazon Web Services, Microsoft Azure, Google Cloud, IBM Cloud
- Virtual machines, of different grades
- An endless, always updating list of specialized services

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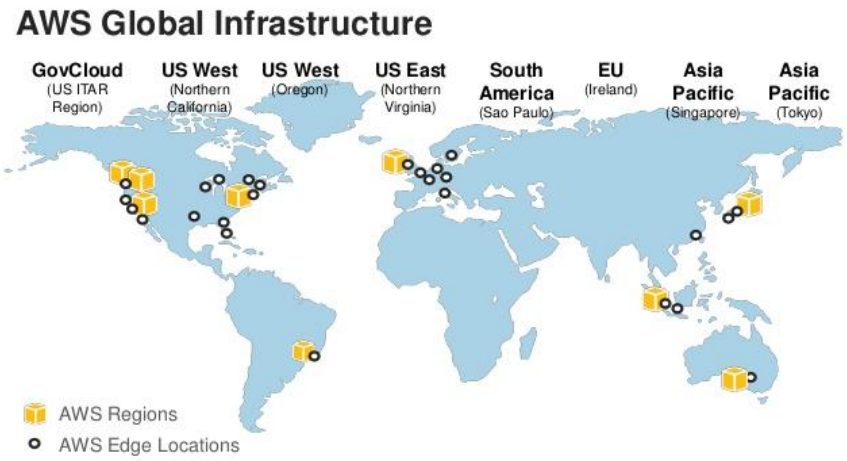
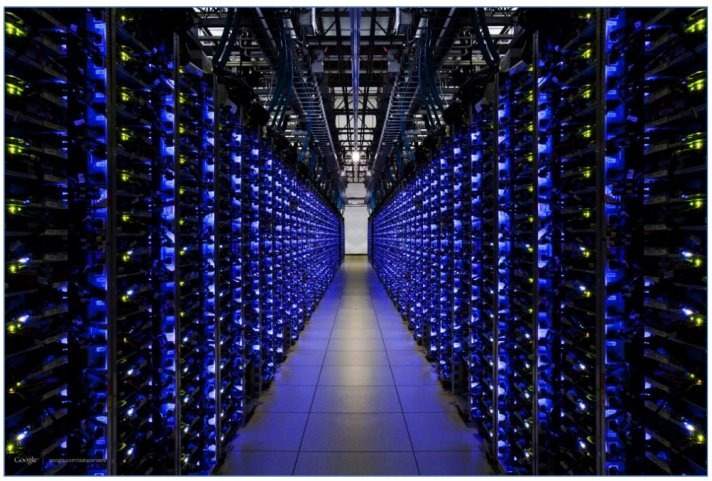
Cloud Services: AWS



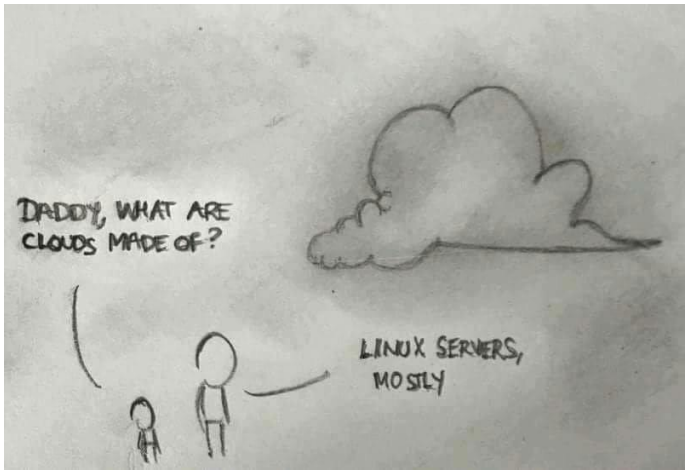
Cloud Services: Microsoft Azure

The Cloud: Massive Operation (1/2)

The Cloud: Massive Operation (2/2)



The Cloud: Shared Substrate



- Shared servers
- Shared cores
- Shared network

- Datacenter networking: a research area of its own

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Cloud Enabled Vibrant Web Ecosystem

- Enabled by pervasive connectivity
- Spurred innovation

Overleaf
Duo for Cloud
Google Apps
Office 365
amazon web services
salesforce
box
Dropbox
slack
workday.
Cisco webex

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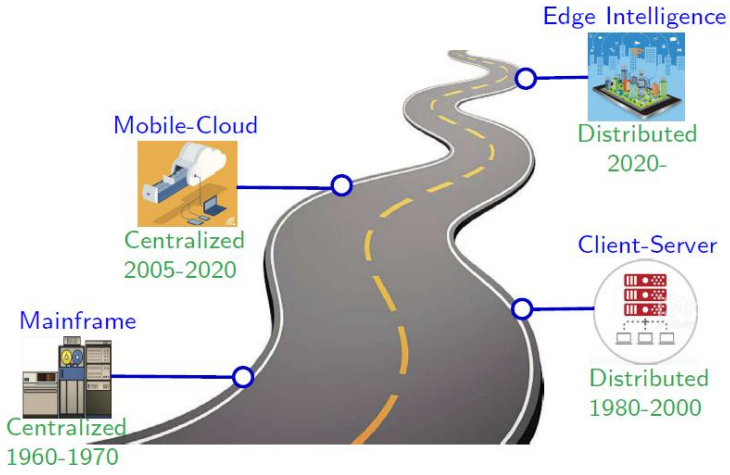
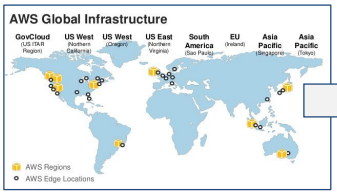
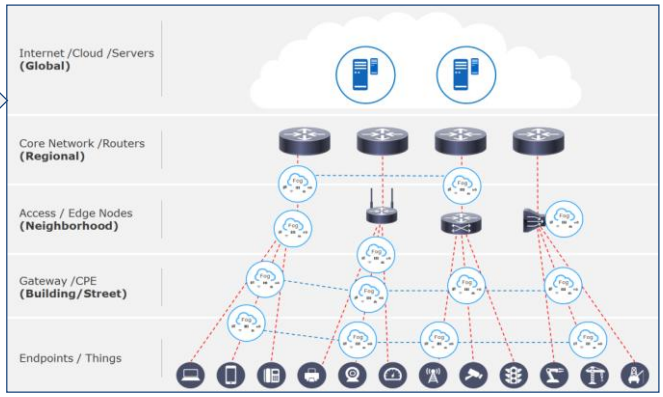
The Pendulum



Edge/Fog: Computing Closer to the Users



- Data processing, business logic, decision-making at multiple points in the hierarchy



Smart city IoT deployments: computing in buildings, neighborhoods, zip codes

What Does Edge Provide?

- Latency, bandwidth
- Cognition – advanced intelligence close to the users
- Privacy

- **Improve the performance of existing applications** and **enable new ones**

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Lecture Summary

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