南京大学 软件学院
NANJING UNIVERSITY · SOFTWARE INSTITUTE

Transport Layer

OSI Layer 4: Transport Layer

- An overview of layer 4
- TCP (Transmission Control Protocol)
- UDP(User Datagram Protocol)
- An application: NAT and PAT

OSI Layer 4: Transport Layer

- Layer 4 performs multiple functions:
  - segmenting upper-layer application data
  - establishing end-to-end operations
  - sending segments from one end host to another
  - Flow control and reliability
    - can be compared to talking to a foreigner.
    - Often you would ask the foreigner to repeat his/her words (reliability) and to speak slowly (flow control)

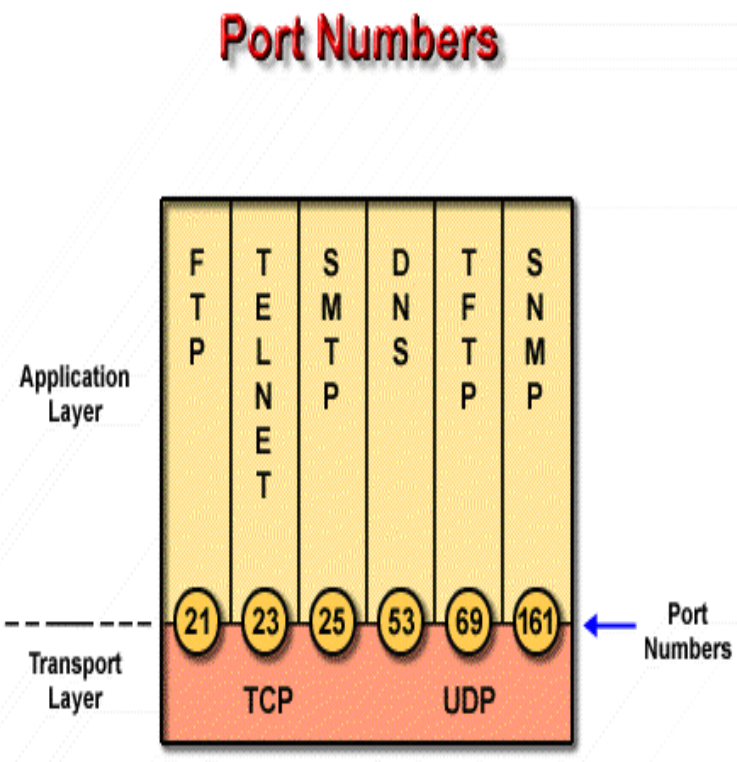
Layer 4: The Transport Layer

- Two particularly important Layer 4 protocols:
  - Transmission Control Protocol (TCP)
  - User Datagram Protocol (UDP)

Layer 4: The Transport Layer

- Divide outgoing messages into segments
- Reassemble messages at the destination station
- *TCP* : reliable
  - Connection -oriented
  - Software checking for segment
  - Re-send anything lost or error
  - Uses acknowledgments
  - Provides flow control
- *UDP:* unreliable
  - connectionless
  - provides no software checking for segment
  - uses no acknowledgments
  - provides no flow control

Service Model



- Both TCP and UDP use *port* to keep track of different conversations that cross the network at the same time
- Application software developers have agreed to use the well-known port numbers that are defined in RFC1700
- Port numbers below 255 are reserved for TCP and UDP public applications.

Socket

- Socket is presented as (IP_address, port)
- Every connection is expressed as ($socket_{source}$, $socket_{destination}$), which is a point-to-point full-duplex channel
- TCP does not support multicast and broadcast

Layer 4: The Transport Layer

- An overview of layer 4
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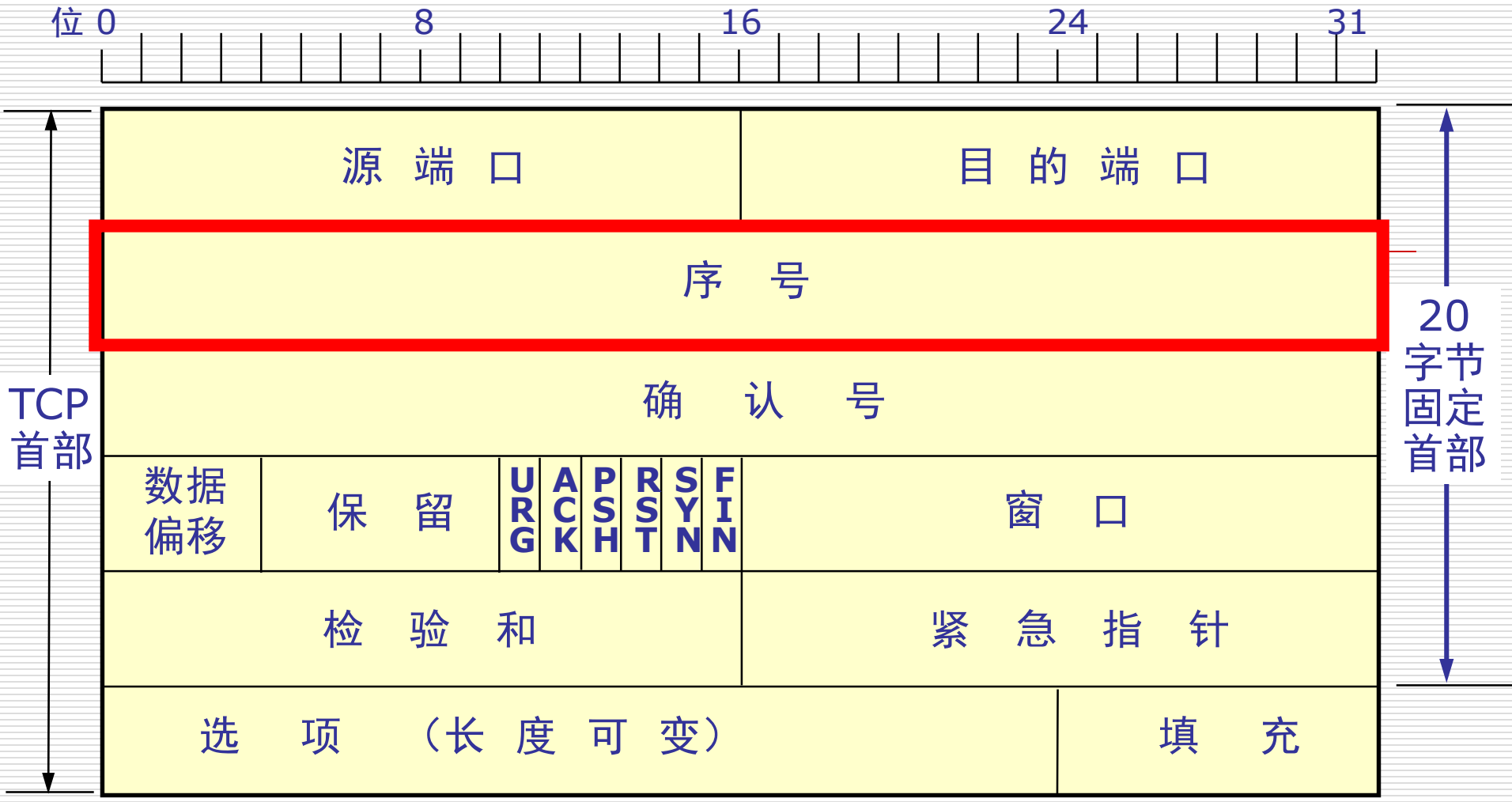
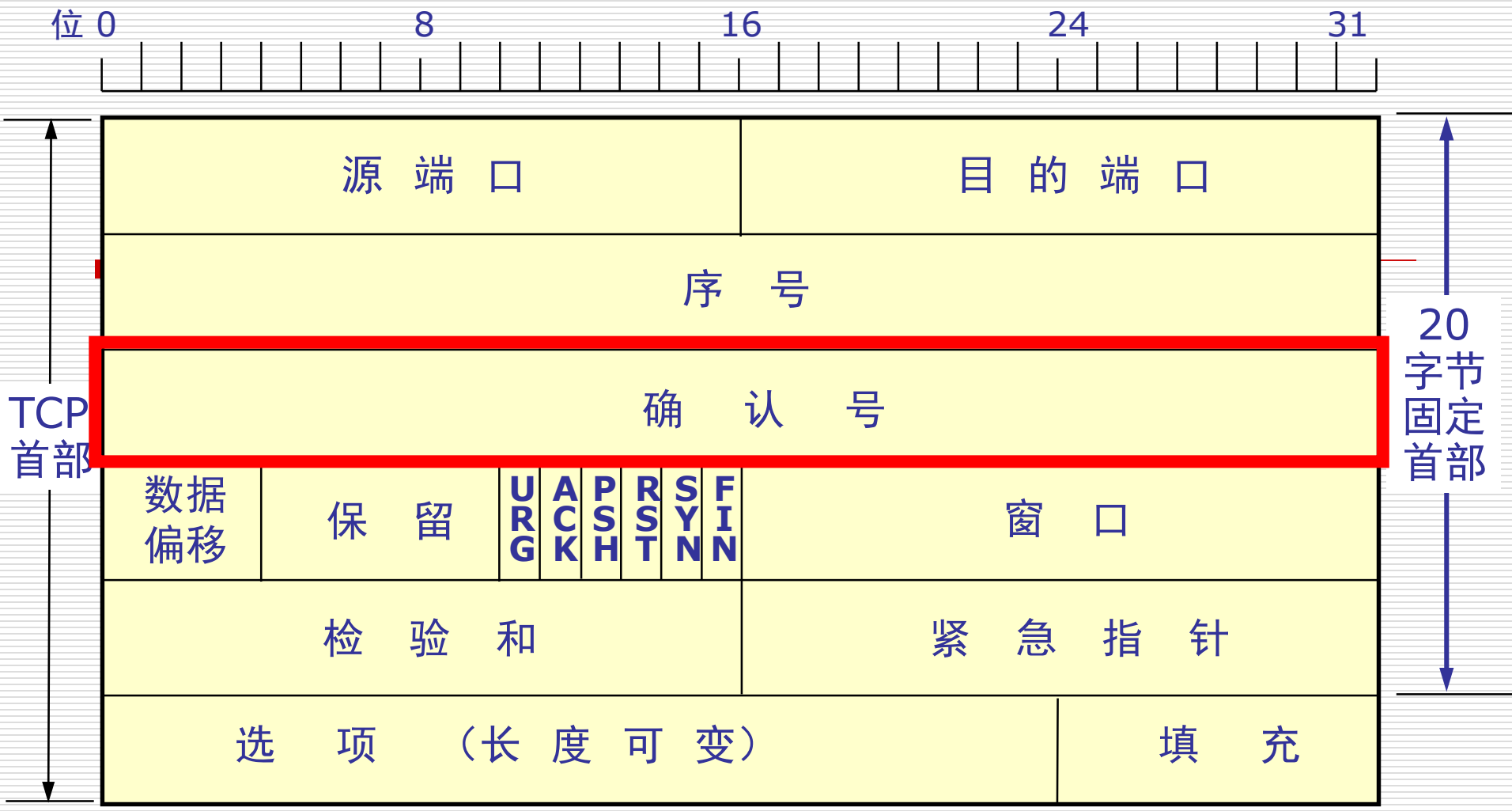
TCP Service Model

- Problems must be solved in TCP:
  - Reliable transfer
  - Flow control
    - Sliding window
    - congestion avoidance…
  - Connection management
    - Establish connection：three handshakes
    - Release connection： four handshakes

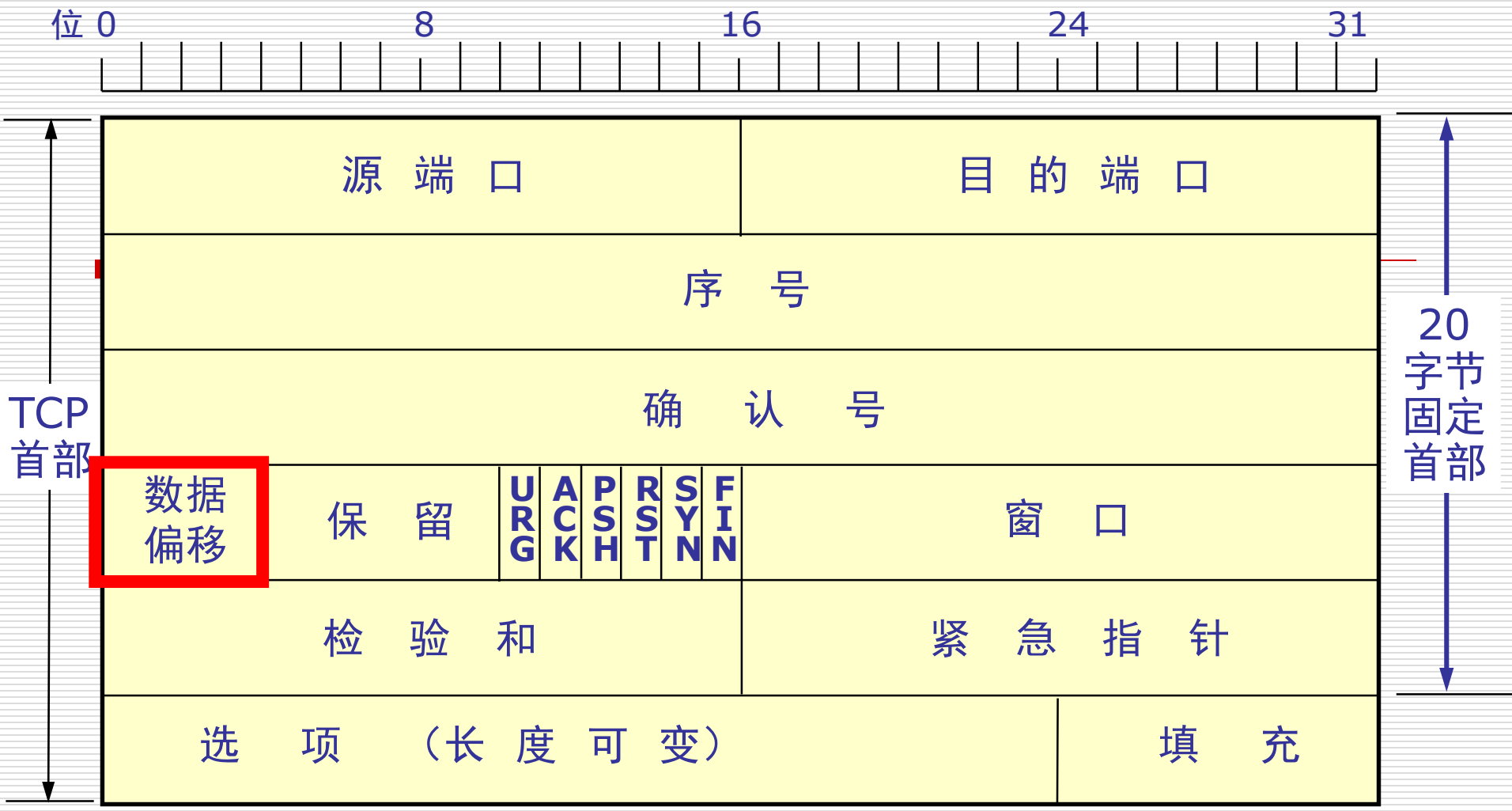
- 源端口和目的端口字段——各占 2 字节
- 端口是运输层与应用层的服务接口
- 运输层的复用和分用功能都要通过端口才能实现



- 序号字段——占 4 字节
- TCP 传送的数据流中的每一个字节都编上一个序号
- 序号字段的值指本报文段所发送的数据的第一个字节的序号

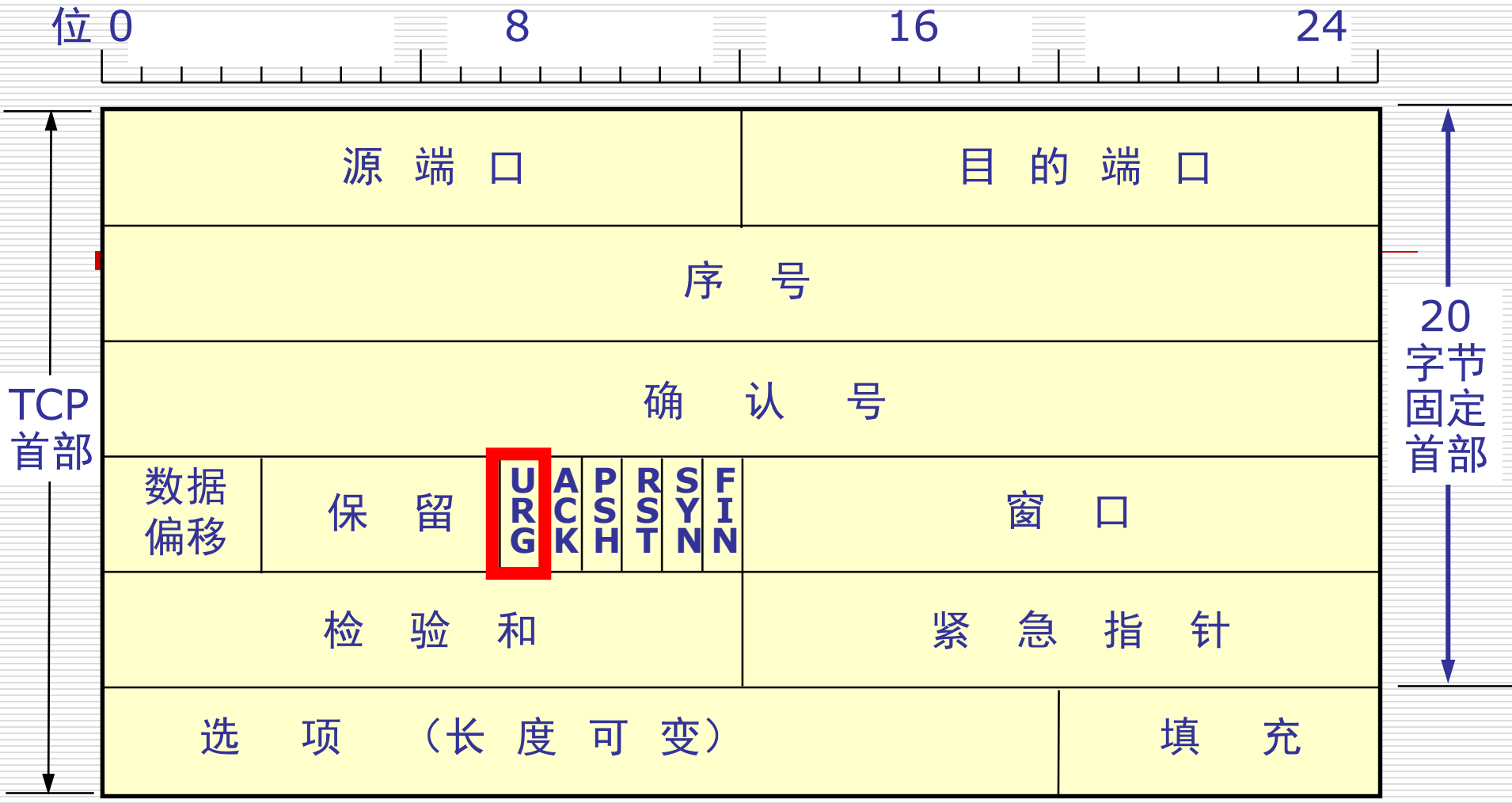


- 确认号字段——占 4 字节，是期望收到对方的下一个报文段的数据的第一个字节的序号

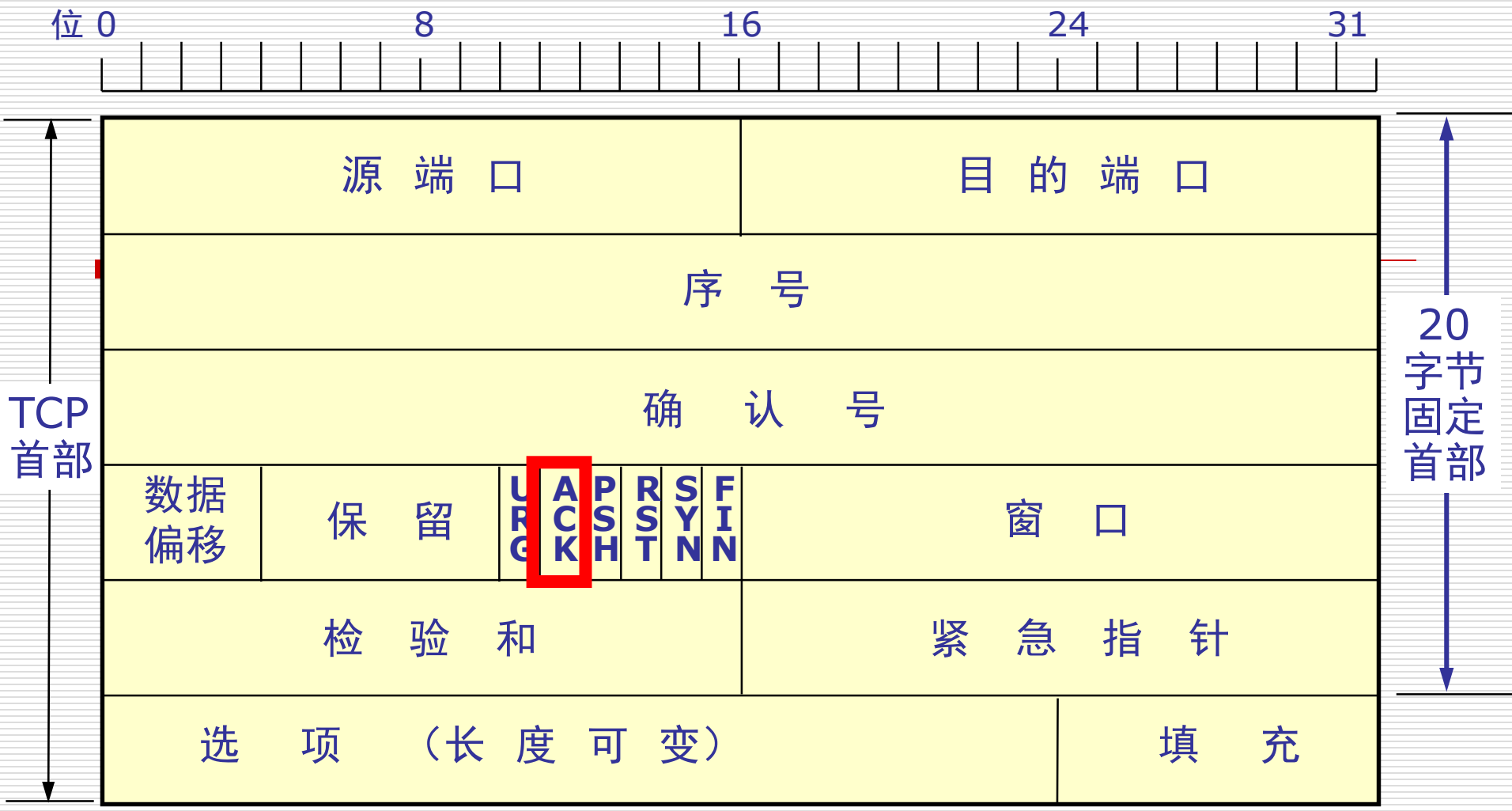


- 数据偏移（即首部长度）——占 4 位
- 指出 TCP 报文段的数据起始处距TCP 报文段的起始处的长度
- 单位是 32 位字（以 4 字节为计算单位）

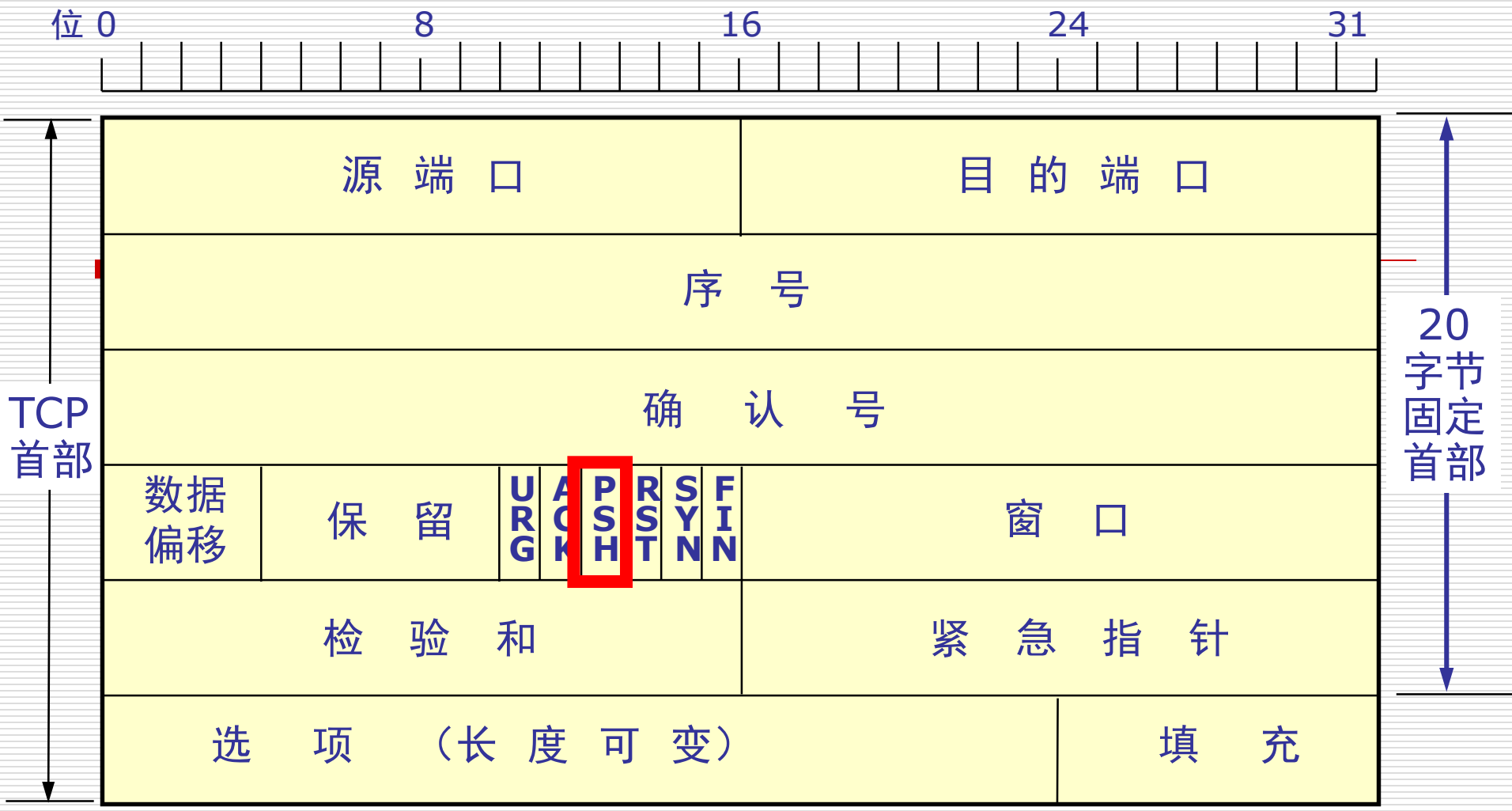
- 保留字段——占 6 位，保留为今后使用，目前置 0



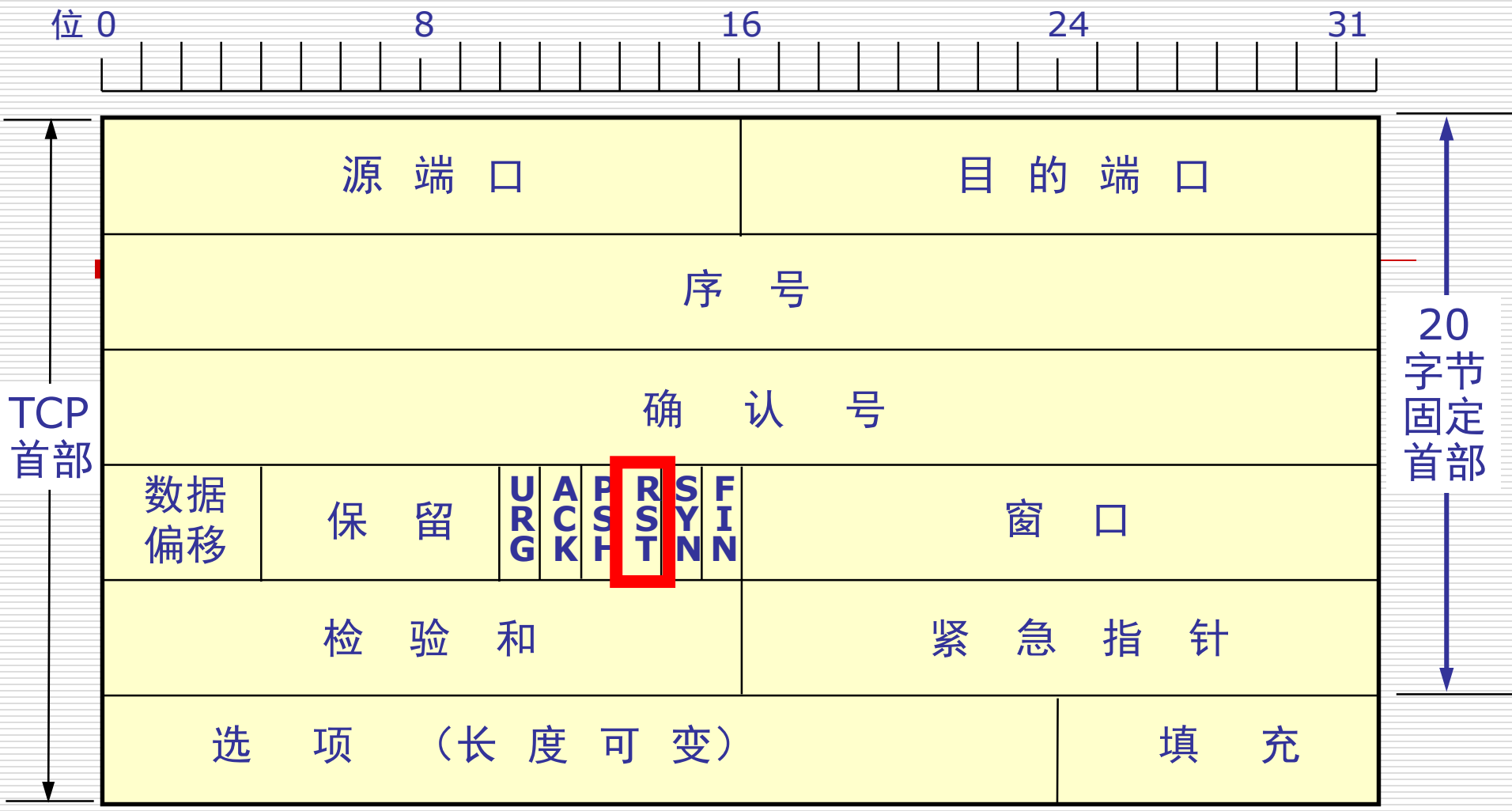
- 紧急 URG = 1 时，表明紧急指针字段有效
- 告诉系统此报文段中有紧急数据，应尽快传送(相当于高优先级的数据)



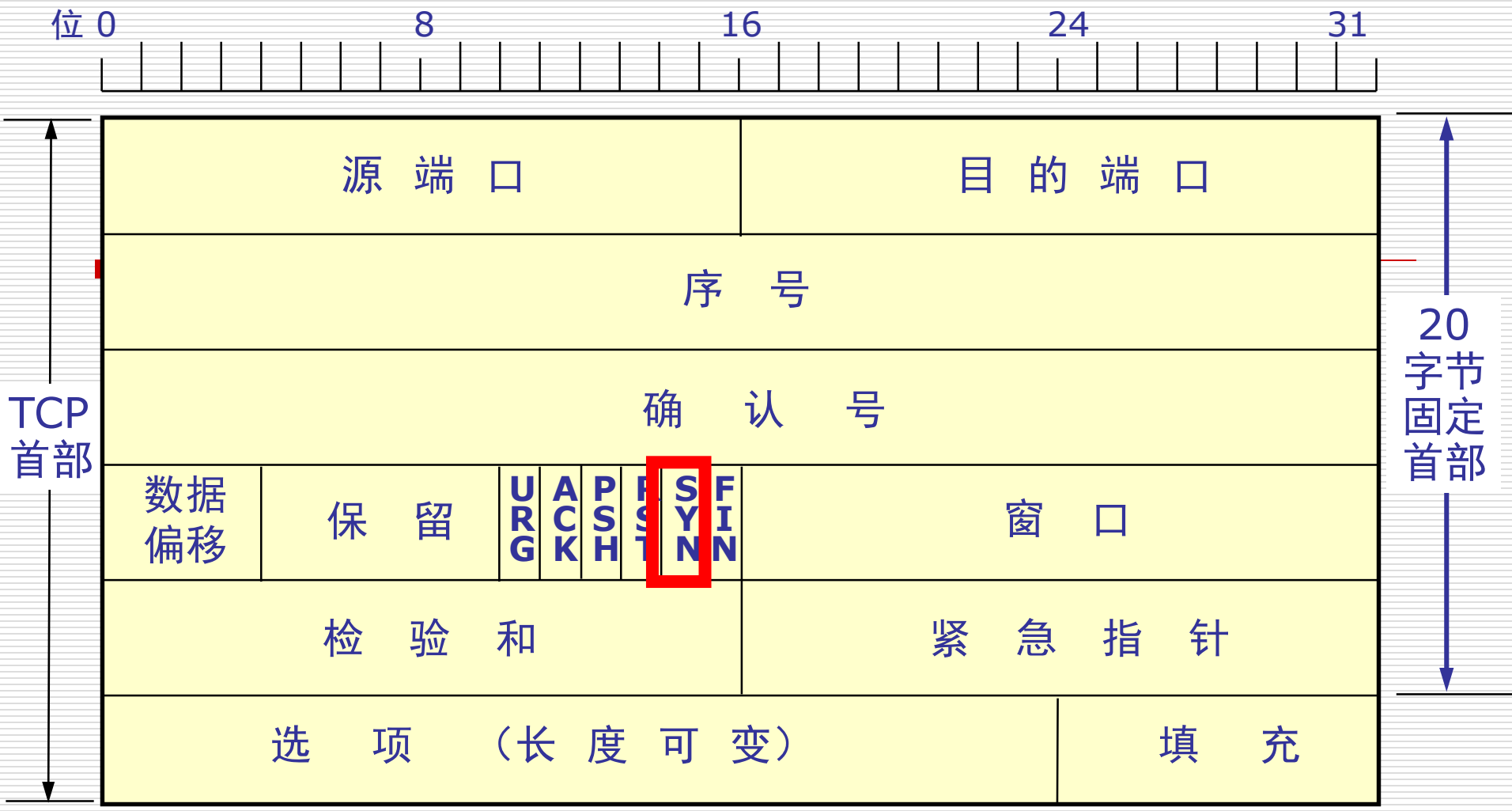
- ACK = 1 时确认号字段有效
- ACK = 0 时确认号字段无效



- 推送 PSH (PuSH) —— 接收 TCP 收到 PSH = 1 的报文段，就尽快地交付接收应用进程，而不再等到整个缓存都填满了后再向上交付

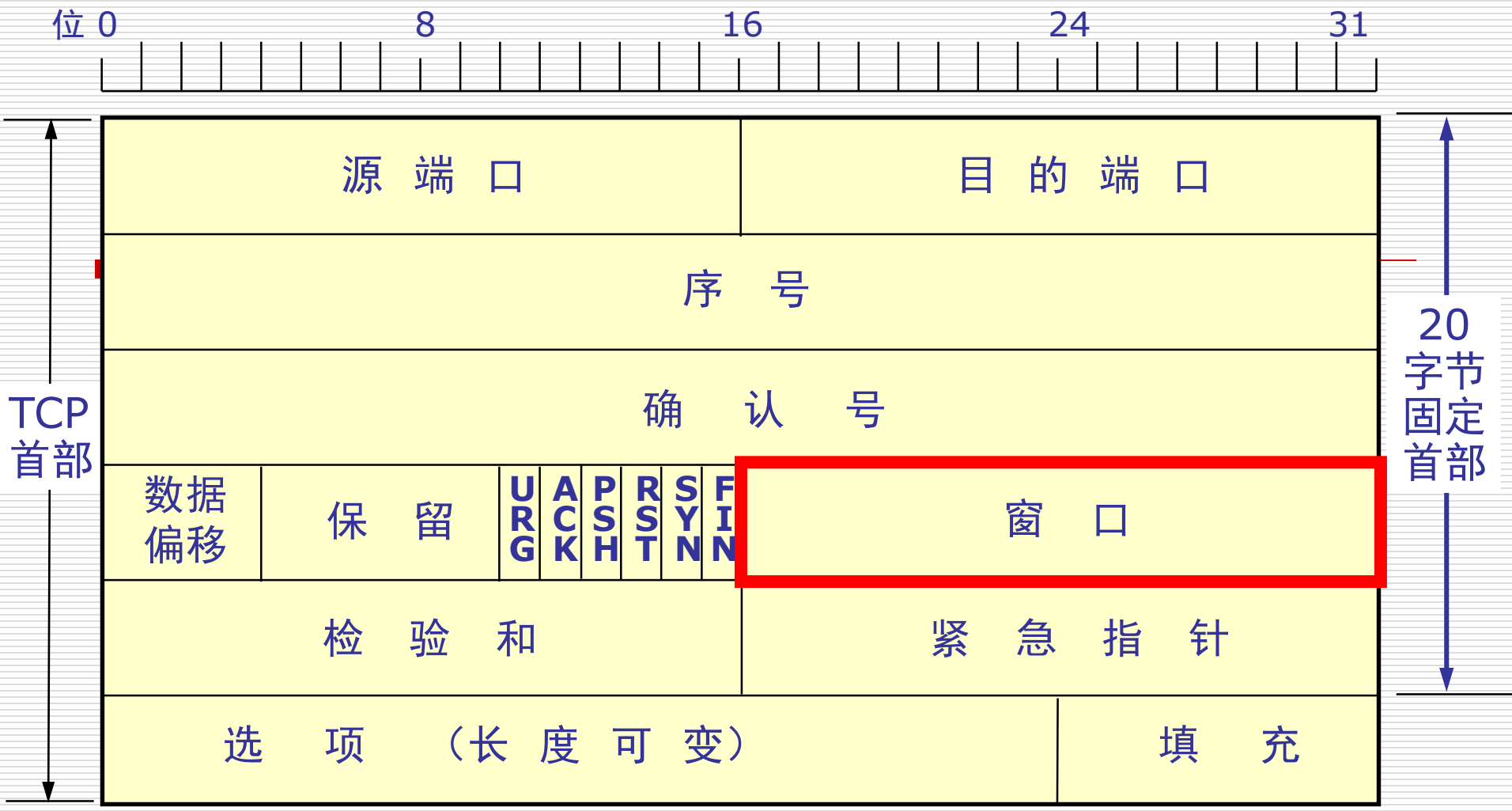


- 复位 RST (ReSeT= 1 时，表明 TCP 连接中出现严重差错（如由于主机崩溃或其他原因），必须释放连接，然后再重新建立运输连接



- 同步 SYN=1 表示这是一个连接请求或连接接受报文

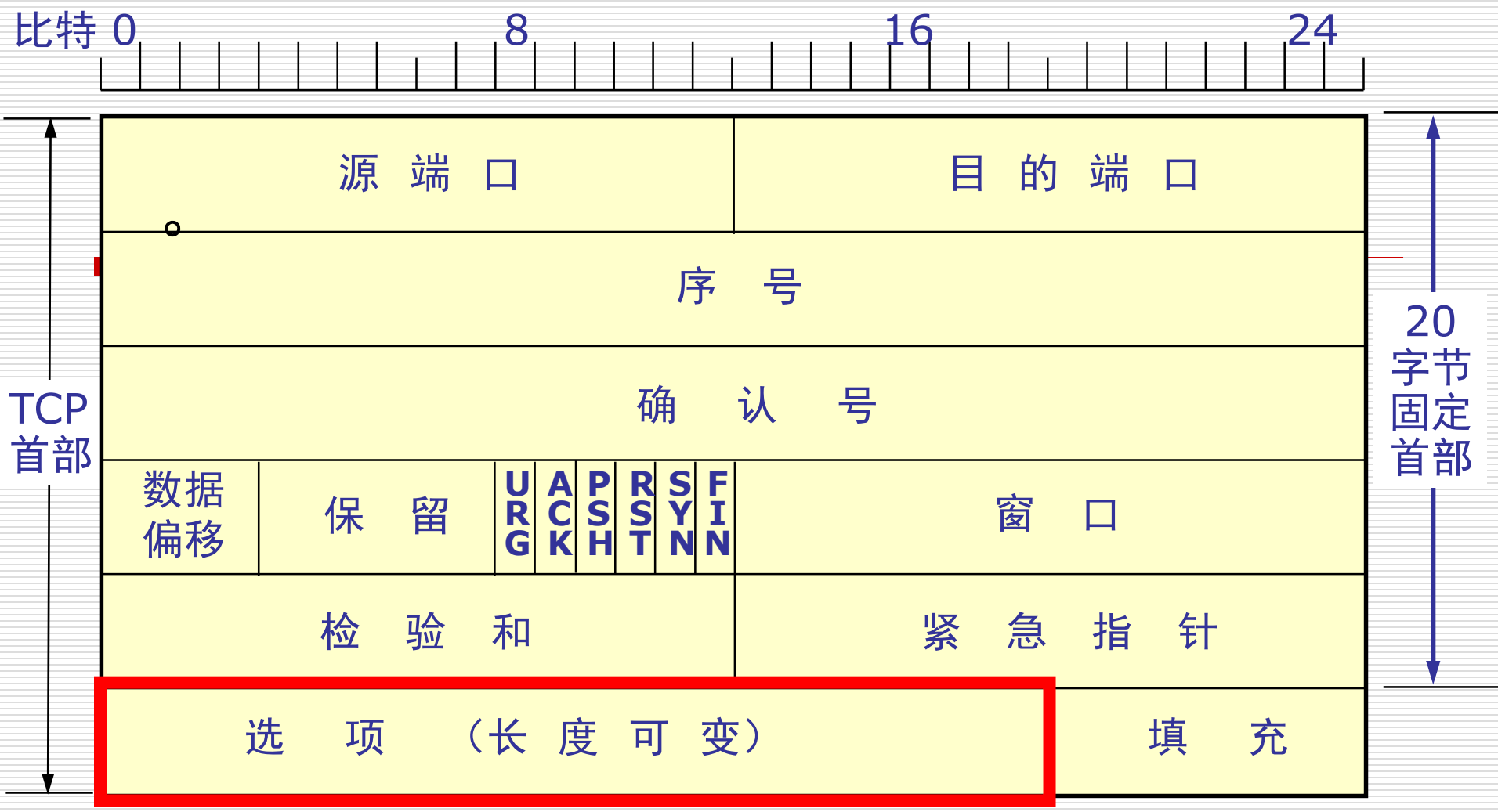
- 终止 FIN (FINis) —— 用来释放一个连接。FIN = 1 表明此报文段的发送端的数据已发送完毕，并要求释放运输连接。



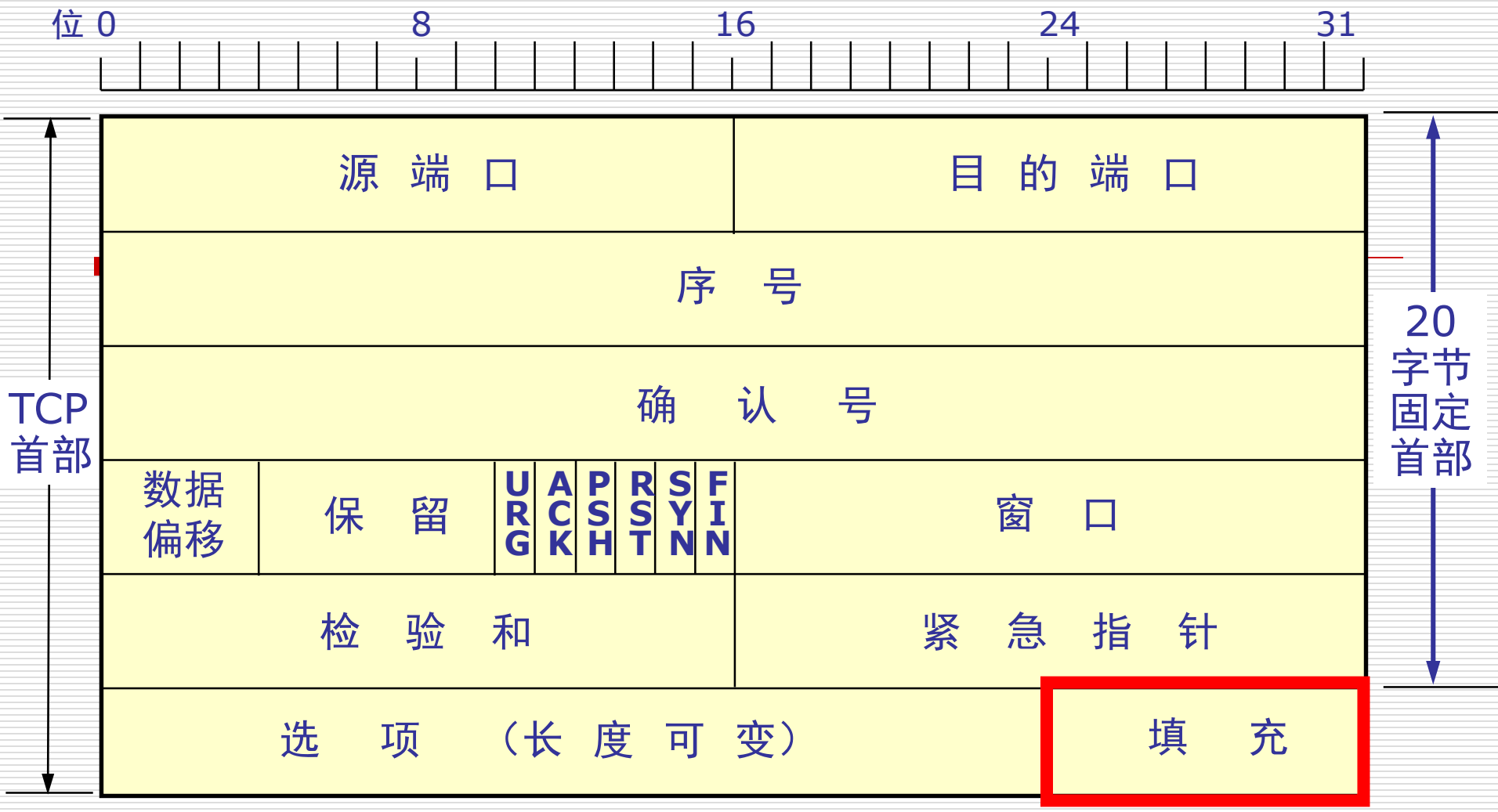
- 窗口字段 —— 占 2 字节，用来让对方设置发送窗口的依据，单位为字节。

- 检验和 —— 占 2 字节。检验和字段检验的范围包括首部和数据这两部分

- 紧急指针字段 —— 占 16 位，指出在本报文段中紧急数据共有多少个字节（紧急数据放在本报文段数据的最前面）



- TCP 最初只有一种选项，即最大报文段长度 MSS(Maximum Segment Size)
- MSS 告诉对方缓存所能接收的报文段的数据字段的最大长度是 MSS 个字节
- 数据字段加上 TCP 首部才等于整个的 TCP 报文段

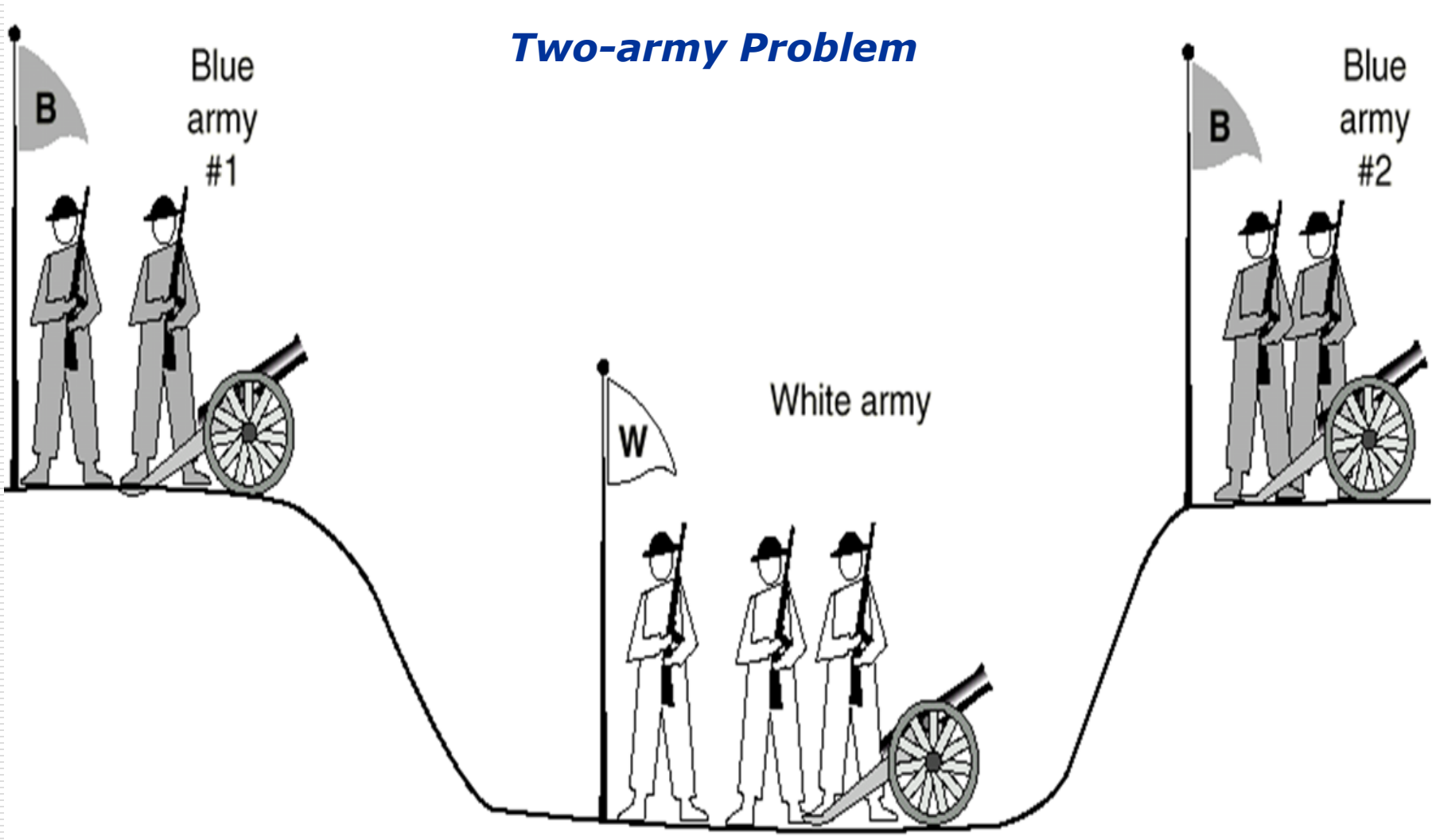


- 填充字段 —— 这是为了使整个首部长度是 4 字节的整数倍。

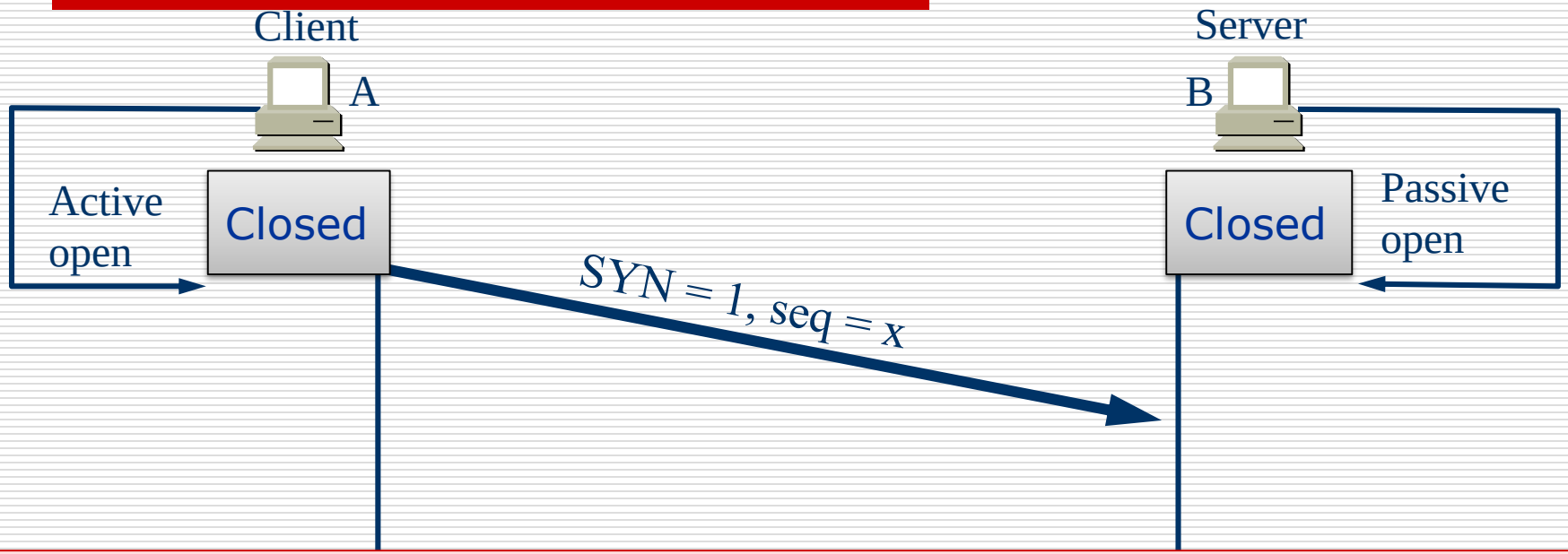
TCP Protocol

- Hosts exchange data by using segment(TPDU)
- Each segment has:
  - a header of 20 bytes(except optional parts)
  - 0 or more data bytes
- The size of the segment must be matched with IP packets, and also must satisfy the demand of bottom layers
  - For example, the MTU(Maximal Transfer Unit) of Ethernet is 1500 bytes
- Each byte has a 32 bits sequence number

Reliable Connection?

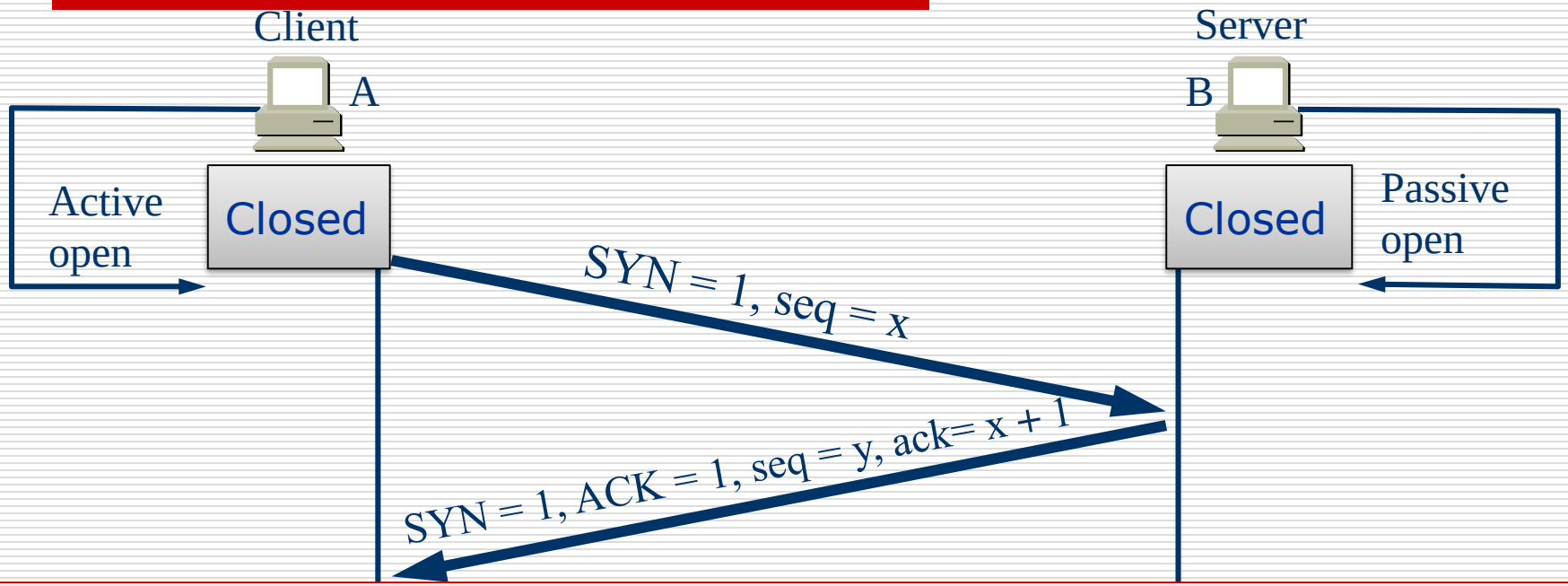


TCP: Establish Connection



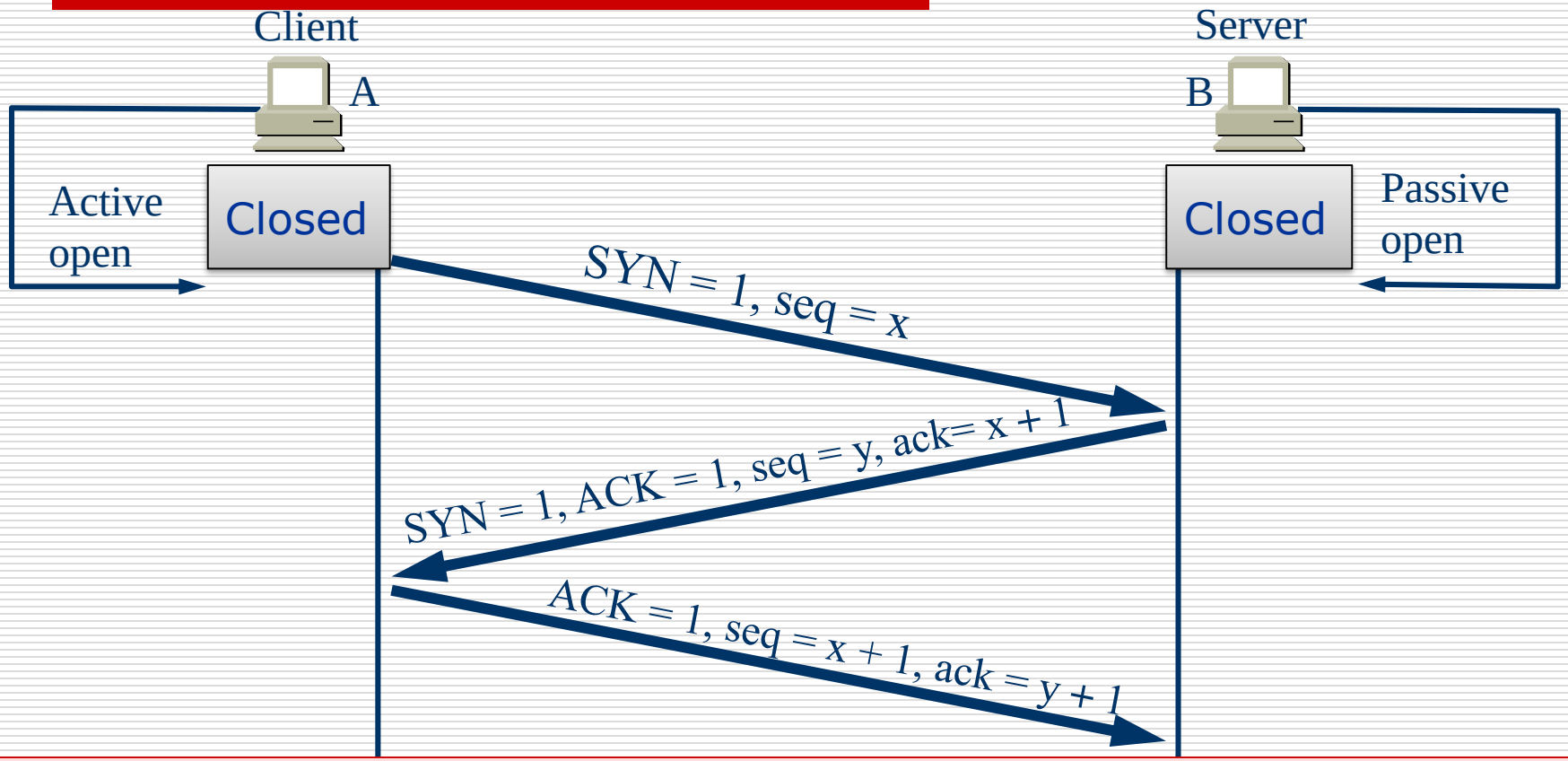
- ***The First Handshake***
  - Server: executes LISTEN and ACCEPT primitive, and monitors passively
  - Client: executes CONNECT primitive, generate a TCP segment with SYN=1 and ACK=0,which stands for connection request

TCP: Establish Connection



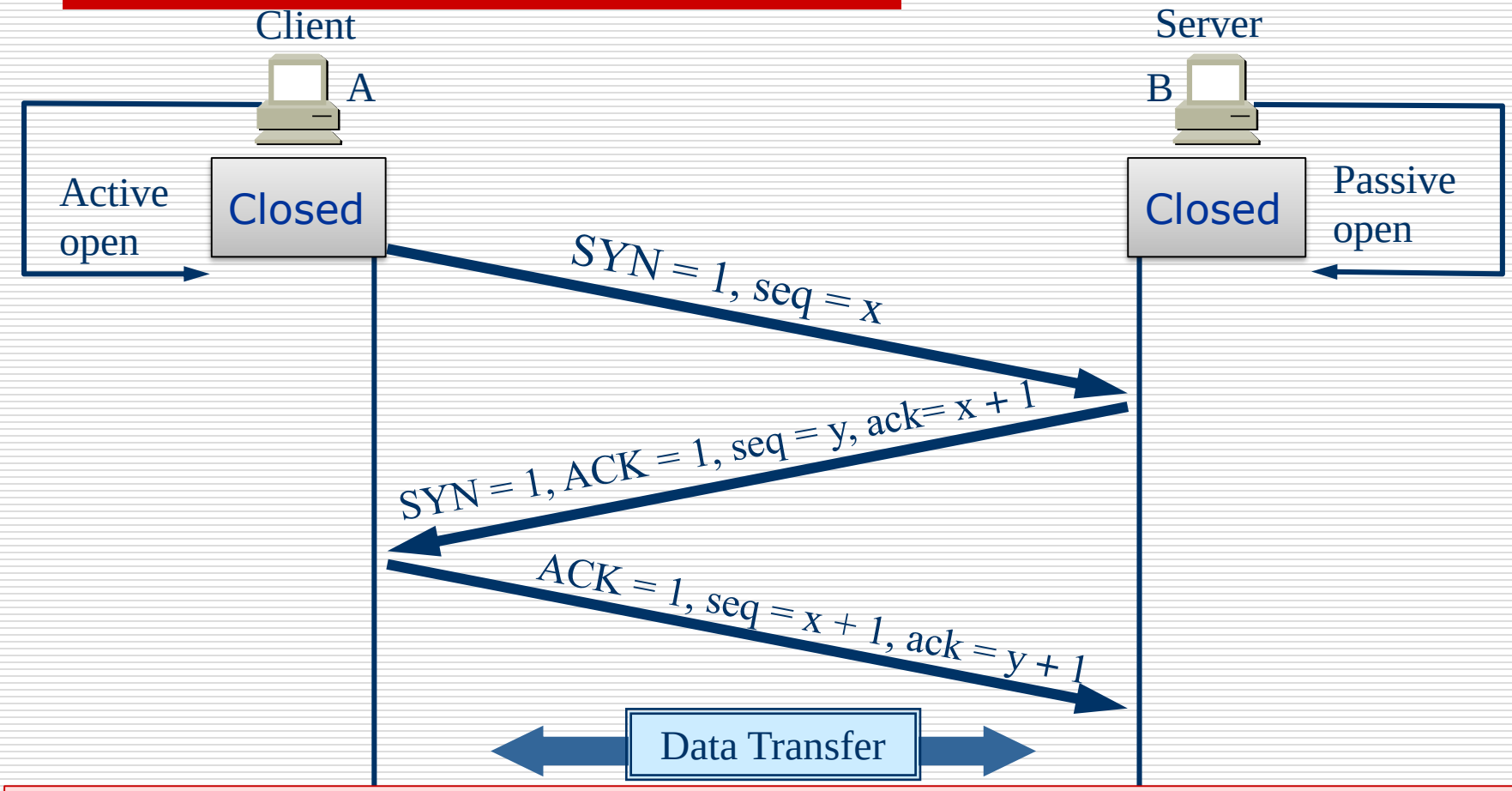
- ***The Second Handshake***
  - Server checks if exists service process monitoring the port
    - If none process, answer a TCP segment with RST=1
    - If exists process, decides to reject or to accept the request
    - If accept the connection request, send a segment with SYN=1 and ACK=1

TCP: Establish Connection



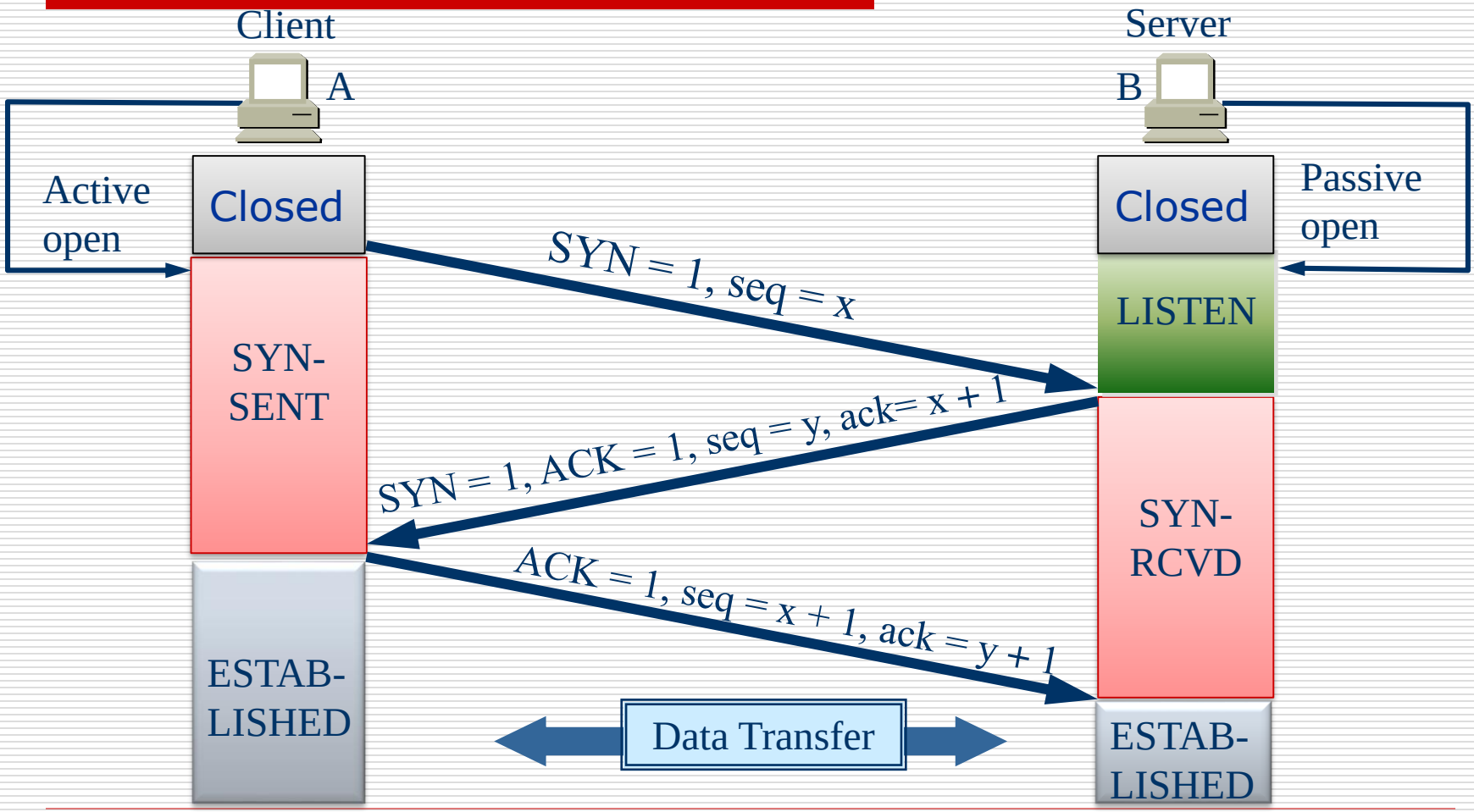
- ***The Third Handshake***
  - The client sends a segment with SYN=0 and ACK=1 to acknowledge the connection

TCP: Establish Connection



- When the server receives the acknowledgement, it informs the upper layer applications

TCP: Establish Connection



Example: Establish Connection

TCP A TCP B

1. CLOSED LISTEN

2. SYN-SENT --> <SEQ=100><CTL=SYN> --> SYN-RECEIVED

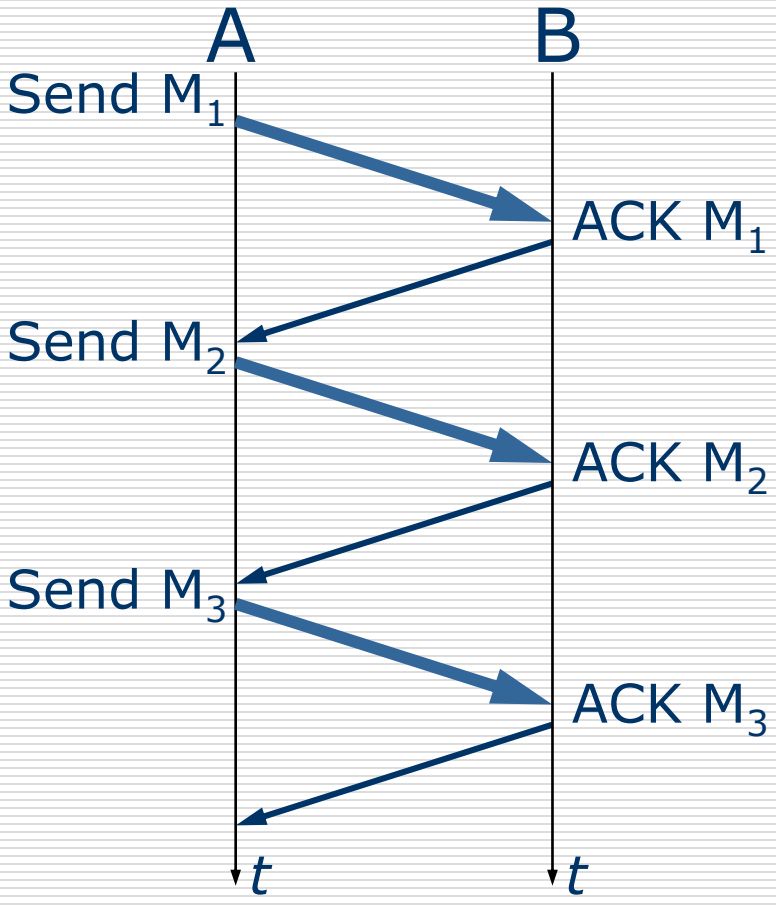
3. ESTABLISHED <-- <SEQ=300><ACK=101><CTL=SYN,ACK> <-- SYN-RECEIVED

4. ESTABLISHED --> <SEQ=101><ACK=301><CTL=ACK> --> ESTABLISHED

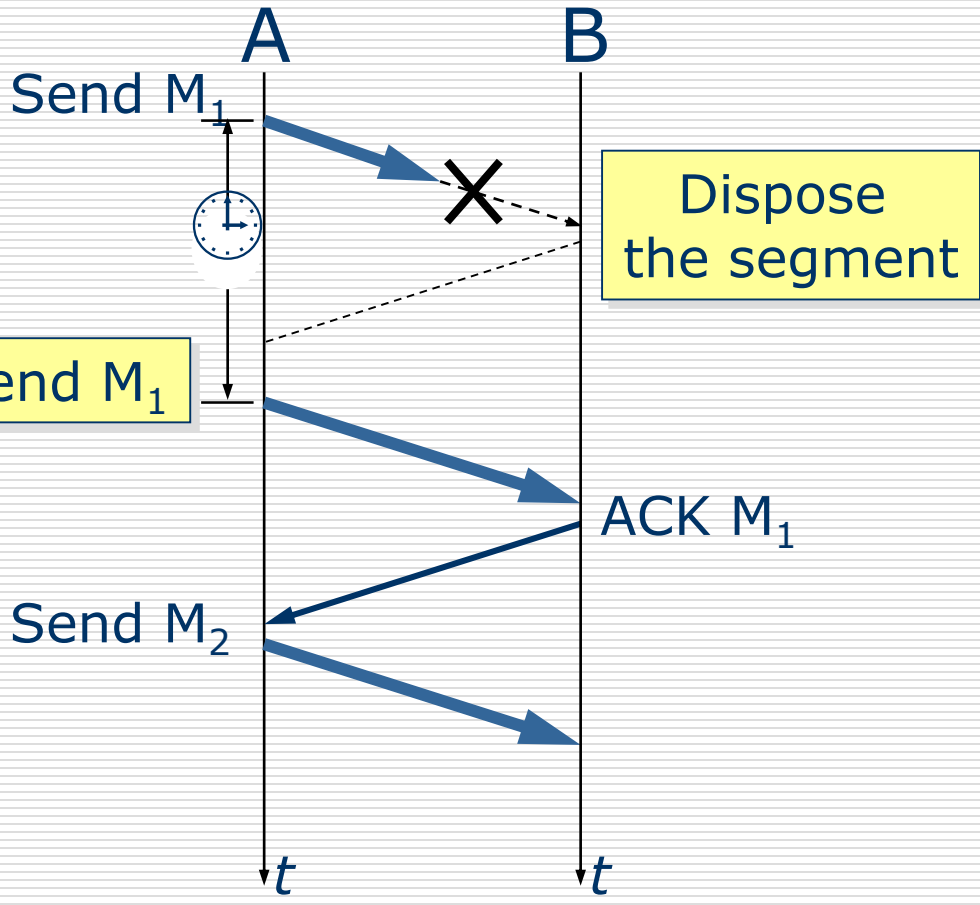
5. ESTABLISHED --> <SEQ=101><ACK=301><CTL=ACK><DATA> --> ESTABLISHED

- **Basic 3-Way Handshake for Connection Synchronization**
- **Note that the ACK does not occupy sequence number space (if it did, we would wind up ACKing ACK's!)**

Data transfer
——stop-and-wait protocol



(a) No error

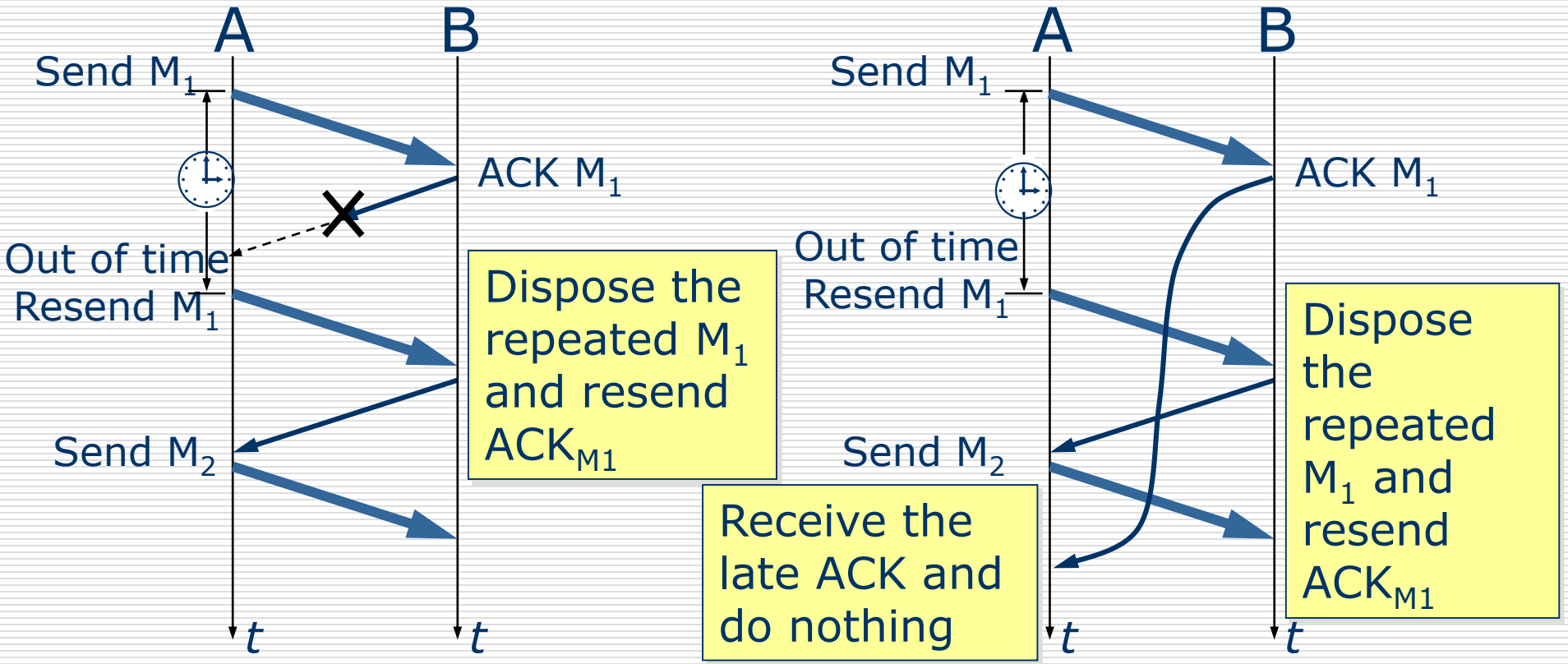


(b) Out of time

Data transfer ——stop-and-wait protocol

- After sending a segment, preserve a backup temporarily
- Each segment and ACK must have ID
- The resend-time must be more than average-travel-time *2
- stop-and-wait protocol is a simple protocol, but has poor efficiency

Data transfer
——Lost ACK and Late ACK



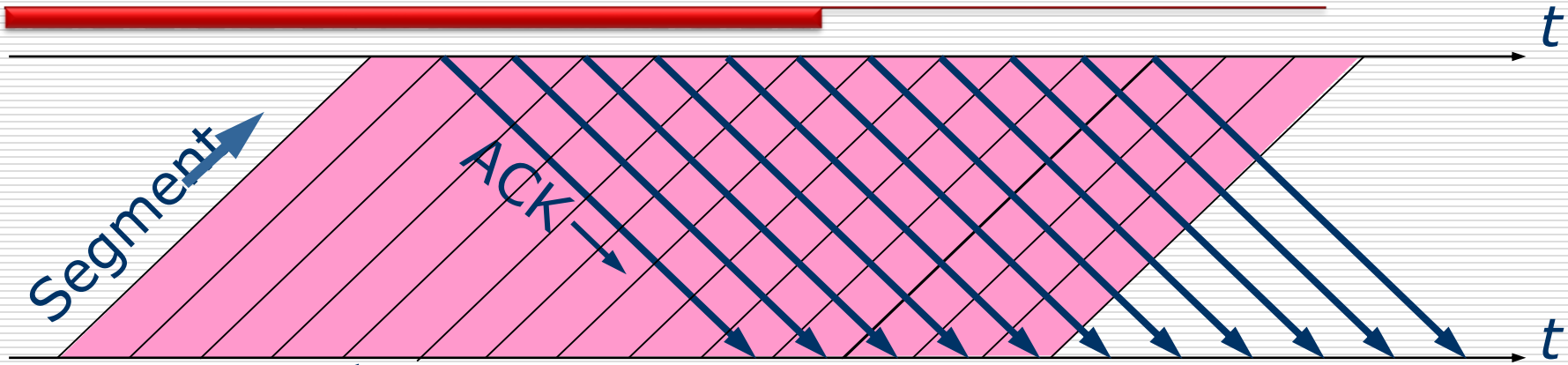
(a) Lost ACK

(b) Late ACK

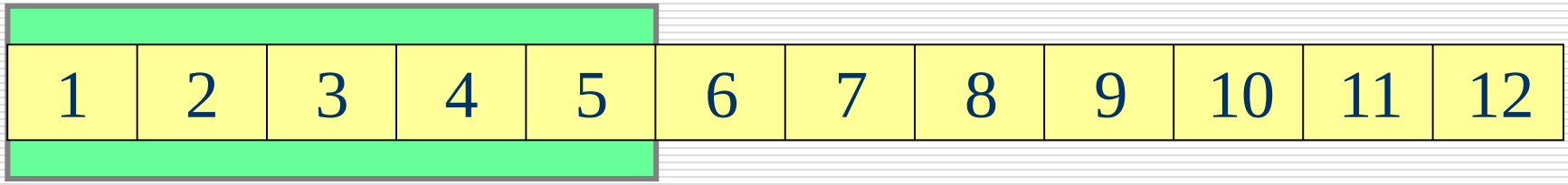
Reliable Communication

- ARQ (Automatic Repeat reQuest)。
  - It means the ‘resend request’ is automatically sent and the receiver need not request the sender to resend the error segment

Contiguous ARQ Protocol



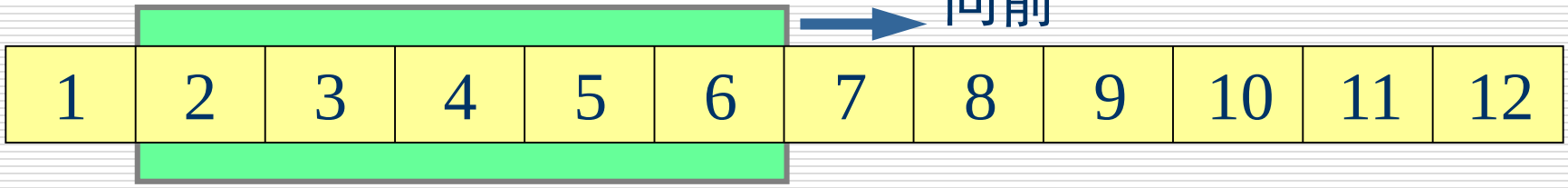
发送窗口



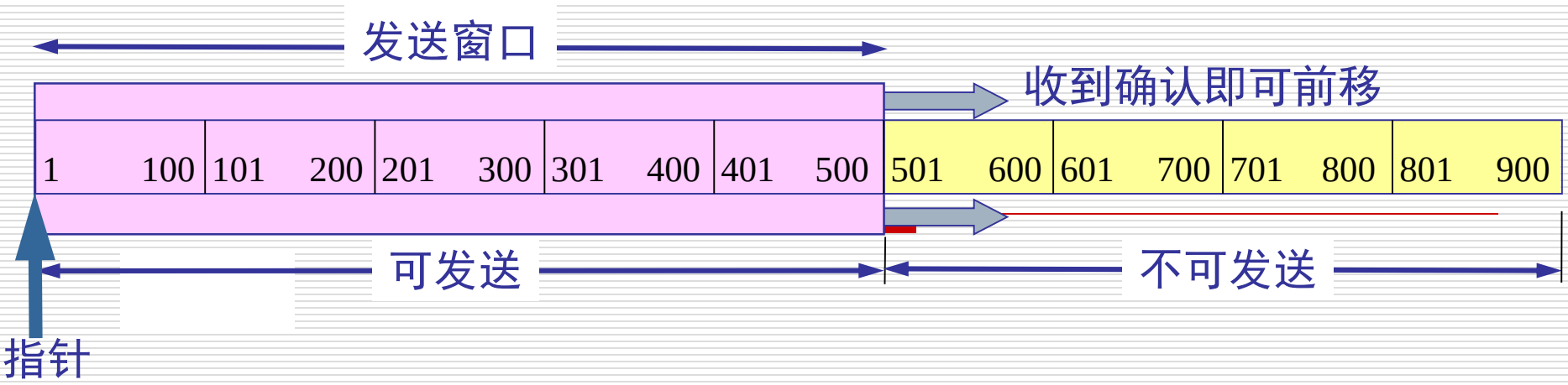
(a) 发送方维持发送窗口（发送窗口是 5）

发送窗口

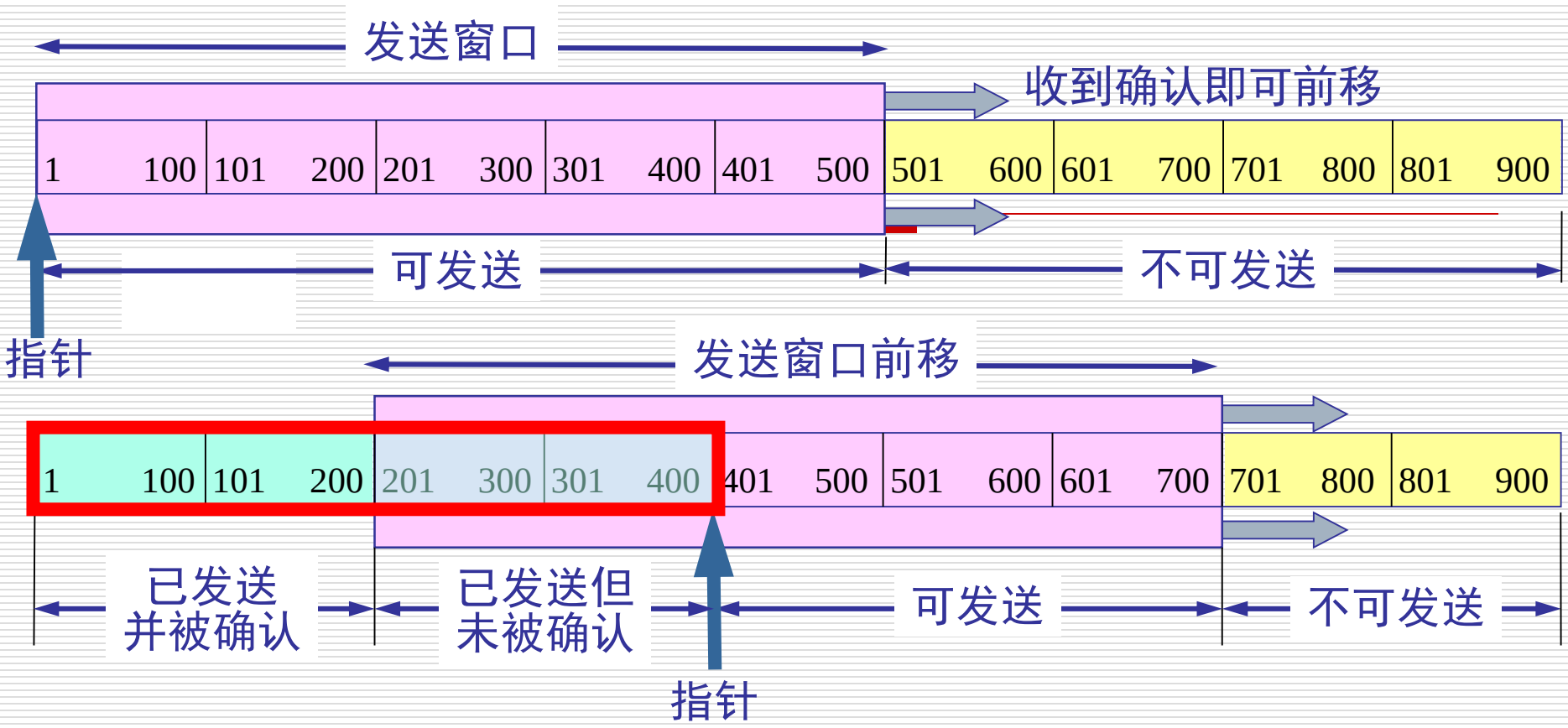
向前



(b) 收到一个确认后发送窗口向前滑动

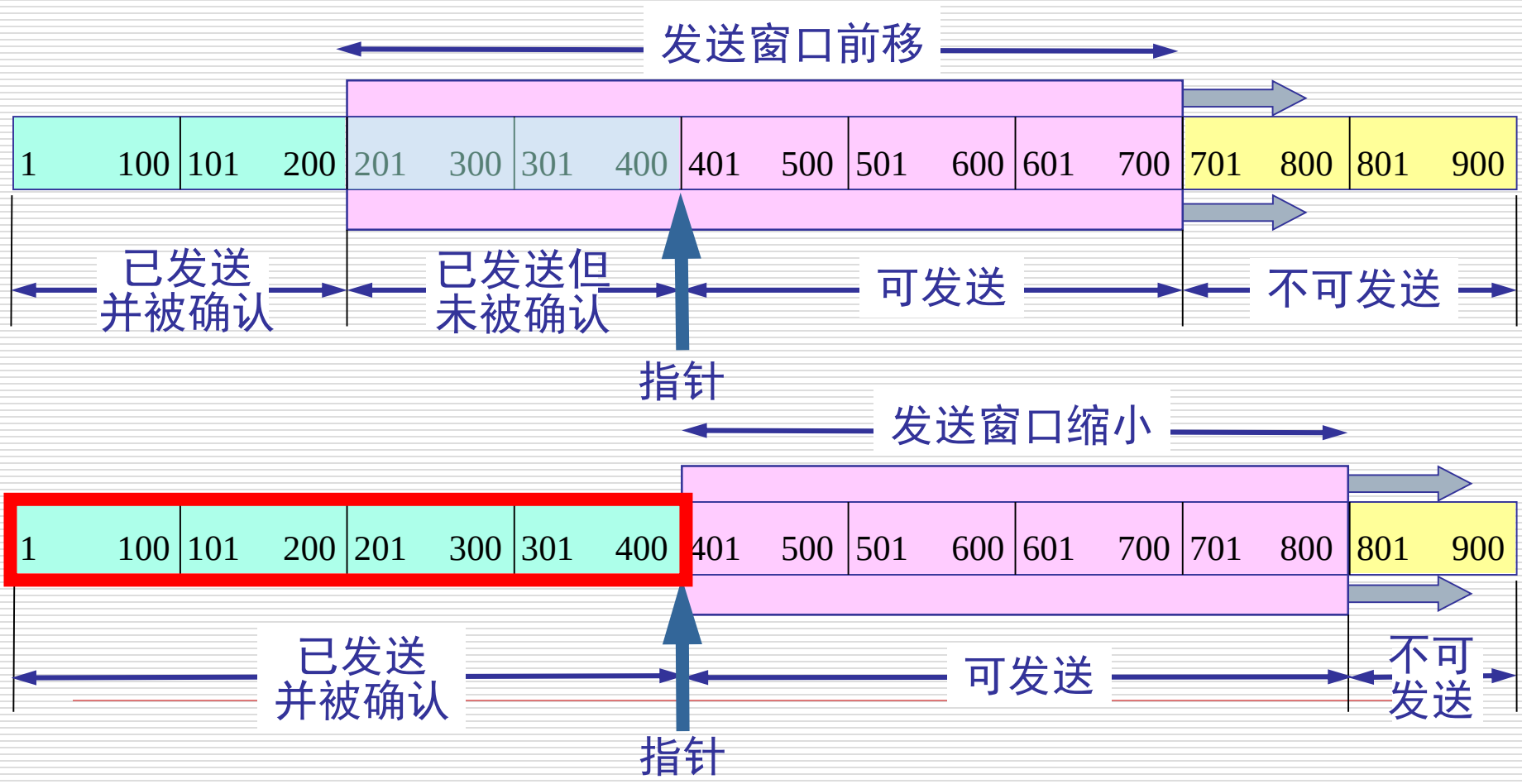


- 发送端要发送 900 字节长的数据，划分为 9 个 100 字节长的报文段，而发送窗口确定为 500 字节。
- 发送端只要收到了对方的确认，发送窗口就可前移。
- 发送 TCP 要维护一个指针。每发送一个报文段，指针就向前移动一个报文段的距离。



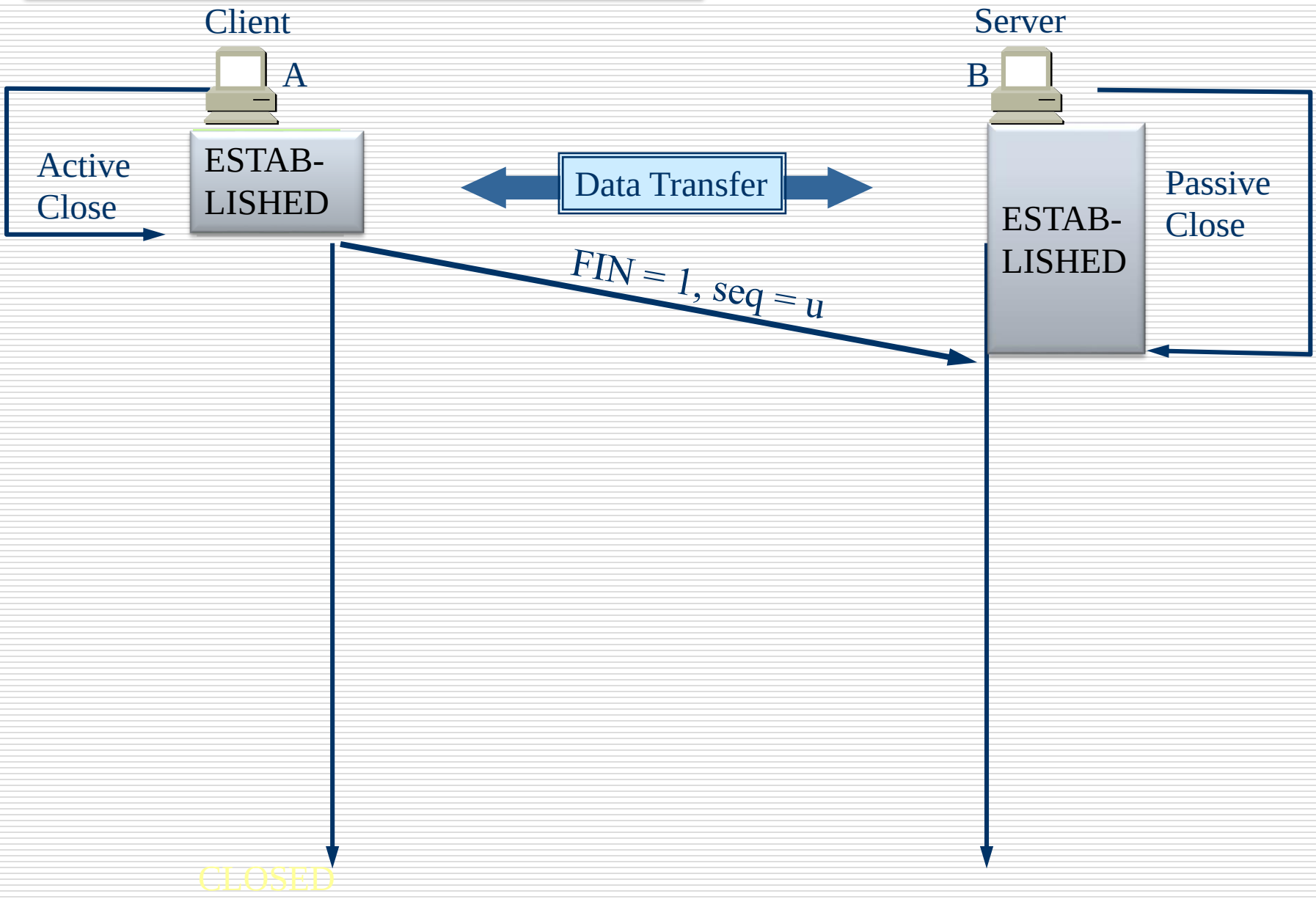
- 发送端已发送了 400 字节的数据，但只收到对前 200 字节数据的确认，同时窗口大小不变。
- 现在发送端还可发送 300 字节。

- 发送端收到了对方对前 400 字节数据的确认，但对方通知发送端必须把窗口减小到 400 字节。
- 现在发送端最多还可发送 400 字节的数据。

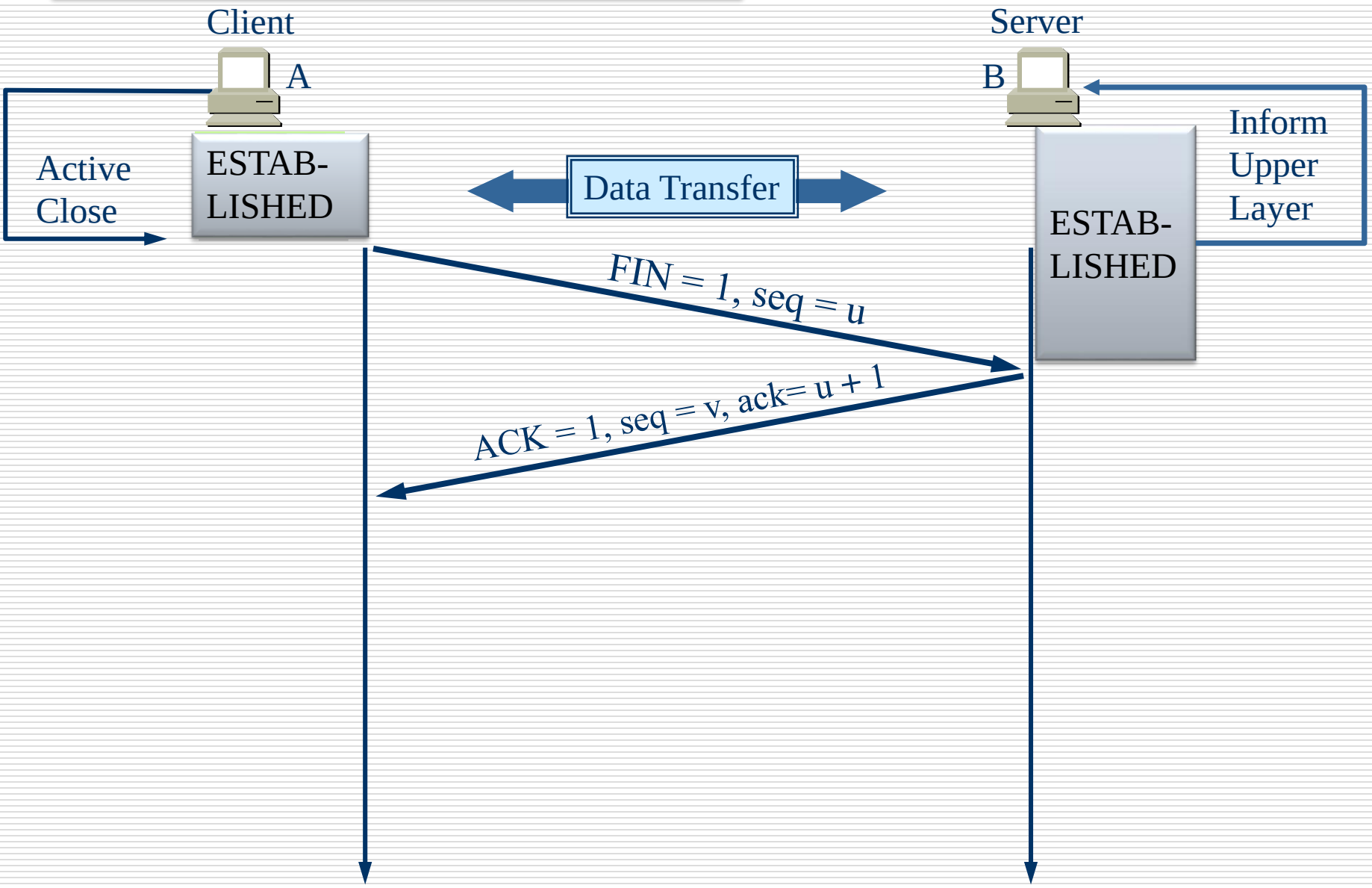


利用可变窗口大小进行流量控制
双方确定的窗口值是 400

TCP: Release Connection



TCP: Release Connection



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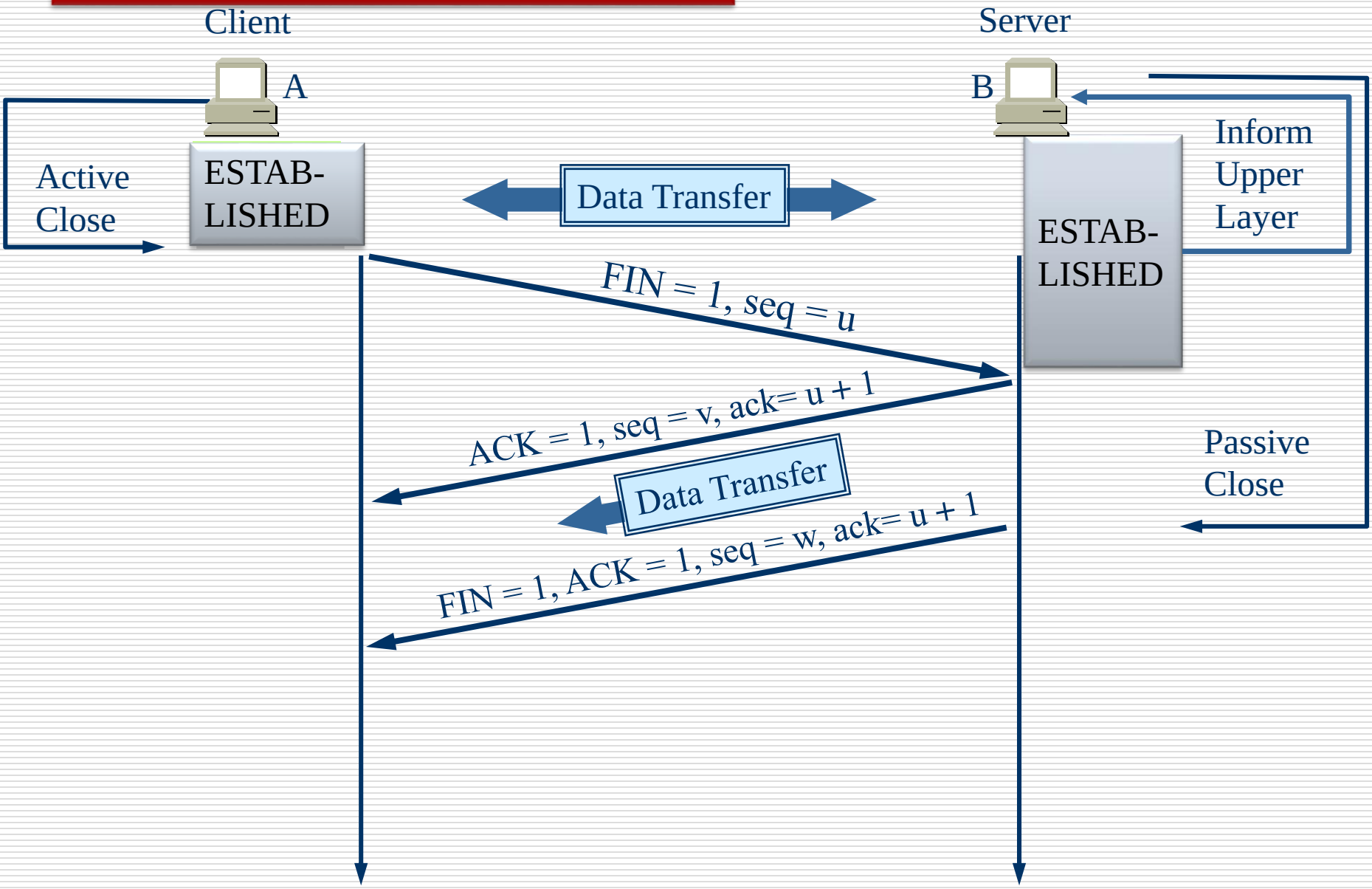

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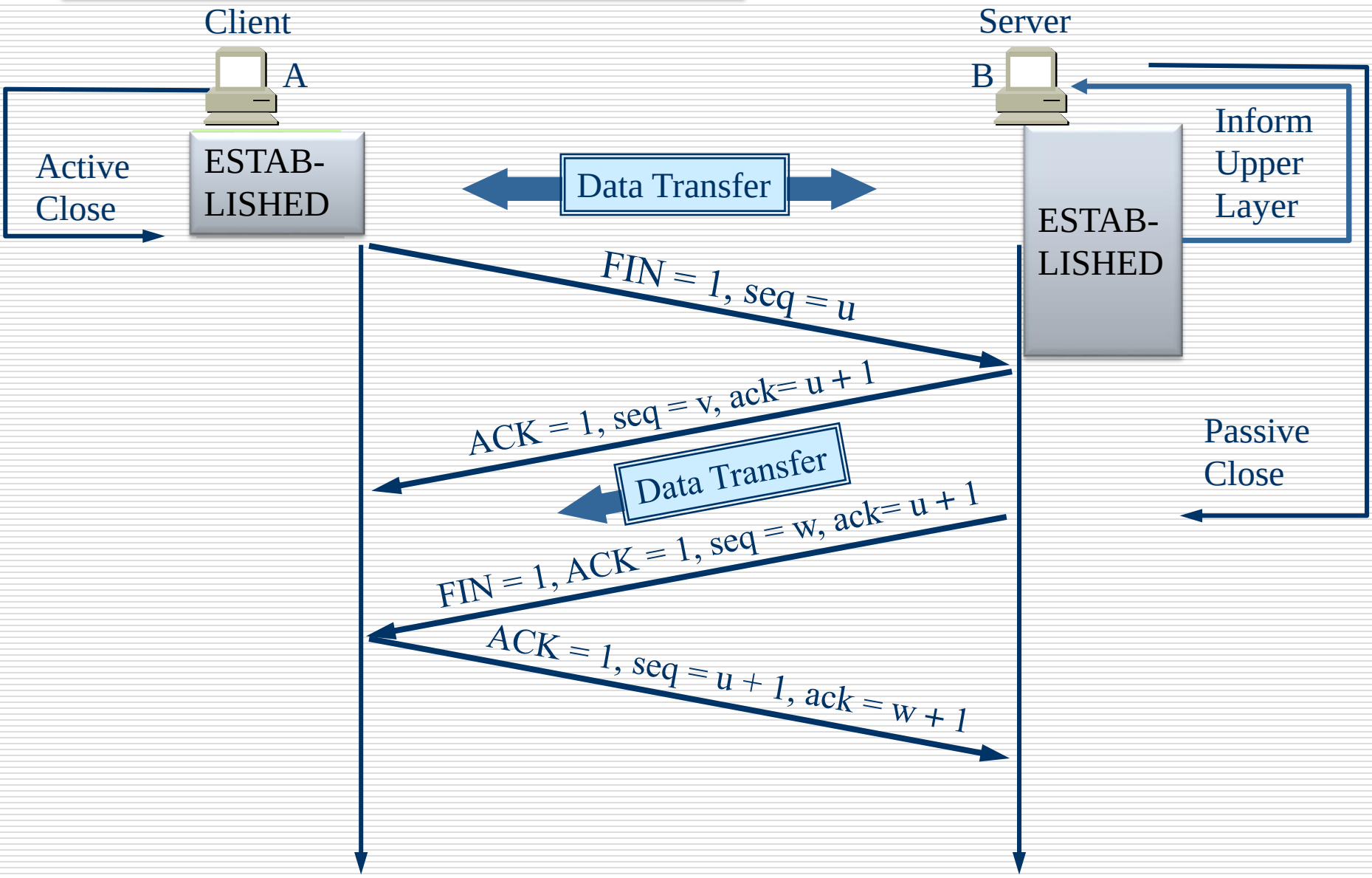
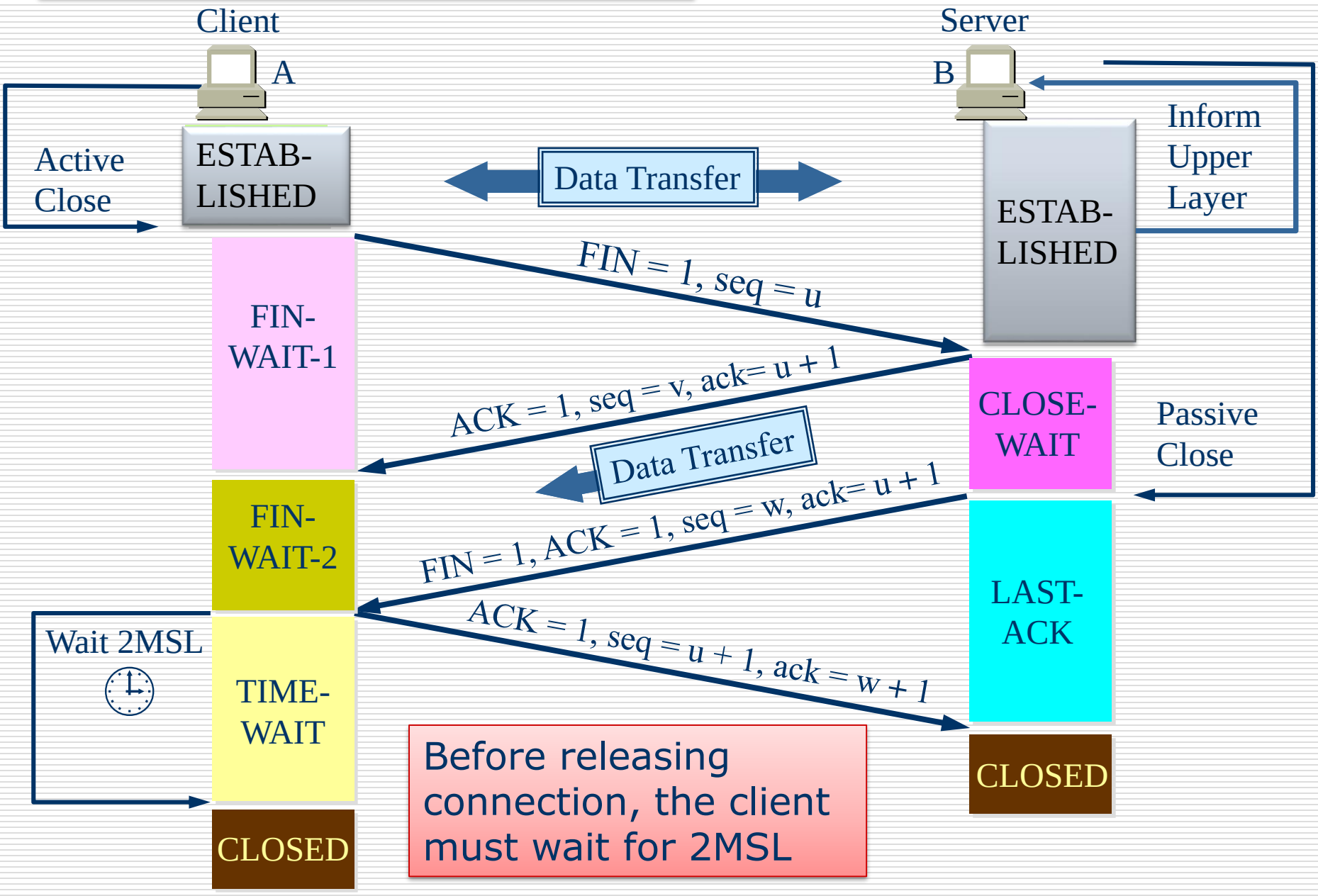


TCP: Release Connection

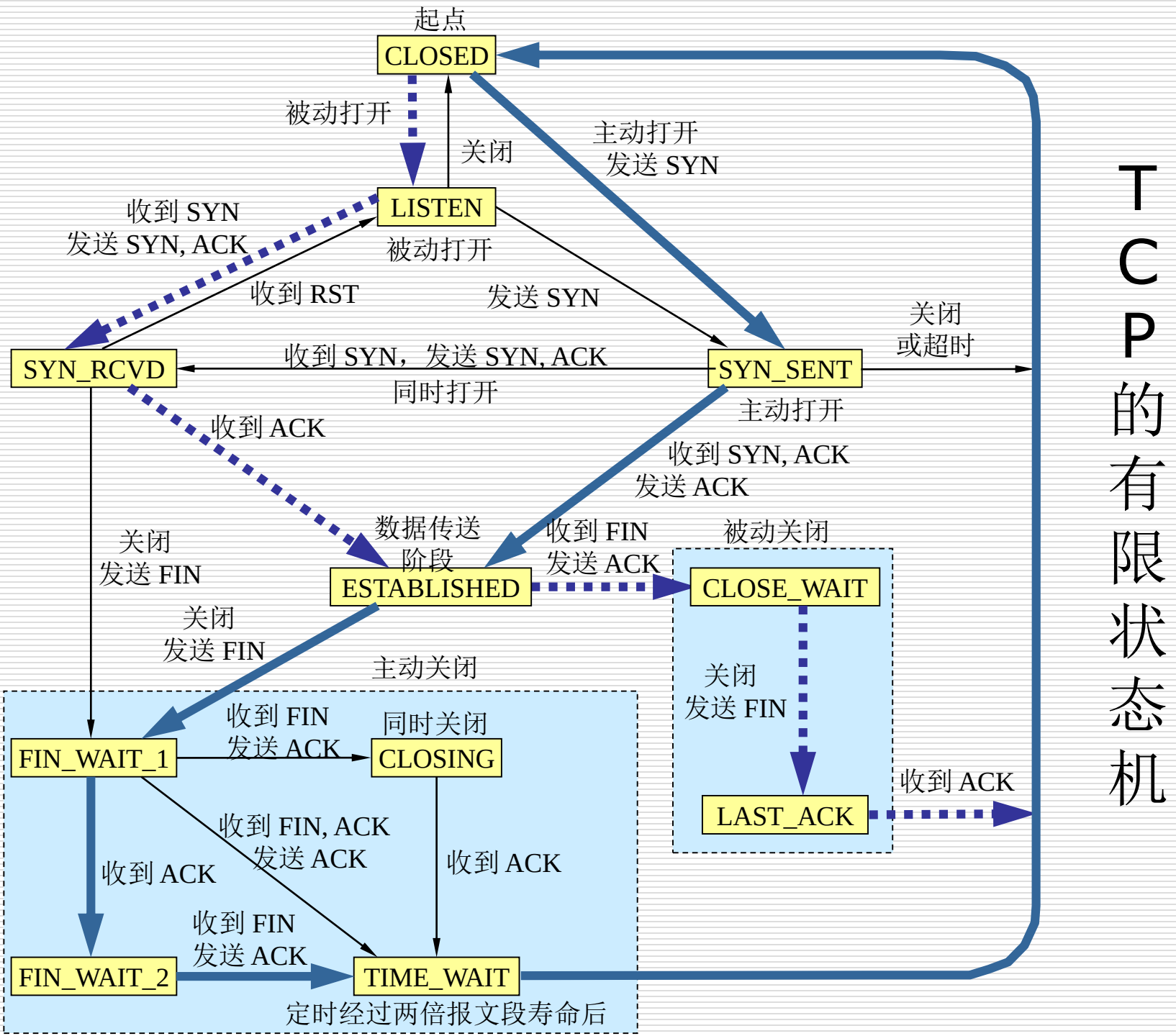


Why must wait for 2MSL?

- To ensure the last ACK sent by A can reach B
- To prevent any invalid connection request segment from emerging
  - After waiting for 2MSL , we can make sure that all segments on the connection have disappeared

TCP的计时器

- 重传计时器
- 坚持计时器
- 保持计时器
- 时间等待计时器


起点
CLOSED
被动打开
关闭
主动打开
发送 SYN
LISTEN
收到 SYN
发送 SYN, ACK
被动打开
收到 RST
发送 SYN
关闭
或超时
SYN_RCVD
收到 SYN，发送 SYN, ACK
同时打开
SYN_SENT
主动打开
收到 ACK
收到 SYN, ACK
发送 ACK
关闭
发送 FIN
数据传送
阶段
收到 FIN
发送 ACK
被动关闭
ESTABLISHED
CLOSE_WAIT
关闭
发送 FIN
主动关闭
关闭
发送 FIN
收到 FIN
发送 ACK
同时关闭
FIN_WAIT_1
CLOSING
关闭
发送 FIN
收到 ACK
收到 FIN, ACK
发送 ACK
收到 ACK
LAST_ACK
收到 ACK
收到 FIN
发送 ACK
FIN_WAIT_2
TIME_WAIT
定时经过两倍报文段寿命后

TCP的有限状态机

Layer 4: The Transport Layer

- **An Overview of Layer 4**
- **TCP (Transmission Control Protocol)**
- **UDP(User Datagram Protocol)**
- **An application: NAT and PAT**

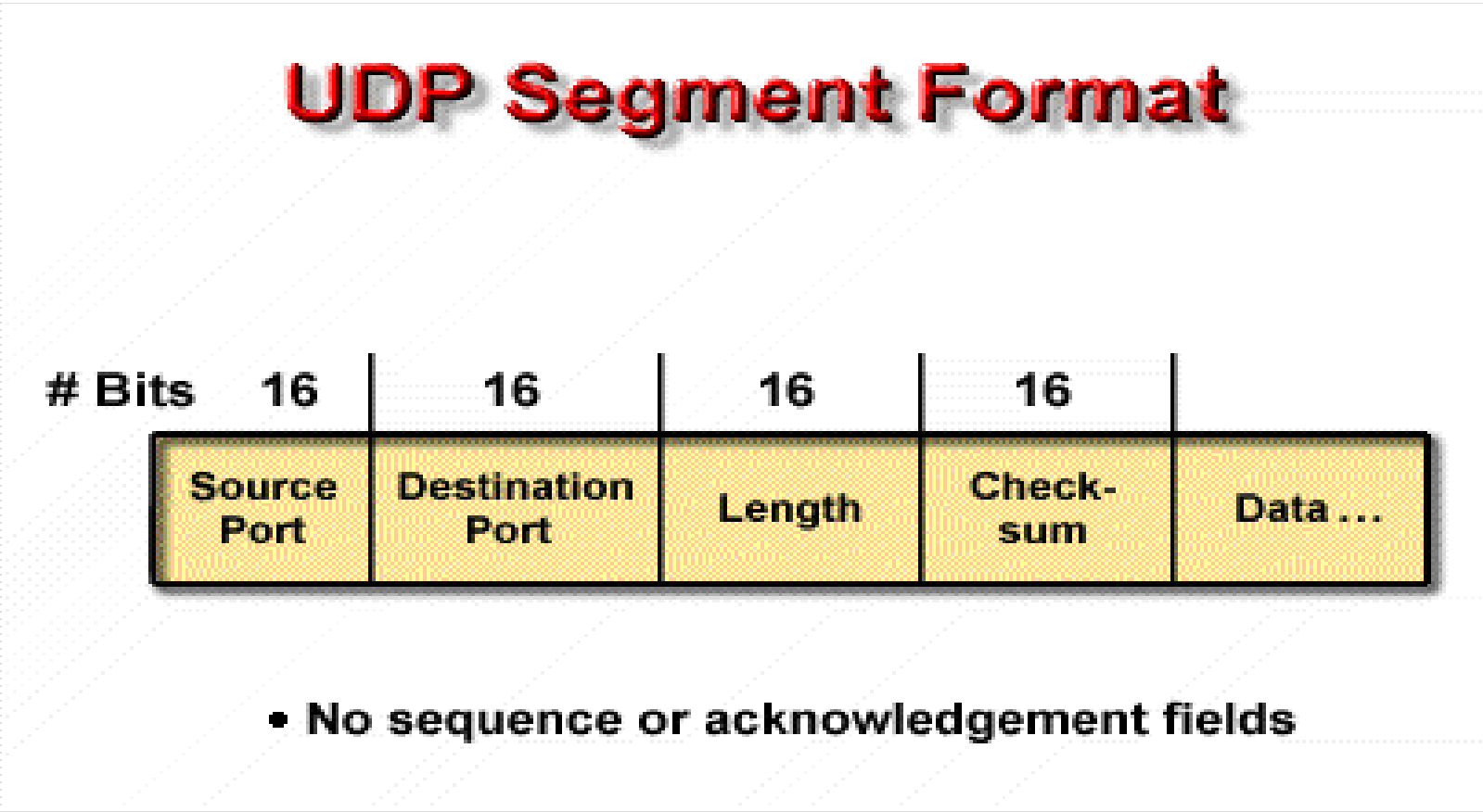
UDP (User Datagram Protocol)

- Why do we need UDP?
  - No connection establishment (which can add delay)
  - Simple: no connection state at sender, receiver
  - Small segment header
  - No congestion control: UDP can blast away as fast as desired

UDP (User Datagram Protocol)

- Connectionless:
  - no handshaking between UDP sender, receiver
  - each UDP segment handled independently of others
- Often used for streaming multimedia applications
  - loss tolerant
  - rate sensitive
- UDP are used in:
  - RIP: To send the route information periodically
  - DNS: Avoid the delay to setup the TCP connection
  - SNMP: When congestion, SNMP must still runable. Without the congestion and reliability control mechanism, UDP has better performance than TCP under the circumstances.
  - Other protocols include TFTP, DHCP
- Add reliability at application layer if necessary

UDP (User Datagram Protocol)



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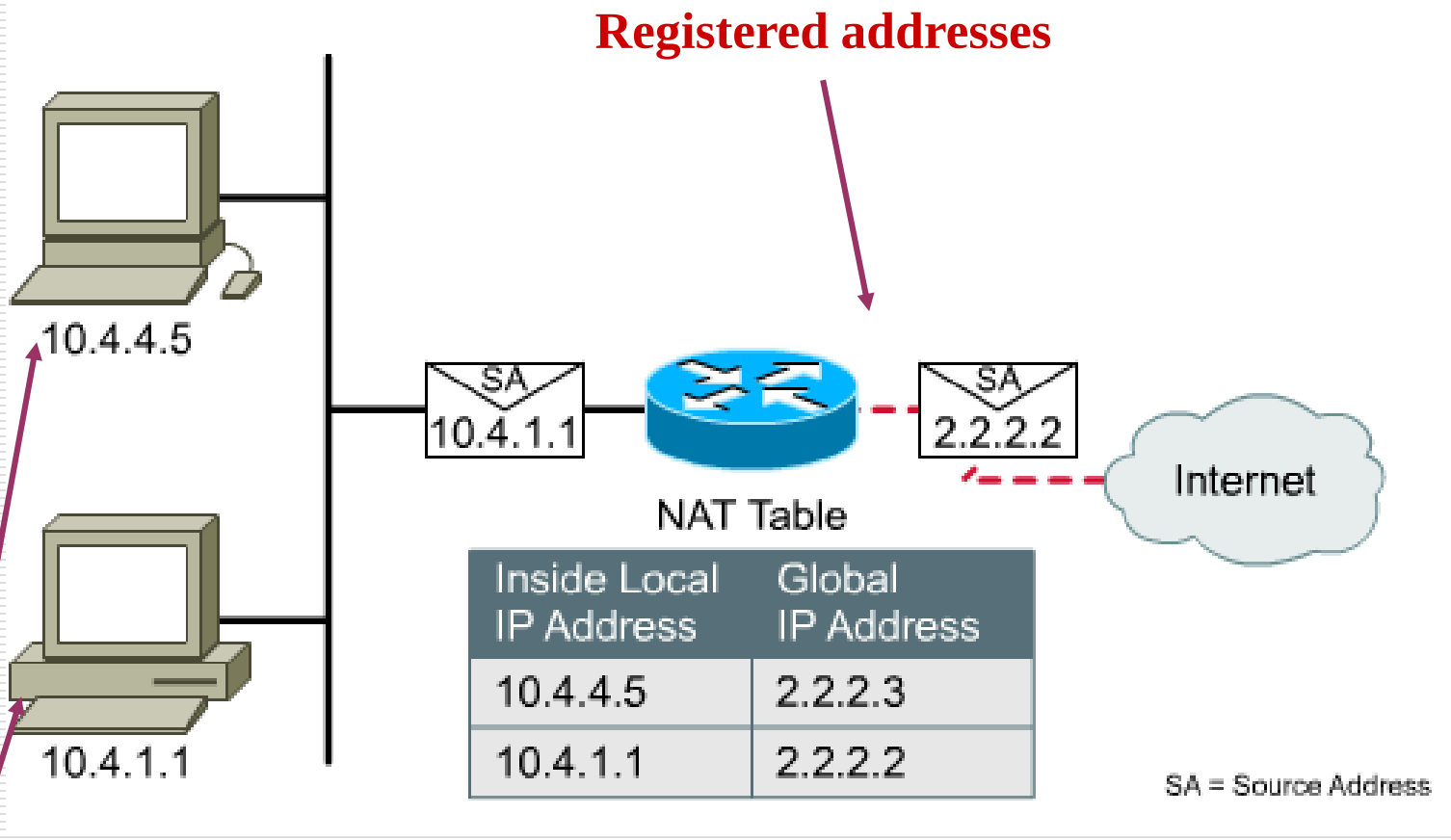
- UDP(User Datagram Protocol)
- An application: NAT and PAT

What is NAT?

- **NAT**, is the process of swapping one address for another in the IP packet header
- In practice, NAT is used to allow hosts that are privately addressed to access the Internet
- One of solutions to IP address depletion
  - Conserves registered (legal) addresses
  - Increases Flexibility when connecting to Internet
- RFC 1631 - Network Address Translator *(NAT)*

NAT a simple concept



NAT types

- Static NAT:

  Fixed mapping of an internal address to an registered address

- Dynamic NAT:

  Mapping is done dynamically on a first come first served basis

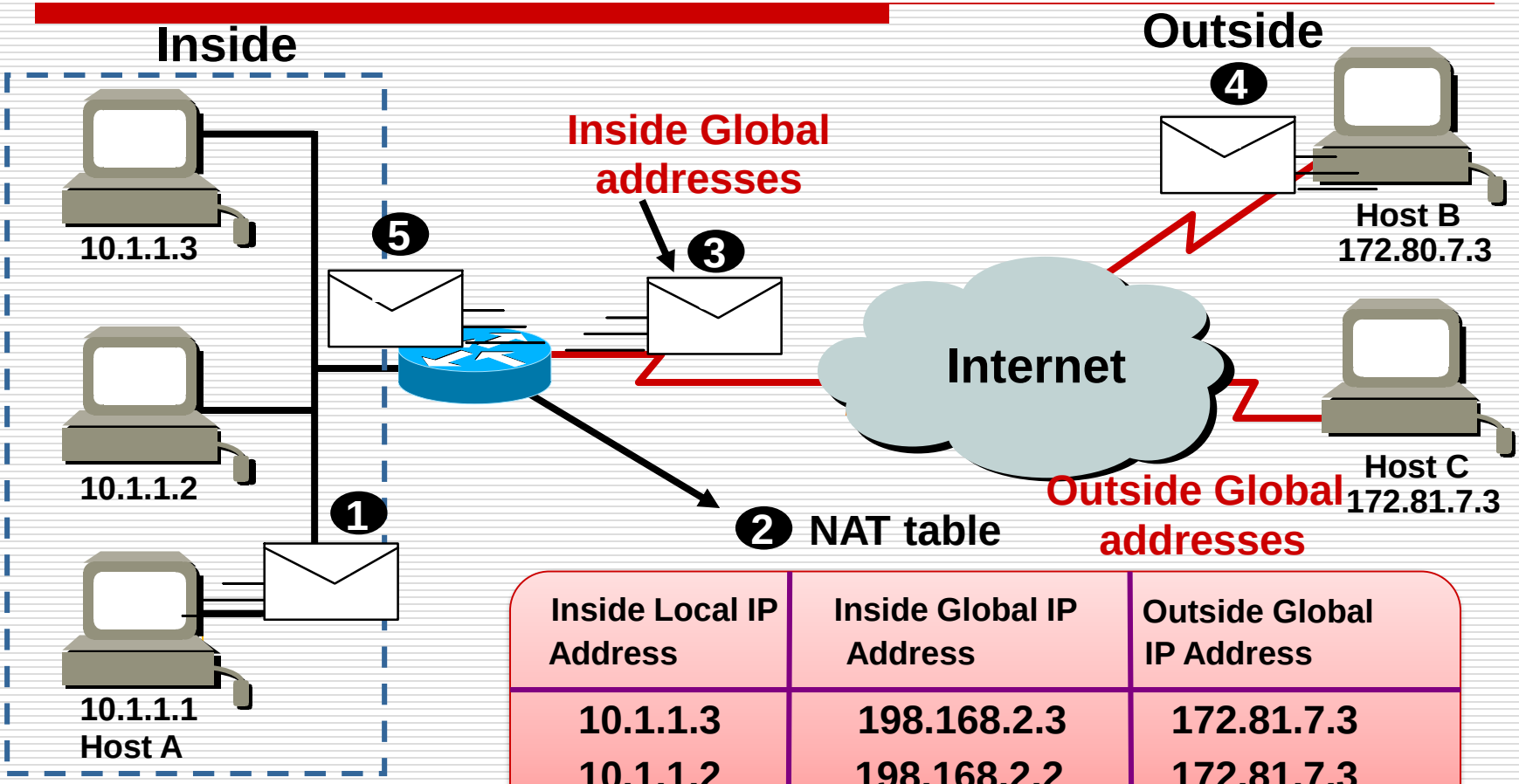
- PAT (Overload):

  Port address translation is used to allow many internal users to share a single ‘inside global’ address

NAT address types

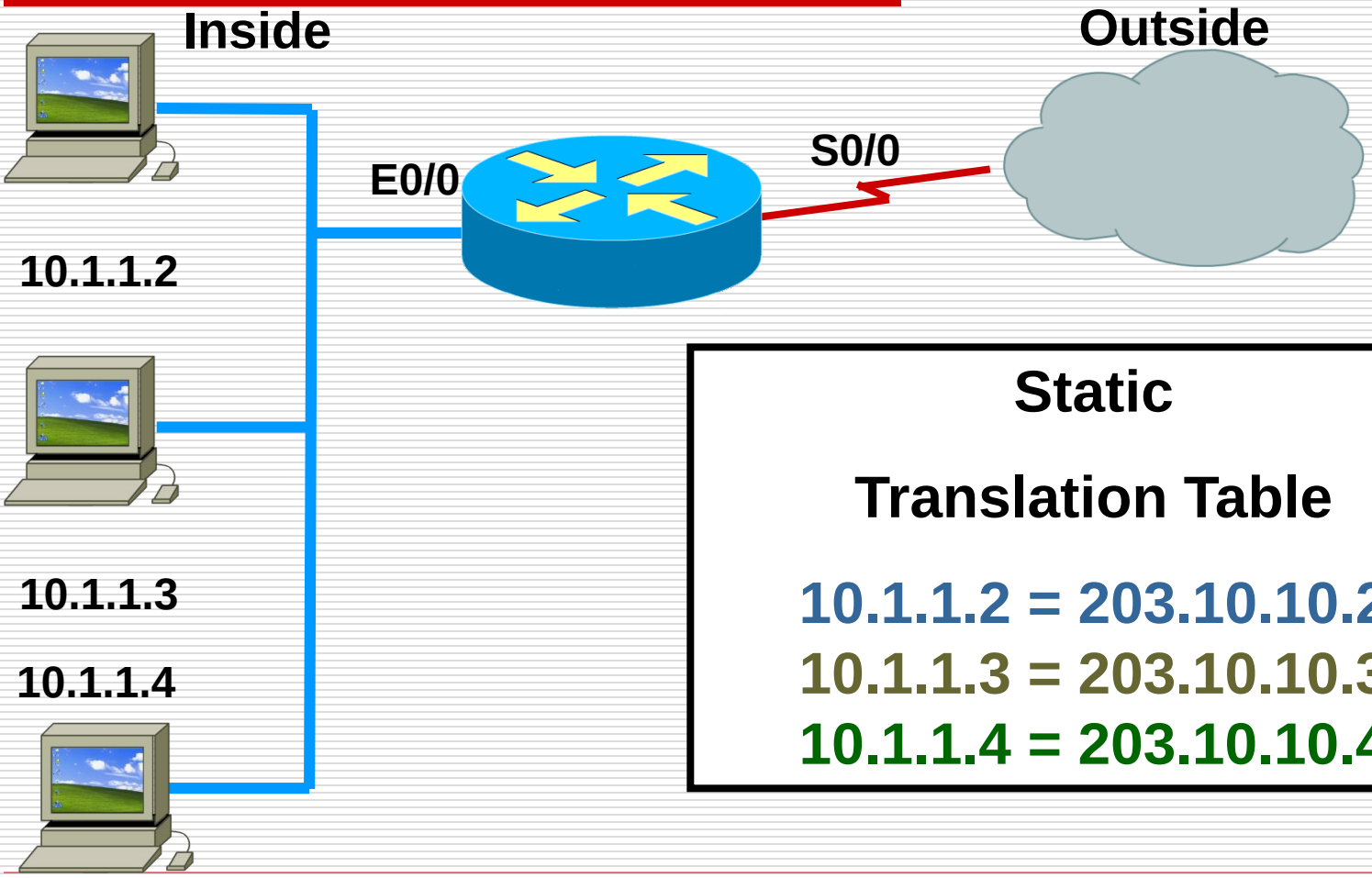
- **Inside Local address (内部本地地址):内网IP地址**
- **Inside Global address (内部全局地址): 注册IP地址, 对外部展示的内部地址**
- **Outside Global address (外部全局地址):由主机所有者分配的IP地址。通常是注册地址。**

NAT address types



Inside Local IP Address	Inside Global IP Address	Outside Global IP Address
10.1.1.3	198.168.2.3	172.81.7.3
10.1.1.2	198.168.2.2	172.81.7.3
10.1.1.1	198.168.2.1	172.80.7.3

Static: How does it work?

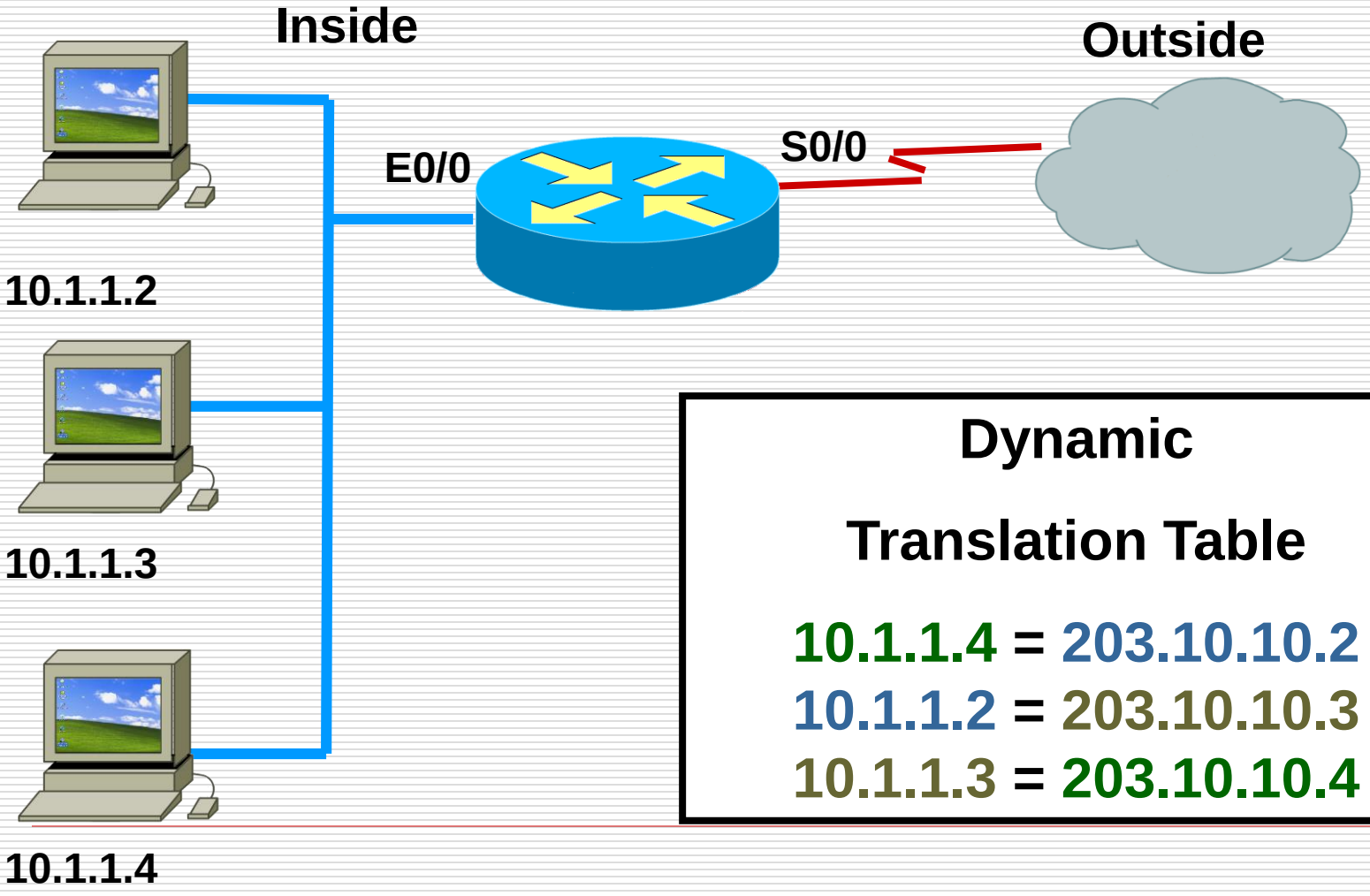


Static

Translation Table

10.1.1.2 = 203.10.10.2
10.1.1.3 = 203.10.10.3
10.1.1.4 = 203.10.10.4

Dynamic:How does it work?



Dynamic

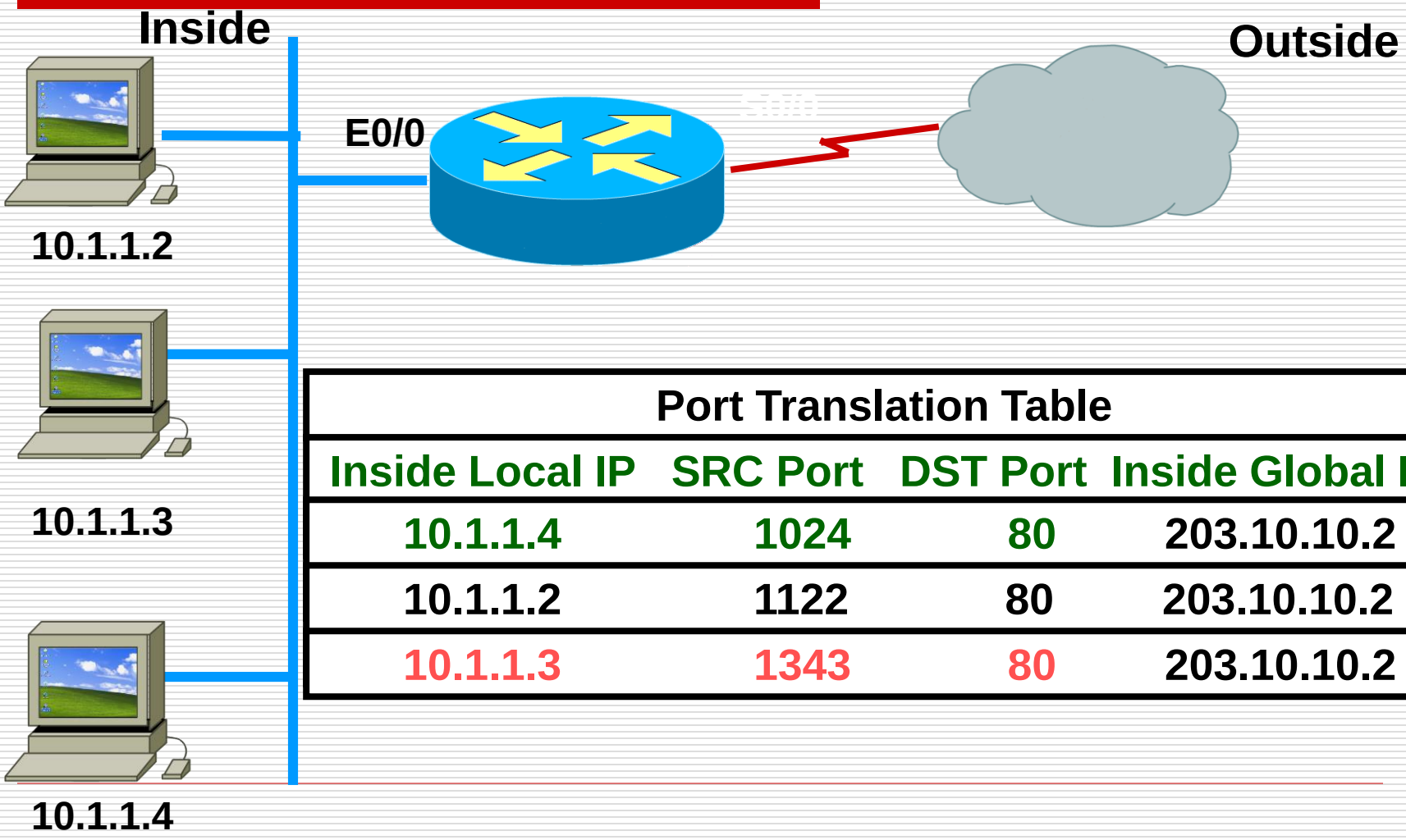
Translation Table

10.1.1.4 = 203.10.10.2
10.1.1.2 = 203.10.10.3
10.1.1.3 = 203.10.10.4

Advantages and Disadvantages of NAT

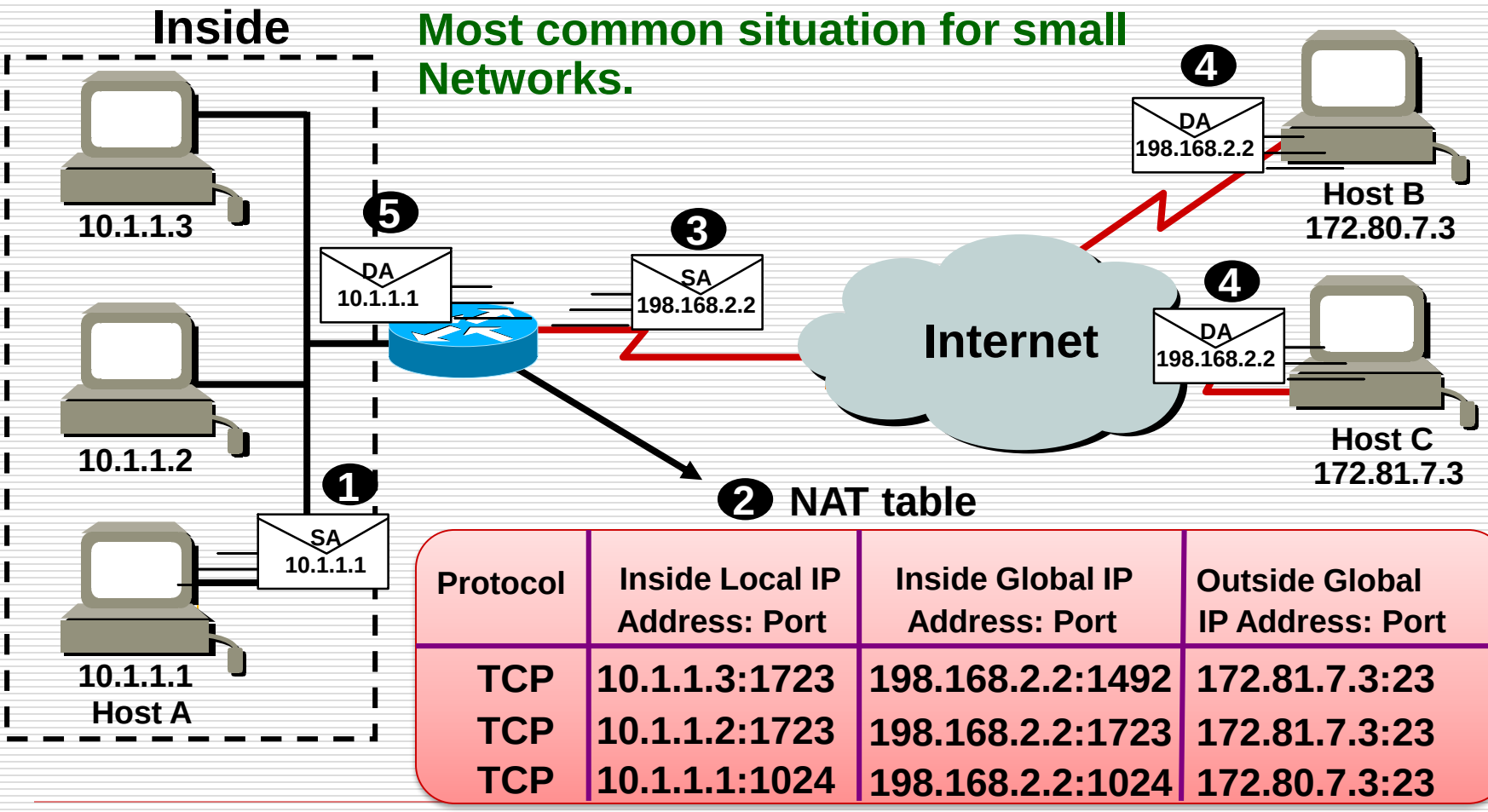
- Advantage: since not every inside host needs outside access at the same time, you can get away with using a small pool of globally unique addresses to serve a relatively large number of privately addressed hosts.
- Disadvantage: one-to-one mapping.
- That is, if the private address space is a /8, but the public address is a /24, only 254 hosts can access the Internet at a time.

PAT: How does it work?



Port Translation Table			
Inside Local IP	SRC Port	DST Port	Inside Global IP
10.1.1.4	1024	80	203.10.10.2
10.1.1.2	1122	80	203.10.10.2
10.1.1.3	1343	80	203.10.10.2

PAT Operation



Protocol	Inside Local IP Address: Port	Inside Global IP Address: Port	Outside Global IP Address: Port
TCP	10.1.1.3:1723	198.168.2.2:1492	172.81.7.3:23
TCP	10.1.1.2:1723	198.168.2.2:1723	172.81.7.3:23
TCP	10.1.1.1:1024	198.168.2.2:1024	172.80.7.3:23

谢 谢！