National University of Computer & Emerging Sciences

CS 3001 - COMPUTER NETWORKS

Lecture 13
Chapter 3

11th March, 2025

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Office Hours: 11:30 am till 01:00 pm (Every Tuesday & Thursday)

Chapter 3
Transport Layer

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- If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)
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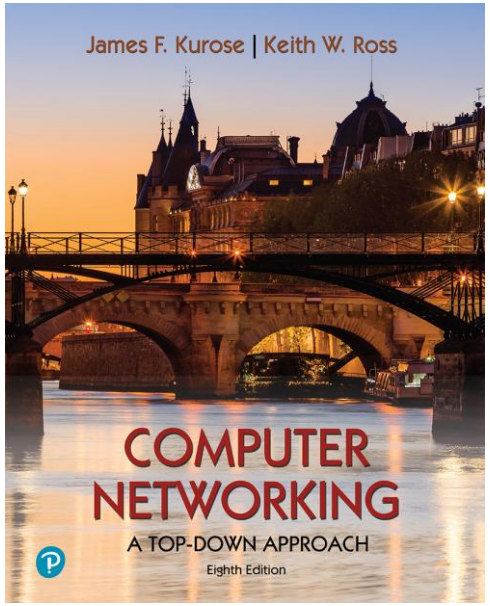
For a revision history, see the slide note for this page.

Thanks and enjoy! JFK/KWR



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Chapter 3: roadmap

- Transport-layer services
- Multiplexing and demultiplexing
- Connectionless transport: UDP
- Principles of reliable data transfer
- Connection-oriented transport: TCP
  - segment structure
  - reliable data transfer
  - flow control
  - connection management
- Principles of congestion control
- TCP congestion control

TCP Sender (simplified)

event: data received from application

- create segment with seq #
- seq # is byte-stream number of first data byte in segment
- start timer if not already running
  - think of timer as for oldest unACKed segment
  - expiration interval: **`TimeOutInterval`**

event: timeout

- retransmit segment that caused timeout
- restart timer

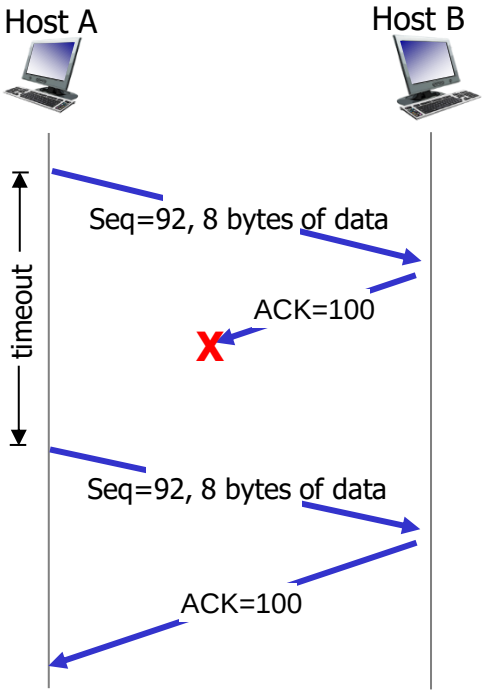
event: ACK received (cumulative ACK)

- if ACK acknowledges previously unACKed segments
  - update what is known to be ACKed
  - start timer if there are still unACKed segments

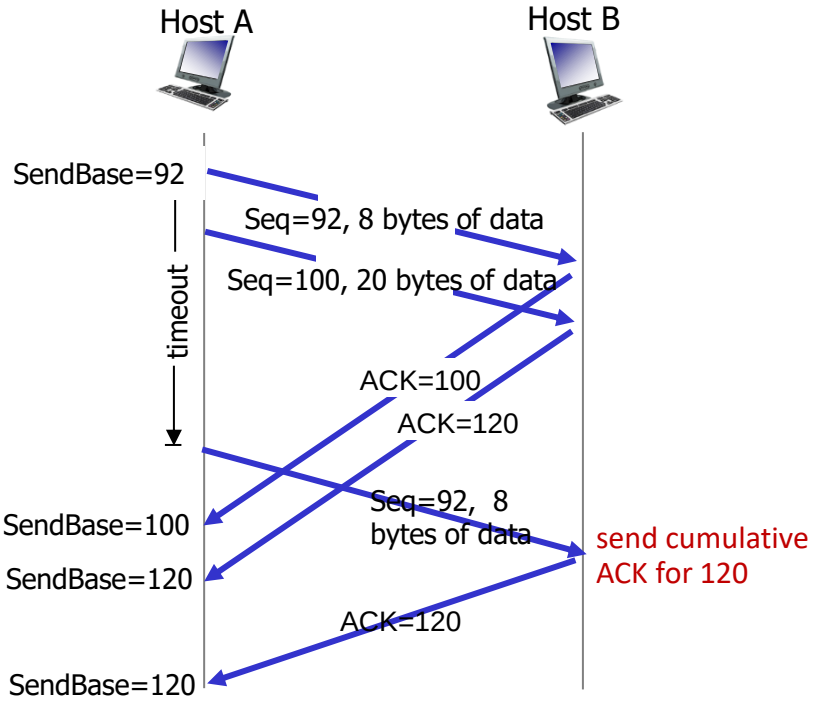
TCP Receiver: ACK generation [RFC 5681]

Event at receiver	*TCP receiver action*
arrival of in-order segment with expected seq #. All data up to expected seq # already ACKed	delayed ACK. Wait up to 500ms for next segment. If no next segment, send ACK
arrival of in-order segment with expected seq #. One other segment has ACK pending	immediately send single cumulative ACK, ACKing both in-order segments
arrival of out-of-order segment higher-than-expect seq. # . Gap detected	immediately send *duplicate ACK*, indicating seq. # of next expected byte
arrival of segment that partially or completely fills gap	immediate send ACK, provided that segment starts at lower end of gap

TCP: retransmission scenarios

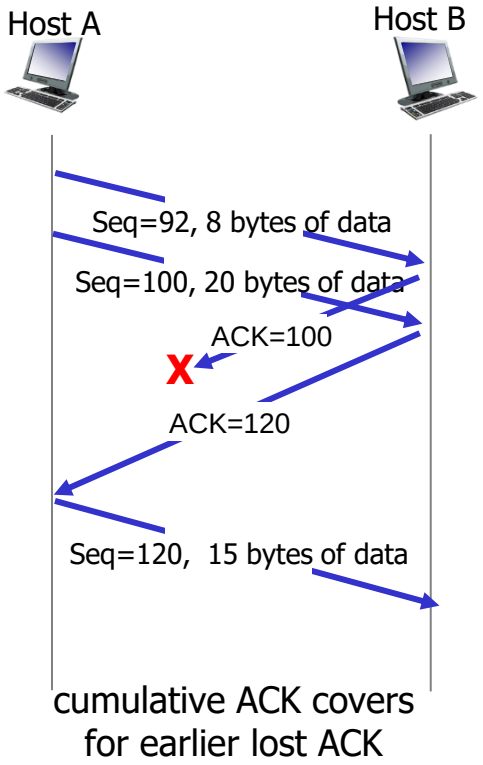


lost ACK scenario



premature timeout

TCP: retransmission scenarios



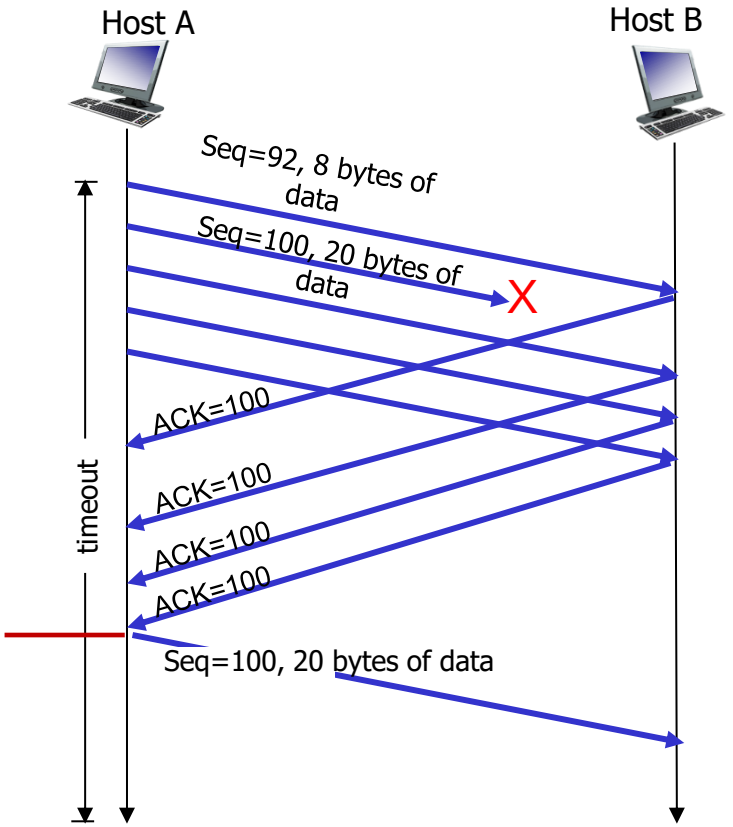
TCP fast retransmit

TCP fast retransmit

if sender receives 3 additional ACKs for same data ("triple duplicate ACKs"), resend unACKed segment with smallest seq #

- likely that unACKed segment lost, so don't wait for timeout

Receipt of three duplicate ACKs indicates 3 segments received after a missing segment – lost segment is likely. So retransmit!



So is TCP Go Back-N or Selective Repeat???

- *TCP (error / loss recovery mechanism) is best categorized as a hybrid of GBN & SR*

- *Please refer to Page 246 of the Course Textbook for further details.*

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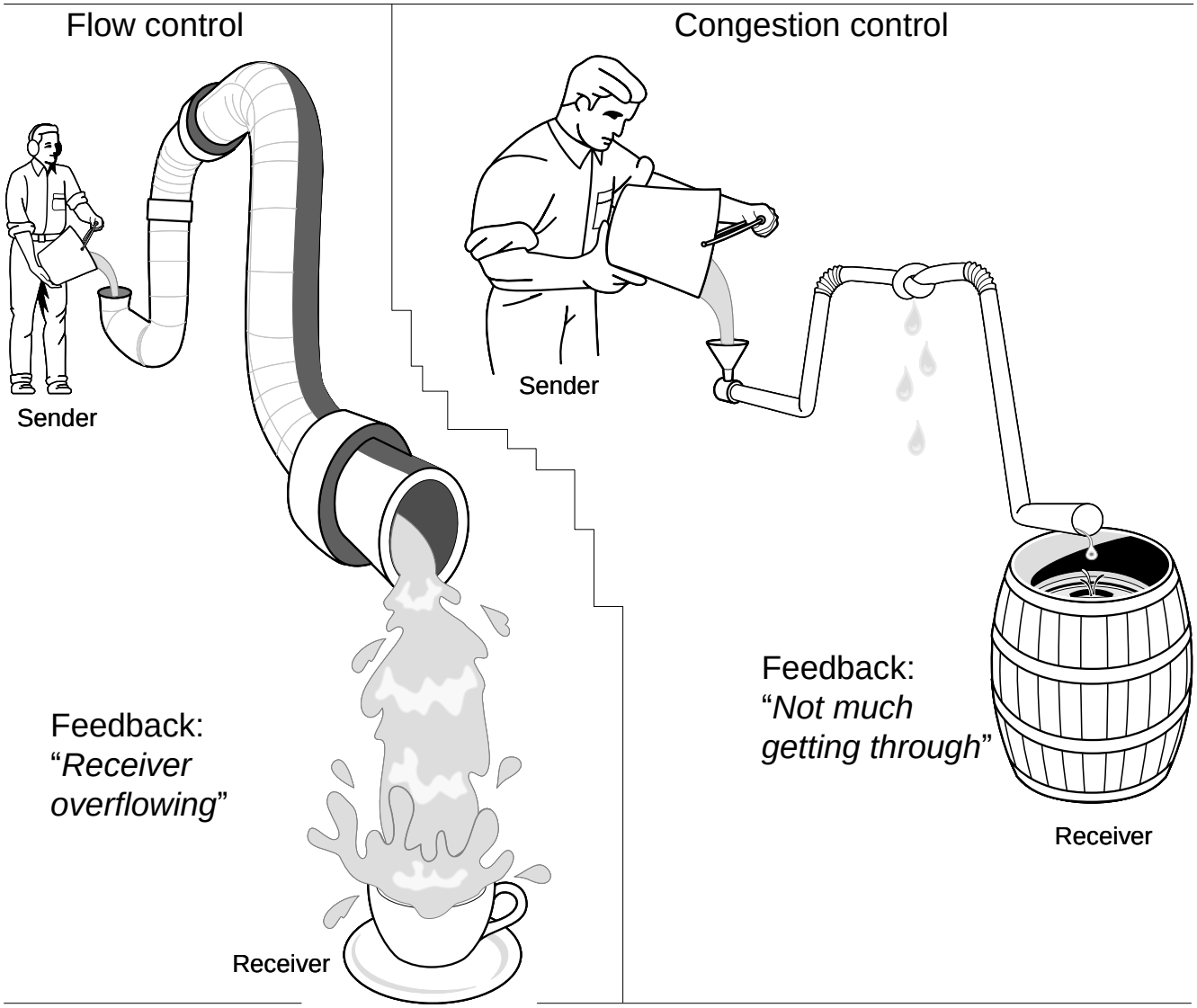
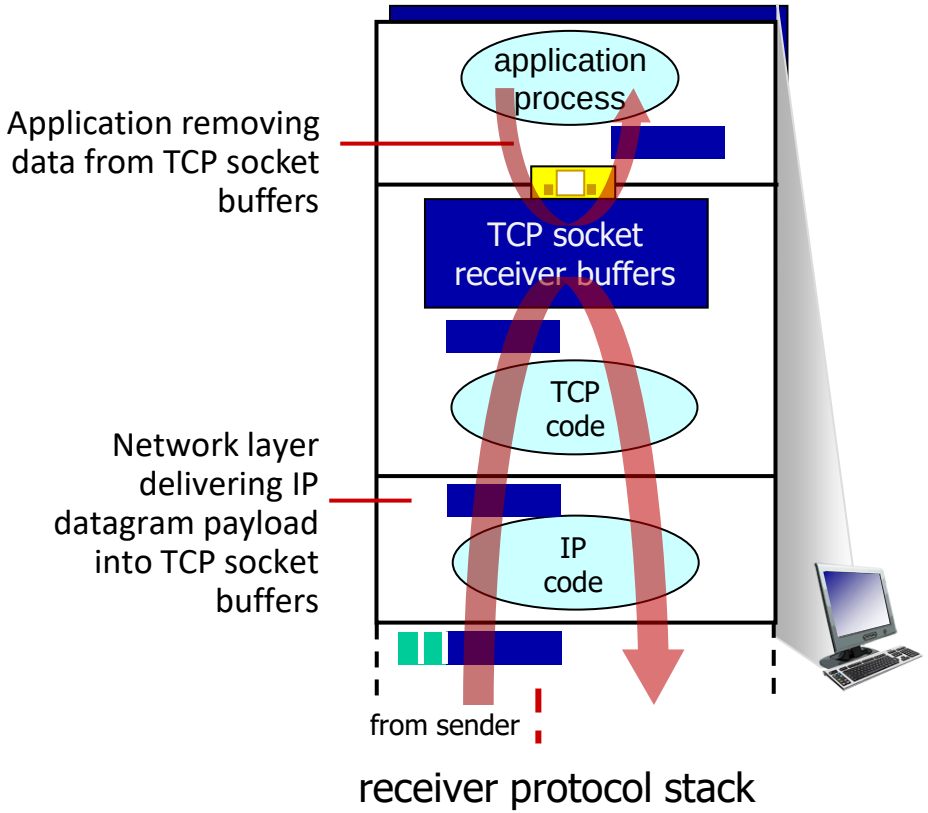
Flow Control vs Congestion Control (Courtesy Rutgers University)



TCP flow control

Q: What happens if network layer delivers data faster than application layer removes data from socket buffers?



TCP flow control

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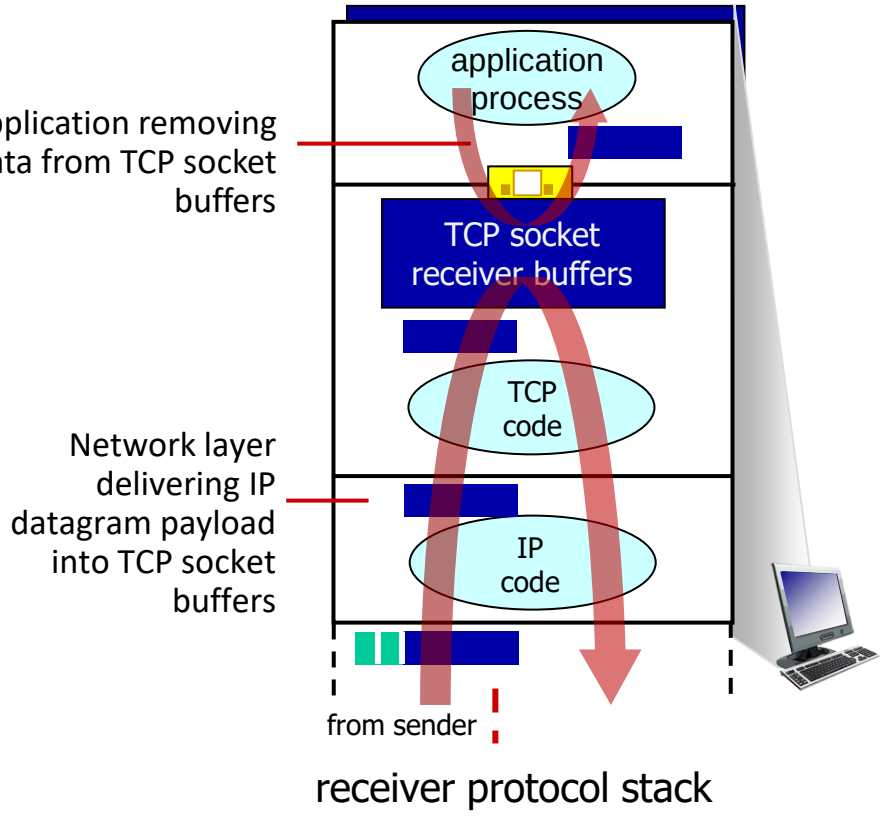

TCP flow control

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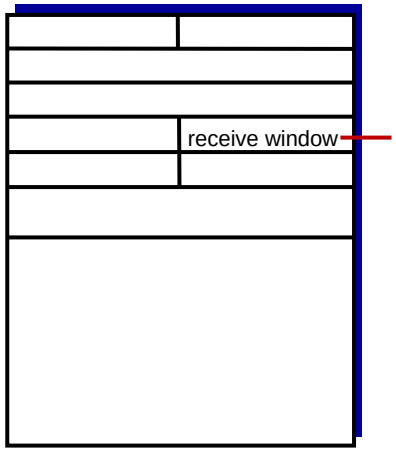
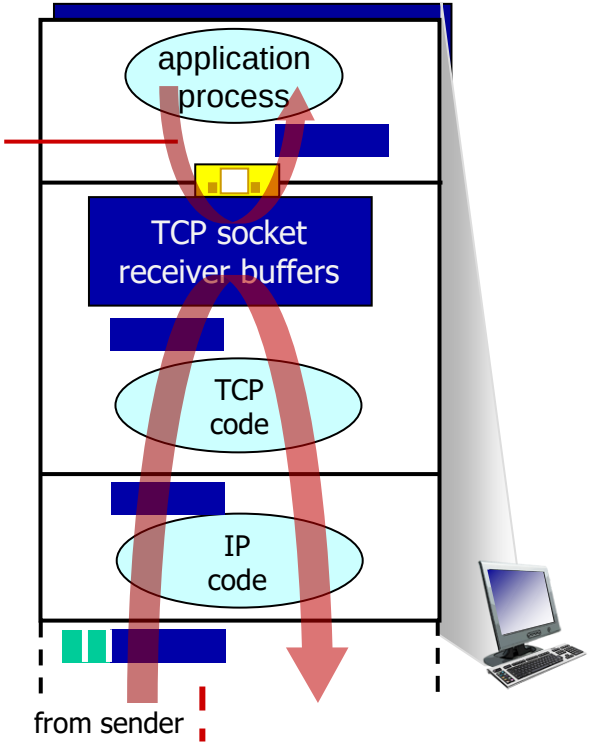


flow control: # bytes receiver willing to accept



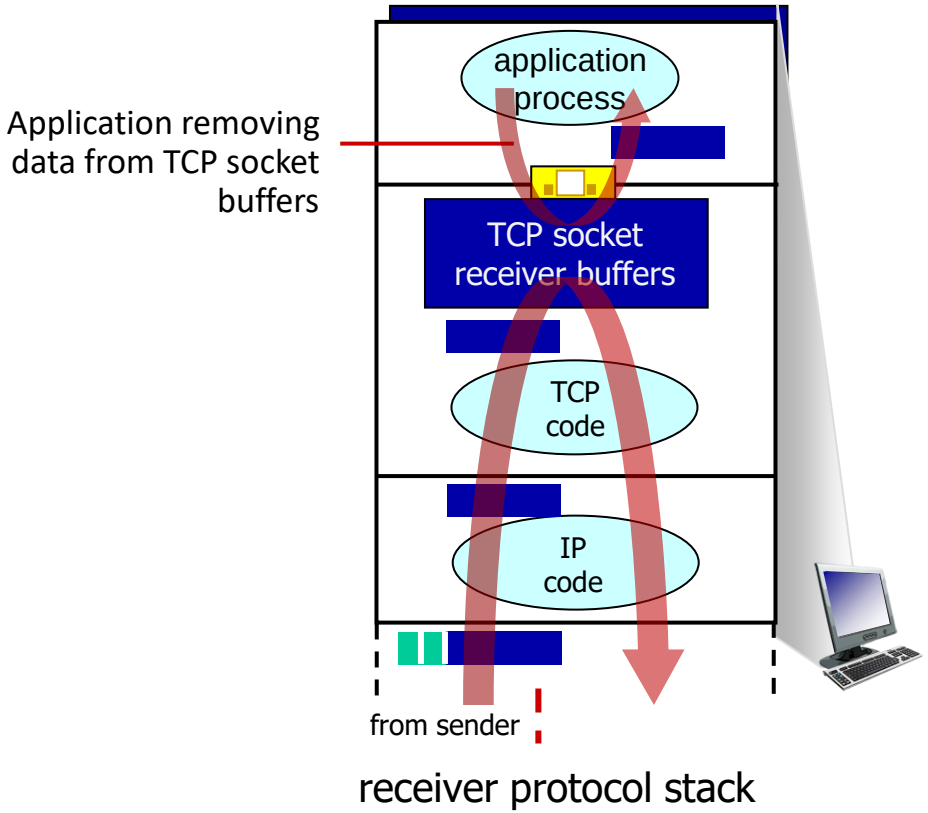
receiver protocol stack

TCP flow control

Q: What happens if network layer delivers data faster than application layer removes data from socket buffers?

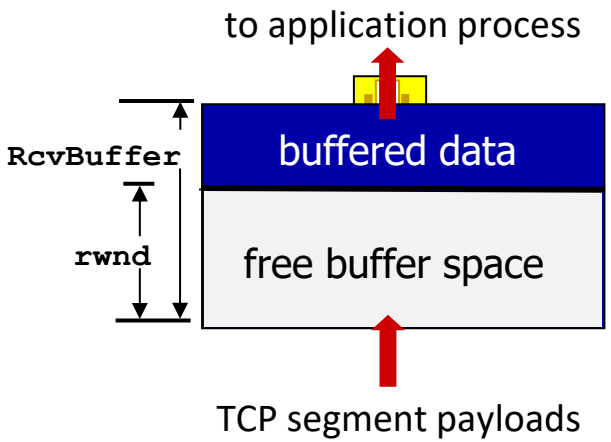
flow control

receiver controls sender, so sender won't overflow receiver's buffer by transmitting too much, too fast



TCP flow control

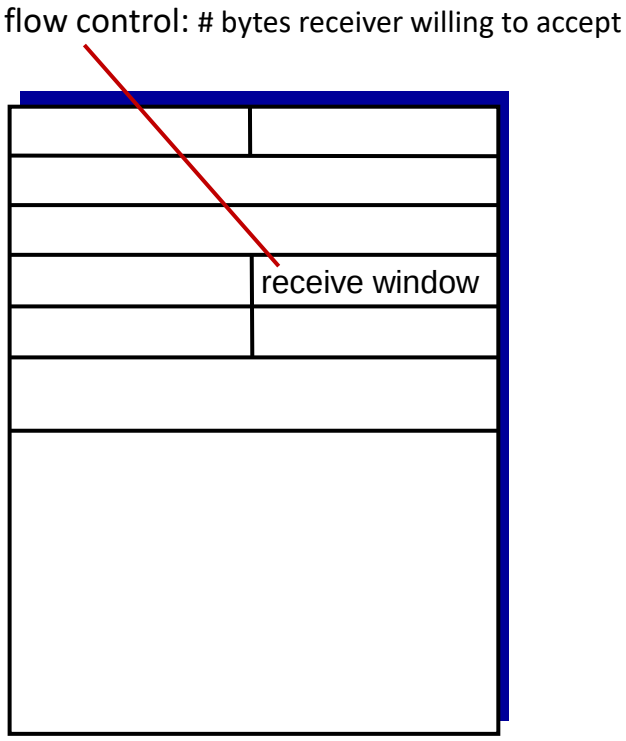
- TCP receiver "advertises" free buffer space in **`rwnd`** field in TCP header
  - **`RcvBuffer`** size set via socket options (typical default is 4096 bytes)
  - many operating systems auto-adjust **`RcvBuffer`**
- sender limits amount of unACKed ("in-flight") data to received **`rwnd`**
- guarantees receive buffer will not overflow



TCP receiver-side buffering

TCP flow control

- TCP receiver "advertises" free buffer space in **`rwnd`** field in TCP header
  - **`RcvBuffer`** size set via socket options (typical default is 4096 bytes)
  - many operating systems auto-adjust **`RcvBuffer`** **`(i.e. dynamic)`**
- sender limits amount of unACKed ("in-flight") data to received **`rwnd`**
- guarantees receive buffer will not overflow
- (Assumption: TCP receiver discards out-of-order segments)



TCP segment format

TCP Flow Control - Implementation

- **TCP provides flow control by having the sender maintain a dynamic variable called the receive window (rwnd)**

(Since TCP is not permitted to overflow the allocated buffer, we must have)

LastByteRcvd – LastByteRead <= RcvBuffer *(where:*

- RcvBuffer is the size of the buffer allocated at the receiver for this connection,
- LastByteRcvd is the number of the last byte in the data stream received from the network and placed in the receive buffer, &
- LastByteRead is the number of the last byte in the data stream read by the application process from the receive buffer), **thus**

rwnd = RcvBuffer – [LastByteRcvd – LastByteRead]

- **While the receiver is keeping track of many variables as seen above, the sender is keeping track of primarily two variables, (**i.e. LastByteSent & LastByteAcked**)**

LastByteSent – LastByteAcked <= rwnd (i.e. the **UnAckedData**.)

- By maintaining this throughout the connection's life, i.e. keeping the UnAckedData less than or equal to the rwnd, the sender ensures it doesn't overflow the buffer at the receiver

TCP Flow Control - Issue

Issue: One minor technical problem with this scheme.

- To see this, suppose Host B's (receiver) receive buffer becomes full so that rwnd = 0.
- After advertising rwnd = 0 to Host A (sender), also suppose that B has nothing to send to A.
- As the application process at B empties the buffer, TCP does not send new segments with new rwnd values to Host A (indeed, TCP sends a segment to Host A only if it has data to send or if it has an acknowledgment to send)

Therefore, Host A is never informed that some space has opened up in Host B's receive buffer (i.e. **Host A is blocked and can transmit no more data!**)

- To solve this problem, the TCP specification requires Host A to continue to send segments with one data byte when B's receive window is zero.
- These segments will be acknowledged by the receiver.
- Eventually the buffer will begin to empty and the acknowledgments will contain a non-zero rwnd value.

Assignment # 3 (Chapter – 3)

- *3rd Assignment will be uploaded on Google Classroom on Thursday, 13th March, 2025, in the Stream - Announcement Section*

- *Due Date: ~~Thursday, 20th March~~ Tuesday, 25th March, 2025 (Handwritten solutions to be submitted during the lecture; deadline extended due to LAB midterms next week)*

- *Please read all the instructions carefully in the uploaded Assignment document, follow & submit accordingly*

Quiz # 3 (Chapter – 3)

- *On: ~~Thursday, 20th March, 2025~~ , Tuesday, 25th March, 2025(During the lecture; deadline extended due to LAB midterms next week)*

- *Quiz to be taken during own section class only*