Introduction to Layering and Network Layering

COS 316: Principles of Computer System Design

Lecture 11

Amit Levy & Ravi Netravali

Barbara Liskov

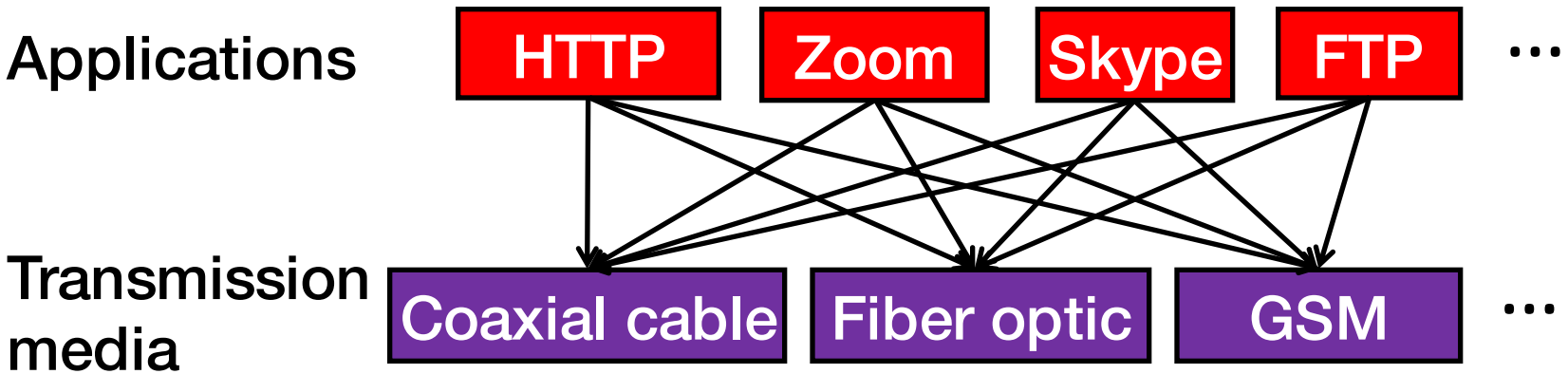
“Modularity based on abstraction is the way things get done”

2009 Turing Award Lecture

Modularity Through Layering

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

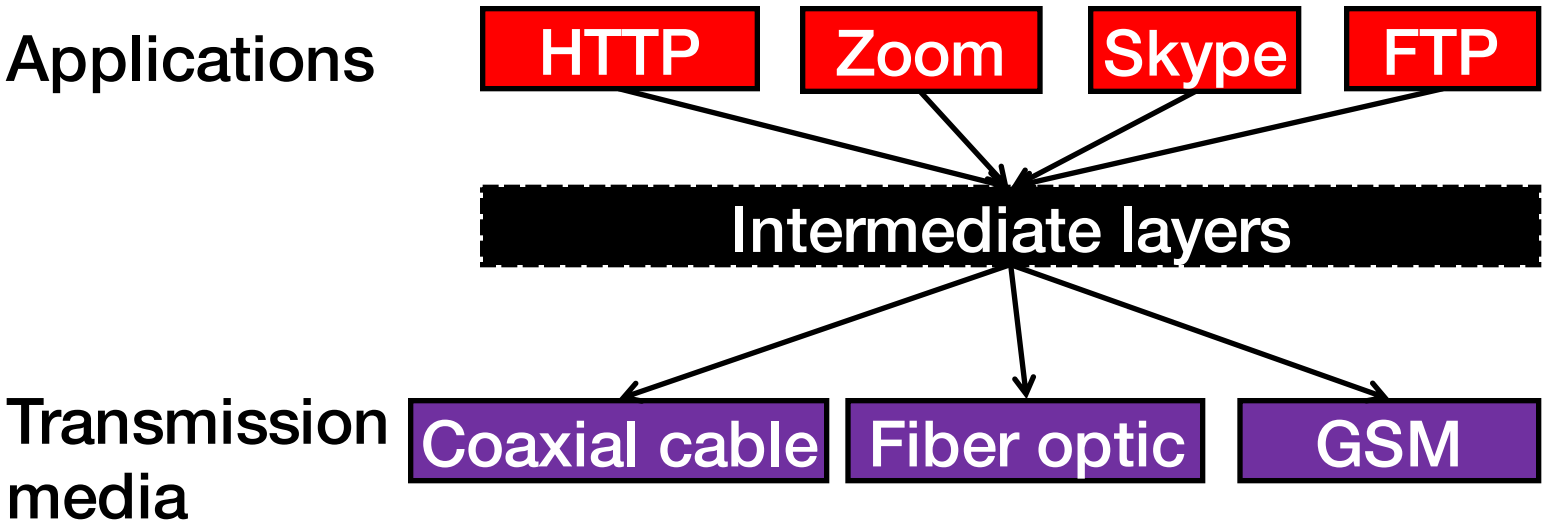
The Problem of Communication



- 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?

Solution: Layering

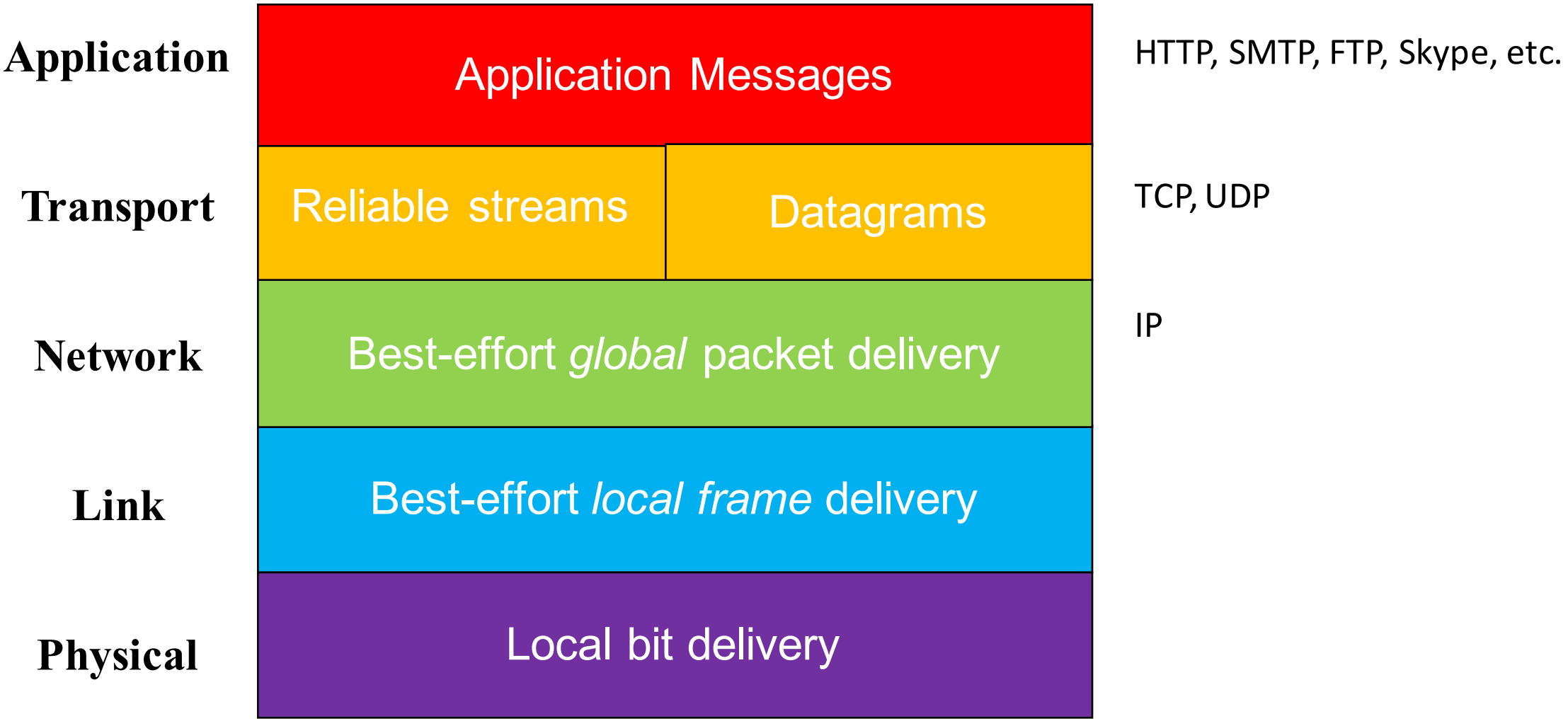


- Intermediate **layers** provide a set of abstractions for applications and media
- New applications or media need only implement for intermediate layer's interface

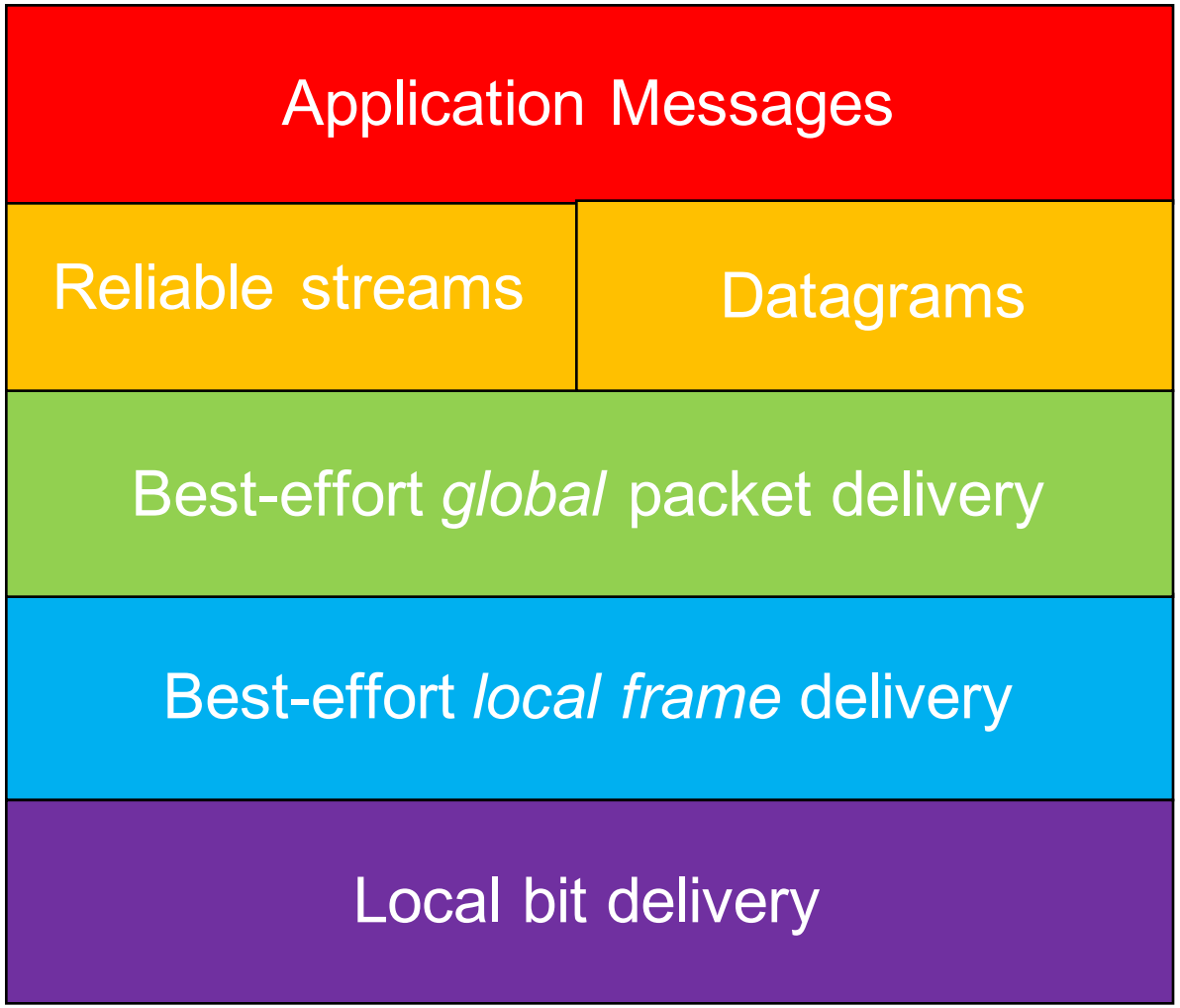
The Art of Layering

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

Internet Protocol Layers



Internet Protocol Layers



HTTP, SMTP, FTP, Skype, etc.

TCP, UDP

IP

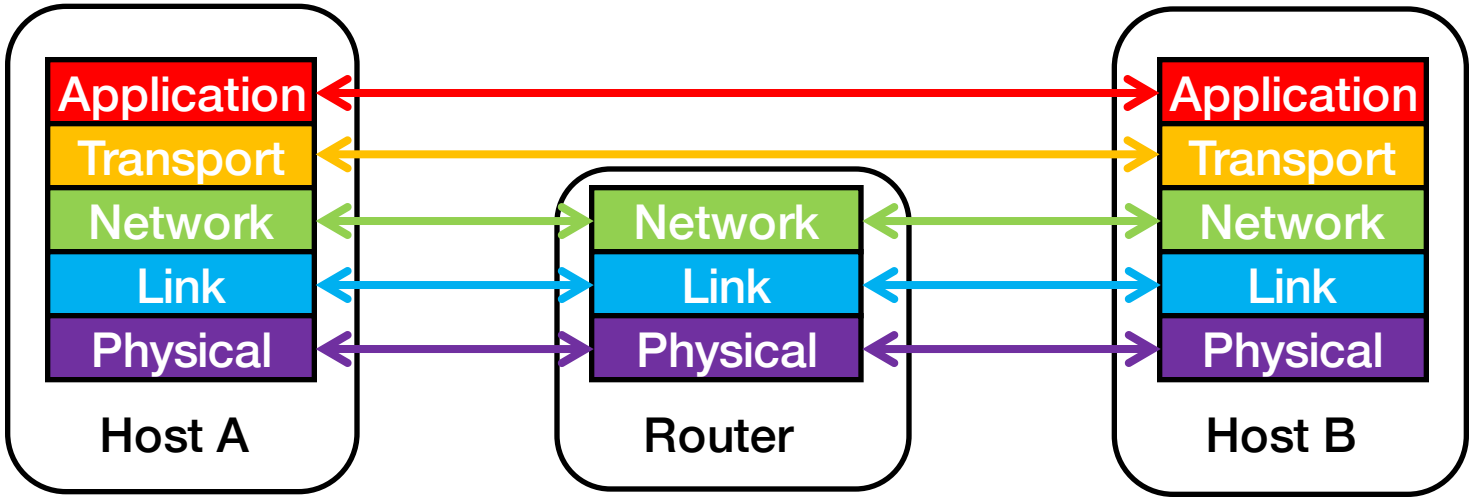
Ethernet, WiFi, etc.

Coaxial cable, fiber optic cable, etc.

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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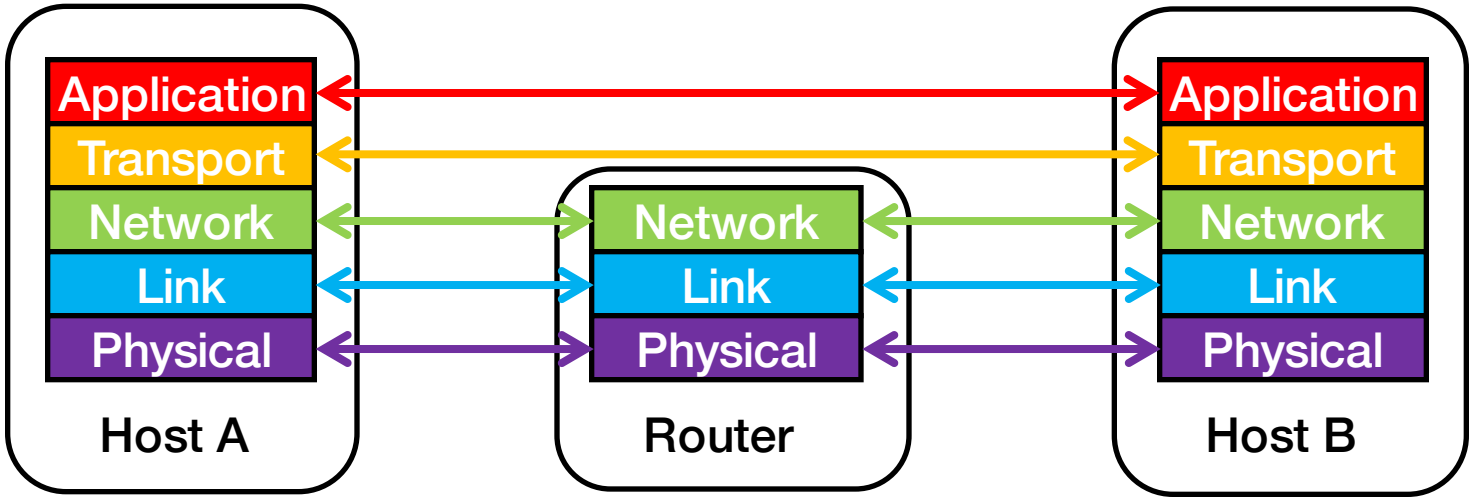
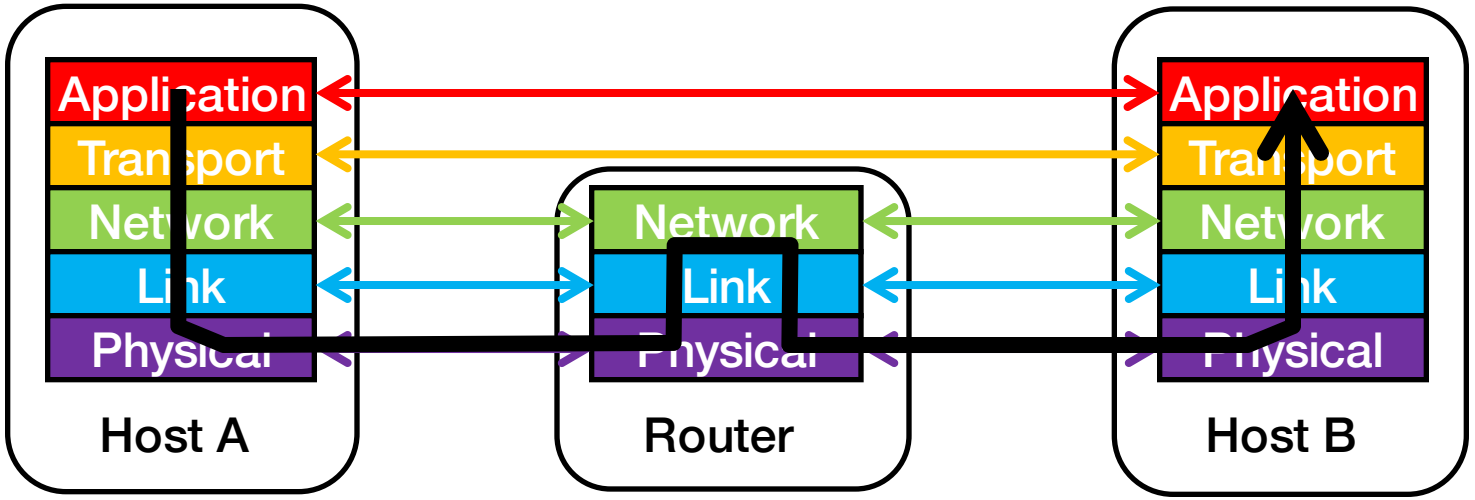


Physical communication

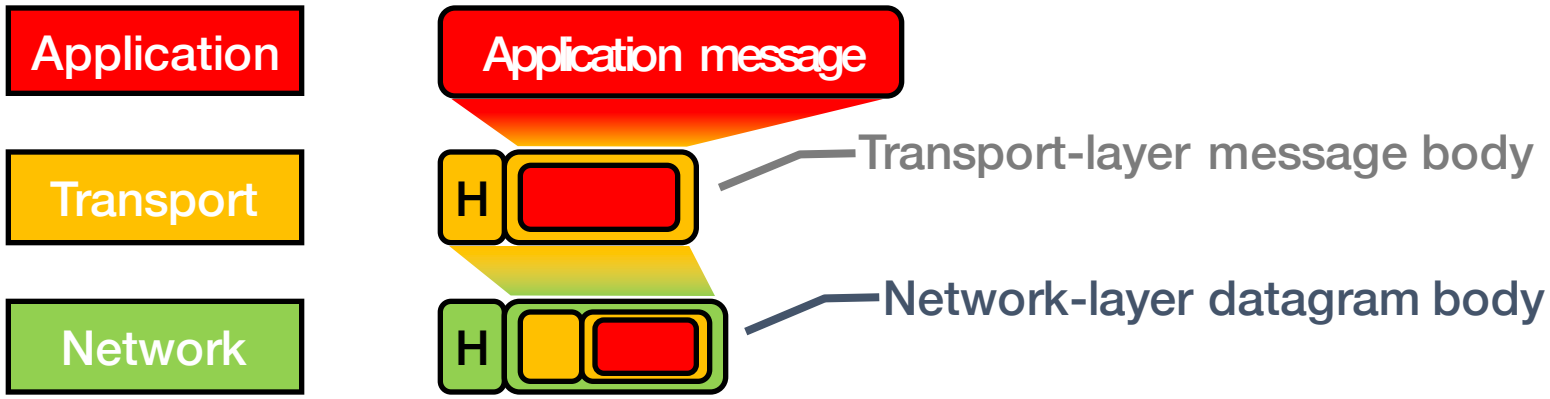
- Communication goes down to the **physical network**
- Then from **network** peer to peer
- Then up to the **relevant application**



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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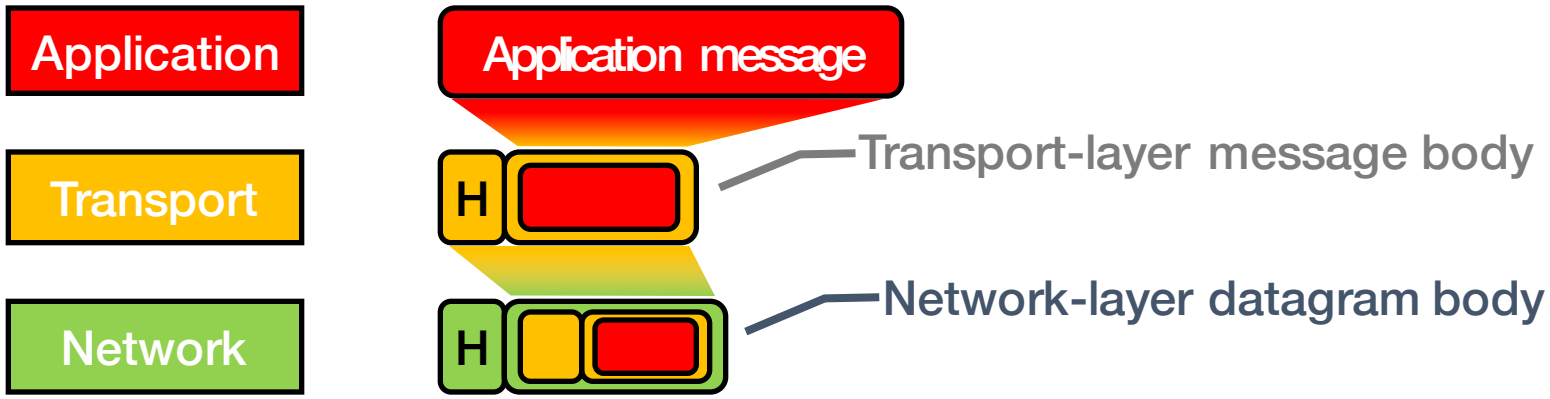

IP is the “Narrow Waist” of the Internet

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

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

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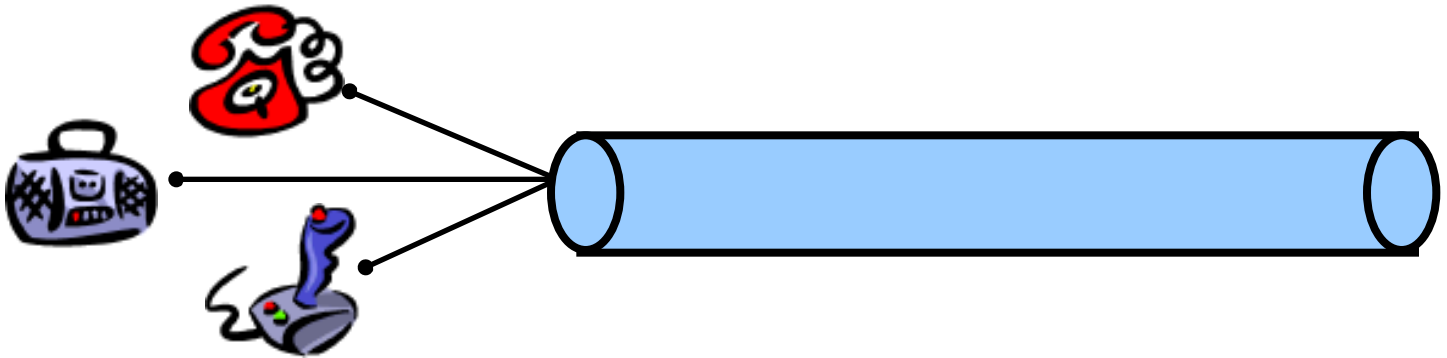
- Easier to survive failures
  - Transient disruptions are okay during failure recovery
- Can run on nearly any link technology
  - Greater interoperability and evolution
  - RFC 1149: IP Datagrams Over Avian Carriers

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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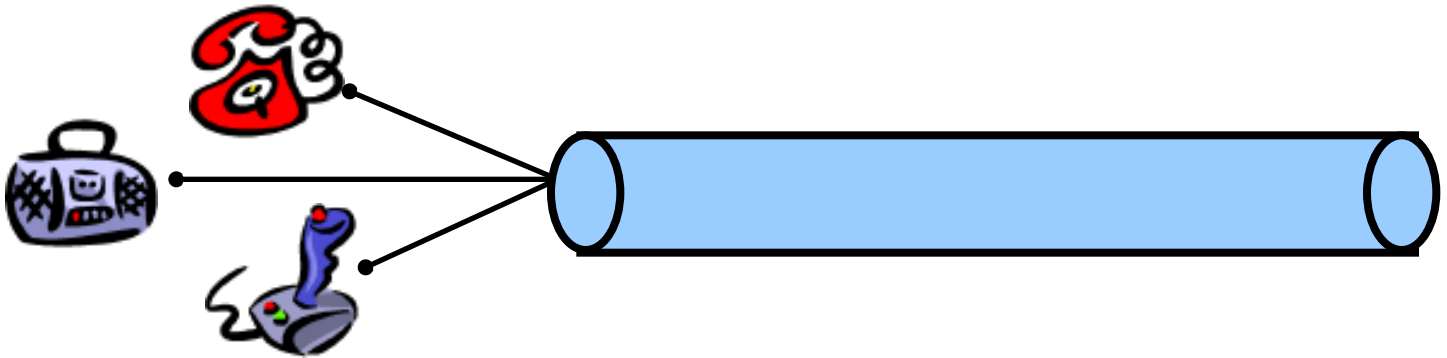


Transport: Application to Application

- 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?*

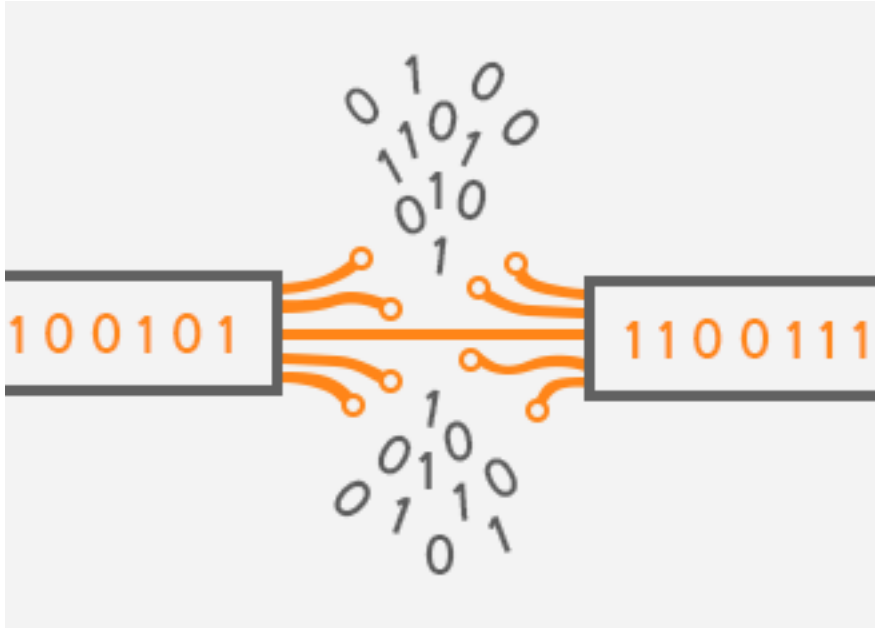
Transport: Application to Application

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

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

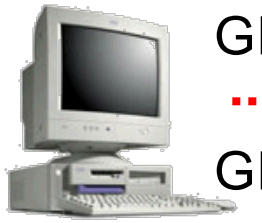


TCP: Lost or Delayed Packets

Problem: Lost or Delayed Data

GET index.html

Solution: Timeout and Retransmit



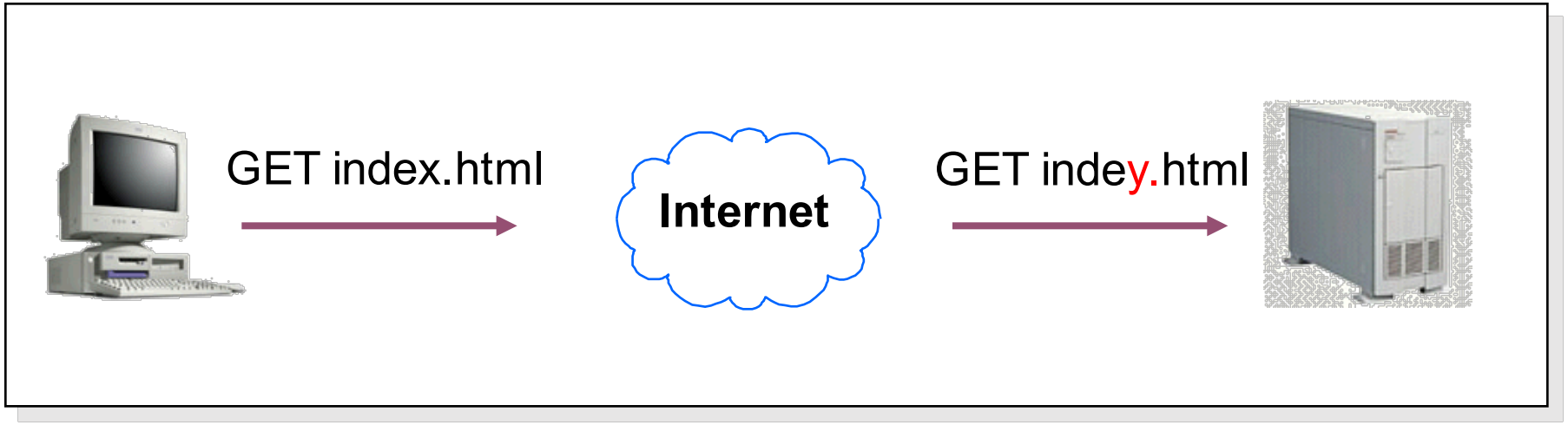
GET index.html

GET index.html

GET index.html

Waiting for an acknowledgment…

TCP: Corrupted Data



- Sender computes a checksum
  - Sender sums up all bytes in the payload
  - And sends the sum to the receiver

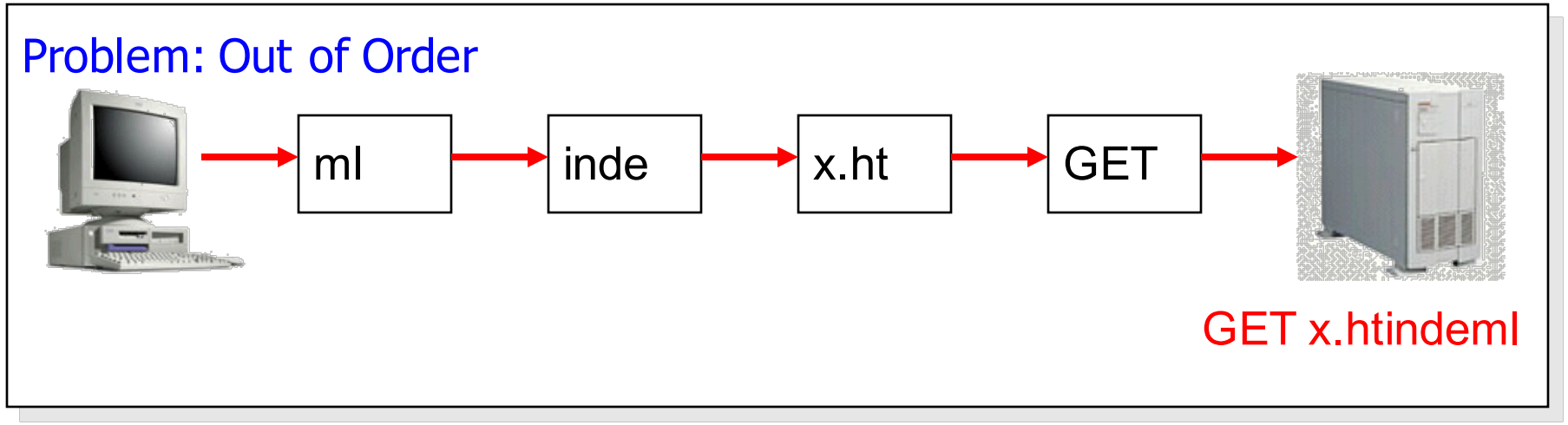
```
  134
+ 212
= 346
```

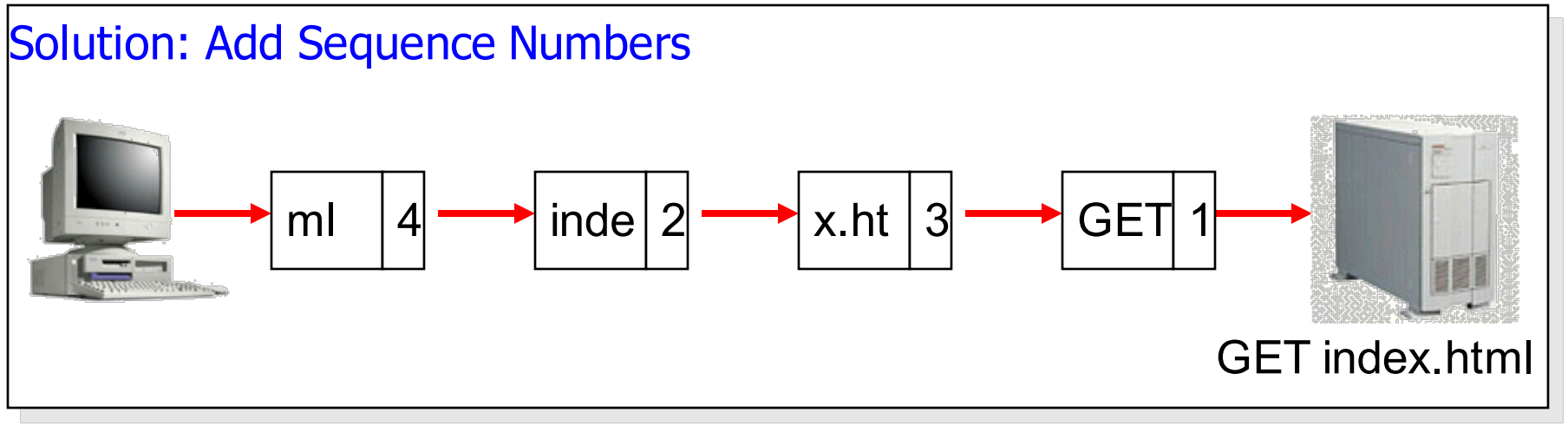
- Receiver checks a checksum
  - Recevier sums up all bytes in the payload
  - And compares against the checksum

```
  134
+ 216
= 350
```

Then what?

TCP: Out-of-Order Packet Arrivals





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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Flow control!

TCP: Network that Cannot Handle the Load

- Problem: Too many packets at once

- Solution: Congestion control
  - Future lecture!

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?

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