# Last Lecture: TCP

1. *Multiplexing and Demultiplexing* ✔
2. *Byte-stream service* ✔
   - Stream of bytes sent and received, not stream of packets
3. *Reliable data transfer* ✔
   - A combination of go-back-N and selective repeat, and performance tuning heuristics
4. *Connection management*
   - Connection establishment and tear down
5. *Flow control*
   - Prevent sender from overflowing receiver
6. *Congestion control* (later)

# This Lecture: TCP

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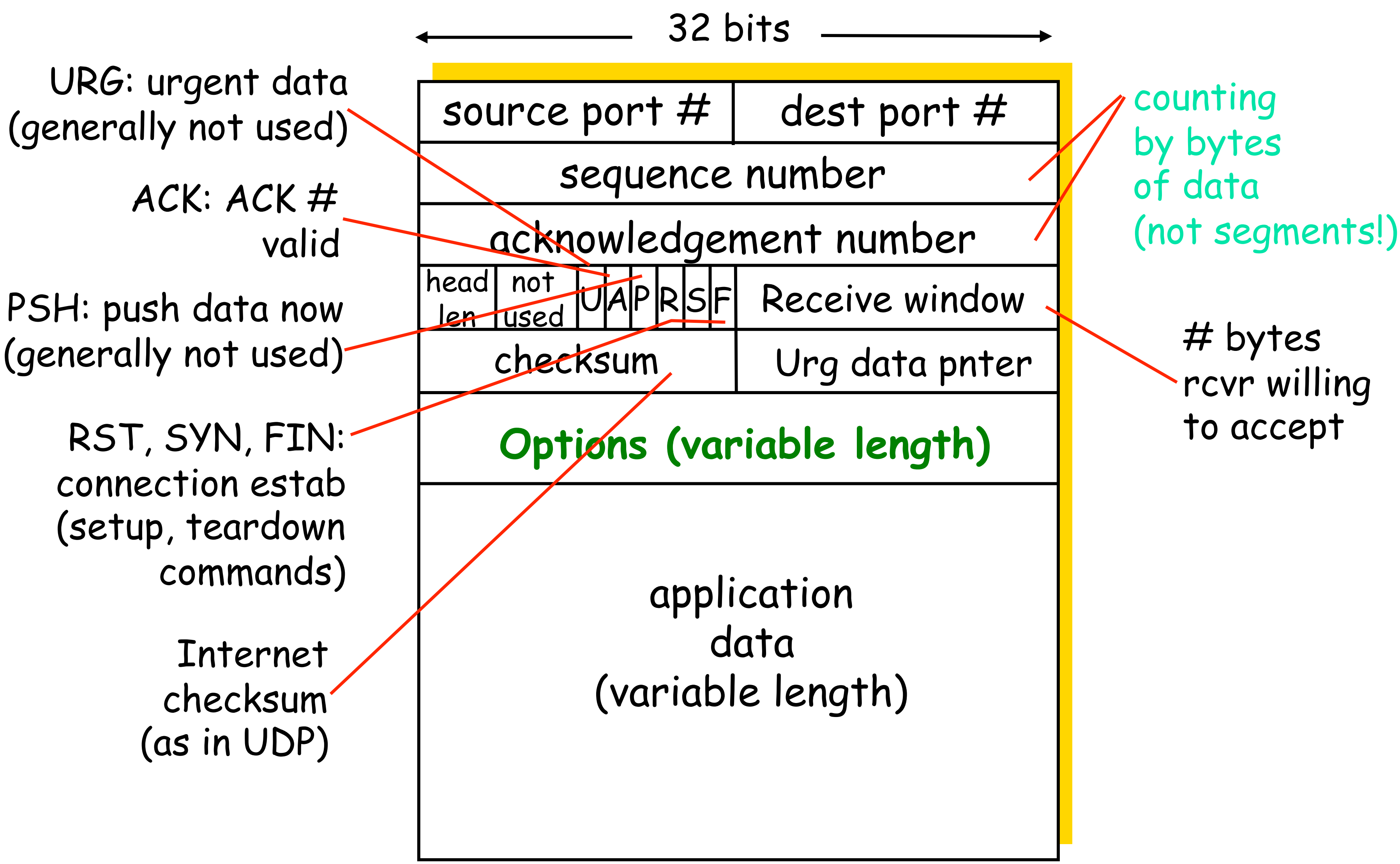
# TCP Segment Structure



# TCP Options

*Options* is a list of options, in one of two formats:

- *(kind)* [1 byte]
- *(kind, length, data)* [1 byte, 1 byte, N bytes]
  - *length* counts all bytes in the option

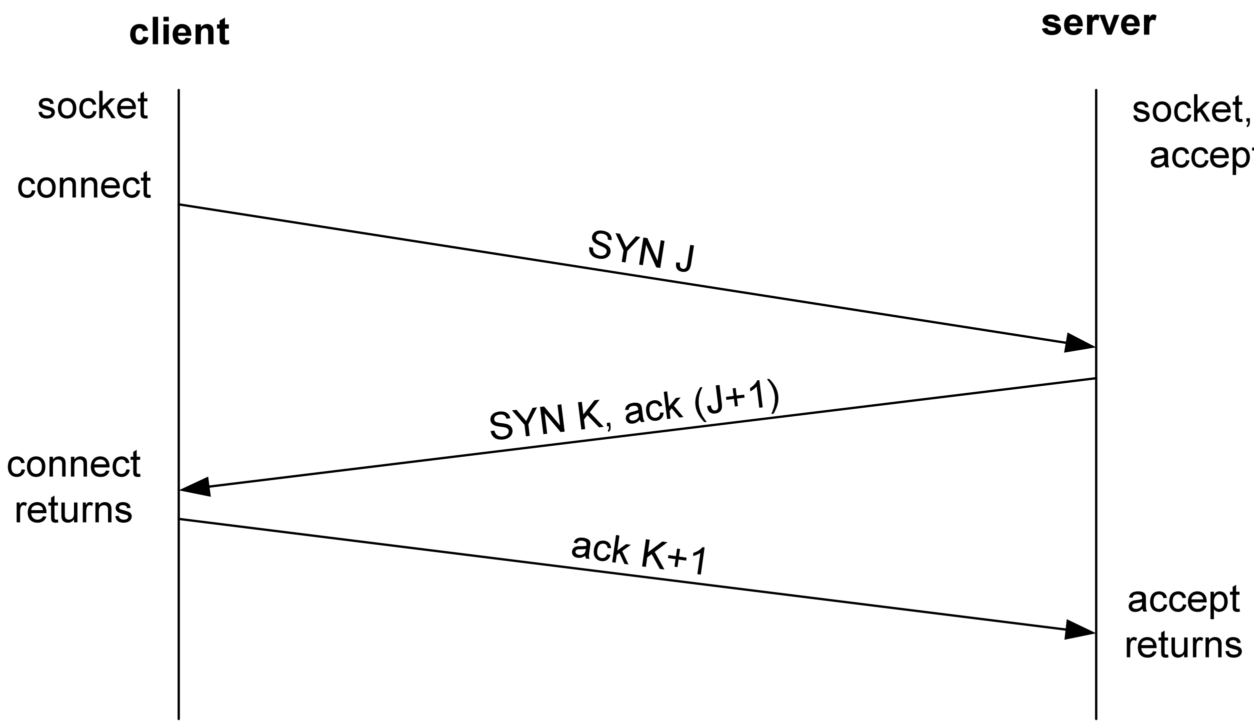
List of common options:

| Kind | Length | Meaning | RFC |
|---|---|---|---|
| 0 | - | End of option list | 793 |
| 1 | - | No Operation, for padding | 793 |
| 2 | 4 | MSS | 793 |
| 3 | 3 | Window Scale | 1323 |
| 4 | 2 | SACK permitted | 2018 |
| 5 | N | SACK | 2018 |
| 8 | 10 | Timestamp option | 1323 |

# 4. TCP Connection Management

- *Connection establishment*
  - Allow each end to know the other exists
    - Trigger allocation of transport entity resources
    - Buffer
    - Timers (if any), …
  - Set up optional parameters
    - Max segment size (MSS)
    - Initial Sequence Numbers (ISN)
    - Window size, …
- *Connection termination*
  - Tell the other end you're done
  - Clean up after yourself (e.g., wait for delayed duplicates to die)

# Establishment Using 3-way Handshake




Each side tells its ISN to the other side.

- Three-way handshake to establish connection
  1. Host A sends a **SYN** (open) to the host B
  2. Host B returns a SYN acknowledgment (**SYN ACK**)
  3. Host A sends an **ACK** to acknowledge the SYN ACK

# Step 1: A's Initial SYN Segment

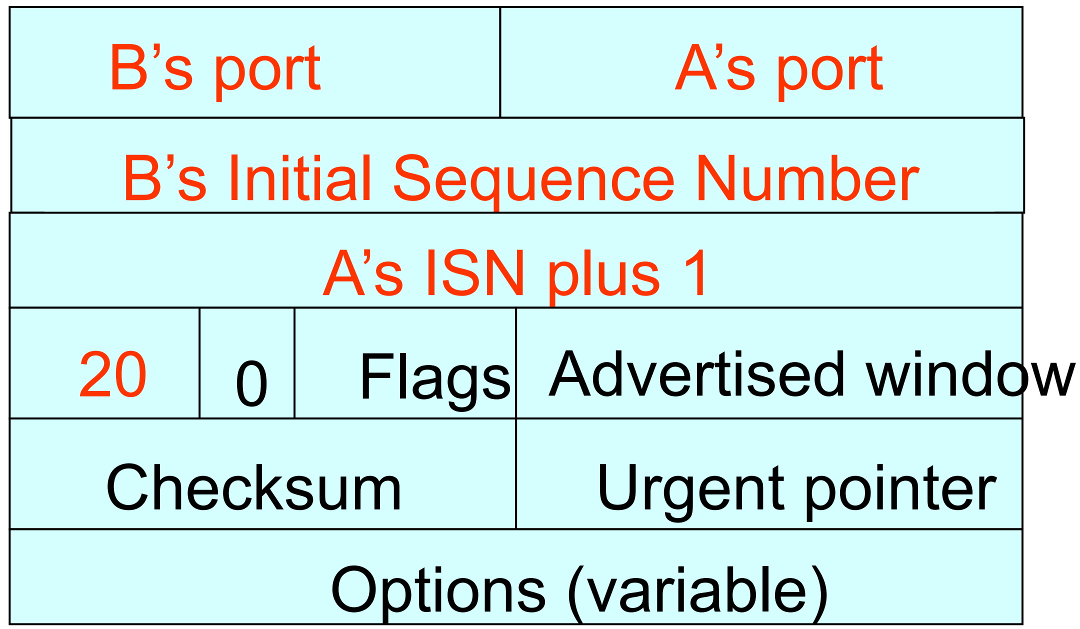
Flags: SYN
FIN
RST
PSH
URG
ACK

| | | | |
|---|---|---|---|
| A's port | | B's port | |
| A's Initial Sequence Number | | | |
| Acknowledgment | | | |
| 24 | 0 | Flags | Advertised window |
| Checksum | | Urgent pointer | |
| Options (variable) (MSS here) | | | |

A tells B it wants to open a connection…

# Step 2: B's SYN/ACK Segment

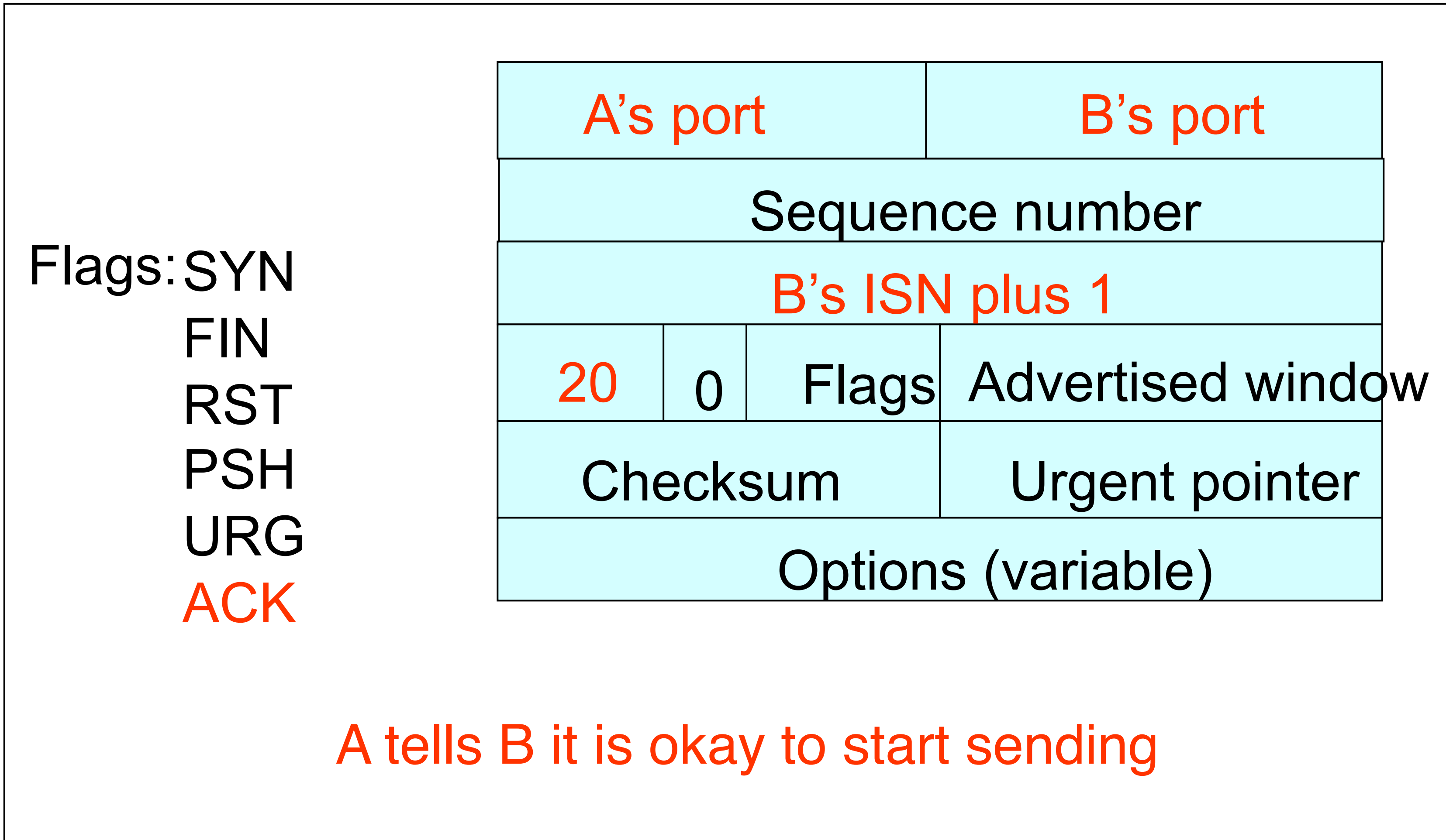
Flags: SYN
FIN
RST
PSH
URG
ACK




B tells A it accepts, and is ready to hear the next byte…

… upon receiving this packet, A can start sending data

# Step 3: A Acknowledges the SYN/ACK




… upon receiving this packet, B can start sending data

# Timeout for SYN Retransmission

On BSD and the likes:

- 6 seconds after the first SYN
- 24 seconds after the second SYN
- 48 seconds after the third SYN
- give up

- Most Berkeley-derived OS have an upper limit of 75 seconds

# SYN Loss and Web Download

- User clicks on a hypertext link
  - Browser creates a socket and does a "connect"
  - The "connect" triggers the OS to transmit a SYN
- If the SYN is lost…
  - The 6 seconds of delay may be very long
  - The user may get impatient
  - … and click the hyperlink again, or click "reload"
- "Reload" triggers an "abort" of the "connect"
  - Browser creates a new socket and does  a "connect"
  - Essentially, forces a faster send of a new SYN packet!
  - Sometimes very effective, and the page comes fast

# Tips and Tricks

- *The Morris attack (1985)*
  - Robert H. Morris is the father of the other Morris
  - He worked for Bell Labs, then chief scientist at NSA
- Up to the early 90's, ISN is chosen sort of like this
  - RFC 793 says: "counter++ every 4µs", use counter for ISN
  - Berkeley-derived kernels: "counter += *C* every second, and += D for every new connection", C&D are constants
- To attack server S who trusts host A (rlogin/rsh)
  - Wait for A to be turned off (or DoS it)
  - Spoof a SYN from A, ignore the SYN/ACK from S
  - Send final ACK from A with correct ISN + 1 (how?)
  - Send commands to server S

# Security Issue: SYN Flooding

- The attack:
  - IP-spoof a SYN packet, send it to server.
  - Server sends back SYN-ACK, wait for connection timeout (typically 75 seconds)
  - Thousands of SYN packets can eat up server's resources and new requests can't be granted

- No "best" solution
  - Routers can reduce IP-spoofed packets
  - Routers (Cisco & others) have the "*TCP intercept*" mode
  - *SYN cookies*, SYN cache, SYN proxying, SYNkill, etc.
  - (Some defenses subject to the attack themselves!!!)

# History of SYN Flooding

- Discovered in 1994 (Bill Cheswick, Bellovin)
  - "Firewalls and Internet Security: Repelling the Wily Hacker"
  - No countermeasure developed in next 2 years
- Description and exploit tool: *Phrack P48-13* (1996)
- Sep 1996, SYN Flooding attacks seen in the wild
  - CERT Advisory released
- Remedies quickly developed (partial solution)
  - Some made their ways to OS codes

# SYN Flooding – Some Technical Details

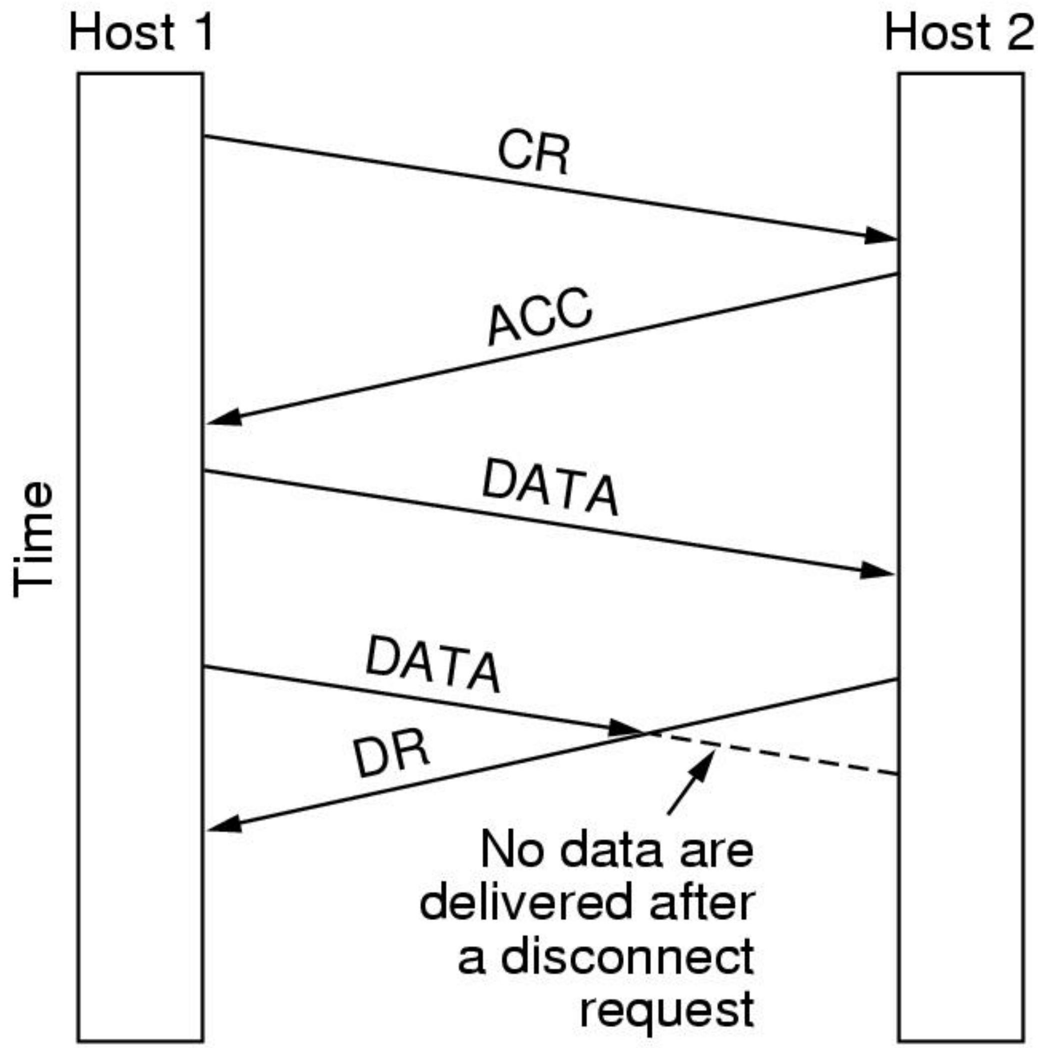
- Implementation dependent
  - Linux kernel 2.6.10: 1300-byte “sock” structure per SYN
  - Other OS: at least 280 bytes
  - The “backlog” parameter of listen() has an effect on the queue size
- Defenses
  - Avoid IP-spoofing (more later): RFCs 2827, 3013, 3704
  - SYN Cache, SYN Cookies:
    - Drawback: can’t pigging back application data in SYN segment
    - Sometime disabled by default in implementations
    - Most BSD-derived OS implement one of these
    - Linux version > 2.6.5 does too
    - Windows 2K and later does too (modify some registry)

# Connection Termination

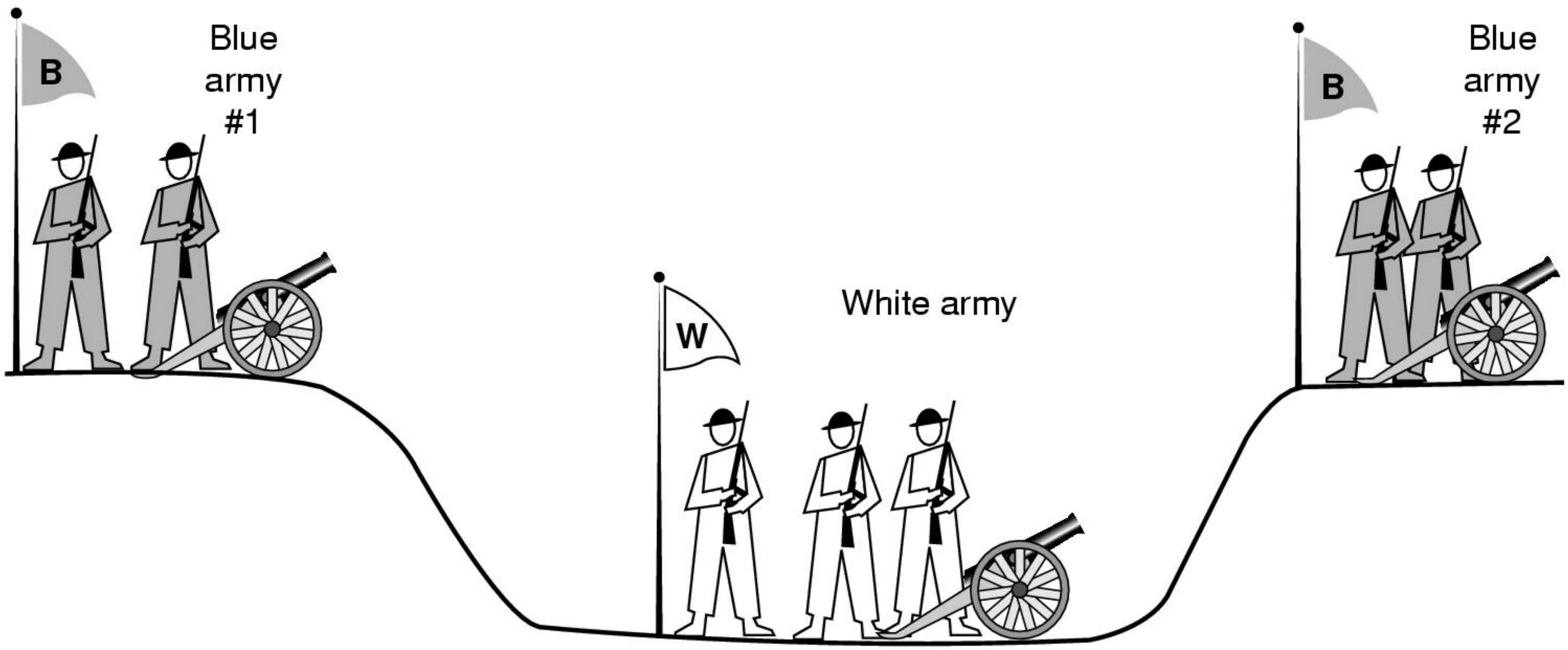
- *Asymmetric release*: close the connection when one side asks for it
  - Abrupt and may result in data loss

- *Symmetric release*: two separate directions
  - FIN and ACK for each direction
  - Not an easy task.
  - What about a 3-way handshake?

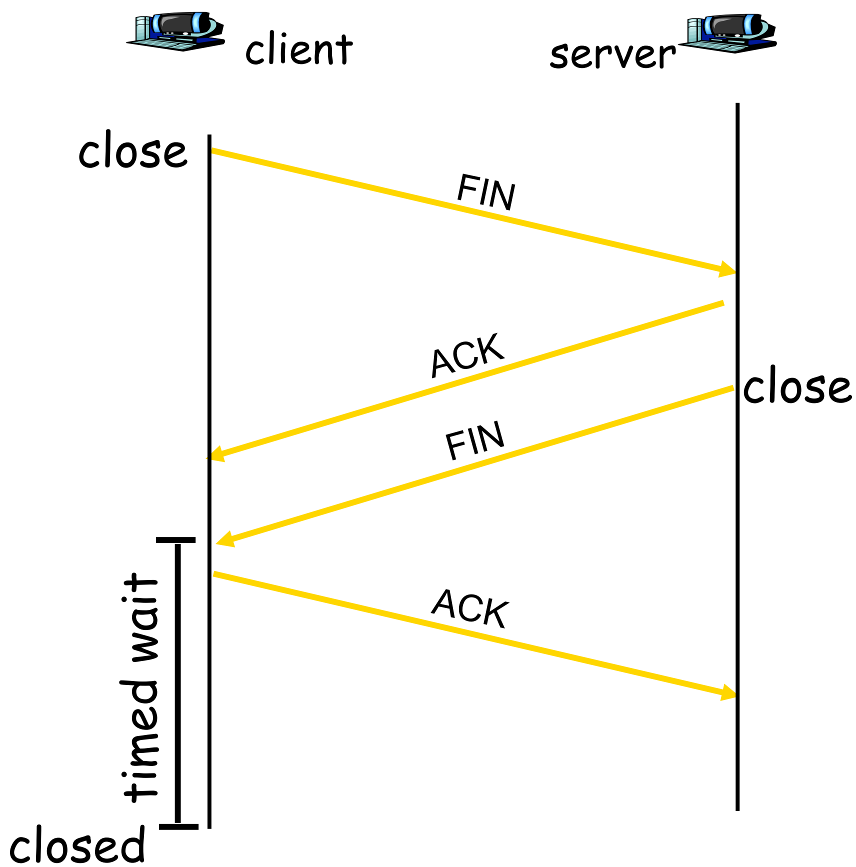
# Data Loss in Asymmetric Release

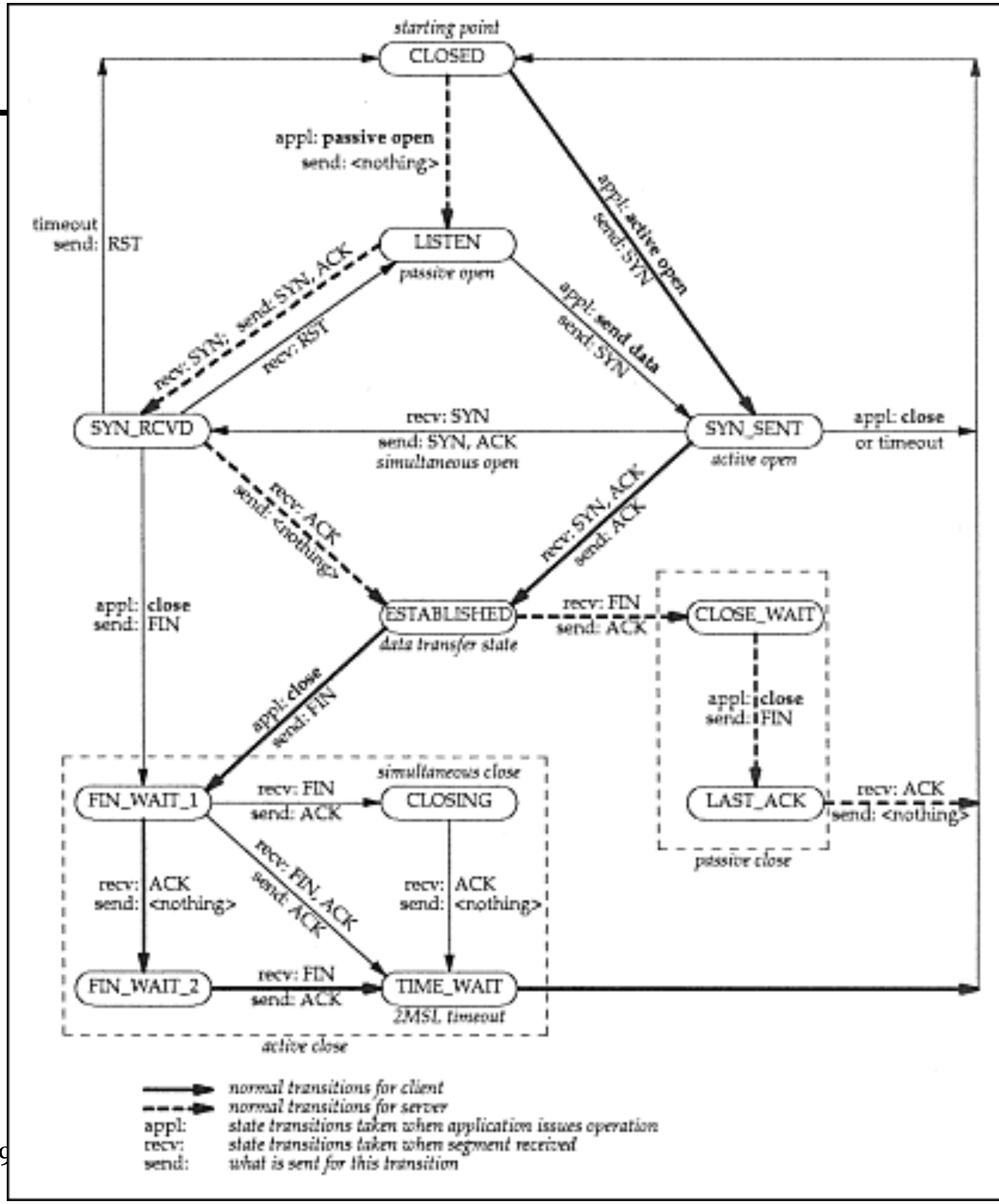


# Symmetric Release is Hard Too

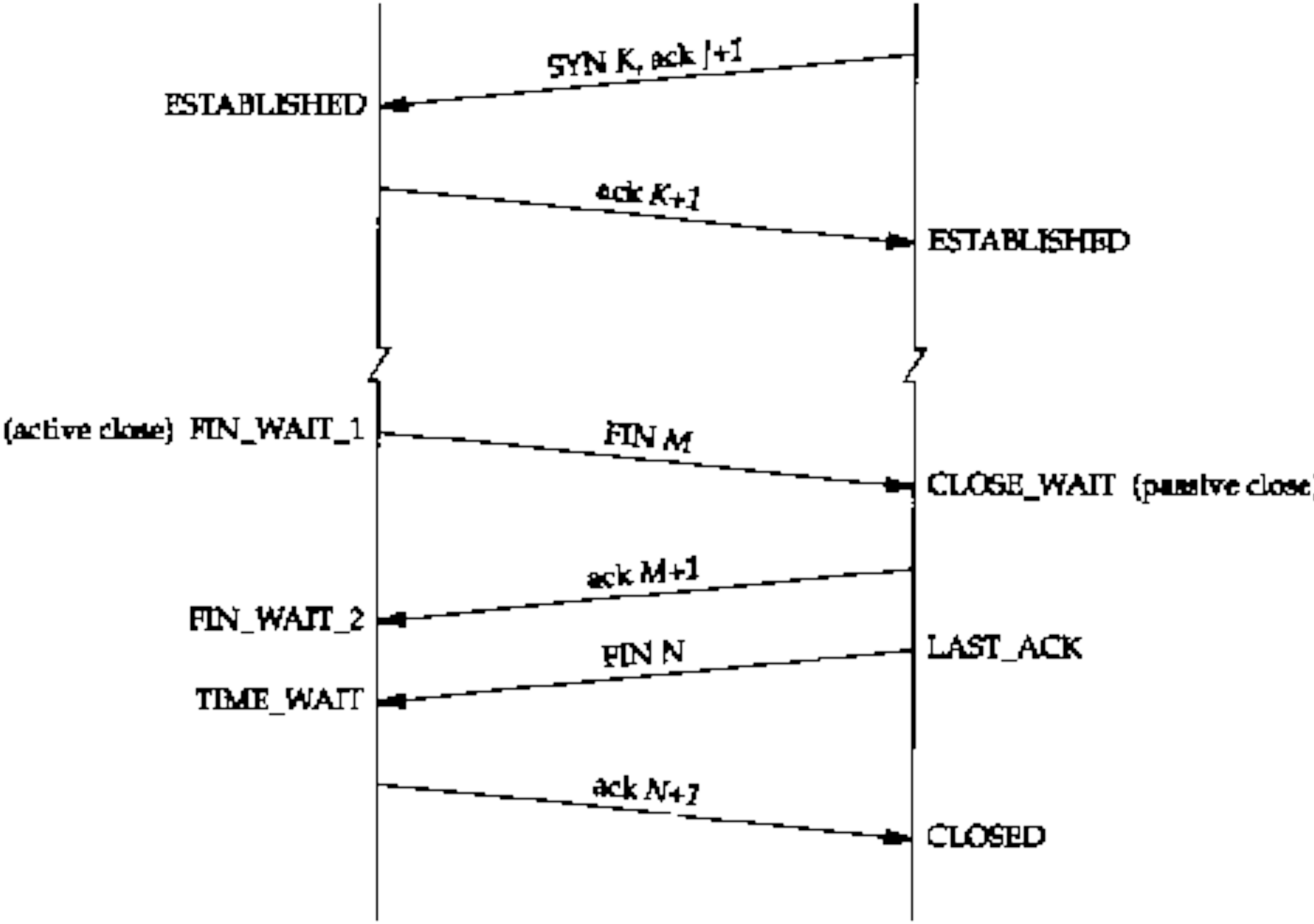


# TCP's Connection Termination

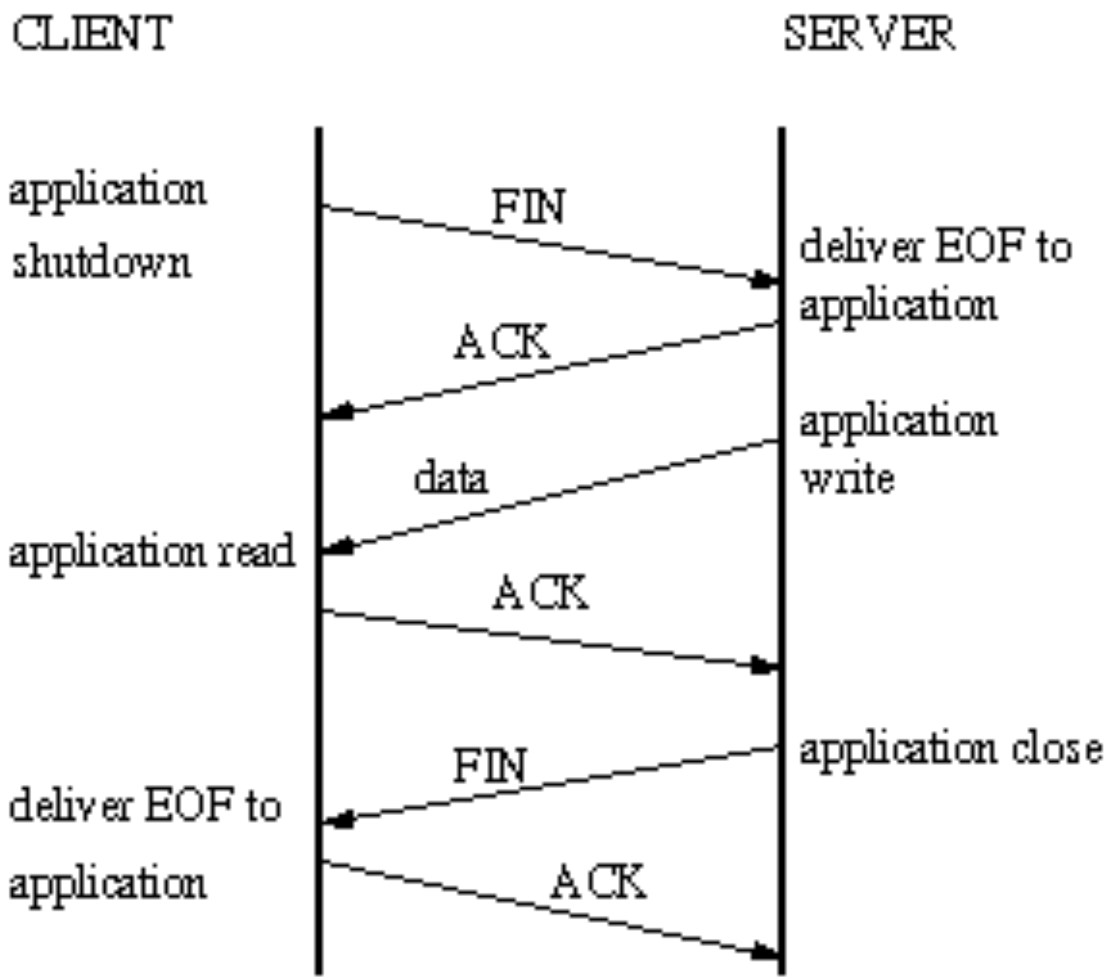



starting point
CLOSED
appl: passive open
send: <nothing>
timeout
send: RST
LISTEN
passive open
recv: SYN; send: SYN, ACK
recv: RST
appl: active open
send: SYN
appl: send data
send: SYN
SYN_RCVD
recv: SYN
send: SYN, ACK
simultaneous open
SYN_SENT
active open
appl: close
or timeout
recv: ACK
send: <nothing>
recv: SYN, ACK
send: ACK
appl: close
send: FIN
ESTABLISHED
data transfer state
recv: FIN
send: ACK
CLOSE_WAIT
appl: close
send: FIN
appl: close
send: FIN
LAST_ACK
recv: ACK
send: <nothing>
passive close
simultaneous close
FIN_WAIT_1
recv: FIN
send: ACK
CLOSING
recv: ACK
send: <nothing>
recv: FIN, ACK
send: ACK
recv: ACK
send: <nothing>
FIN_WAIT_2
recv: FIN
send: ACK
TIME_WAIT
2MSL timeout
active close
normal transitions for client
normal transitions for server
appl: state transitions taken when application issues operation
recv: state transitions taken when segment received
send: what is sent for this transition

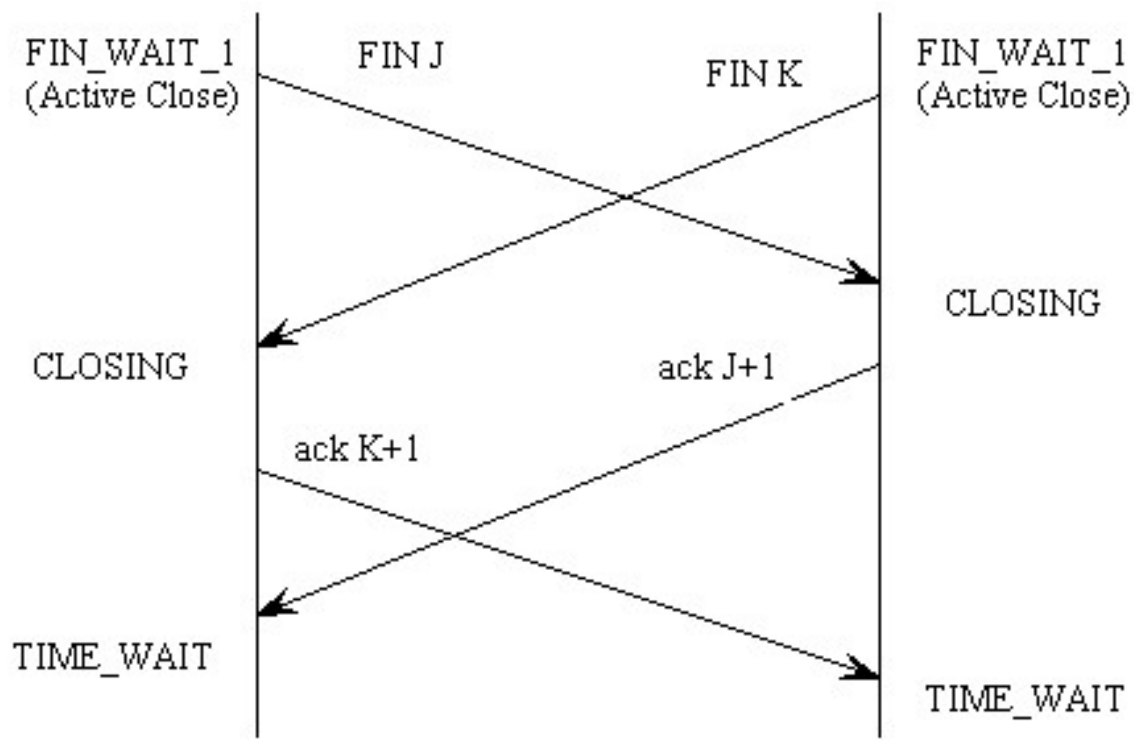
# Normal Operations



# TCP Allows Half-Close with Shutdown()

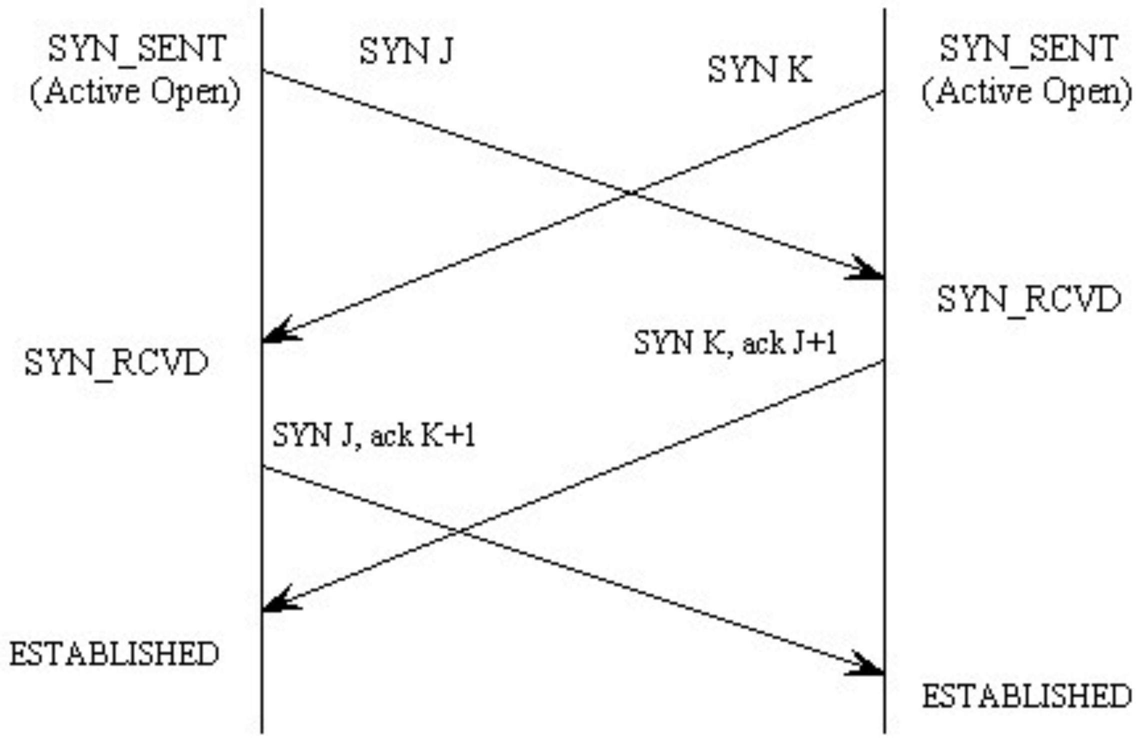


# Simultaneous Close Allowed




state transitions in simultaneous close

# BTW, Simultaneous Open is Possible Too




state transitions in simultaneous open

# The Time_Wait (2MSL) state

- *MSL* stands for *Maximum Segment Lifetime*
  - Common implementations are either 30sec, 1min, 2min
- Purposes of the 2MSL state
  - Let TCP resend the final ACK if needed (when?)
  - The socket can only be reused after 2MSL (why?)
    - Sometime you can’t bind a server port because of this 2MSL state
    - However, setting socket option SO_REUSEADDR allows us to reuse the port number (violation of RFC)
    - But still, no two identical socket quadruples
- “*Quiet time*” (RFC 793):
  - no connection creation within 2MSL after crashing (why?)

# RESET Segments

RST is used to

- Reply to connection requests to some port no-one is listening on
  - In UDP, an *ICMP port unreachable* is generated instead
- Reply to connection requests within 2MSL after crashing
- Abort an existing connection

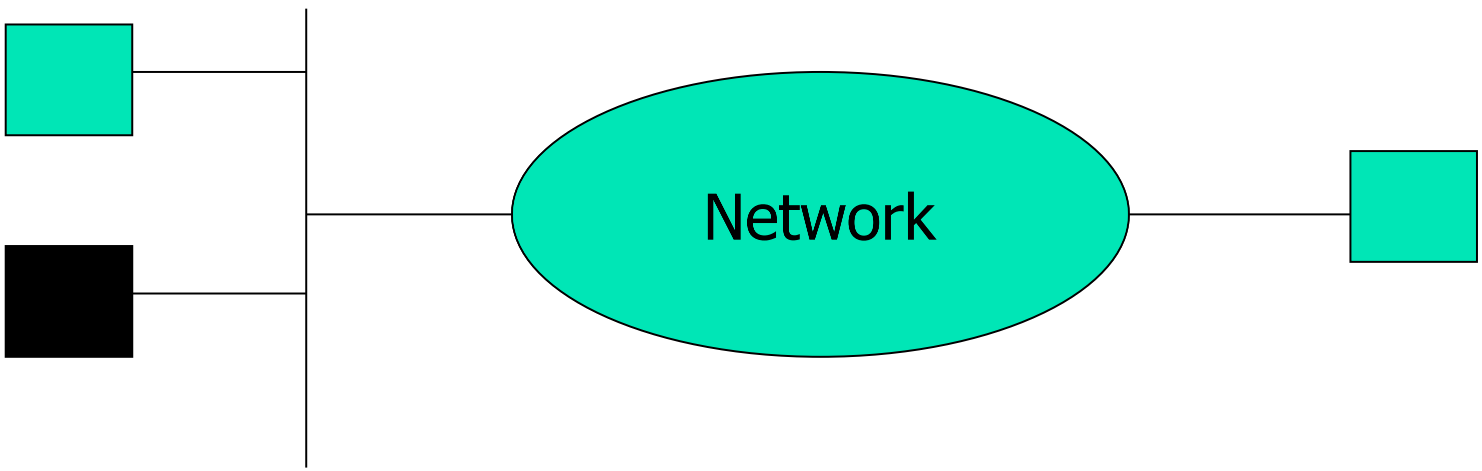
Note: RST has its own sequence number

# Crash Recovery

- After restart all state information is lost
- Connection is *half open*
  - Side that did not crash still thinks it is connected
- We should close connections using *keep-alive timer*
  - This is controversial: is TCP or application responsible?
  - *Implementation dependent*
- Crashed side (after reboot) sends *RST i* in response to any *segment i* arriving
- User must decide whether to reconnect
  - Problems with lost or duplicate data

# Tips and Tricks

- *TCP Connection Killing*
  - Using RST
  - Using FIN
  - Again, just need to know the right sequence number

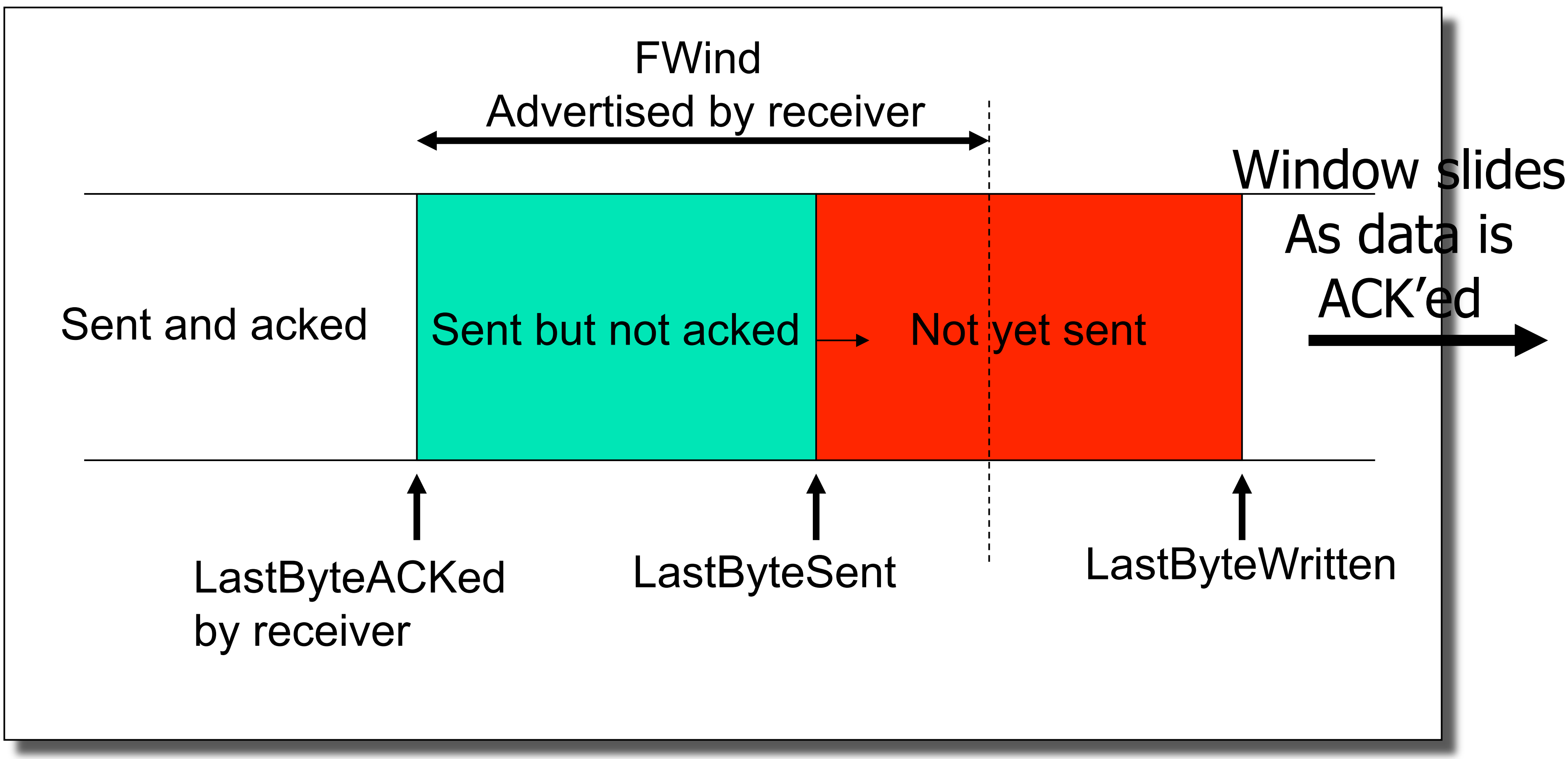


# 5. Flow Control in TCP

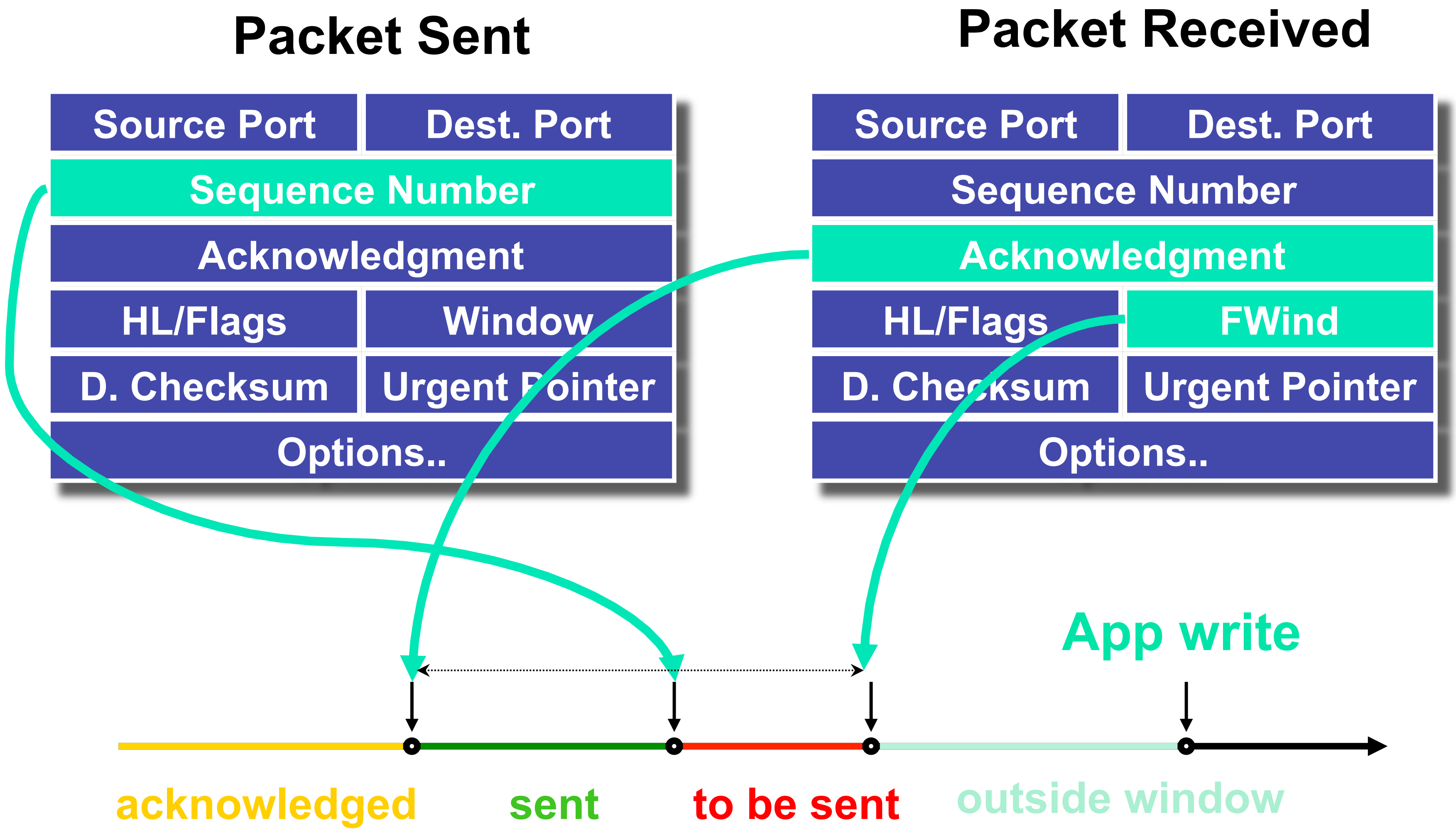
- *Flow Control*:
  - Avoid fast sender overflowing slow receiver

- Basic Mechanism:
  - Receiver advertises its available window size (FWind)
  - Sender ensures that
    LastByteSent – LastByteAcked ≤ FWind
  - FWind is re-advertised in packets flowing back

# TCP Flow Control: Sender Side

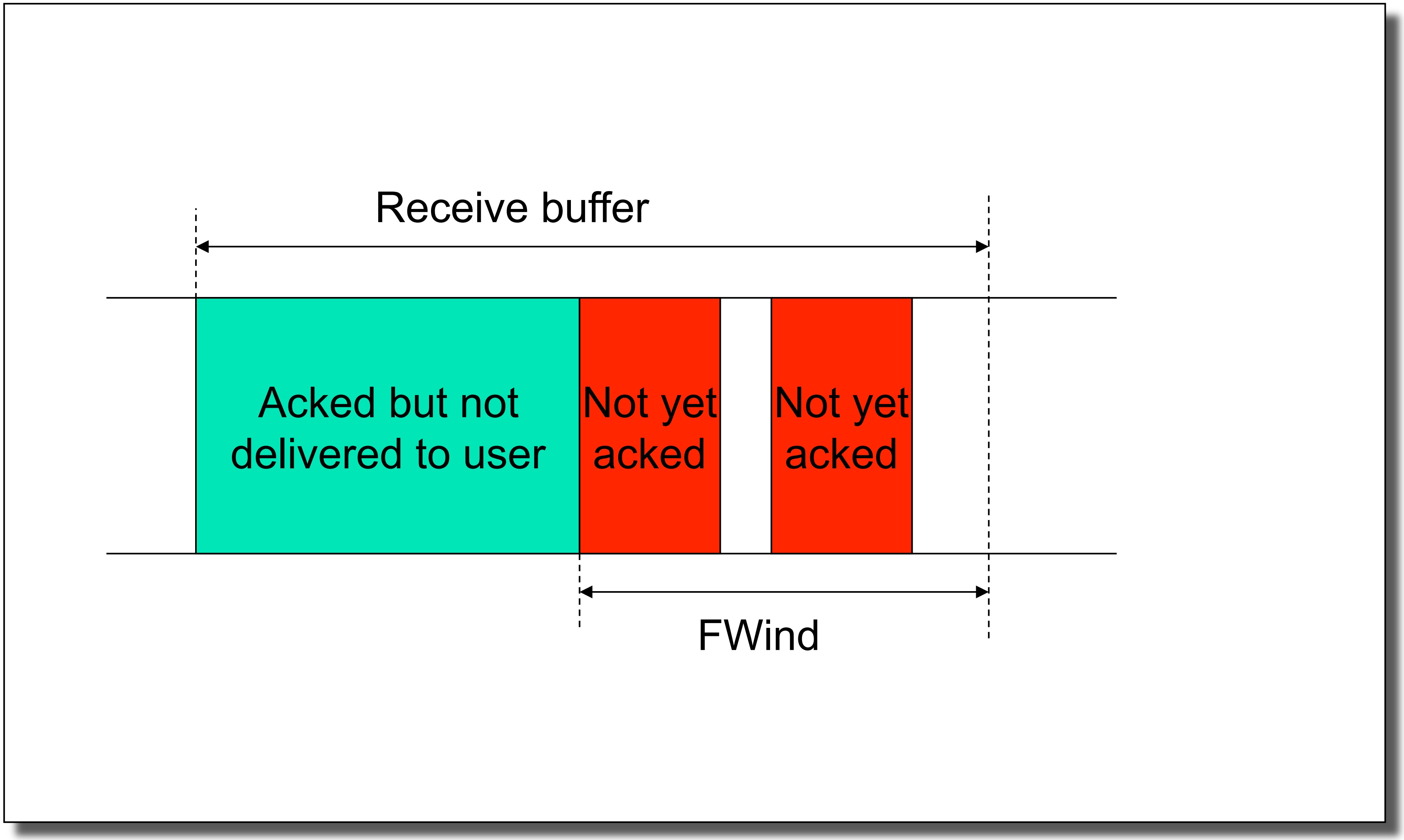


# TCP Flow Control: Sender Side




Picture taken and modified from **Shiv Kalyanaraman**'s slides

# TCP Flow Control: Receiver Side




Picture taken and modified from **Shiv Kalyanaraman**'s slides

# FWind Size In Practice

- Old implementations' default: 4KB
- Newer implementations: up to 16KB
- How large should it be, suppose we have plenty of memory and receiver's CPU is infinitely fast?
- Recall the *bandwidth-delay product*:
  - RTT x transmission rate
  - For T1 link across US: 60ms x 1.544M bps → 11.58 KB
  - For T3 link across US: 60ms x 45 Mbps → 337.5 KB
  - Note: *337.5 KB >> 16-bit window size ≈ 65KB*
  - For OC-12 link across US: 60ms x 622 Mbps → 4.7MB
- Solution: use the Window Scale option

# Technical Issues with Flow Control

A. *Deadlock*
   - Can deadlock occur with current flow control mechanism?

B. Performance tuning for *interactive data flow*
   - telnet, SSH, Rlogin, …, 10% of TCP segments (with a few to tens of data bytes per segment)

C. Performance tuning for *bulk data flow*
   - FTP, Email, HTTP, …, 90% of TCP segments (with hundred of data bytes)

# A. Deadlock & TCP Persistence Timer

- To prevent deadlock, *persistence timer* is used to send *window probes*
  - Normal segment with just *one* byte of data (past current window)
  - Host required to respond to data sent past window

- Exponential back-off is used for persistence timer
  - Start with 1.5 seconds
  - Double every time up to 60 seconds

# Tips and Tricks

- Talking about interactive data flows: how fast can people type?
- Guinness record is about *190 wpm* (Natalie Lantos, 1999)
  - If each word has 5 letters on average, then it is about 950cpm or 15.8 characters per second.
  - If each word has 10 letters on average, then it's still only about 31 characters per second! (or ~ 1 byte for each 32ms, twice longer than typical local RTT)

# B. TCP Interactive Data Flow

- Data might be sent 1 byte at a time
- Heuristics to improve performance for interactive data flow?
  - *Delayed ACK* (200ms, or every other segment)
  - *Nagle Algorithm*: try to delay sending "small" segments until outstanding data is acknowledged or a full-sized segment is available
    - *This algorithm is self-clocking!*
    - In an Ethernet with RTT ≈ 16ms, would Nagle algorithm have any effect for an interactive data flow ?
    - Sometime Nagle needs to be turned off (e.g. for X-server, each mouse movement needs to be reported), using TCP_NODELAY socket option

# Nagle's Algorithm in More Details

Sender does not transmit unless one of the following conditions is true:

- a full-sized segment can be sent
- at least ½ of the maximum FWind which has ever been advertised
- no outstanding unacknowledged data

*What are the pros and cons of Nagle's algorithm?*

# Silly Window Syndrome

- Receiver advertises small FWind gradually
  - Suppose starting from FWind=0, application reads 1 byte of data at a time, slowly
  - Sender then would send a few bytes at a time, wasting lots of header overhead

- Symmetric to Nagle's algorithm, we can impose the following rule (*David Clark's algorithm*)
  - receiver should not advertise larger window than the current FWind until FWind can be increased by min(MSS, ½ buffer space)

# C. Bulk Data Flow

- Sliding window with scale option
- Delayed ACK also helps