Lecture 5:

# The Transport Layer

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| | |
|---|---|
| application | web BitTorrent DNS |
| transport | TCP UDP |
| network | IP |
| link | Ethernet |
| physical | |

# Outline

- Interaction with application layer
  - UDP
  - TCP
- Reliable data delivery
  - Imaginary protocol
  - (TCP at the next lecture)

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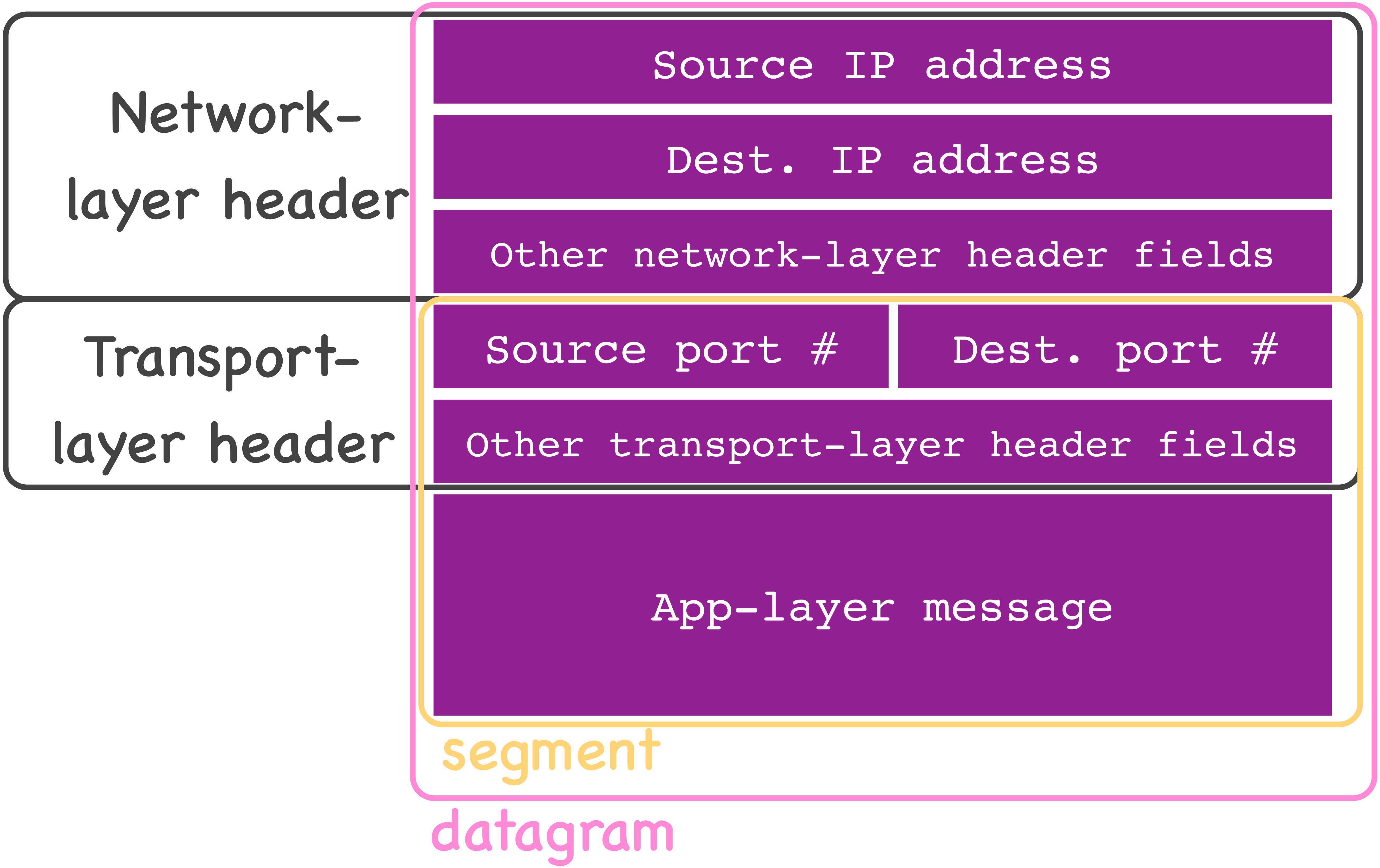

Network-
layer header
Transport-
layer header
Source IP address
Dest. IP address
Other network-layer header fields
Source port #
Dest. port #
Other transport-layer header fields
App-layer message
segment
datagram

application layer

Process S

```
socket = new socket (UDP type)

socket.bind (IP address: 1.1.1.1, port: 1000)

socket.sendto (message, dest. IP address: 5.5.5.5,
                        dest. port: 5000)

socket.close ( )
```

UDP socket

```
for process S

IP address: 1.1.1.1
port: 1000
```

| | |
|---|---|
| Source IP address: 1.1.1.1 | |
| Dest. IP address: 5.5.5.5 | |
| Source port: 1000 | Dest. port: 5000 |
| message | |

transport layer

## application layer

### Process R

```
socket = new socket (UDP type)
socket.bind (IP address: 5.5.5.5, port: 5000)
message = socket.recvfrom (100 bytes)
socket.close ( )
```

### UDP socket

```
for process R

IP address: 5.5.5.5
port: 5000
```

| Source IP address: 1.1.1.1 | |
|---|---|
| Dest. IP address: 5.5.5.5 | |
| Source port: 1000 | Dest. port: 5000 |
| message | |

## transport layer

# UDP sockets

- Each UDP socket has a unique (IP address, port #) tuple
- A process may use the same UDP socket to communicate with many remote processes

## application layer

Process S

```
socket = new socket (TCP type)
socket.bind (IP address: 1.1.1.1, port: 1000)
socket.connect (rem. IP address: 5.5.5.5, rem. port: 5000)
socket.send (message)
socket.close ( )
```

TCP socket

```
for process S

IP address:1.1.1.1
port:1000

rem. IP address:5.5.5.5
rem. port:5000
```

| | |
|---|---|
| Source IP address: 1.1.1.1 | |
| Dest. IP address: 5.5.5.5 | |
| Source port: 1000 | Dest. port: 5000 |
| message | |

## transport layer

application layer

**Process R**

```
socket = new socket (TCP type)
socket.bind (IP address: 5.5.5.5, port: 5000)
socket.listen (for N connections)
connSocket = socket.accept ( )
```

**TCP socket**

for process R

IP address:5.5.5.5
port:5000

listening for N conn.

| | |
|---|---|
| Source IP address: 1.1.1.1 | |
| Dest. IP address: 5.5.5.5 | |
| Source port: 1000 | Dest. port: 5000 |
| connection-setup request | |

transport layer

## application layer

**Process R**

```
socket = new socket (TCP type)
socket.bind (IP address: 5.5.5.5, port: 5000)
socket.listen (for N connections)
connSocket = socket.accept ( )
message = connSocket.recv (100 bytes)
connSocket.close ( )
```

**TCP socket**

```
for process R

IP address:5.5.5.5
port:5000

rem. IP address:1.1.1.1
rem. port:1000
```

| Source IP address: 1.1.1.1 | |
|---|---|
| Dest. IP address: 5.5.5.5 | |
| Source port: 1000 | Dest. port: 5000 |
| message | |

## transport layer

# TCP sockets

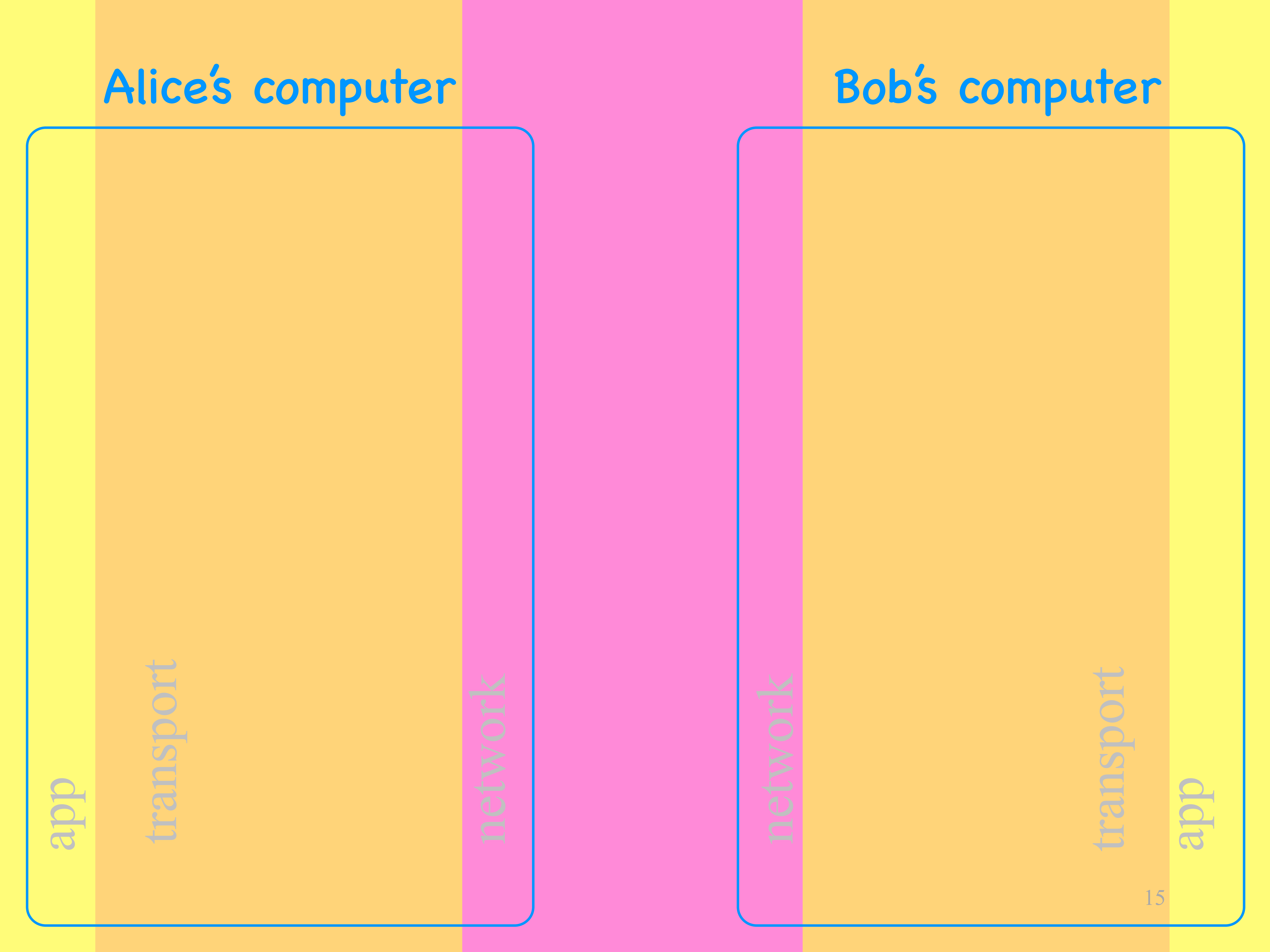
- Listening & connection sockets
- Each connection socket has a unique (local IP, local port, remote IP, remote port) tuple
- A process must use a different TCP connection socket per remote process

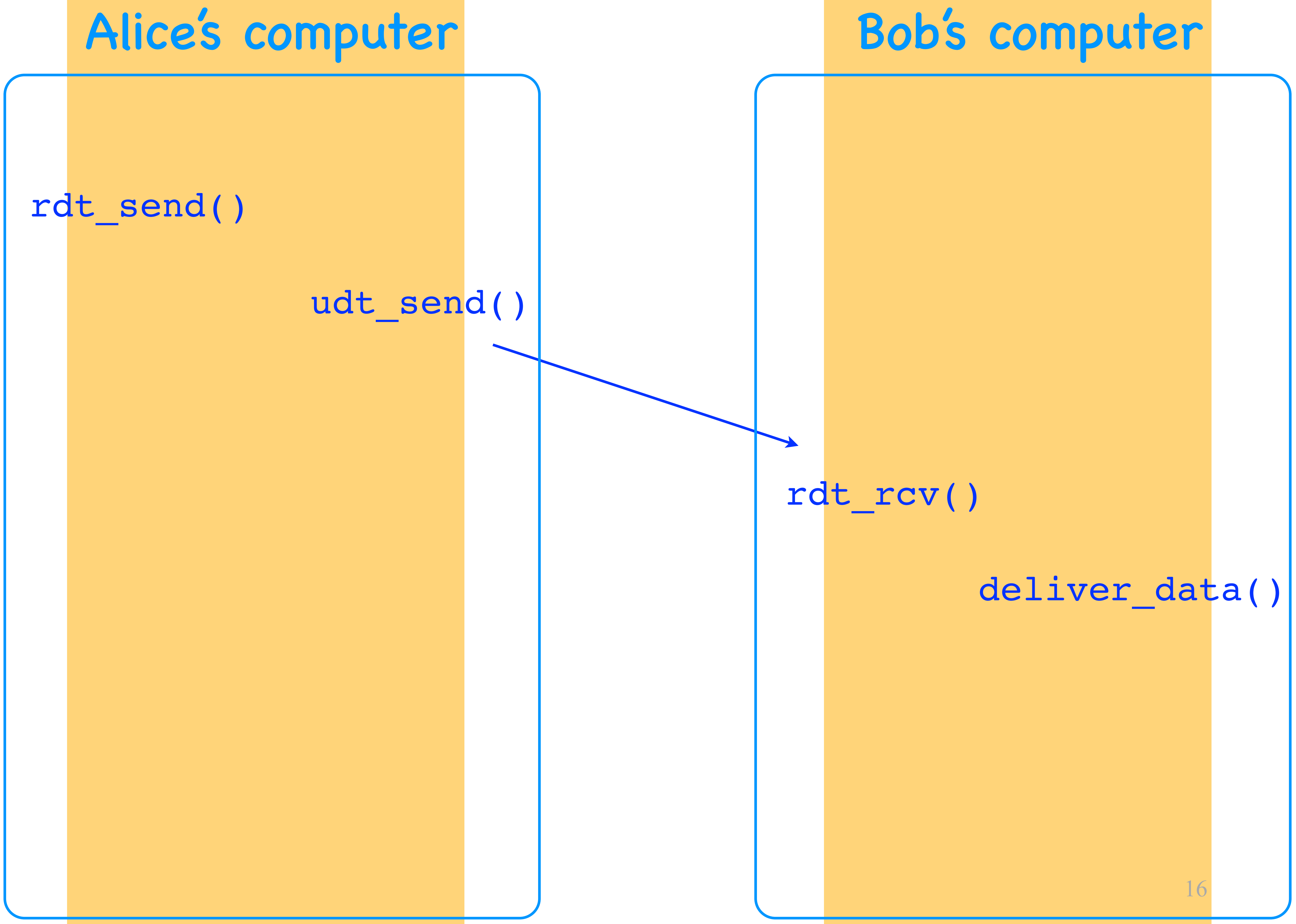
# Interaction with application layer

- Multiplexing
  - upon receiving a new message from a process, create new packets
  - identify the correct IP addresses and ports
- Demultiplexing
  - many processes running in app layer
  - upon receiving a new packet from the network, identify the correct dest. process

# Outline

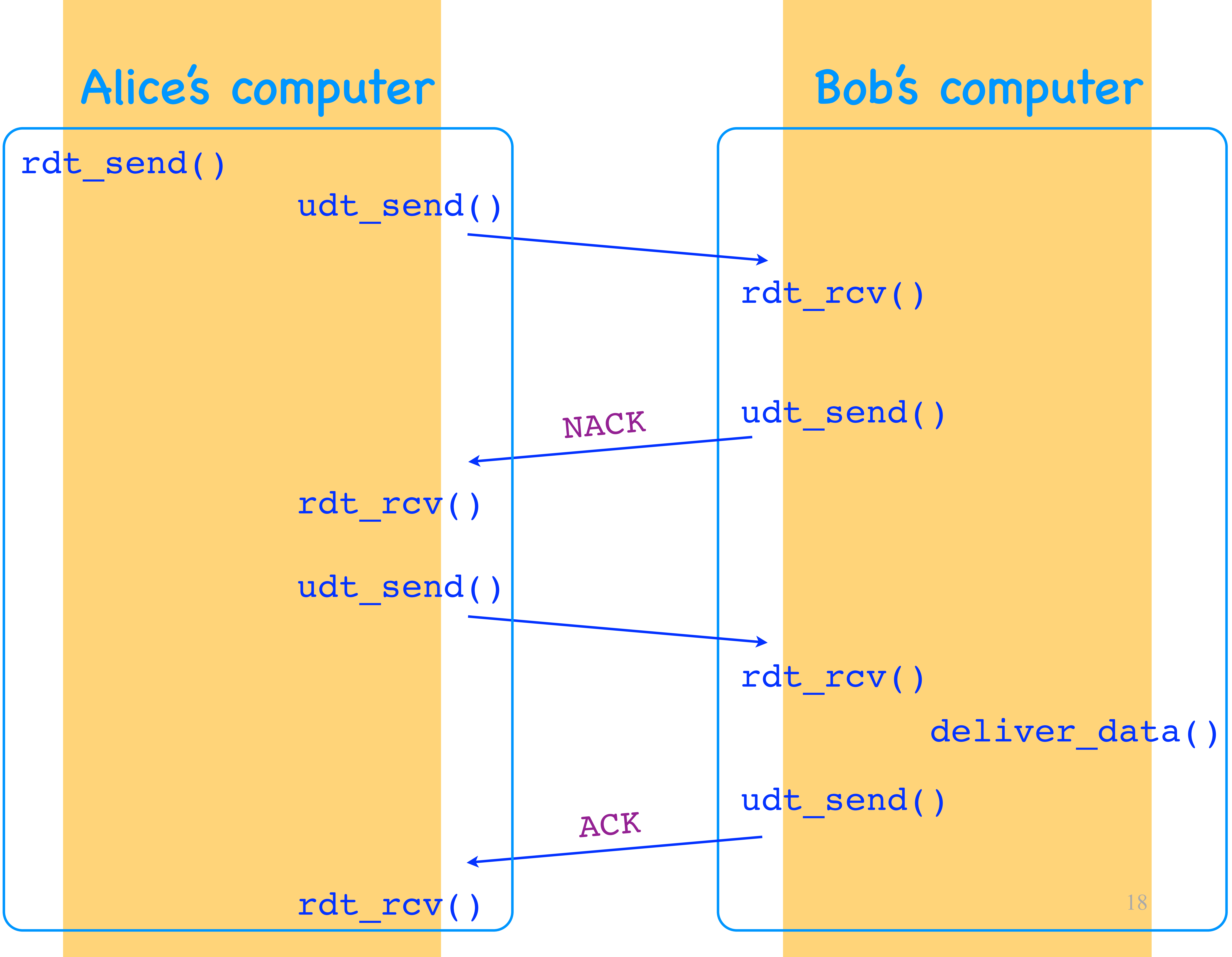
- Interaction with application layer
  - UDP
  - TCP
- Reliable data delivery
  - Imaginary protocol
  - (TCP at the next lecture)


Alice's computer
Bob's computer
app
transport
network
network
transport
app


Alice's computer
Bob's computer
rdt_send()
udt_send()
rdt_rcv()
deliver_data()

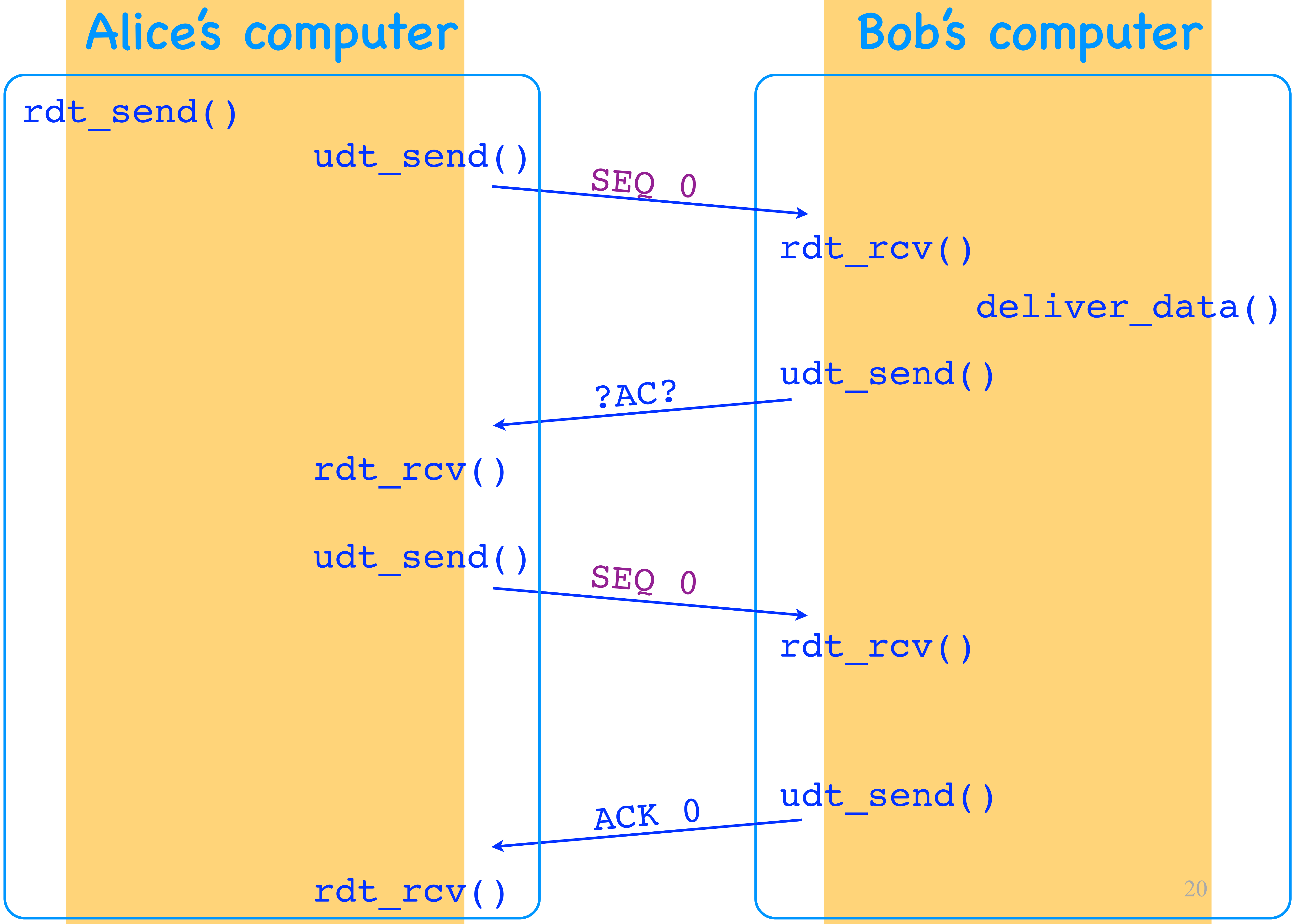
# Checksum

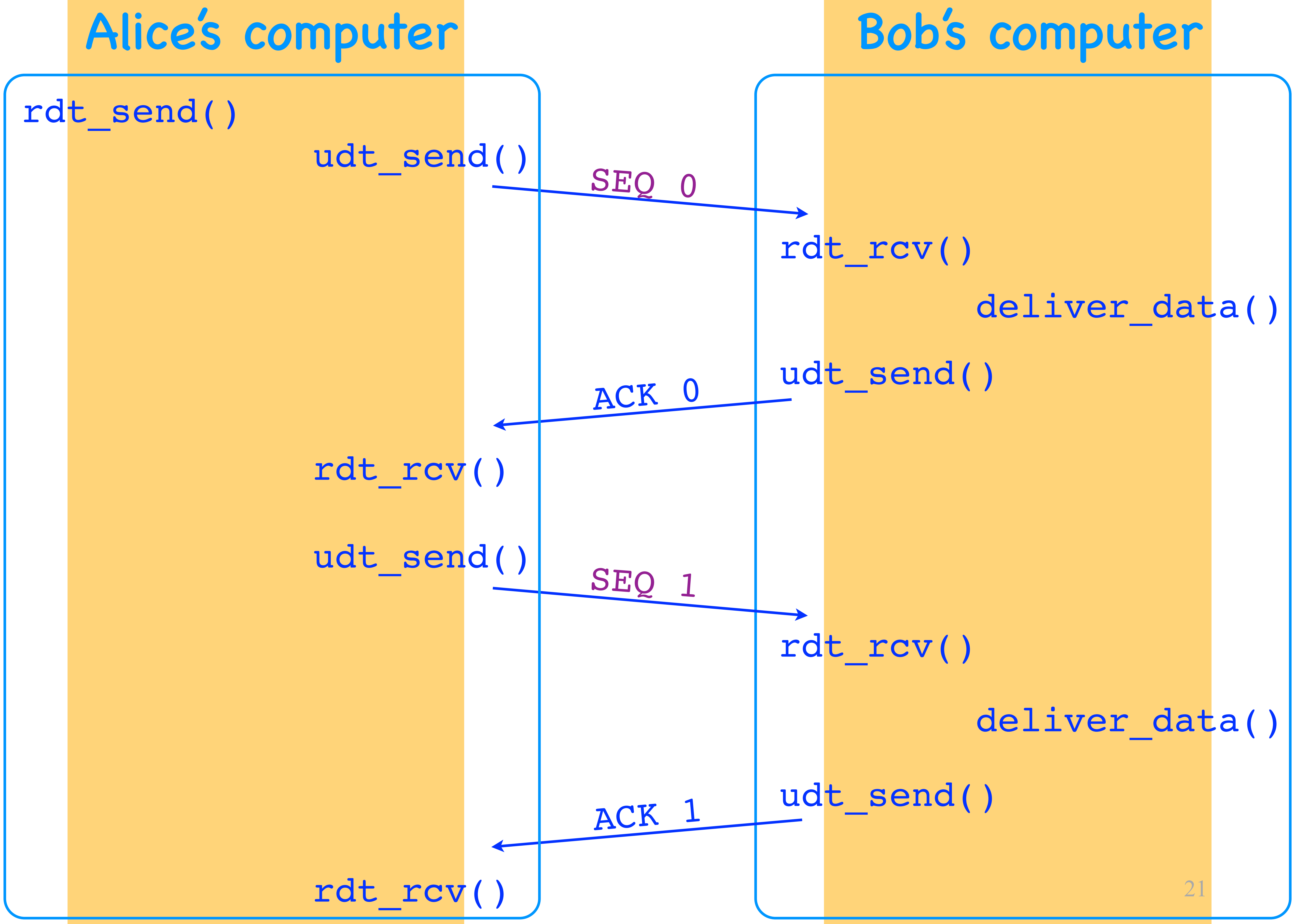
- Redundant information
  - e.g., the binary sum of all data bytes
- Sender adds checksum C to each segment
  - transport-layer header field
- Receiver uses it to detect data corruption
  - receiver recomputes checksum C'
  - if C'!= C, segment was corrupted


Alice's computer
Bob's computer
rdt_send()
udt_send()
rdt_rcv()
udt_send()
NACK
rdt_rcv()
udt_send()
rdt_rcv()
deliver_data()
udt_send()
ACK
rdt_rcv()

# Acknowledgment

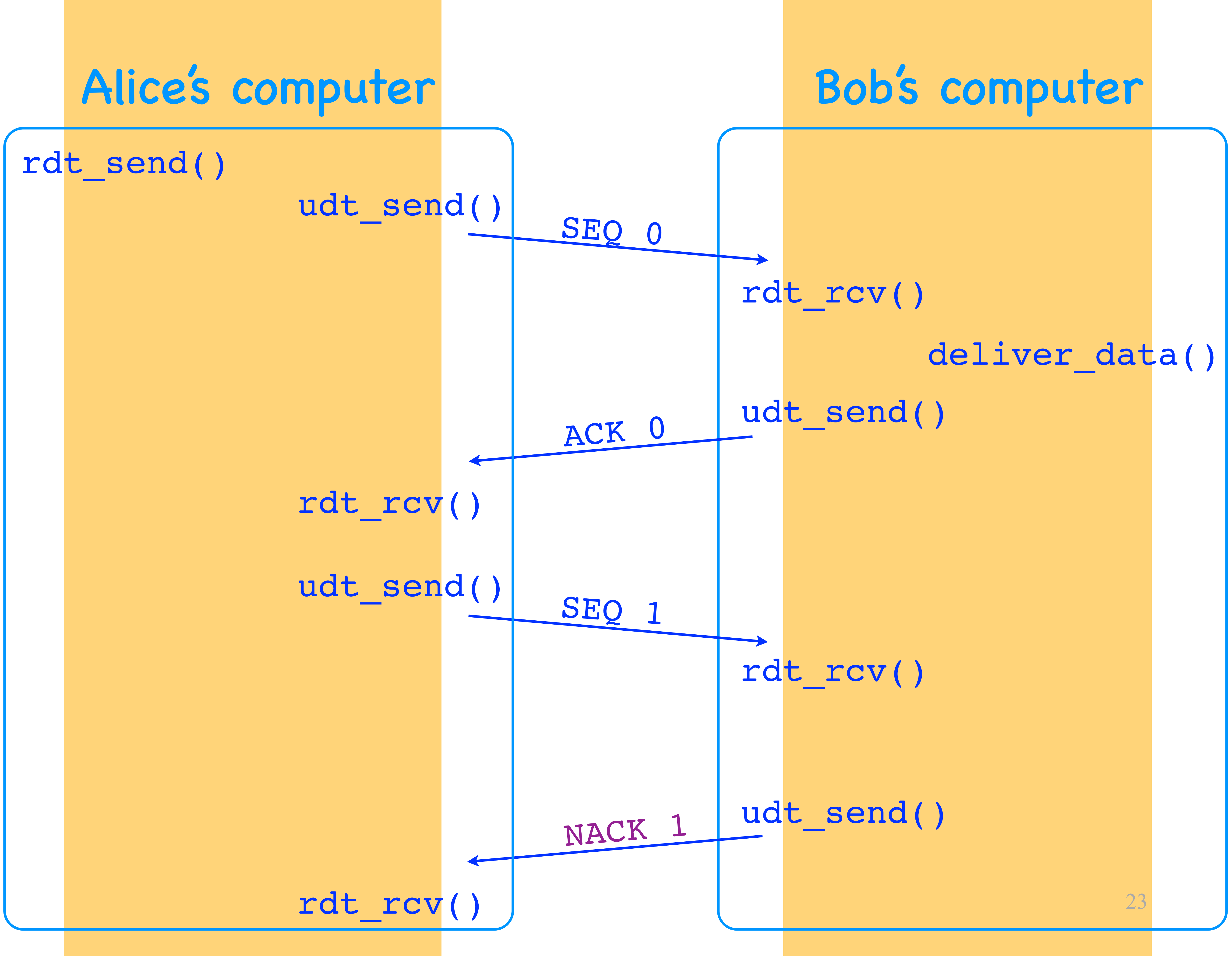
- Feedback from receiver to sender
- Receiver adds ACK to each segment
  - transport-layer header field
- Sender uses it to detect and overcome data corruption
  - if sender gets negative ACK, it retransmits the data

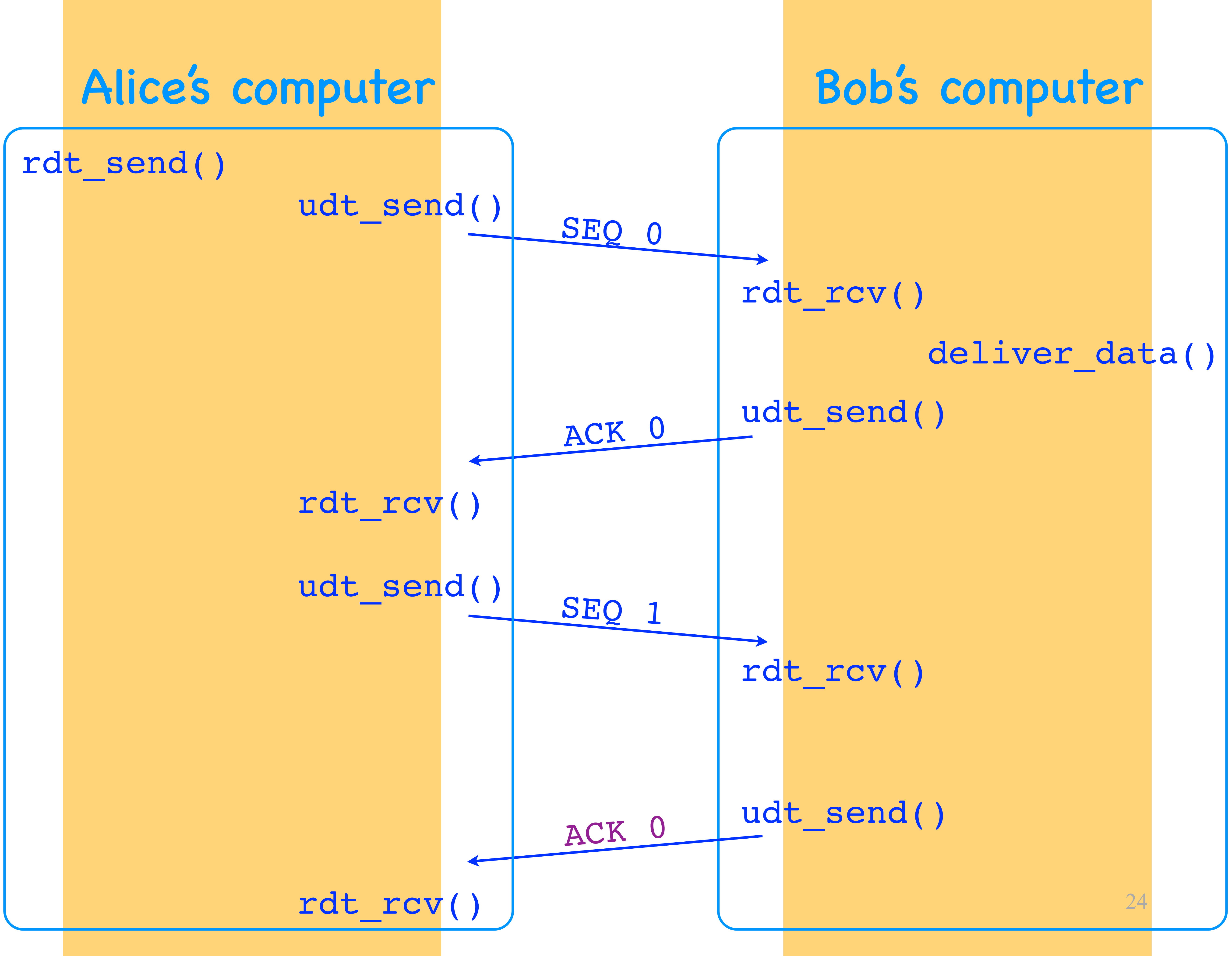

Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
?AC?
rdt_rcv()
udt_send()
SEQ 0
rdt_rcv()
udt_send()
ACK 0
rdt_rcv()

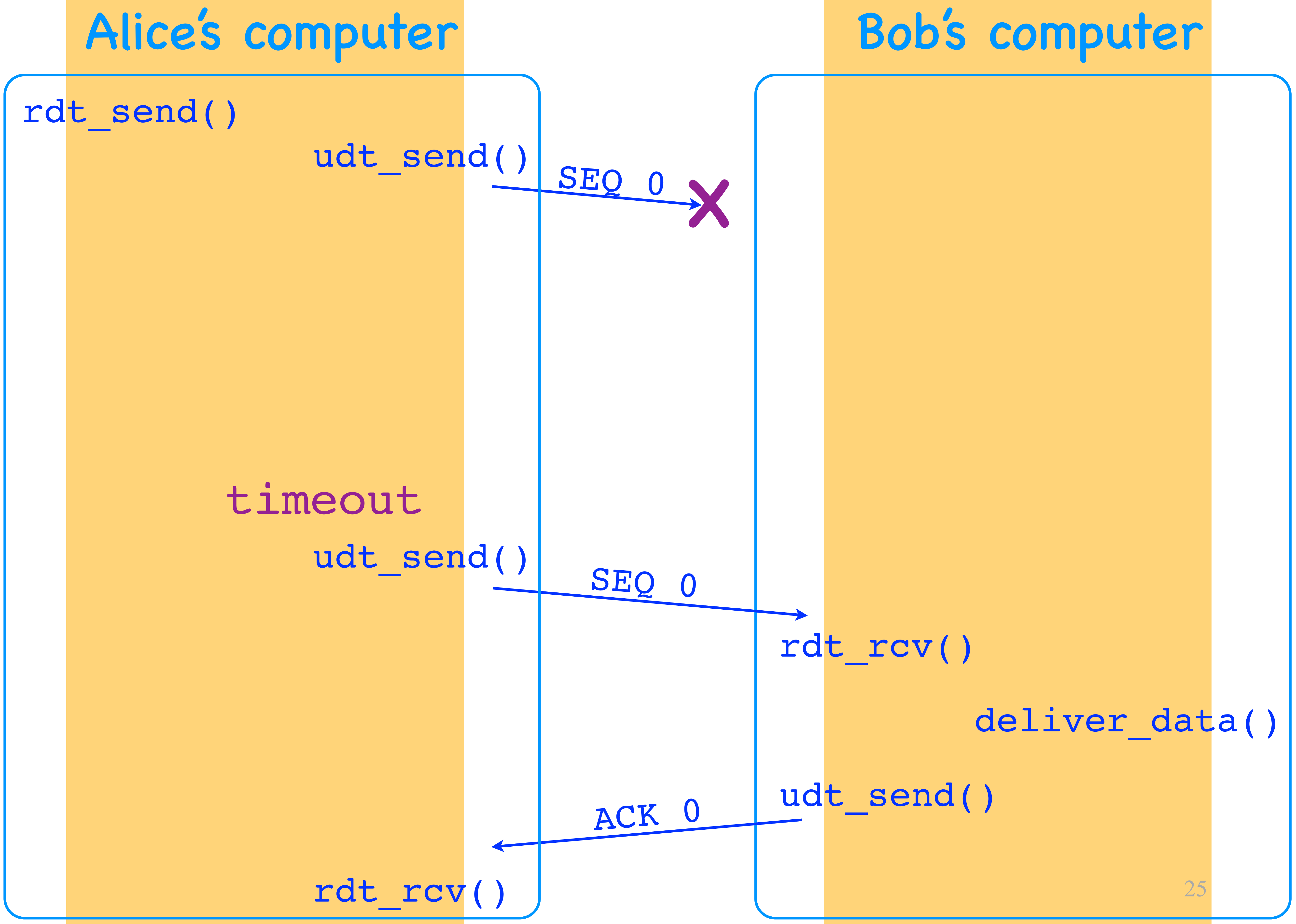

Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
ACK 0
rdt_rcv()
udt_send()
SEQ 1
rdt_rcv()
deliver_data()
udt_send()
ACK 1
rdt_rcv()

# Sequence number

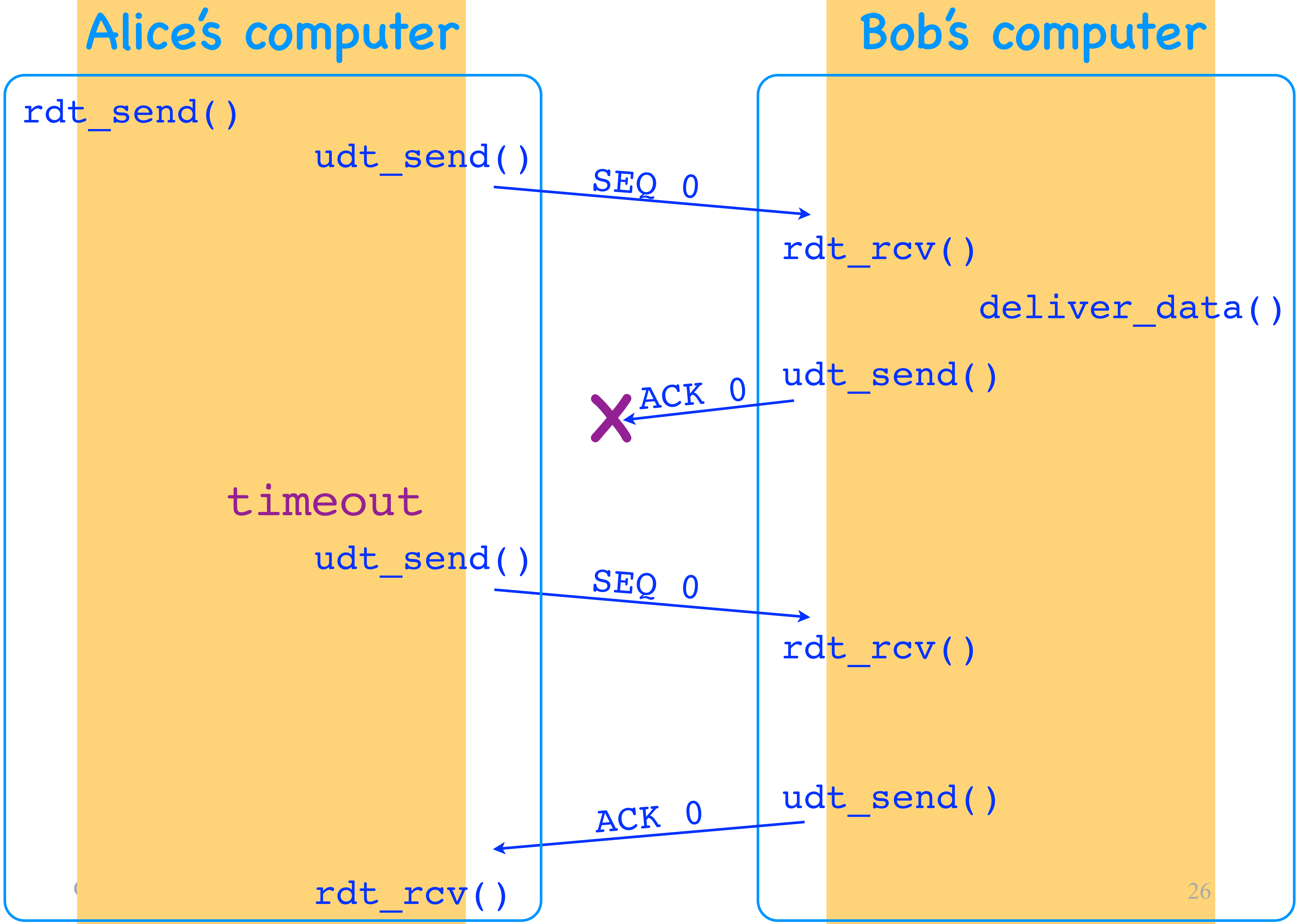
- An identifier for data
- Sender adds SEQ to each segment
  - transport-layer header field
- Receiver uses it to disambiguate data

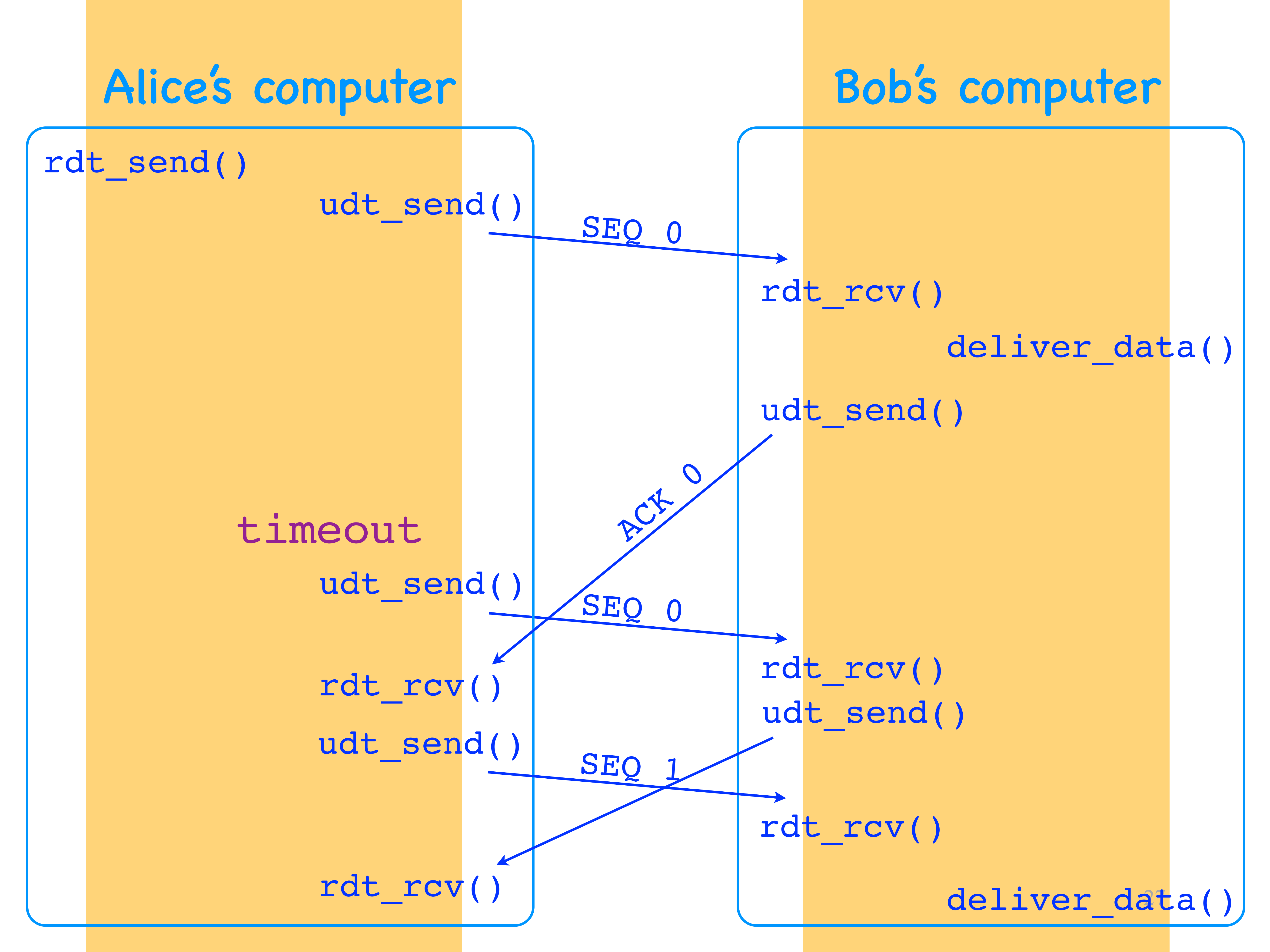

Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
ACK 0
rdt_rcv()
udt_send()
SEQ 1
rdt_rcv()
udt_send()
NACK 1
rdt_rcv()


Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
ACK 0
rdt_rcv()
udt_send()
SEQ 1
rdt_rcv()
udt_send()
ACK 0
rdt_rcv()



Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
timeout
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
ACK 0
rdt_rcv()


Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
ACK 0
timeout
udt_send()
SEQ 0
rdt_rcv()
udt_send()
ACK 0
rdt_rcv()



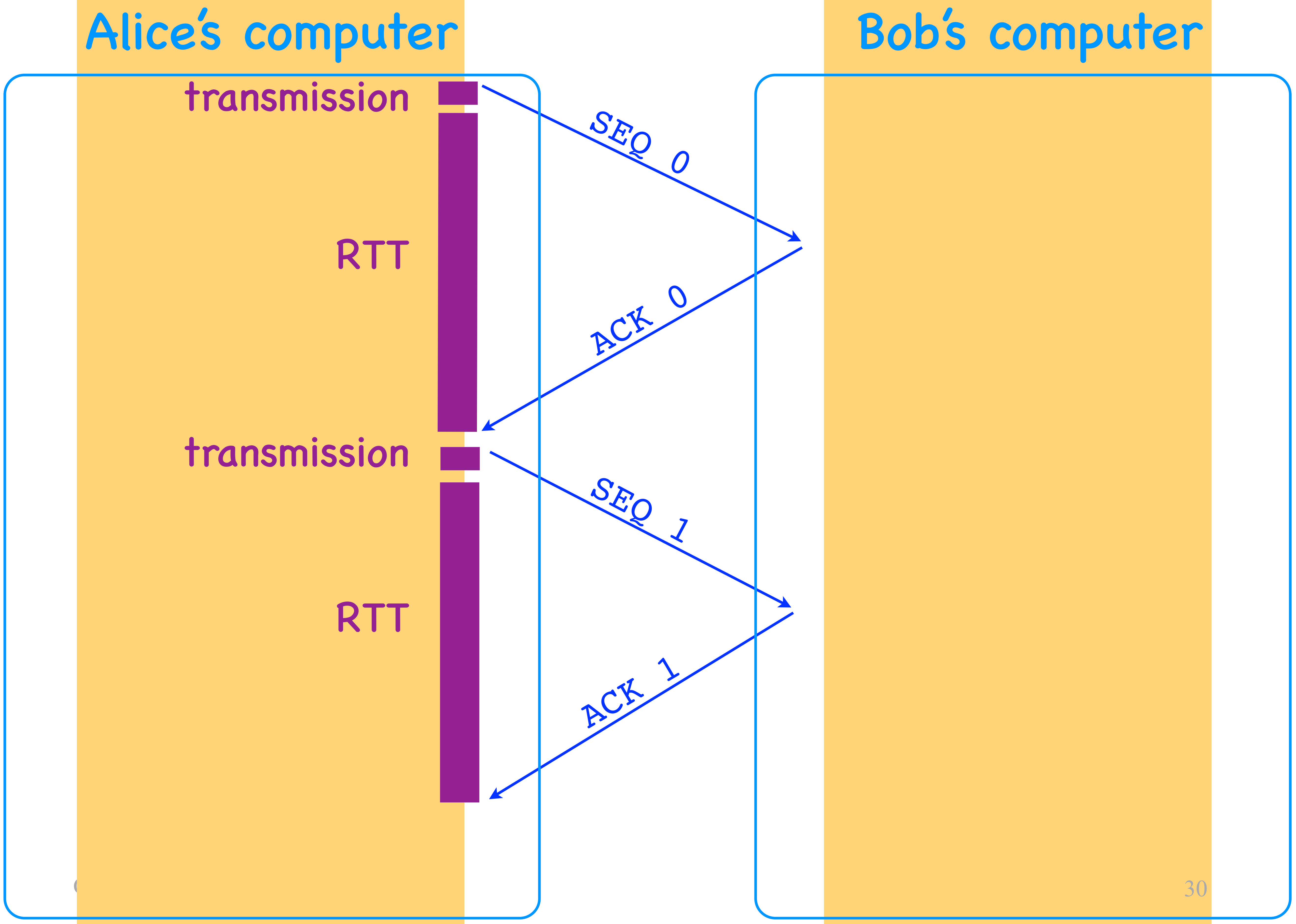
Alice's computer
Bob's computer
rdt_send()
udt_send()
SEQ 0
rdt_rcv()
deliver_data()
udt_send()
ACK 0
timeout
udt_send()
SEQ 0
rdt_rcv()
rdt_rcv()
udt_send()
udt_send()
SEQ 1
rdt_rcv()
rdt_rcv()
deliver_data()

# Timeout

- No arrival of an expected ACK
  - a segment was lost or delayed
  - the ACK for a segment was lost or delayed
- Sender uses it to overcome data loss
  - if the sender times out, it retransmits

# Basic elements

- Checksums
  - detect data corruption
- ACKs + retransmissions + SEQs
  - overcome data corruption
- Timeouts + ACKs + retransmissions + SEQs
  - detect and overcome data loss


Alice's computer
Bob's computer
transmission
RTT
transmission
RTT
SEQ 0
ACK 0
SEQ 1
ACK 1

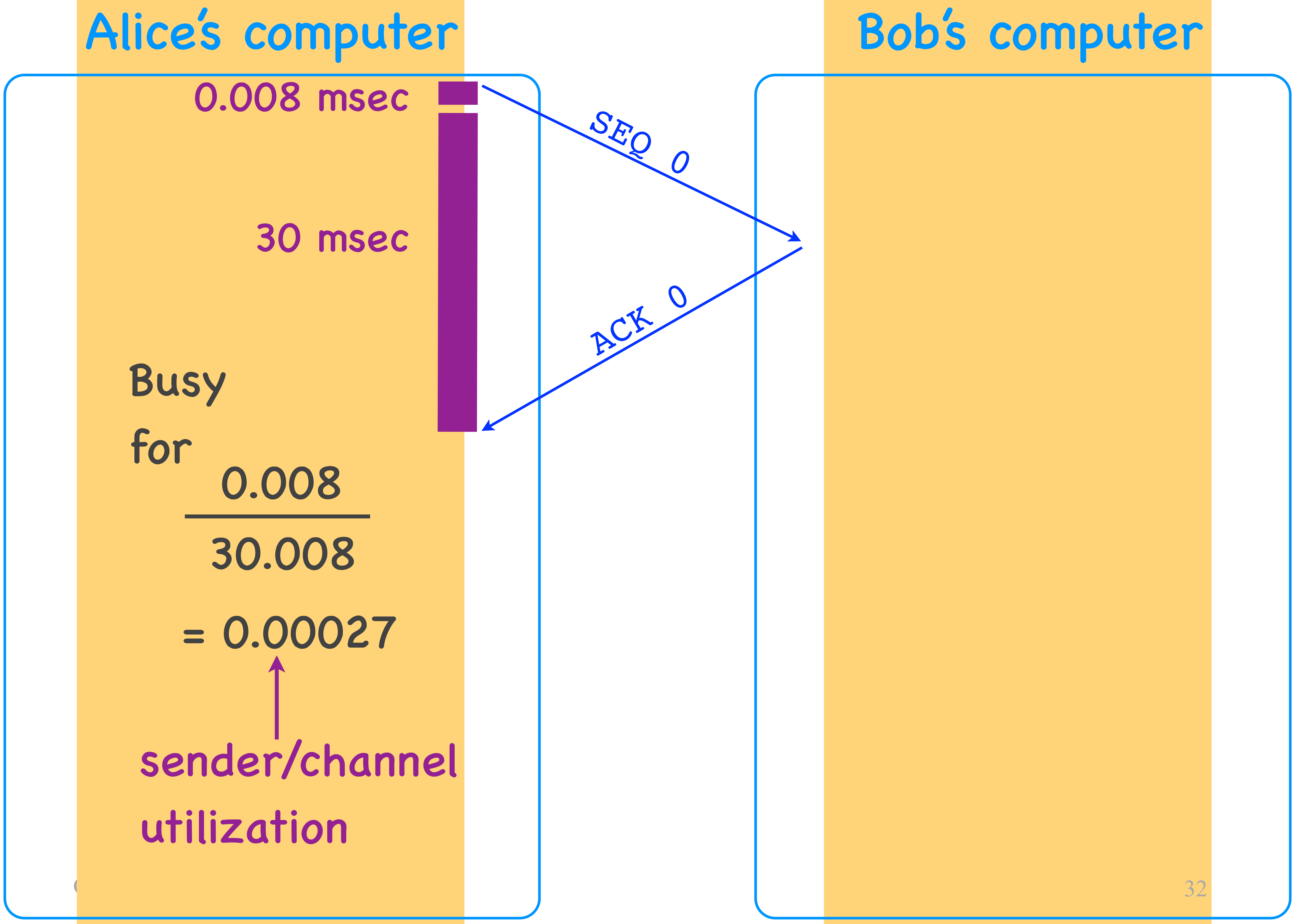
Alice's computer　　　　Bob's computer

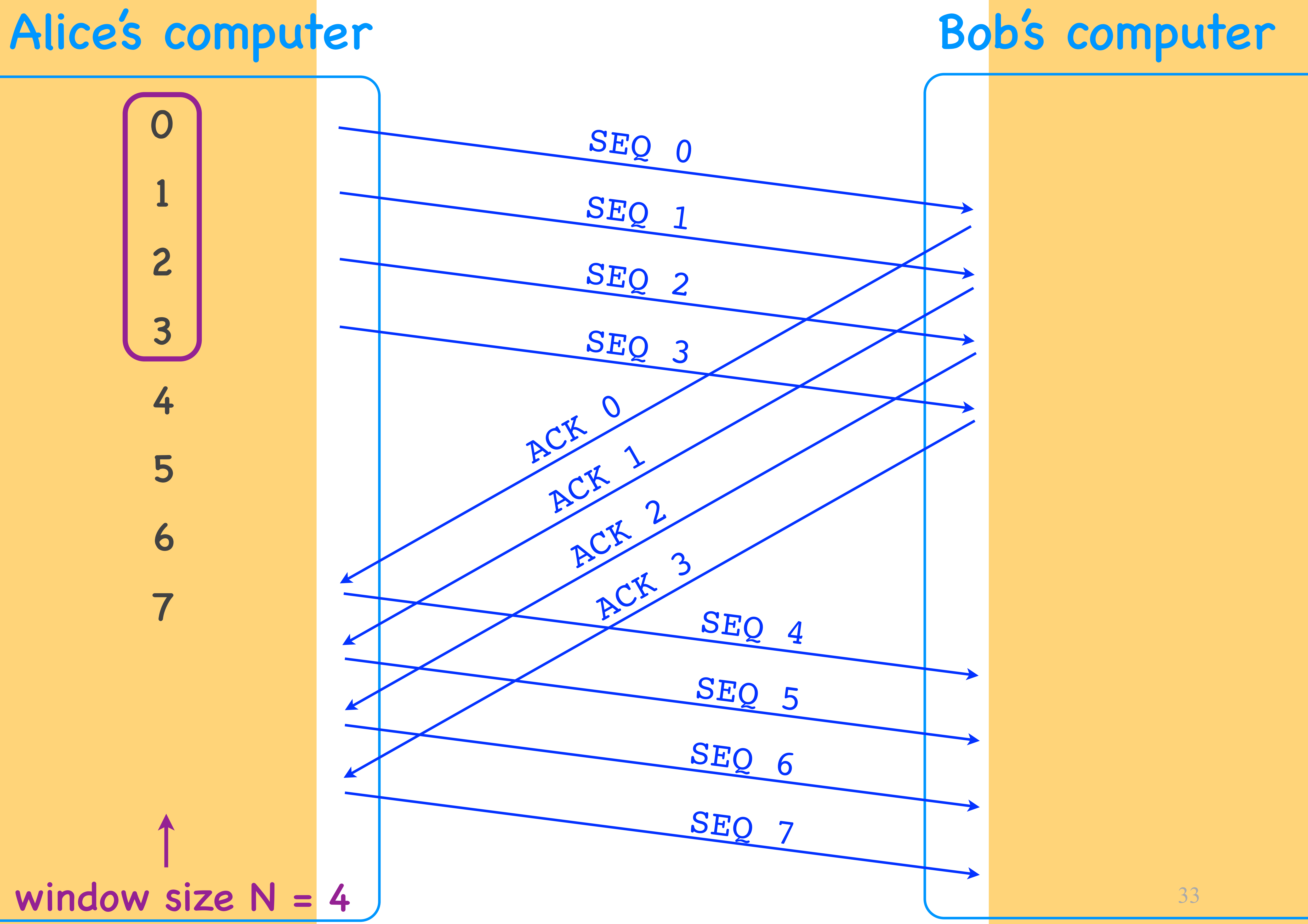
transmission rate R=1 Gbps

packet size L = 1000 bytes

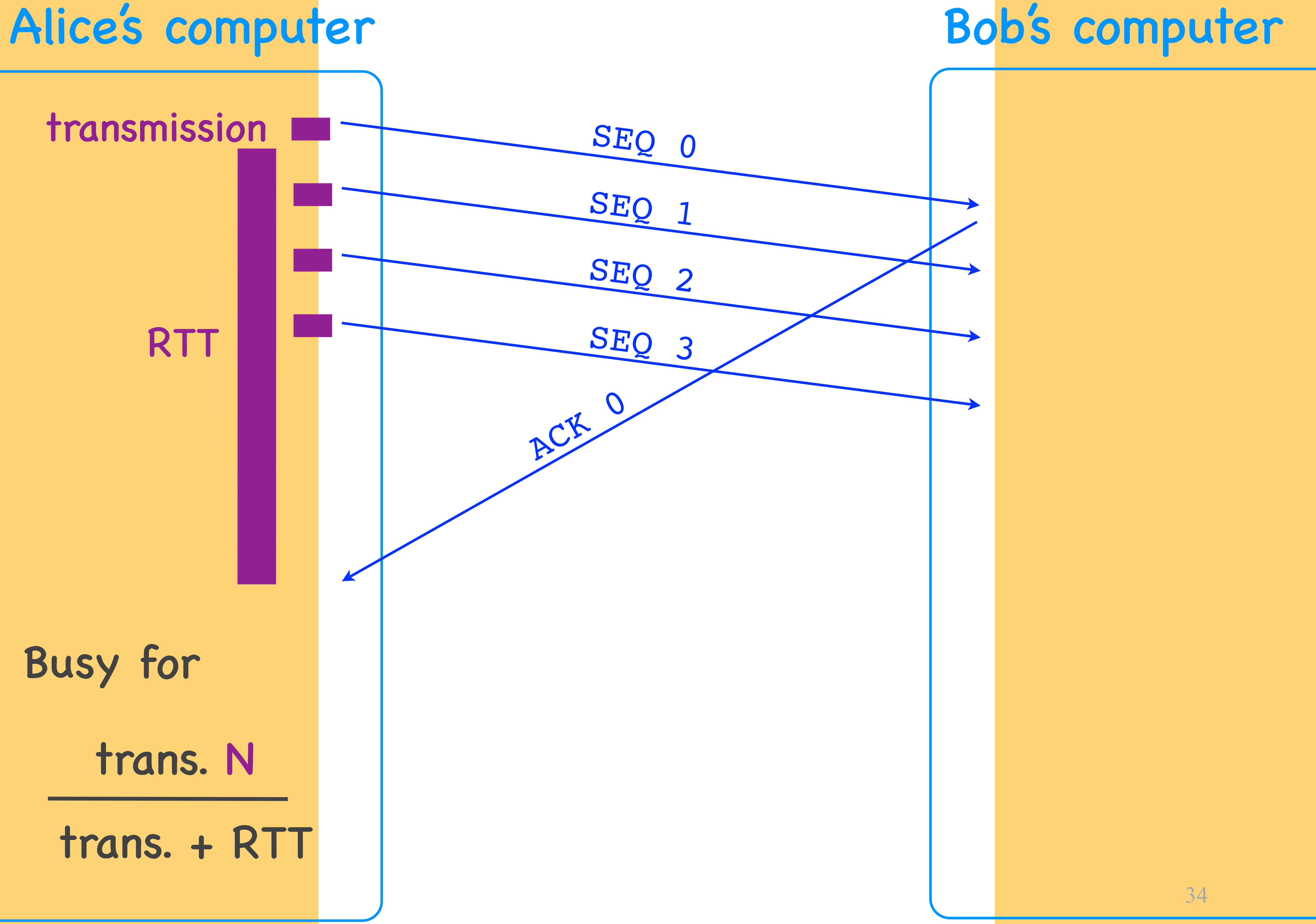
transmission delay = L/R = 8 usec

propagation delay = 15 msec


Alice's computer
Bob's computer
0.008 msec
30 msec
SEQ 0
ACK 0
Busy
for
0.008
30.008
= 0.00027
sender/channel
utilization



Alice's computer
Bob's computer
0
1
2
3
4
5
6
7
SEQ 0
SEQ 1
SEQ 2
SEQ 3
ACK 0
ACK 1
ACK 2
ACK 3
SEQ 4
SEQ 5
SEQ 6
SEQ 7
window size N = 4




Busy for

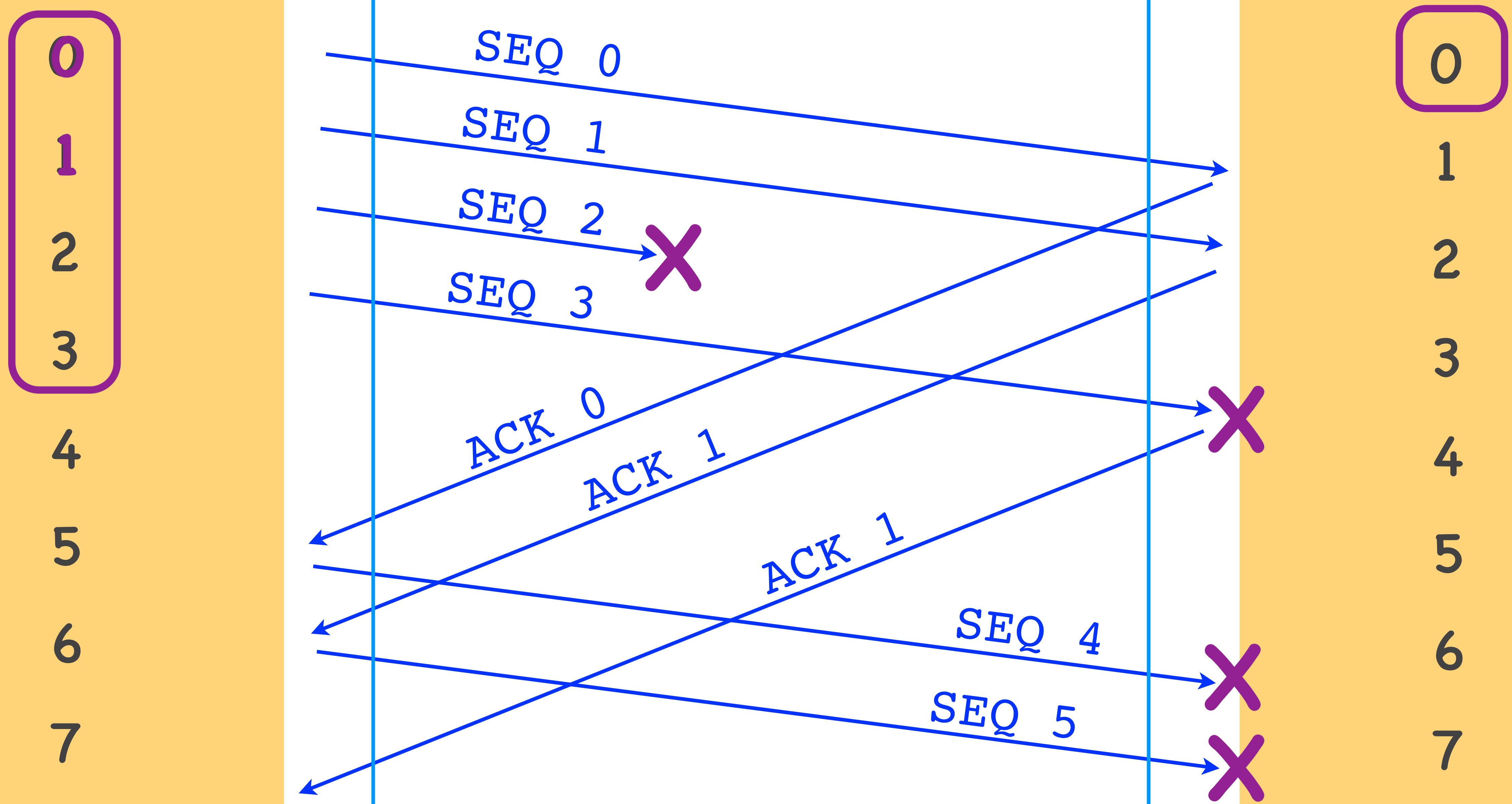
$$\frac{\text{trans.}\ N}{\text{trans.} + \text{RTT}}$$

# Sender utilization

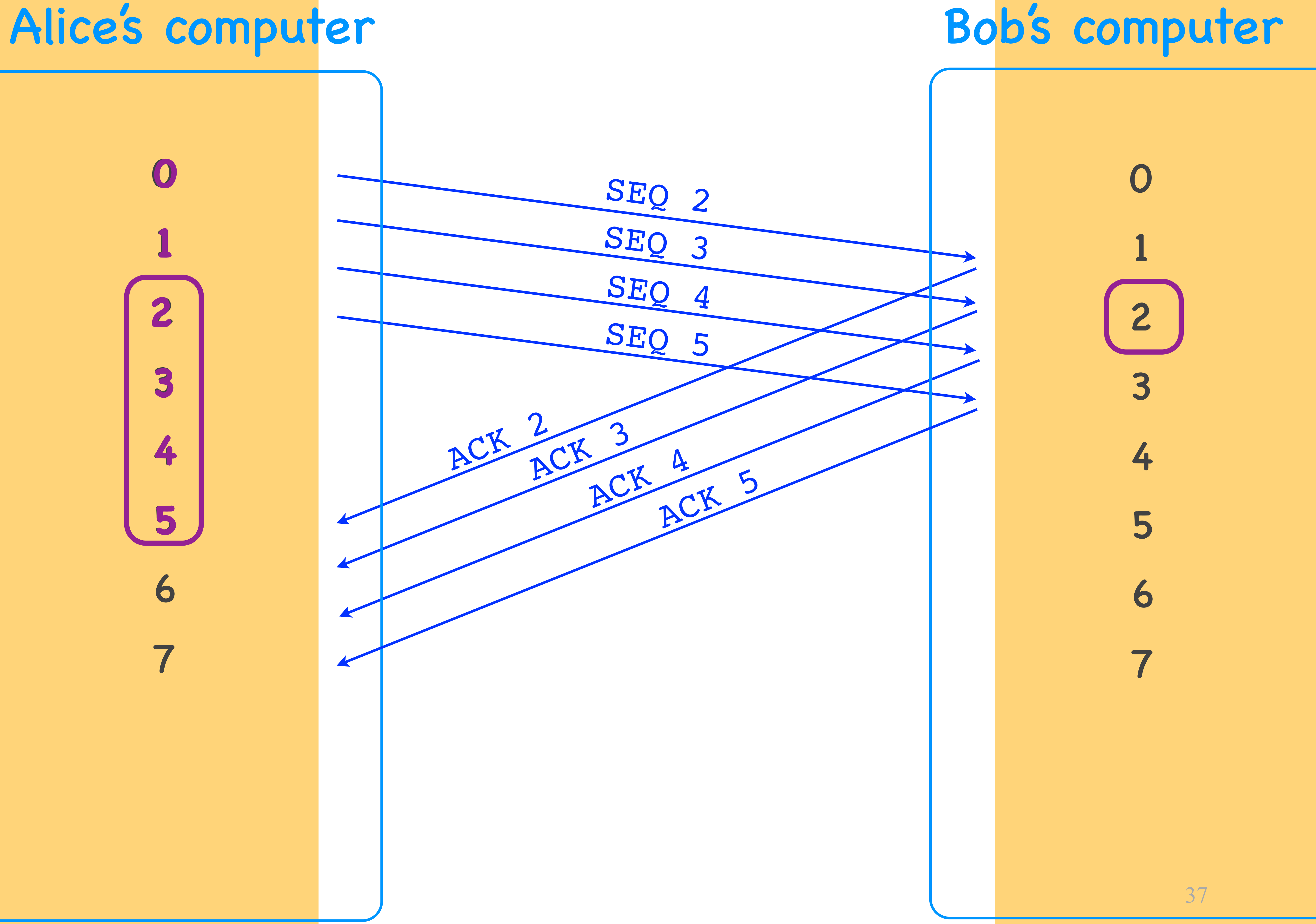
- Stop and wait: poor sender utilization
  - the sender does nothing while waiting for the receiver's ACK or the timeout
- Pipelining: better utilization
  - the sender sends up to N un-ACKed segments
  - N = sliding window size

Alice's computer

Bob's computer

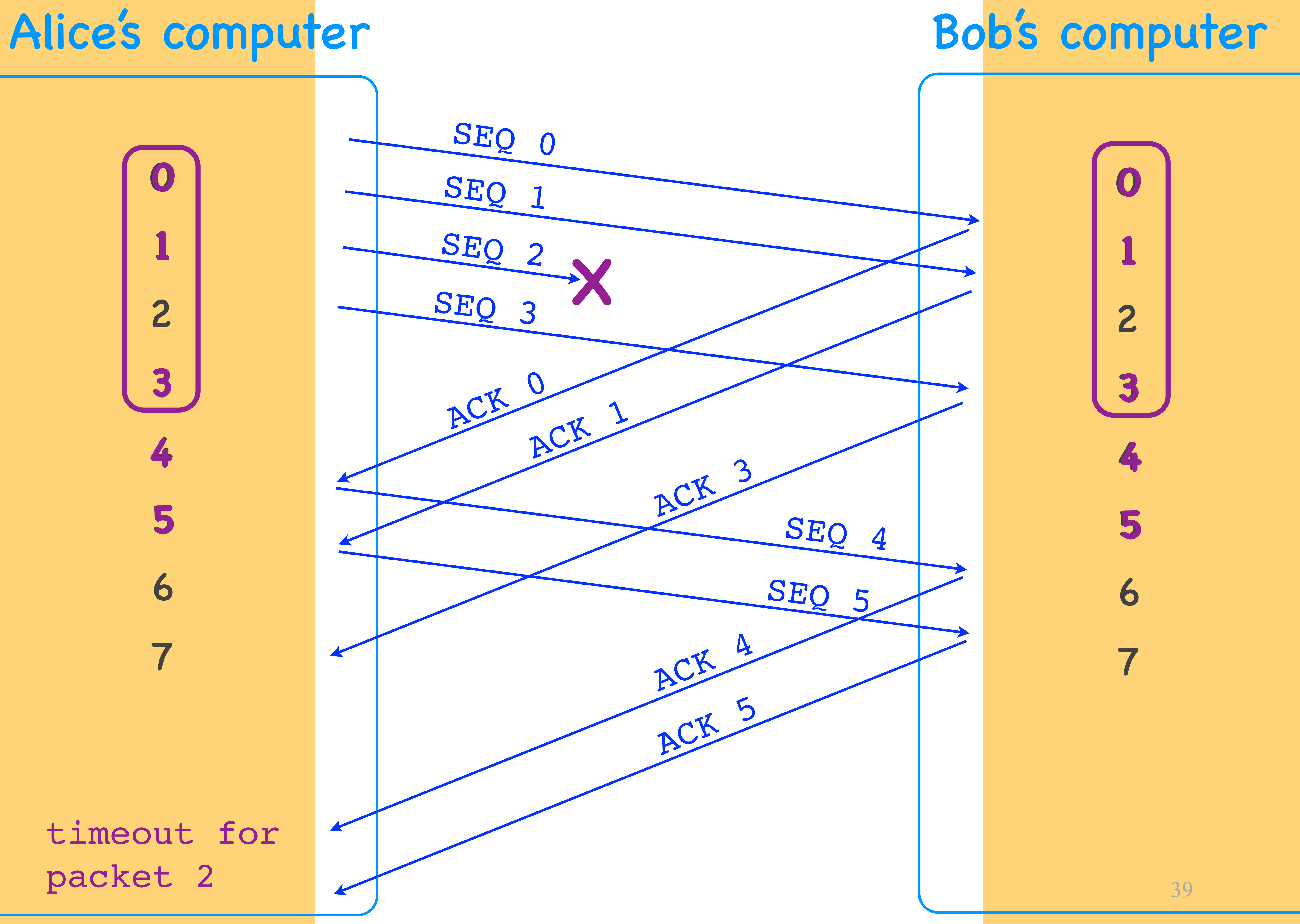


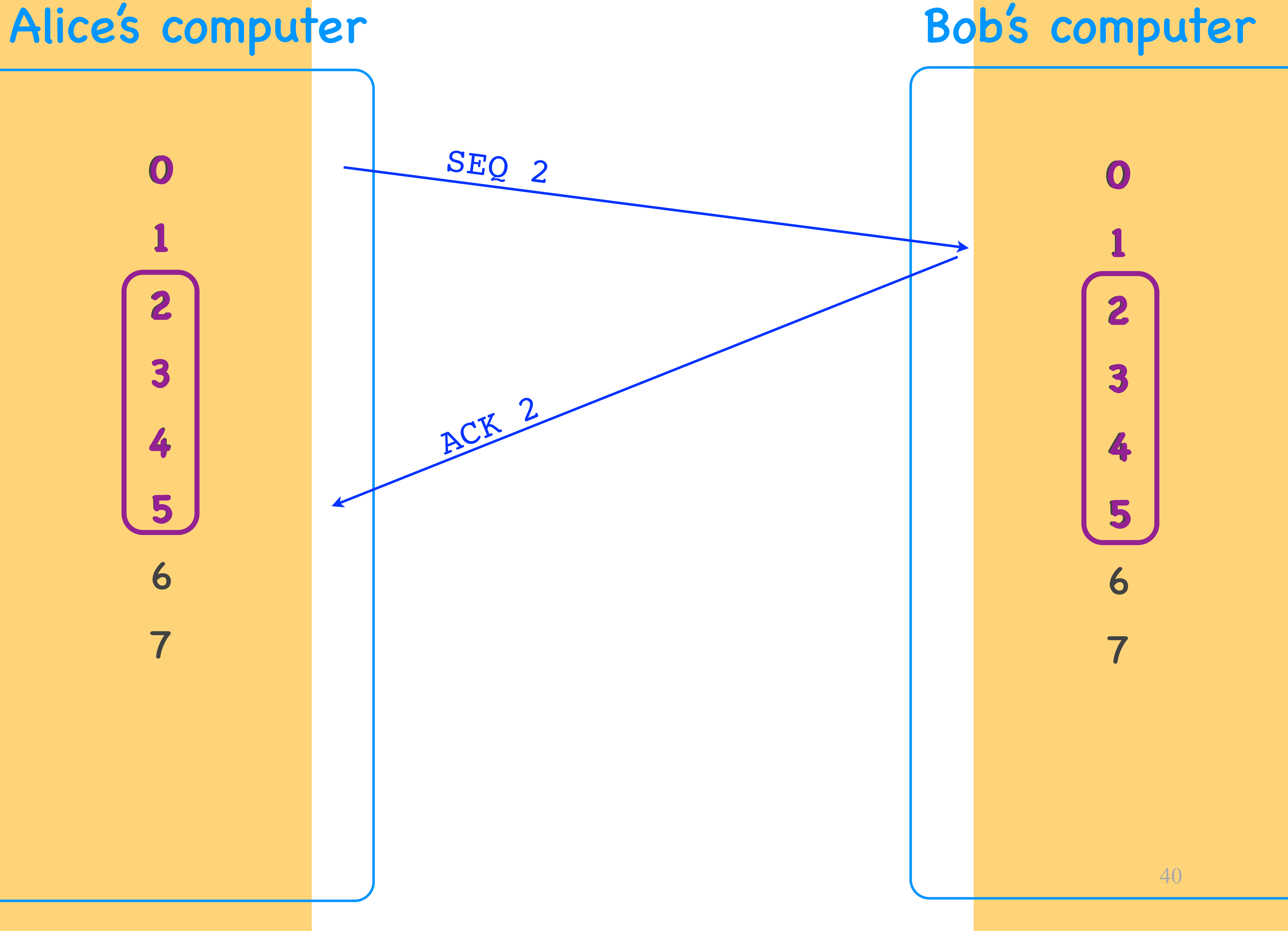

timeout for
packet 2


Alice's computer
Bob's computer
0
1
2
3
4
5
6
7
SEQ 2
SEQ 3
SEQ 4
SEQ 5
ACK 2
ACK 3
ACK 4
ACK 5
0
1
2
3
4
5
6
7

# Go-back-N

- The receiver accepts no out-of–order segments
- ACKs are cumulative
  - an ACK for segment 10 indicates that all segments until and including 10 have been received
- When the sender retransmits, it retransmits all the un-ACK-ed segments


Alice's computer
Bob's computer
0
1
2
3
4
5
6
7
SEQ 0
SEQ 1
SEQ 2
SEQ 3
ACK 0
ACK 1
ACK 3
SEQ 4
SEQ 5
ACK 4
ACK 5
0
1
2
3
4
5
6
7
timeout for
packet 2

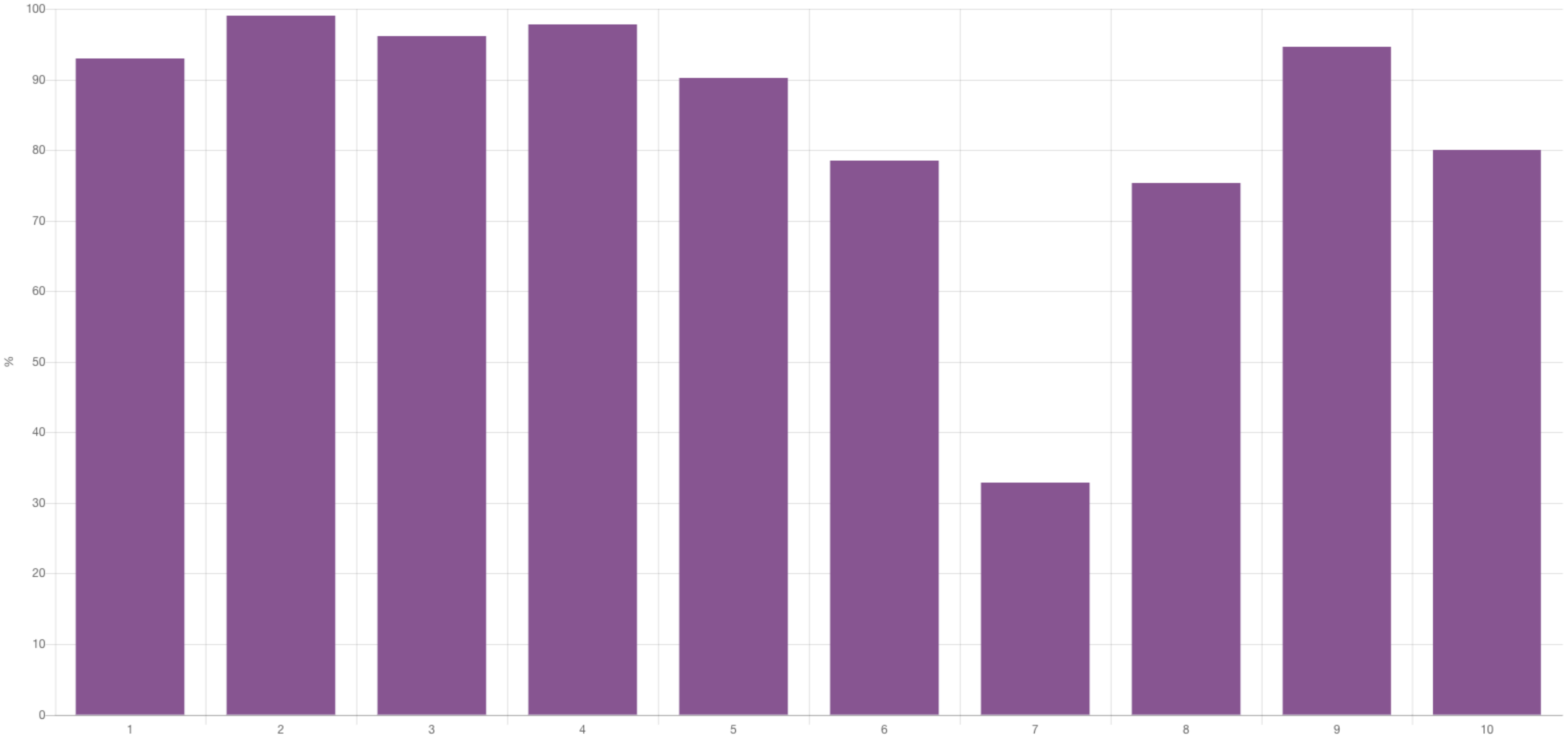


Alice's computer
Bob's computer
0
1
2
3
4
5
6
7
SEQ 2
ACK 2
0
1
2
3
4
5
6
7

# Selective Repeat

- The receiver accepts N-1 out-of-order segments
- ACKs are selective
  - an ACK for segment 10 indicates that segment 10 has been received
- When the sender retransmits, it retransmits only one segment

# Quiz 1



End-system A is sending traffic to end-system B. The average throughput from A to B is T. This means that:

(a) Somewhere between A and B there must exist a link with transmission rate T.

(b) When A sends a packet of size L bits to B, the transmission delay is L/T.

(c) None of the above.

A packet is about to traverse a known set of links with known properties. Can you predict the total propagation delay that the packet will encounter?

(a) Yes.

(b) No, because I don't know what other traffic the packet will encounter.

(c) No, because I don't know the processing capabilities of the packet switches that will process the packet.

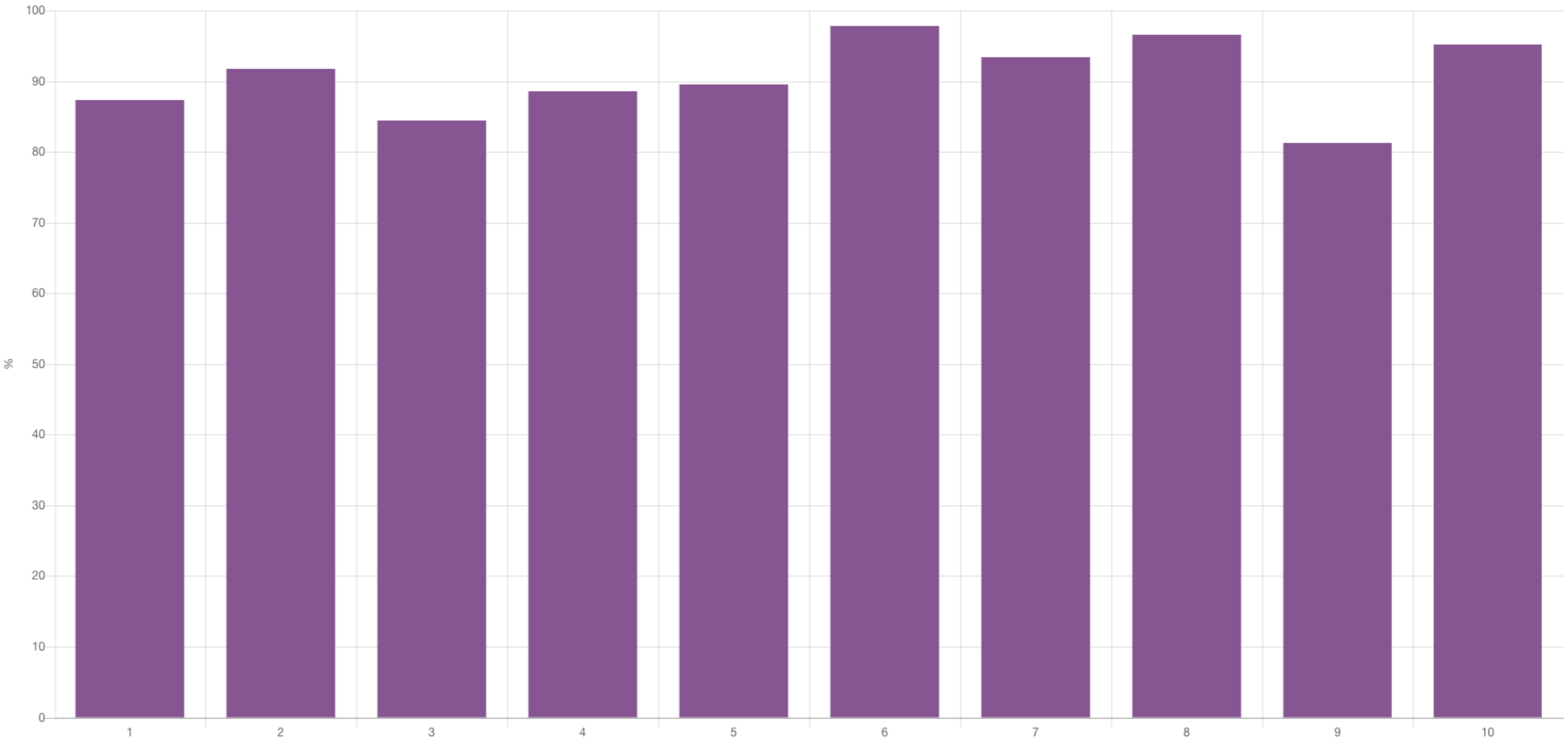
Packets of size L arrive at a queue that feeds a network link of transmission rate R. Assume 0 processing delay. The max queuing defat a packet may encounter at this queue is 3L/R. How many packets does the queue fit?

(a) Three.

(b) Four.

(c) I don't have enough information to answer.

# Quiz 2



Your computer never sends out any DNS requests, even when you type in your browser new URLs. What could be the reason?

(a) Your DNS client uses caching.

(b) Your web browser uses cookies.

(c) Your web browser uses a proxy web server.

You type in your web browser a URL. As a result, your web browser makes a single HTTP request. From this, you conclude that:

(a) Your web browser does not use cookies.

(b) Your web browser had cached the requested object.

(c) The base file for the requested object does not contain any references.

## If you open a packet carrying an HTTP request, you may find inside:

(a) An Ethernet header, then an IP header, then a UDP header, then the HTTP request.

(b) n Ethernet header, then an IP header, then a TCP header, then the HTTP request.

(c) n Ethernet header, then an IP header, then a TCP header, then a DNS request, then the HTTP request.