Introduction to Layering and Network Layering

COS 316: Principles of Computer System Design

Lecture 11

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Barbara Liskov

"Modularity based on abstraction is the way things get done"

2009 Turing Award Lecture

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Modularity Through Layering

- Systems on systems on systems though layering
- Each layer hides complexity with abstraction
- Network layers today!

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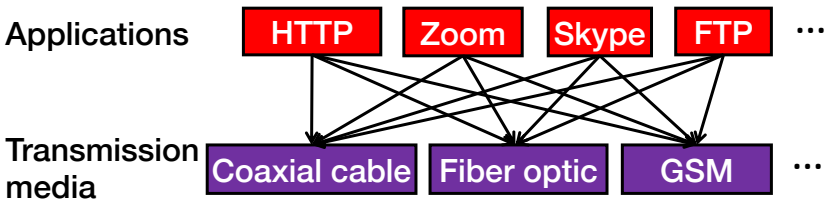
The Problem of Communication



- Re-implement every application for every new transmission medium?
- Change every application on any change to a transmission medium?
- No! But how does the Internet design avoid this?

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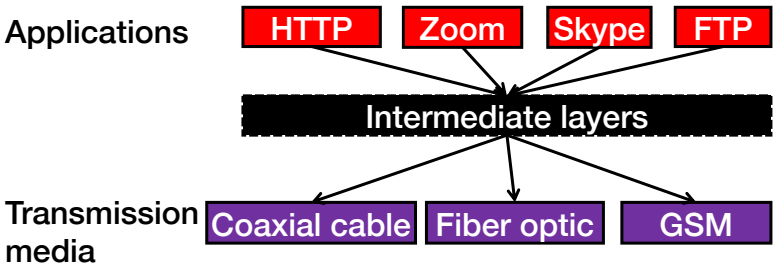
Solution: Layering



- Intermediate **layers** provide a set of abstractions for applications and media
- New applications or media need only implement for intermediate layer's interface

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The Art of Layering

- How many layers?
- What goes in each layer?
- What abstraction (interface) does each layer provide?

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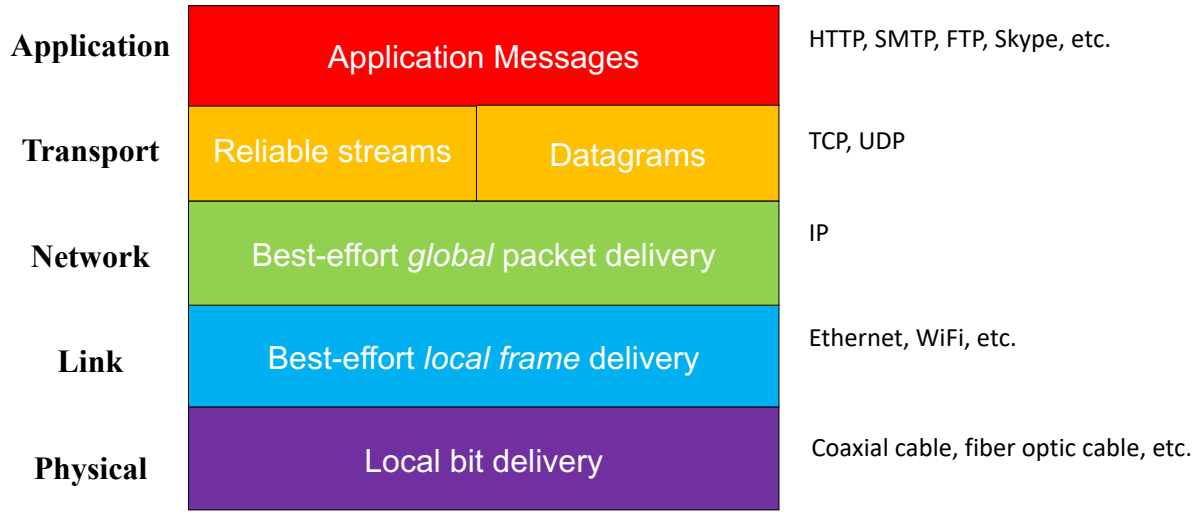
Internet Protocol Layers



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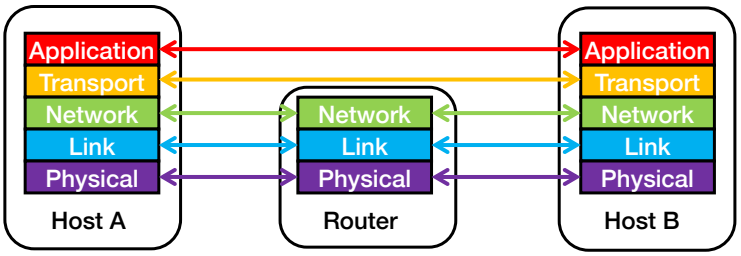
Logical Communication Between Layers

- How to forge agreement on meaning of bits exchanged between two hosts?

- **Protocol:** Rules that govern the format, contents, and meaning of messages
  - Each layer on a host interacts with peer host's corresponding layer via **protocol interface**



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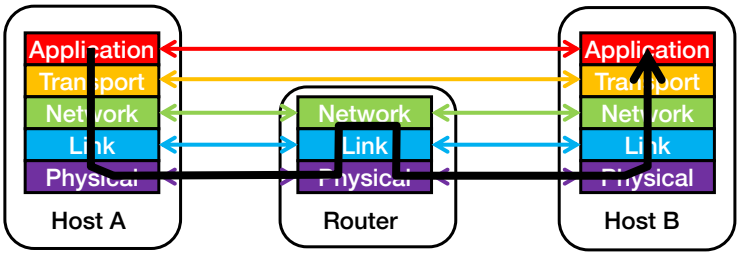
Physical communication

- Communication goes down to the **physical network**
- Then from **network** peer to peer
- Then up to the **relevant application**



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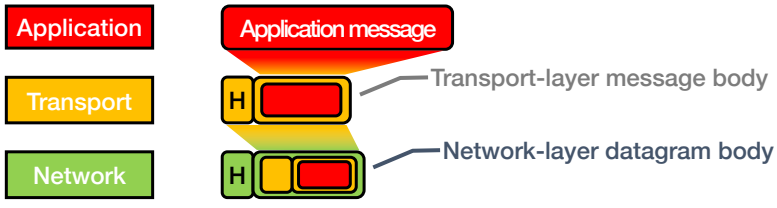
Communication Between Peers

- How do peer protocols coordinate with each other?
- Layer attaches its own header (H) to communicate with peer
  - Higher layers' headers, data encapsulated inside message
  - Lower layers generally do not inspect higher layers' headers



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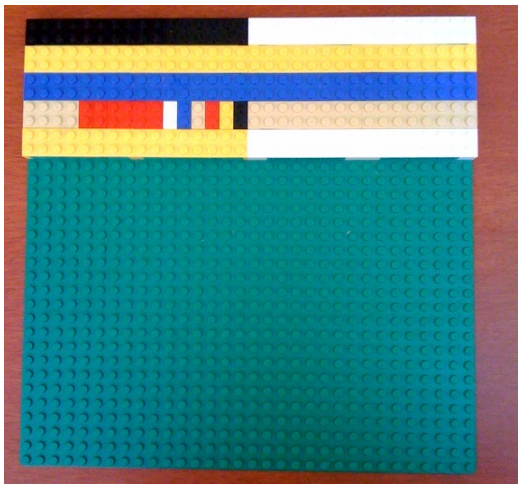
Teaching TCP/IP Headers With Legos



https://boingboing.net/2013/04/30/teaching-tcpip-headers-with-l.html

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IP is the "Narrow Waist" of the Internet

- **The** network-layer protocol
  - Enables portability above and below
- Lots of link layer protocols underneath
- Several transport protocols on top
  - TCP, UDP, QUIC

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IP: **Best-Effort** Global Packet Delivery

- Never having to say you're sorry
  - Don't have to reserve bandwidth and memory
  - Don't have to do error detection and correction
  - Don't have to remember anything across packets
- Easier to survive failures
  - Transient disruptions are okay during failure recovery
- Can run on nearly any link technology
  - Greater interoperability and evolution
  - RFC 1149: IP Datagrams Over Avian Carriers

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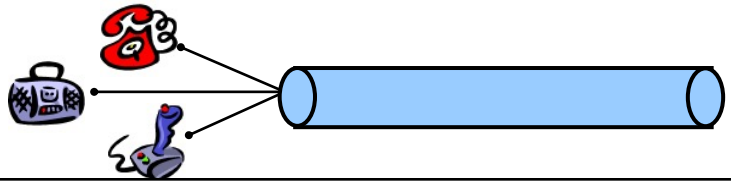
IP: Statistical Multiplexing

- Data traffic is bursty
  - Logging in to remote machines
  - Exchanging e-mail messages
- Don't waste bandwidth
  - No traffic exchanged during idle periods
- Better to allow multiplexing
  - Different transfers share access to same links



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Transport: Application to Application

- Network layer is host-to-host
- Transport layer is port-on-host-to-port-on-host
  - think application to application
  - demultiplexing
  - e.g., port 80 is HTTP, port 443 is HTTPS, port 22 is SSH
- *Why transport and not network layer?*

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Transport: Application to Application

- Network doesn't have error detection
- Transport layer does have error detection
- *Why transport and not network layer?*
- *Why not both?*

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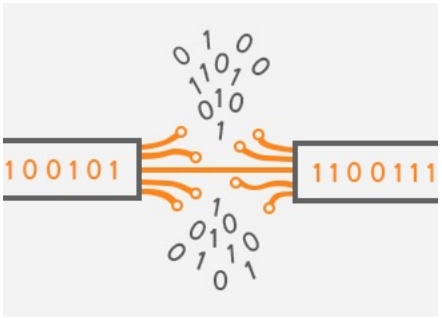
Transport: Transmission Control Protocol (TCP)

- Ordered, reliable stream of bytes
  - Built on top of best-effort packet delivery at the network layer

- Challenges with IP
  - Lost or delayed packets
  - Corrupted packets
  - Out-of-order packet arrivals
  - Receiver runs out of space
  - Network cannot handle current load



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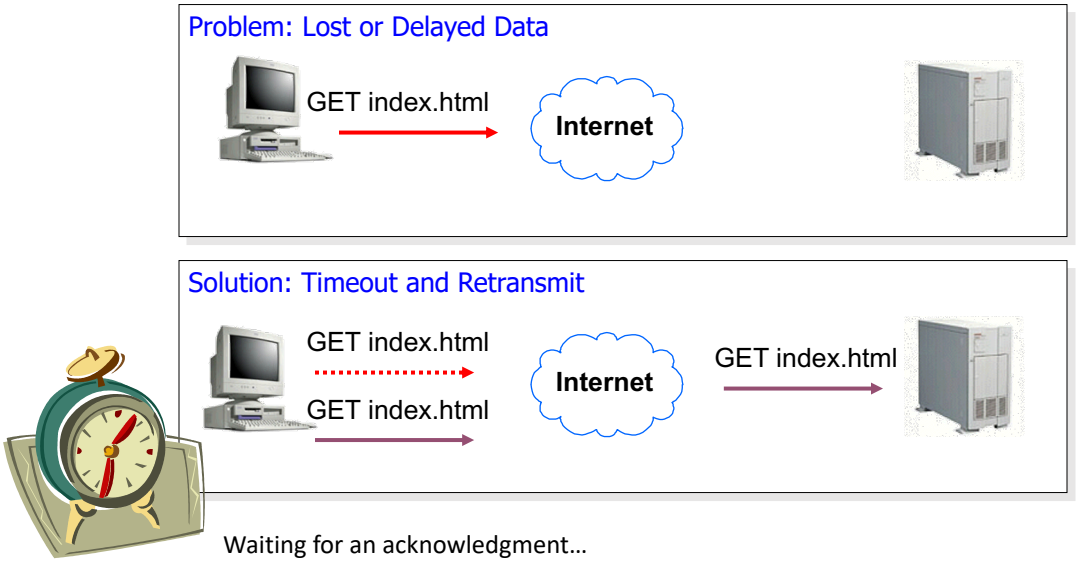
TCP: Lost or Delayed Packets



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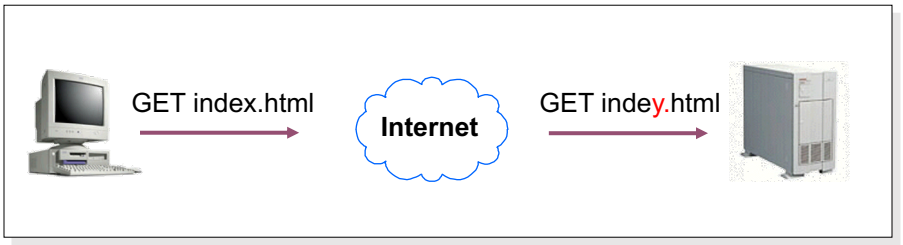
TCP: Corrupted Data



- Sender computes a checksum
  - Sender sums up all bytes in the payload
  - And sends the sum to the receiver
- Receiver checks a checksum
  - Recevier sums up all bytes in the payload
  - And compares against the checksum

```
  134
+ 212
= 346

  134
+ 216
= 350
```

Then what?

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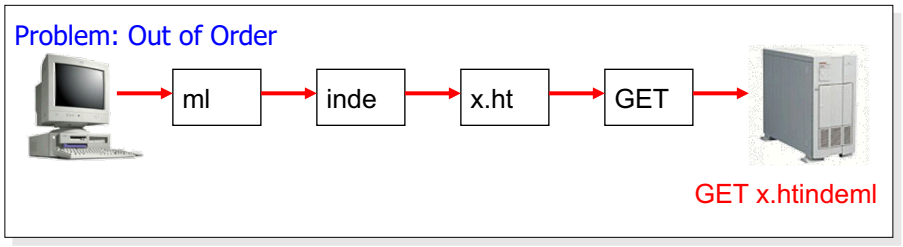
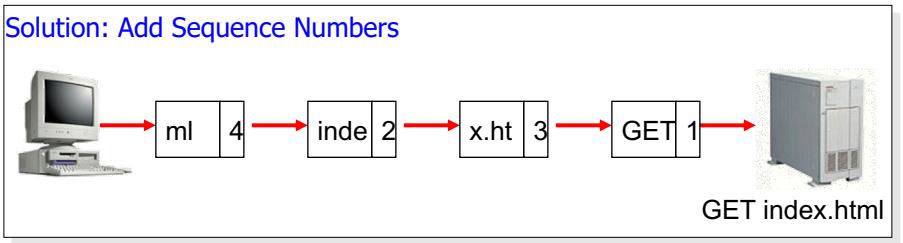
TCP: Out-of-Order Packet Arrivals





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TCP: Receiver that Runs Out of Space

- Receiver maintains a *window size*
  - Amount of data it can buffer
- Advertises window to the sender
  - Amount sender can send without acknowledgment
- Ensures that sender does not send too much
  - While still sending as much as possible

Flow control!

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TCP: Network that Cannot Handle the Load

- Problem: Too many packets at once
- Solution: Congestion control
  - Future lecture!

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Transport: User Datagram Protocol (UDP)

- Datagram of bytes
  - A message

- Challenges with IP
  - Lost or delayed packets X
  - Corrupted packets √
  - Out-of-order packet arrivals X
  - Receiver runs out of space X
  - Network cannot handle current load X

UDP does less than TCP, why do we want UDP too?

My favorite UDP joke
"I'd tell you a joke about UDP packets, but I'm not sure you'd get it."

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Layering & Network Layers Conclusion

- The art of layering

- Network layers
  - Protocol, headers, encapsulation

- IP layer: best-effort global packet delivery between host

- TCP layer: ordered, reliable byte stream between applications

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