Introduction to Layering
&
Network Layering

COS 316: Principles of Computer System Design

Lecture 7

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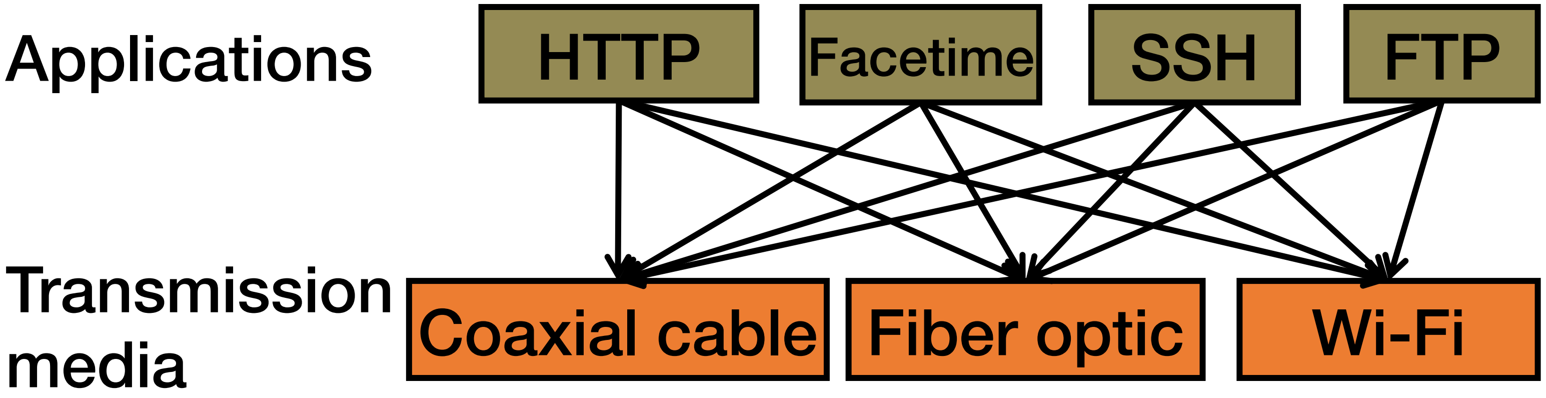
“Modularity based on abstraction is the way things get done”

2009 Turing Award Lecture

Modularity Through Layering

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

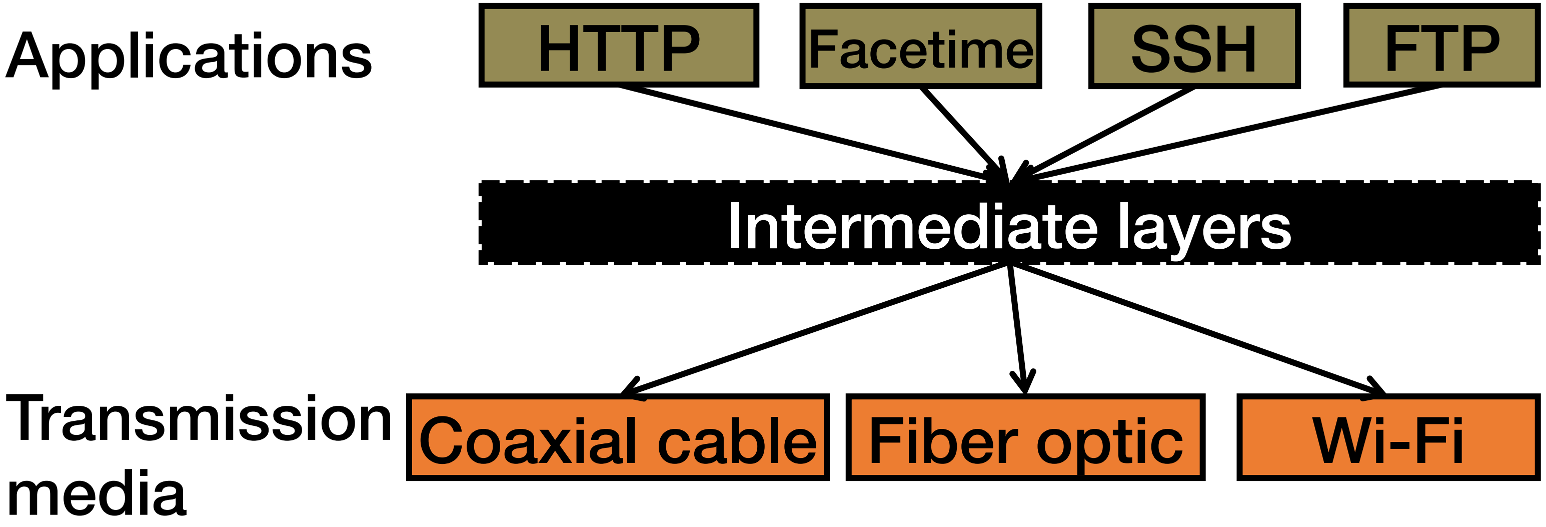
The Problem of Communication



- Re-implement every application for every new underlying transmission medium?
- Change every application on any change to an underlying transmission medium?

- No! But how does the Internet design avoid this?

Solution: Layering



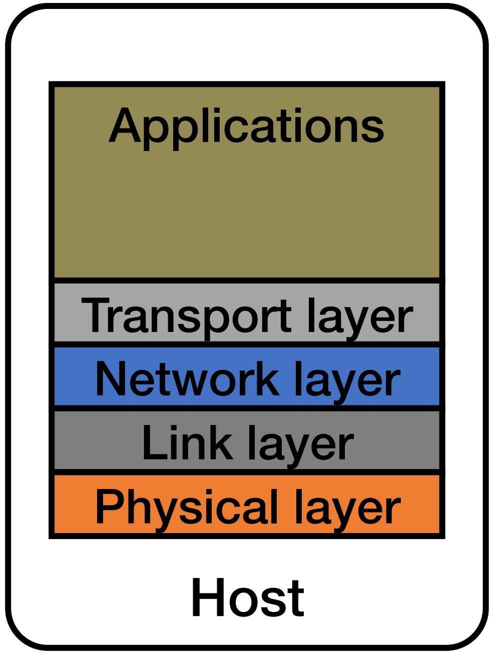
- Intermediate layers provide a set of abstractions for applications and media

- 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?

Layering in the Internet

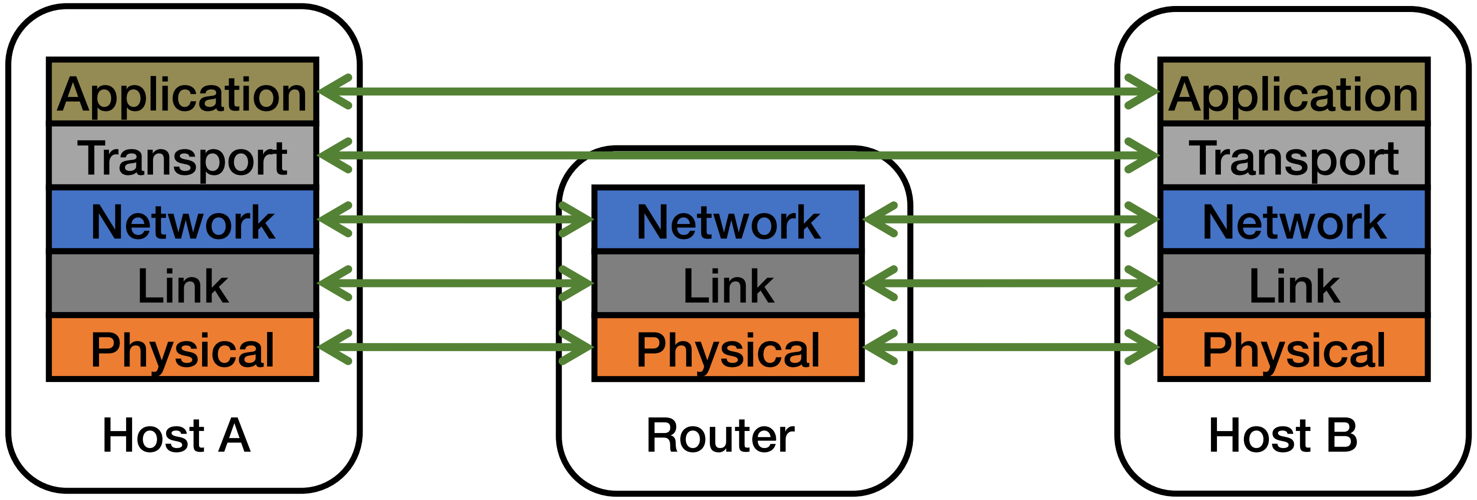


- Transport: Provide end-to-end communication between processes on different hosts
- Network: Deliver packets to destinations on other (heterogeneous) networks
- Link: Enables end hosts to exchange atomic messages with each other
- Physical: Moves bits between two hosts connected by a physical link

Logical Communication Between Layers

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

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

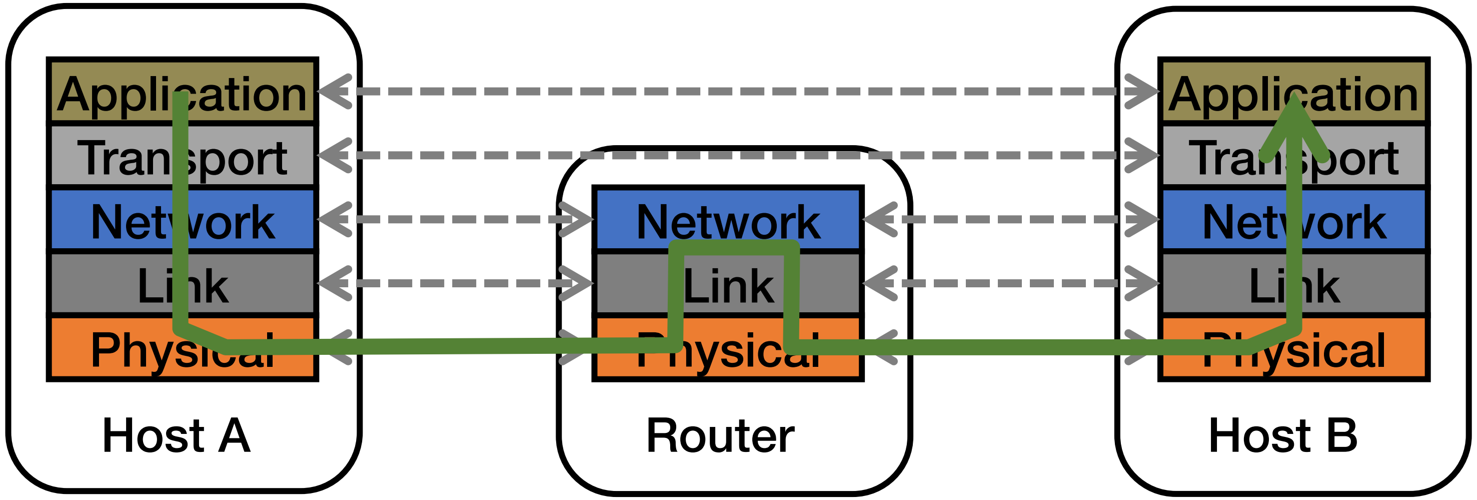


Physical communication

- Communication goes down to the physical network

- Then from network peer to peer

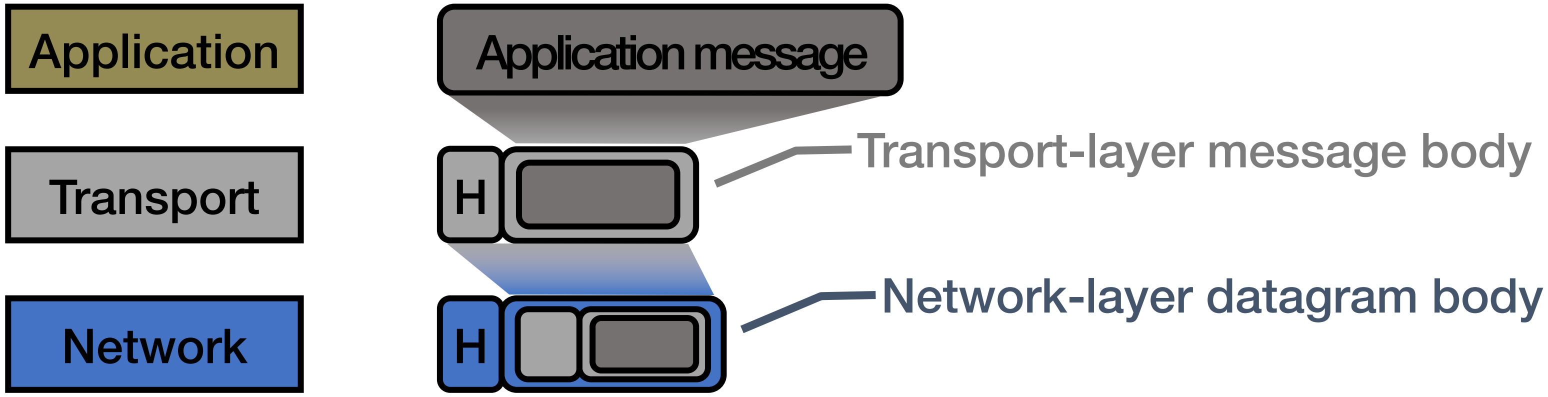
- Then up to the relevant application



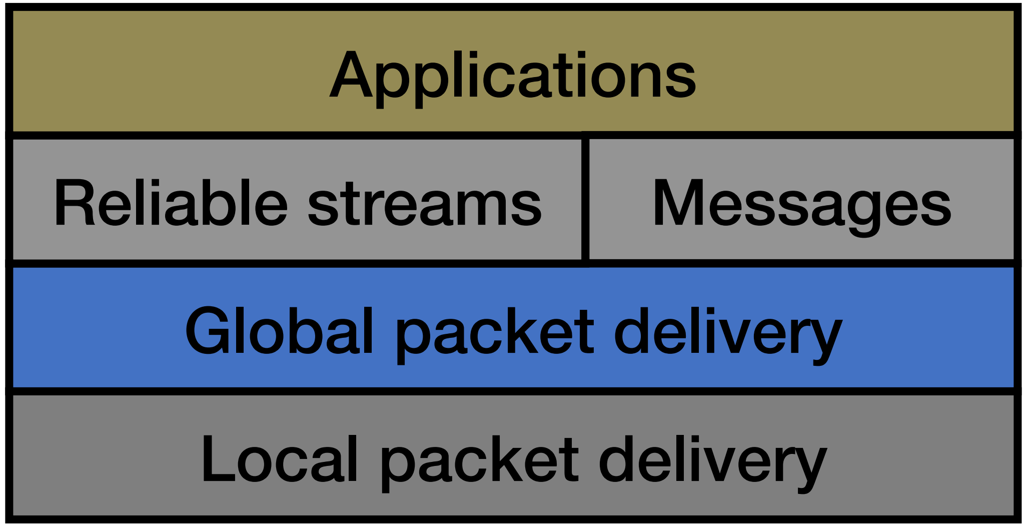
Communication Between Peers

- 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 don't generally inspect higher layers' headers



Internet Protocol Layers



Application	Applications		HTTP …
Transport	Reliable streams	Messages	TCP, UDP
Network	Global packet delivery		IP
Link	Local packet delivery		Ethernet, Optical, WiFi, …

IP is the “Narrow Waist” of the Internet

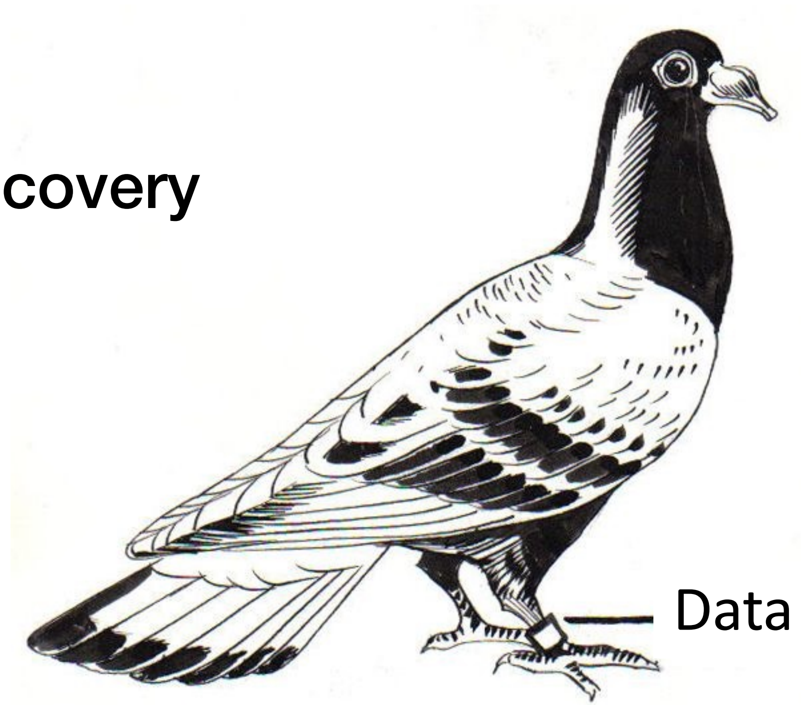
- The network layer protocol
  - Enables portability above and below
- Lots of link layer protocols underneath
- Several transport protocols on top
  - TCP, UDP, QUIC

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 from one packet to the next

- Easier to survive failures
  - Transient disruptions are okay during failure recovery

- Can run on nearly any link technology
  - Greater interoperability and evolution
  - RFC 1149…



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?*

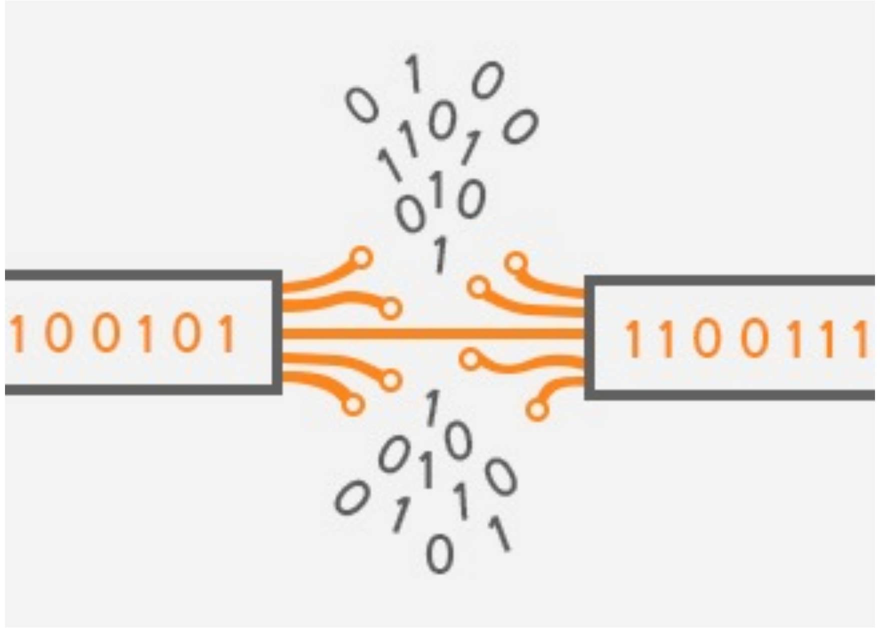
Transport: Application to Application

- 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

- Solution: Timeout and retransmit
  - Receiver sends acknowledgement of data

TCP: Corrupted Data

- Problem: Data corrupted during transmission

- Solution: checksums

- 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

- Problem: Our of order packets:
  - Application: GET index.html
  - Sent packets: |GET| |inde| |x.ht| |ml|
  - Received packets: |ml| |inde| |x.ht| |GET|

- Solution: Add sequence numbers
  - Received packets: |4|ml| |2|inde| |3|x.ht| |1|GET|

TCP: Receiver Runs Out of Space

- Problem: No more space to receive packets

- Solution: Flow control
    - Receiver maintains a window size
        - Amount of data it can buffer
    - Advertises window to the sender
        - Amount sender can send without acknowledgement
    - Ensures that sender does not send too much

TCP: Network that Cannot Handle the Load

- Problem: Too many packets at once

- Solution: Congestion control
  - Future lectures!

TCP’s reliable byte stream

Transport: User Datagram Protocol (UDP)

- Datagram of bytes
  - A message

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

- 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

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