Transmission Control Protocol (TCP)

Outline

- TCP connections
- Segmentation and acknowledgement
- Flow control
- TCP header

Key features

- Transmission Control Protocol (TCP)
- Operates above IP to offer a number of additional features, and address issues not tackled by IP
- **Reliability**: Data transmitted is checked and re-transmitted where necessary
- **Multiplexing**: Two hosts can have multiple simultaneous 'conversations' without getting confused about which data belongs to which conversation
- **Flow/Congestion Control**: A receiving host/network can only accept and process a given amount of data at once, so the sender must control how fast they send data

Multiplexing

- How does an host running multiple networked applications differentiate between messages?
- TCP conceptually divides the communications a host can be involved with into **ports**
- This allows two hosts to perform several simultaneous communications without getting data confused between them
- A port is identified by a number, used in each message between hosts so that they know which communication the message belongs to
- A few ports are reserved for specific application protocols, e.g.
  - FTP: 20/21
  - SMTP (e-mail): 25
  - HTTP: 80
  - HTTPS: 443

Connections

- In using TCP, hosts must establish a **connection**
  - Data can only be sent during the connection
  - Requires connection setup/teardown
- Why?
  - To exchange 'extra' information between hosts
  - Reliability
  - Resource reservation to ensure quality of service
  - Flow/congestion control
- A TCP connection is one kind of **session**, and many other protocols use sessions

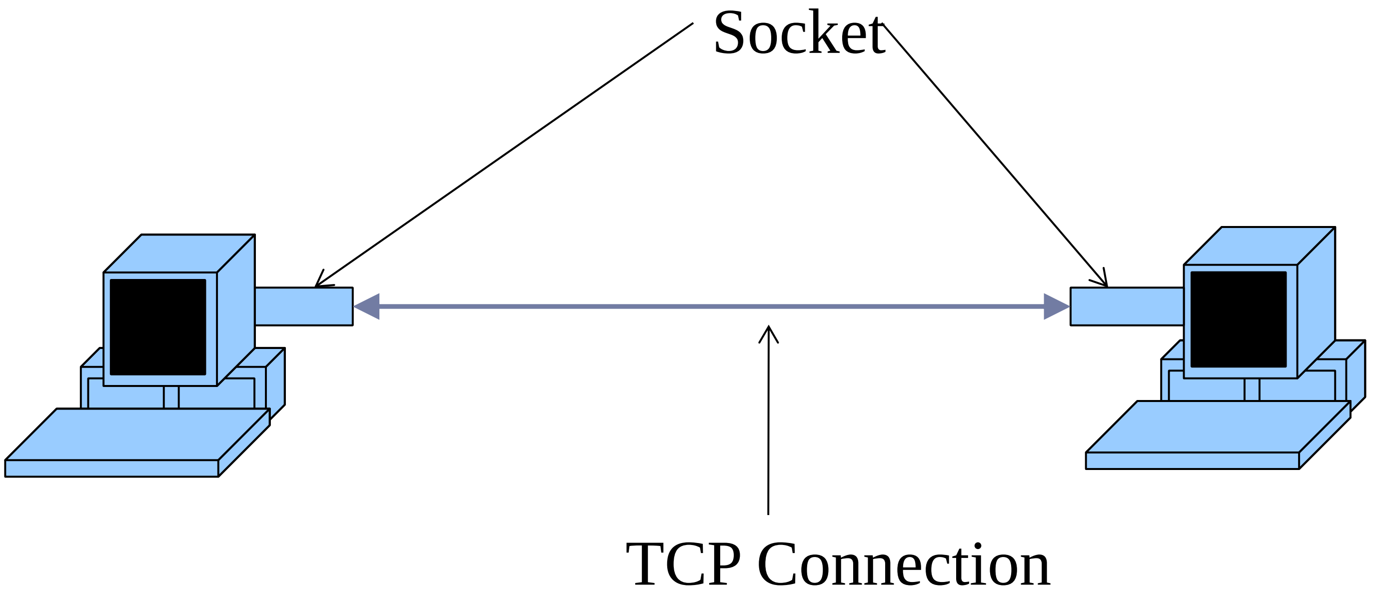
Sockets

- A **socket** is the combination of a host's IP address and a port number

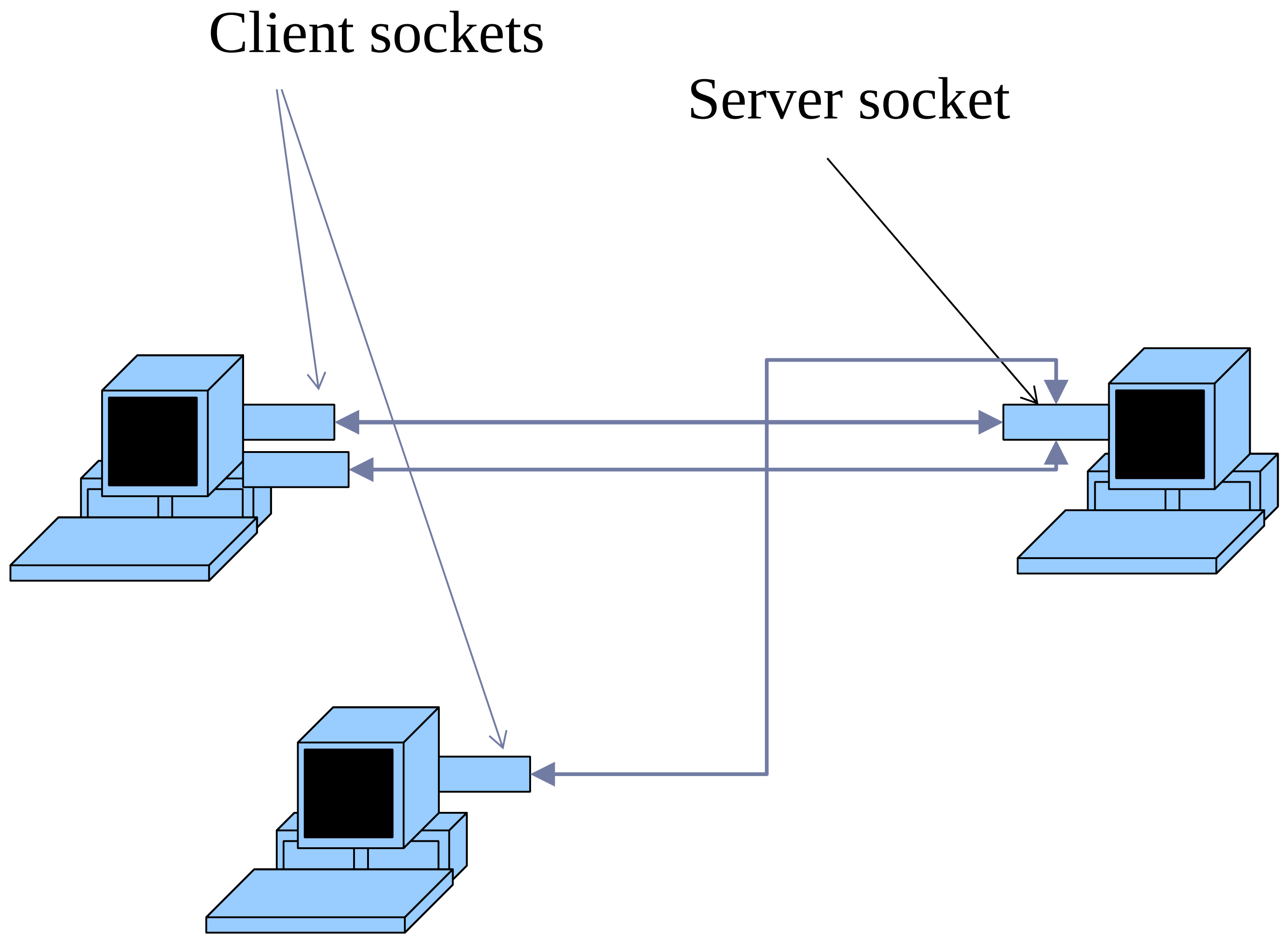
  137.73.9.232:8080

- Every communication in TCP is between two sockets, i.e. two hosts using particular ports.
- Initially, a server will LISTEN on a particular socket.
- Multiple clients can connect to the **same** server socket from different client sockets.
- Once a pair of sockets is connected, data can be sent in both directions between client and server:
  - Connections are **full-duplex**

TCP connections



TCP connections



Client and server

- **Server**: a process that is ready to accept connections on one or more ports
  - The server signals that it is ready to receive connections on a port by informing the TCP software on the host: a Passive OPEN request
  - For example a web server application running on www.google.com
- **Client**: a process that communicates with a server
  - A client signals that it wishes to connect to a server's socket by sending a message to the server: an Active OPEN request
  - For example, a web browser running on your local PC
- Both processes can reside on the same or different hosts.

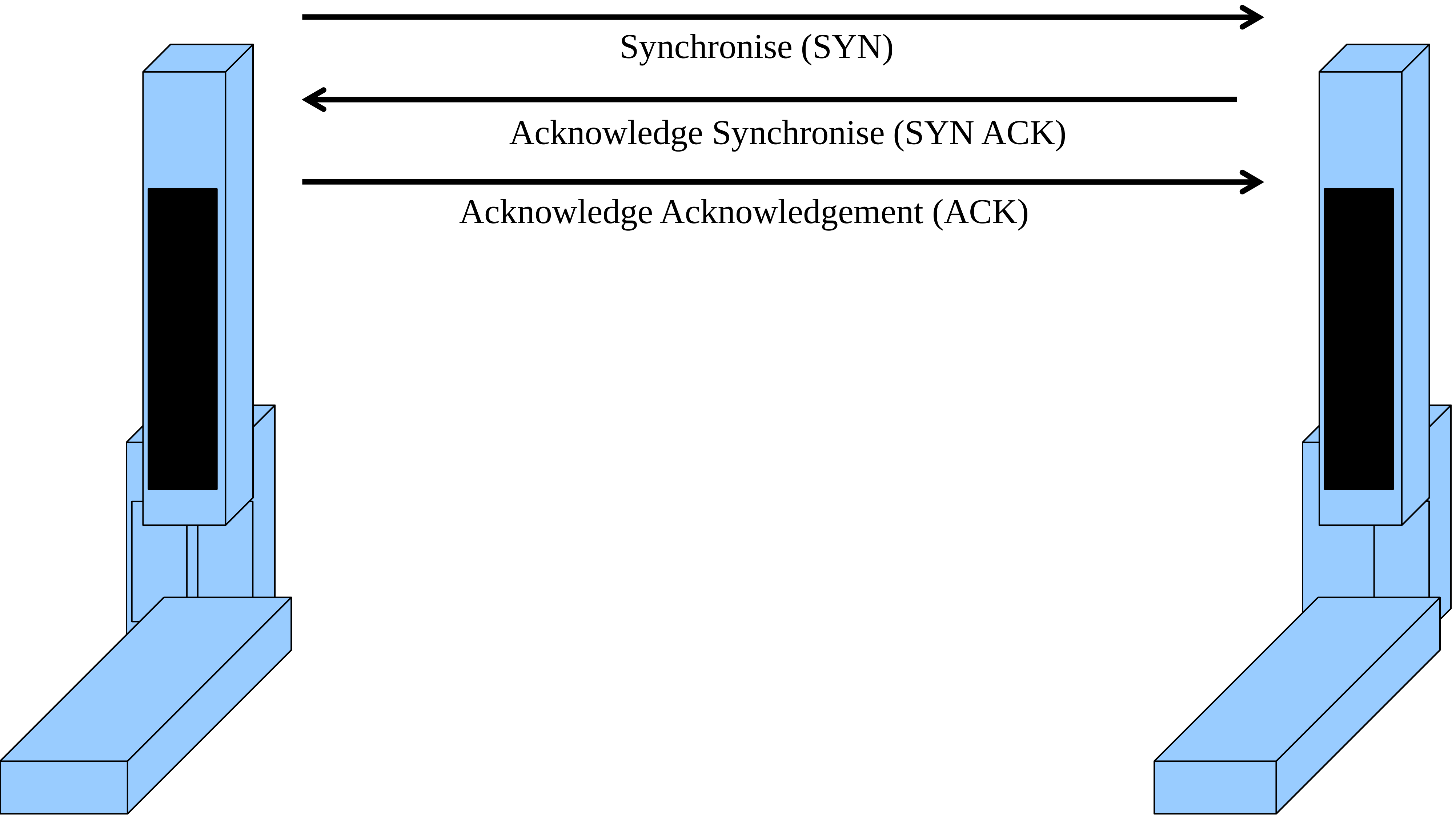
Connection set-up

- A **handshake** is a sequence of messages sent between a client and server to set up the connection before the message data is sent
- The handshake involves three steps:
  - Client sends a synchronise message to the server
  - Server sends a message back acknowledging the synchronise, and giving permission for communication to take place
  - Client sends a message acknowledging the acknowledgement
- The processes can then start sending data to each other.

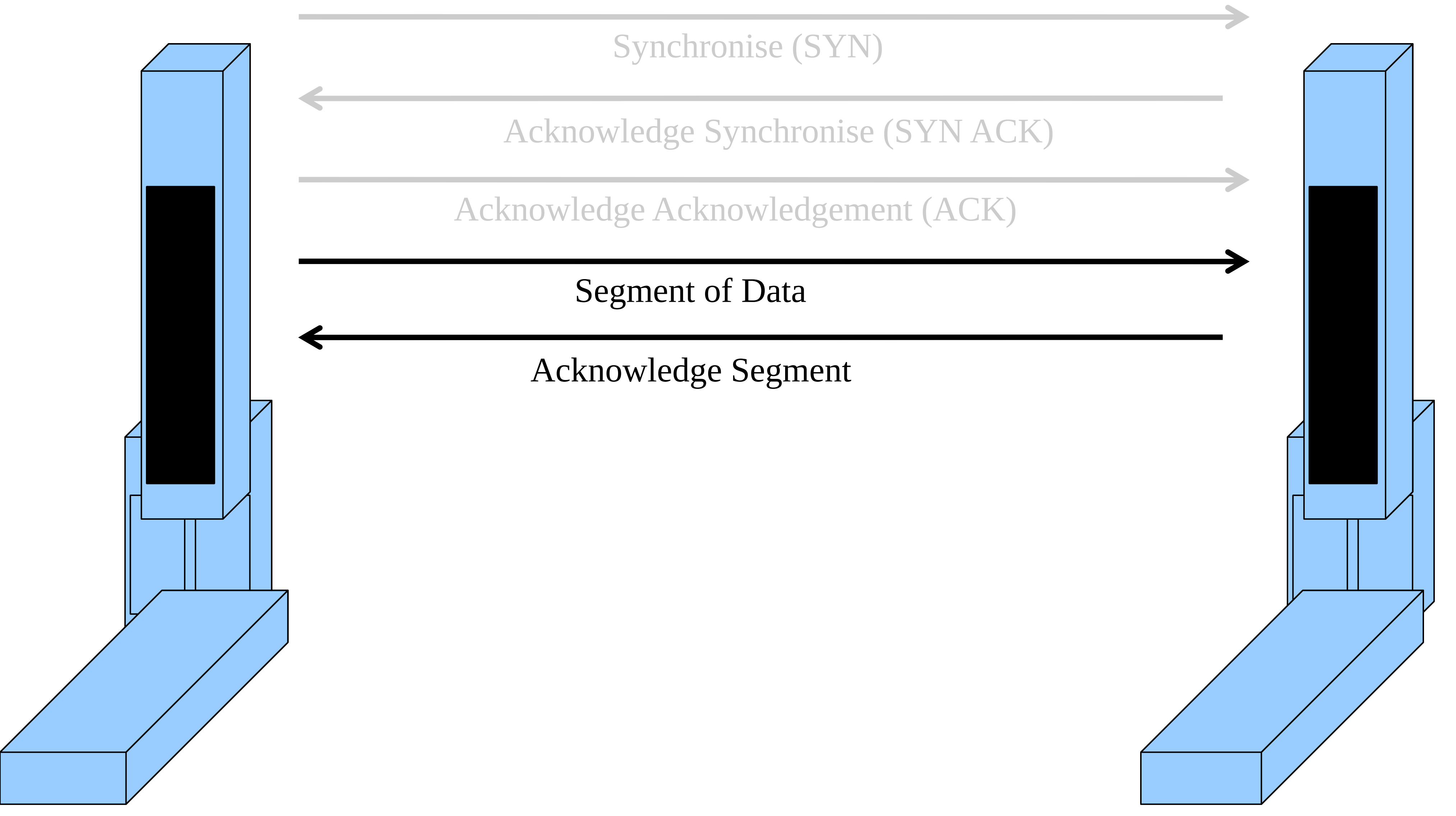
Connection tear-down

- A handshake is also used to close the connection
  - When a sender has finished and wishes to close the connection it sends a finalise message
  - The receiver responds with an acknowledgement of the finalise
  - Finally, the sender responds with an acknowledgement of the acknowledgement
  - Because connections are full-duplex, client and server can close their side of the connection independently.
  - Connections in which only one end-point has closed the connection are in a half-closed state.

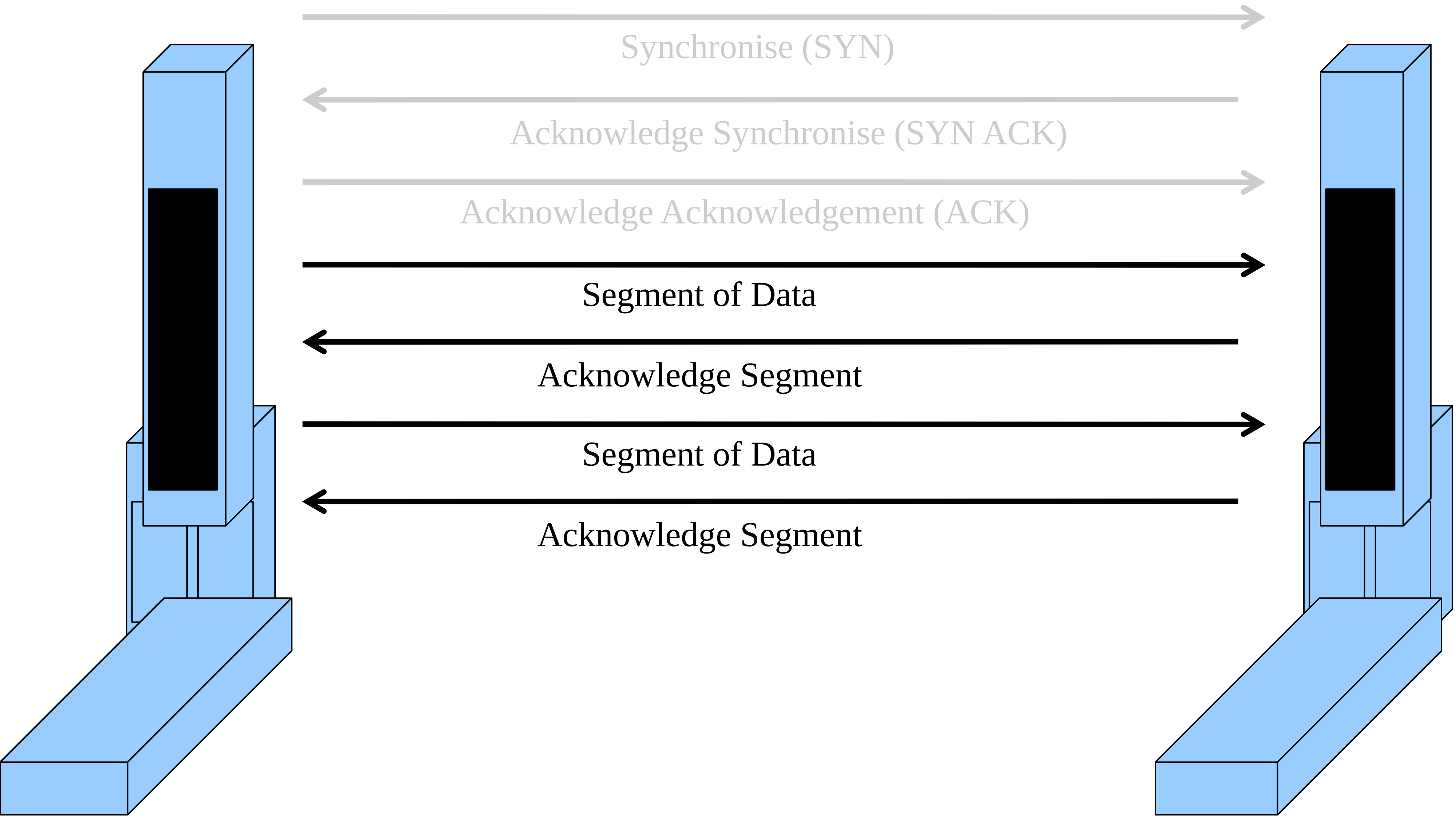
TCP communication sequence



TCP communication sequence



TCP communication sequence



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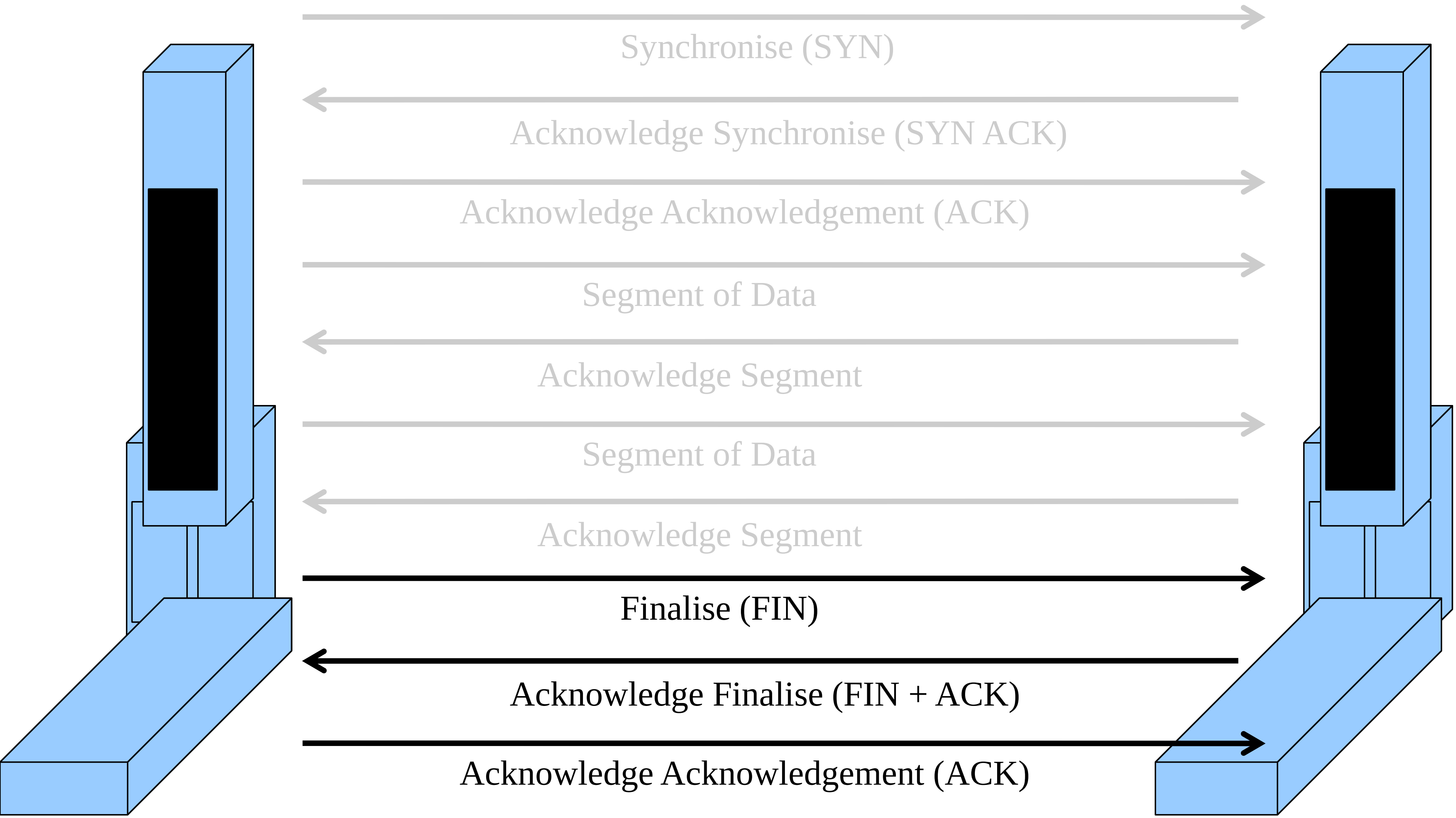


Flow control

- A host can only receive and process data at a certain rate
- At some point its buffers get full and it would have to either overwrite unprocessed data or ignore incoming data
- To resolve this, TCP allows the sender to tell the receiving end how much data it can handle
- The sender will then reduce or increase the rate at which it sends data to match the server

Segmentation

- One part of flow control is to split the message to be sent into separately transmitted **segments**
- This is like fragmentation in IP, but is independent and for different reasons
- In IP, fragments are used to not exceed the limits of the physical networks and network access layer protocols
- In TCP, segments are used to not exceed the limits of the receiving host, flow control, and to aid reliability of communication

Sequence numbers

- Every byte in a message sent from a client to a server has a **sequence number**
- For a given connection and host, there is an **initial sequence number (ISN)** for bytes it sends
- The 1st byte of the message has sequence number ISN+1
- The 2nd byte has sequence number ISN+2
- A segment will contain all data within a range of sequence numbers: ISN+a to ISN+b
- Client communicates its ISN in synchronisation

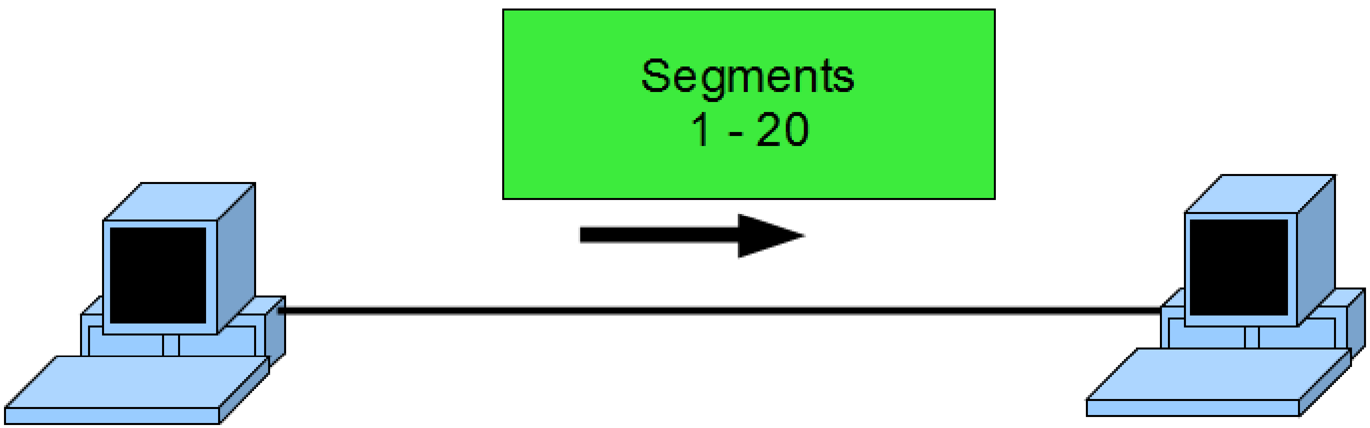
Reliability

- The main method by which TCP provides reliable communication is for the receiver to send back an **acknowledgement** back to the sender for every segment it receives
- A sender (whether client or server) uses acknowledgements to determine whether a segment has been lost
- If it believes a segment is lost, it will re-send it

Acknowledging sequences

- An acknowledgement states that the receiver has received all data in the message before a given sequence number
- If the receiving end has received segments with sequence numbers (1 - 20) and (21 - 30), it will send an acknowledgement with sequence number 31
- The segments may be lost
  - Server receives segments (1 - 20) and (50 - 60)
  - Sends an acknowledgement with sequence number 21, as it has all data up to there

Acknowledgements



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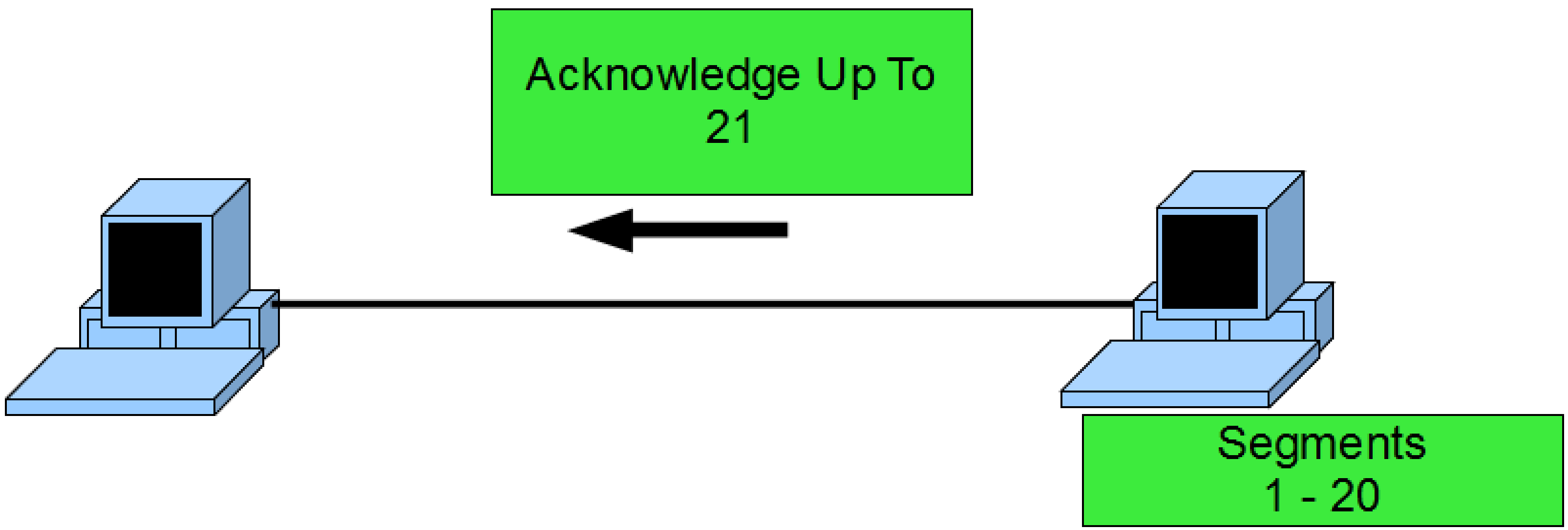

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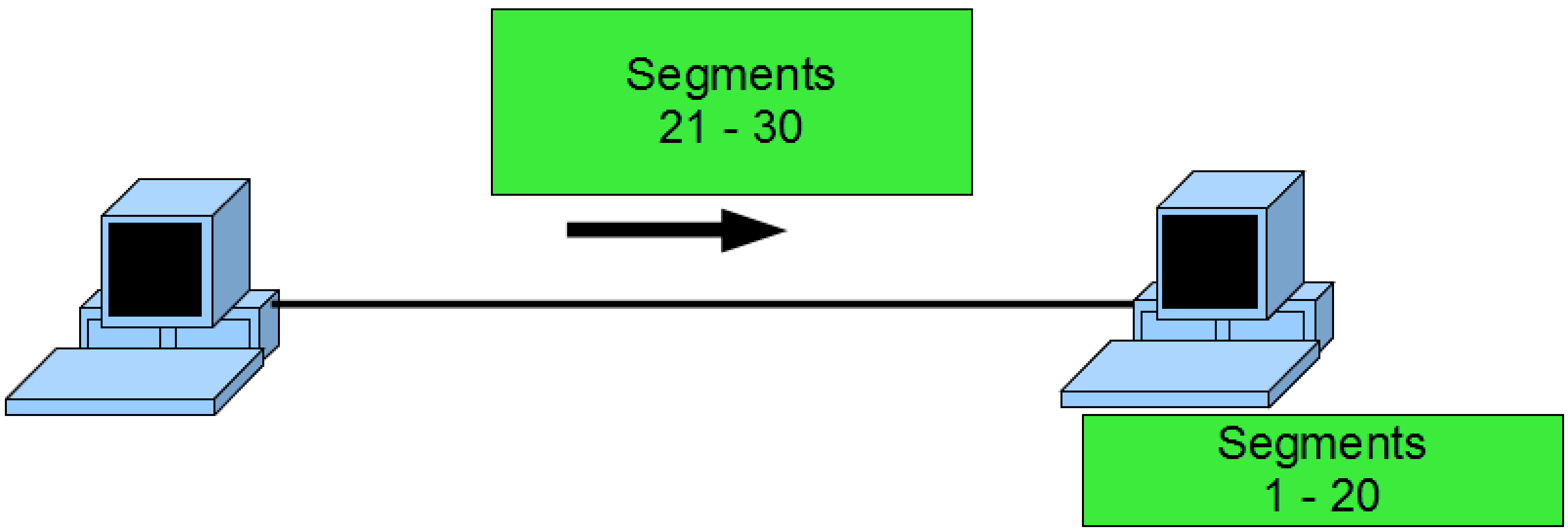

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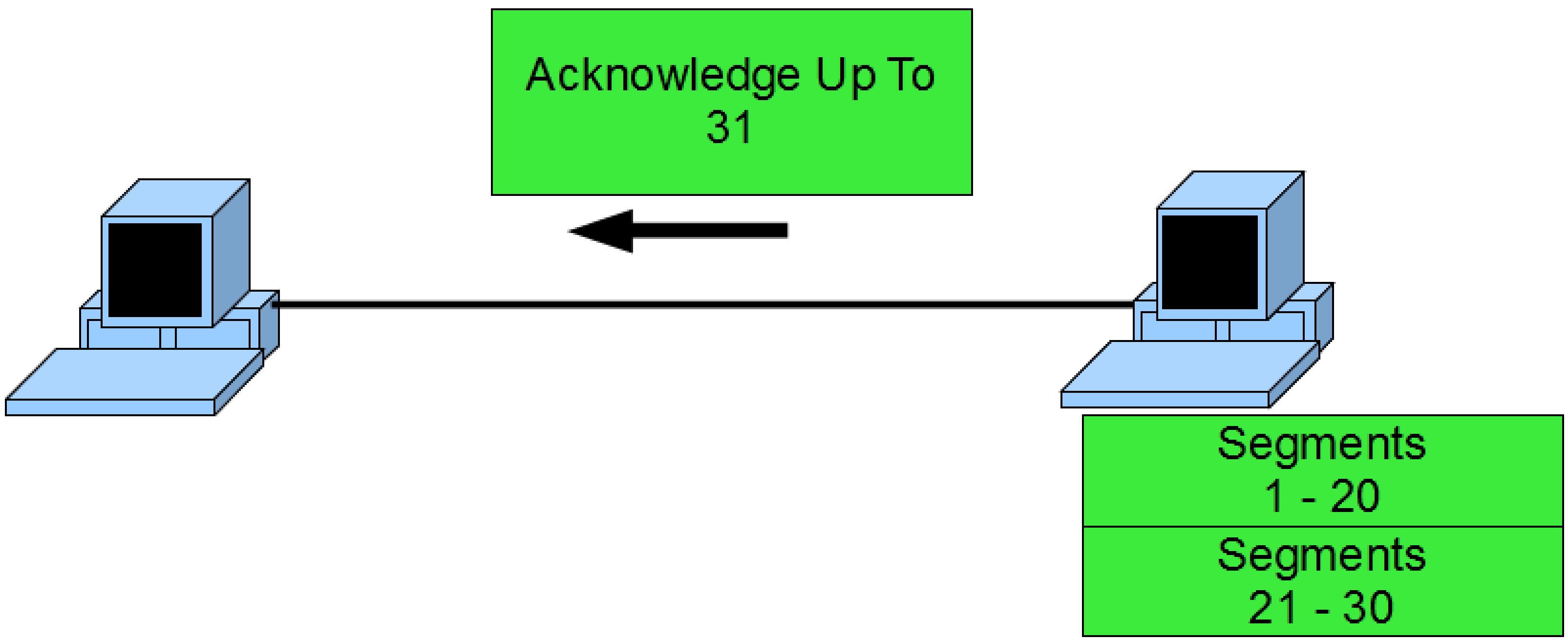

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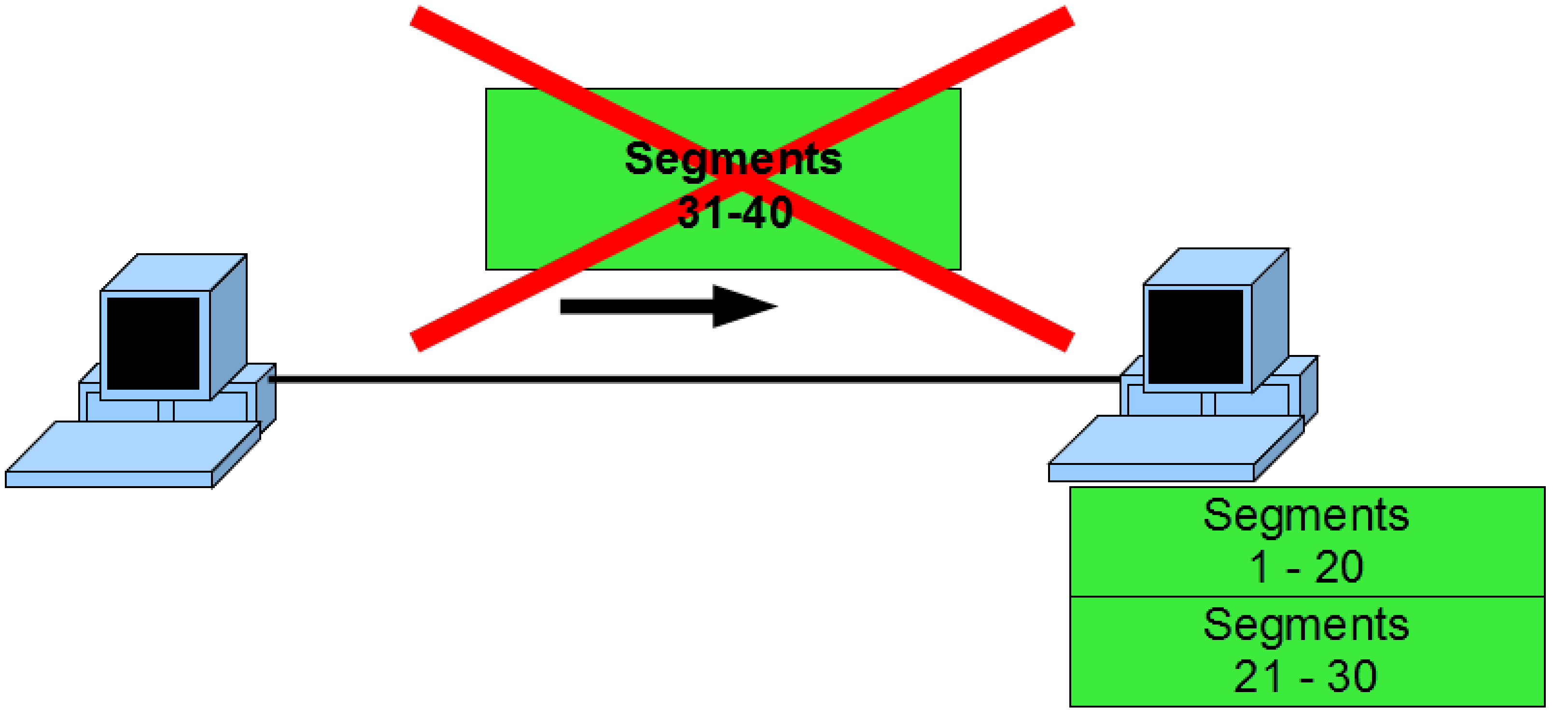

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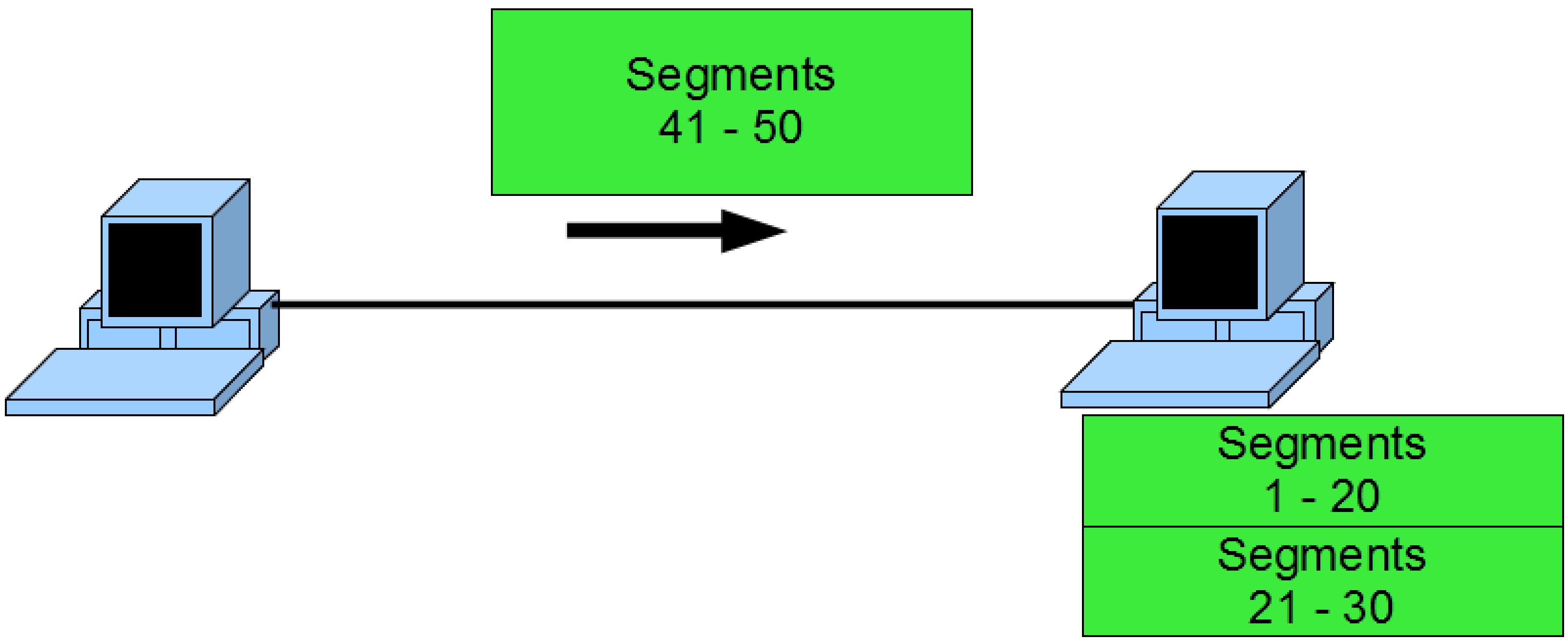

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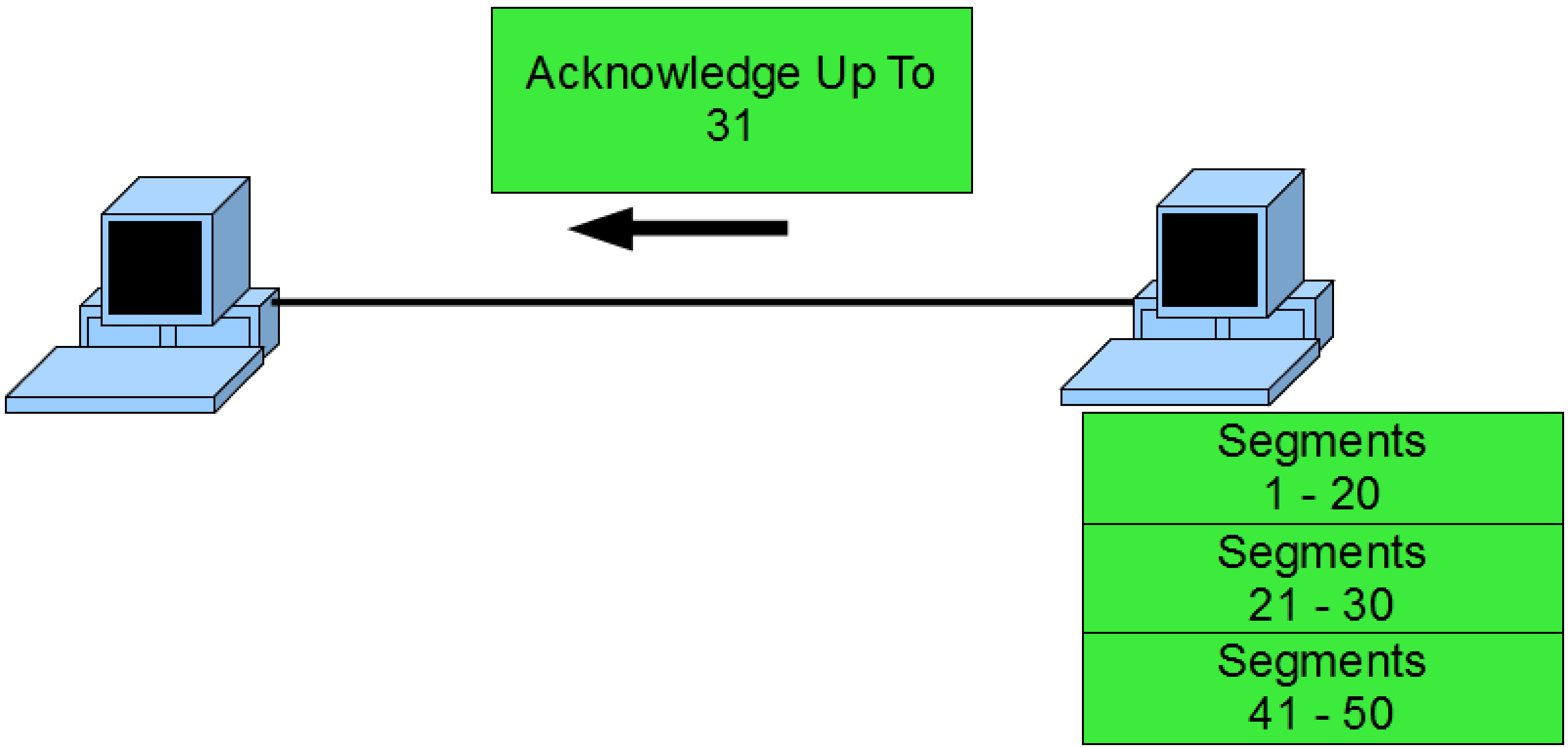


Resending strategies

- When will a client know to resend a segment?
- **Time-out**: A client may resend a segment if it has not received an acknowledgement for it after a given period of time after sending the segment
- **Repetition**: A client may resend a segment, X, if it receives acknowledgements suggesting other segments are being received but X has not, e.g.
  - If the server receives segments

    (1-20), (30-40), (41-44), (45-50)
  - then it will send an acknowledgement with sequence number 21 for each segment received: 4 times acknowledgement up to 21
  - The repetition suggests to the client that the segment starting 21 is lost and needs resending

Maximum segment size

- A **maximum segment size** (MSS) for a connection is maximum amount of data allowed in one segment transmitted to a particular socket.

- It is specified by each connection end-point during synchronisation handshake
- Note that the client and server can have different MSS for the same connection.

Window size

- Because of the limits on the processes receiving data, segments should often be smaller than the end-point's maximum segment size
- The amount of data that the receiving end can process is called the **window size**
- No segment sent by the client should be larger than the window size, as data is then lost
- The receiver can adjust the window size during communication if it can accept more or less data, through a message to the sender

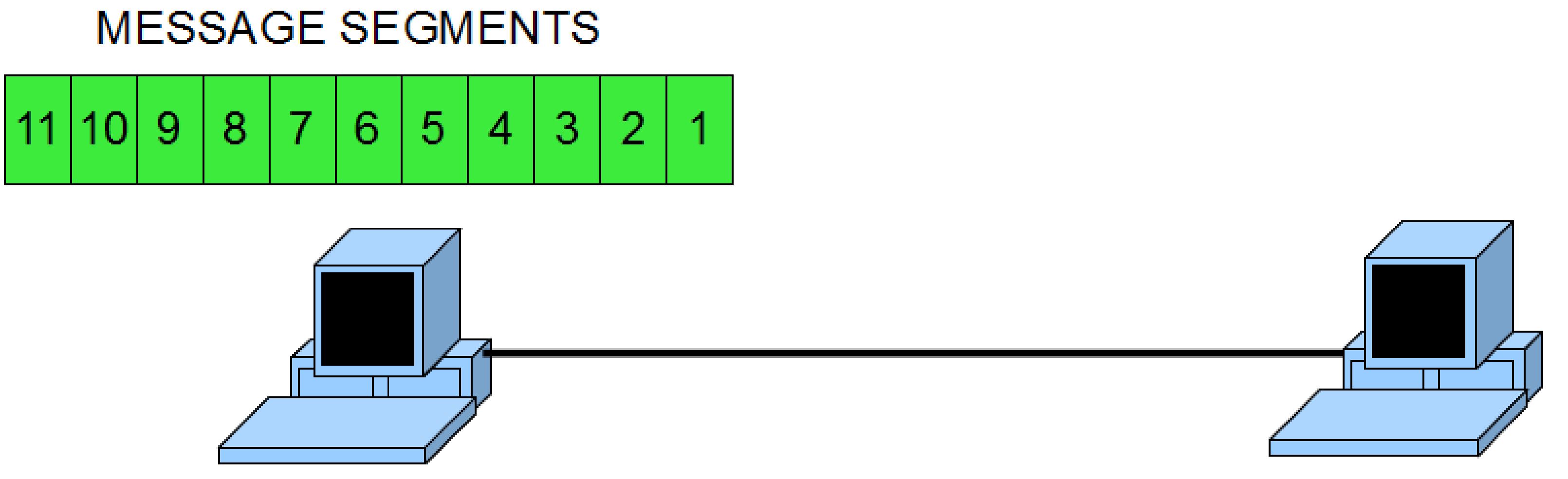
Segment sizing problem

- However, it is more complex than that...

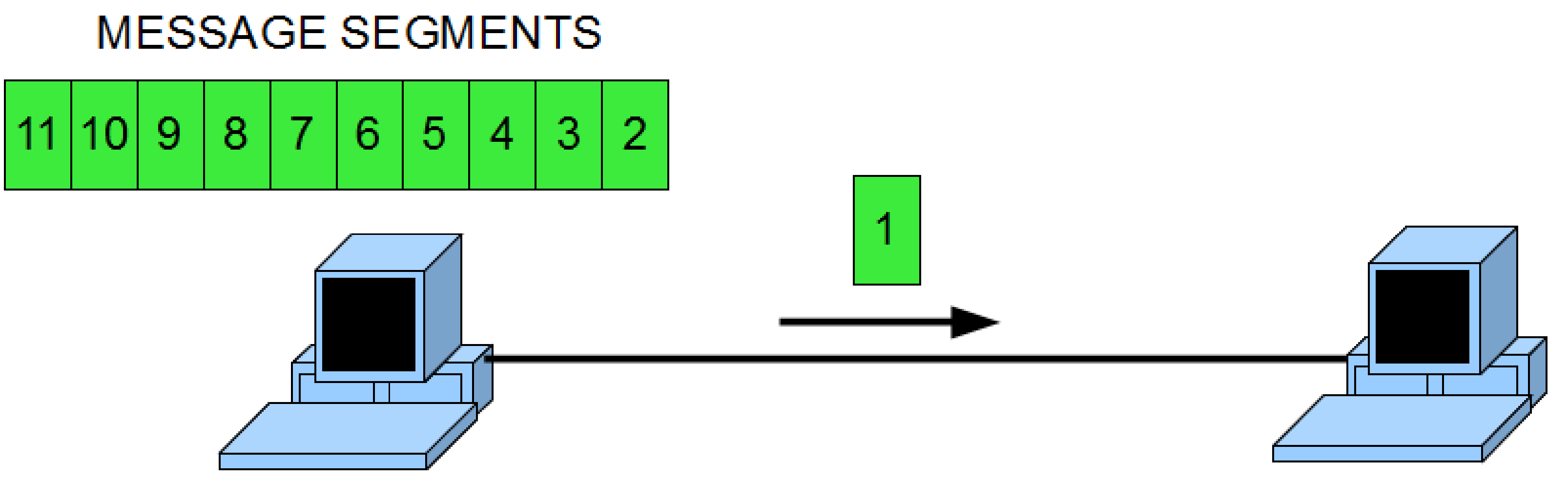
- The amount of data a process can accept depends on how fast it is processing the already received data
- The sender can only be sure that data which has been acknowledged has actually been received

Flow control

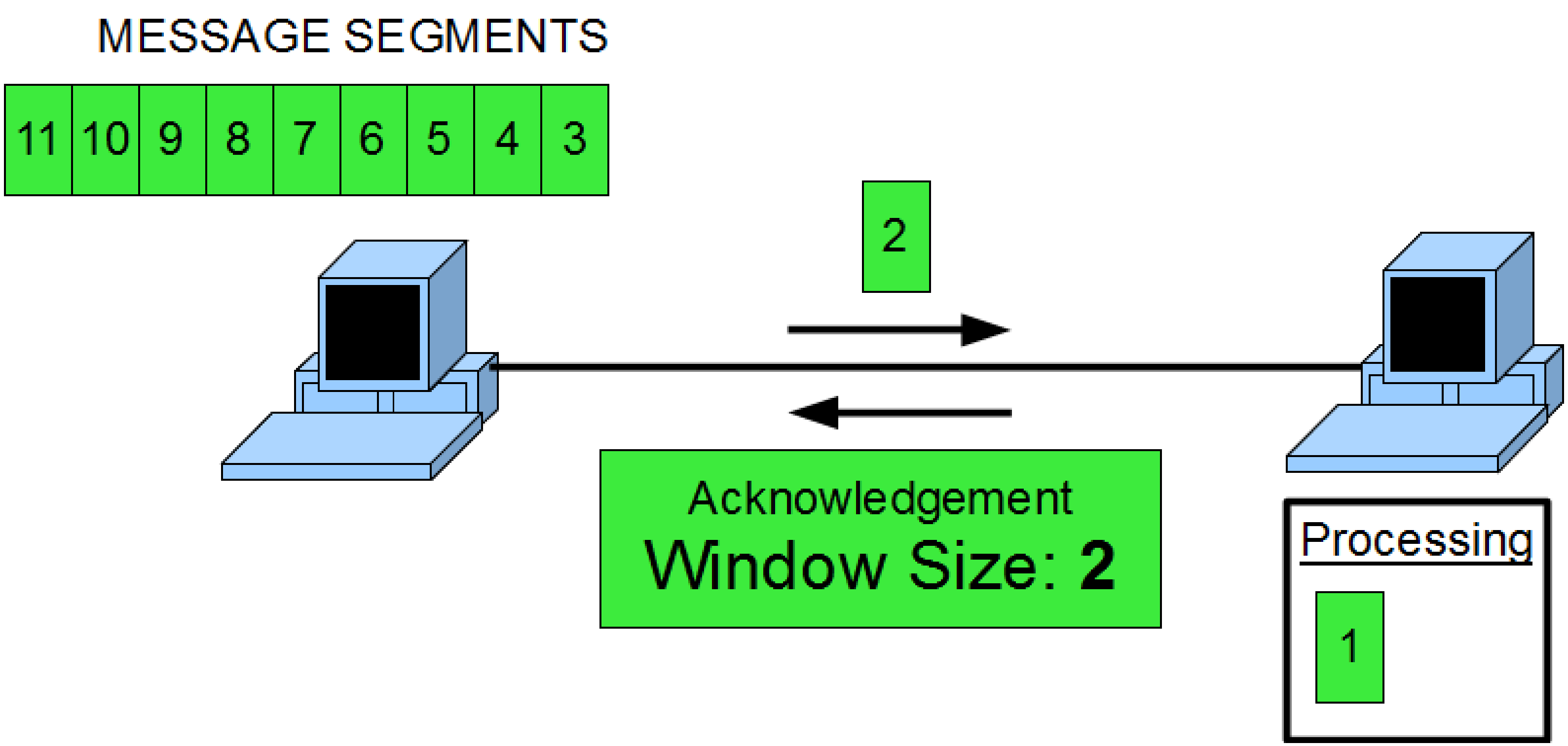
Flow control



Flow control



Flow control



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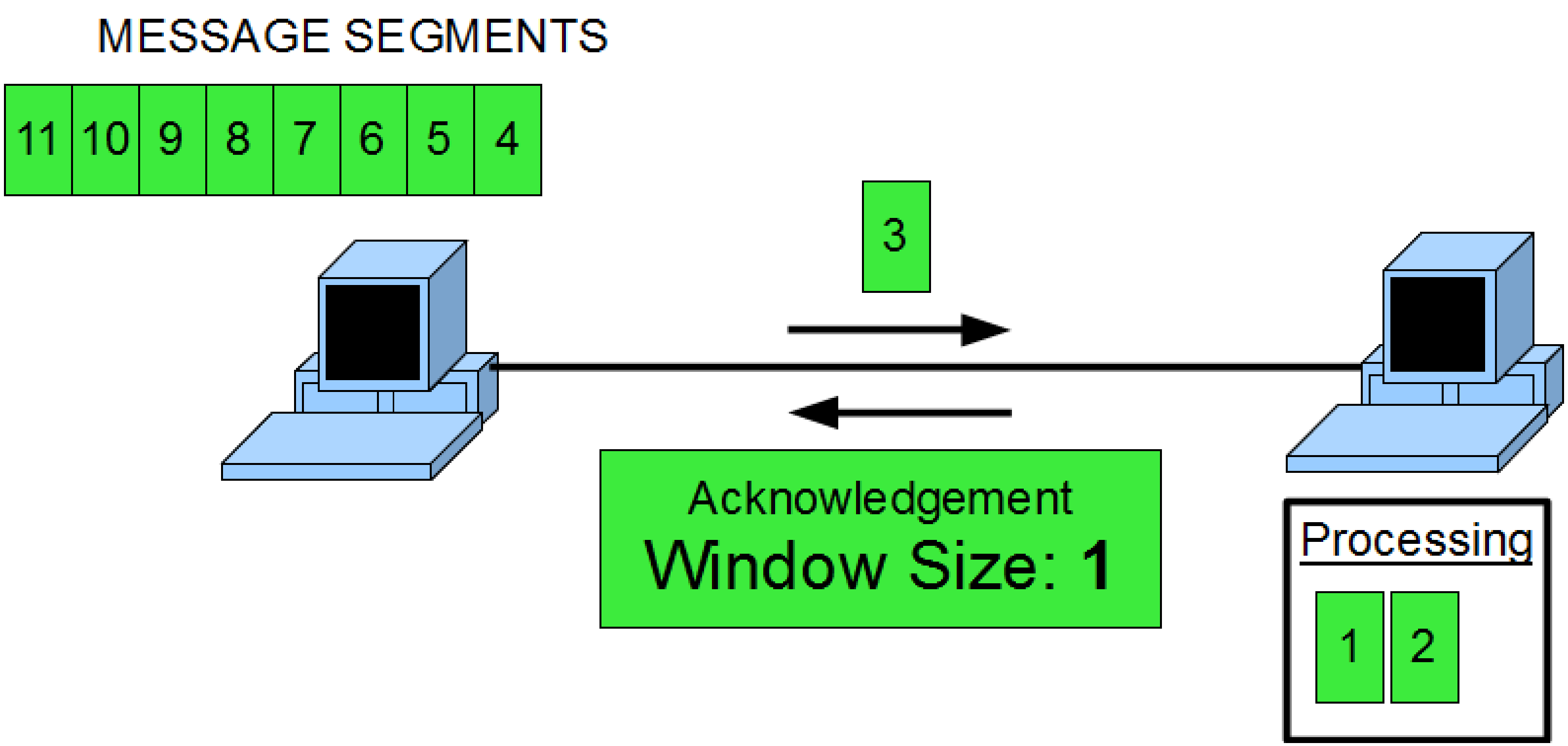

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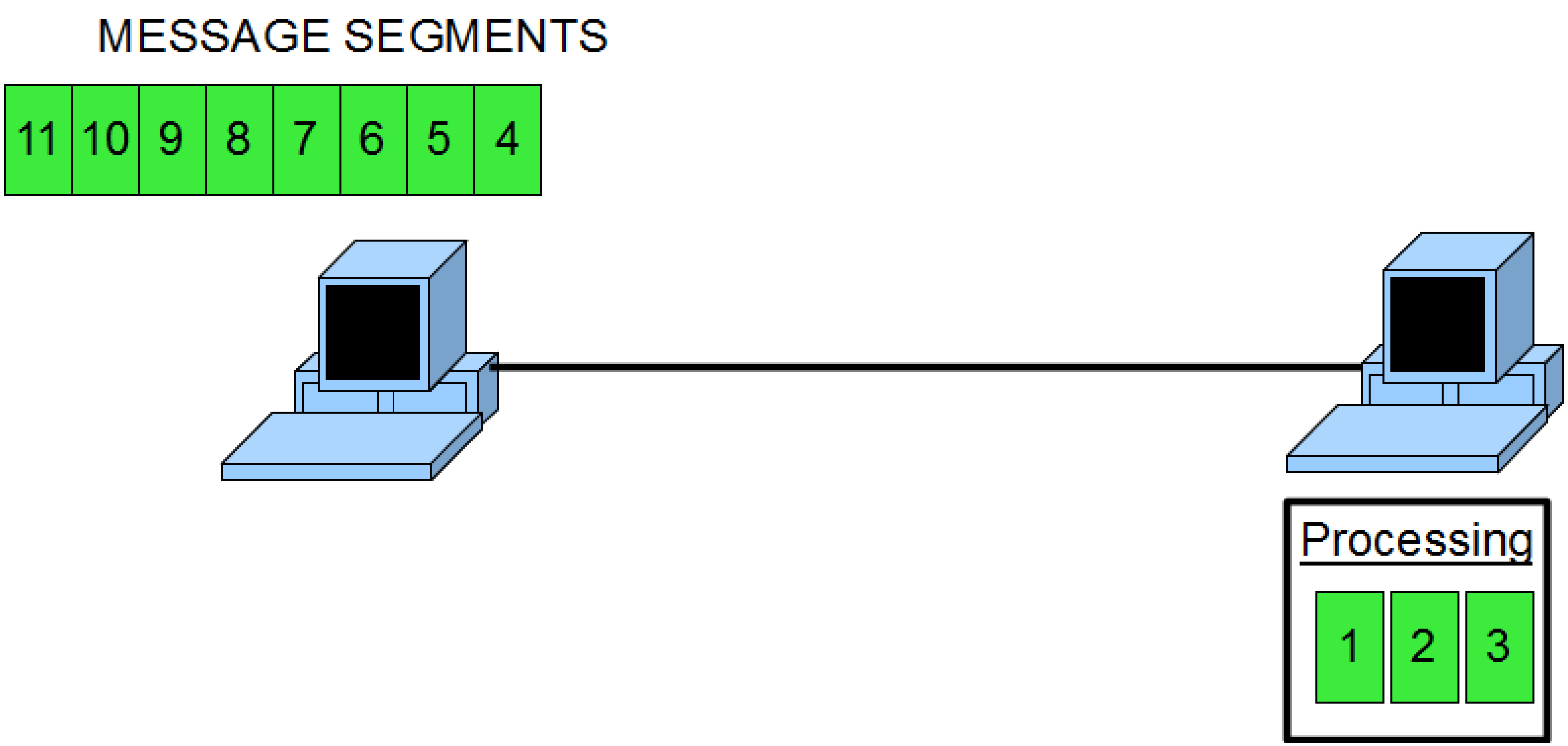
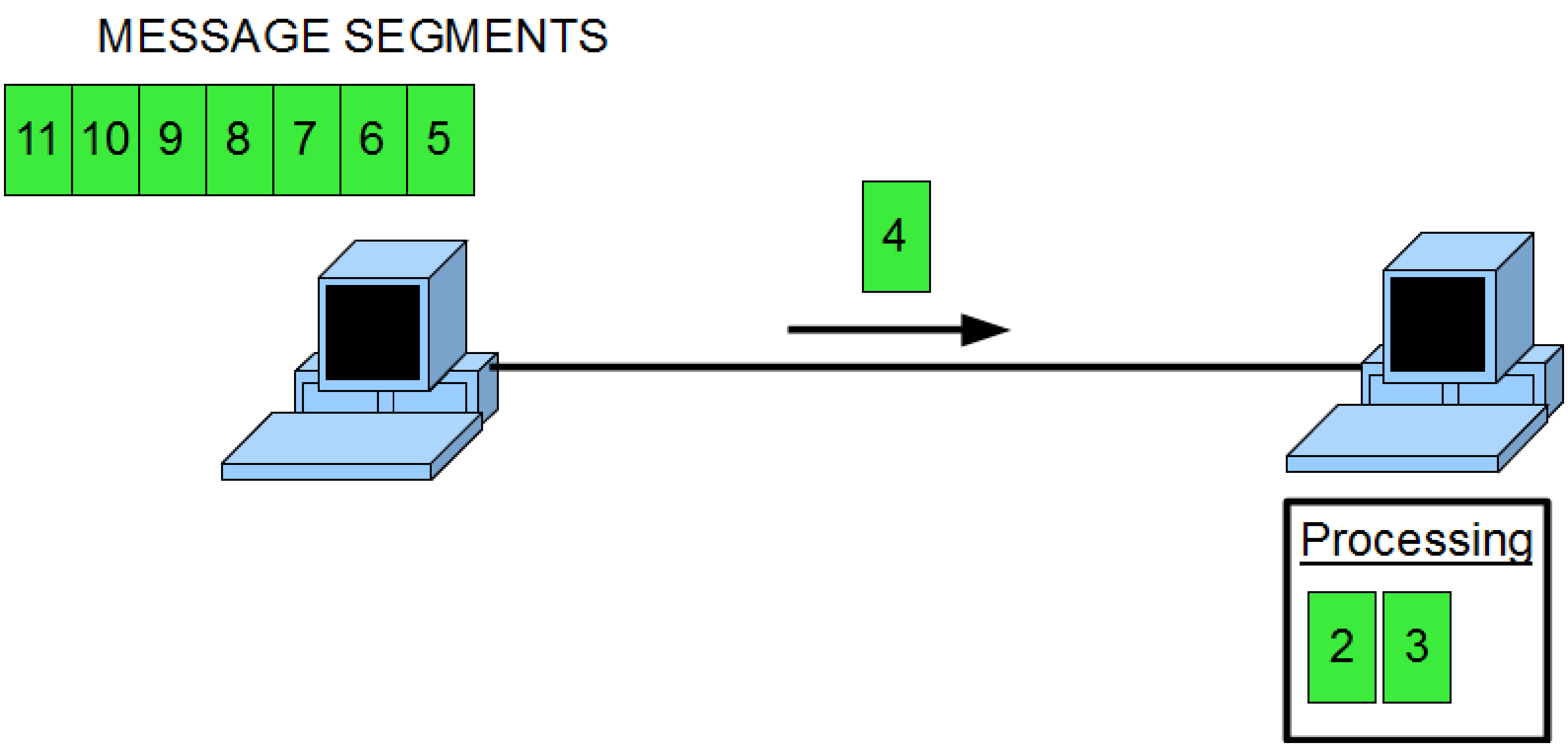


Flow control

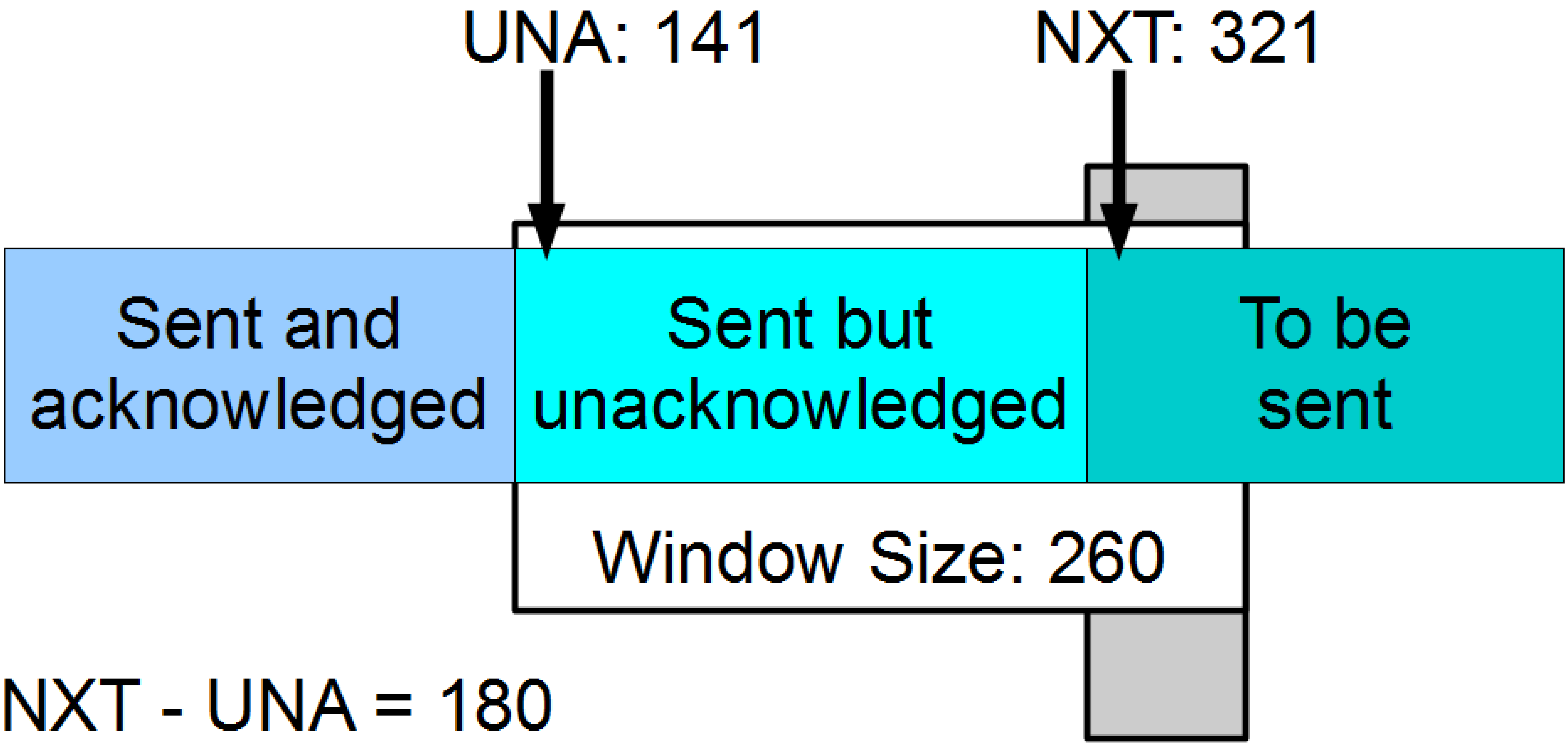


Segment sizing algorithm

- The sender keeps track of three variables:
  - Sequence number of the first byte sent but not yet acknowledged (UNA)
  - Sequence number of next byte to be sent (NXT)
  - The window size (WND)
- The **usable window** is the range of bytes that have not yet been sent, but the client believes the server is ready to receive
- The usable window size is calculated:

$$UNA + WND - NXT$$

Usable send window



NXT - UNA = 180
WND - 180 = 80
UNA + WND - NXT = **80**

Usable Window =
UNA + WND - NXT

Silly Window Syndrome

- If the receiver adjusts the window size to be too small, bandwidth usage becomes very inefficient
- This is because lots of very small segments will be sent and there will be an acknowledgement for each
- This is called silly window syndrome

Nagle’s algorithm

- Both sender and reciever can help tackle problem
- Sender’s strategy: not send further data until either:
  - All sent has been acknowledged, or
  - The data to be sent reaches the MSS

- The receiver’s strategy is to, as it becomes able to accept more data, not tell the client about this larger window size until it reaches either:
  - MSS
  - Half the server's maximum buffer size

Push

- Because of the flow control strategies, there is a delay between the client having data available to send and the client's TCP software sending it
- In some cases, this is unacceptable, and a client can request that all the data ready to send should be sent
- This is called a PUSH request
- The sender informs the receiver that the data being sent has been pushed
- In practice, in modern TCP/IP implementations, the PUSH flag is always set.

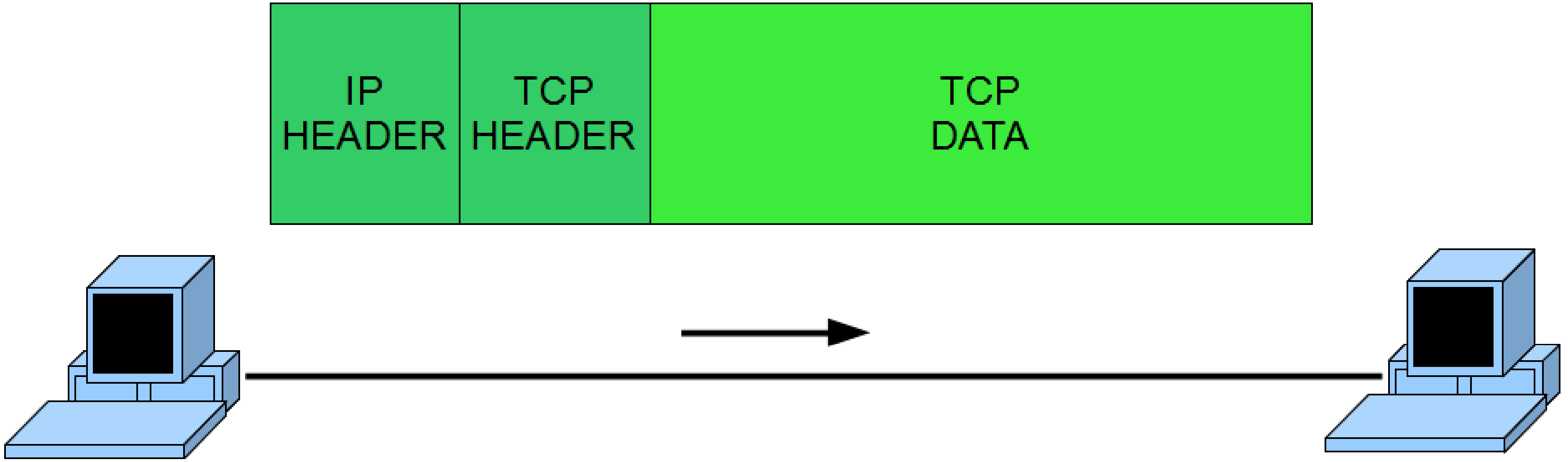
Urgent

- Sometimes data within a segment requires immediate action.
- The client can mark such data in a segment as urgent.
- For example CTRL-C in a remote shell session over TCP.

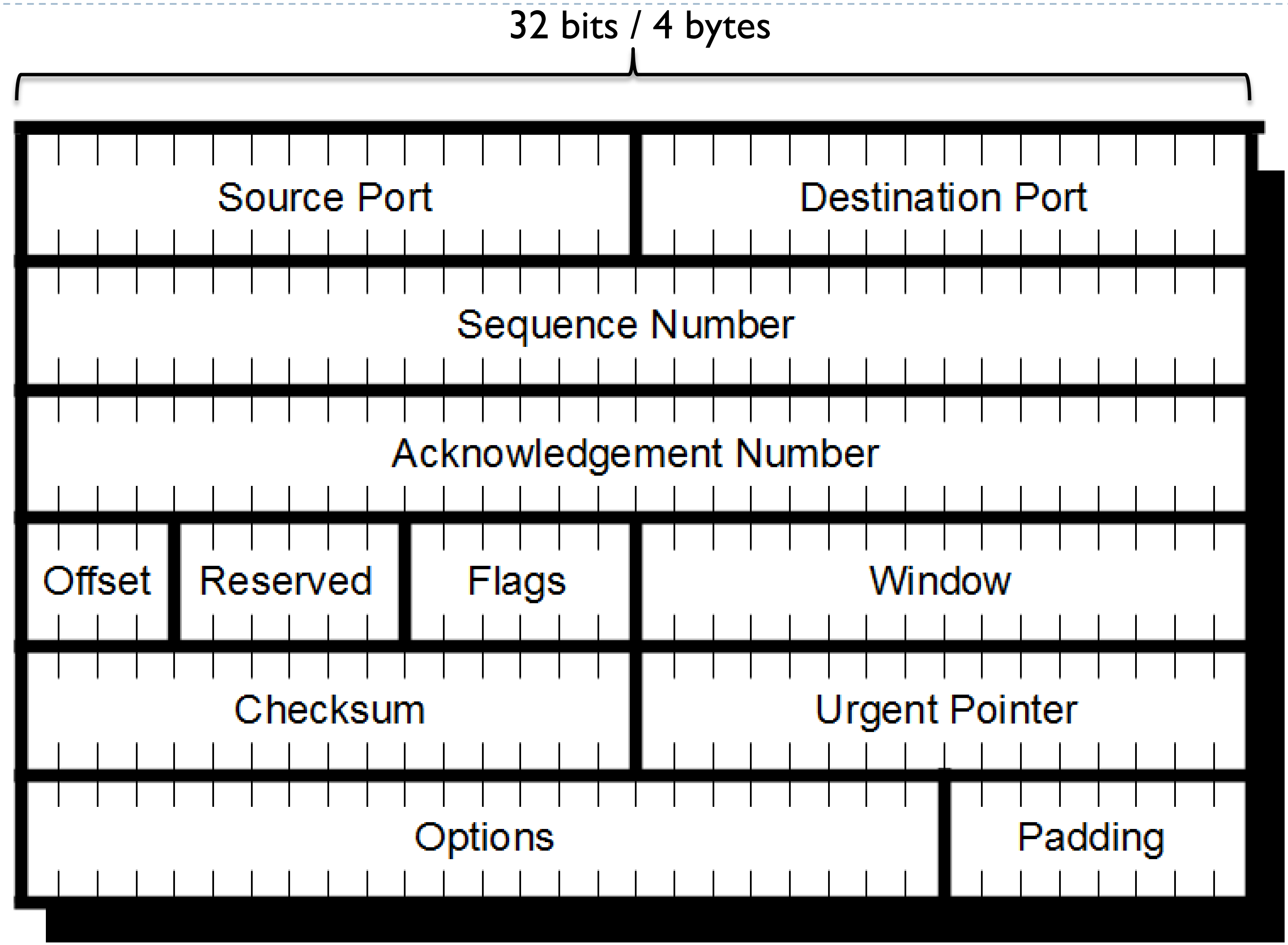
Reset

- If a host crashes or there are severe transmission problems, one host in a connection may lose its knowledge of that connection
- This means that it will not be expecting the data sent from the other host
- If a host receives unexpected TCP data it will respond with a **reset** message to stop the connection and resolve the problem
- Reset also used if a client tries to communicate with a server port that is not open

Combining protocols



TCP header


32 bits / 4 bytes
Source Port
Destination Port
Sequence Number
Acknowledgement Number
Offset
Reserved
Flags
Window
Checksum
Urgent Pointer
Options
Padding

Source and Destination Port fields

- Source Port: the port of the segment sender
- Destination Port: the port of the receiver
- 16 bits each

- Combines with IP address in IP header to make socket address, e.g.
  - IPv4 Header Source Address: 137.73.9.232
  - TCP Port Address: 8080

Sequence Number field

- Sequence Number represents different values depending on the type of message
- 32 bits

- If in a synchronise message setting up the connection, it is the Initial Sequence Number (ISN)
- Otherwise, this is the sequence number of the start of the segment

Acknowledgement Number field

- Acknowledgement Number is used in acknowledgement messages
- 32 bits

- This field contains the sequence number before which the server has all the message data, e.g.

- Received: 0-10, 10-20 Ack number: 21
- Received: 0-10, 20-30 Ack number: 11

Data Offset field

- Data Offset: The length of the TCP header in 32-bit words
- 4 bits: 0 - 15

- Indicates where the data starts within the TCP message
- Minimum value: 5

Reserved field

- Reserved: Not currently used, reserved for future uses
- 6 bits
- All 0s

Urgent Flag field

- URG Flag: Marks that this message contains urgent data

- Urgent data is normally pushed to ensure it is sent immediately

Acknowledgement Flag field

- ACK Flag: Marks that this is an acknowledgement
- The acknowledgement may be of:
  - A segment being received
  - A synchronisation message, in establishing connection
  - An acknowledgement message, in establishing or terminating a connection
  - A finalisation message, in terminating a connection

Push Flag field

- PSH Flag: Marks that this data was pushed

- A client can request that all the data ready to send should be sent
- This is called a PUSH request
- The PSH flag indicates to the server that this has occurred

Reset Flag field

- RST Flag: Marks that this is a reset message

- If a host receives unexpected TCP data it will respond with a reset message to stop the connection and resolve the problem
- Reset is also used if a client tries to communicate with a server port that is not open

Synchronise Flag field

- SYN Flag: Marks that this is a synchronise message or acknowledgement of a synchronise

- The first two messages in a TCP handshake have this flag set
  - From client to server: I wish to connect
  - From server to client: I accept the connection

Finalise Flag field

- FIN Flag: Marks that this is a finalise message or acknowledgement of a finalise
- The first two messages in a TCP finalisation have this flag set
  - From client to server: I wish to end the connection
  - From server to client: I accept the end of the connection

Window field

- Window: The current acceptable window size
- 16 bits: 0 - 65,535

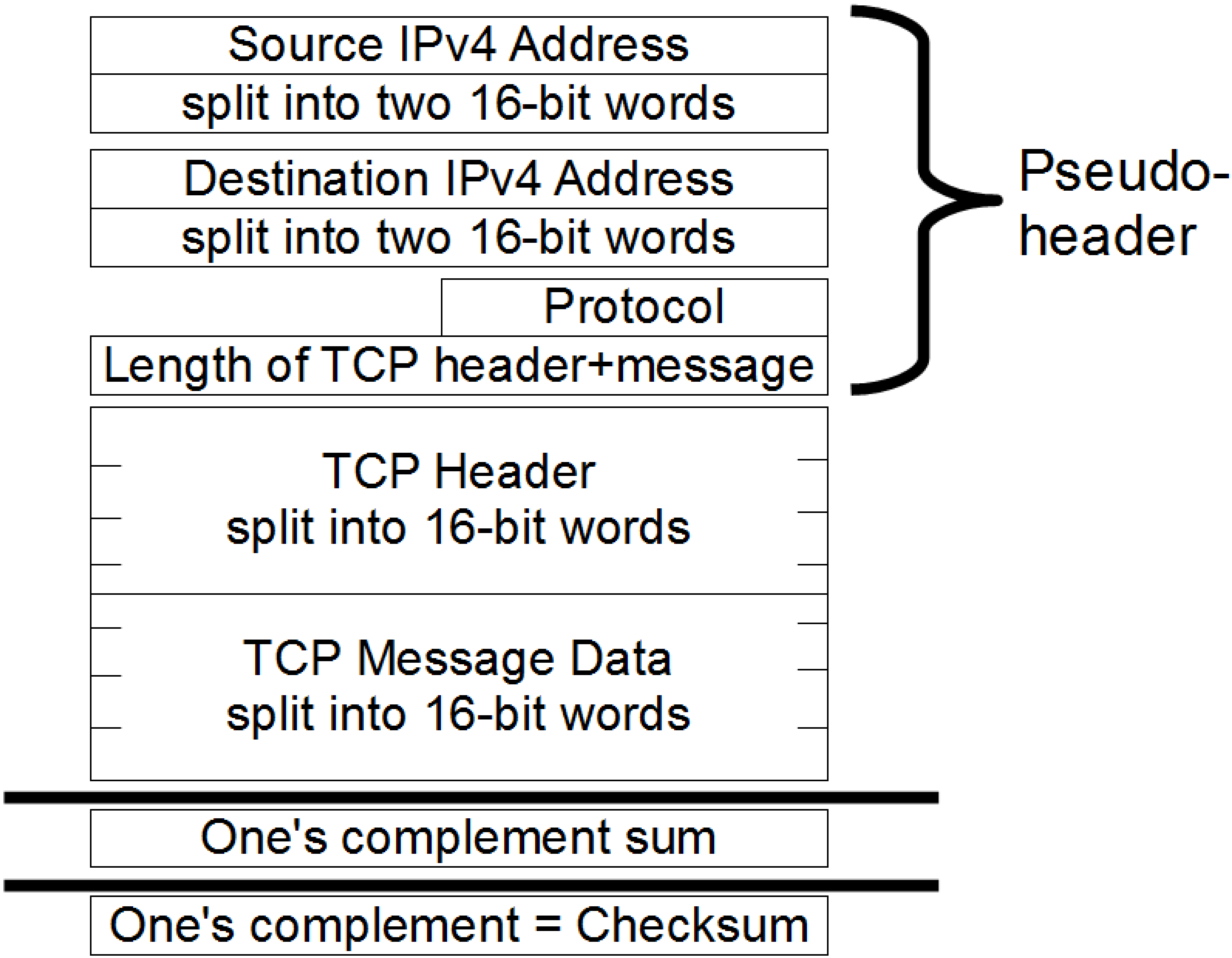
- The server uses this field to adjust the window size during communication if it can accept more or less data
- It is sent in its acknowledgement messages to the client

Checksum field

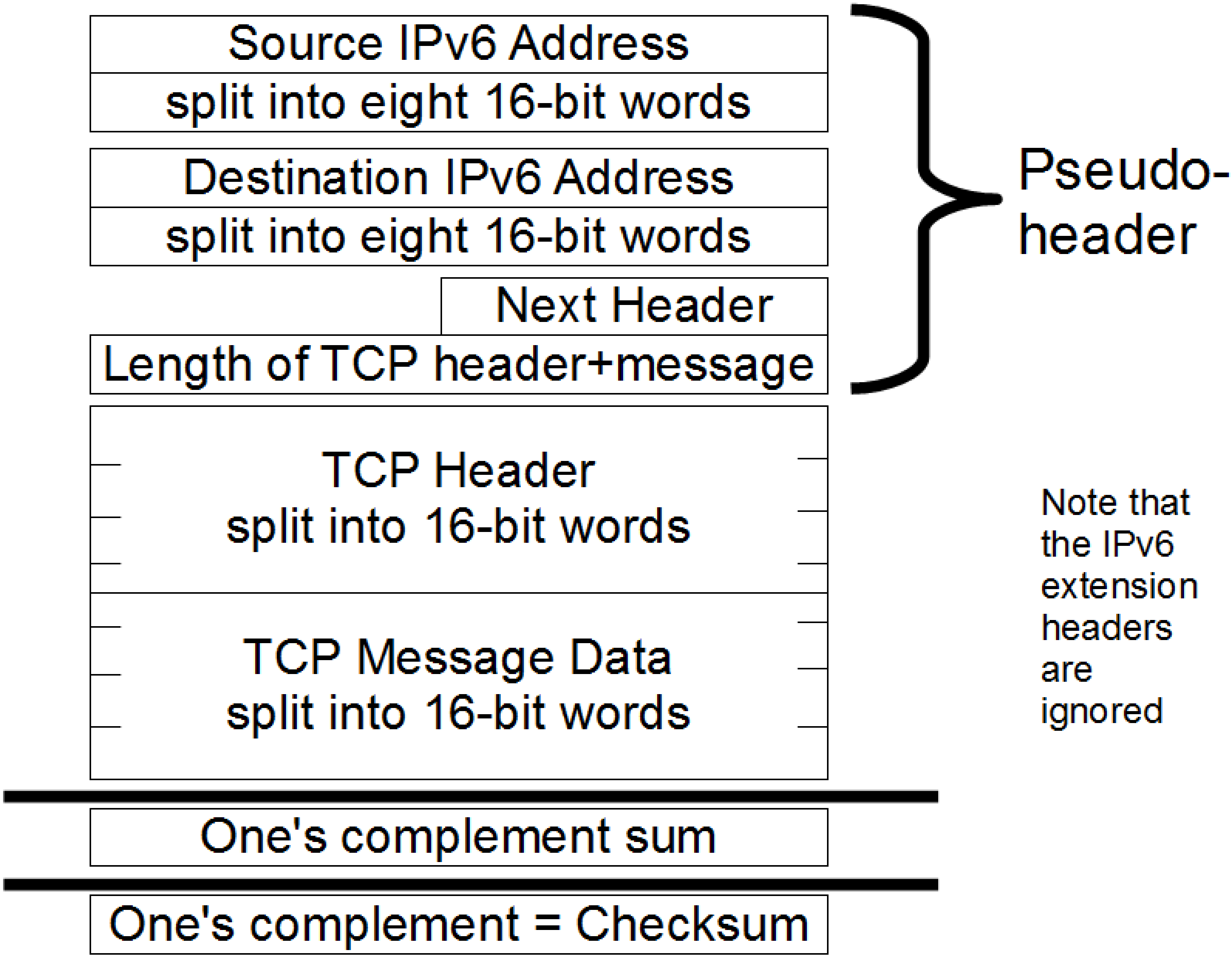
- Checksum: A checksum over the segment, used to check for corruption
- 16 bits

- As with the IPv4 checksum, this is a one's complement of a one's complement sum of 16-bit words
- However, the TCP checksum includes more:
  - The TCP header (taking checksum field as 0)
  - The message data
  - The IP addresses: source and destination
  - The Protocol / Next Header field (from IP header)
  - The length of the TCP message (header + data)

Checksum with IPv4



Checksum with IPv6



Note that the IPv6 extension headers are ignored

Urgent Pointer field

- Urgent Pointer: Position of where the urgent data ends inside the segment
- 16 bits

- Given as a sequence number
- Used when URG Flag is set to Yes (1)
- The message data may mix urgent data with non-urgent data
- The pointer indicates the first byte after the urgent data

Options field

- Options: Various TCP options
- Varies in length

- An important TCP option is the Maximum Segment Size (16 bits)
- This is used for the server to specify the largest segment size it is willing to accept
- It may only be used in synchronisation, i.e. SYN flag is set to Yes (1)
- The server can declare the MSS in the message acknowledging synchronisation

TCP and IP

- TCP is used over IP
- This means that the data using TCP becomes the data content of IP datagrams
- IP deals with:
  - Addressing hosts
  - Fragmentation to ensure the networks can transmit the data
- TCP can somewhat ignore what IP does and just pass it data to send to a given address

RFCs

TCP	793
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Silly Window Syndrome	813
Maximum Segment Size	879
Strategy for Silly Window Syndrome	896
Other issues relevant to TCP	2001

- http://www.tcpipguide.com

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