Introduction to Computer Networks

CS640

Transport Introduction

https://pages.cs.wisc.edu/~mgliu/CS640/F22/

Ming Liu
mgliu@cs.wisc.edu

Today

Last lecture

- How to address some limitations in the IP layer?

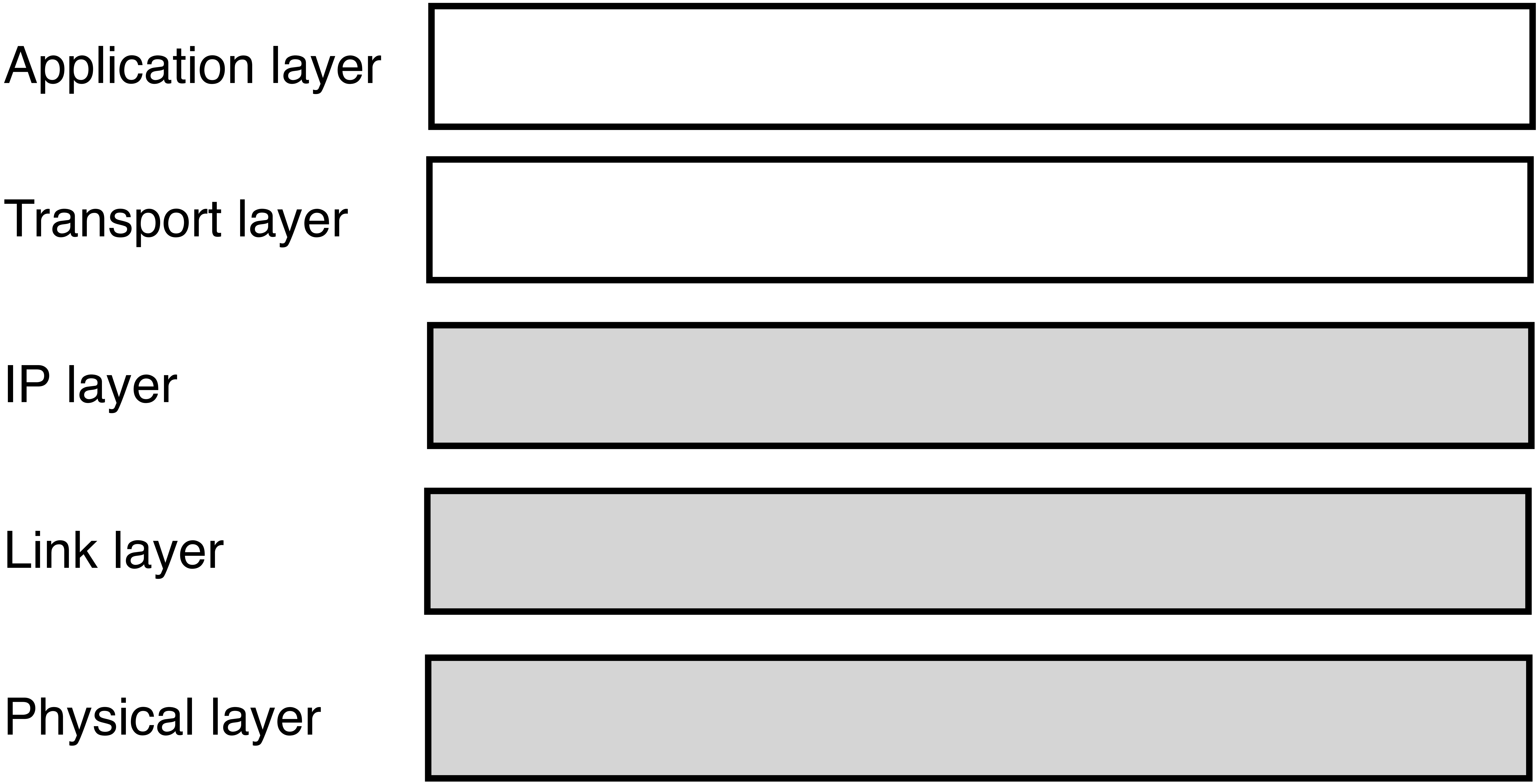
Today

- What functionalities does the transport layer provide?

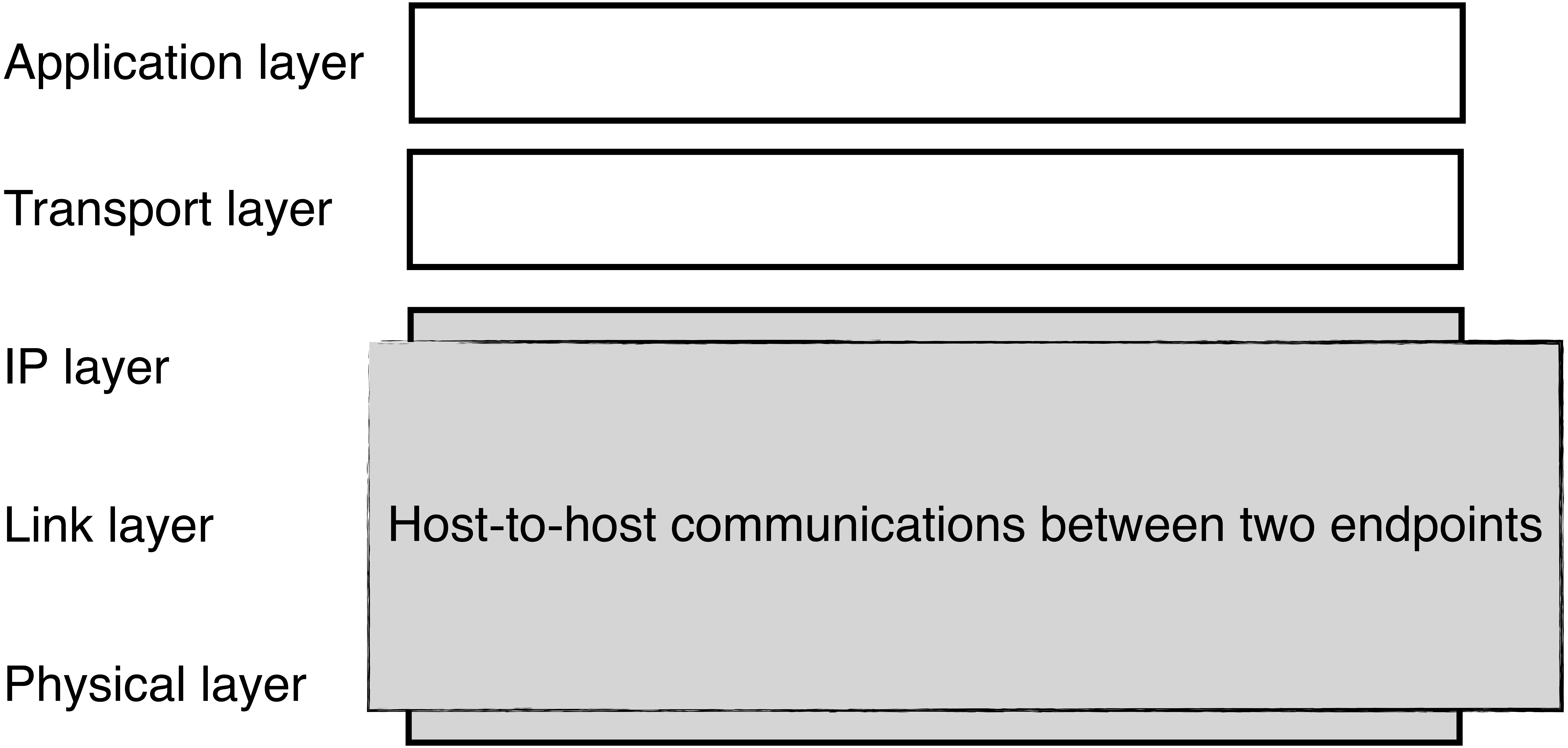
Announcements

- Lab3 is due 11/04/2022, 11:59 PM
- Quiz3 next Tuesday

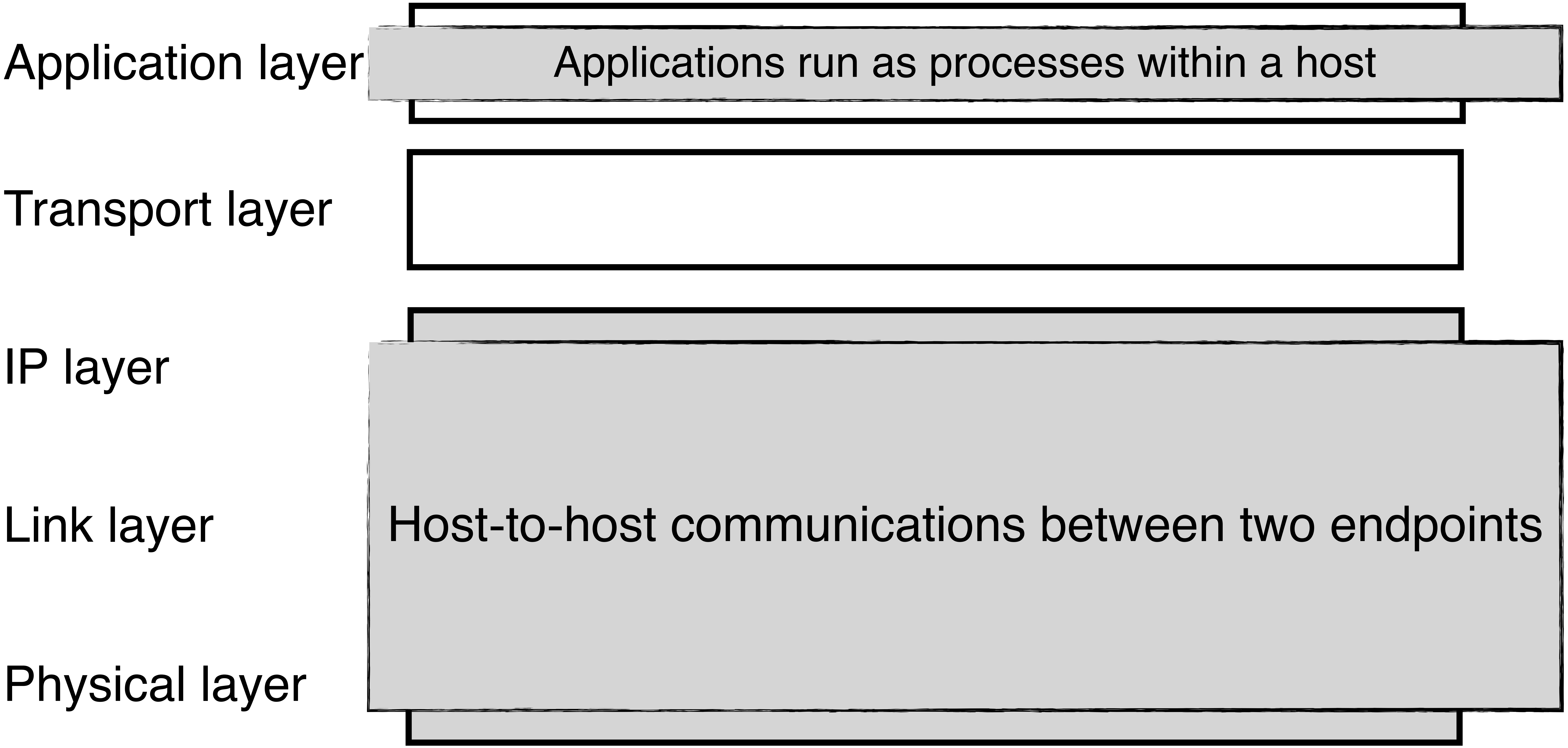
Transport Layer in the TCP/IP Model



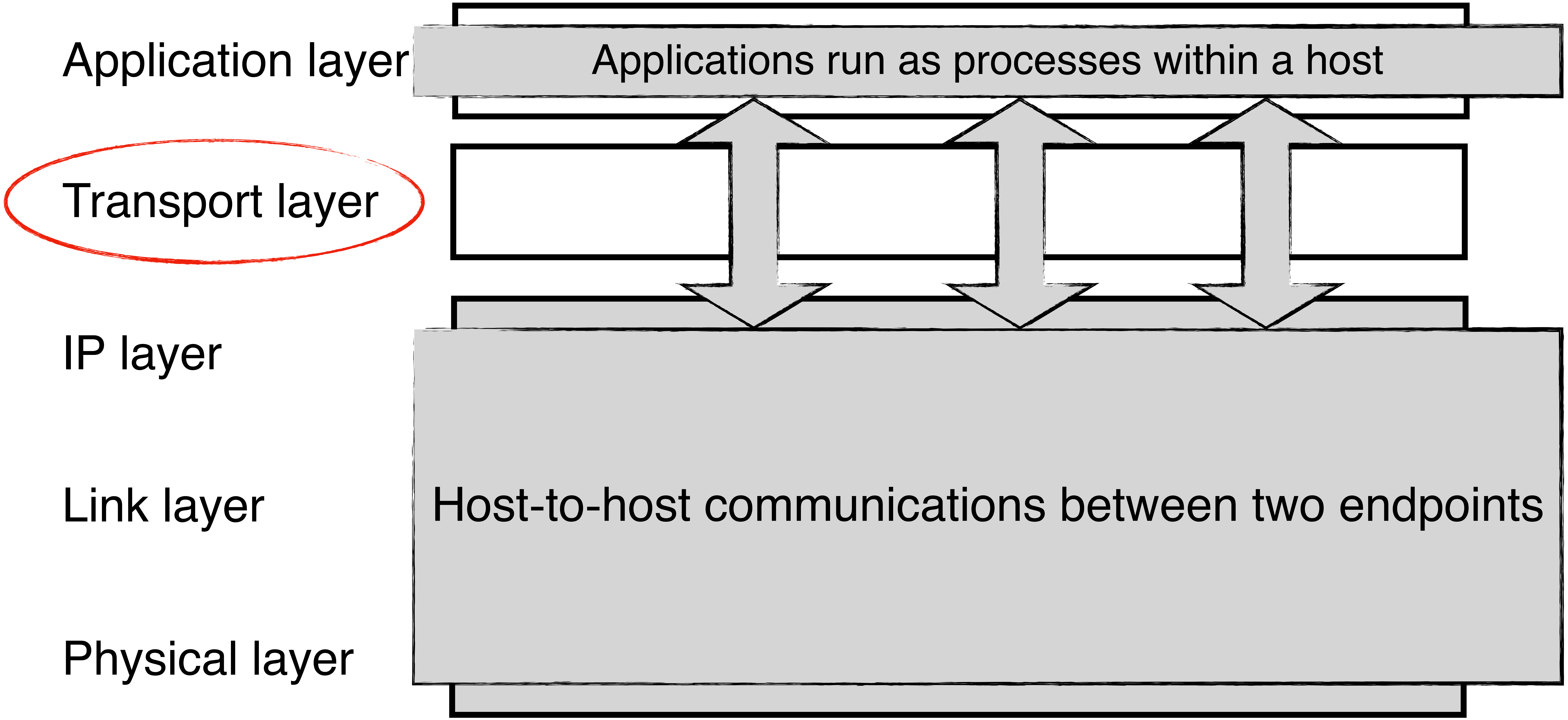
Transport Layer in the TCP/IP Model



Transport Layer in the TCP/IP Model



Transport Layer in the TCP/IP Model



Q: What functionalities does the transport layer provide?

Q: What functionalities does the transport layer provide?

A: Process-to-process communication channels

System Model

Design requirements

- Support arbitrarily large message
- Support multiple application processes on a host (multiplexing)
- Support message delivery with certain guarantees
  - Packet order
  - Exact one copy
  - …

Limitations

- Fixed-sized socket buffer in the OS
- Fixed-sized data transmission unit in the network
- Computing and communication entities run at different speeds

System Model

Design requirements

- Support arbitrarily large message
- Support multiple application processes on a host (multiplexing)
- Support message delivery with certain guarantees
  - Packet order

Challenge: underlying network (IP) is best-effort

- Fixed-sized socket buffer in the OS
- Fixed-sized data transmission unit in the network
- Computing and communication entities run at different speeds

Q: What functionalities does the transport layer provide?

A: Process-to-process communication channels

Q1: How to set up the process-to-process channel?
Q2: How to multiplex concurrent channels over the physical link?
Q3: How to control the transmission rate?
Q4: How to achieve reliability delivery?
Q5: How to share the in-network bandwidth resources?

User Datagram Protocol (UDP)

Extend the IP service model into a process-to-process communication service

- Best-effort
- Unreliable and unordered datagram service

User Datagram Protocol (UDP)

Extend the IP service model into a process-to-process communication service

- Best-effort
- Unreliable and unordered datagram service

UDP is a simple message-oriented transport protocol that is documented in RFC 768

- #1: Add multiplexing/demultiplexing
- #2: Add reliability through optional checksum

Demultiplexing Key: Port

Ports are numeric locators which enable messages to be demultiplexed to proper processes

- Ports are addresses on individual hosts, not across the Internet

Demultiplexing Key: Port

Ports are numeric locators which enable messages to be demultiplexed to proper processes

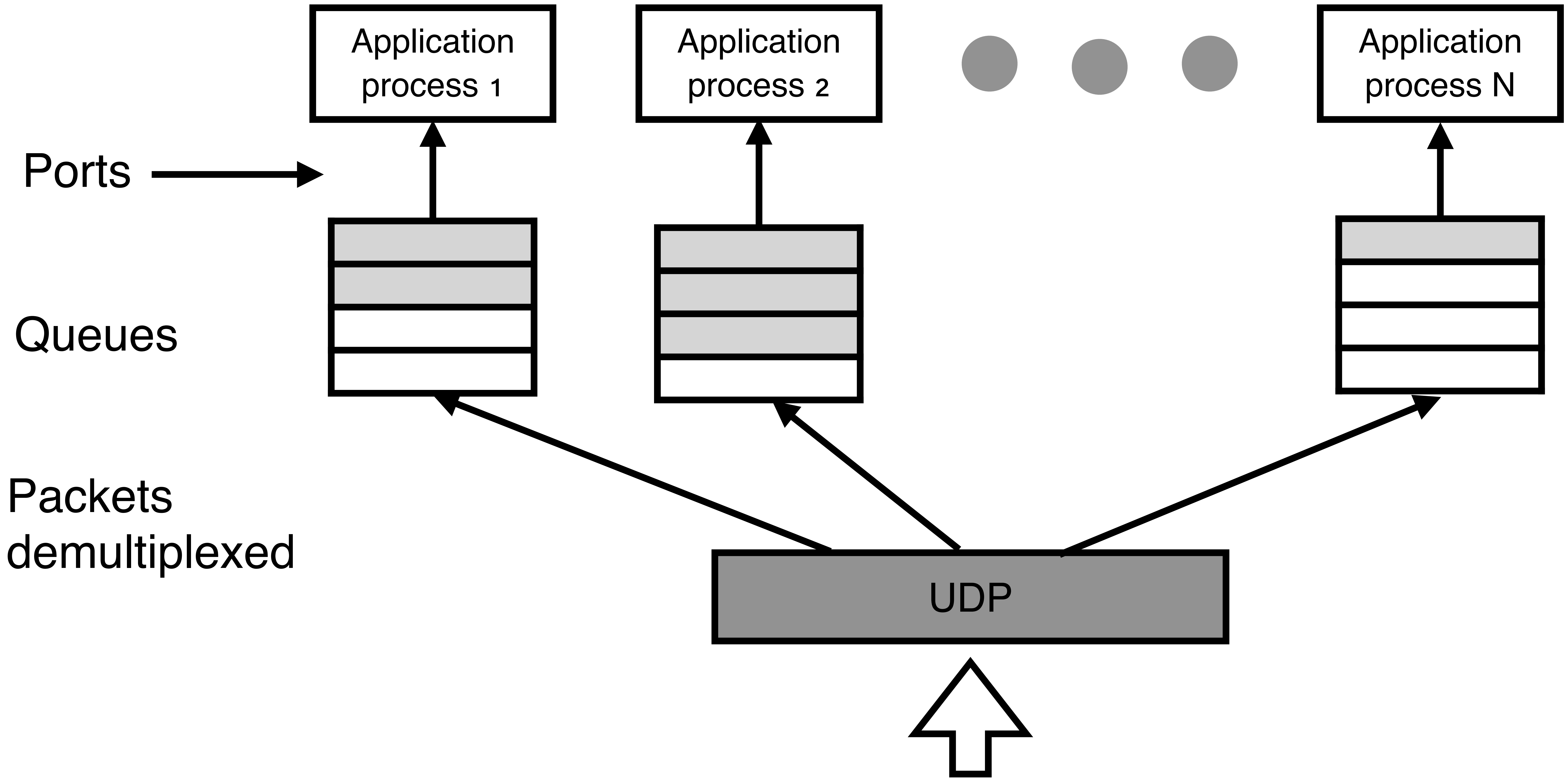
- Ports are addresses on individual hosts, not across the Internet

How to learn the port?

- #1: Servers have well-know ports
  - Port 53= DNS
  - See /etc/services on Unix
- #2: Port mapper service
  - Dynamically allocated

Ports: A System Perspective

Ports are implemented as message queues



UDP Header Format

0	16 31
SrcPort	DstPort
Checksum	Length

- Port: 65536 possible ports
- Length: 65535 bytes (8 bytes header + 65527 bytes data)

UDP Checksum

Optional in current Internet

UDP uses the same checksum algorithm as IP

- Internet checksum

UDP Checksum

Optional in current Internet

UDP uses the same checksum algorithm as IP

- Internet checksum

UDP checksum is computed over **pseudo header** + UDP header + data

UDP Checksum

Optional in current Internet

The psuedo header consists 3 fields from the IP header: protocol number (TCP or UDP), IP src, IP dst, and UDP length field

- The pseudo header enables verification that message was delivered between the correct source and destination
- IP dest address was changed during delivery, checksum would reflect this

UDP checksum is computed over **pseudo header** + UDP header + data

UDP Checksum Example

	Decimal	Binary	Hex
Source IP	192.168.0.31	1100 0000 1010 1000 0000 0000 0001 1111	C0 A8 00 1F
Destination IP	192.168.0.30	1100 0000 1010 1000 0000 0000 0001 1110	C0 A8 00 1E
UDP protocol	17	0000 0000 0001 0001	00 11
Length	10 = 8 + 2	0000 0000 0000 1010	00 0A
UDP Source Port	20	0000 0000 0001 0100	00 14
UDP Destination Port	10	0000 0000 0000 1010	00 0A
UDP Length	10	0000 0000 0000 1010	00 0A
UDP Data	“Hi”	0100 1000 0110 1001	48 69
Add			
Add carry bit			
One’s complement			

UDP Checksum Example

	Decimal	Binary	Hex
Source IP	192.168.0.31	1100 0000 1010 1000 0000 0000 0001 1111	C0 A8 00 1F
Destination IP	192.168.0.30	1100 0000 1010 1000 0000 0000 0001 1110	C0 A8 00 1E
UDP protocol	17	0000 0000 0001 0001	00 11
Length	10 = 8 + 2	0000 0000 0000 1010	00 0A
UDP Source Port	20	0000 0000 0001 0100	00 14
UDP Destination Port	10	0000 0000 0000 1010	00 0A
UDP Length	10	0000 0000 0000 1010	00 0A
UDP Data	“Hi”	0100 1000 0110 1001	48 69
Add		1 1100 1010 0011 1001	1 CA 39
Add carry bit		1100 1010 0011 1001 + 1	CA39 + 0001 = CA3A
One’s complement		0011 0101 1100 0101	35C5

UDP in Linux

```
UDP(7)                    Linux Programmer's Manual                   UDP(7)
```

NAME top

```
       udp - User Datagram Protocol for IPv4
```

SYNOPSIS top

```
       #include <sys/socket.h>
       #include <netinet/in.h>
       #include <netinet/udp.h>

       udp_socket = socket(AF_INET, SOCK_DGRAM, 0);
```

DESCRIPTION top

```
       This is an implementation of the User Datagram Protocol described
       in RFC 768.  It implements a connectionless, unreliable datagram
       packet service.  Packets may be reordered or duplicated before
       they arrive.  UDP generates and checks checksums to catch
       transmission errors.

       When a UDP socket is created, its local and remote addresses are
       unspecified.  Datagrams can be sent immediately using sendto(2)
       or sendmsg(2) with a valid destination address as an argument.
       When connect(2) is called on the socket, the default destination
       address is set and datagrams can now be sent using send(2) or
       write(2) without specifying a destination address.  It is still
       possible to send to other destinations by passing an address to
       sendto(2) or sendmsg(2).  In order to receive packets, the socket
       can be bound to a local address first by using bind(2).
       Otherwise, the socket layer will automatically assign a free
       local port out of the range defined by
       /proc/sys/net/ipv4/ip_local_port_range and bind the socket to
       INADDR_ANY.
```

```
SEND(2)                   Linux Programmer's Manual                   SEND(2)
```

NAME top

```
       send, sendto, sendmsg - send a message on a socket
```

SYNOPSIS top

```
       #include <sys/socket.h>

       ssize_t send(int sockfd, const void *buf, size_t len, int flags);
       ssize_t sendto(int sockfd, const void *buf, size_t len, int flags,
                      const struct sockaddr *dest_addr, socklen_t addrlen);
       ssize_t sendmsg(int sockfd, const struct msghdr *msg, int flags);
```

```
RECV(2)                   Linux Programmer's Manual                   RECV(2)
```

NAME top

```
       recv, recvfrom, recvmsg - receive a message from a socket
```

SYNOPSIS top

```
       #include <sys/socket.h>

       ssize_t recv(int sockfd, void *buf, size_t len, int flags);
       ssize_t recvfrom(int sockfd, void *restrict buf, size_t len, int flags,
                        struct sockaddr *restrict src_addr,
                        socklen_t *restrict addrlen);
       ssize_t recvmsg(int sockfd, struct msghdr *msg, int flags);
```

UDP in Practice

Minimal specification makes UDP very flexible

- And end-to-end protocol can be built atop of UDP

Examples:

- Most commonly used in multimedia applications
- RPCs
- Many others

UDP in Practice

Minimal spec

- And end-to-end p

Examples:

- Most commonly u
- RPCs
- Many others

The QUIC Transport Protocol: Design and Internet-Scale Deployment

Adam Langley, Alistair Riddoch, Alyssa Wilk, Antonio Vicente, Charles Krasic, Dan Zhang, Fan Yang, Fedor Kouranov, Ian Swett, Janardhan Iyengar, Jeff Bailey, Jeremy Dorfman, Jim Roskind, Joanna Kulik, Patrik Westin, Raman Tenneti, Robbie Shade, Ryan Hamilton, Victor Vasiliev, Wan-Teh Chang, Zhongyi Shi *
Google
quic-sigcomm@google.com

ABSTRACT

We present our experience with QUIC, an encrypted, multiplexed, and low-latency transport protocol designed from the ground up to improve transport performance for HTTPS traffic and to enable rapid deployment and continued evolution of transport mechanisms. QUIC has been globally deployed at Google on thousands of servers and is used to serve traffic to a range of clients including a widely-used web browser (Chrome) and a popular mobile video streaming app (YouTube). We estimate that 7% of Internet traffic is now QUIC. We describe our motivations for developing a new transport, the principles that guided our design, the Internet-scale process that we used to perform iterative experiments on QUIC, performance improvements seen by our various services, and our experience deploying QUIC globally. We also share lessons about transport design and the Internet ecosystem that we learned from our deployment.

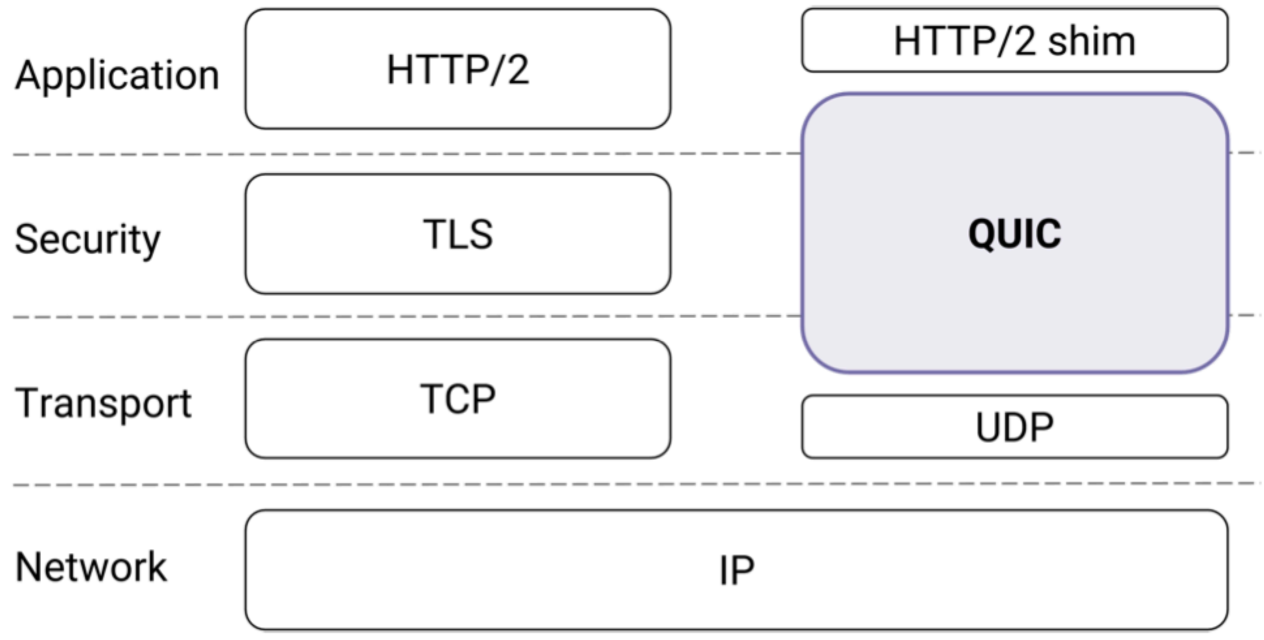


Figure 1: QUIC in the traditional HTTPS stack.

TCP (Figure 1). We developed QUIC as a user-space transport with UDP as a substrate. Building QUIC in user-space facilitated its deployment as part of various applications and enabled iterative

[1] The QUIC Transport Protocol: Design and Internet-Scale Deployment, Sigcomm'17

How does UDP address the following issues?

Q1: How to set up the process-to-process channel?
Q2: How to multiplex concurrent channels over the physical link?
Q3: How to control the transmission rate?
Q4: How to achieve reliability delivery?
Q5: How to share the in-network bandwidth resources?

UDP Issues

#1: Arbitrary communication

- Senders and receivers can talk to each other in any ways

#2: No reliability guarantee

- Packets can be lost/duplicated/reordered during transmission
- Checksum is not enough

#3: No resource management

- Each communication channel works as an exclusive network resource owner
- No adaptiveness support for the physical networks and applications

Transmission Control Protocol (TCP) — RFC793

TCP is the most widely used Internet protocol

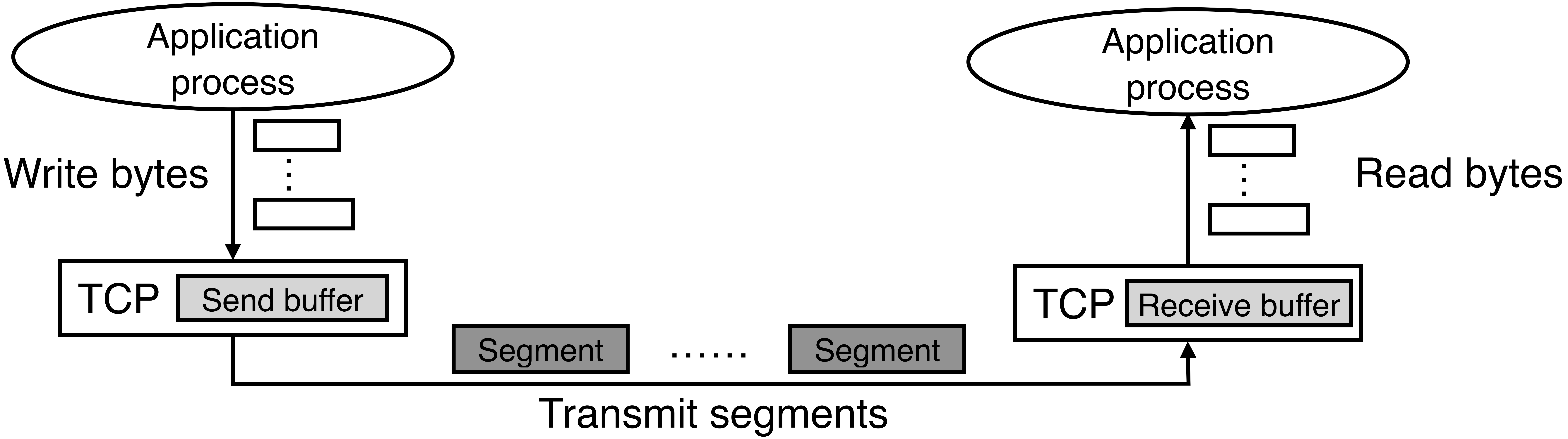
A two-way, reliable, byte stream oriented protocol

Closely tied to the Internet Protocol (IP)

TCP Features

#1: Connection-oriented

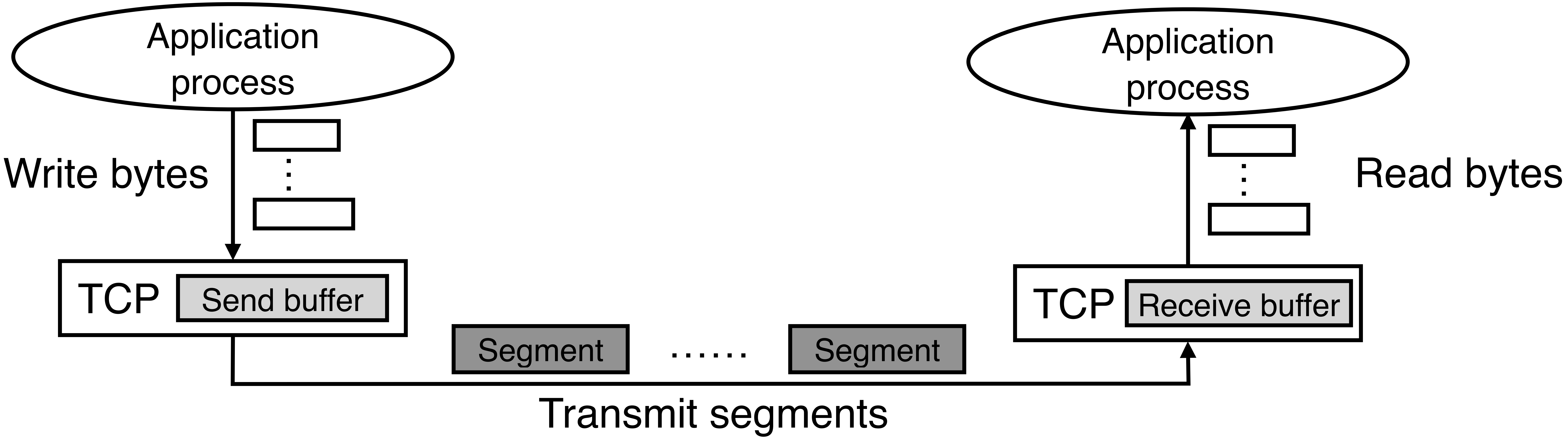
- Communication happens after the connection is established



TCP Features

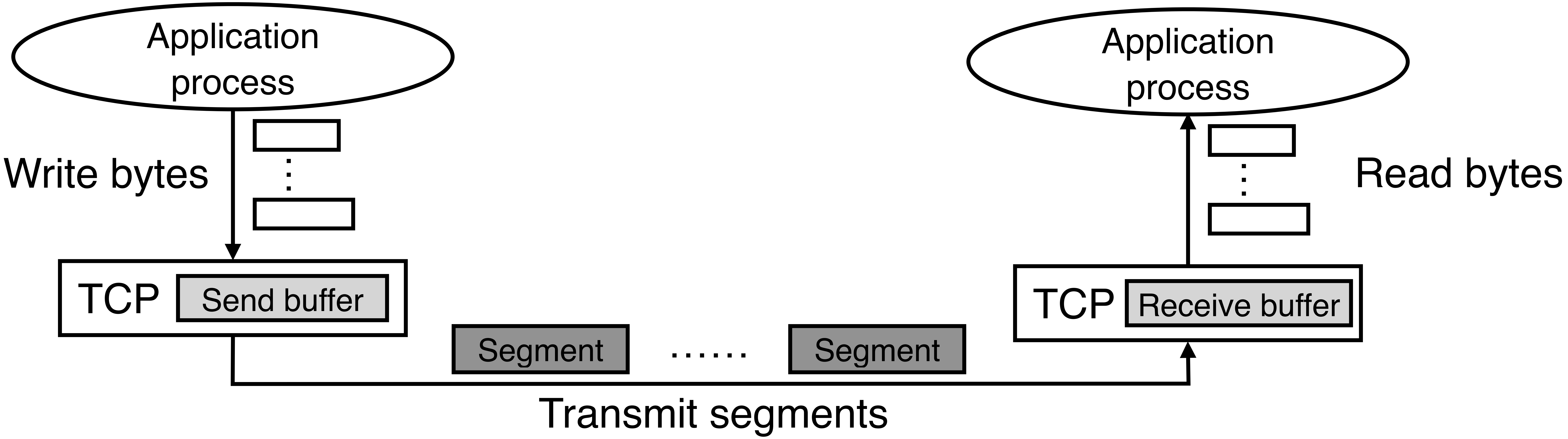
#2: Byte-stream

- Apps write/read bytes
- TCP sends segments



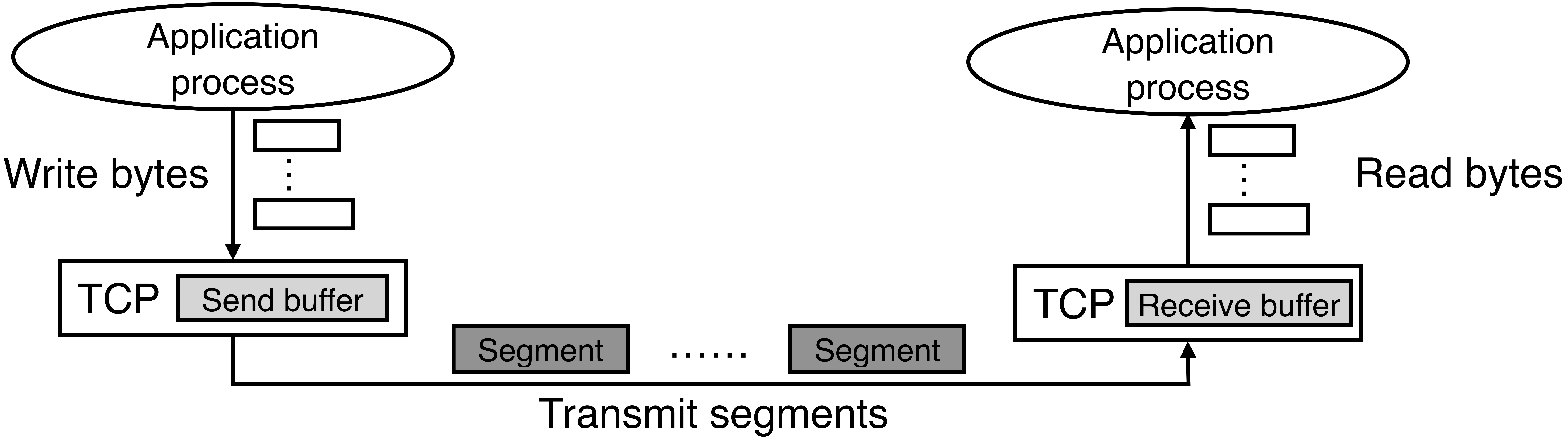
TCP Features

#3: Two-way communication (duplex)



TCP Features

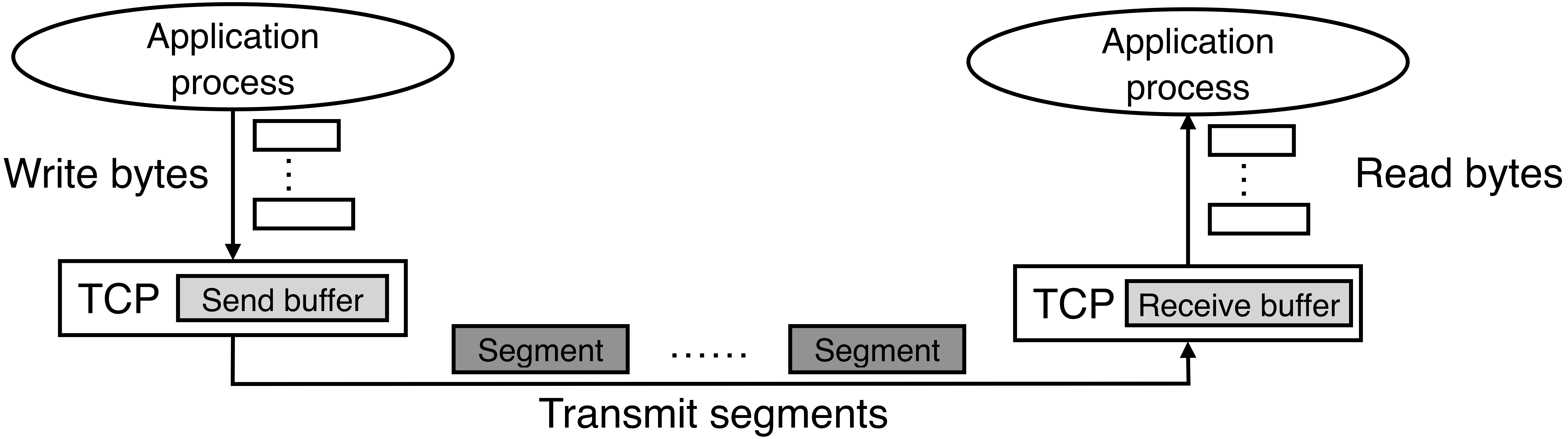
#4: keep sender from over-running receiver (flow control)



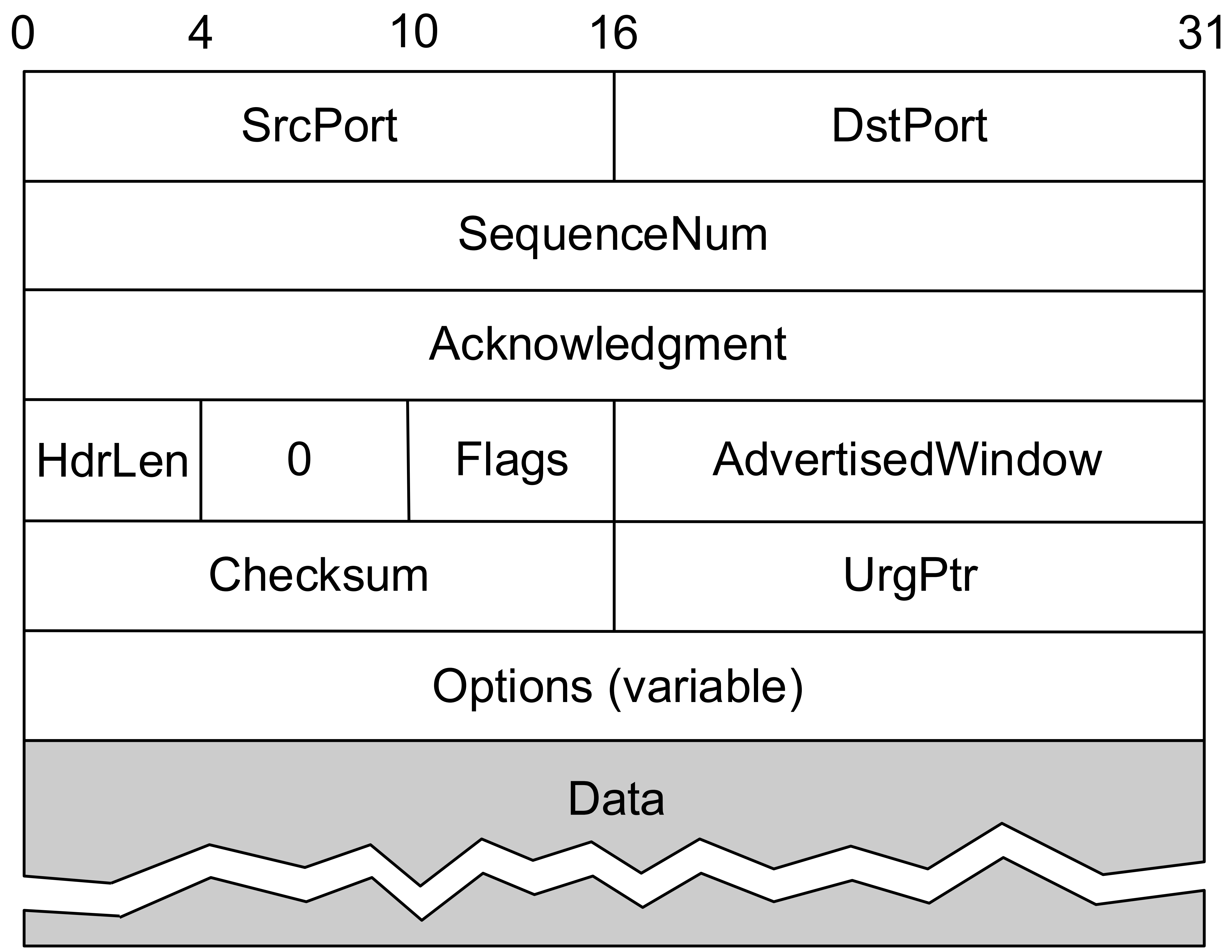
TCP Features

#5: keep sender from over-running network

(congestion control)



TCP Header Format



Terminology

1. Host
2. NIC
3. Multi-port I/O bridge
4. Protocol
5. RTT
6. Packet
7. Header
8. Payload
9. BDP
10. Baud rate
11. Frame/Framing
12. Parity bit
13. Checksum
14. Ethernet
15. MAC
16. (L2) Switch
17. Broadcast
18. Acknowledgement
19. Timeout
20. Datagram
21. TTL
22. MTU
23. Best effort
24. (L3) Router
25. Subnet mask
26. CIDR
27. Converge
28. Count-to-infinity
29. Line card
30. Network processor
31. Gateway
32. Private network
33. IPv6
34. Multicast
35. IGMP
36. SDN
37. (Transport) port
38. Pseudo header

Principle

1. Layering
2. Minimal States
3. Hierarchy

Technique

1. NRZ Encoding
2. NRZI Encoding
3. Manchester Encoding
4. 4B/5B Encoding
5. Byte Stuffing
6. Byte Counting
7. Bit Stuffing
8. 2-D Parity
9. CRC
10. MAC Learning
11. Store-and-Forward
12. Cut-through
13. Spanning Tree
14. CSMA/CD
15. Stop-and-Wait
16. Sliding Window

16. Fragmentation and Reassembly
17. Path MTU discovery
18. DHCP
19. Subnetting
20. Supernetting
21. Longest prefix match
22. Distance vector routing (RIP)
23. Link state routing (OSPF)
24. Boarder gateway protocol (BGP)
25. Network address translation (NAT)
26. User Datagram Protocol (UDP)
27. Transmission Control Protocol (TCP)

Summary

Today's takeaways

#1: The transport layer provides process-to-process communications channels

#2: UDP offers great flexibility by only providing the multiplexing functionality

Next lecture

- TCP connection management