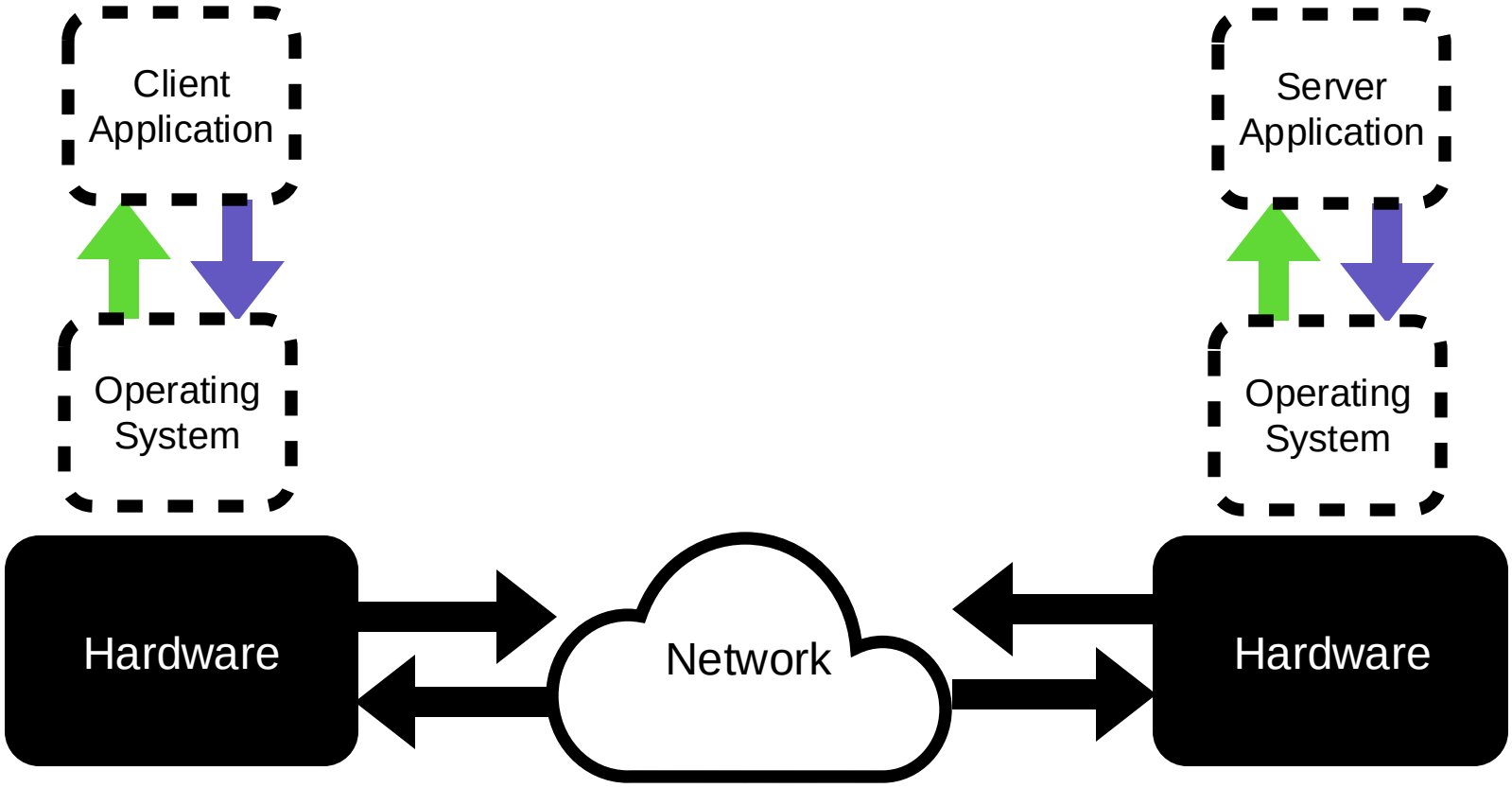
Lecture 25: TCP

CS 105

Fall 2024

Review: Networked Systems

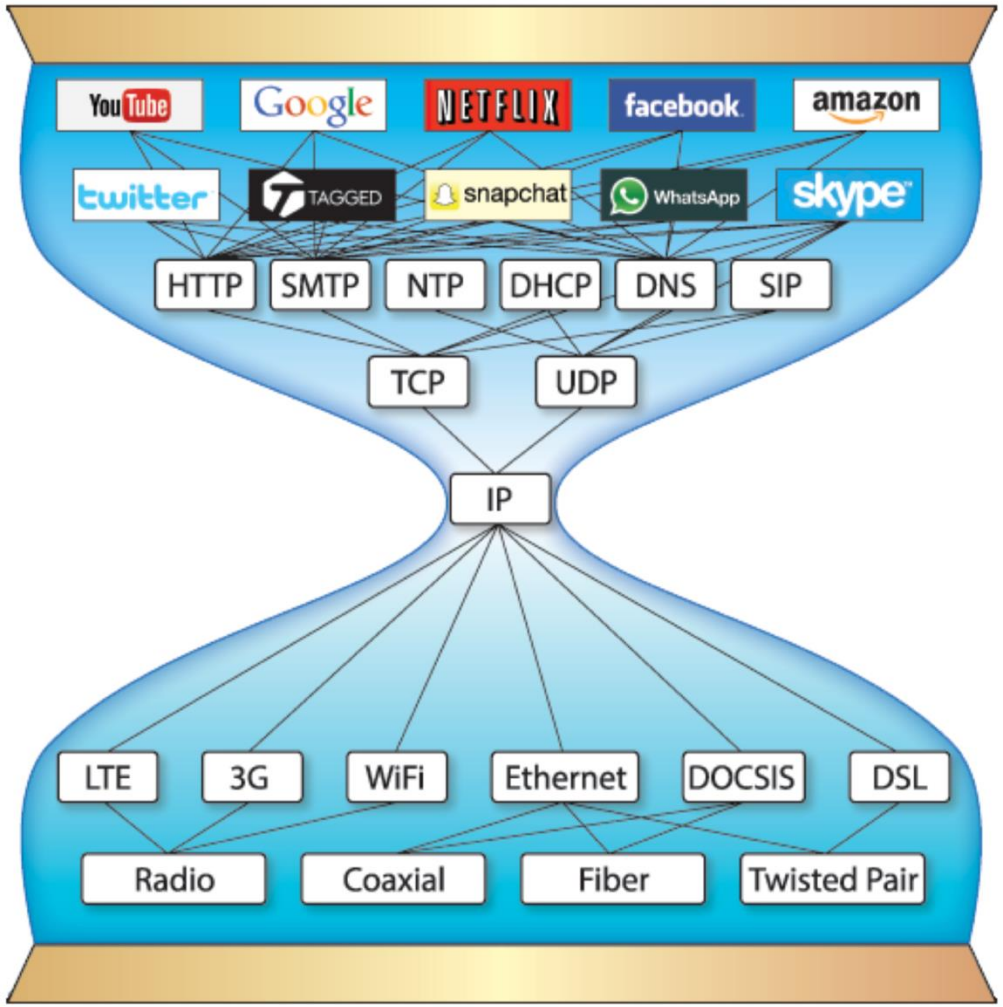


Review: The Network Stack

User-Level Application

Operating System

Hardware (NIC)



Application

Transport

Network

Data Link

Physical

Transport Layer Protocols

User Datagram Protocol (UDP)

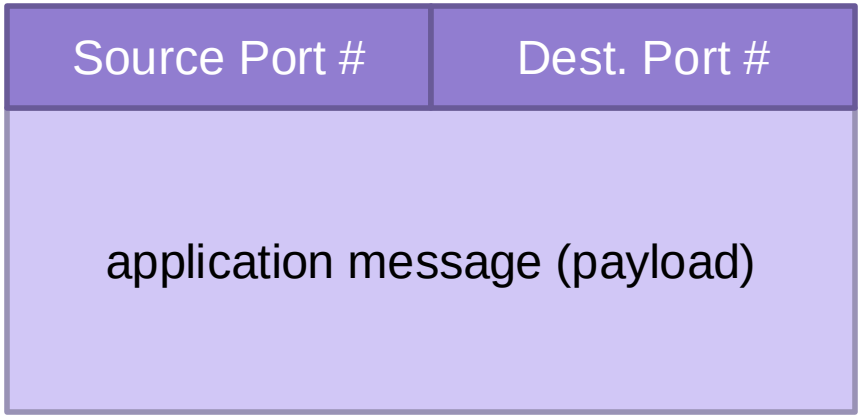
- **unreliable, unordered delivery**
- connectionless
- best-effort, segments might be lost, delivered out-of-order, duplicated
- reliability (if required) is the responsibility of the app

Transmission Control Protocol (TCP)

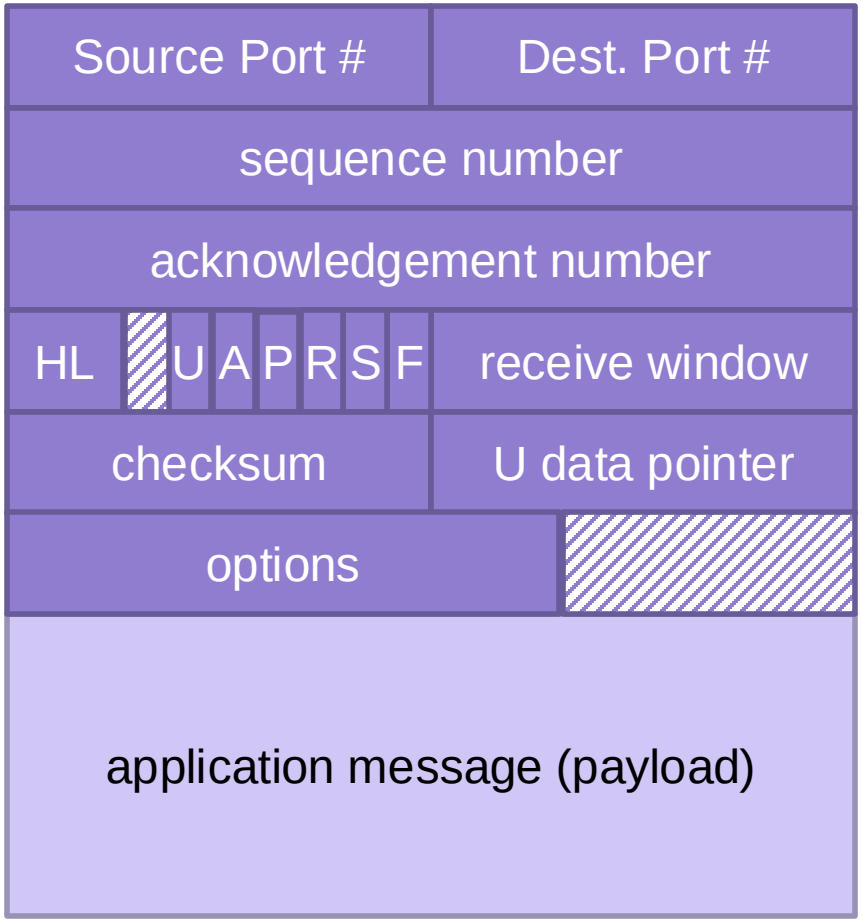
- **reliable, in-order delivery**
- connection setup
- flow control
- congestion control

Transport-Layer Segment Formats

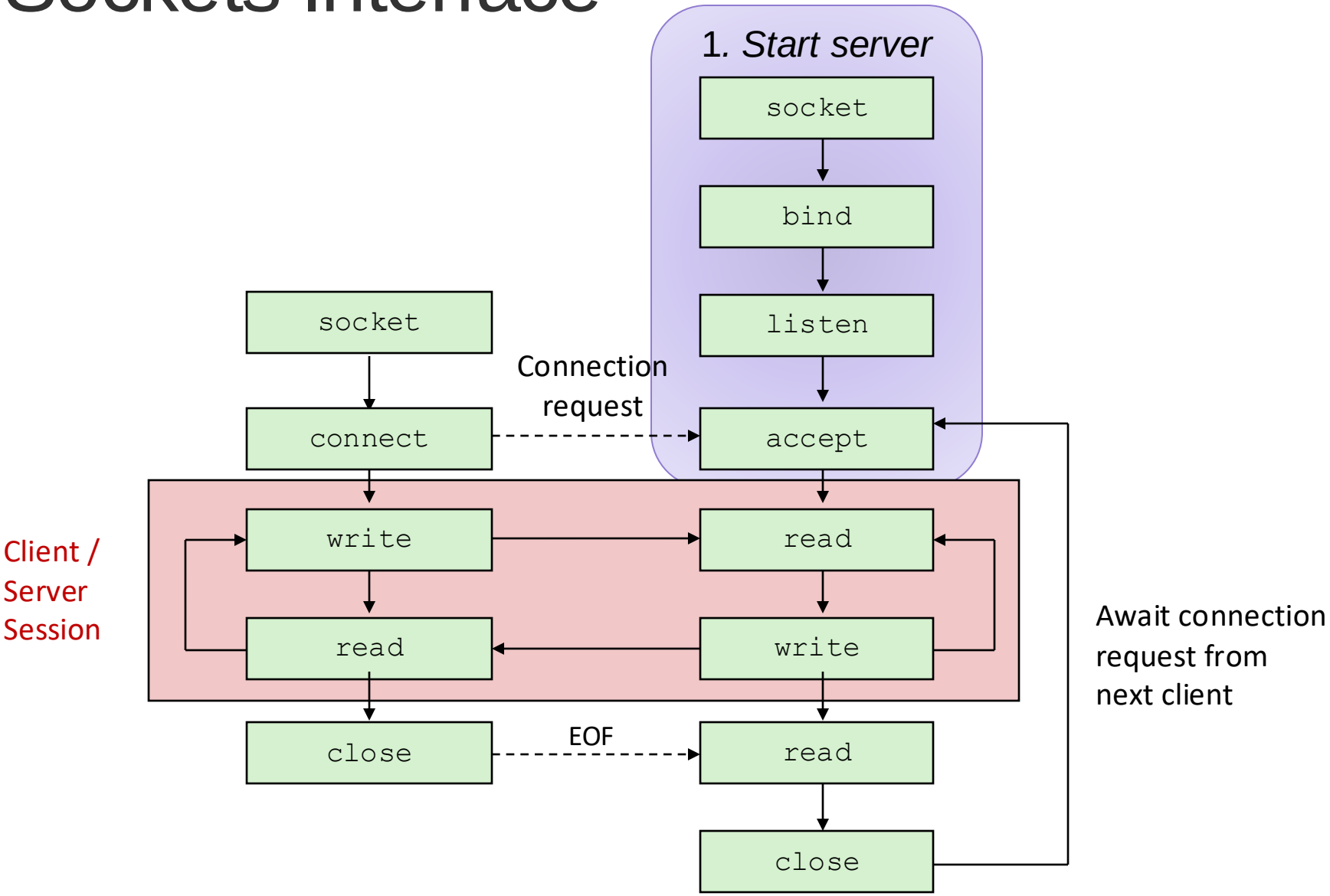
UDP



TCP



Sockets Interface



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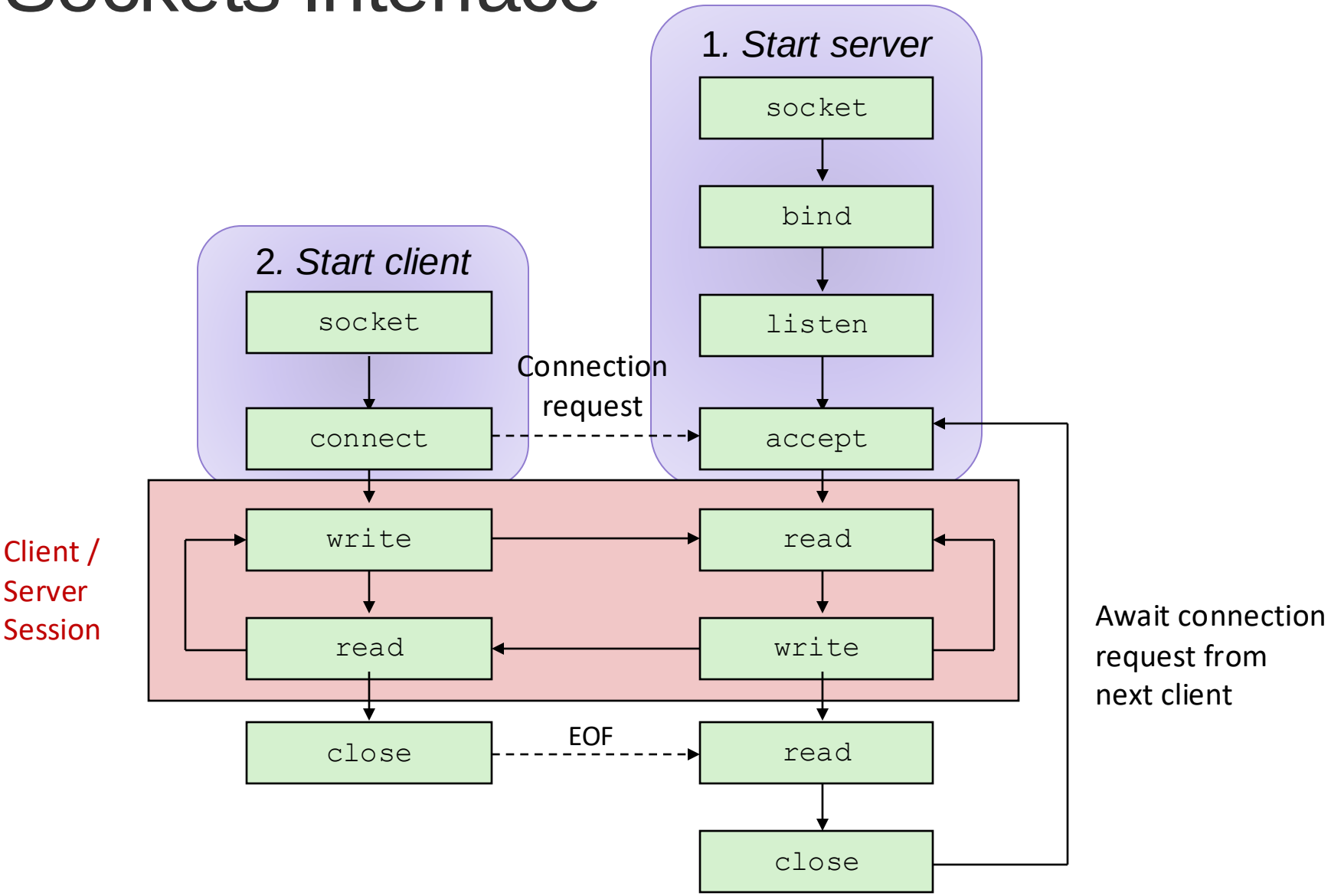
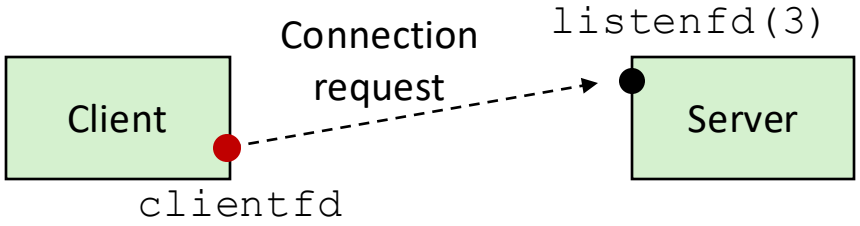
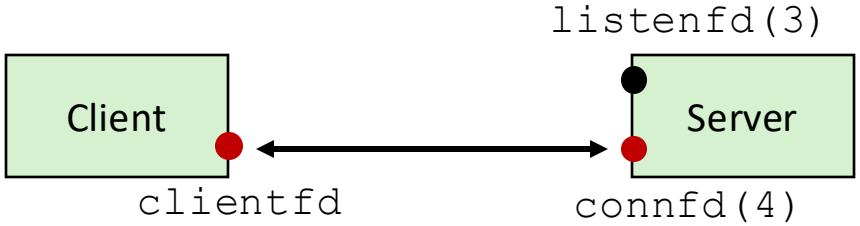


`accept` Illustrated

1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`



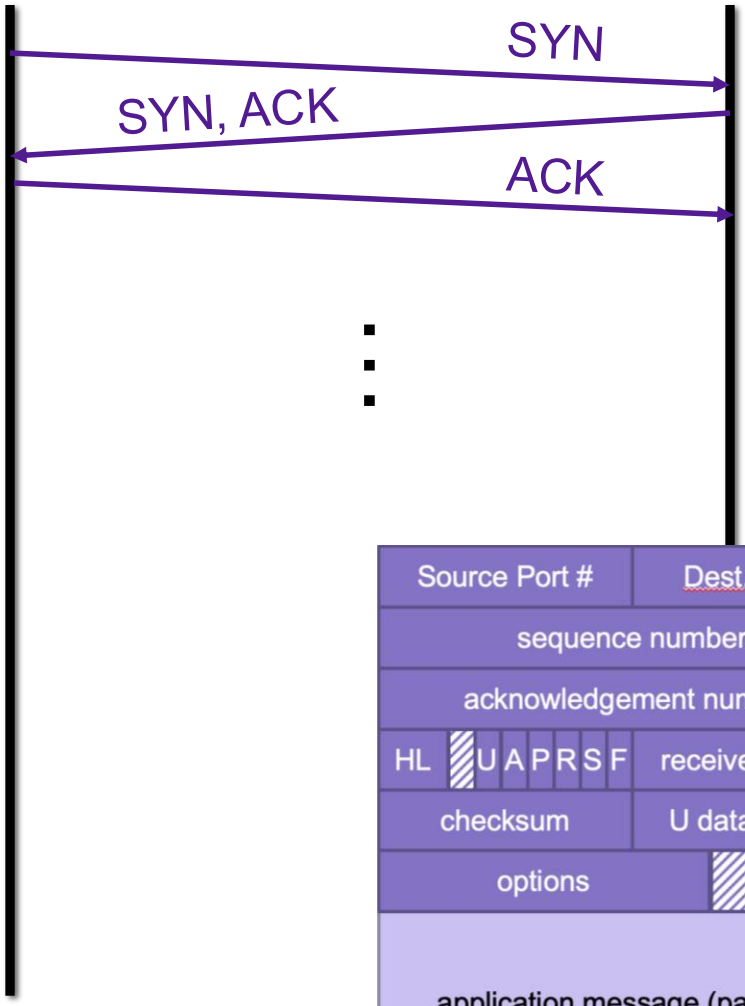
2. Client makes connection request by calling and blocking in `connect`



3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`

TCP Connections

- TCP is connection-oriented
- A connection is initiated with a three-way handshake
- Recall: server will typically create a new socket to handle the new connection



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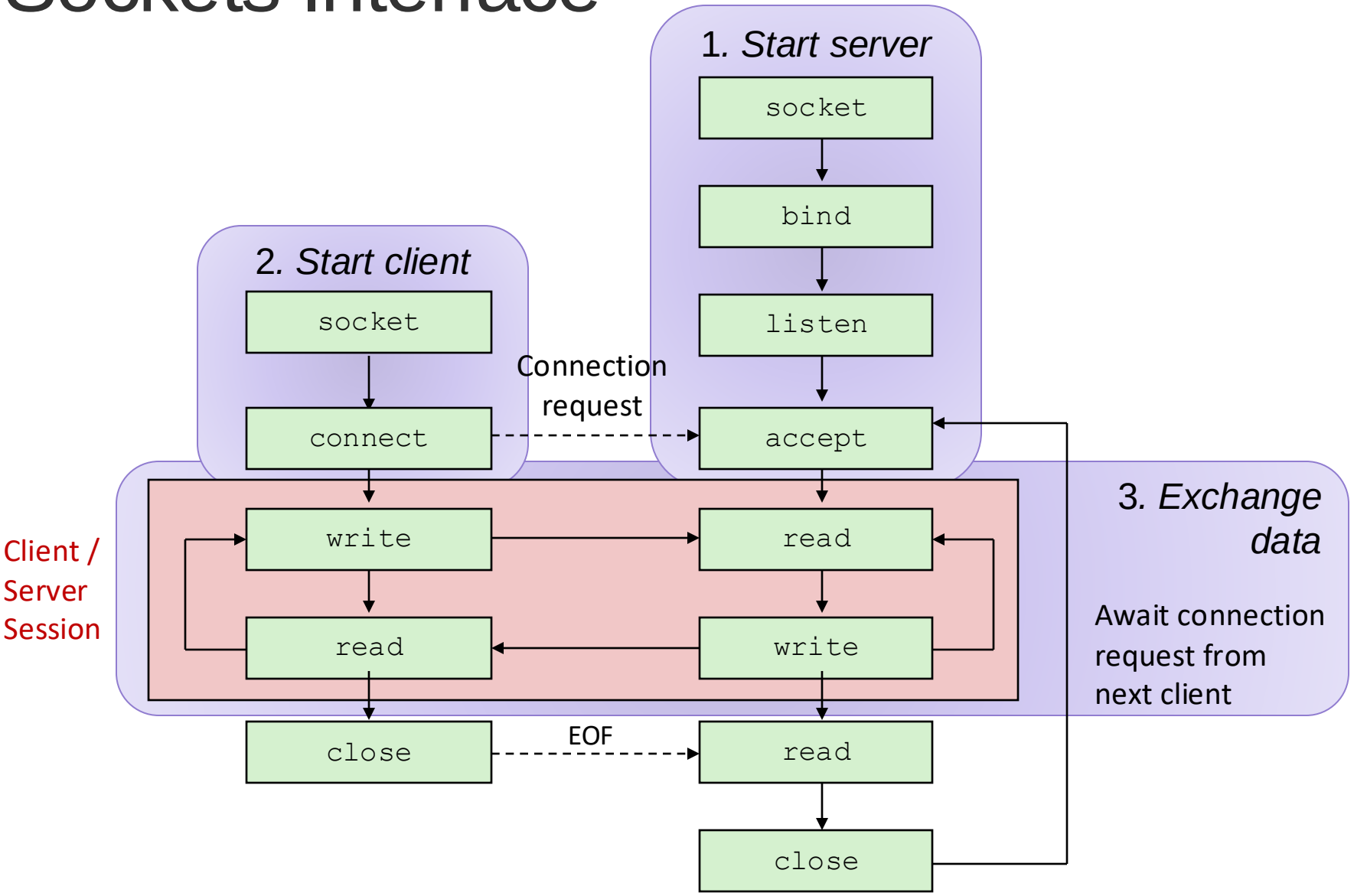
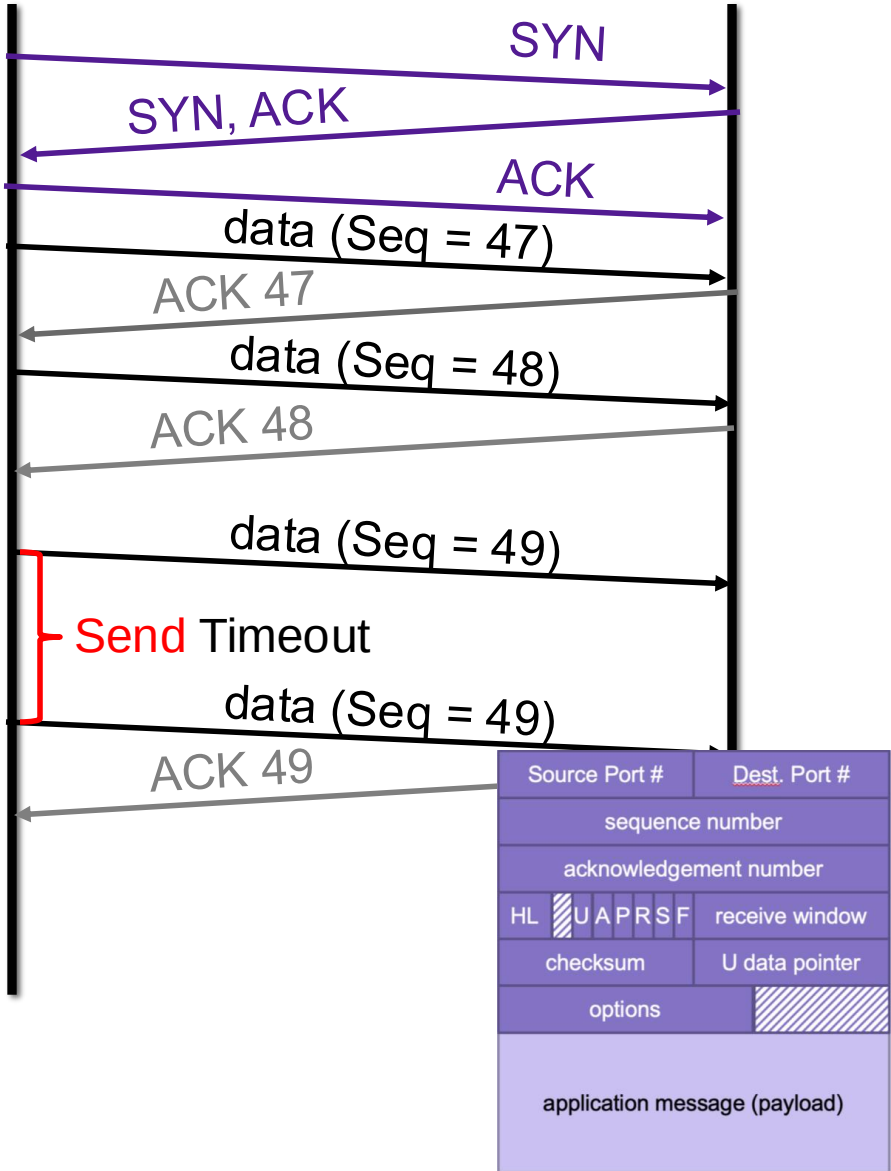


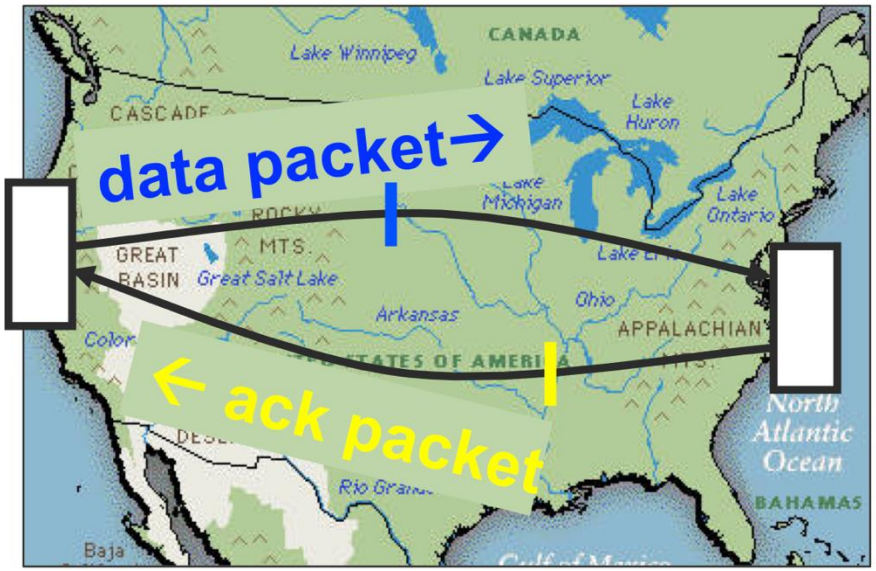
Reliable Transport

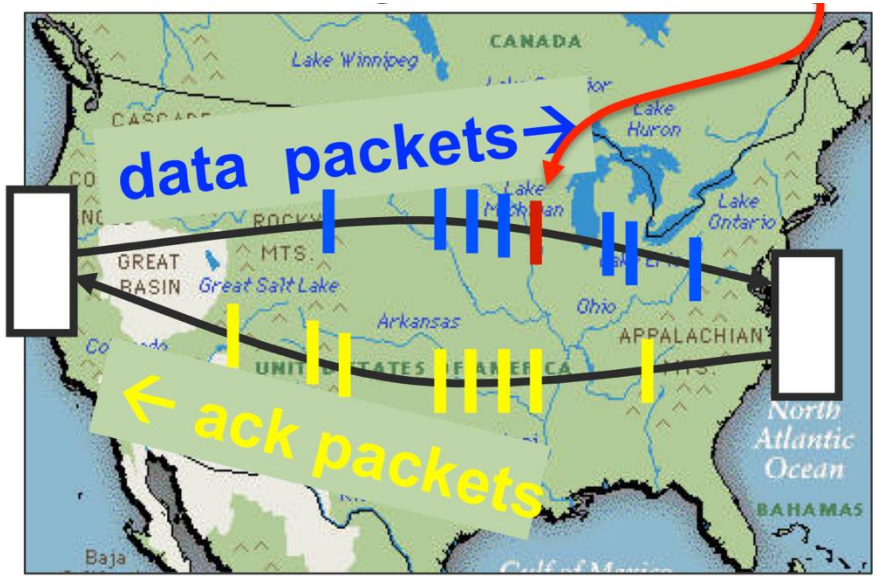
- Each SYN segment will include a randomly chosen sequence number
- Sequence number of each segment is incremented by data length
- Receiver sends ACK segments acknowledging latest sequence number received
- Sender maintains copy of all sent but unacknowledged segments; resends if ACK does not arrive within timeout
- Timeout is dynamically adjusted to account for round-trip delay



Pipelined Protocols

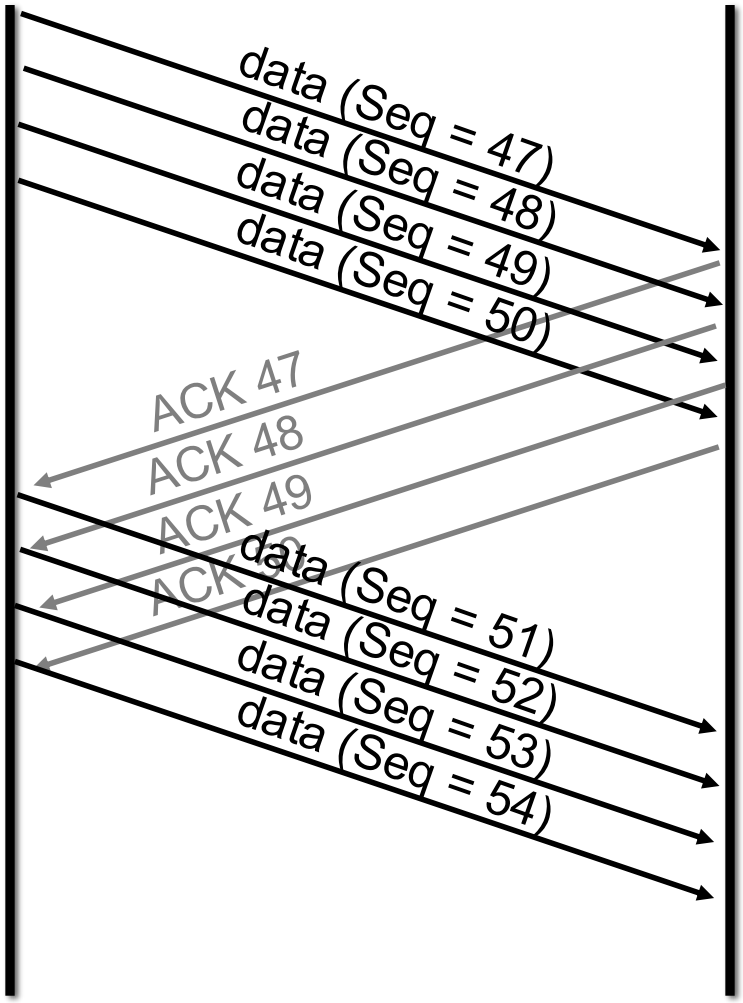
- Pipelining allows sender to send multiple "in-flight", yet-to-be-acknowledged packets
  - increases throughput
  - needs buffering at sender and receiver





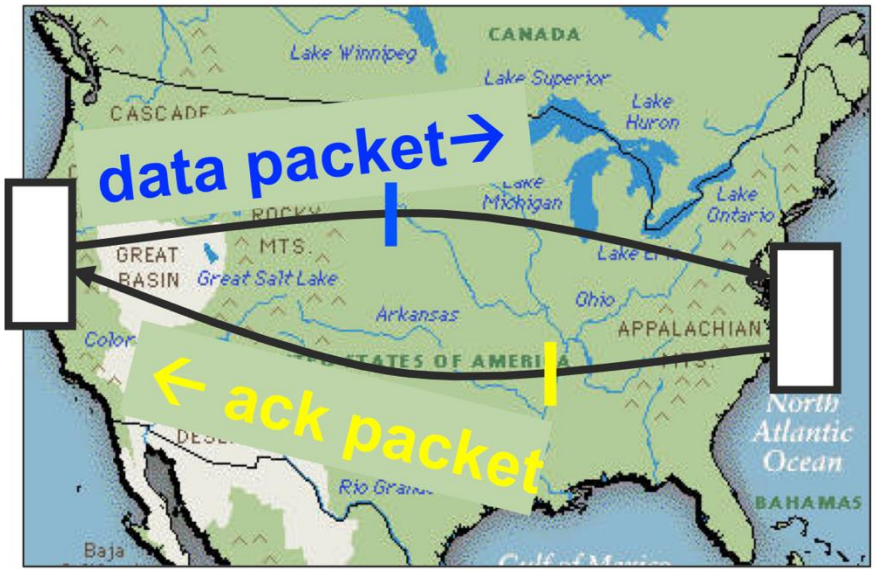
Example: Window Size = 4

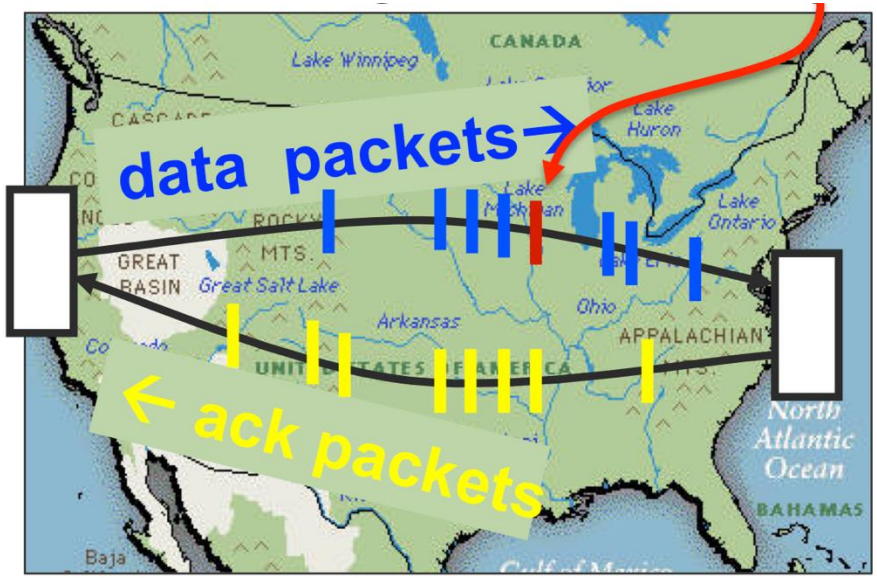
- sender can have up to 4 unacknowledged messages
- when ACK for first message is received, it can send another message



Pipelined Protocols

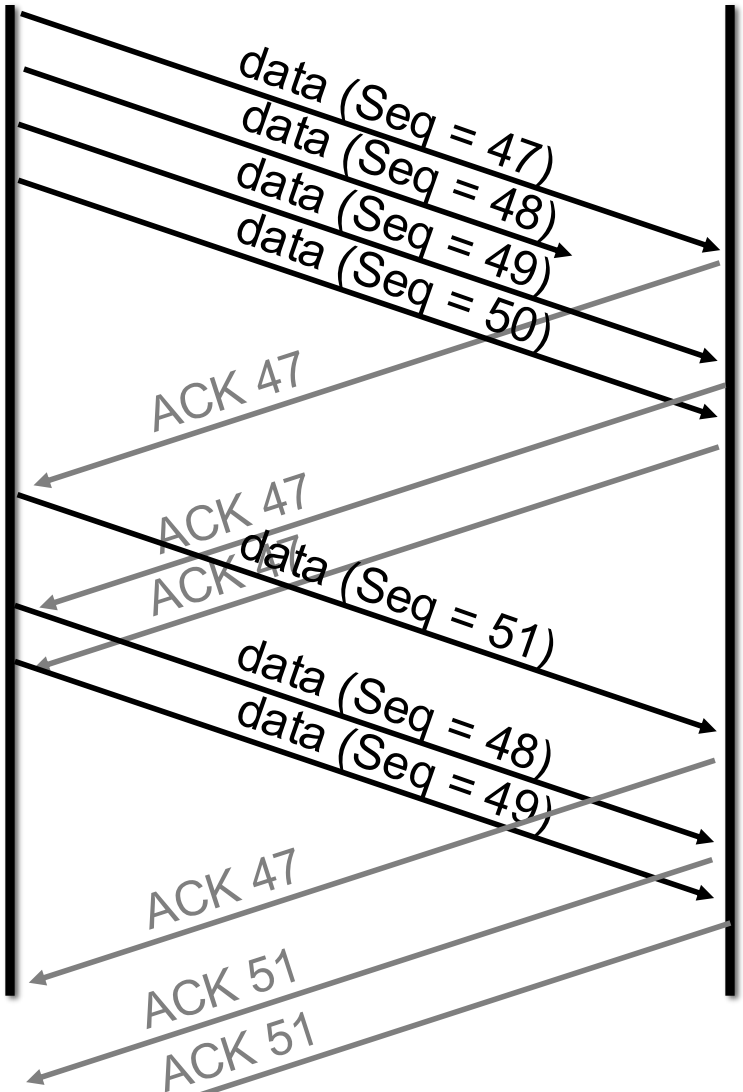
- Pipelining allows sender to send multiple "in-flight", yet-to-be-acknowledged packets
  - increases throughput
  - needs buffering at sender and receiver
- what should we do if a packet goes missing in the middle?





TCP Fast Retransmit

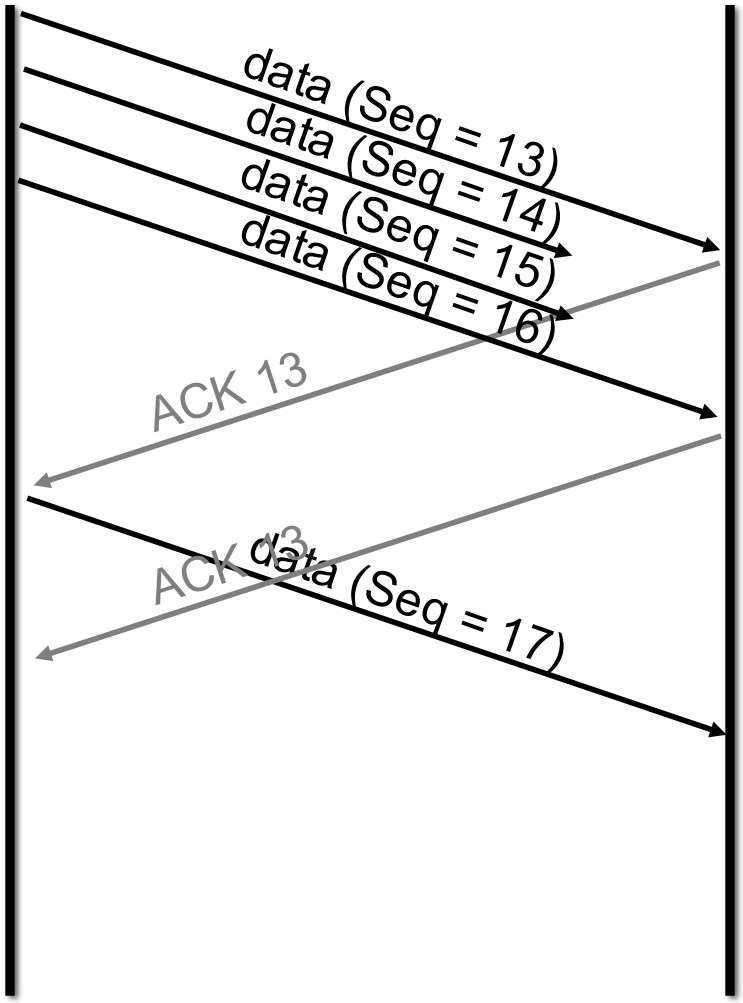
- Receiver always acks the last id it successfully received
- Sender detects loss without waiting for timeout, resends missing packet



Exercise: TCP Sequence Numbers

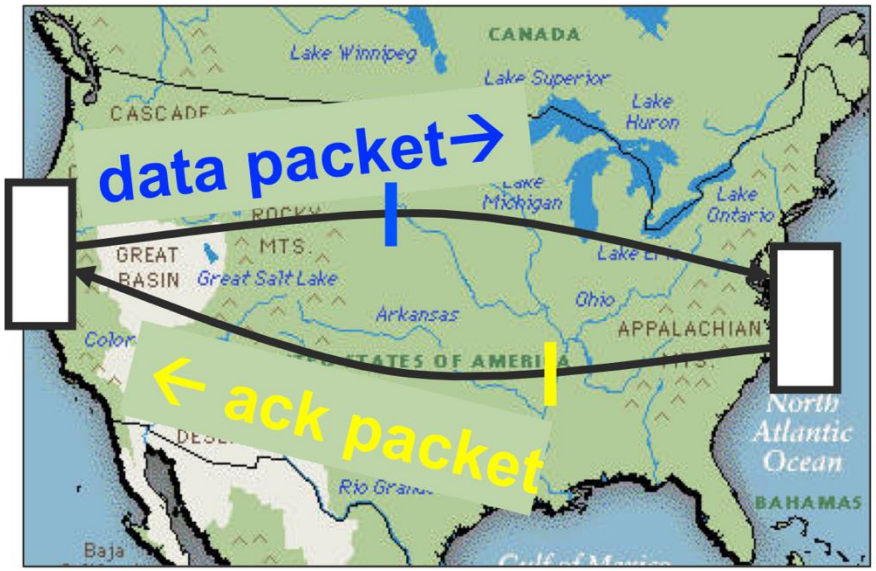
Consider the sequence of transmitted messages shown on the right

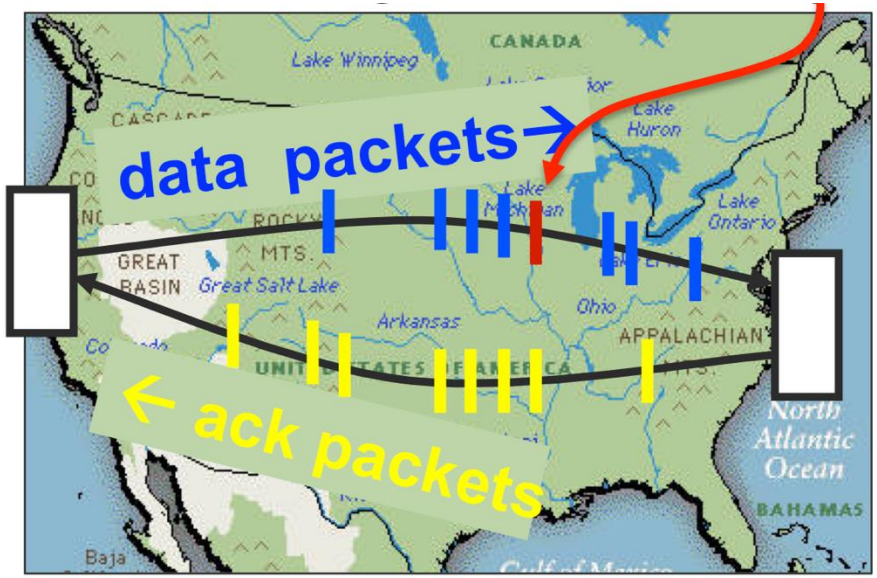
- What will be the next ACK number sent by the server?
- What will be the next Seq number sent by the client?



Pipelined Protocols

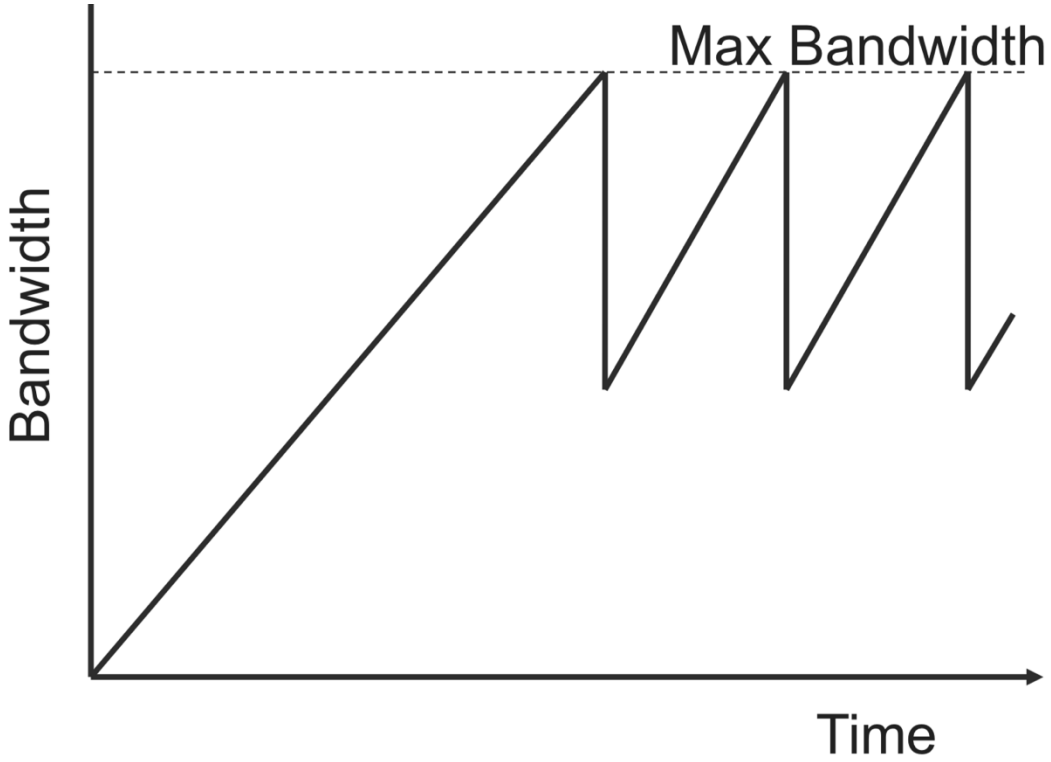
- Pipelining allows sender to send multiple "in-flight", yet-to-be-acknowledged packets
  - increases throughput
  - needs buffering at sender and receiver
- what should we do if a packet goes missing in the middle?
- how big should the window be?





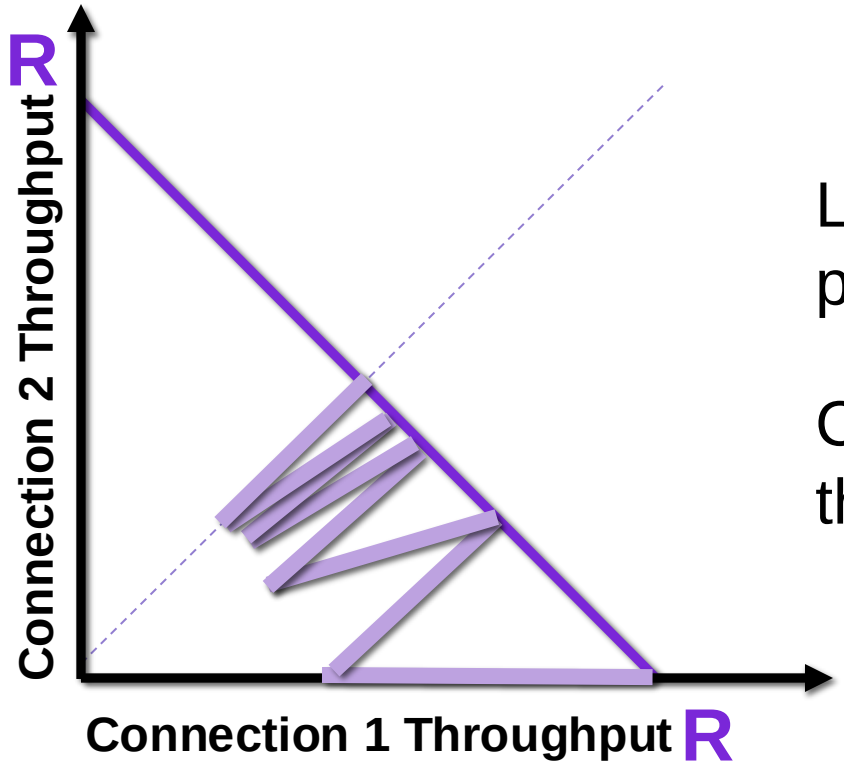
TCP Congestion Control

- TCP operates under a principle of additive increase-multiplicative decrease
  - window size++ every RTT if no packets lost
  - window size/2 if a packet is dropped



TCP Fairness

- Goal: if k TCP sessions share same bottleneck link of bandwidth R, each should have average rate of R/k



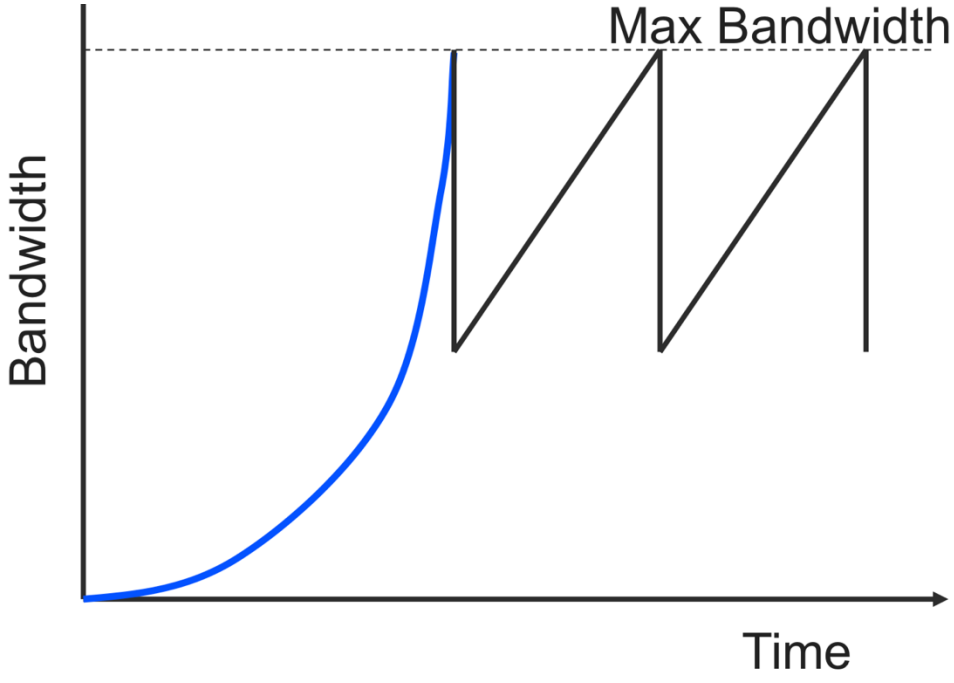
Loss: decreases throughput proportional to current bandwidth

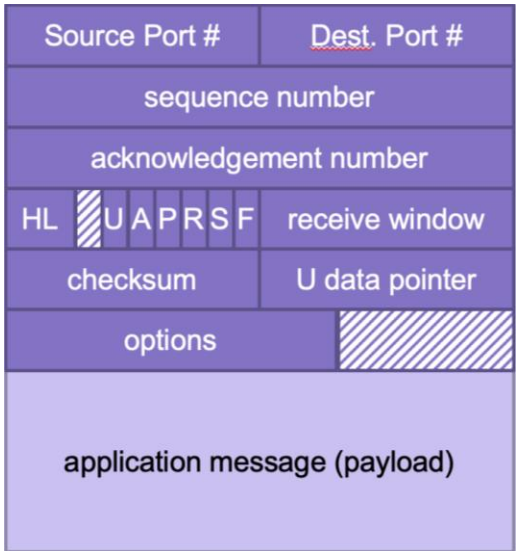
Congestion avoidance: increases throughput linearly (evenly)

TCP Slow Start

- Problem: linear increase takes a long time to build up a decent window size, and most transactions are small

- Solution: allow window size to increase exponentially until first loss

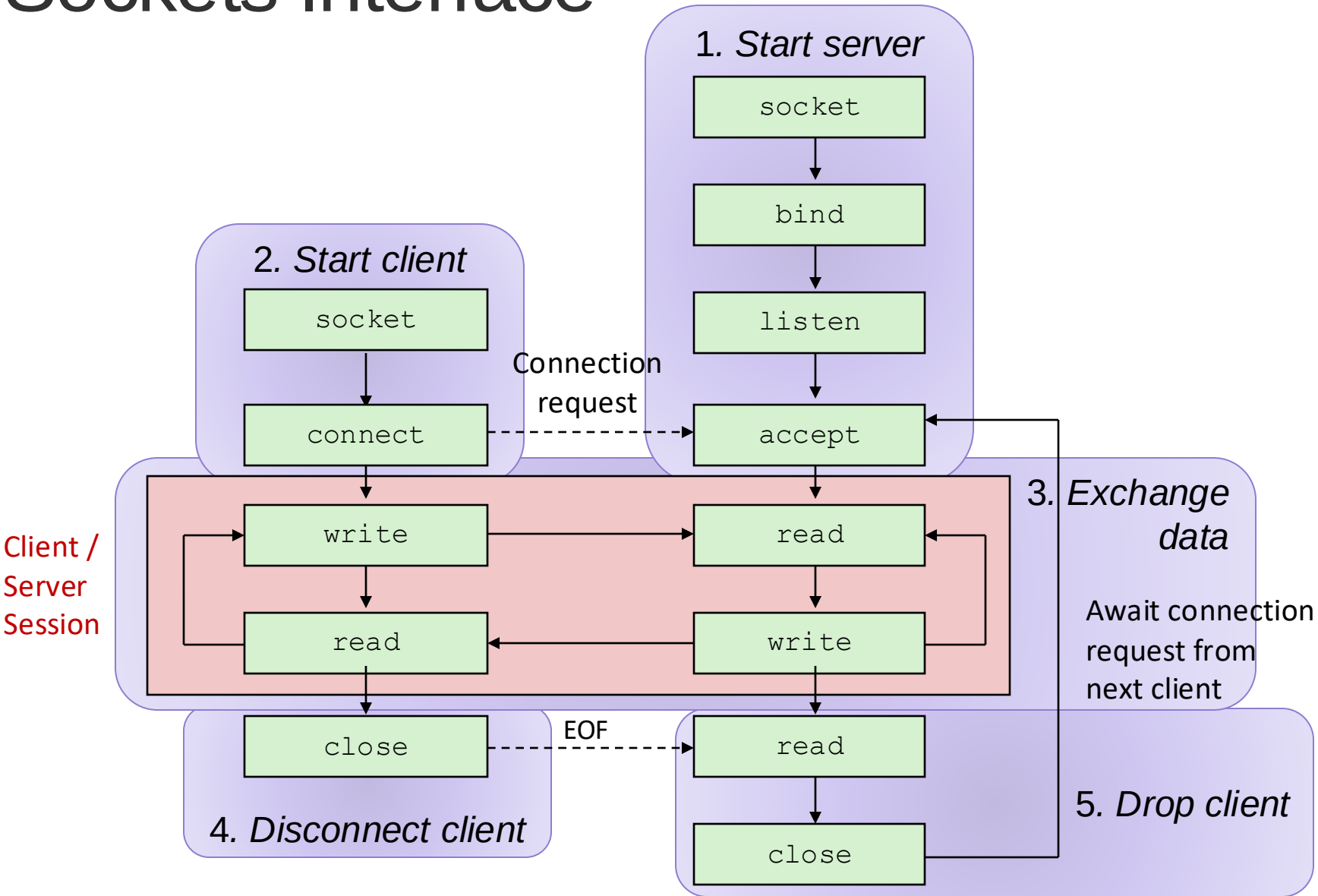




Exercise: TCP Window Size

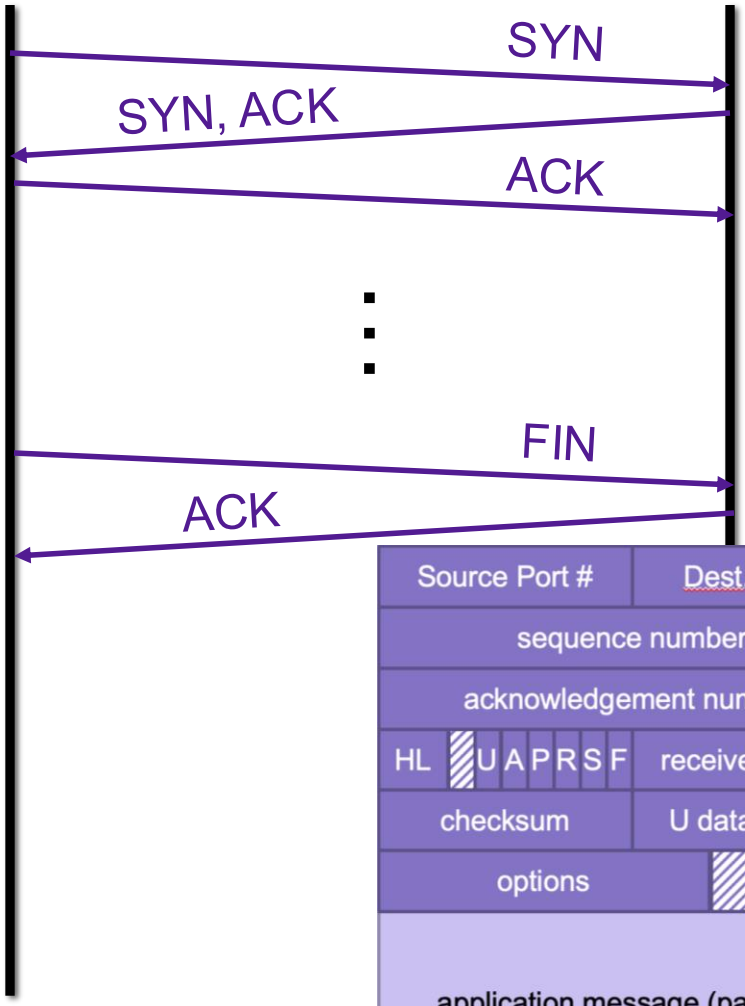
- Assume someone changes the code of their TCP client by modifying the congestion avoidance as follows: instead of increasing the window size by 1 each time an ACK is received, they double the window size each time an ACK is received (like in the slow-start phase).
- What would be the pros and cons of this modification?

Sockets Interface



TCP Connections

- TCP is connection-oriented
- A connection is initiated with a three-way handshake
- Recall: server will typically create a new socket to handle the new connection
- FIN works (mostly) like SYN but to teardown a connection



TCP Summary

- Reliable, in-order message delivery
- Connection-oriented, three-way handshake
- Transmission window for better throughput
  - timeouts based on link parameters (e.g., RTT, variance)
- Congestion control
  - Linear increase, exponential backoff
- Fast adaptation
  - Exponential increase in the initial phase