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A lot of state about each connection needs to be stored by the OS

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But ACKs on their own do not solve all the problem

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But the ACK might be intercepted and A might not get the ACK

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But this might not get through…

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For full reliability it looks like we need an infinite regress!

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Repeat until A gets an ACK (or A gives up)

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- IP datagrams can arrive out of order, so we need some way to recognise which ACK goes with which packet

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- how to manage duplicates? Resends can produce duplicate packets (if the original was not actually lost) so we need some way to recognise and discard extra copies
- Flow control: how to increase the rate of sending packets when things are going well, and decrease the rate when they are not

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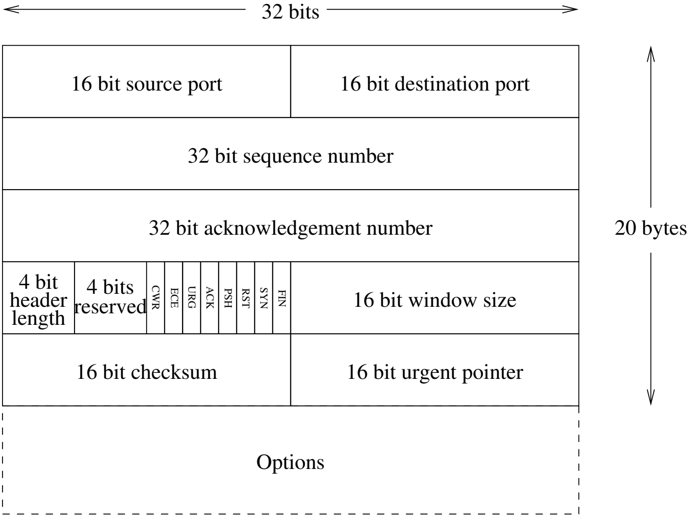
A TCP header is complicated as it must address many complex issues

TCP



32 bits

16 bit source port

16 bit destination port

32 bit sequence number

32 bit acknowledgement number

4 bit header length

4 bits reserved

CWR

ECE

URG

ACK

PSH

RST

SYN

FIN

16 bit window size

16 bit checksum

16 bit urgent pointer

Options

20 bytes

TCP header

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- Two 32 bit values: *sequence* and *acknowledgement*

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So if a segment contains 10 bytes of data, the sequence number on the next segment sent will be 10 greater

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Sequence numbers

The sequence number in the header is the number of the first byte of data in the segment

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The destination acknowledges those bytes it has received by filling in the ACK field with the appropriate byte number and setting the ACK flag

TCP

Sequence numbers

The reverse connection from destination to source has its own sequence number as TCP is fully duplex

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Everything we say here is true for data travelling in the reverse direction: the reverse traffic has its own independent sequence numbers and flow control

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Another reason to avoid fragmentation

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The returning ACK field contains the sequence number of the next byte the destination expects to receive, e.g., if the sequence number is 20001 and 14 bytes are received it returns 20015 in the ACK field

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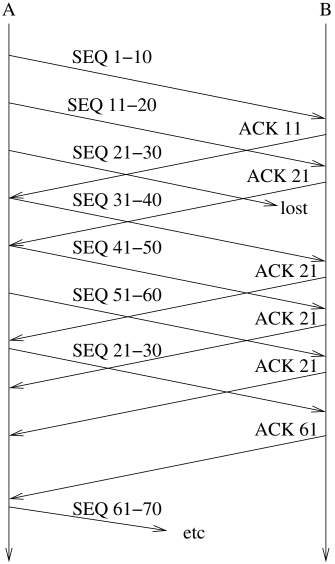
This helps reduce the amount of network traffic

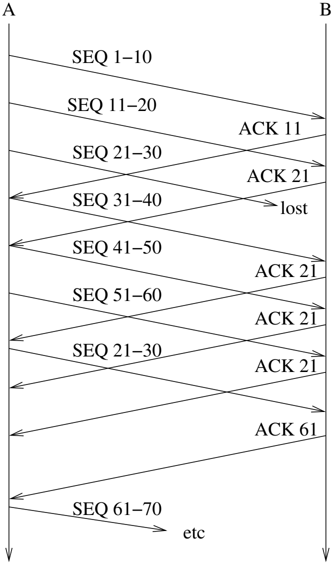
TCP



ACKing lost segments

A is sending 10 byte segments to B, and B is ACKing them;

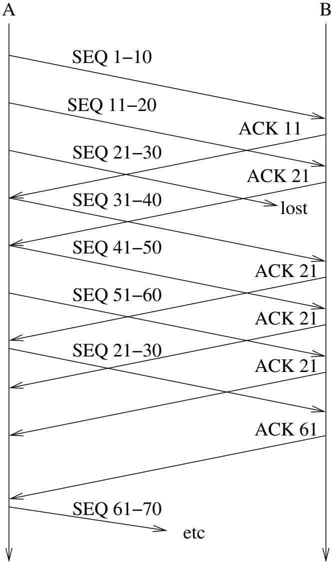
TCP



ACKing lost segments

The segment containing bytes 21-30 is lost;

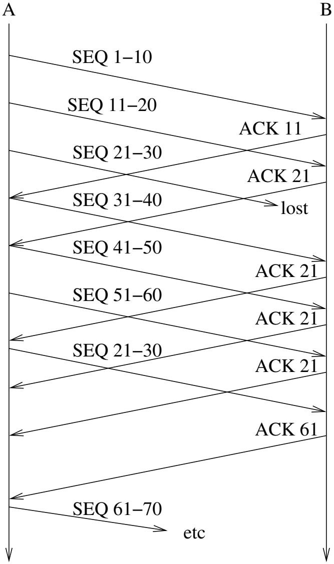
TCP



ACKing lost segments

When B next gets a segment it still ACKS with 21: that’s the byte it wants next;

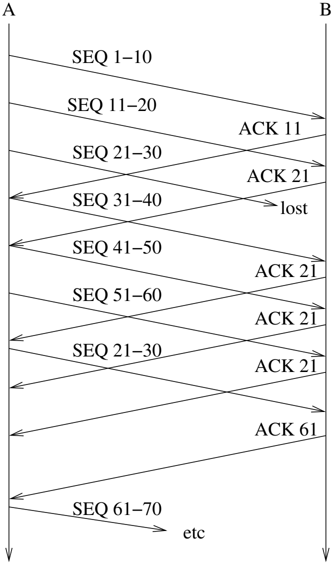
TCP



ACKing lost segments

While the ACK travels back to A, A is still sending new data;

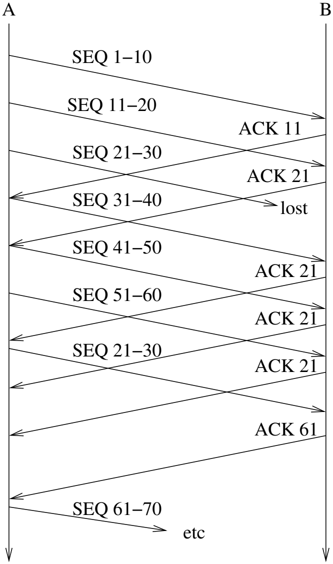
TCP



ACKing lost segments

Eventually A gets duplicate ACKs from B: this is a sign of a problem;

TCP



ACKing lost segments

A resends bytes 21-30;

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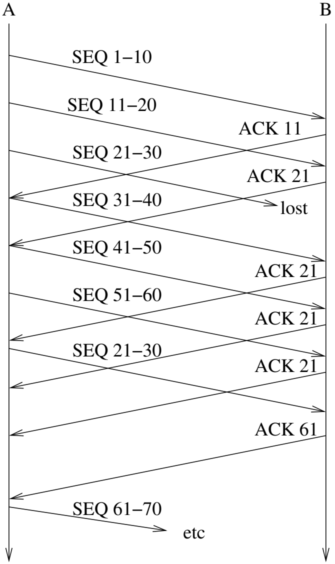

ACKing lost segments

When B gets these bytes it can ACK all the way up to 60

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Sequence numbers

In fact this diagram is not realistic: it is over-simplified to fit on the slide

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Exercise When might we receive many ACKs with the same sequence number, but nothing is in error?

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Exercise E.g., using the TCP header timestamp option. Read about PAWS

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Much more on SEQ and ACKing later, but note that sequence numbers solve the segment ordering problem, too

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- Many flags performing various functions

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Most of these will be described in more detail as we go along:

- URG: urgent data
- ACK: the acknowledgement field is active
- PSH: push this data to the application as fast as possible
- RST: reset (break) the connection
- SYN: synchronise a new connection
- FIN: finish a connection
- ECE: congestion notification
- CWR: congestion window reduced
- 4 reserved bits, set to 0