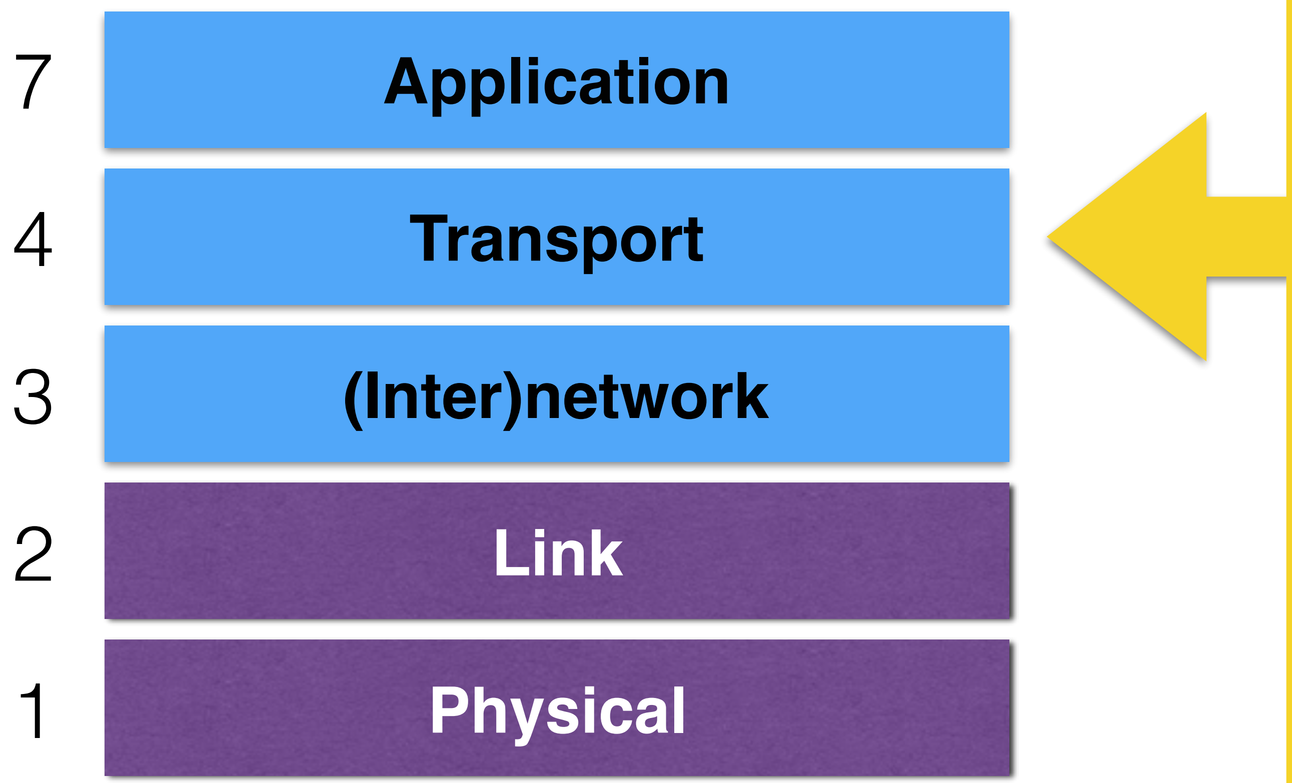
Transport layer attacks

Slides from

- Dave Levin 414-spring2016

Layer 4: Transport layer



- End-to-end communication between **processes**
- Different types of services provided:
  - UDP: unreliable *datagrams*
  - TCP: *reliable* byte stream
- "Reliable" = keeps track of what data were received properly and retransmits as necessary

TCP: reliability

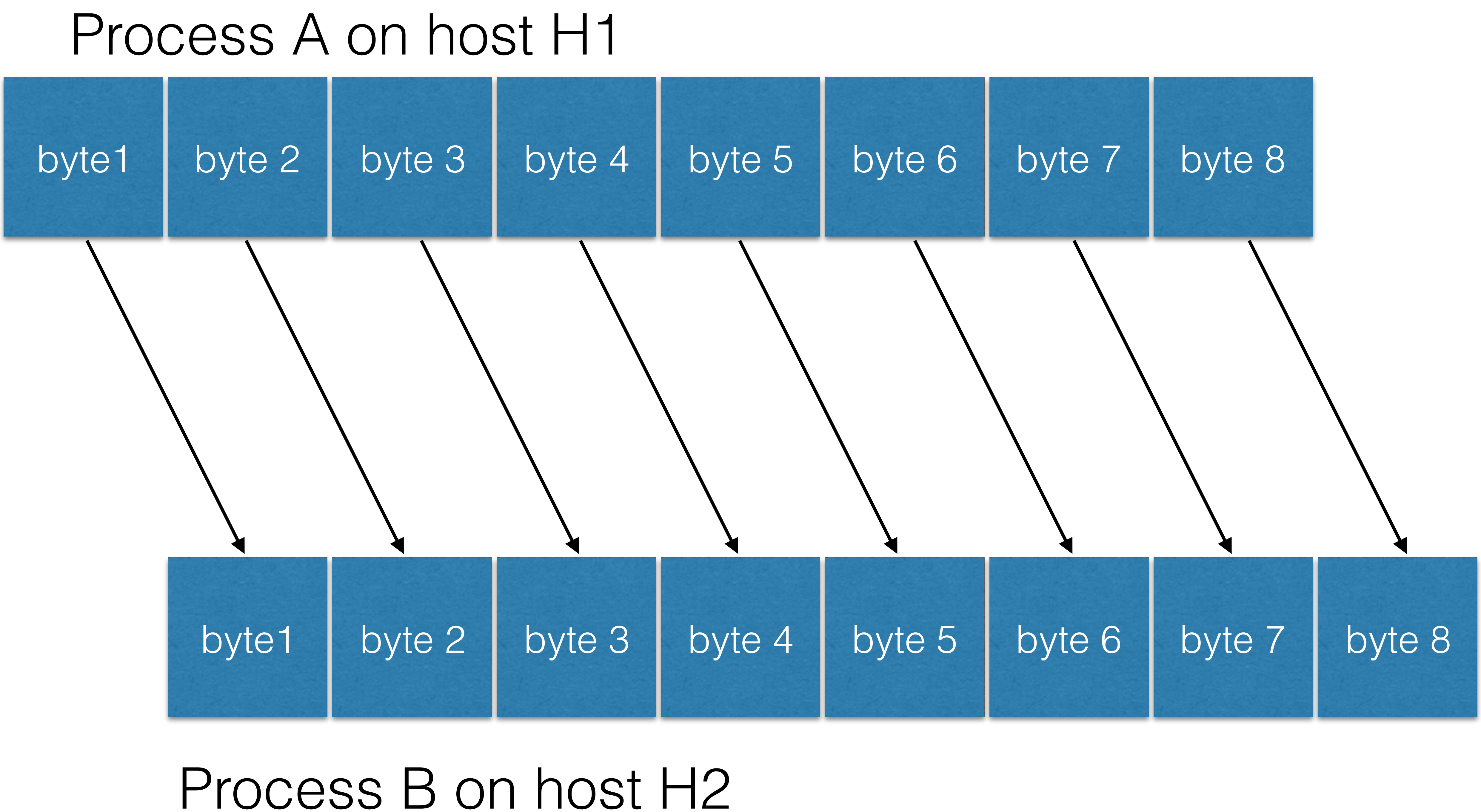
- Given best-effort deliver, the goal is to ensure *reliability*
  - All packets are delivered to applications
  - … in order
  - … unmodified (with reasonably high probability)
- Must robustly detect and retransmit lost data

TCP’s bytestream service

- Process A on host 1:
    - Send byte 0, byte 1, byte 2, byte 3, …
- Process B on host 2:
    - Receive byte 0, byte 1, byte 2, byte 3, …
- The applications do **not** see:
    - packet boundaries (looks like a stream of bytes)
    - lost or corrupted packets (they’re all correct)
    - retransmissions (they all only appear once)

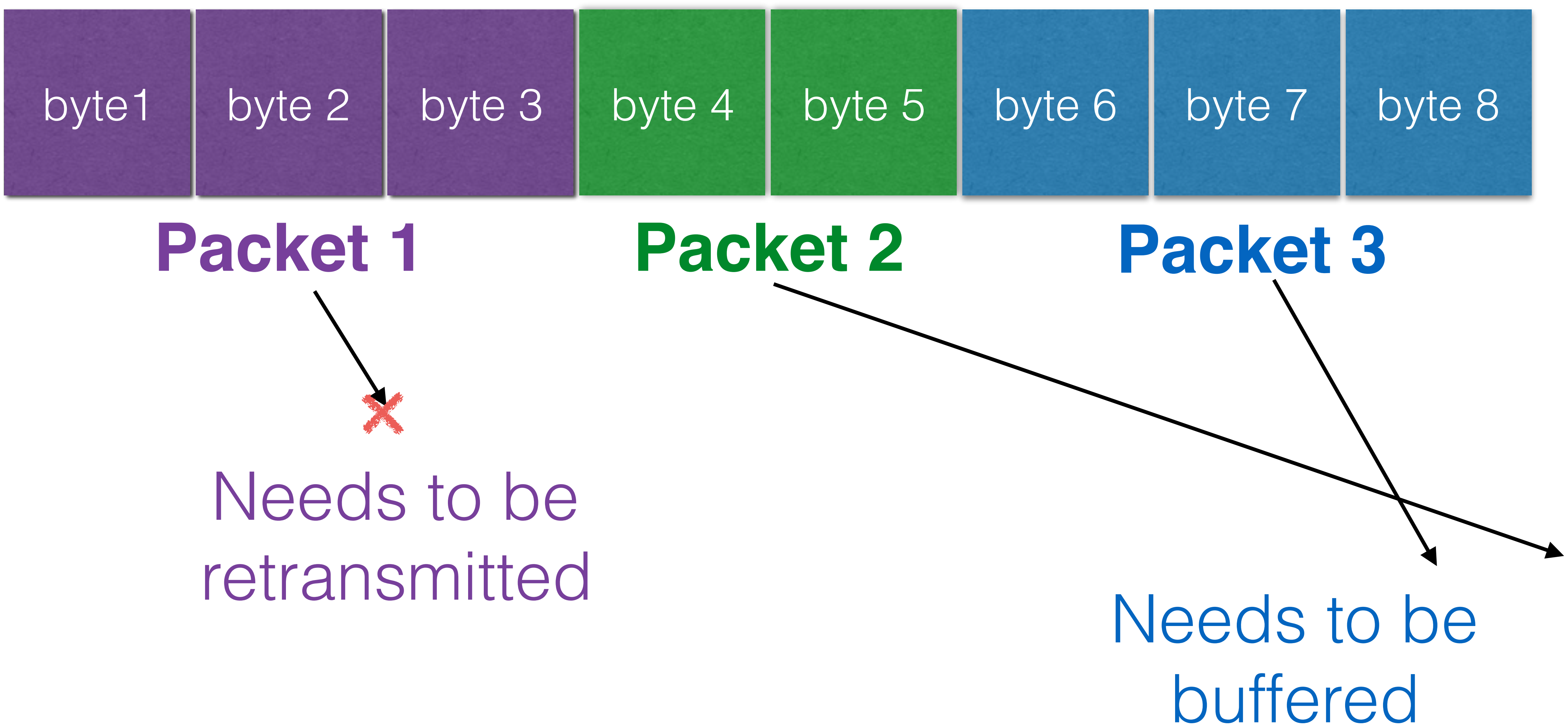
TCP bytestream service

Abstraction: Each *byte* reliably delivered in order



TCP bytestream service

Reality: *Packets* sometimes retransmitted, sometimes arrive out of order



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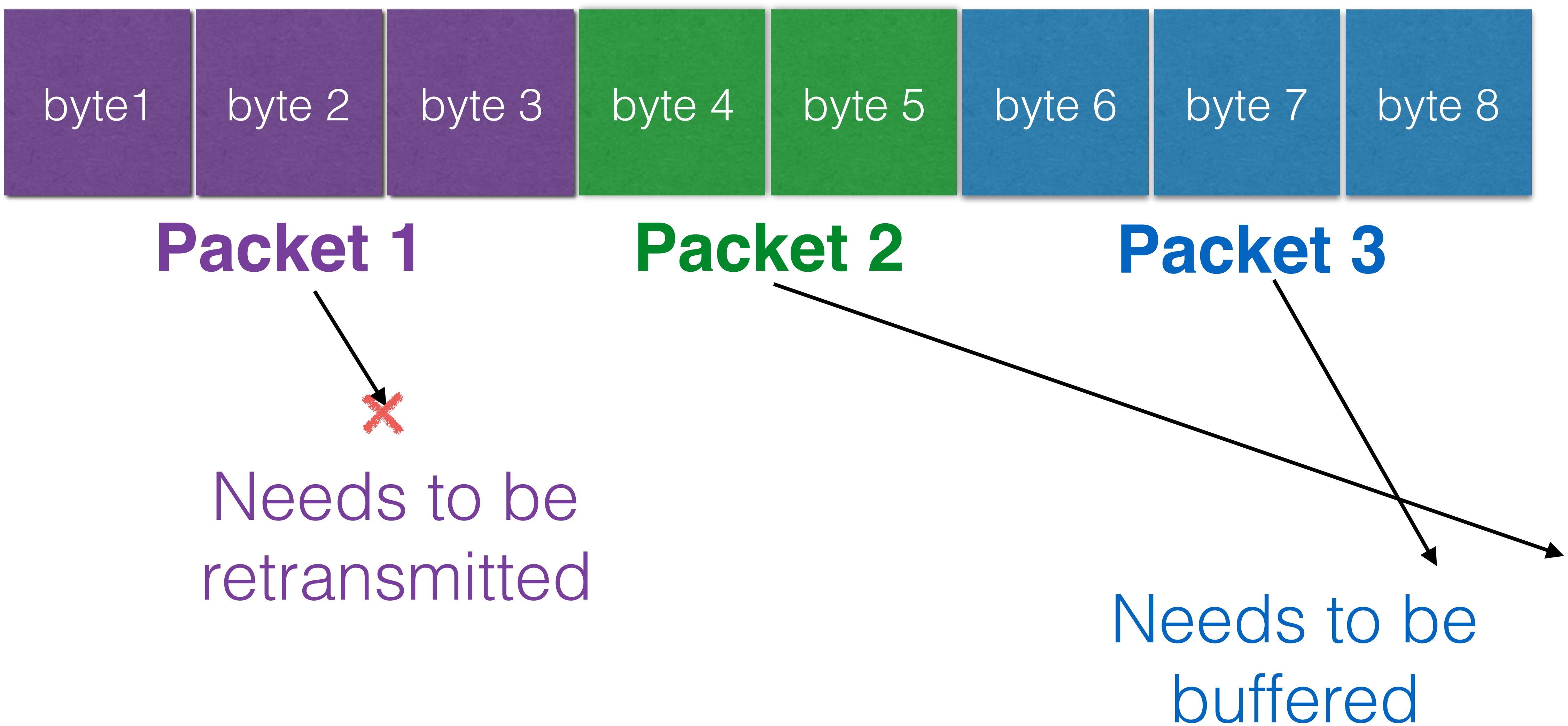
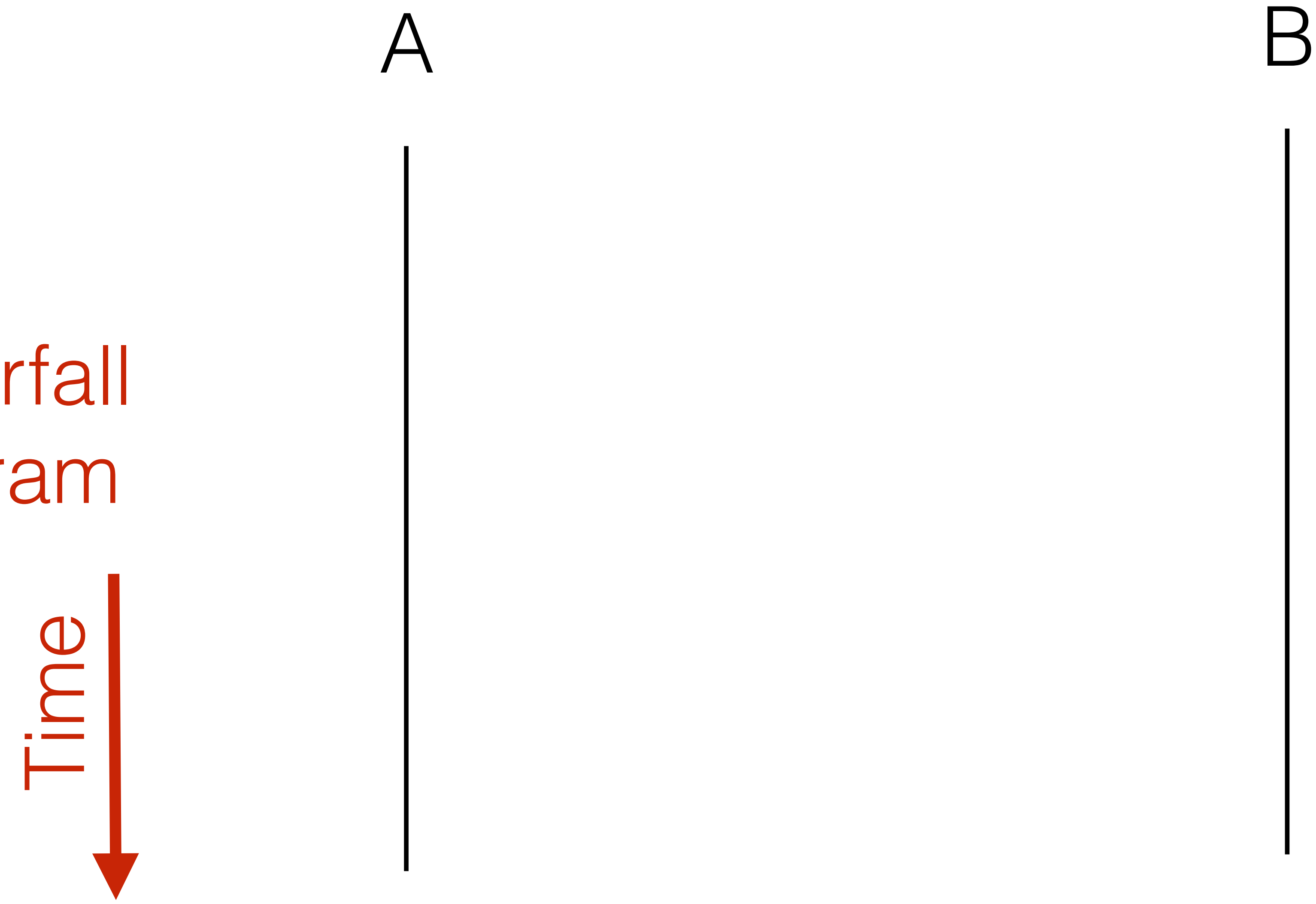


TCP's first job: achieve the abstraction while hiding the reality from the application

How does TCP achieve reliability?



Waterfall diagram

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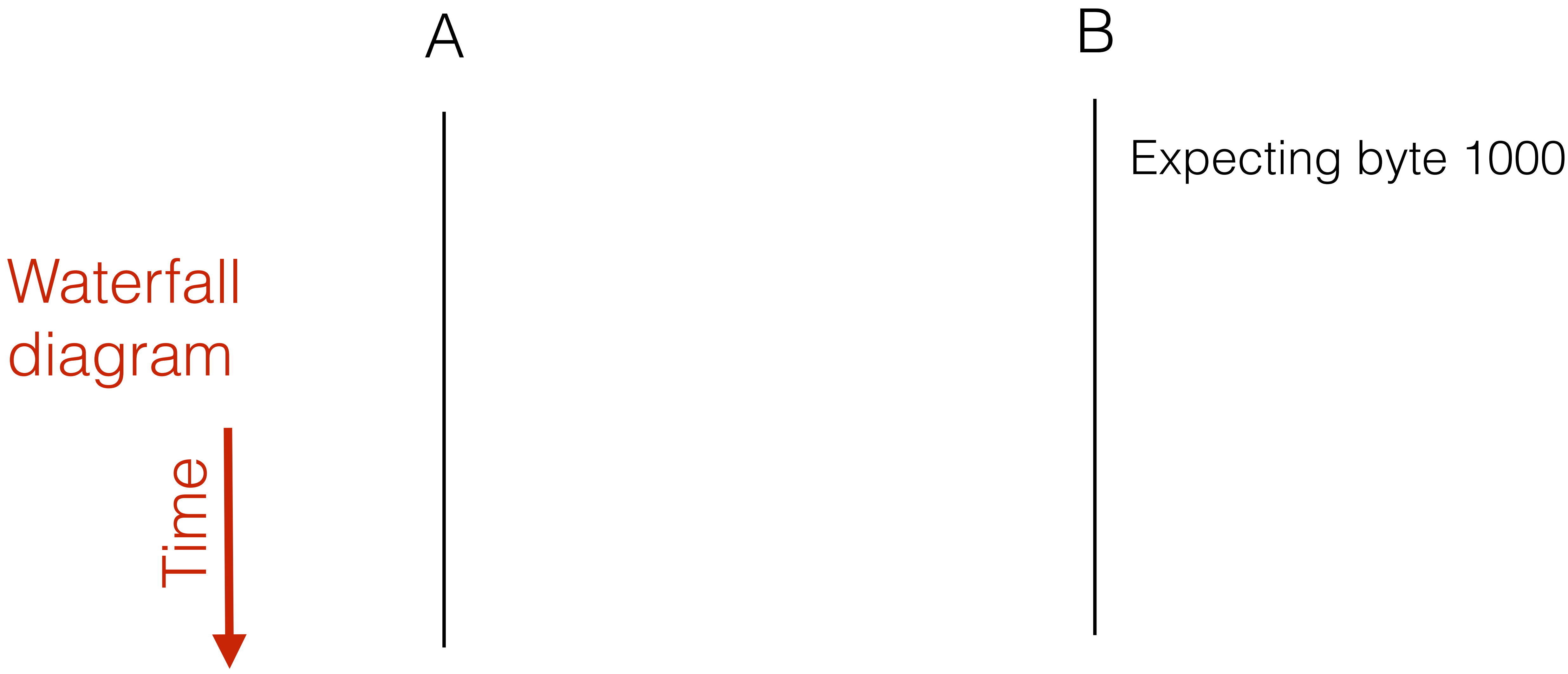

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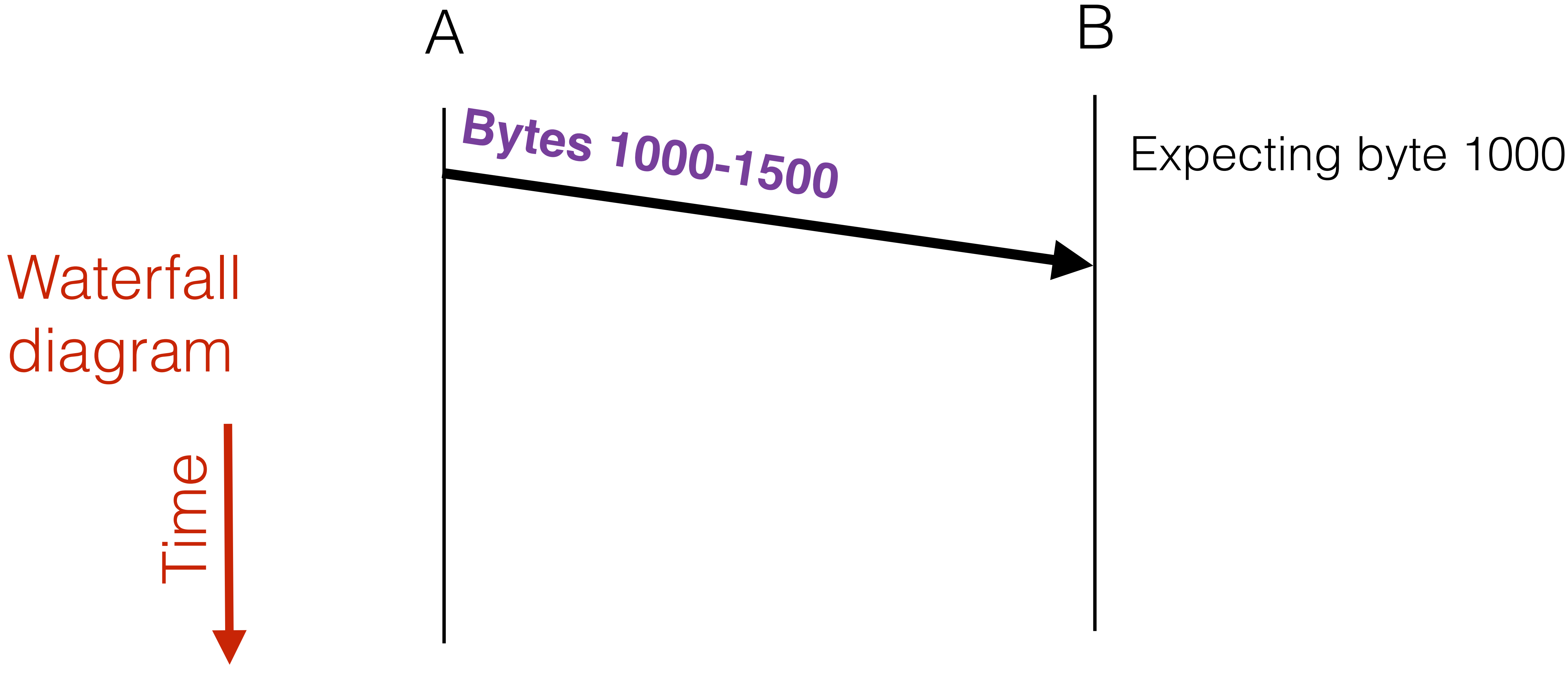

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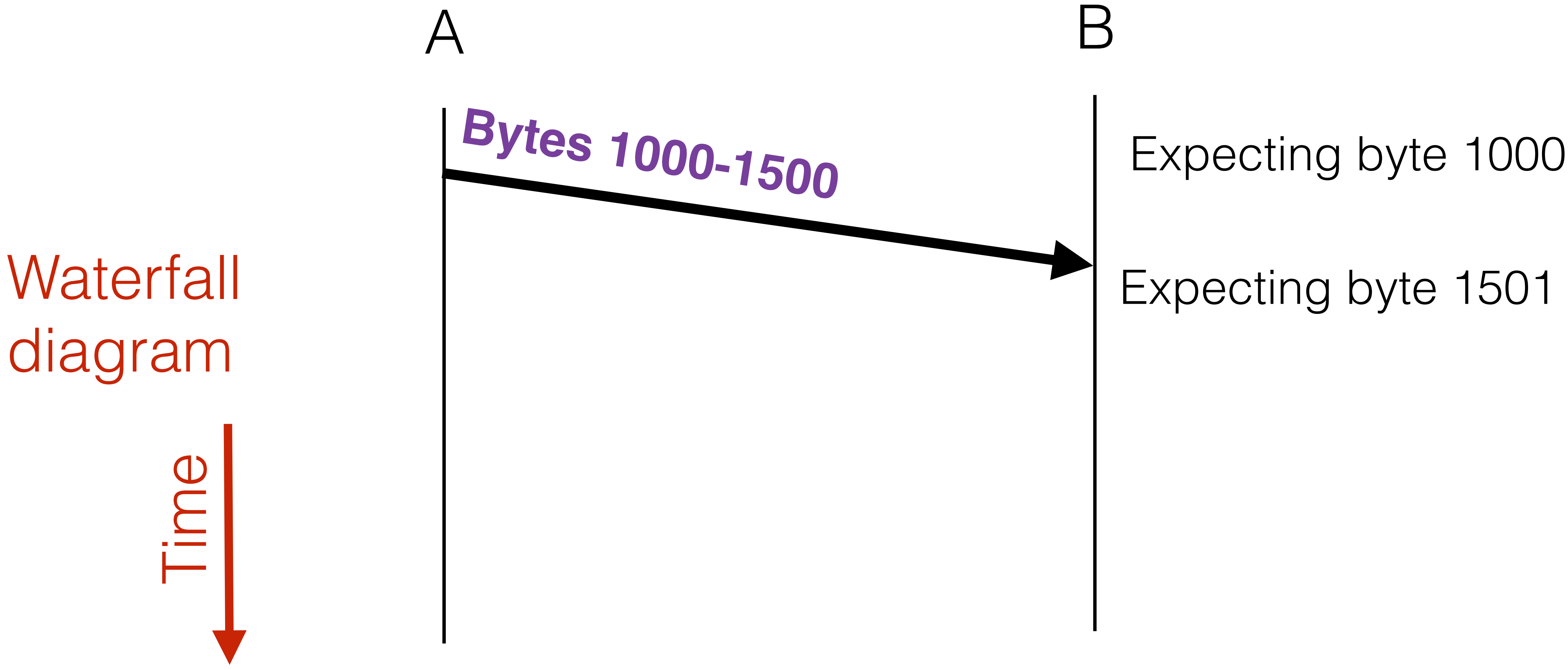

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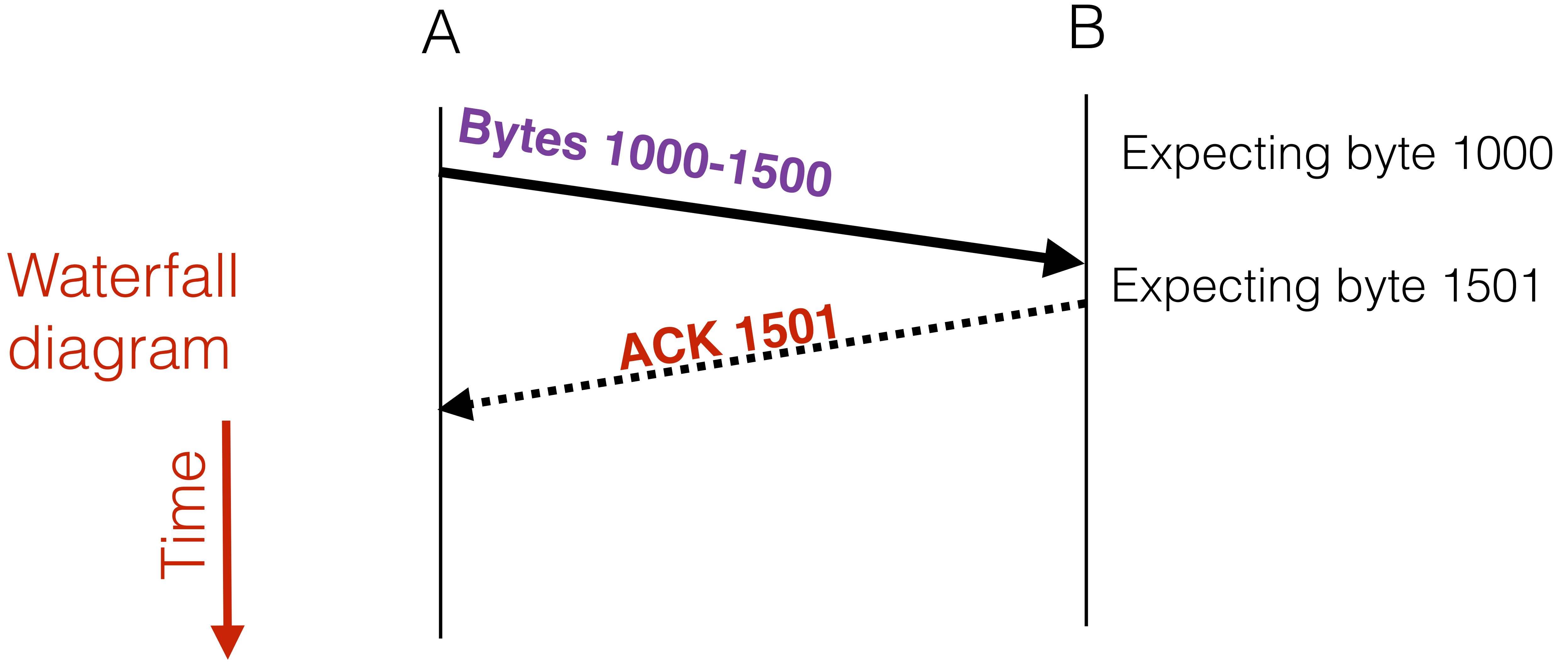

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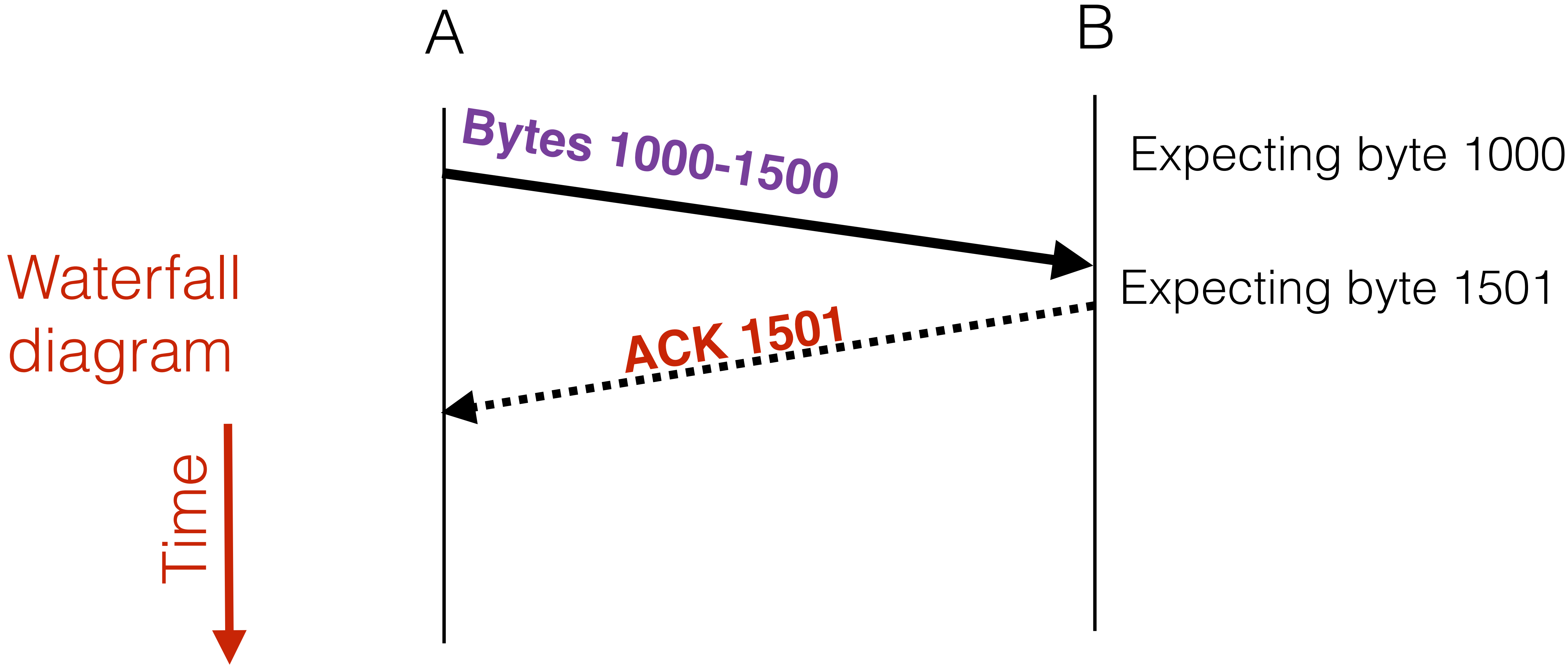
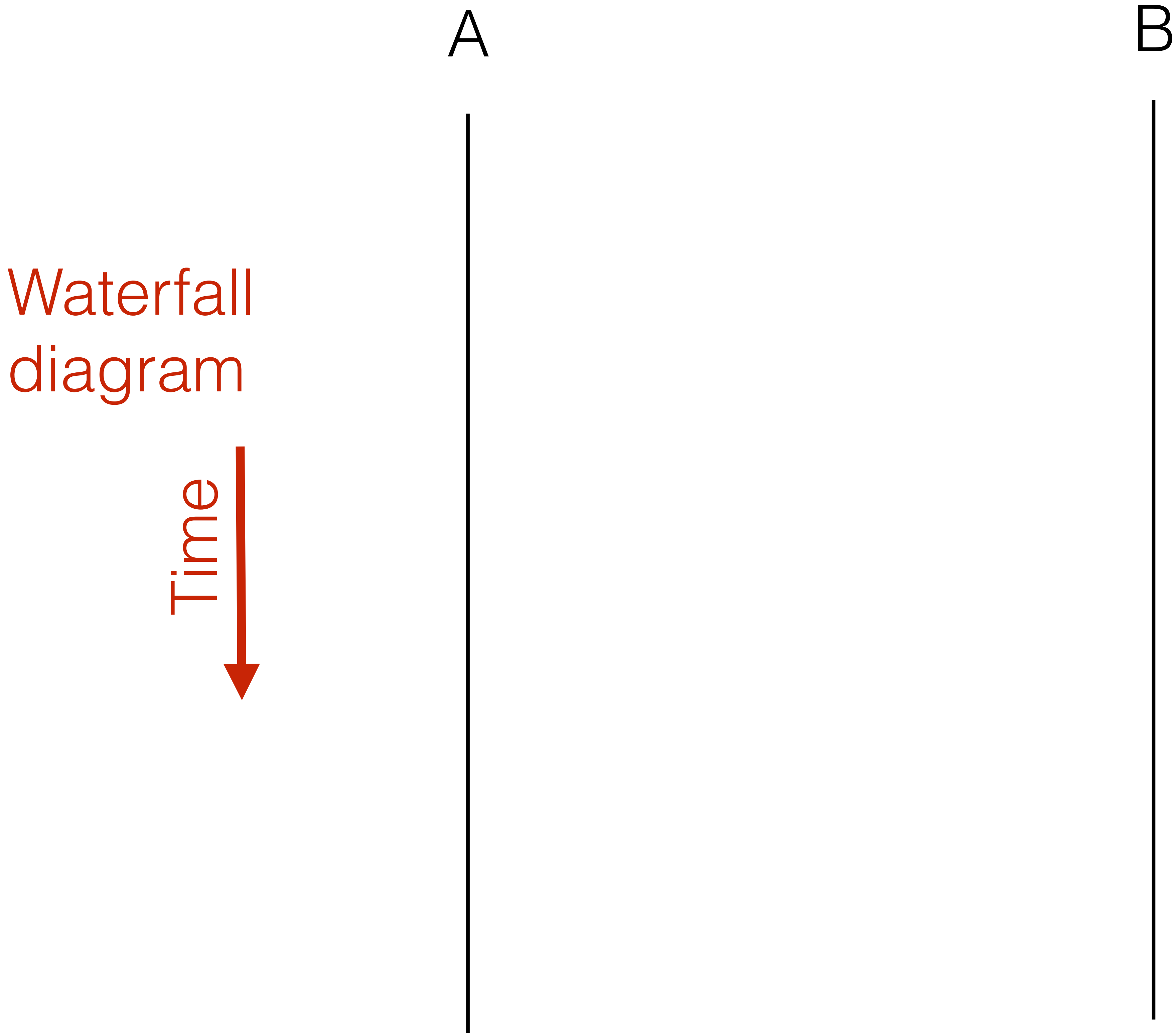


Reliability through acknowledgments
to determine whether something was received.

How does TCP achieve reliability?



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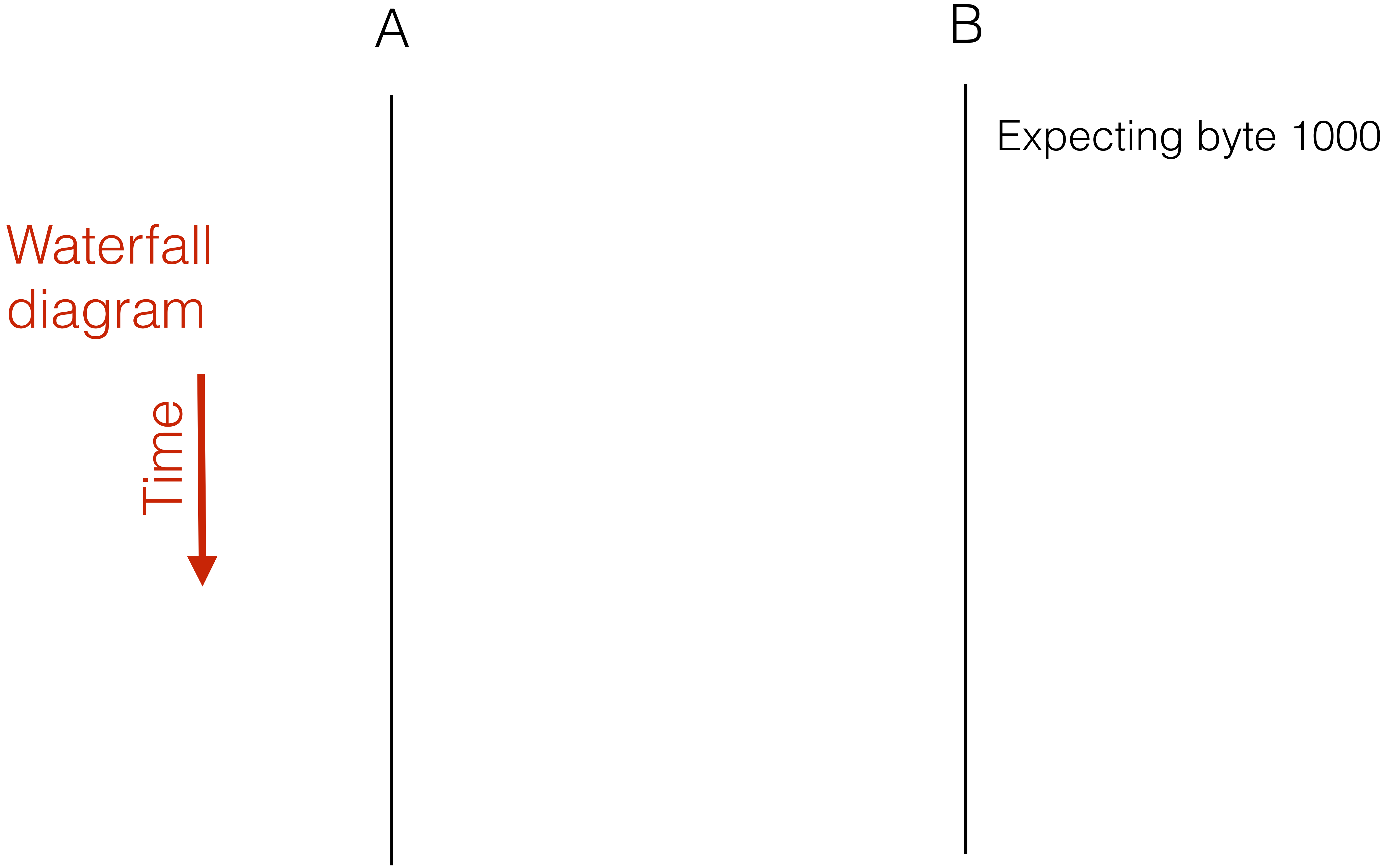

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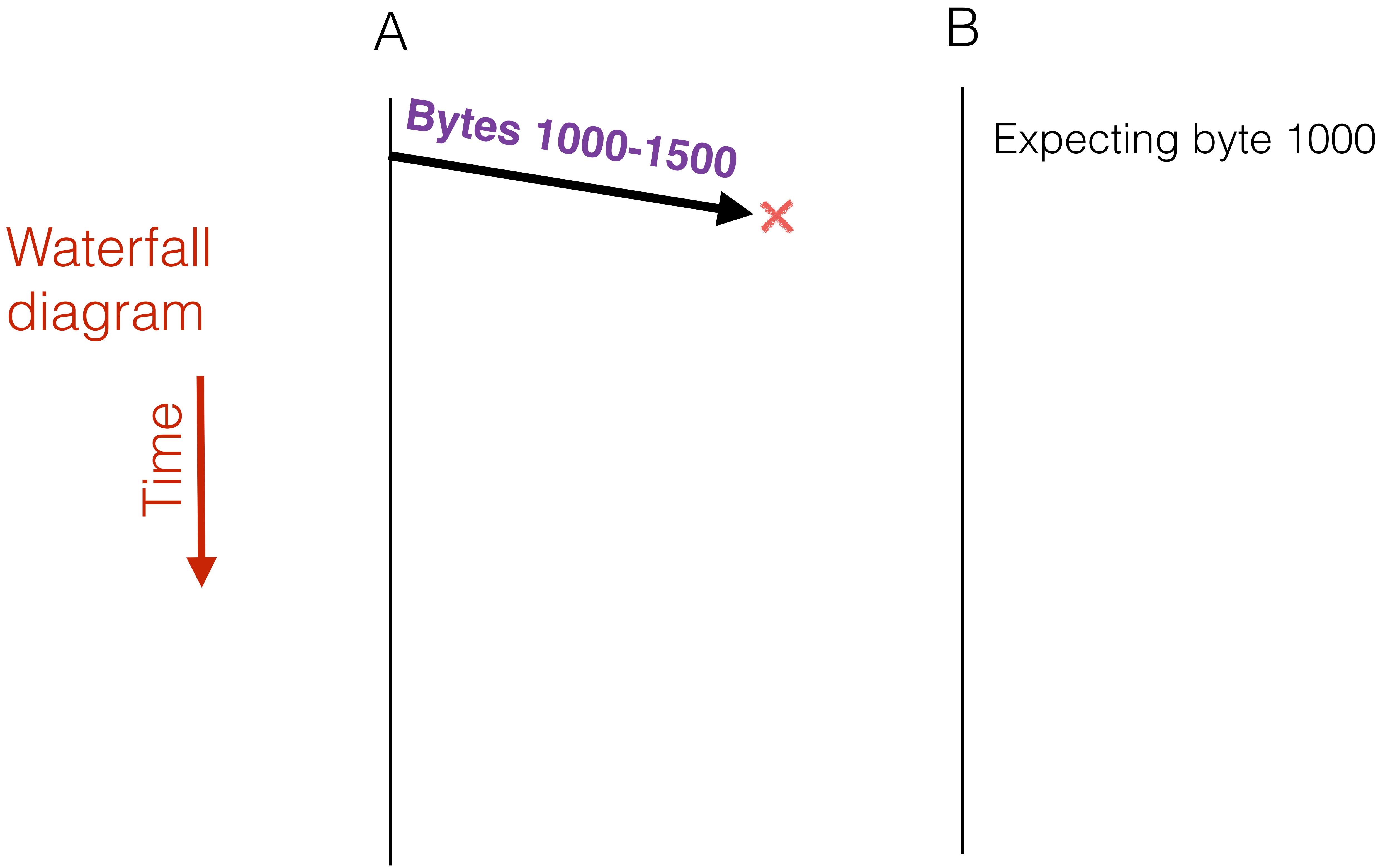

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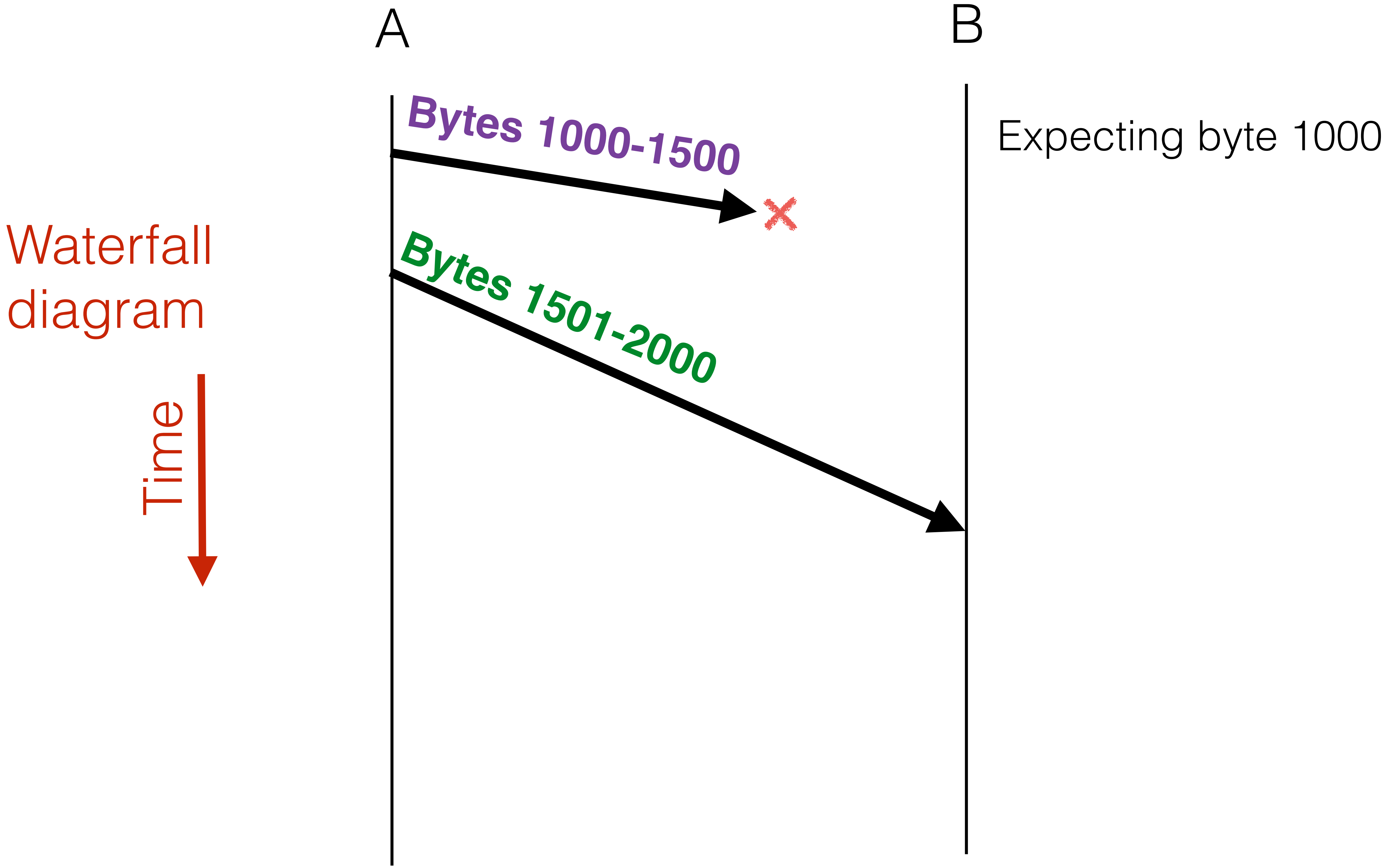

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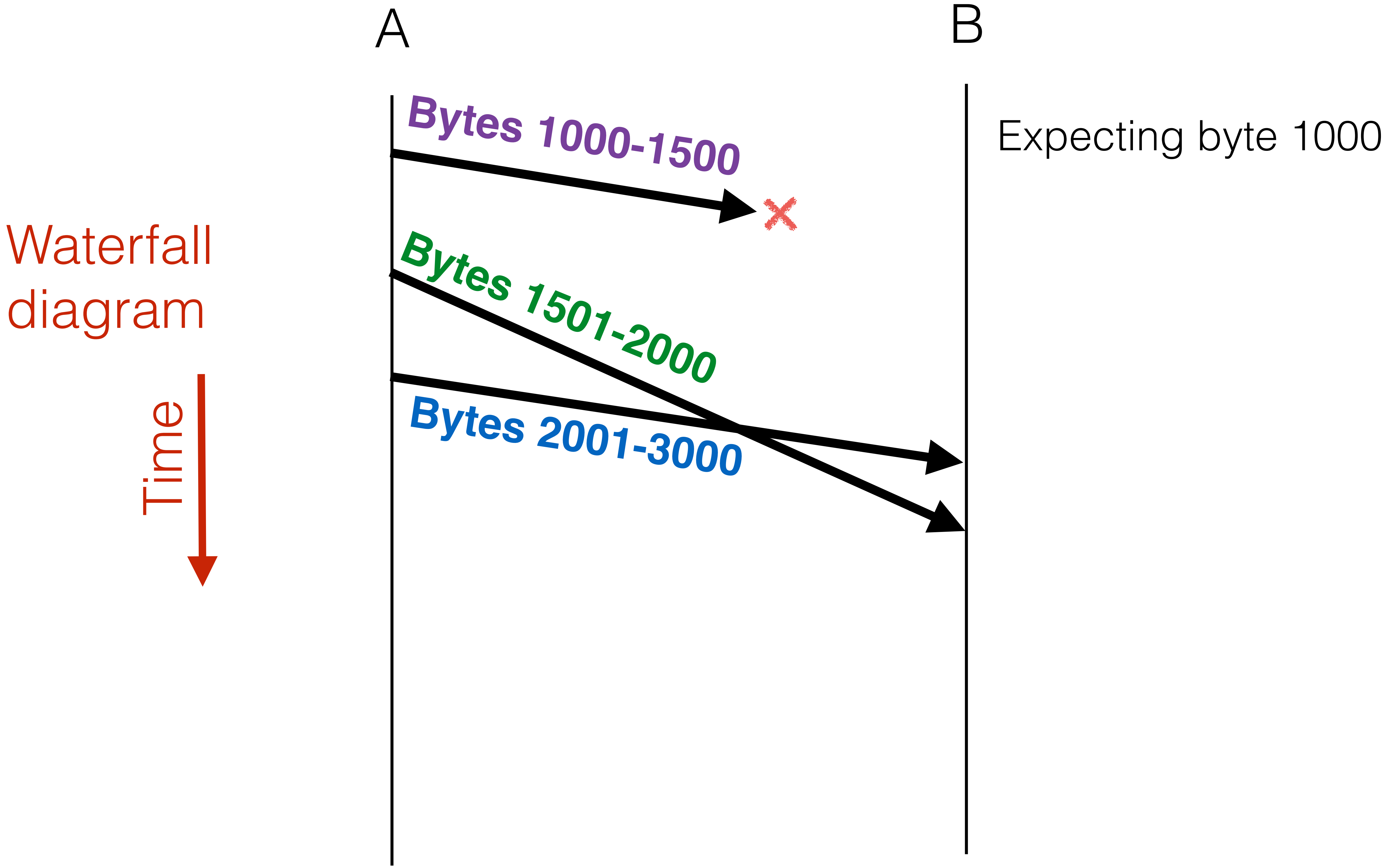

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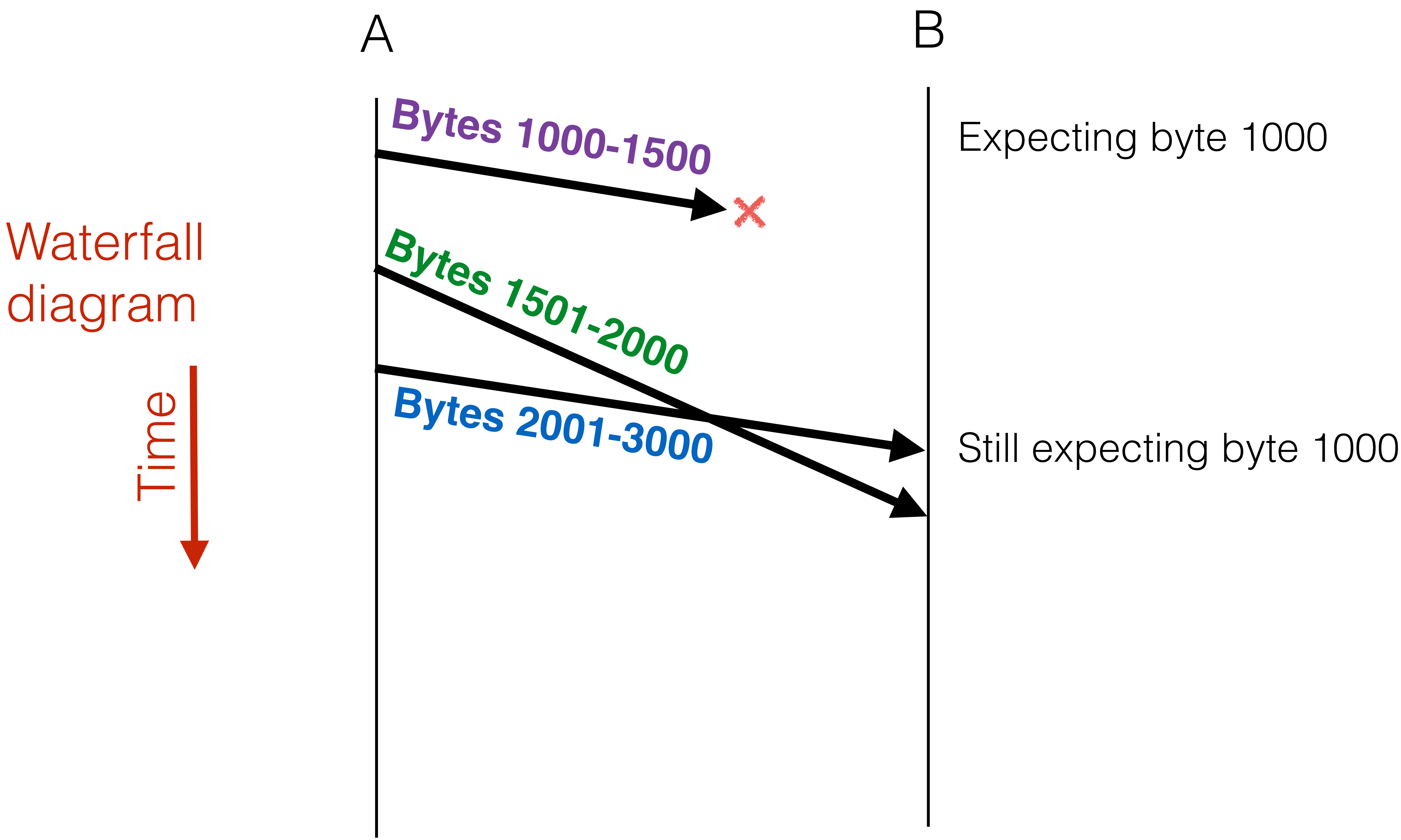

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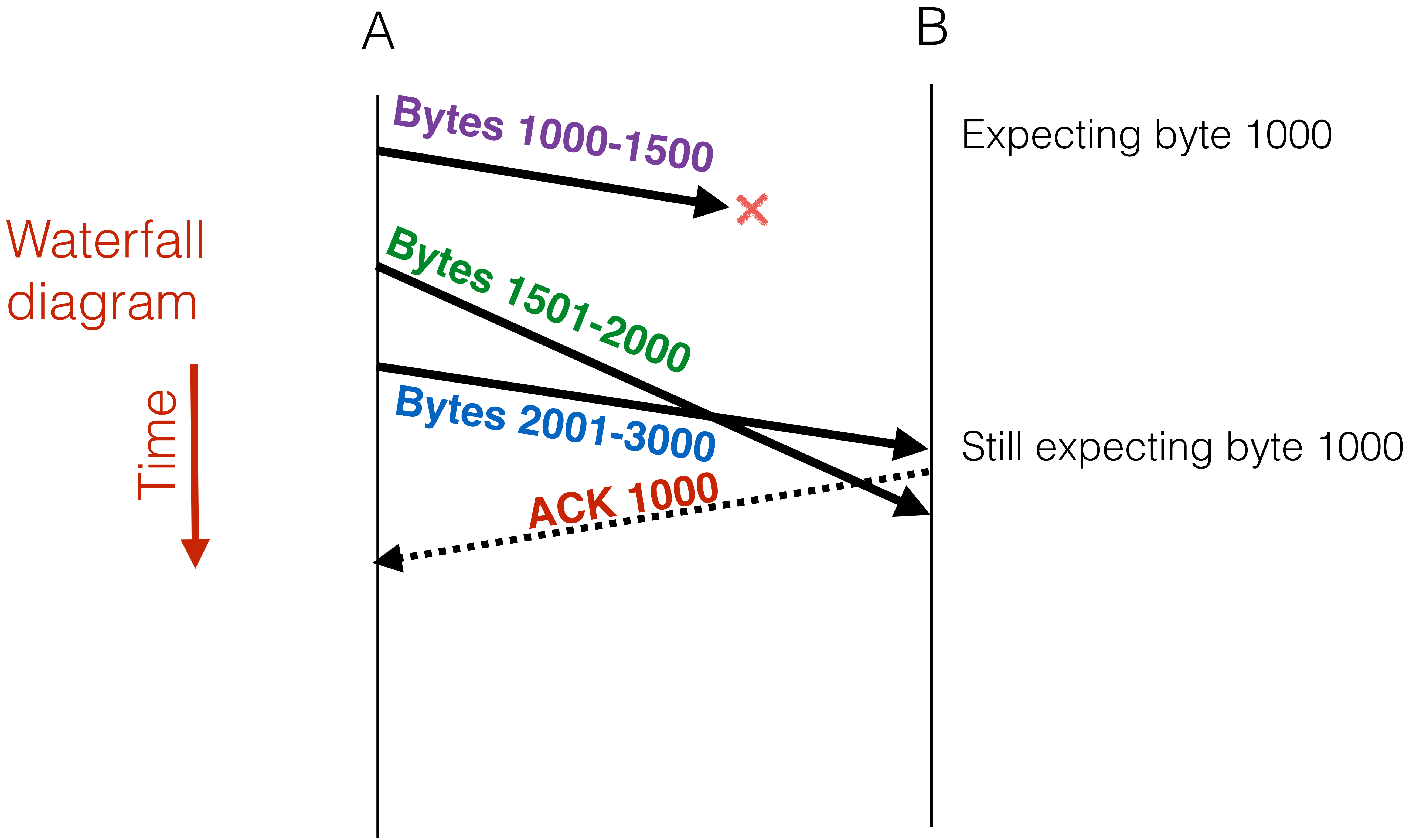

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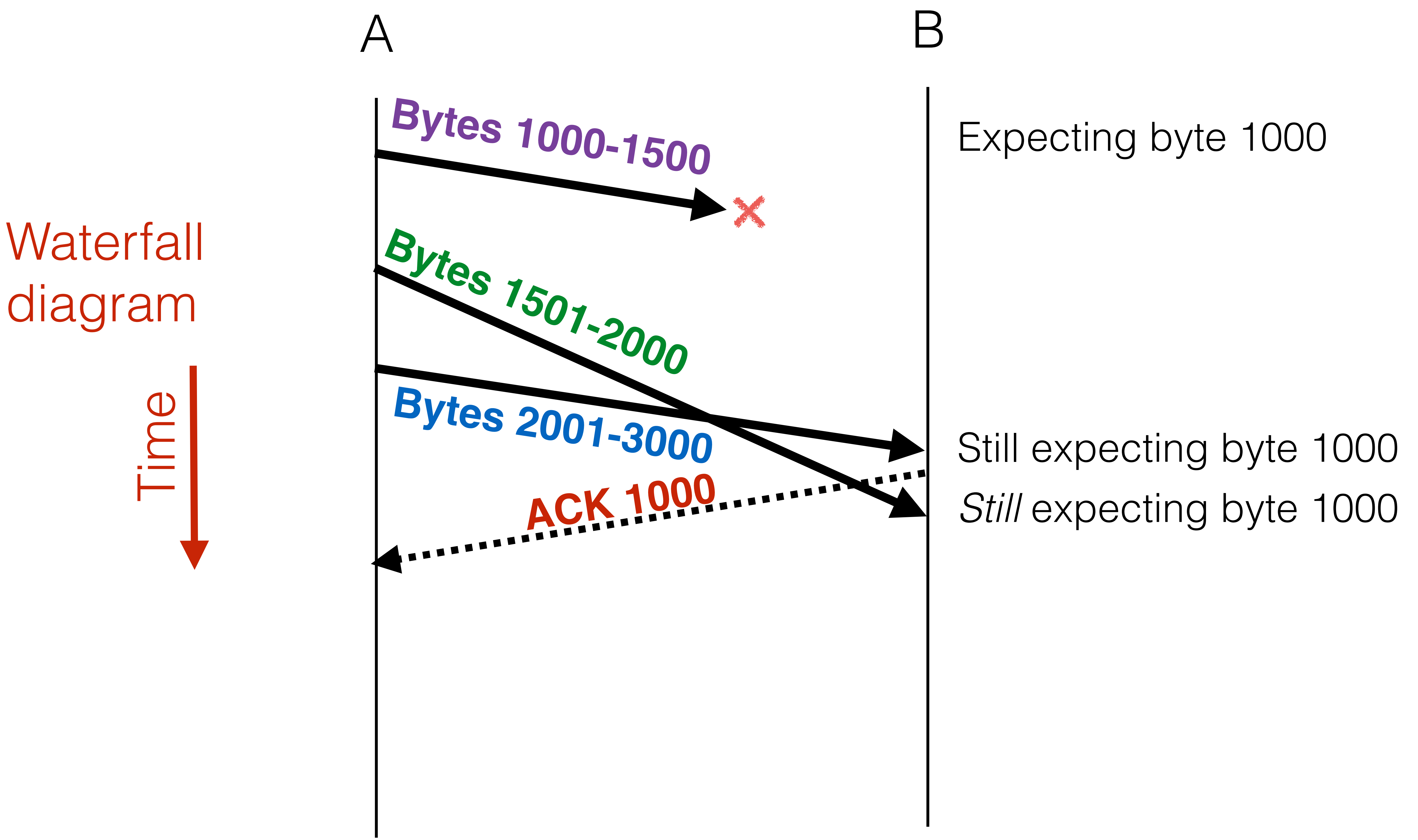

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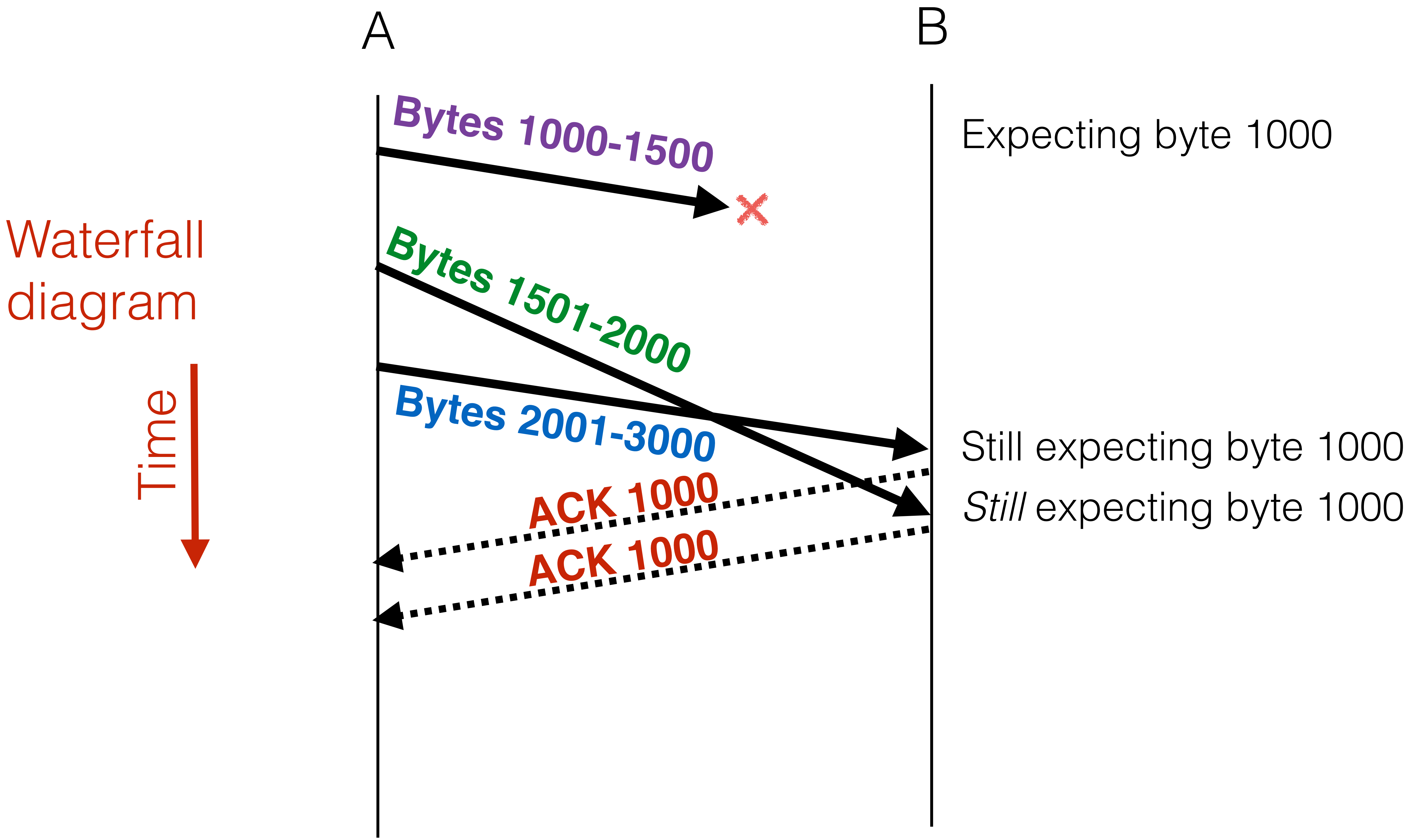

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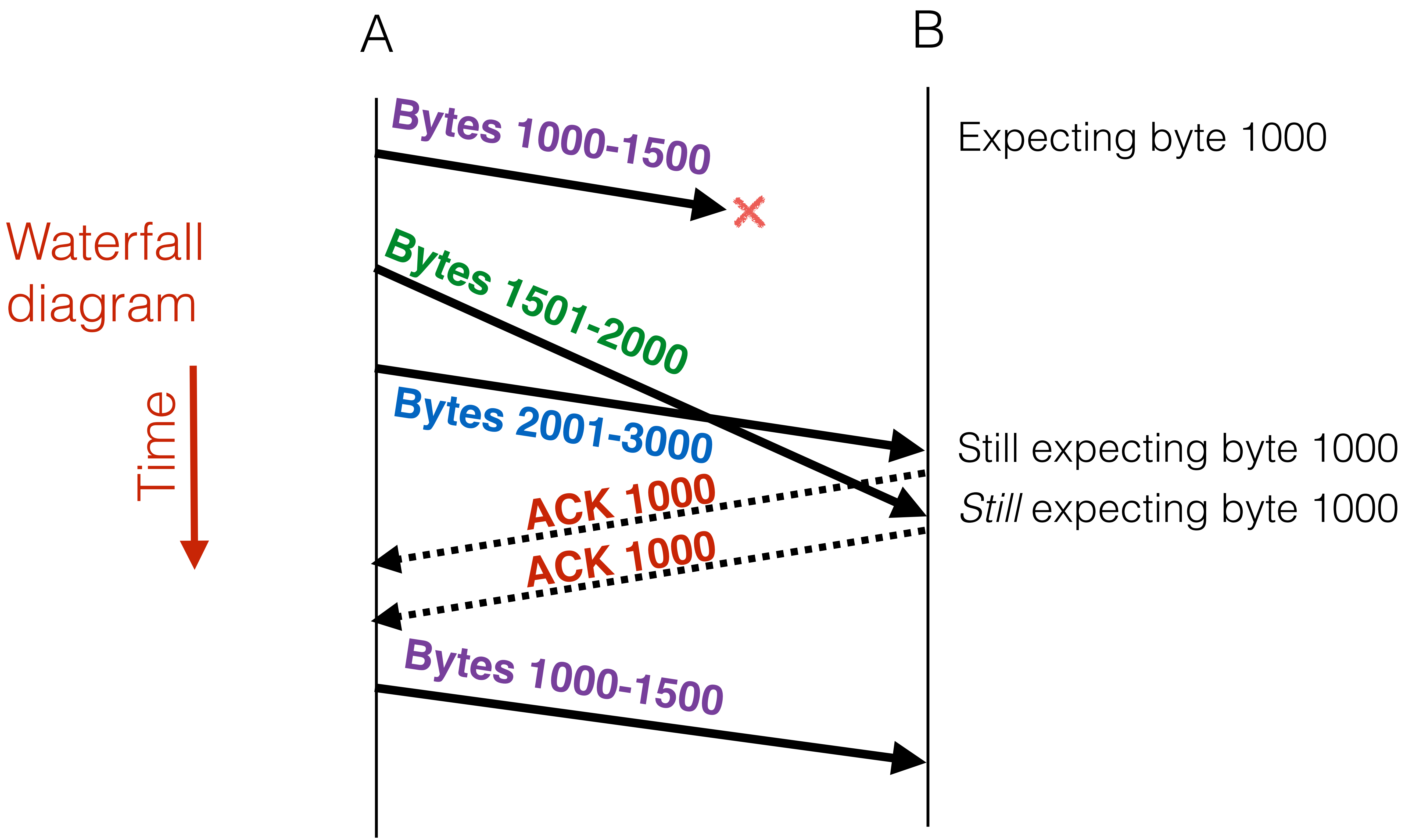

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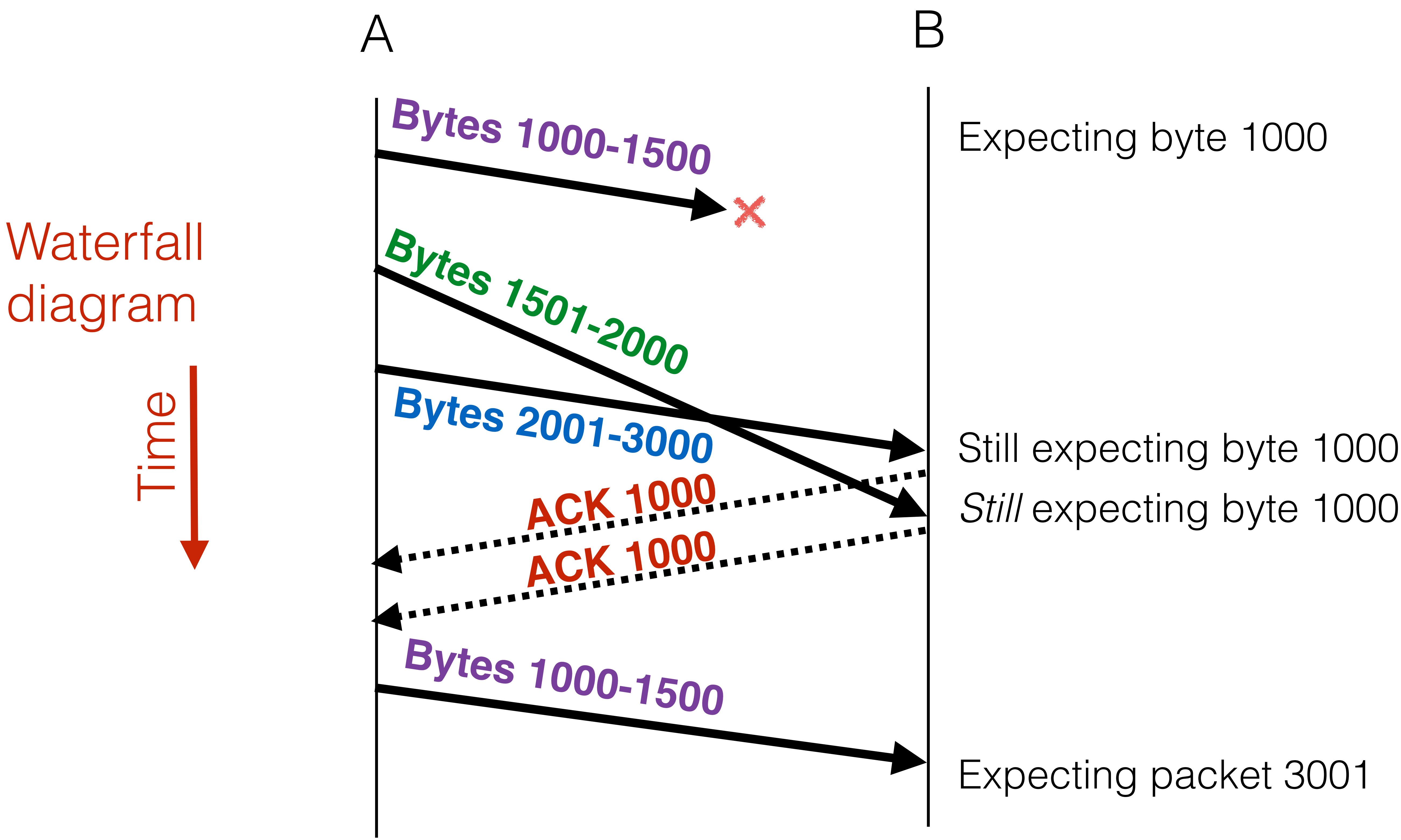

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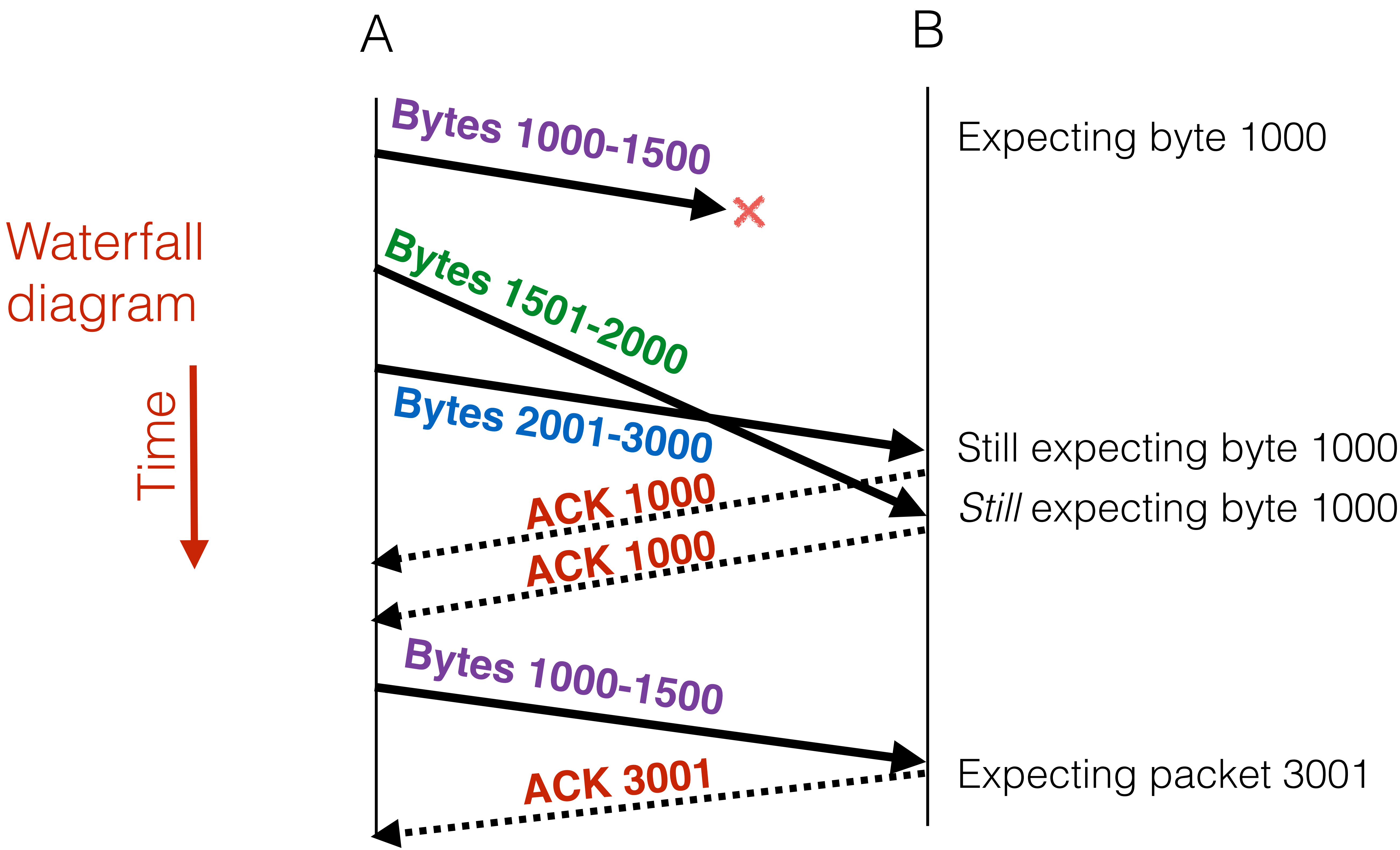

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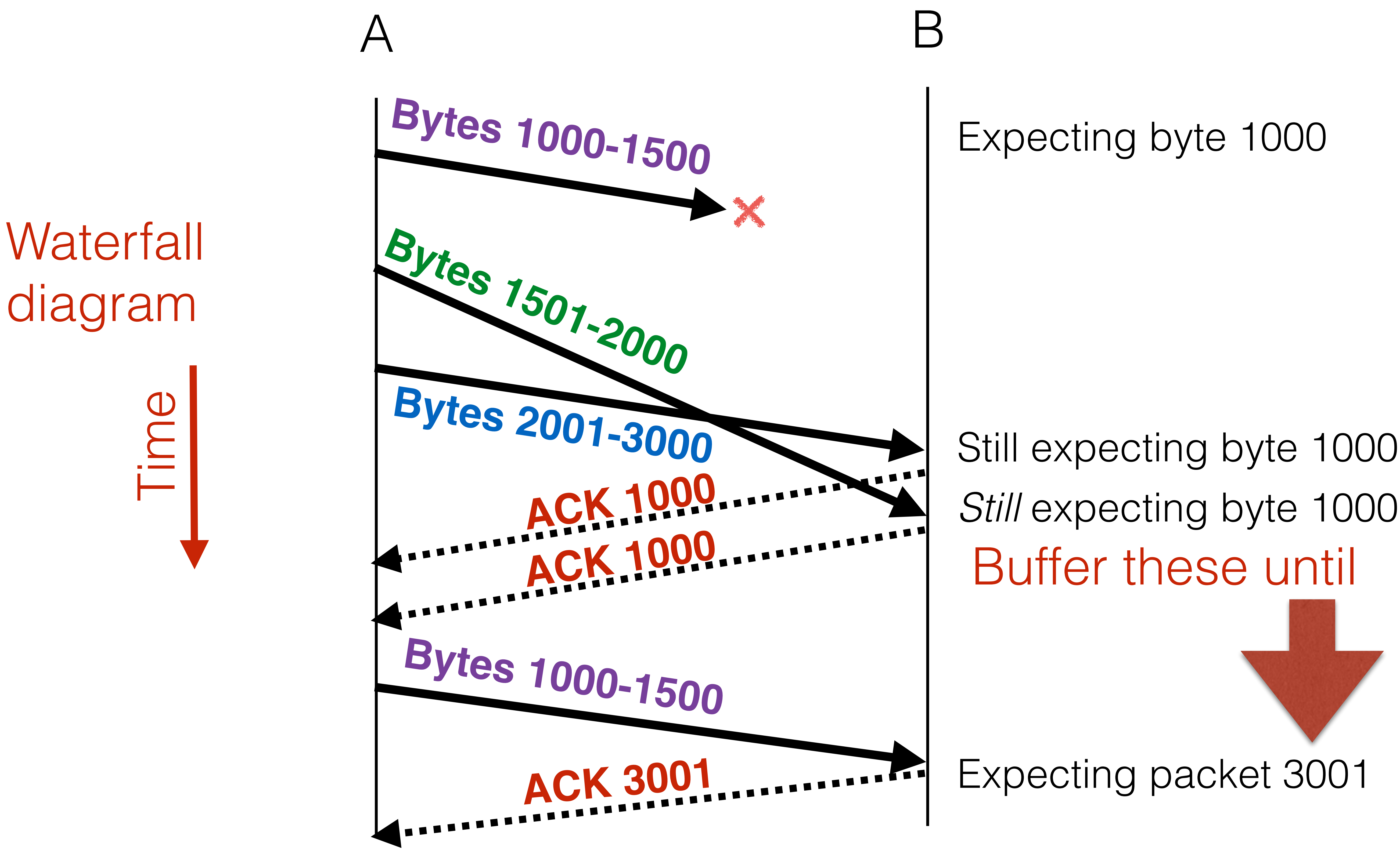
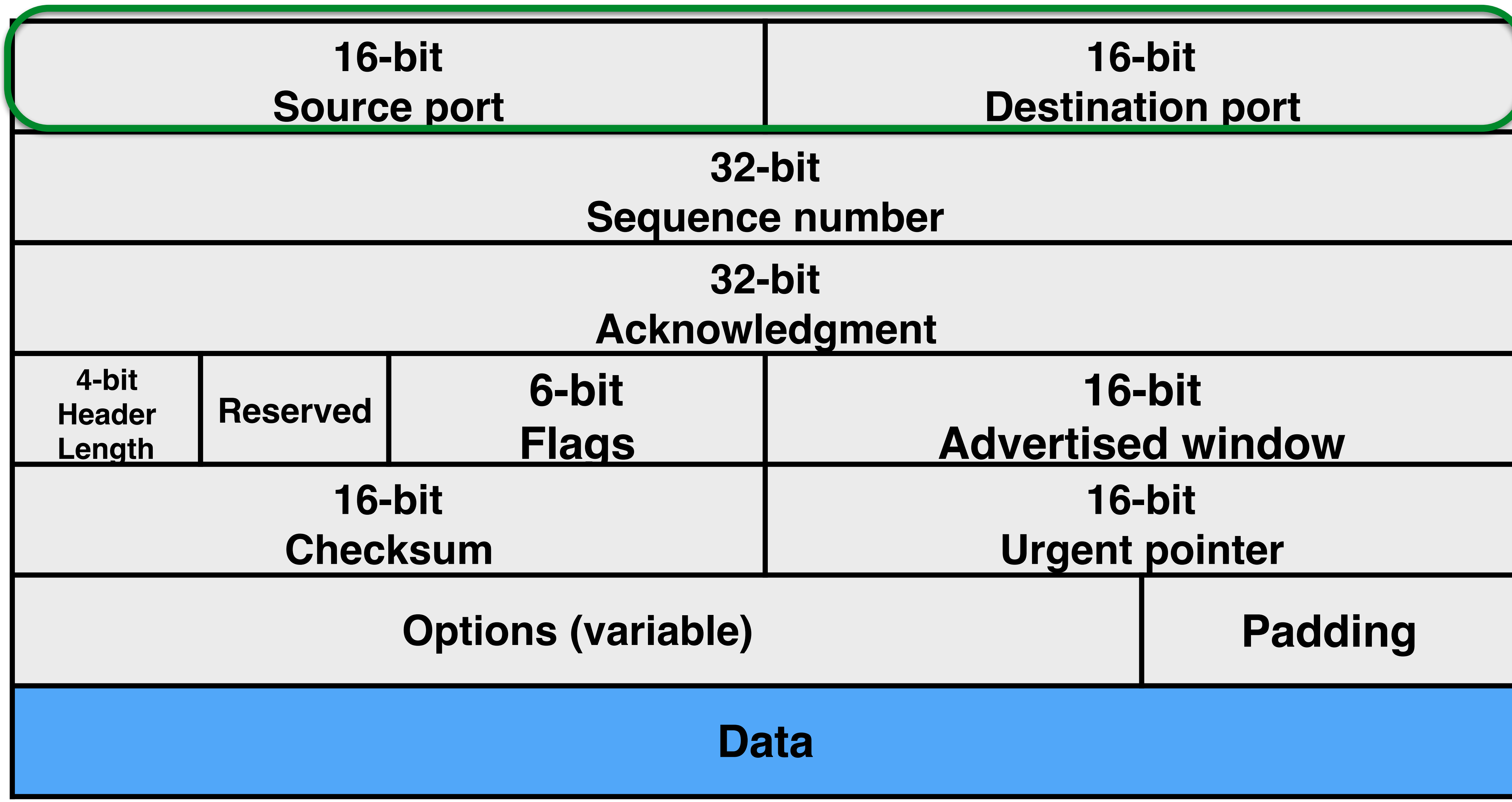


TCP congestion control

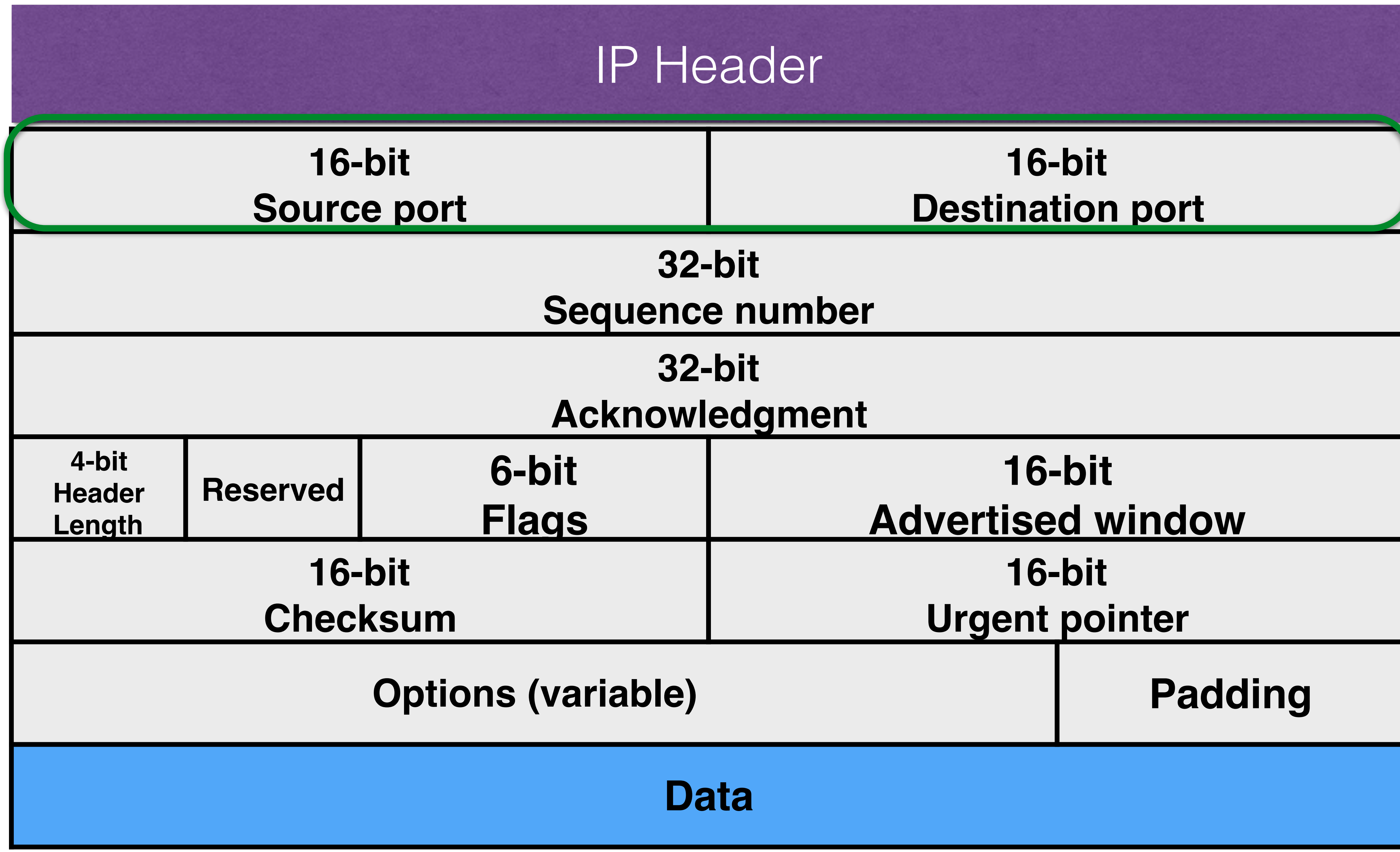
TCP's second job: don't break the network!

- Try to use as much of the network as is safe (does not adversely affect others' performance) and efficient (makes use of network capacity)
- Dynamically adapt how quickly you send based on the network path's capacity
- When an ACK doesn't come back, the network may be beyond capacity: slow down.

TCP header


16-bit
Source port
16-bit
Destination port
32-bit
Sequence number
32-bit
Acknowledgment
4-bit
Header
Length
Reserved
6-bit
Flags
16-bit
Advertised window
16-bit
Checksum
16-bit
Urgent pointer
Options (variable)
Padding
Data

TCP header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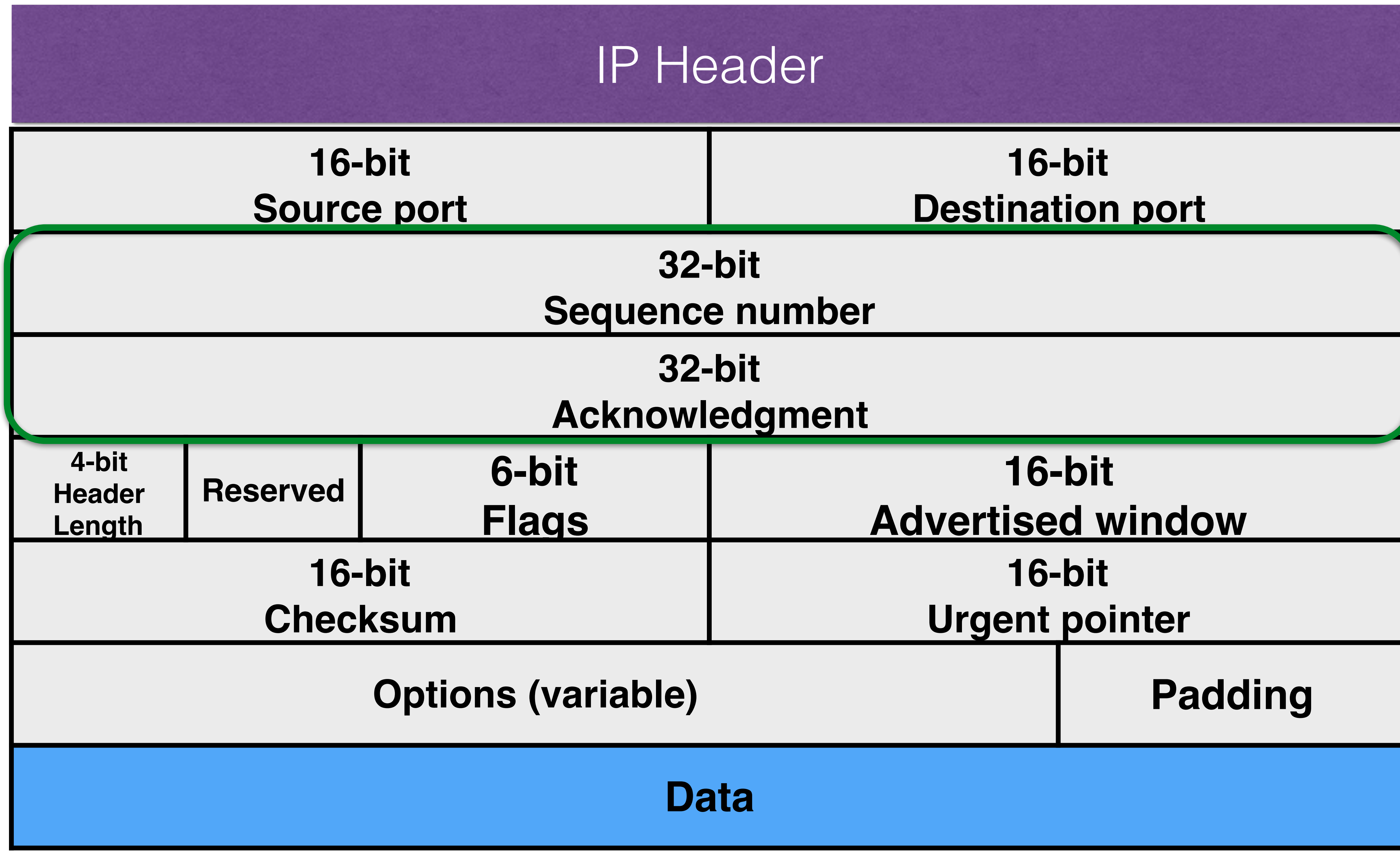
Padding
Data

TCP ports

- Ports are associated with **OS processes**
- Sandwiched between IP header and the application data
- {src IP/port, dst IP/port} : this 4-tuple uniquely identifies a TCP connection
- Some port numbers are well-known
  - 80 = HTTP
  - 53 = DNS

TCP header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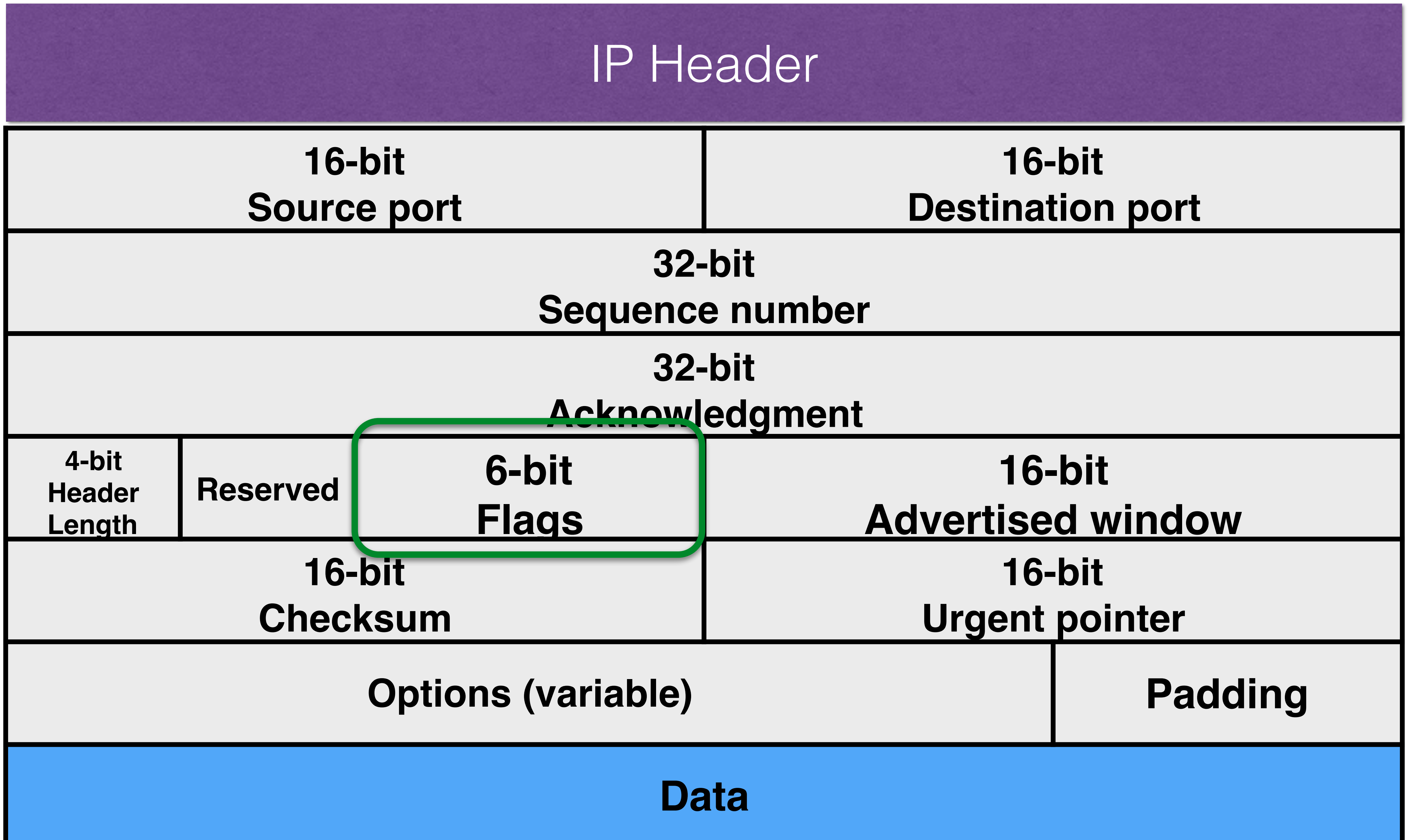
Advertised window
16-bit
Checksum
16-bit
Urgent pointer
Options (variable)
Padding
Data

TCP seqno

- Each byte in the byte stream has a unique "sequence number"
  - Unique for both directions
- "Sequence number" in the header = sequence number of the ***first*** byte in the packet's data
- Next sequence number = previous seqno + previous packet's data size
- "Acknowledgment" in the header = the ***next*** seqno you expect from the other end-host

TCP header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Data

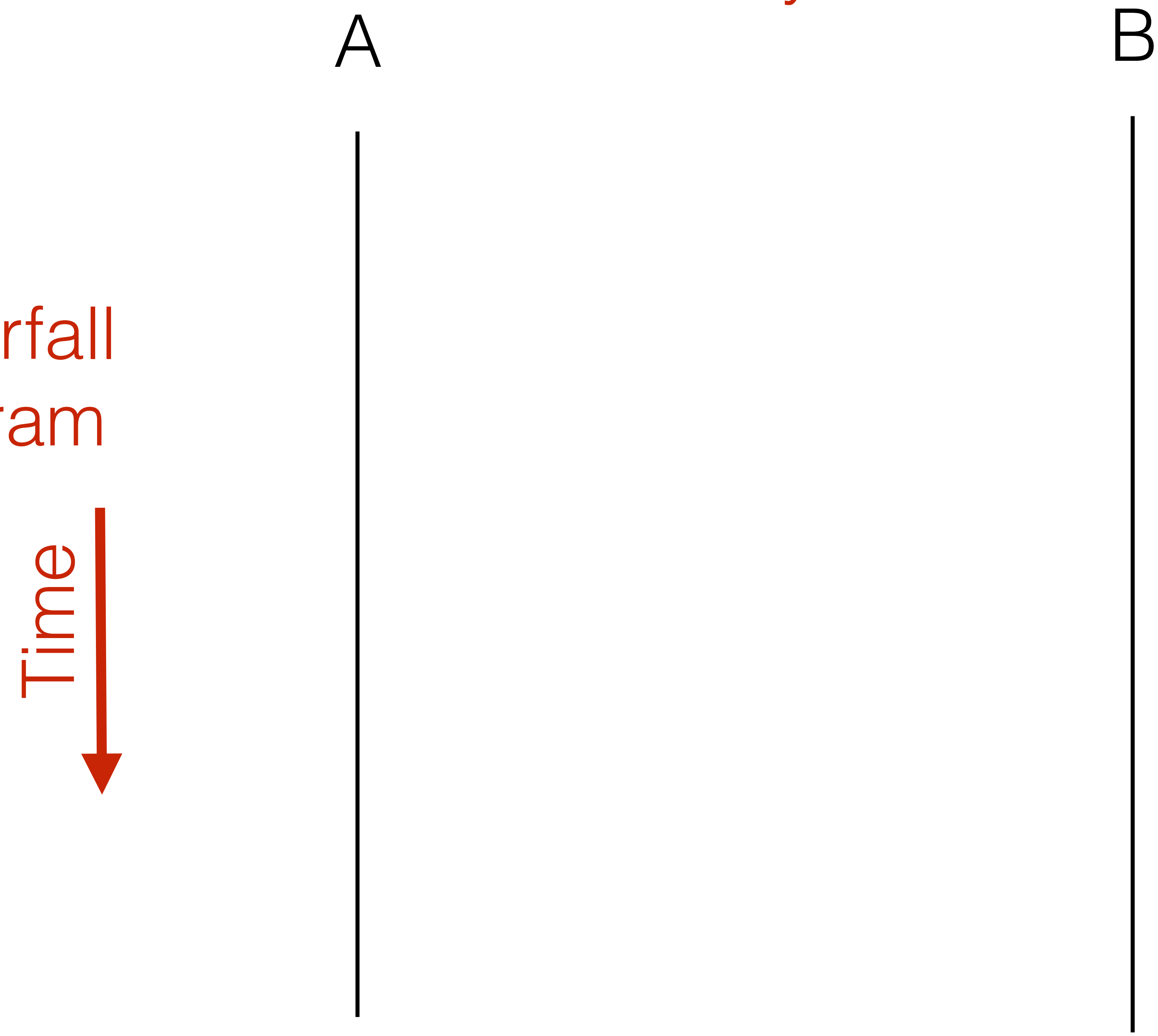
TCP flags

- SYN
  - Used for setting up a connection
- ACK
  - Acknowledgments, for data and “control” packets
- FIN
- RST

Setting up a connection

Three-way handshake

Waterfall diagram



Setting up a connection

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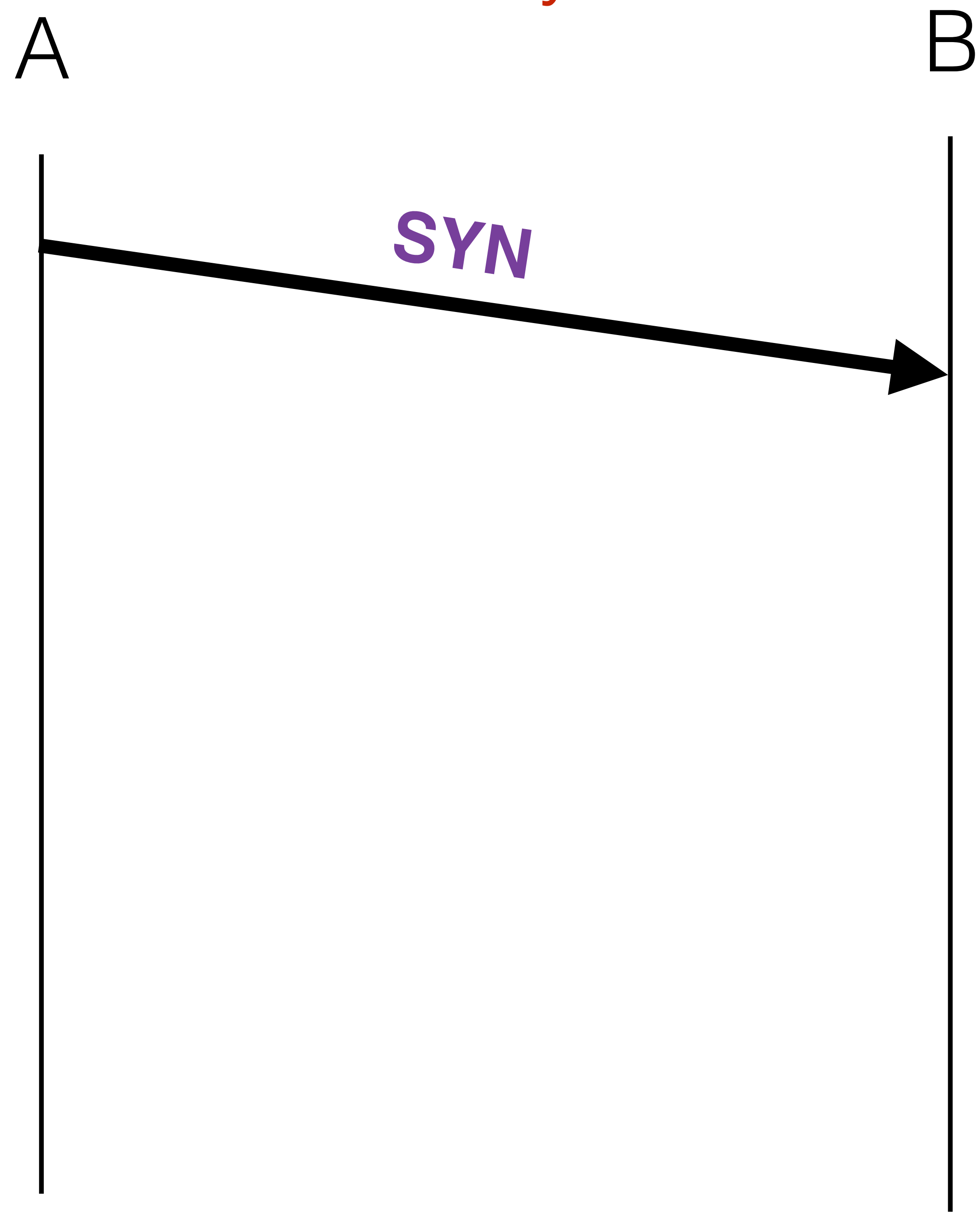

Waterfall diagram

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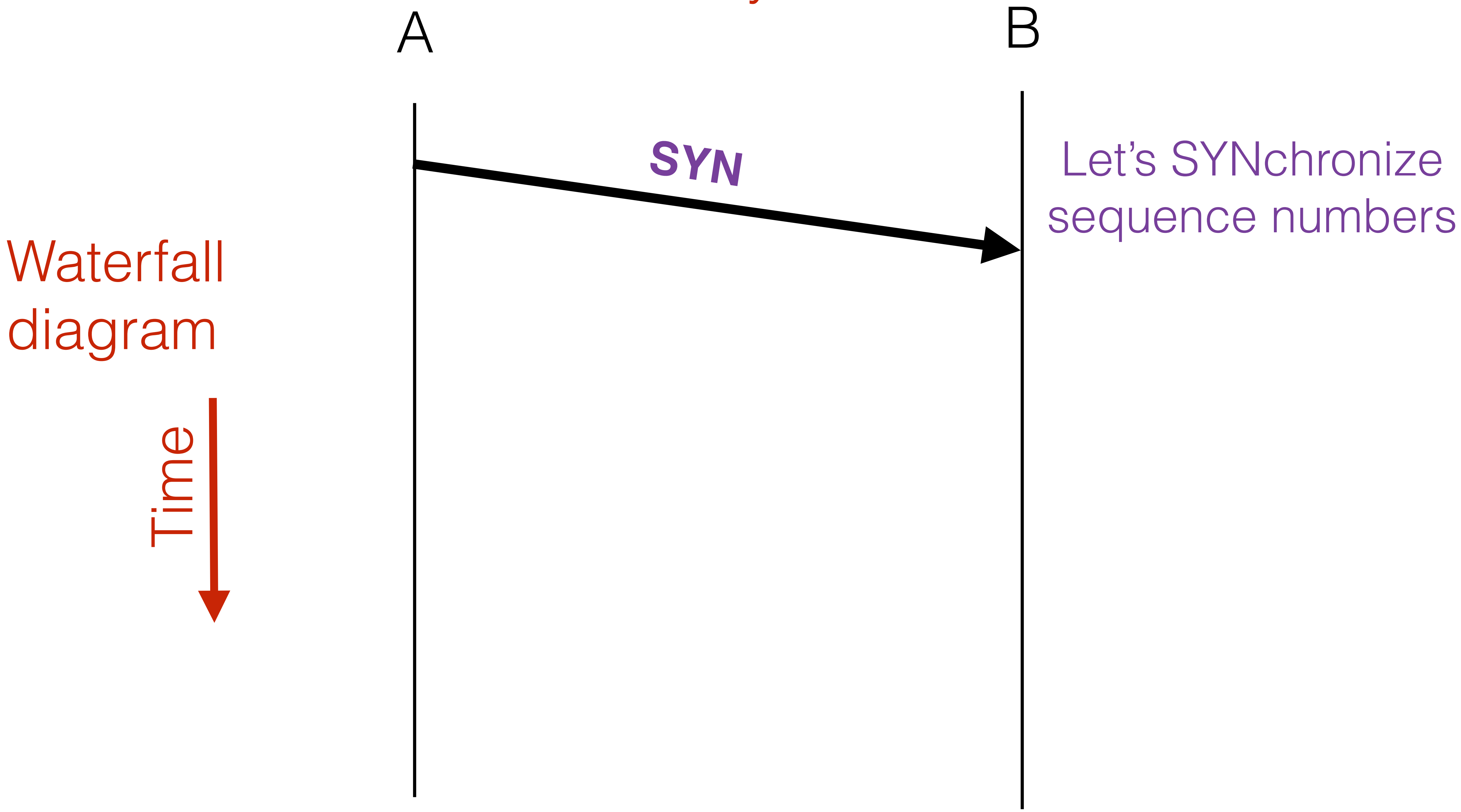

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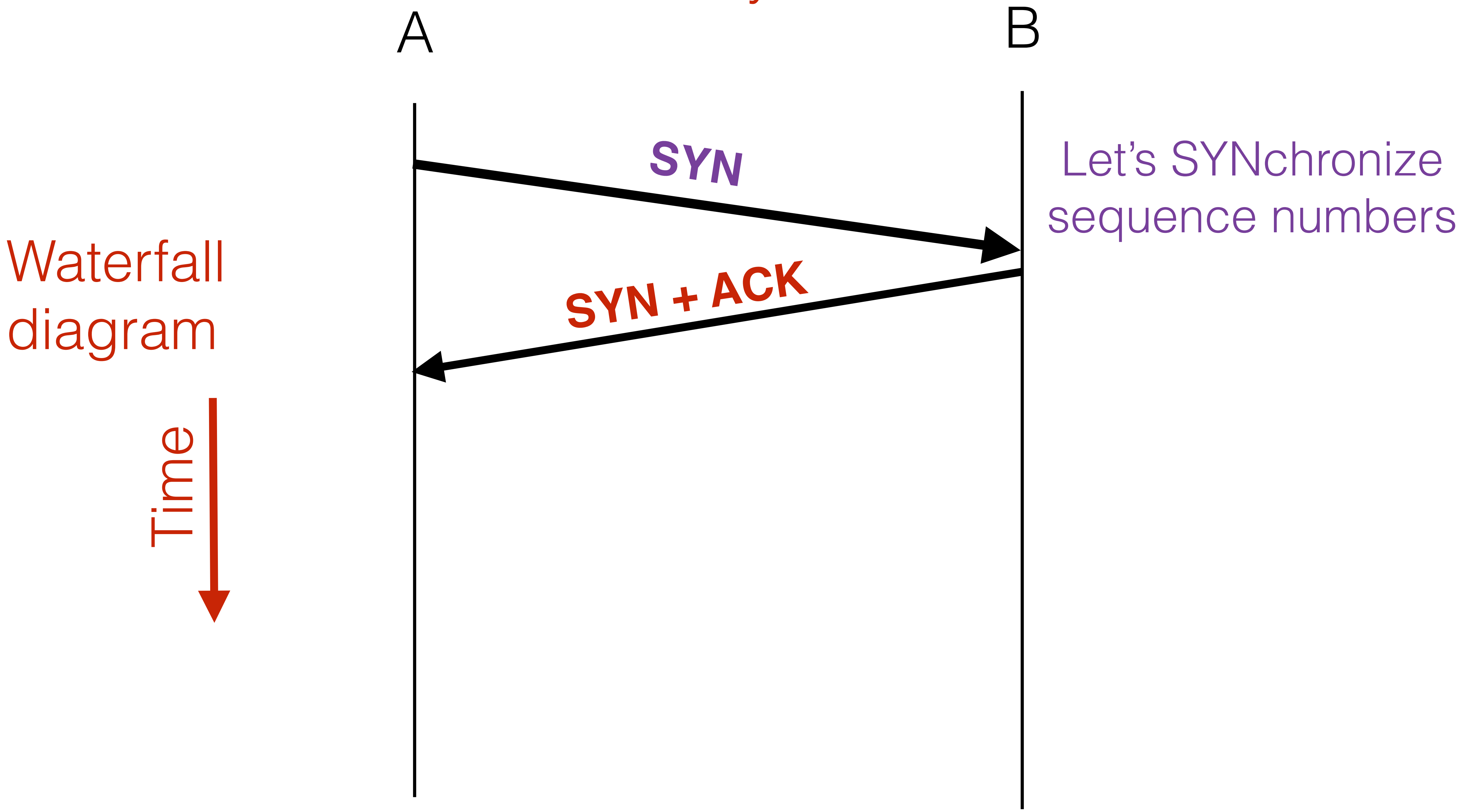

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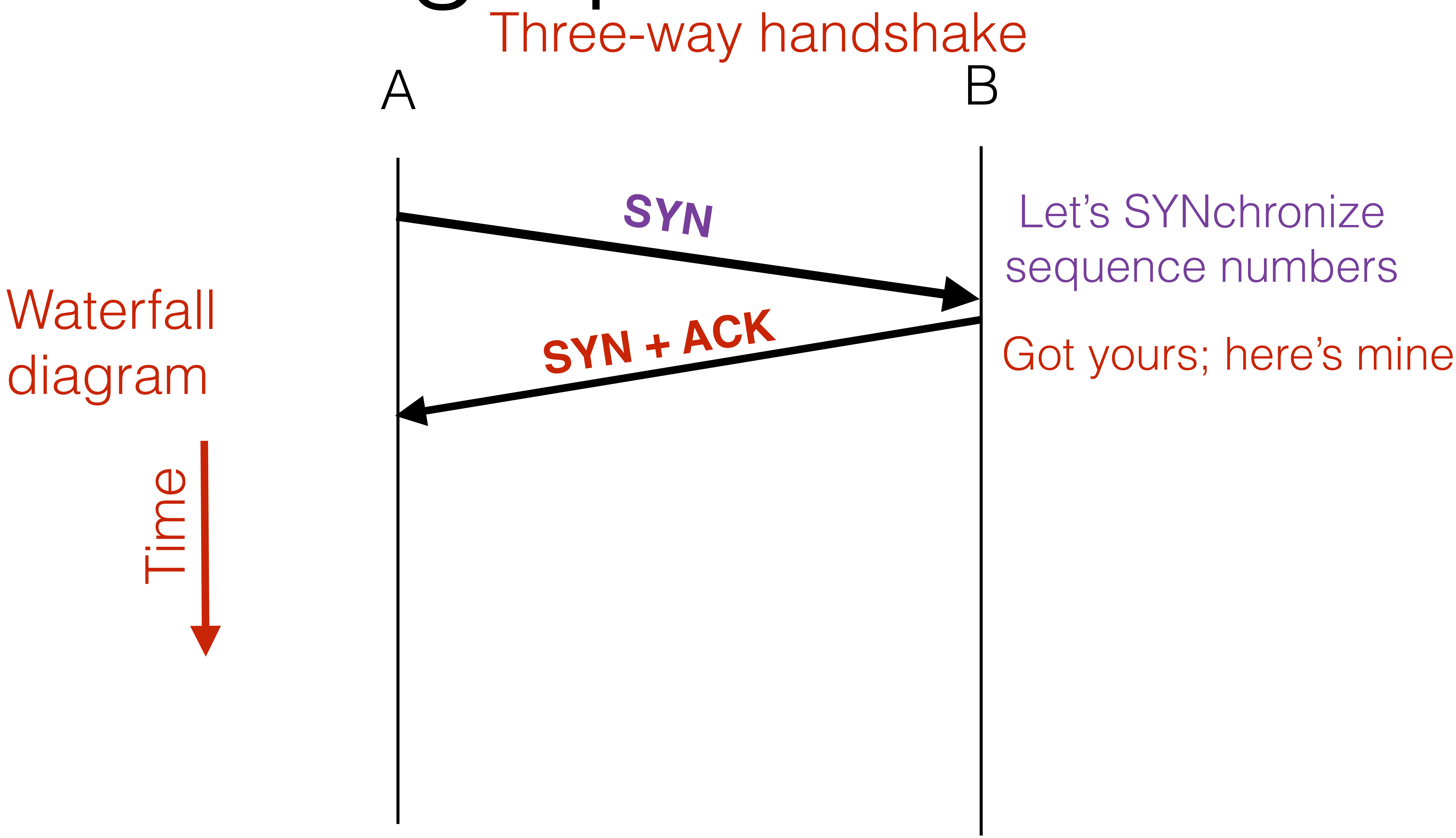

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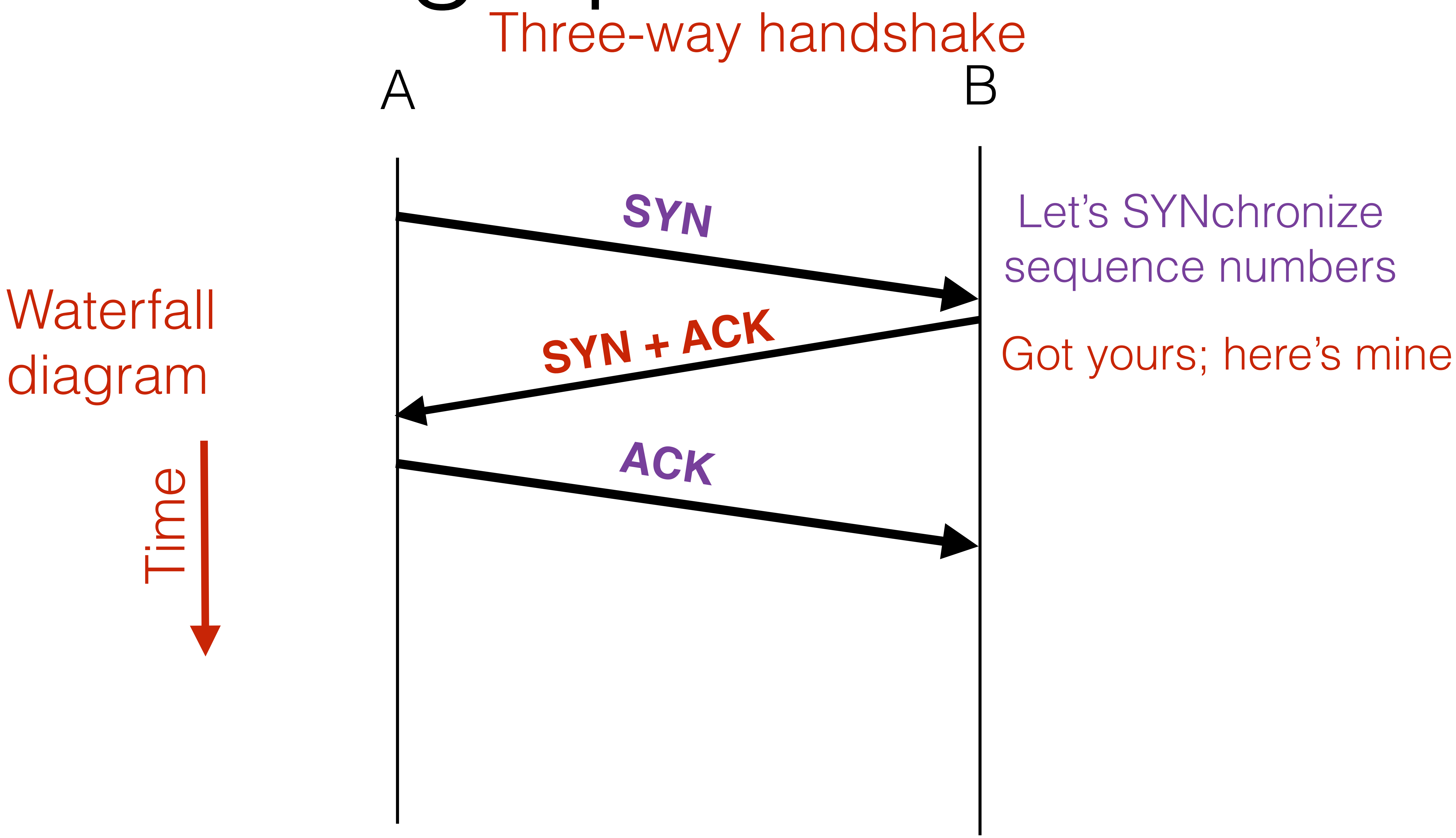

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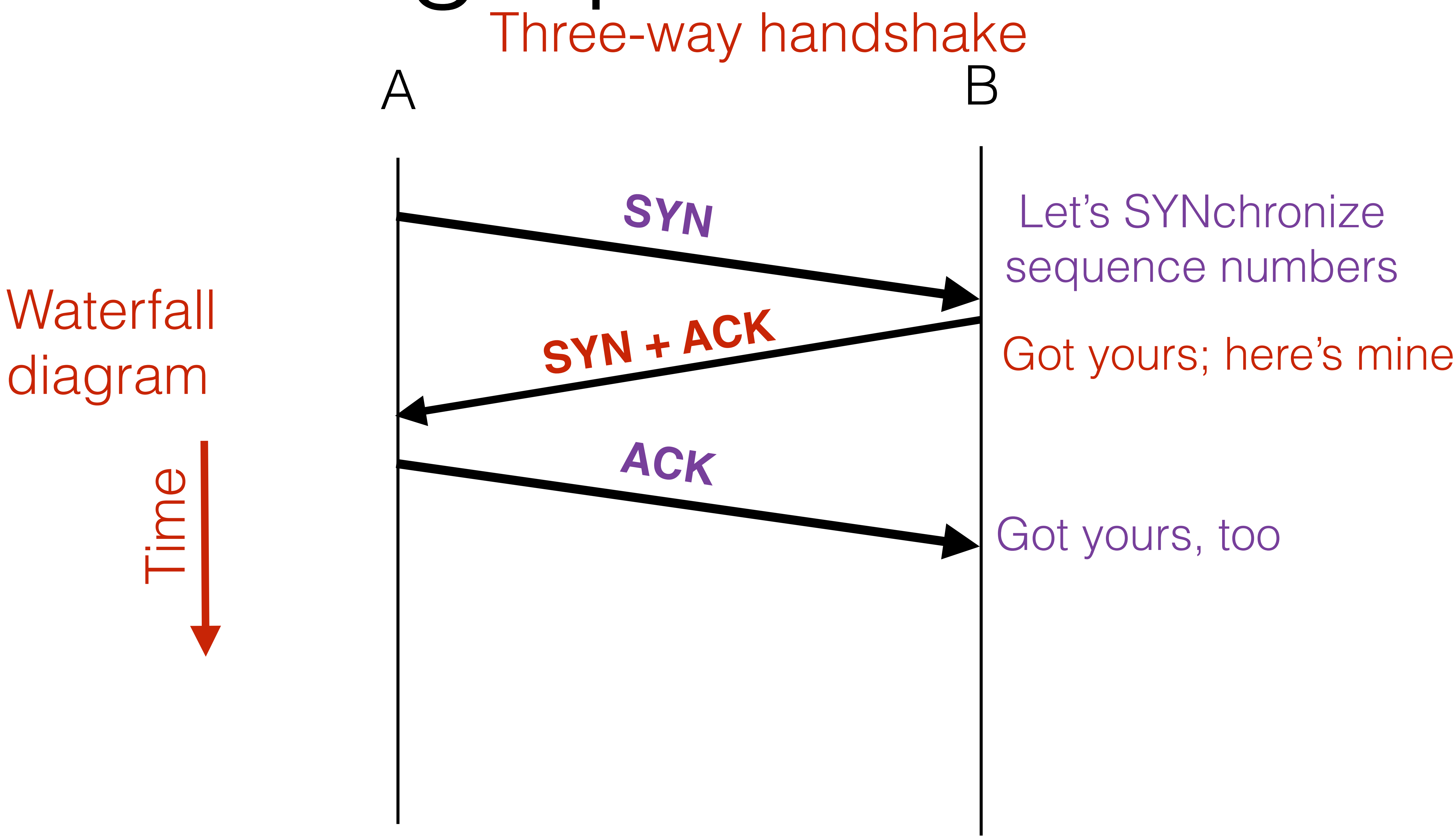

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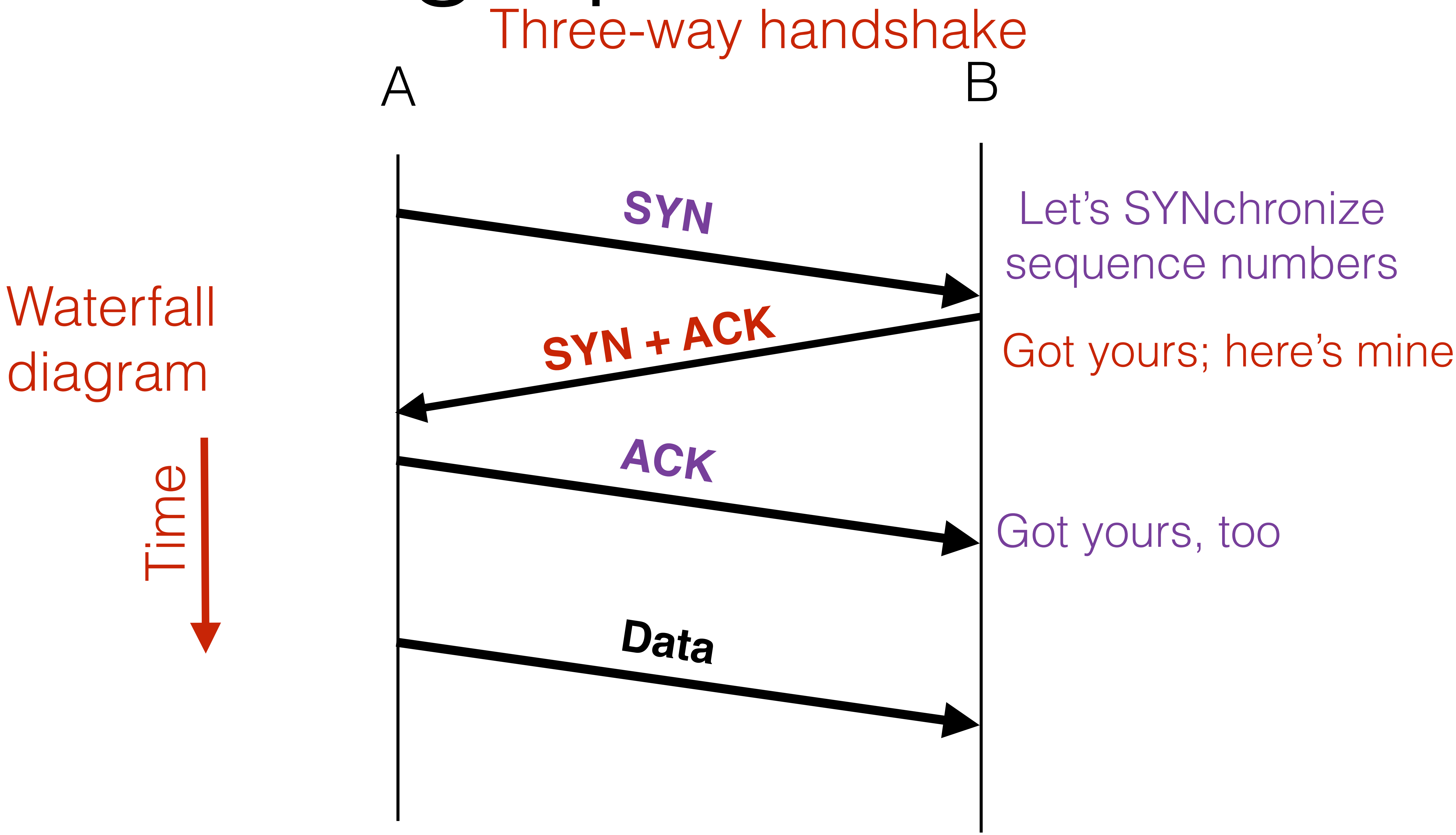

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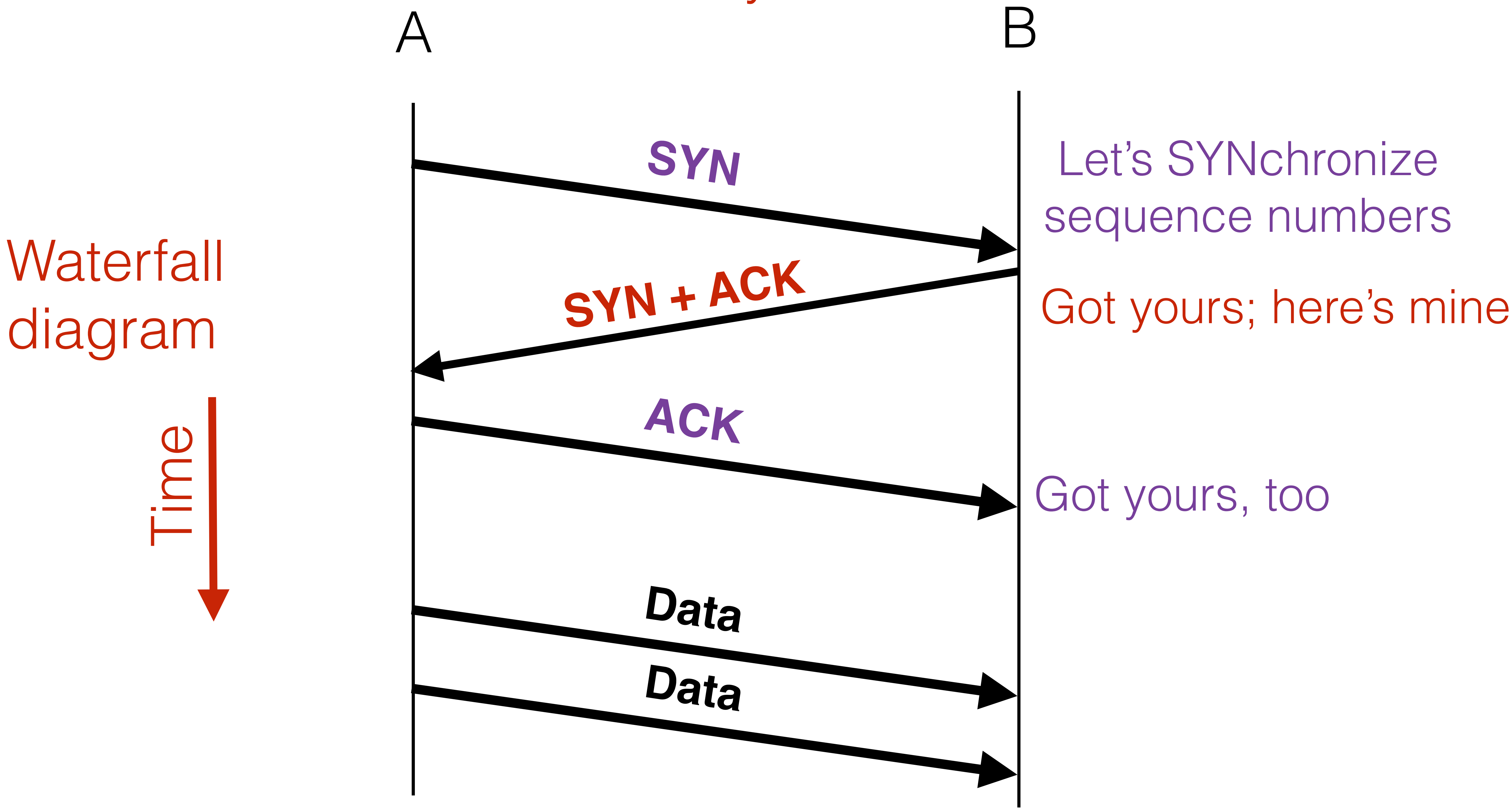

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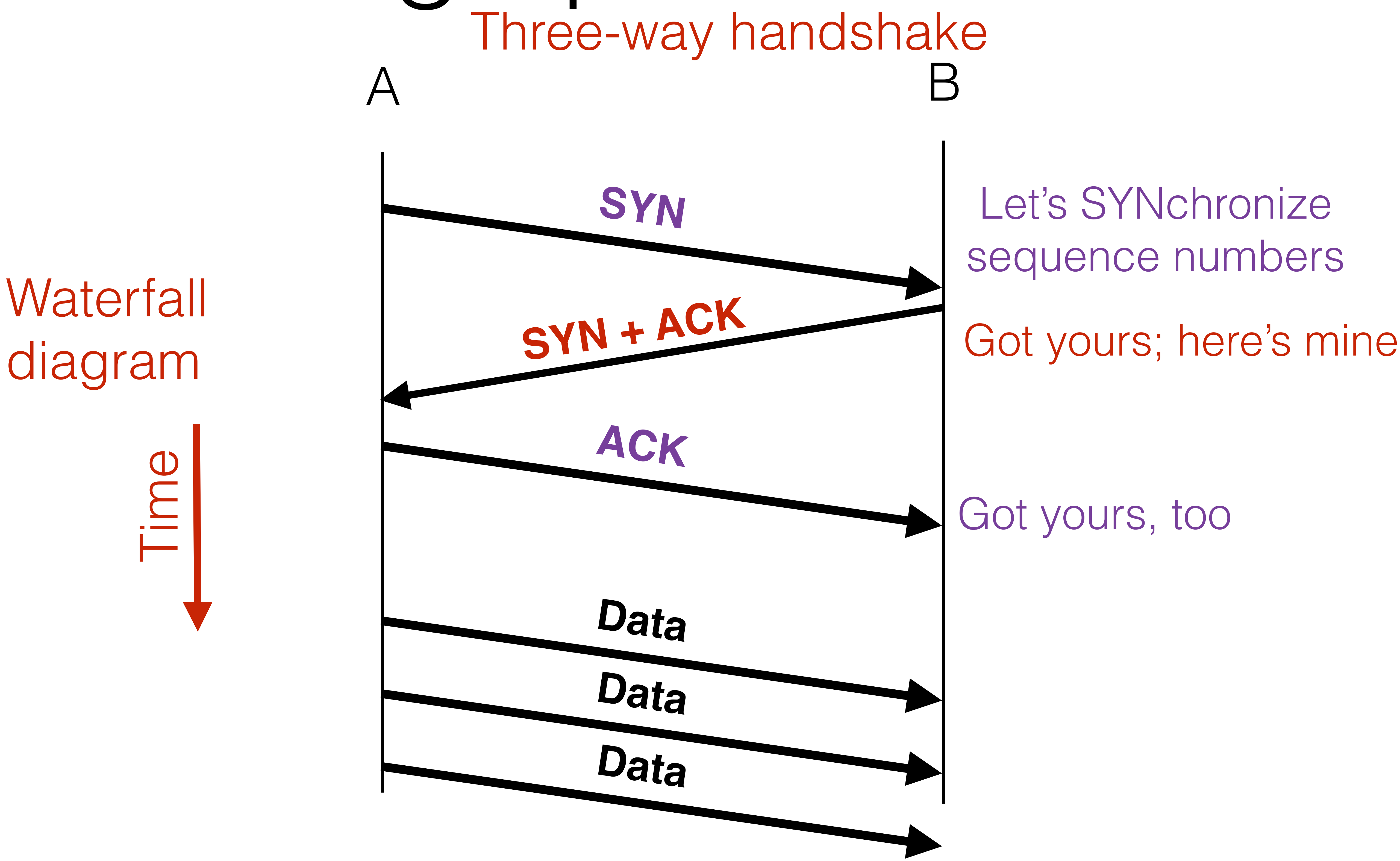

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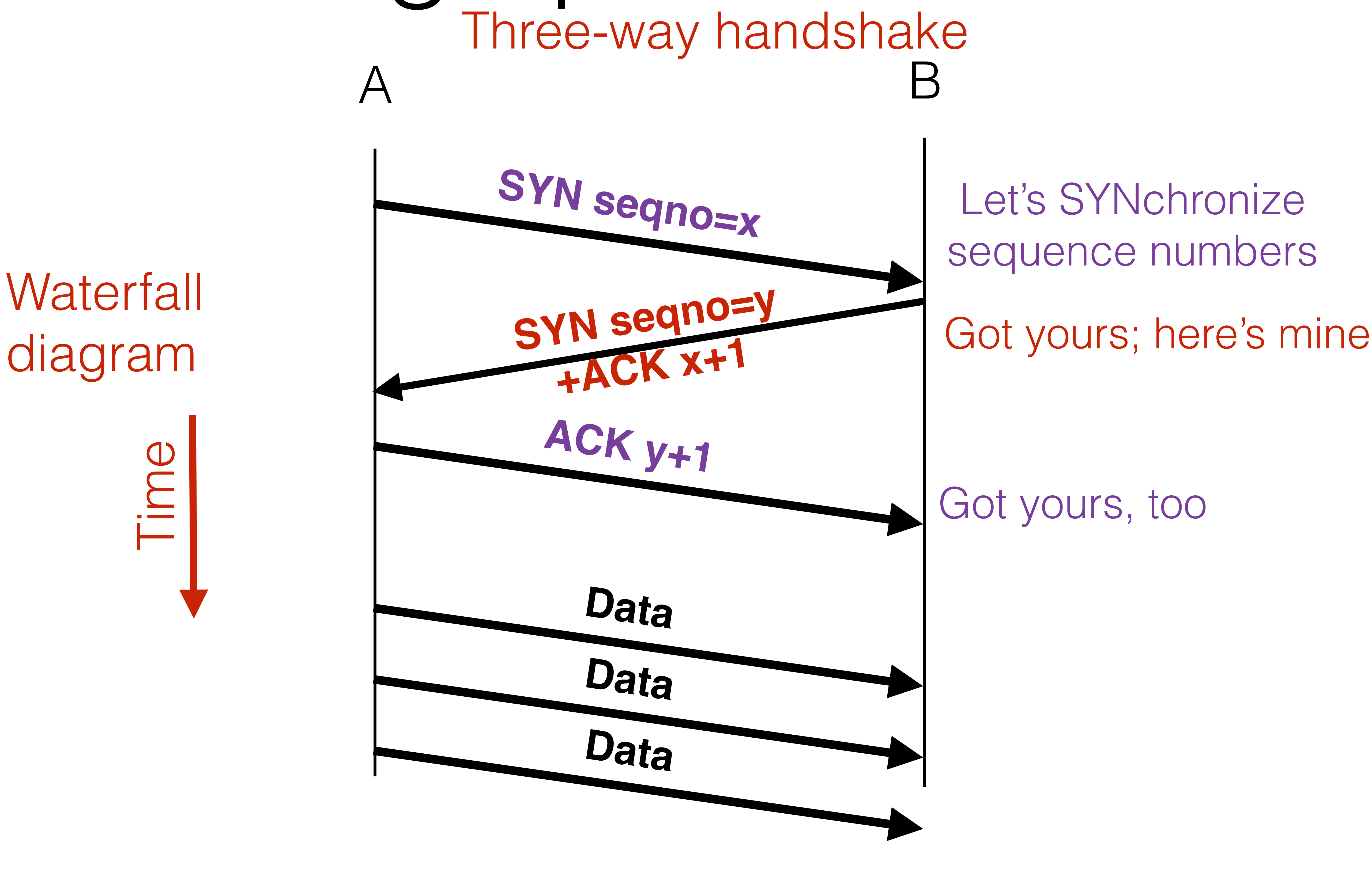


TCP flags

- SYN
- ACK
- FIN: Let’s shut this down (two-way)
  - FIN
  - FIN+ACK
- RST: I’m shutting you down
  - Says “delete all your local state, because I don’t know what you’re talking about

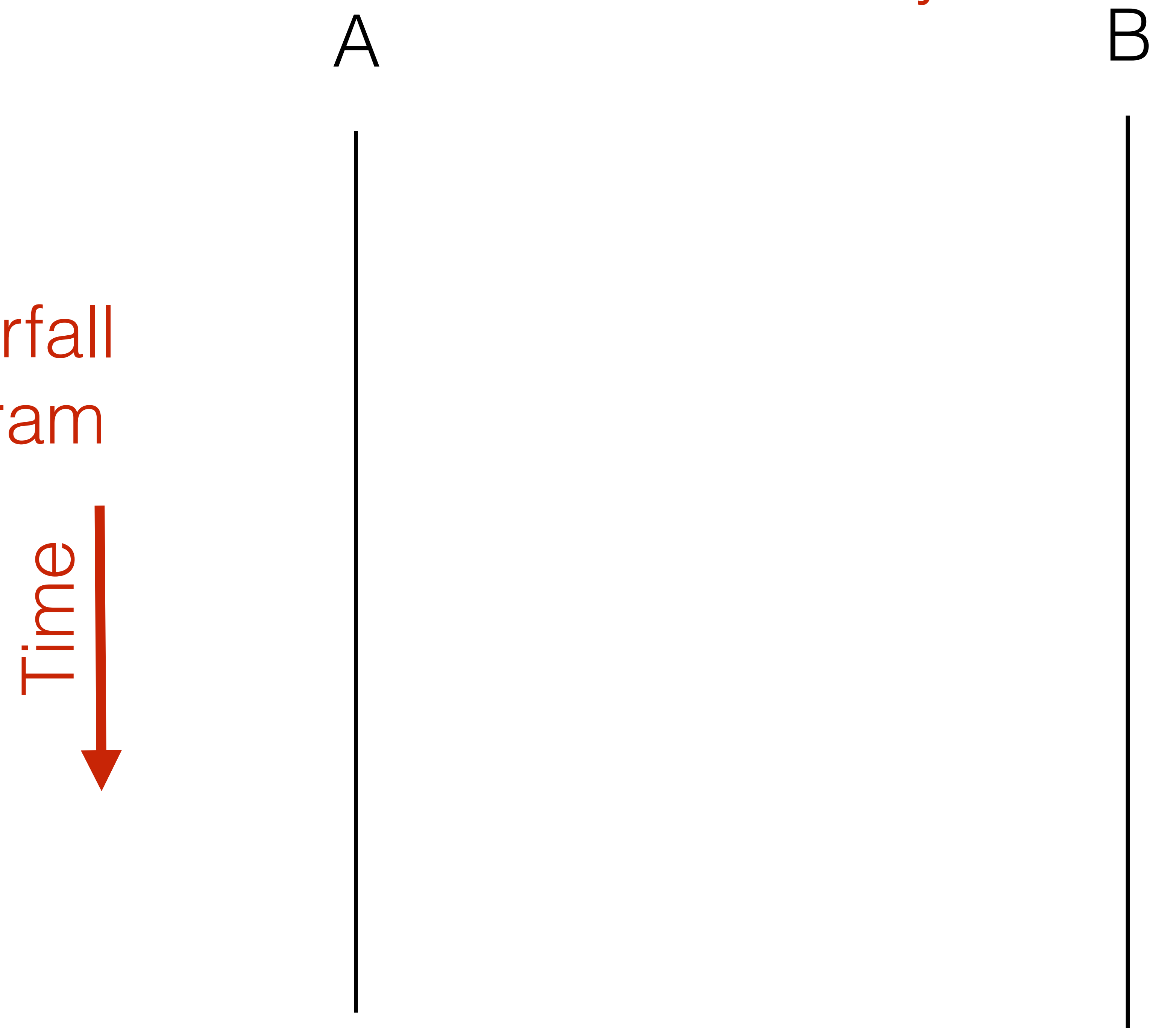
Attacks

- SYN flooding
- Injection attacks
- Opt-ack attack

SYN flooding

SYN flooding

Recall the three-way handshake:



Waterfall diagram

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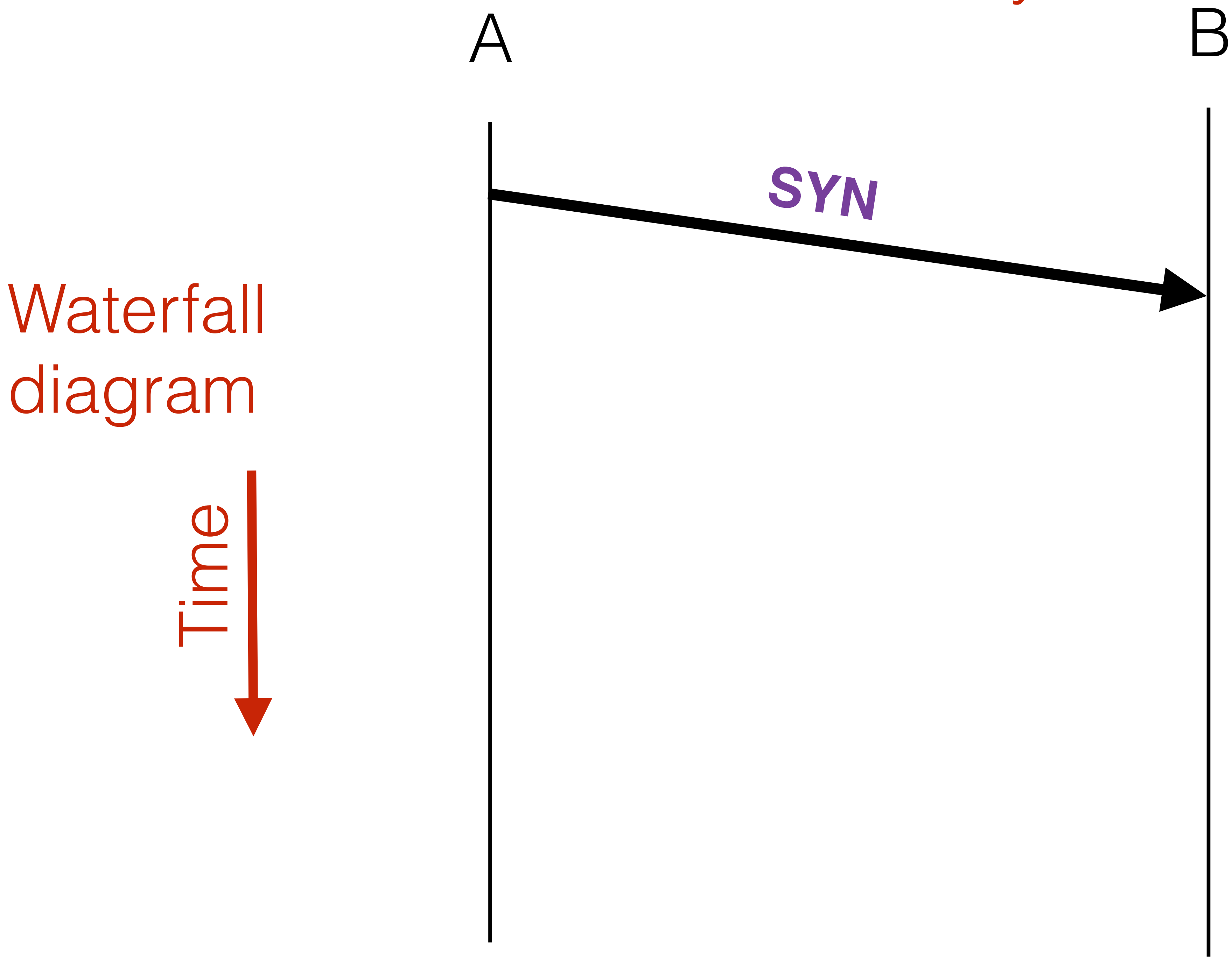

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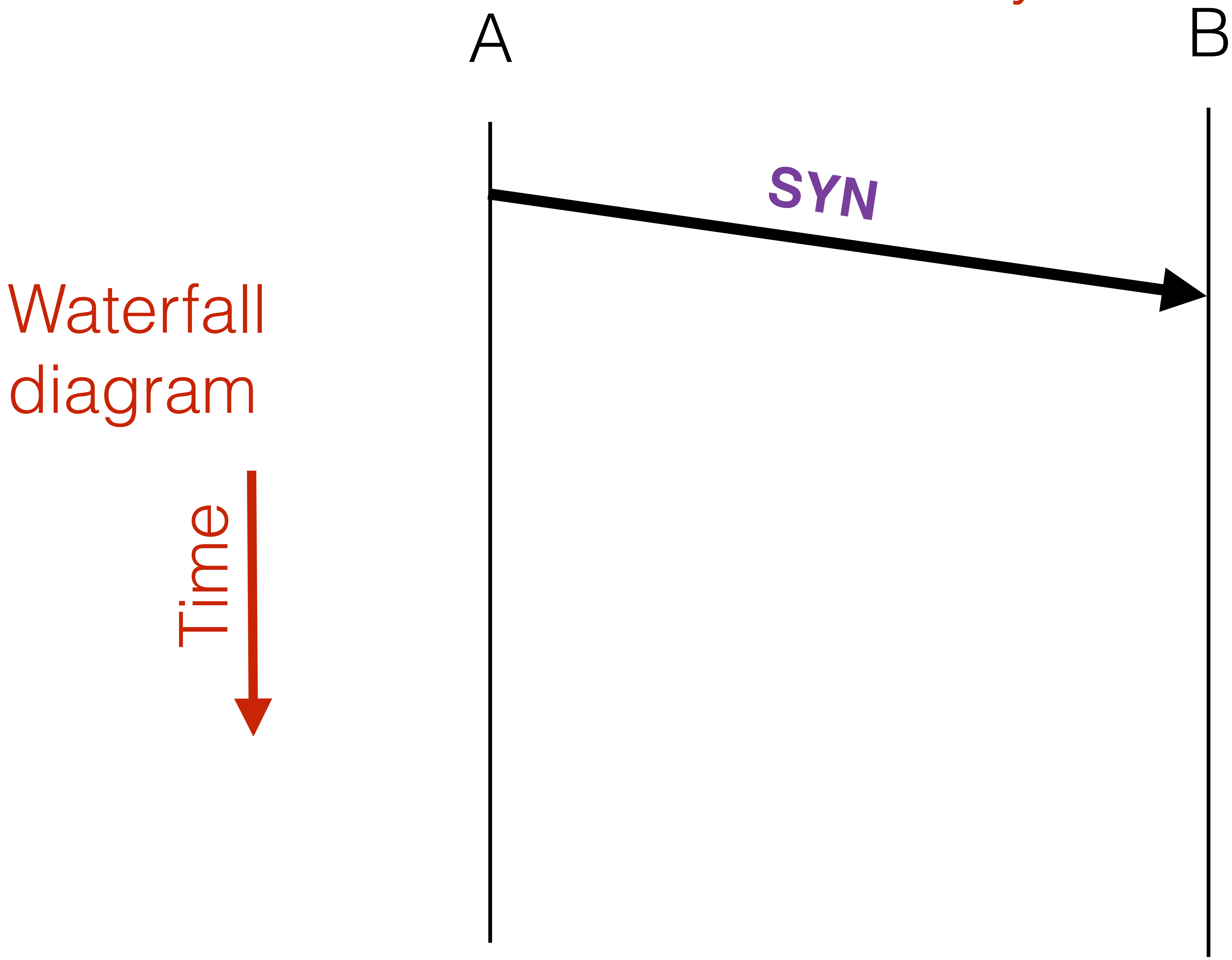

At this point, B allocates state for this new connection (incl. IP, port, maximum segment size)

SYN flooding

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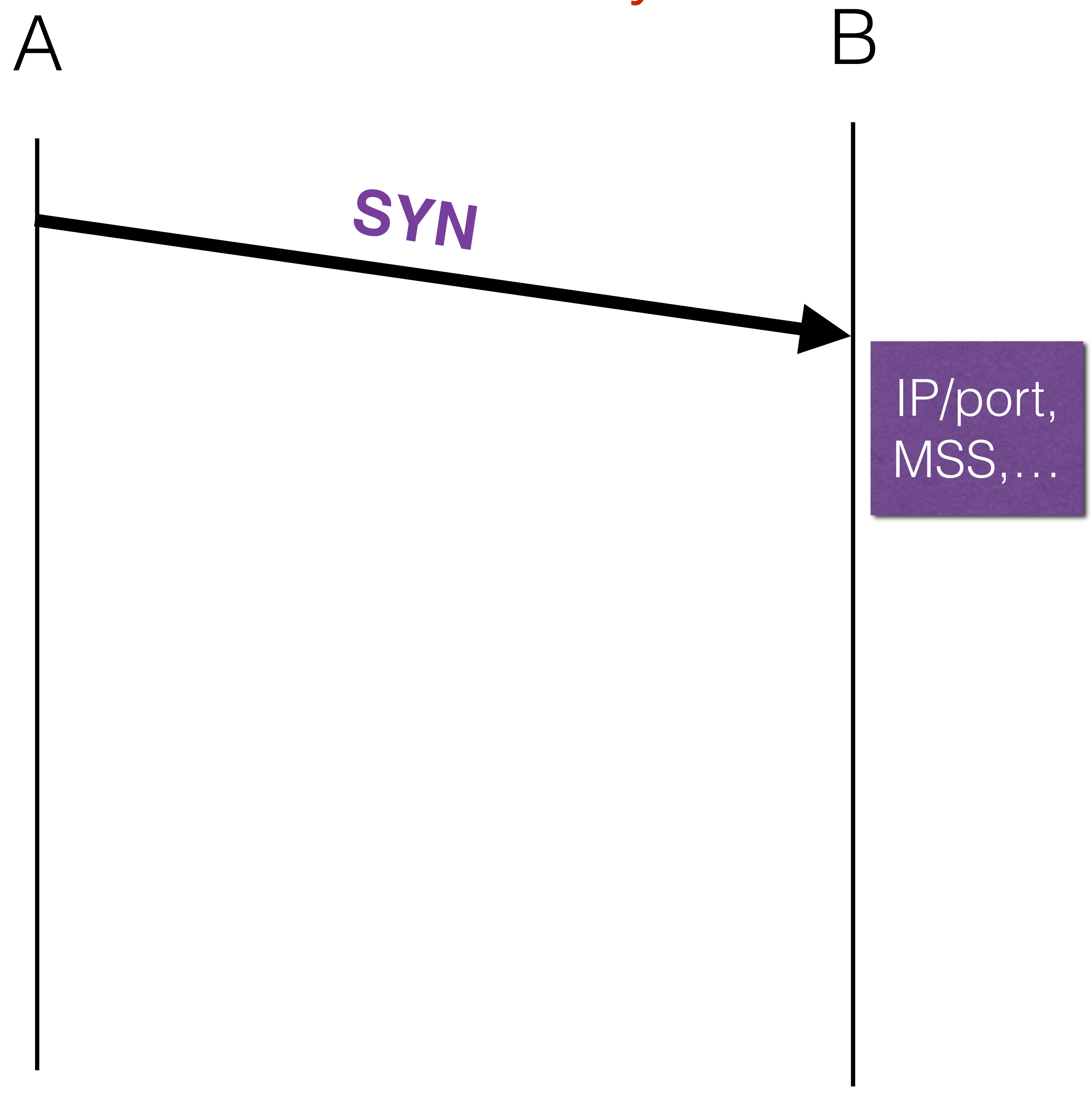

Waterfall diagram

Time

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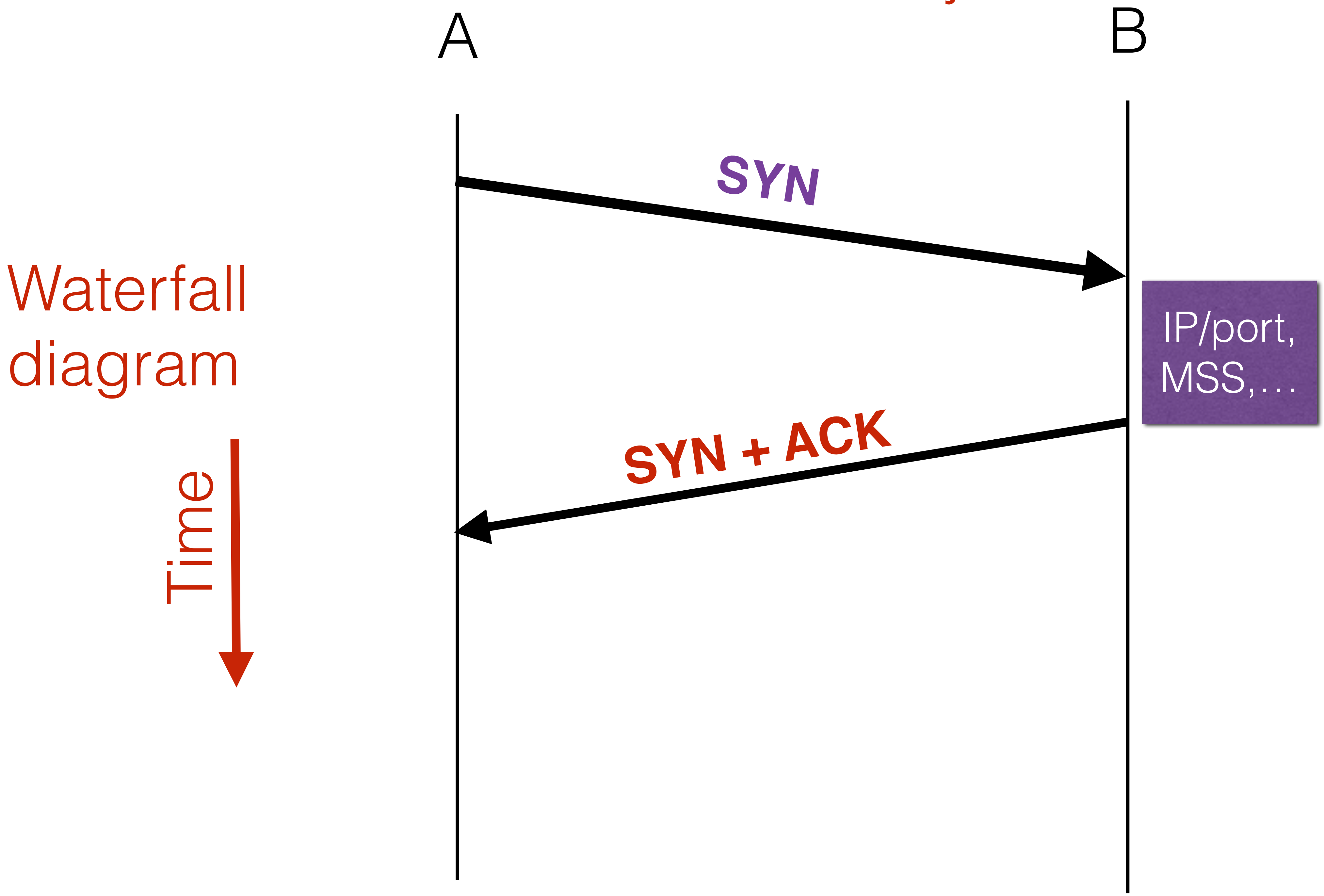

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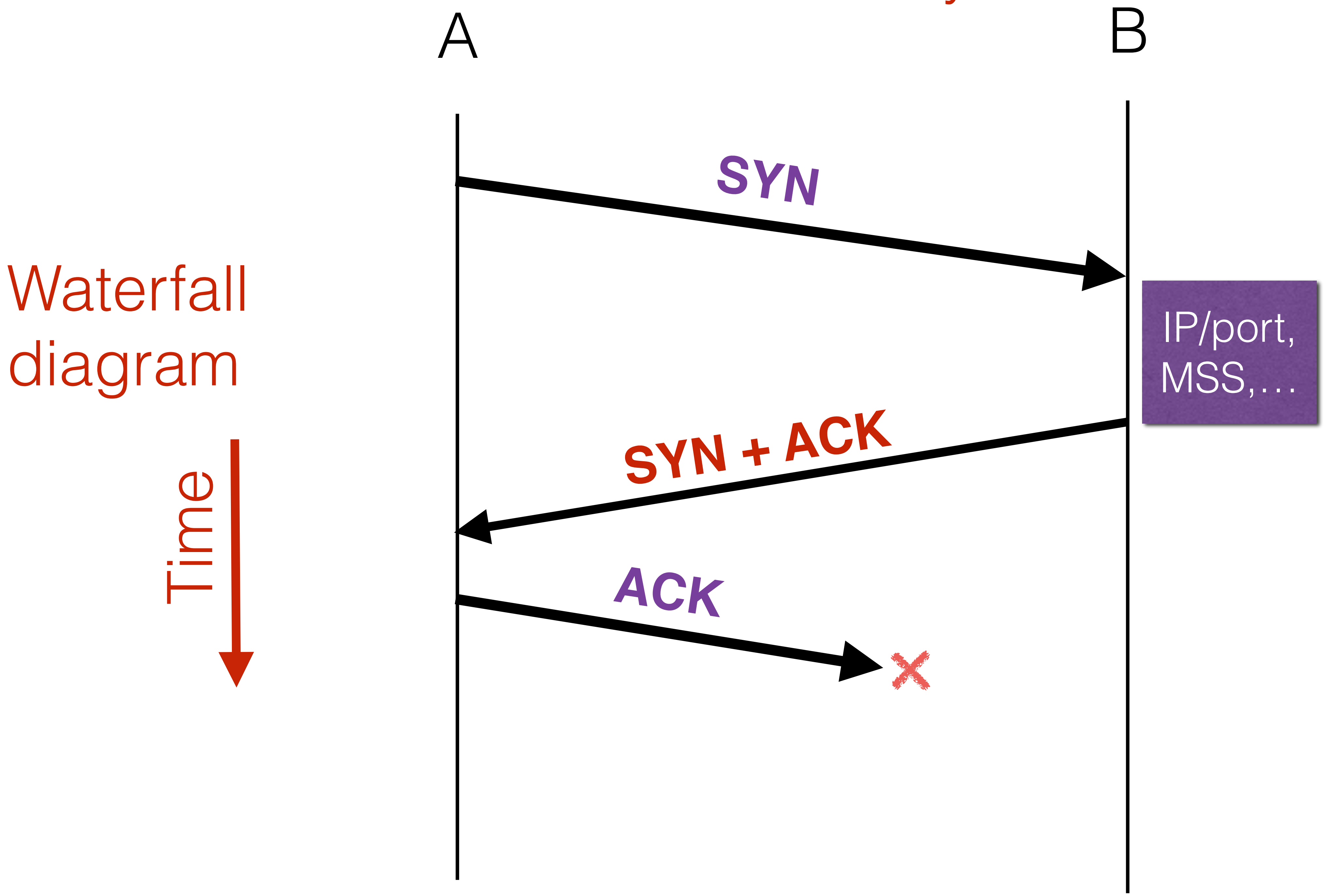

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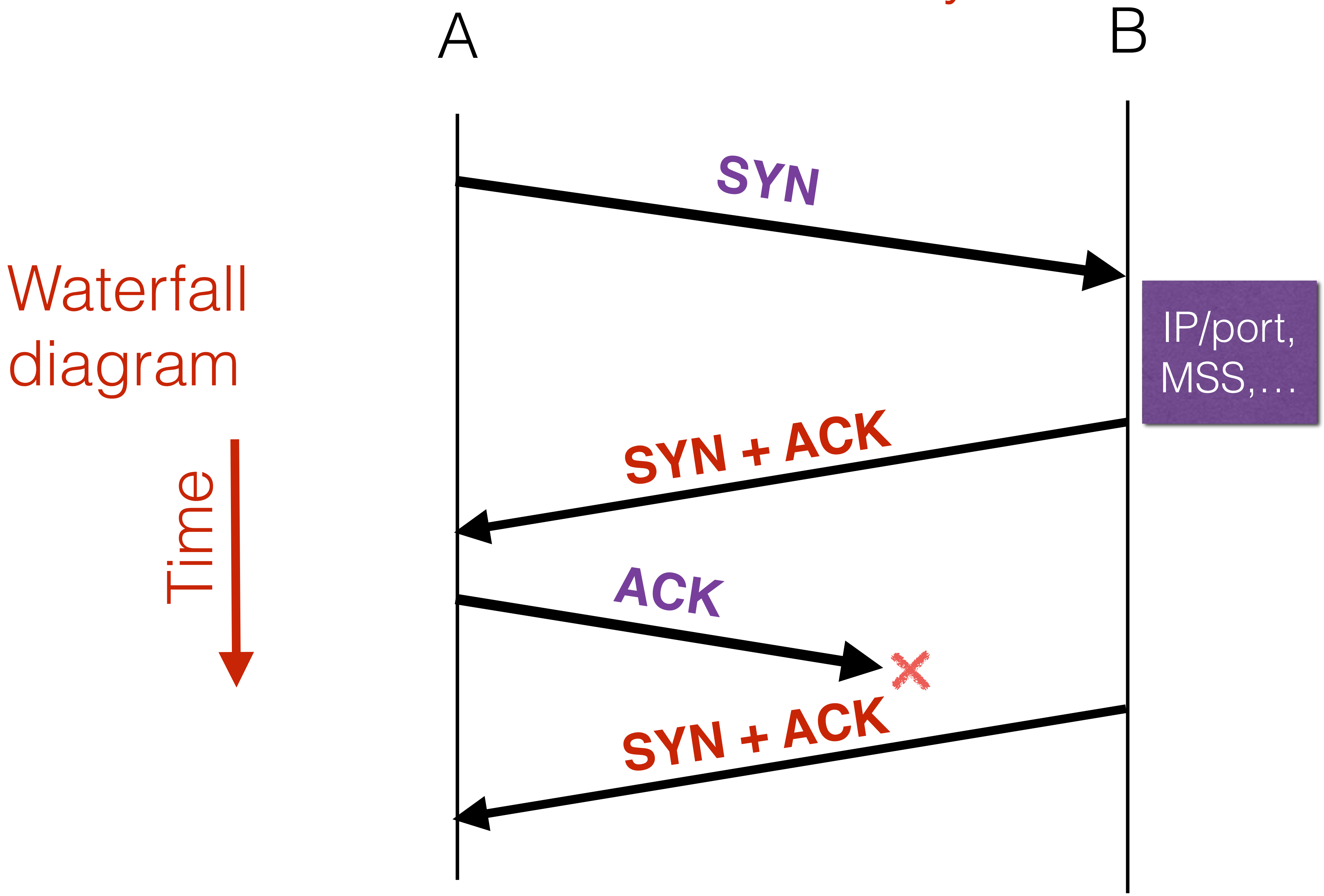

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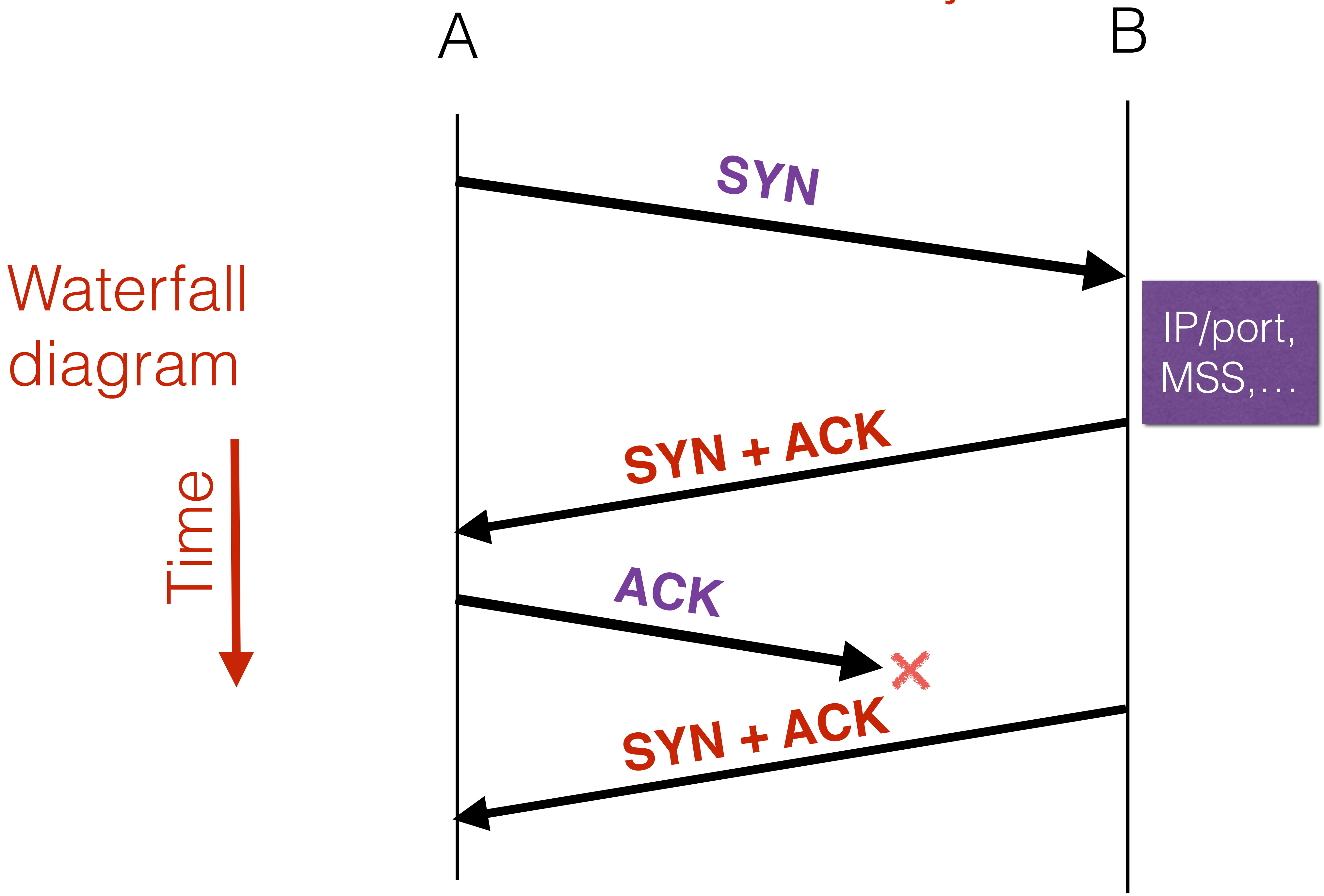
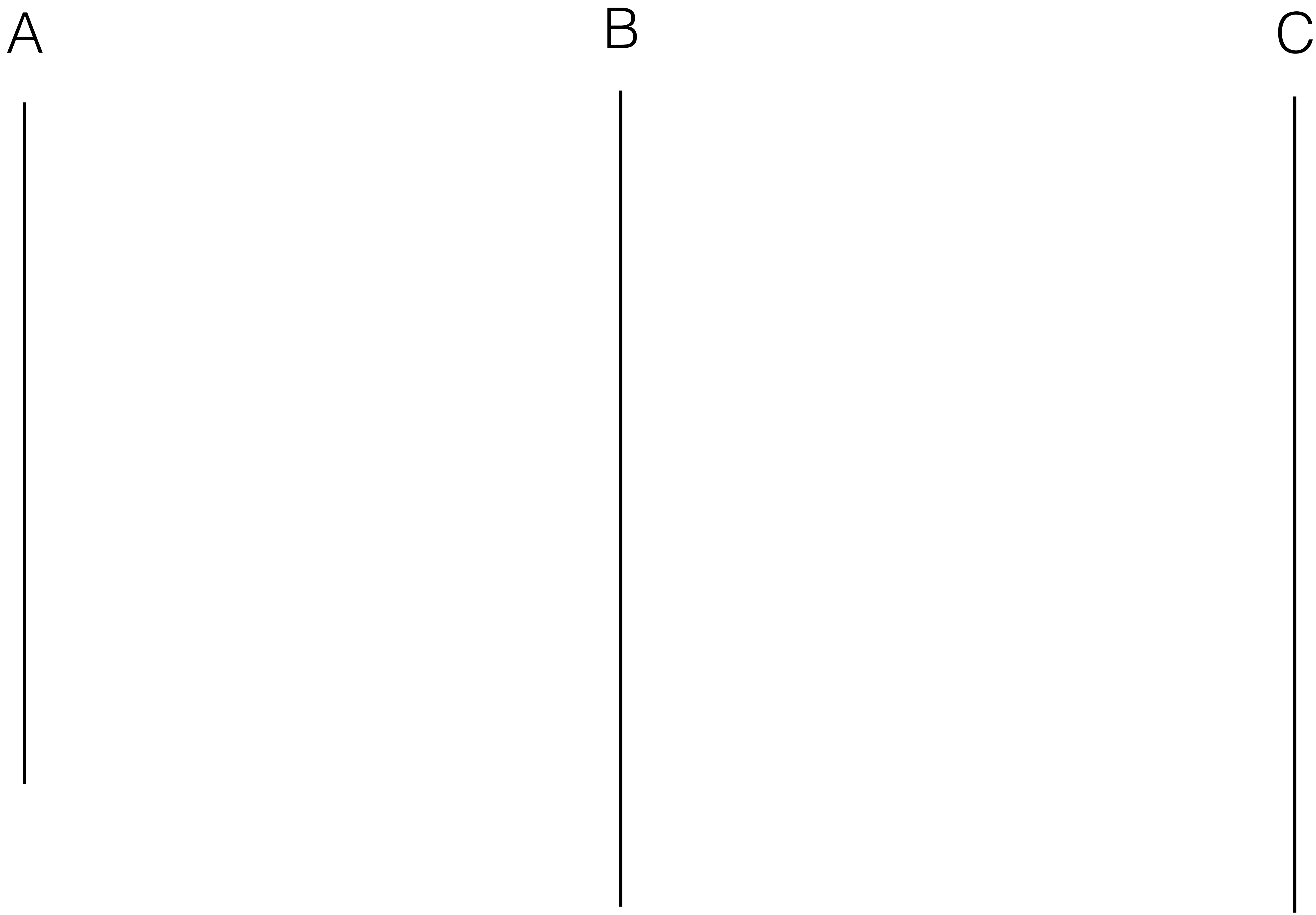


At this point, B allocates state for this new connection (incl. IP, port, maximum segment size)

B will hold onto this local state and retransmit SYN+ACK's until it hears back or times out (up to 63 sec).

SYN flooding

The attack



SYN flooding

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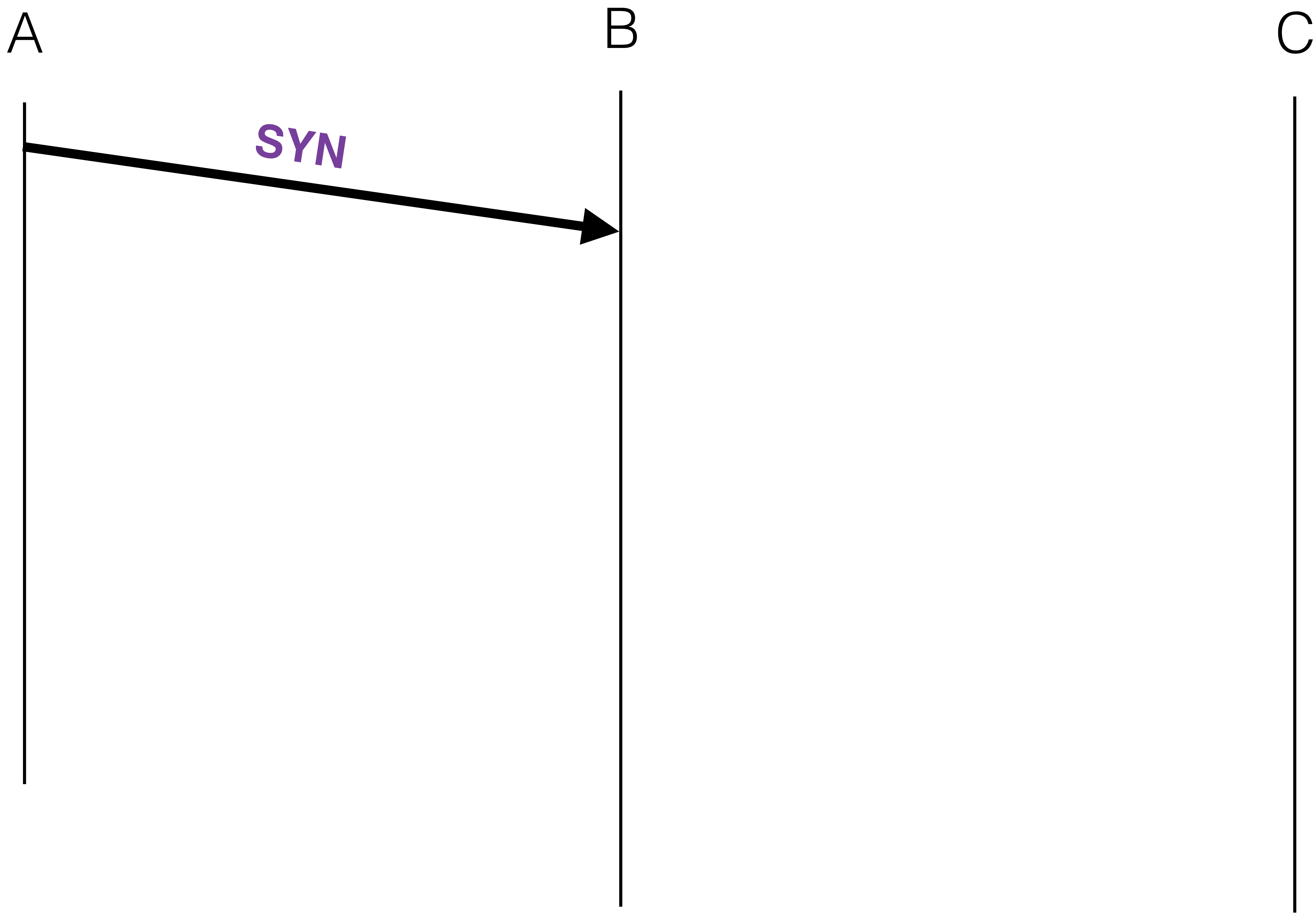

SYN flooding

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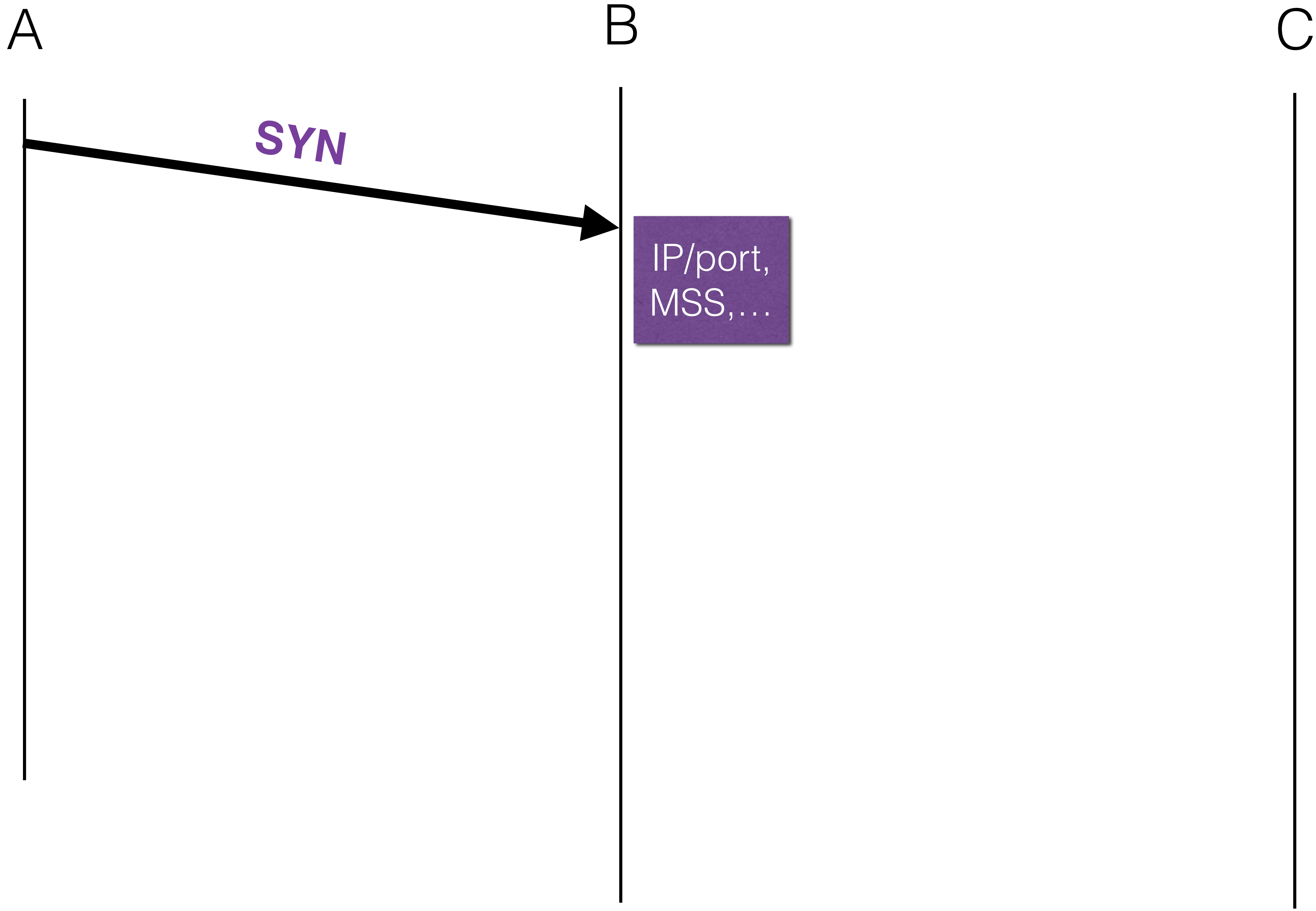

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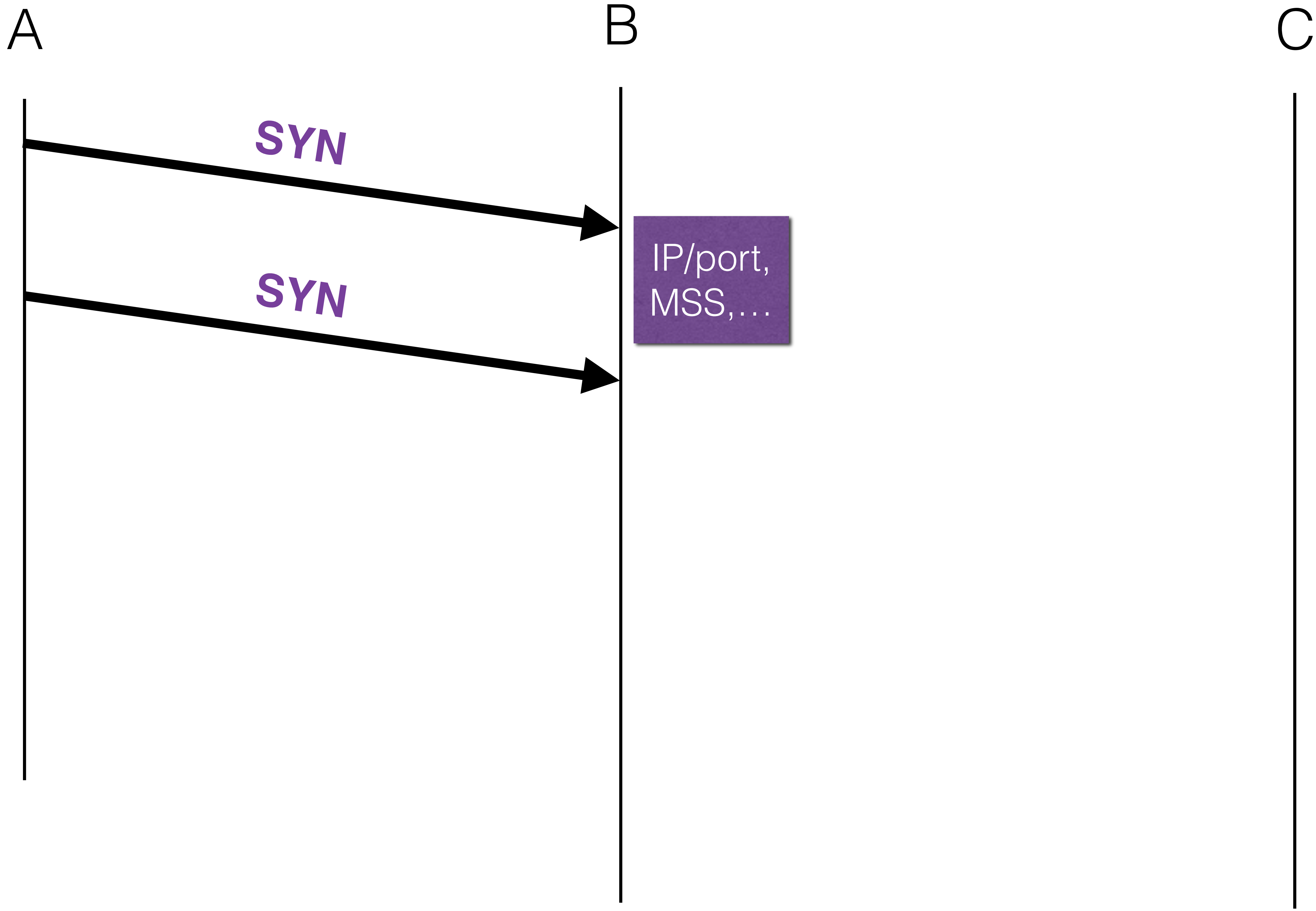

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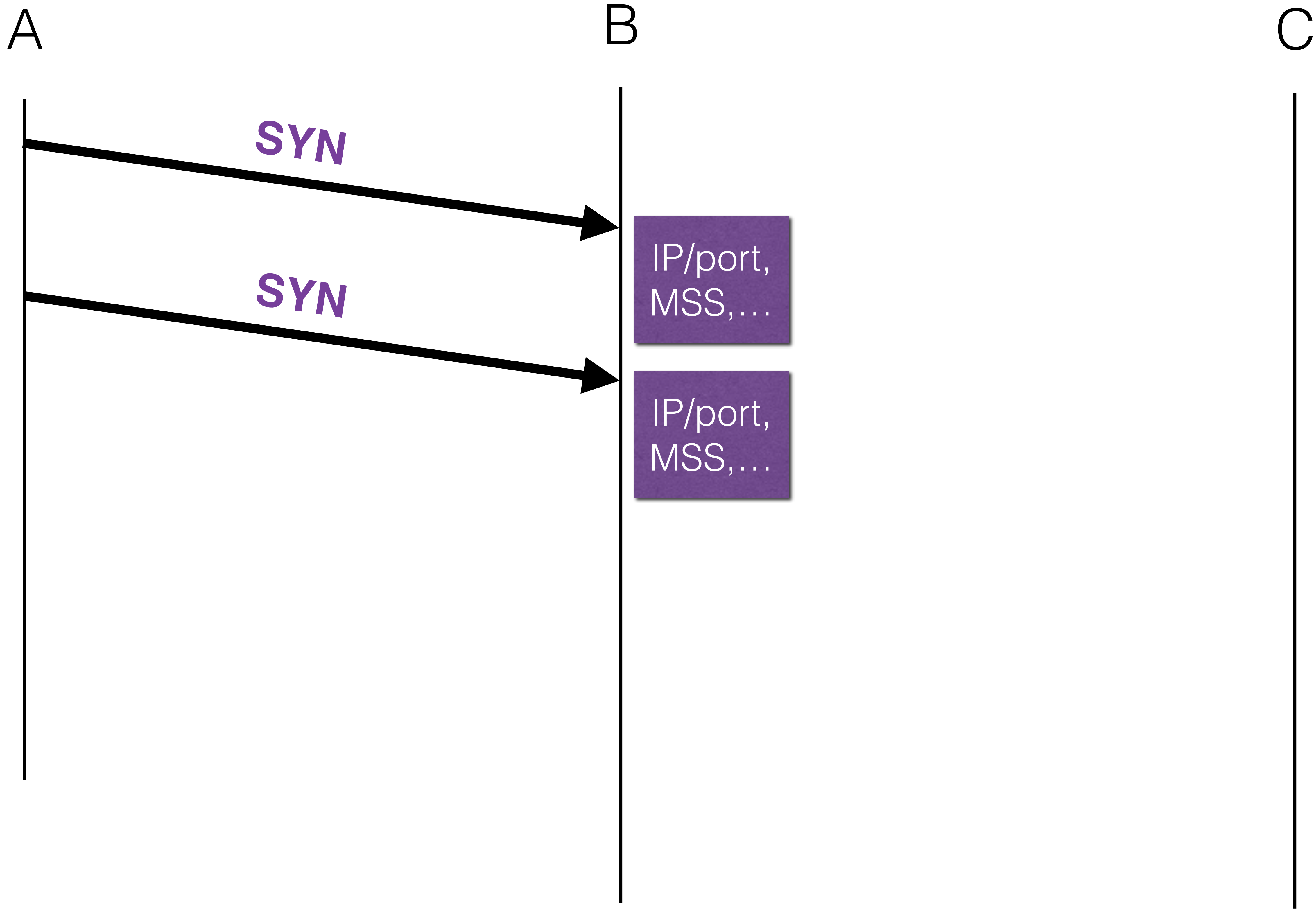

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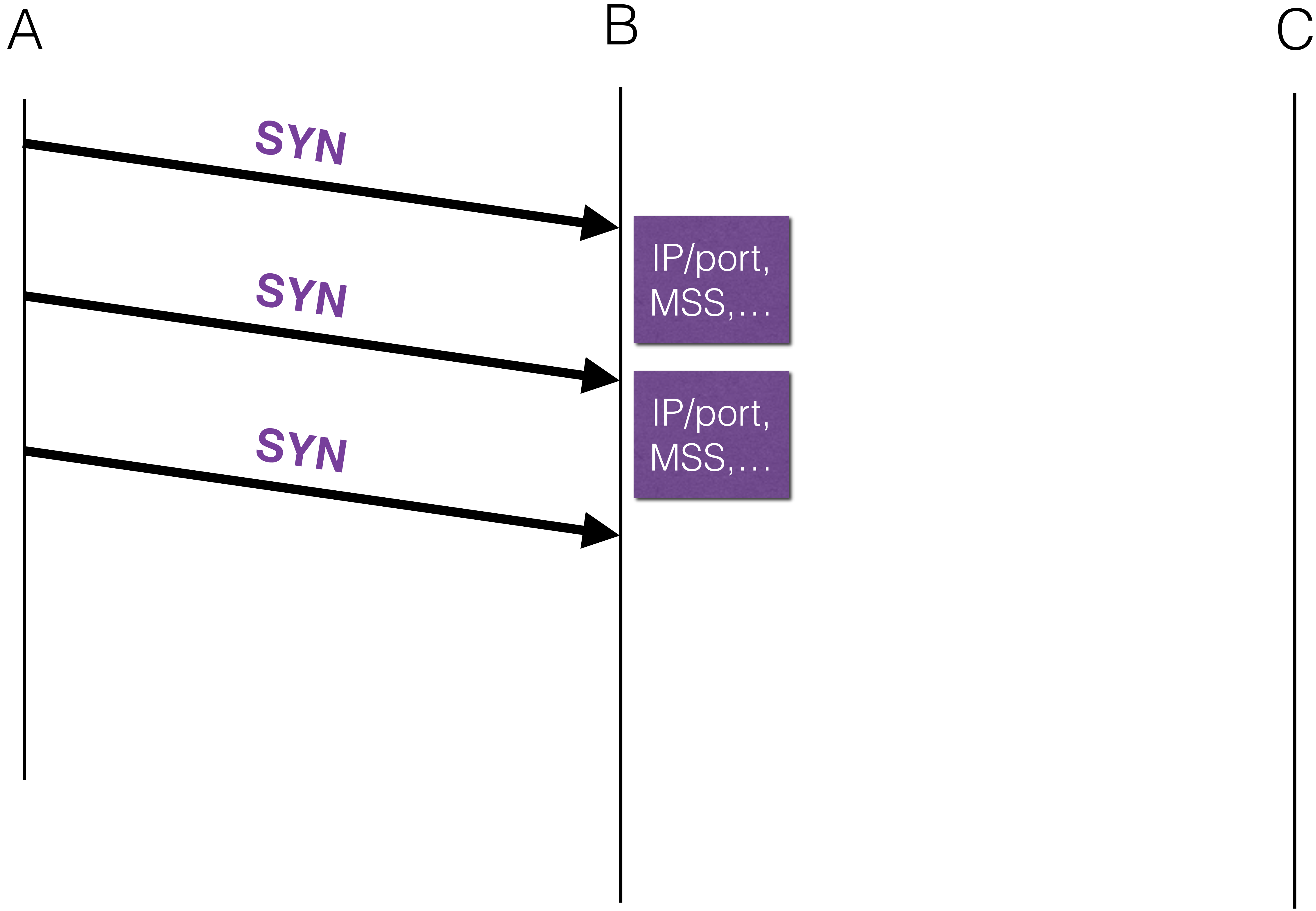

SYN flooding

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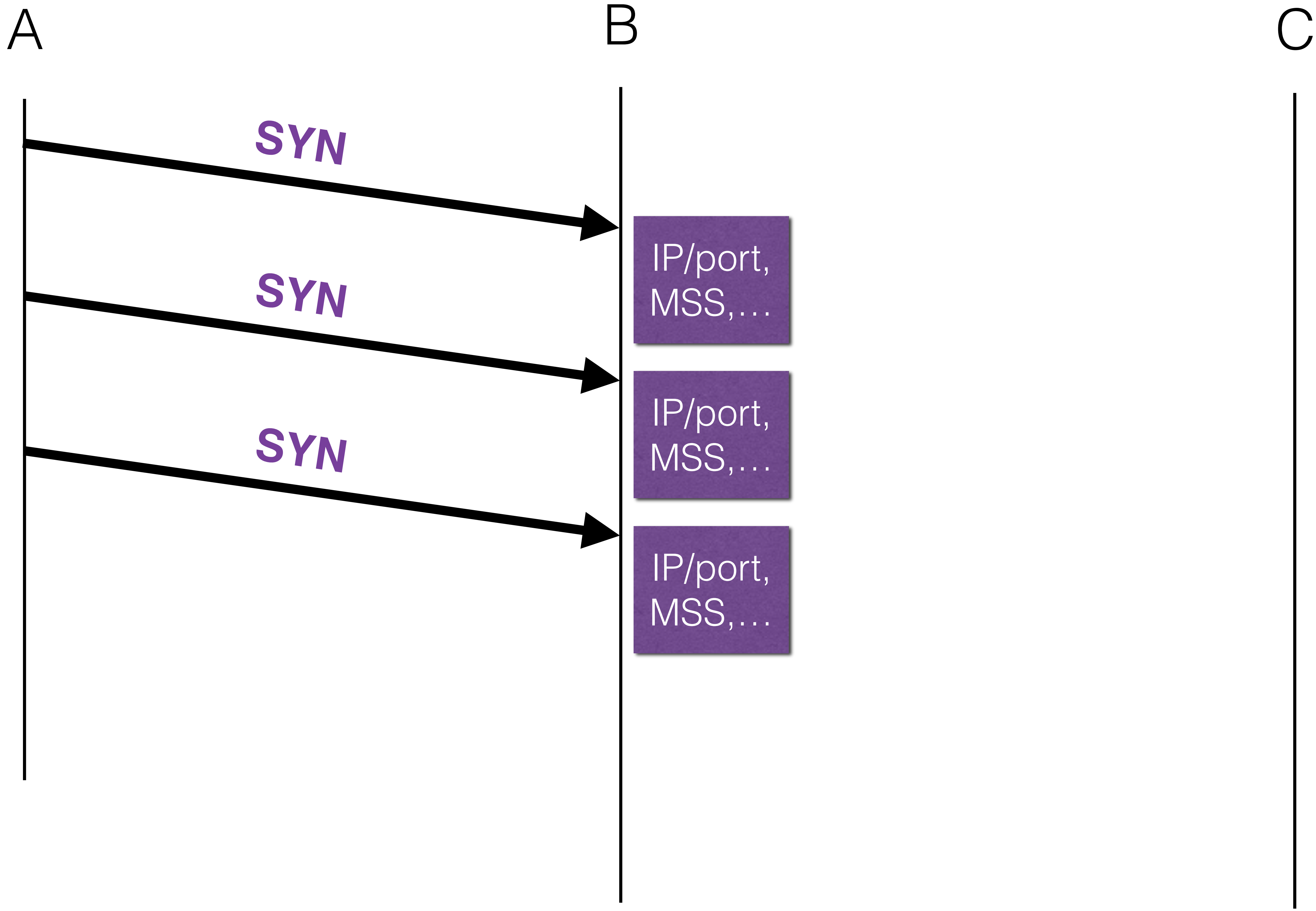

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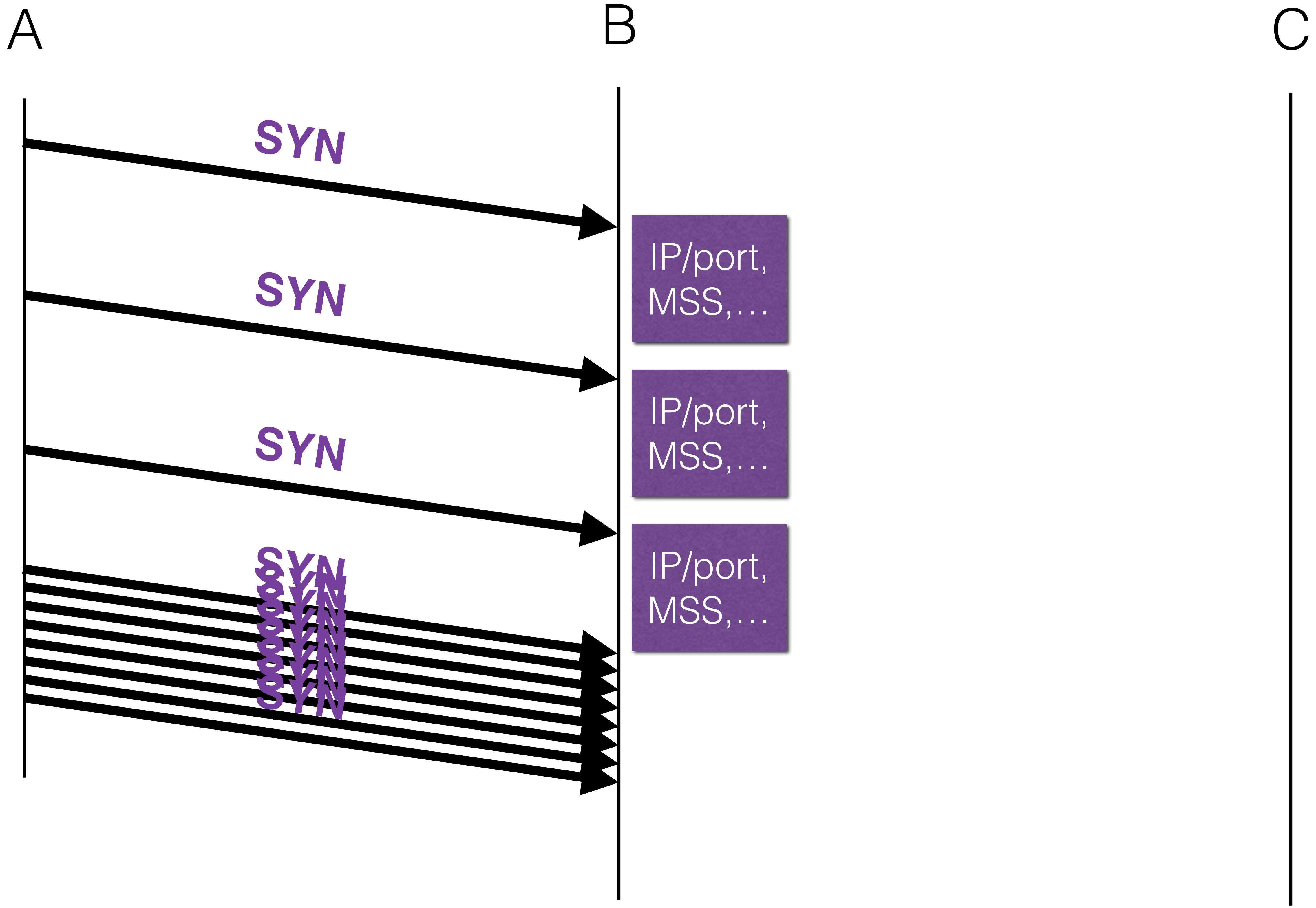

SYN flooding

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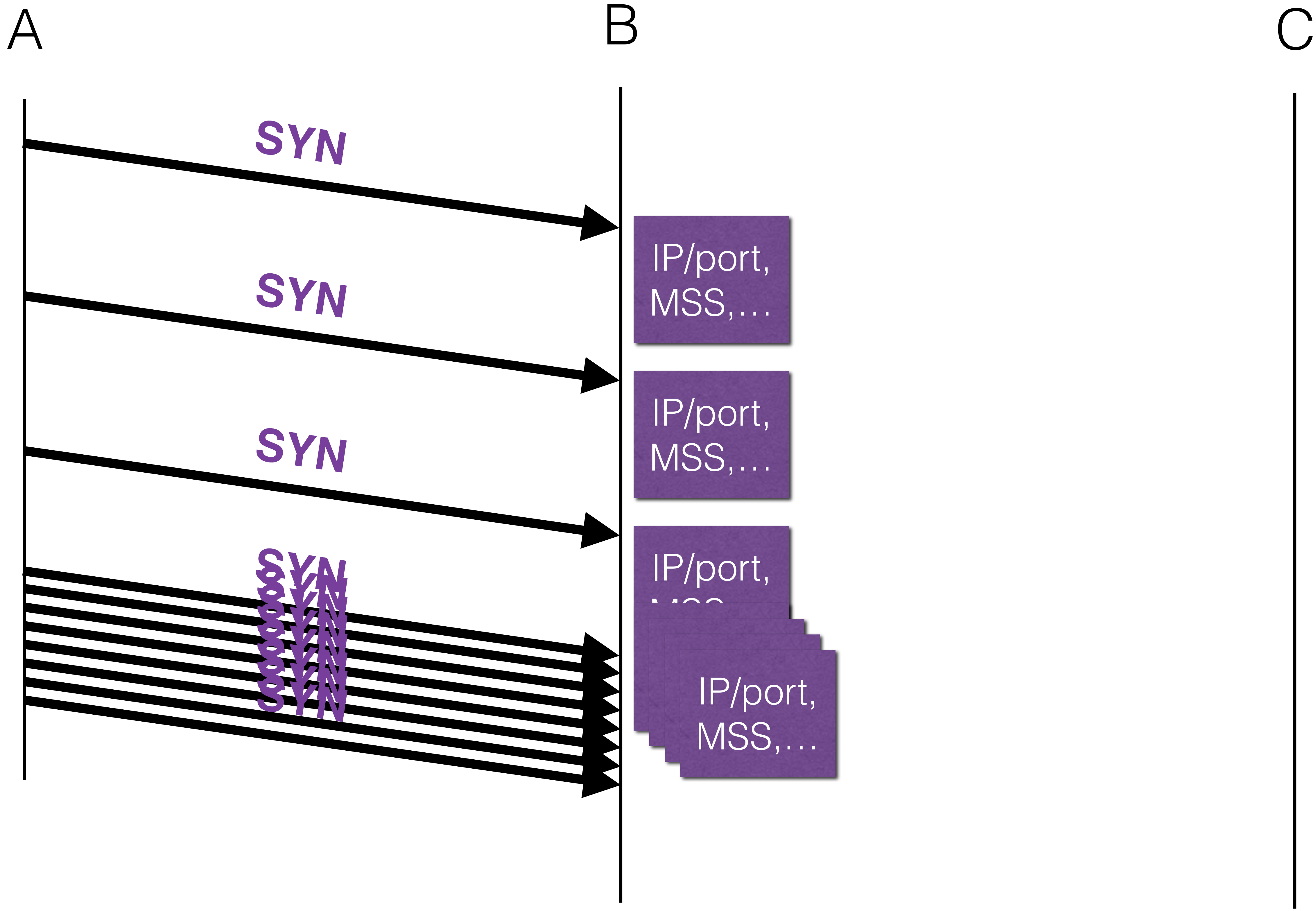

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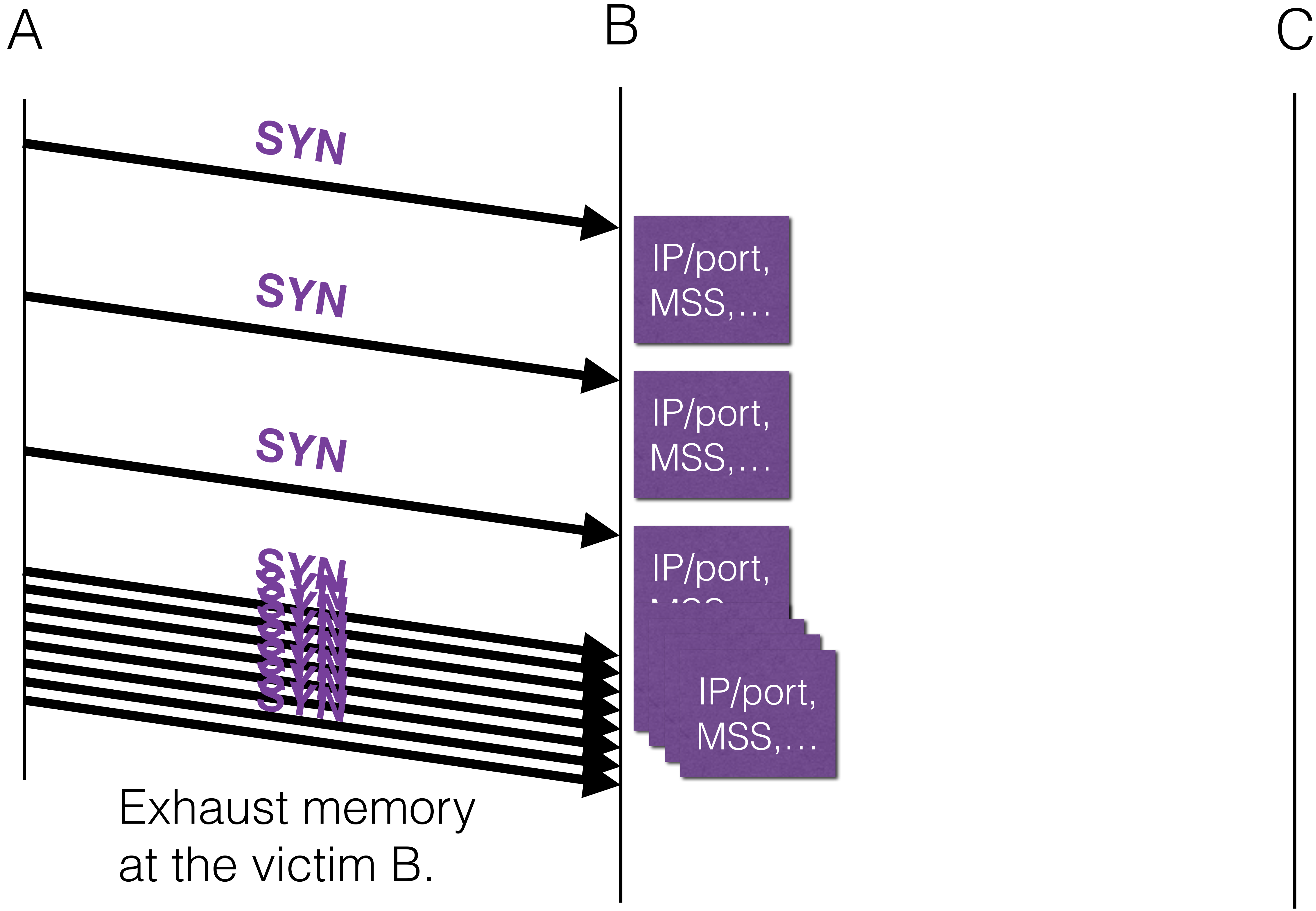

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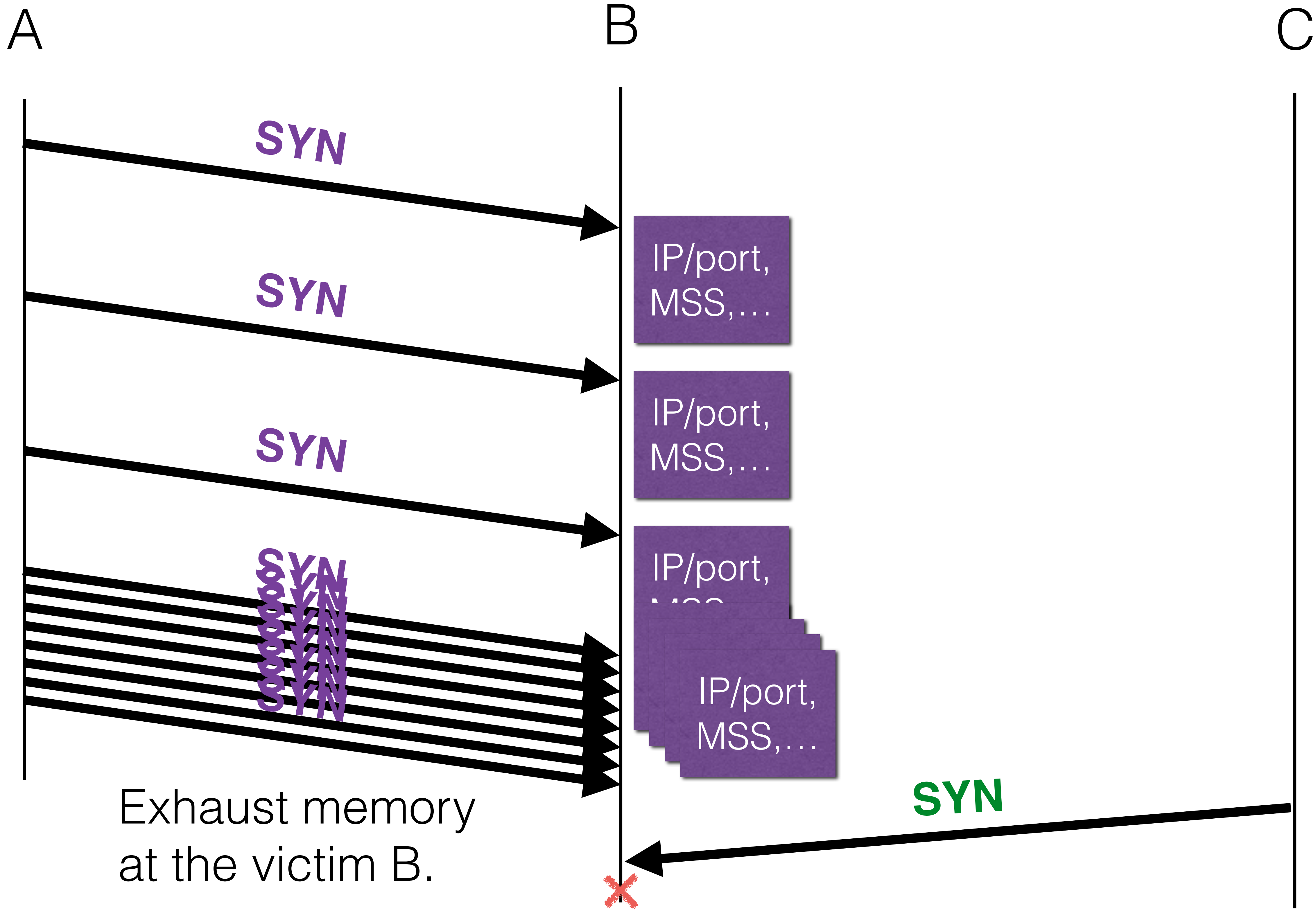
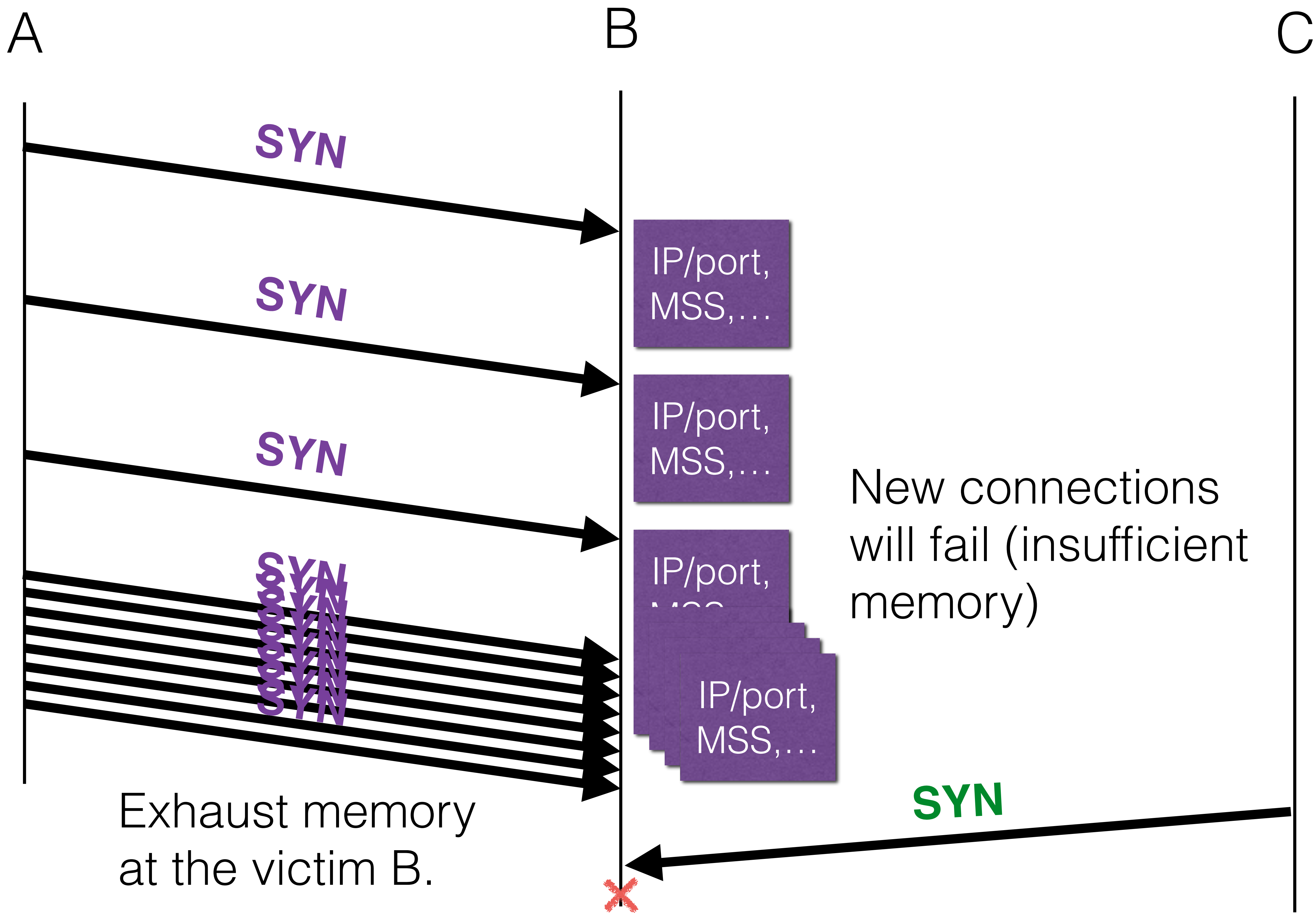


Exhaust memory
at the victim B.

SYN flooding

The attack

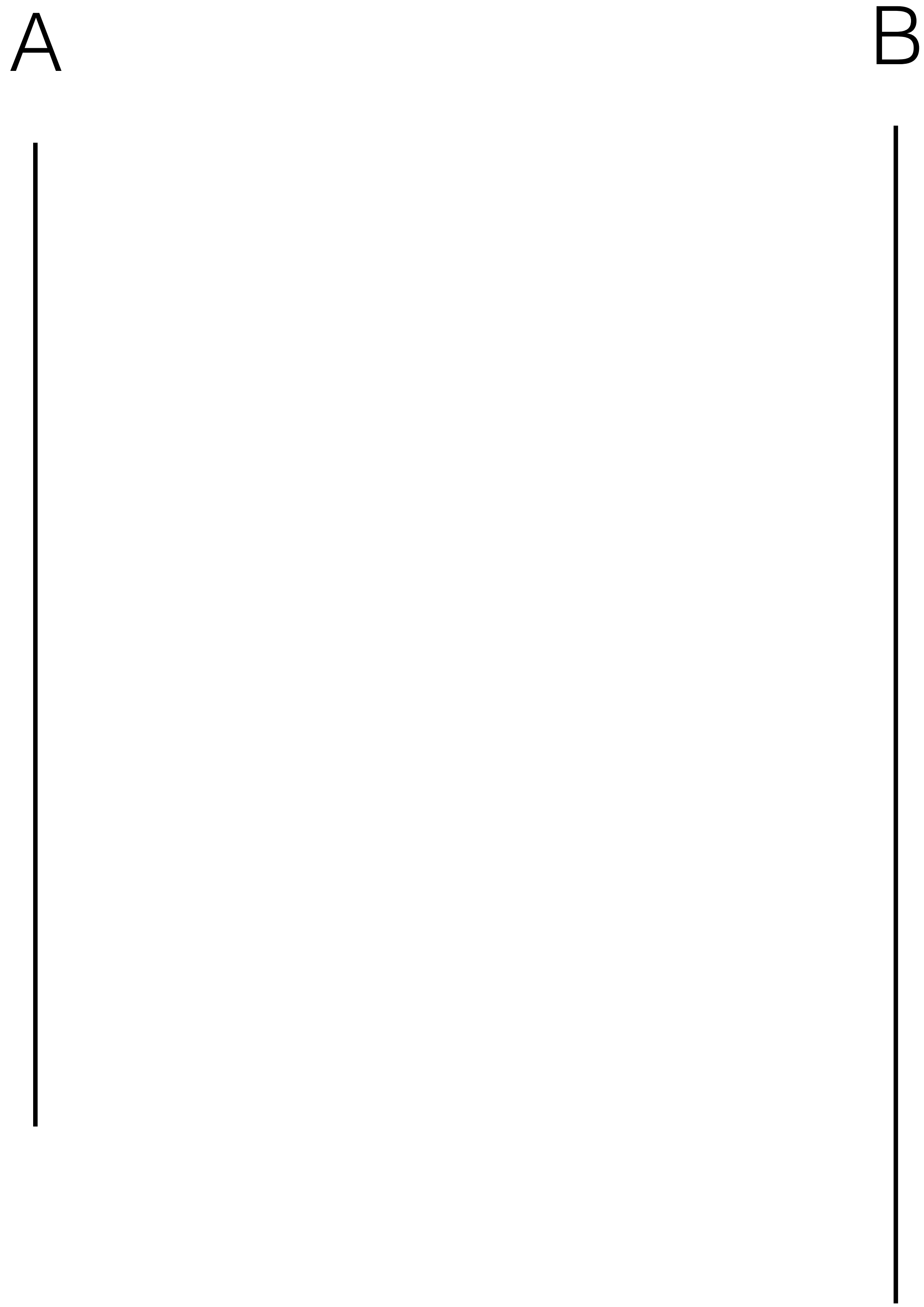


SYN flooding details

- Easy to detect many incomplete handshakes from a single IP address
- *Spoof* the source IP address
  - It's just a field in a header: set it to whatever you like
- Problem: the host who really owns that spoofed IP address may respond to the SYN+ACK with a RST, deleting the local state at the victim
- Ideally, spoof an IP address of a host you know won't respond

SYN cookies

The defense



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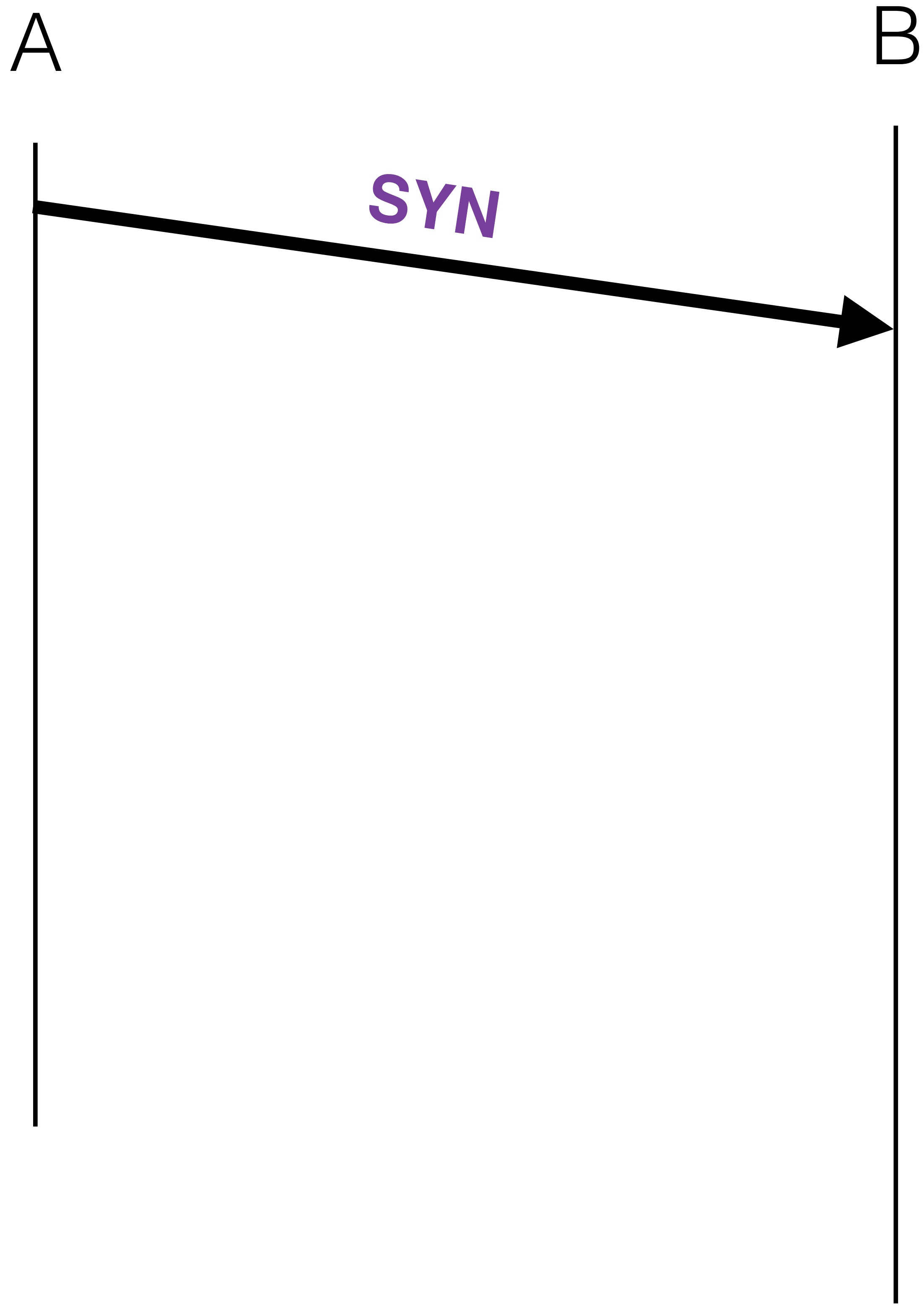

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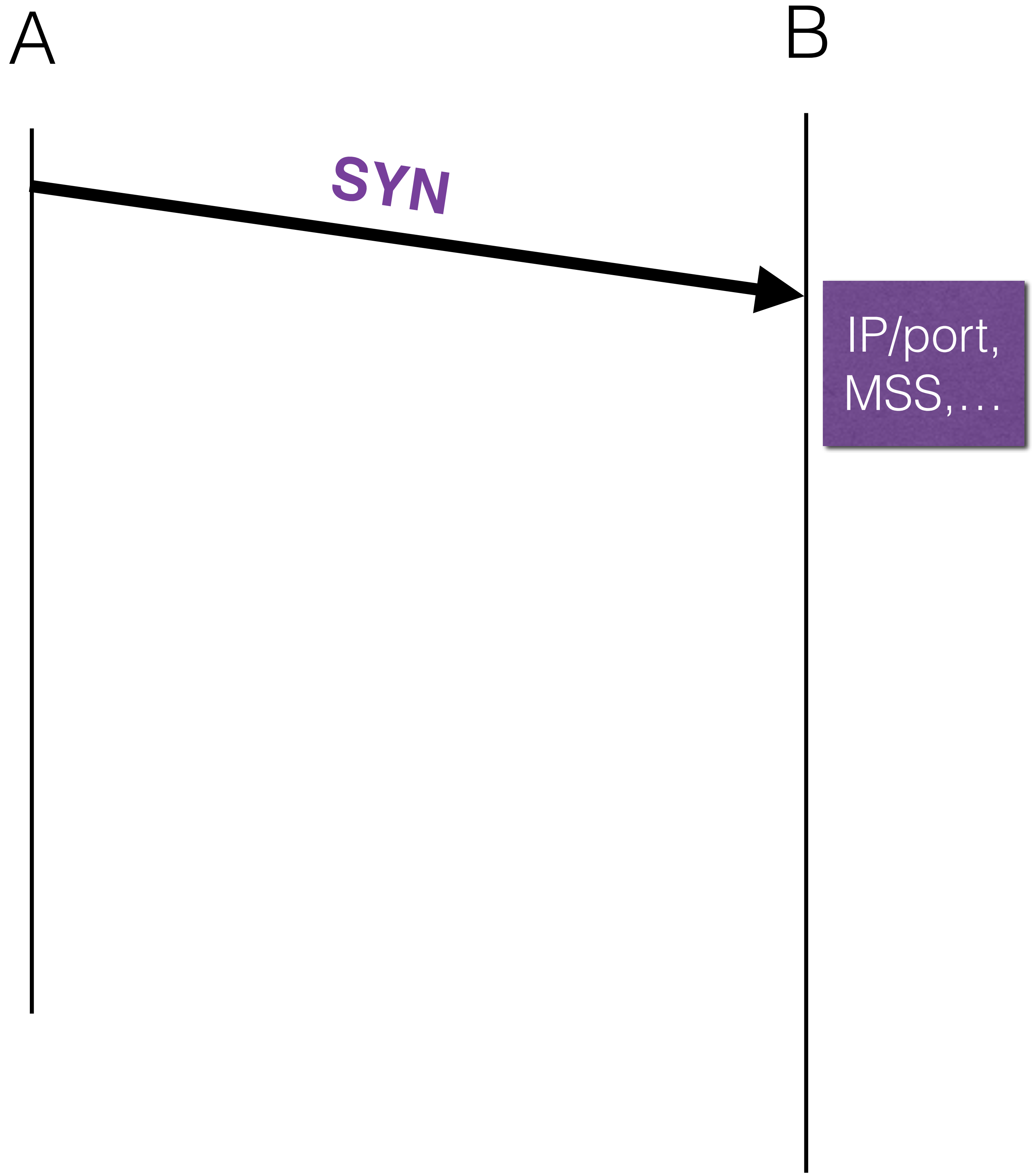

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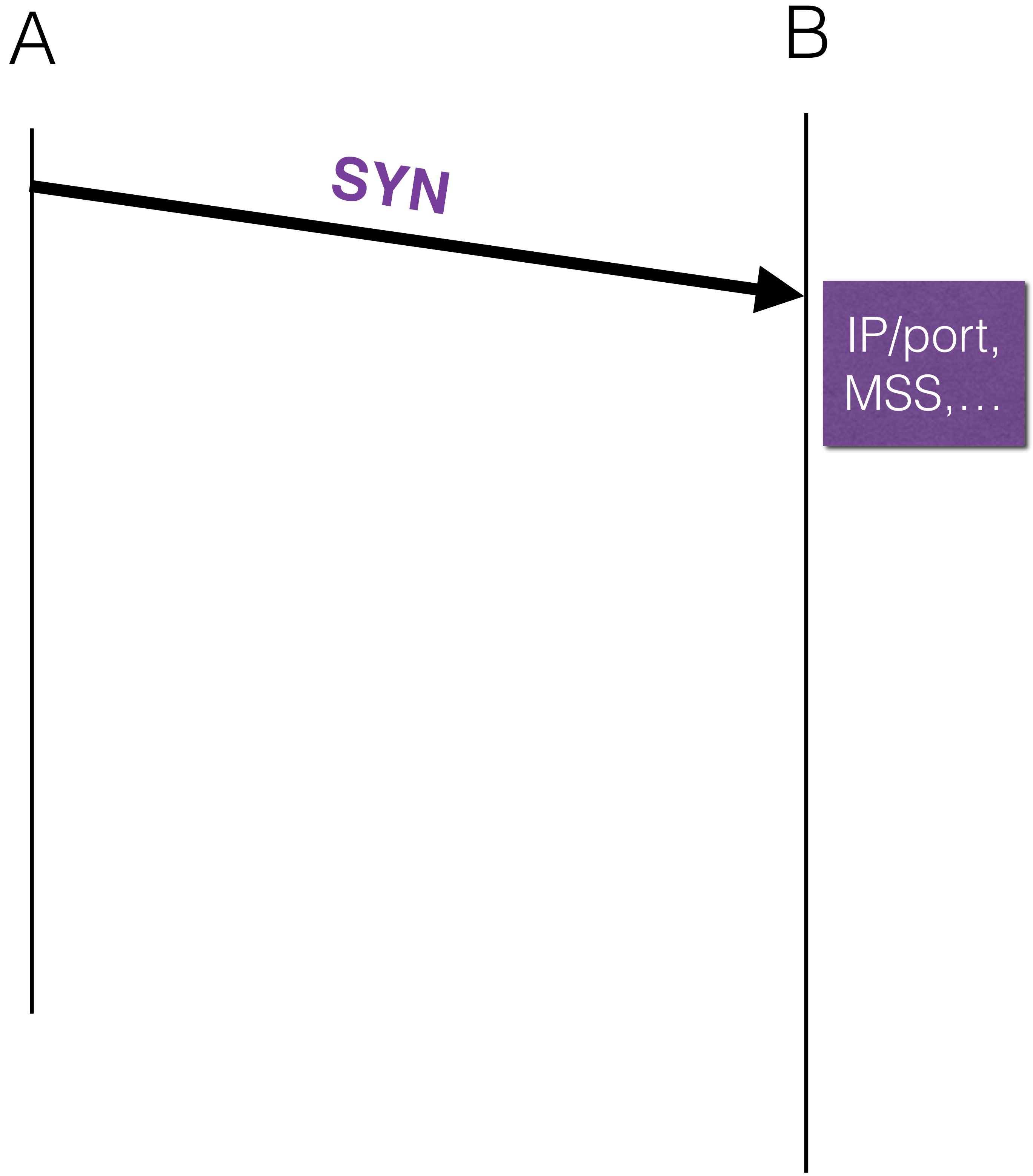

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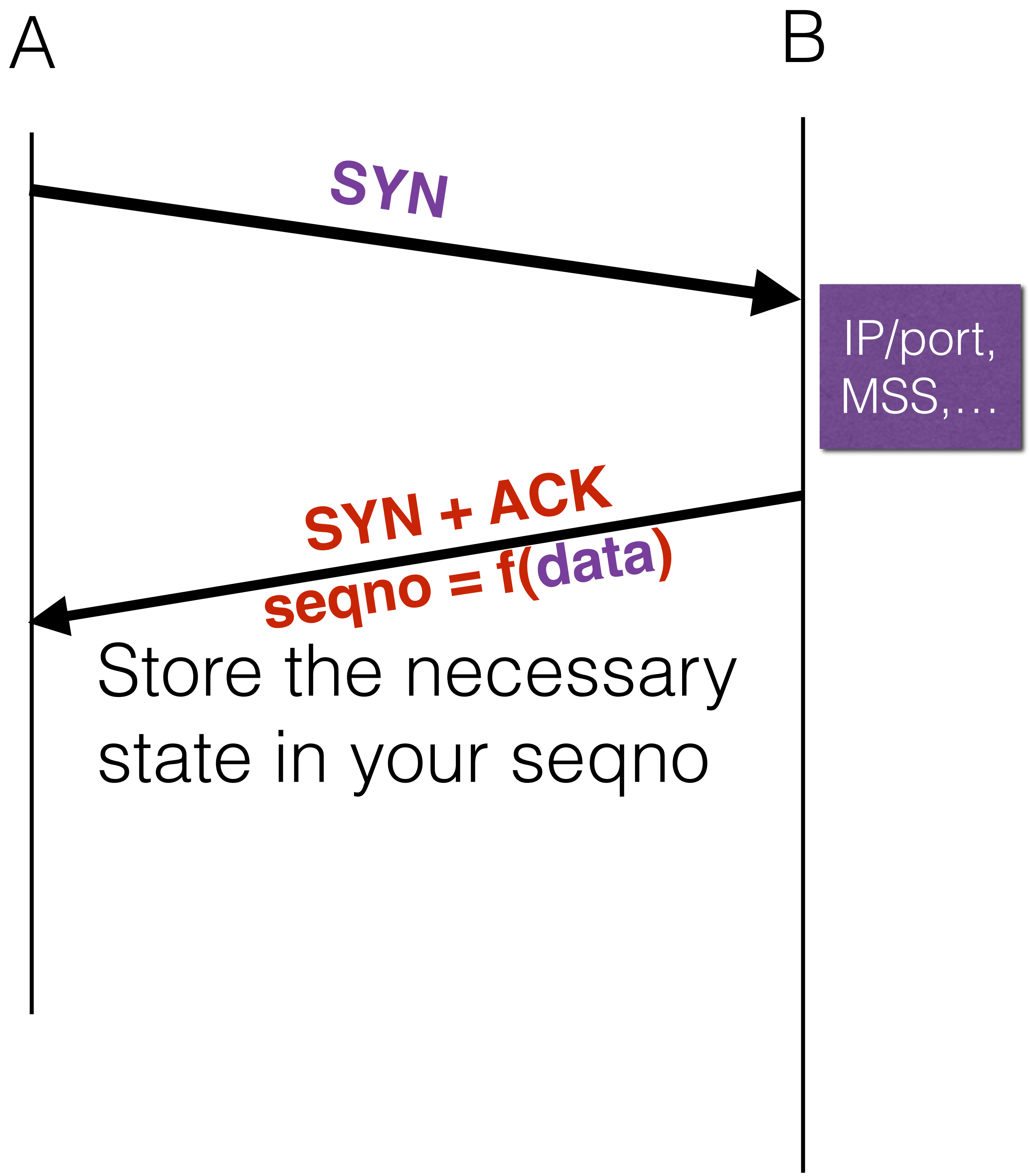

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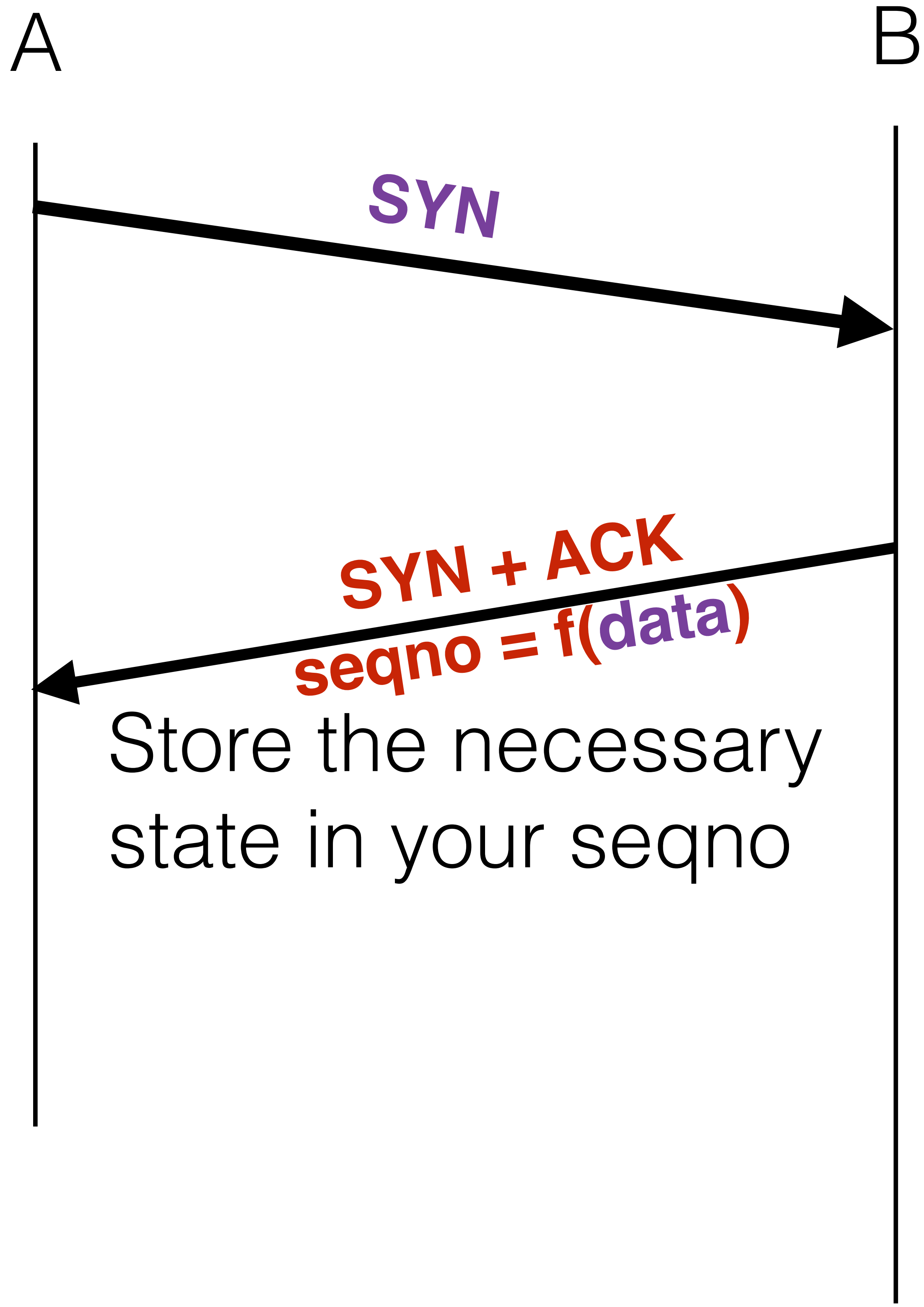

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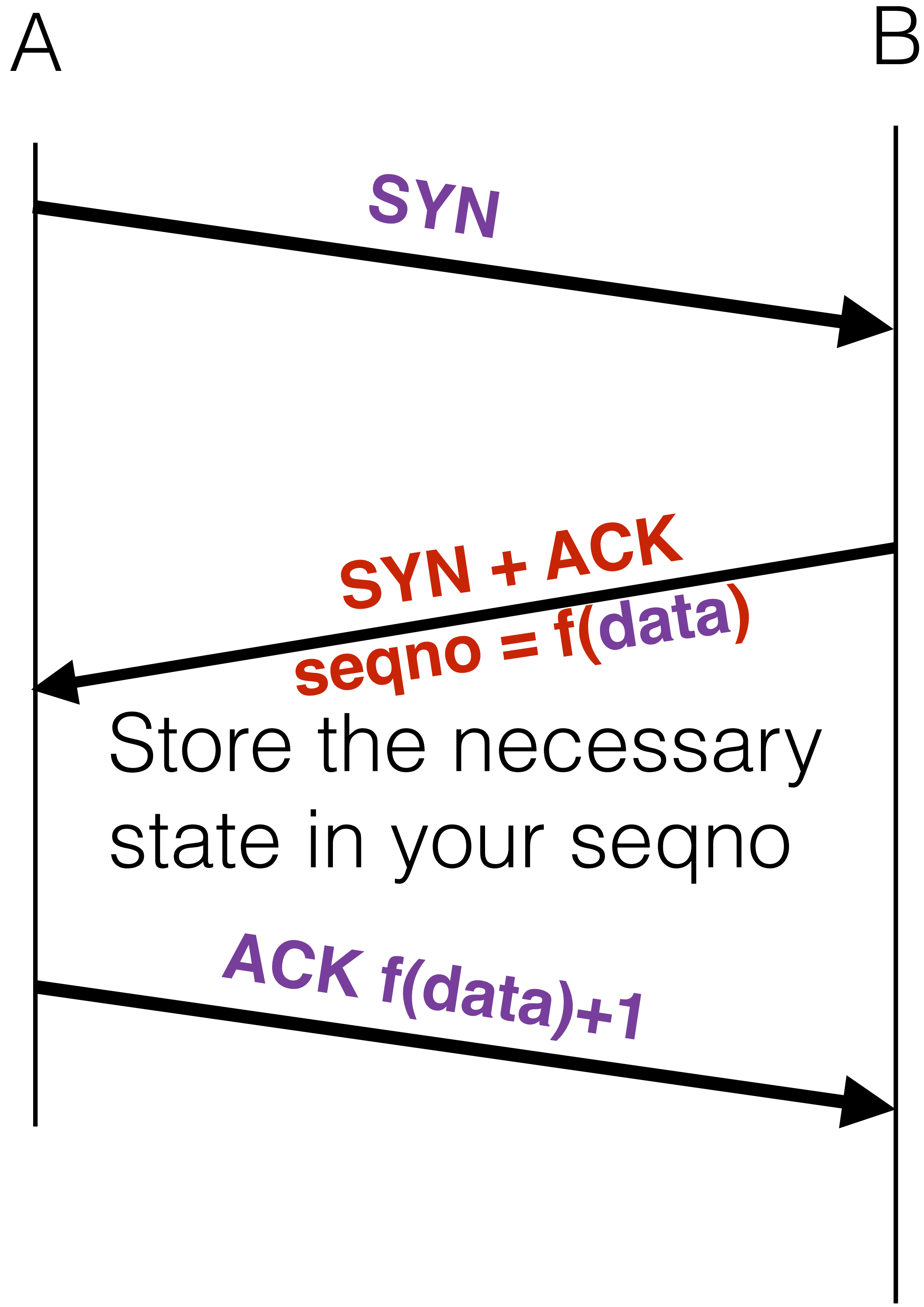

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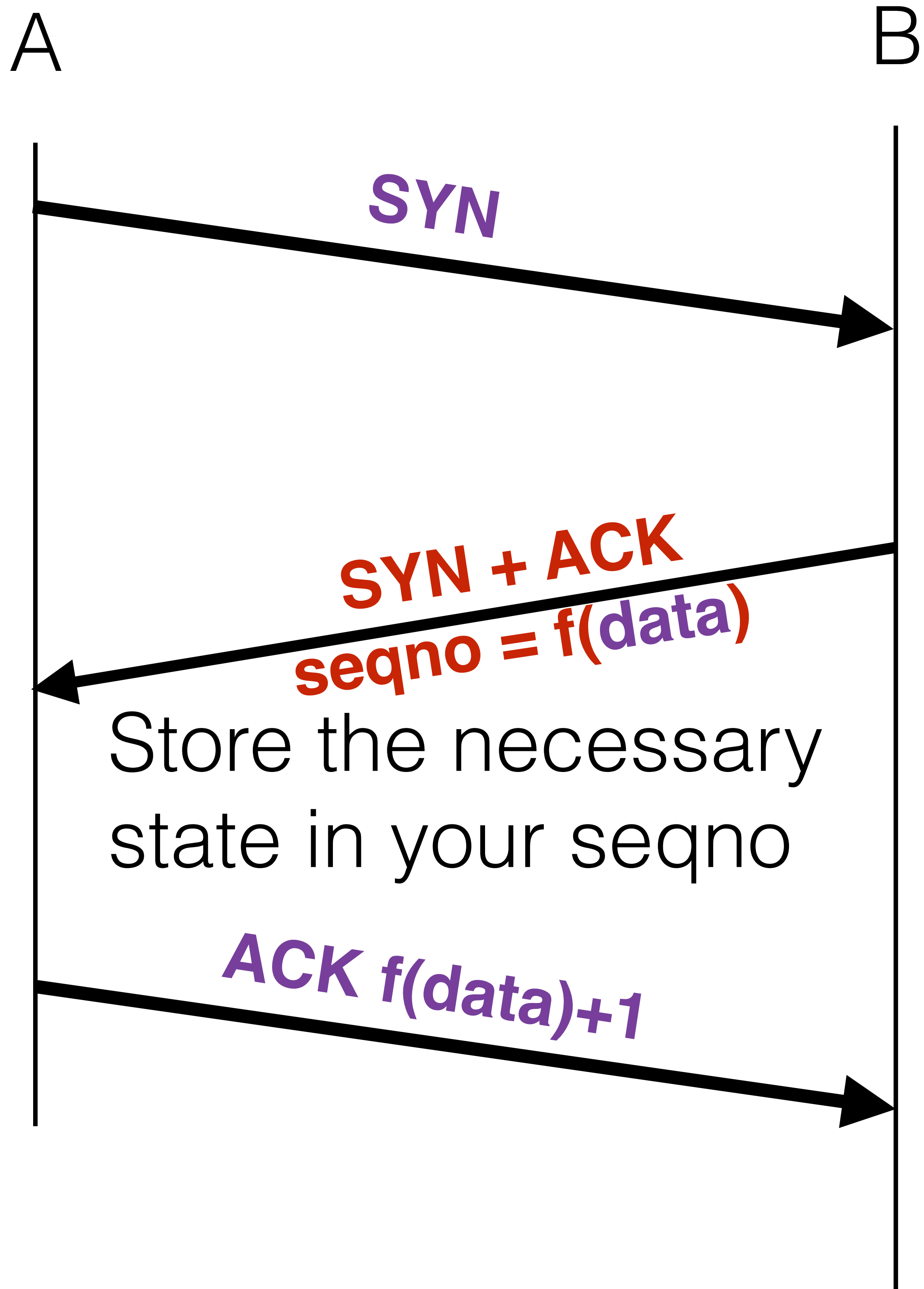

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Check that f(data) is valid for this connection. Only at that point do you allocate state.

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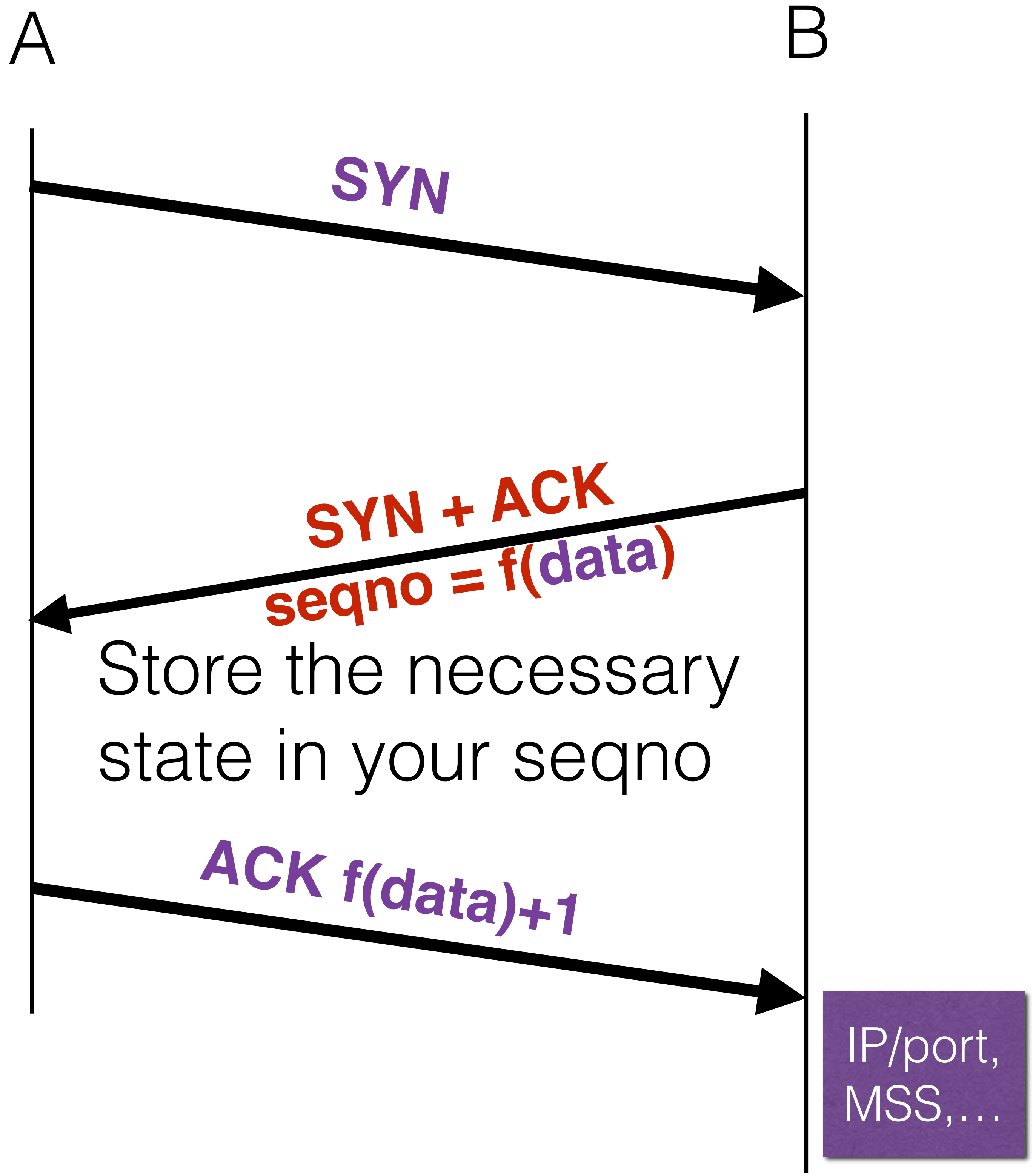

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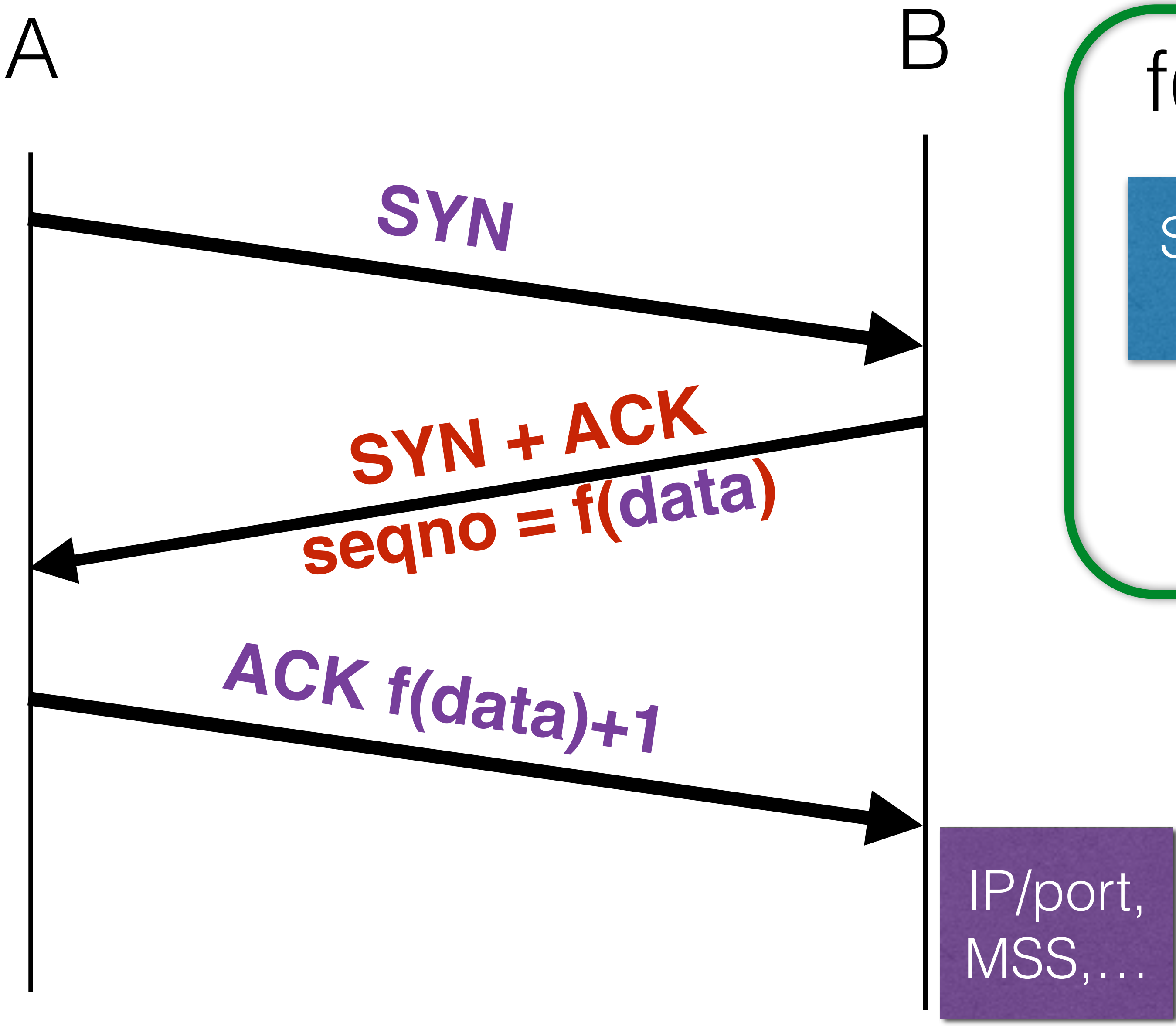
SYN cookie format



f(.) = 32-bit seqno

Slow-moving timestamp	MSS	Secure hash
Prevents replay attacks	The info we need for this connection	Includes: IPs/ports, MSS, timestamp

The secure hash makes it difficult for the attacker to guess what f() will be, and therefore the attacker cannot guess a correct ACK if he spoofs.

Injection attacks

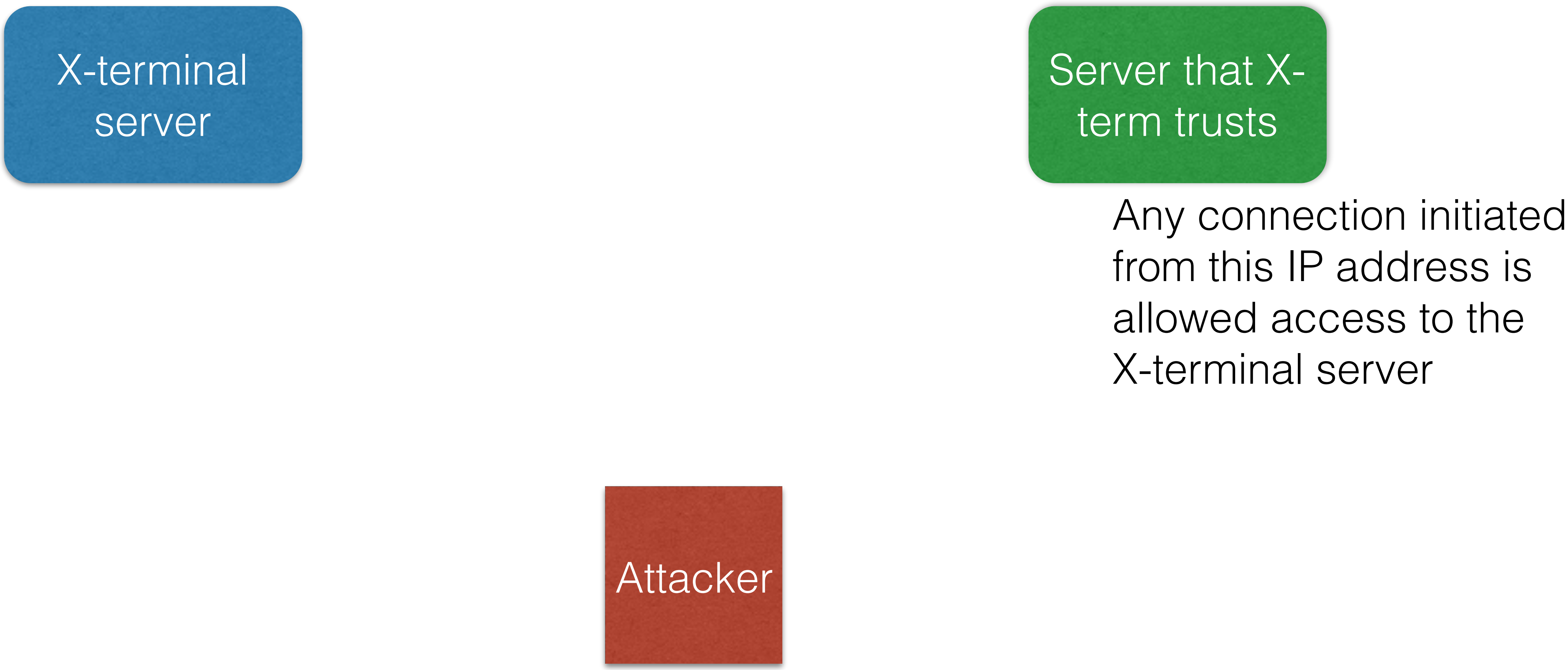
- Suppose you are on the path between src and dst; what can you do?
  - Trivial to inject packets with the correct sequence number

- What if you are not on the path?
  - Need to guess the sequence number
  - Is this difficult to do?

Initial sequence numbers

- Initial sequence numbers used to be deterministic
- What havoc can we wreak?
    - Send RSTs
    - Inject data packets into an existing connection (TCP veto attacks)
    - *Initiate and use an entire connection without ever hearing the other end*

Mitnick attack



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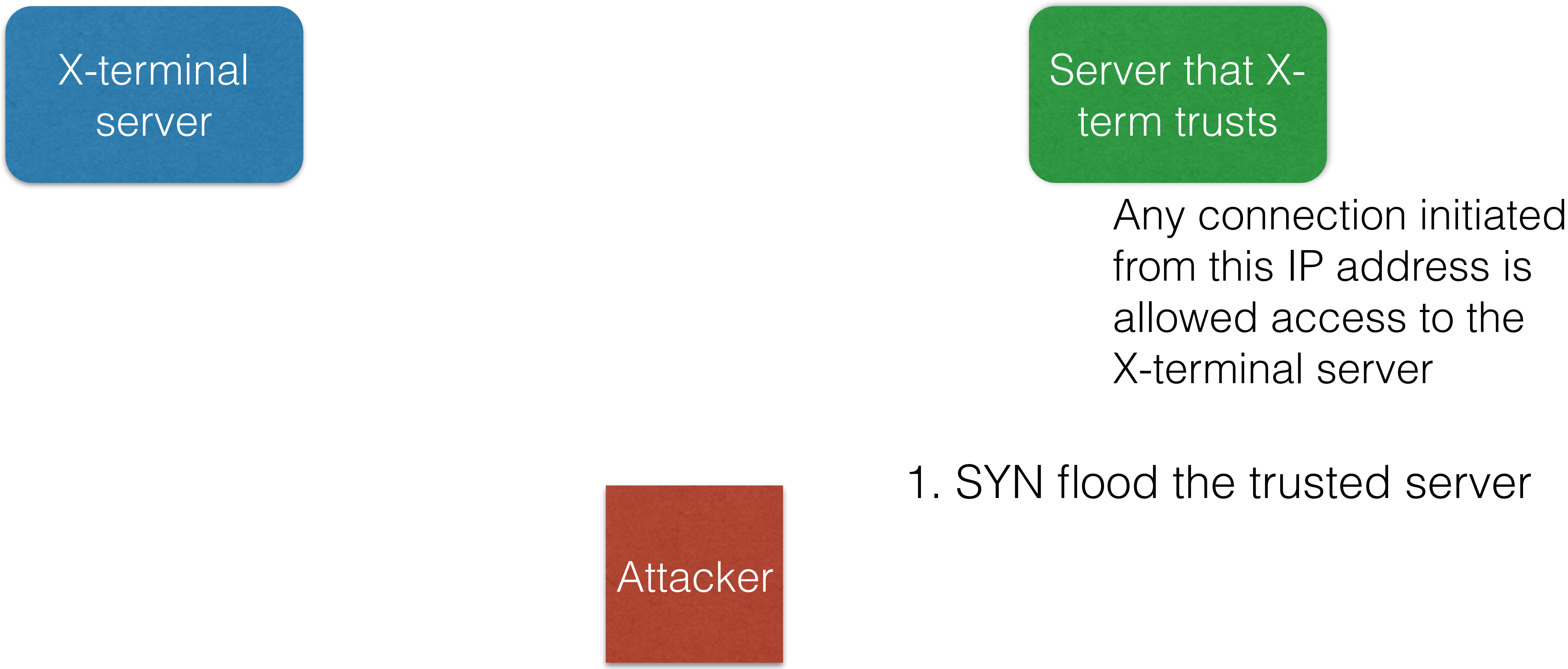

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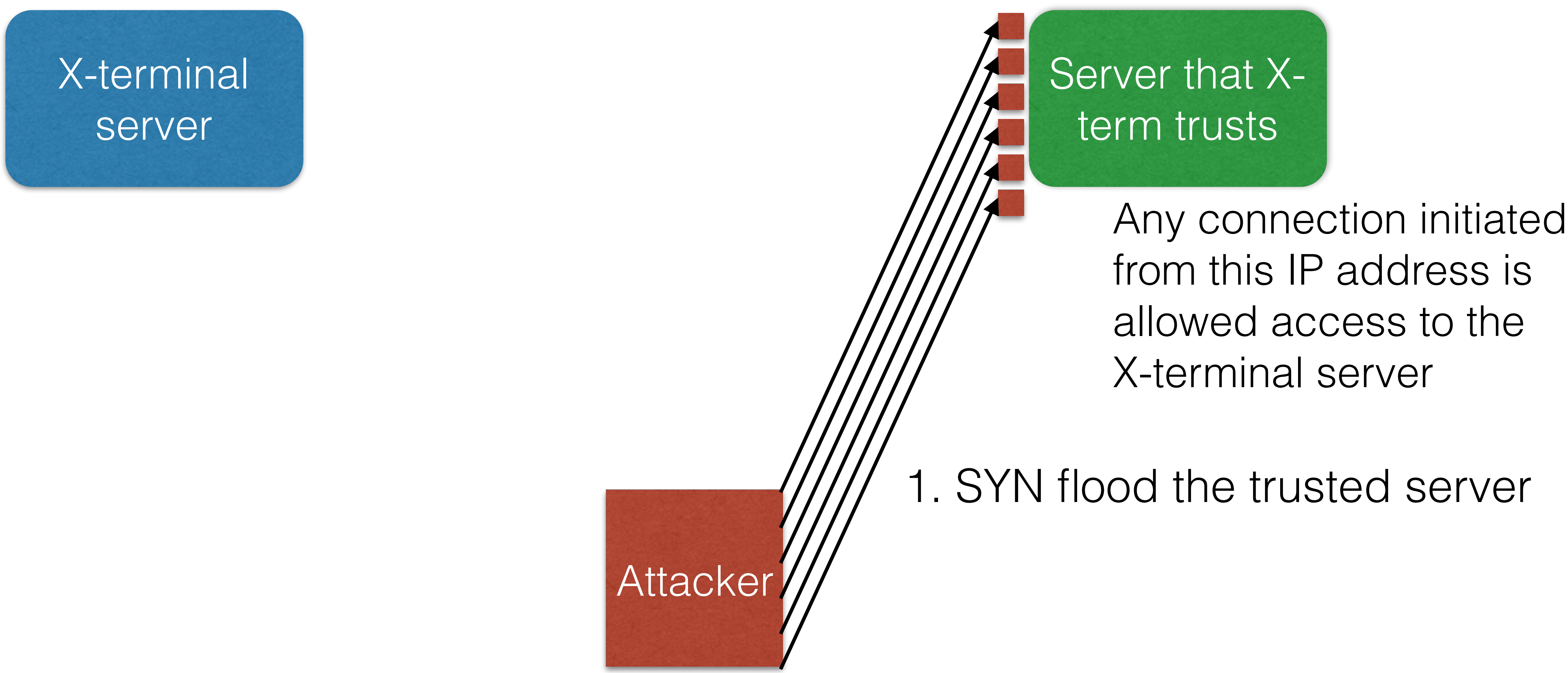

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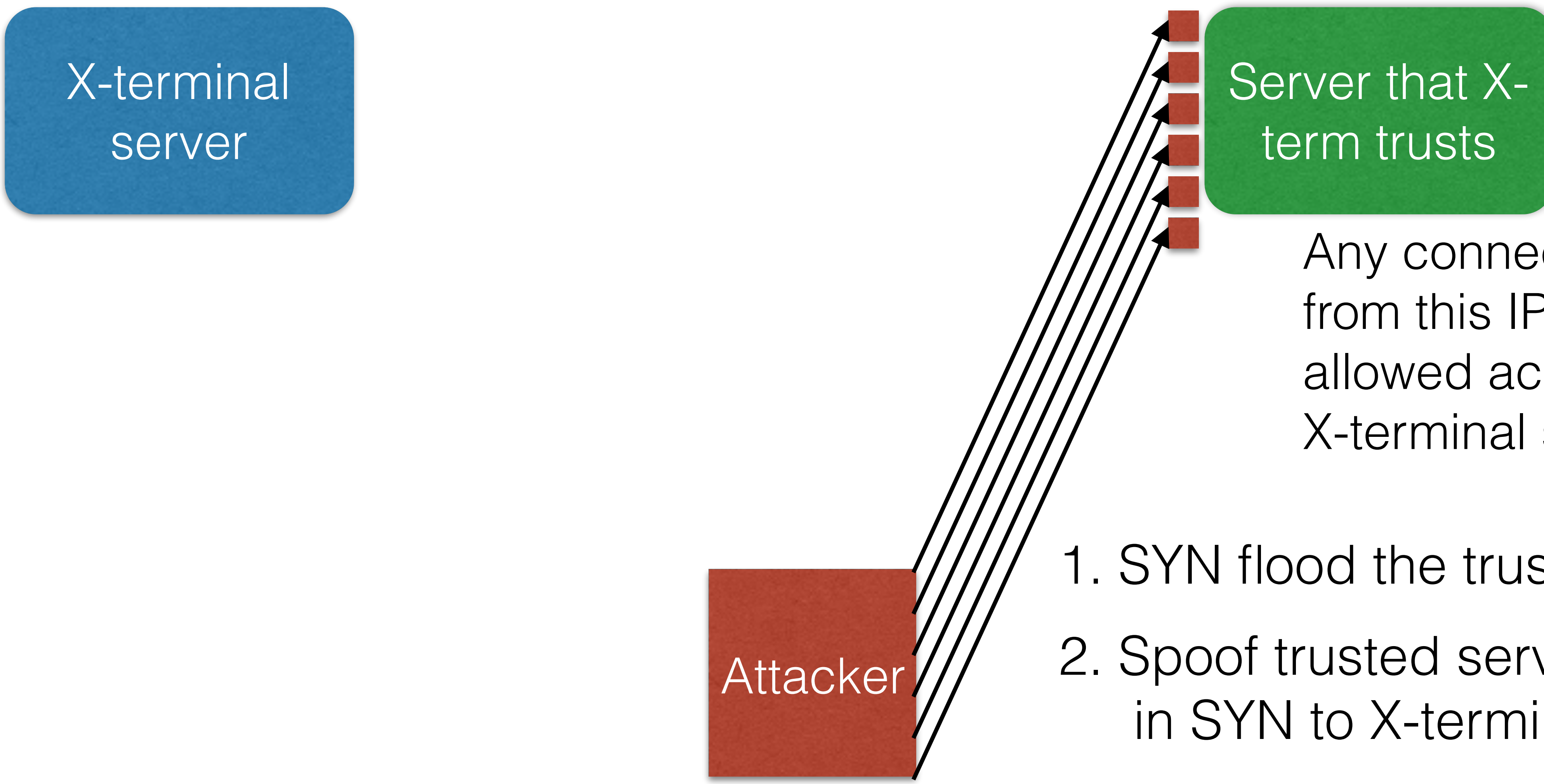

Any connection initiated from this IP address is allowed access to the X-terminal server

1. SYN flood the trusted server
2. Spoof trusted server's IP addr in SYN to X-terminal

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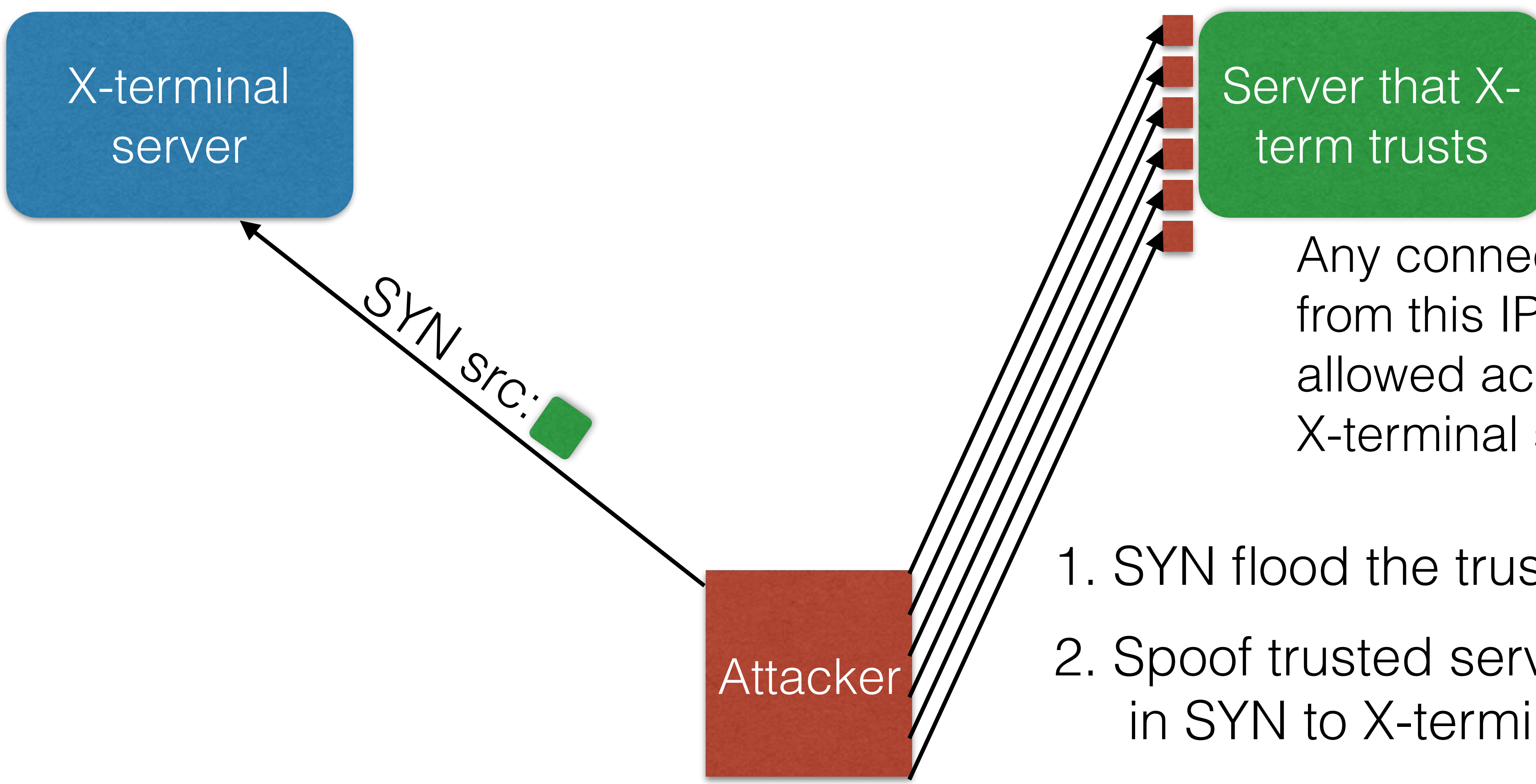

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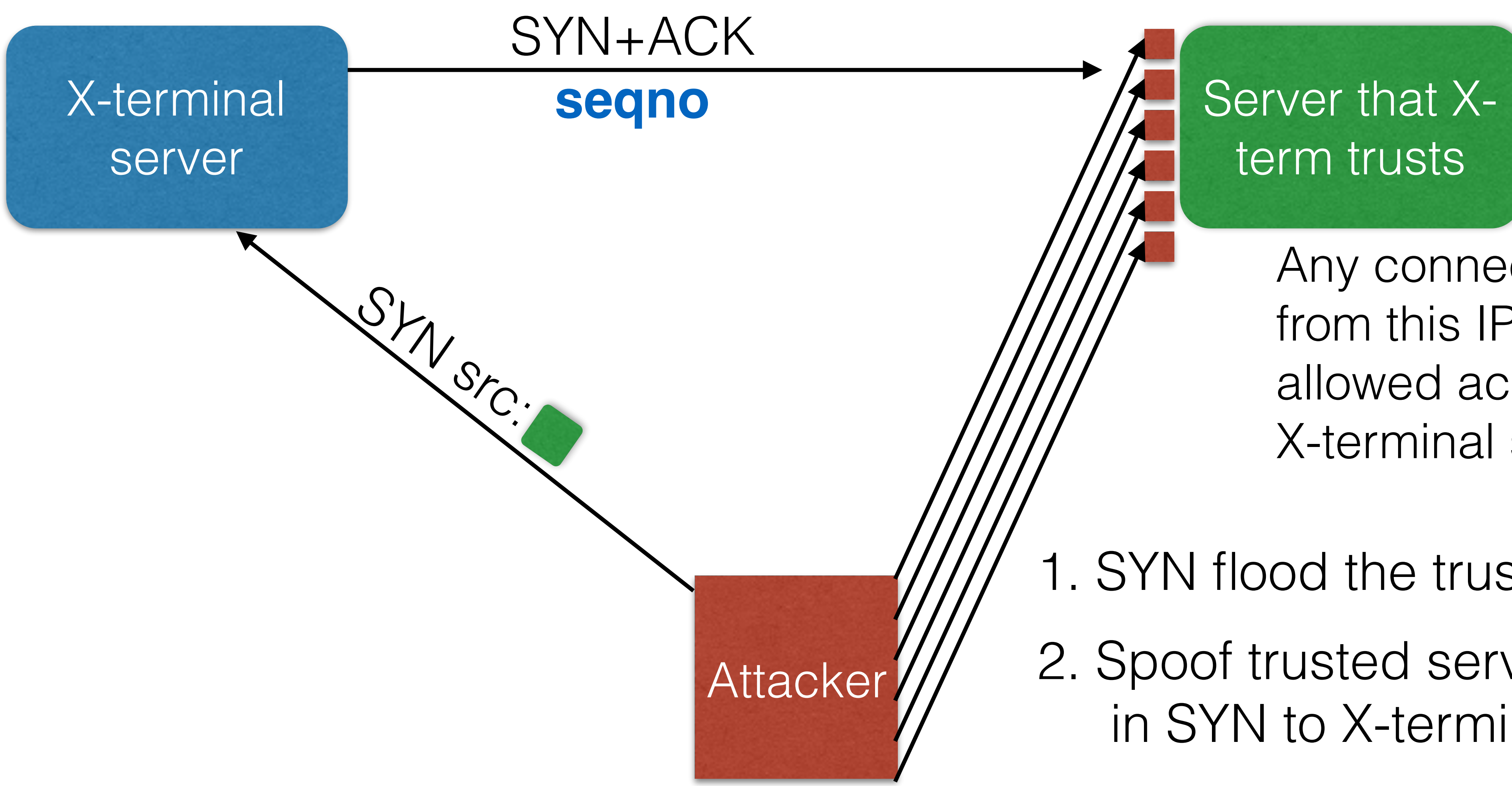

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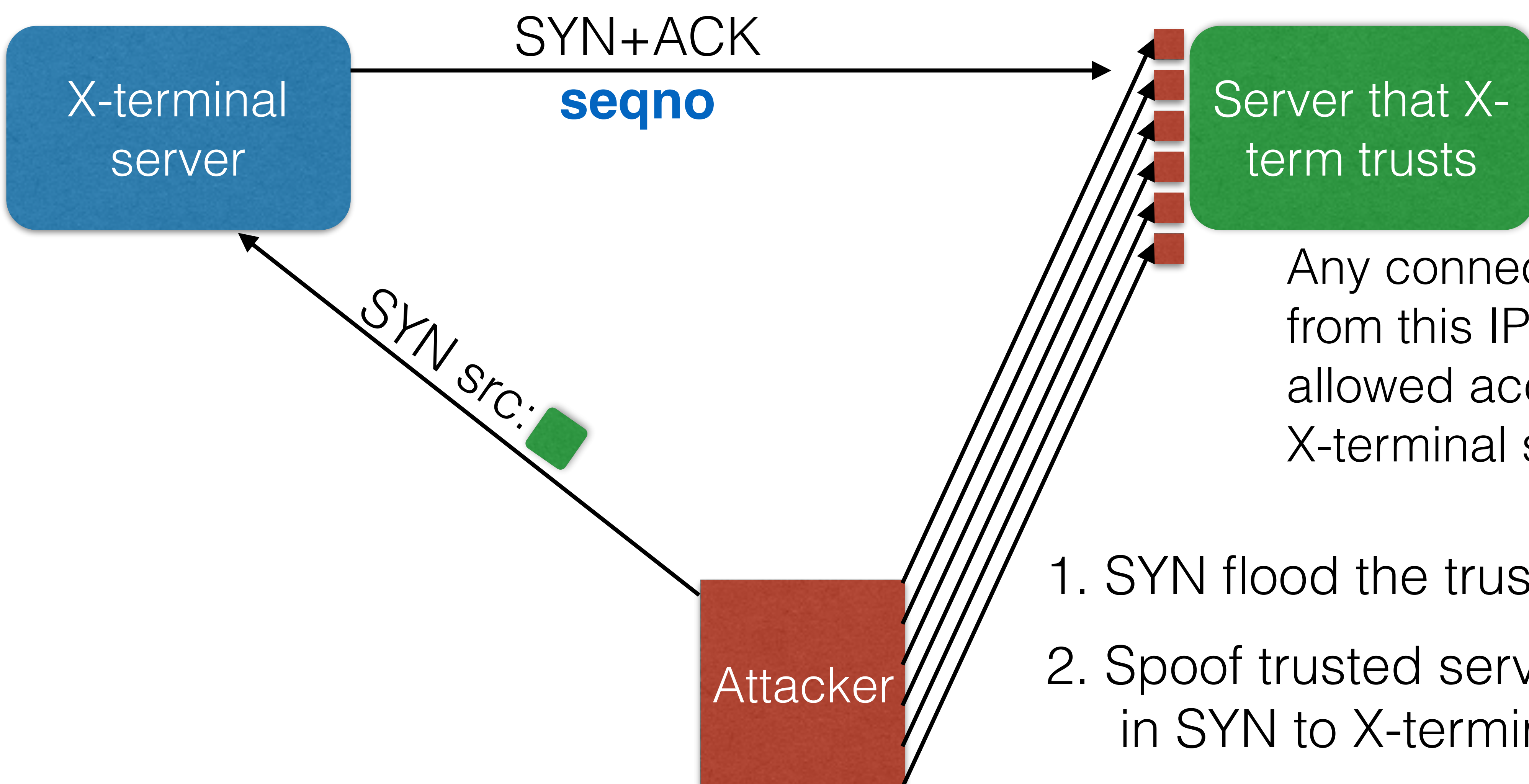

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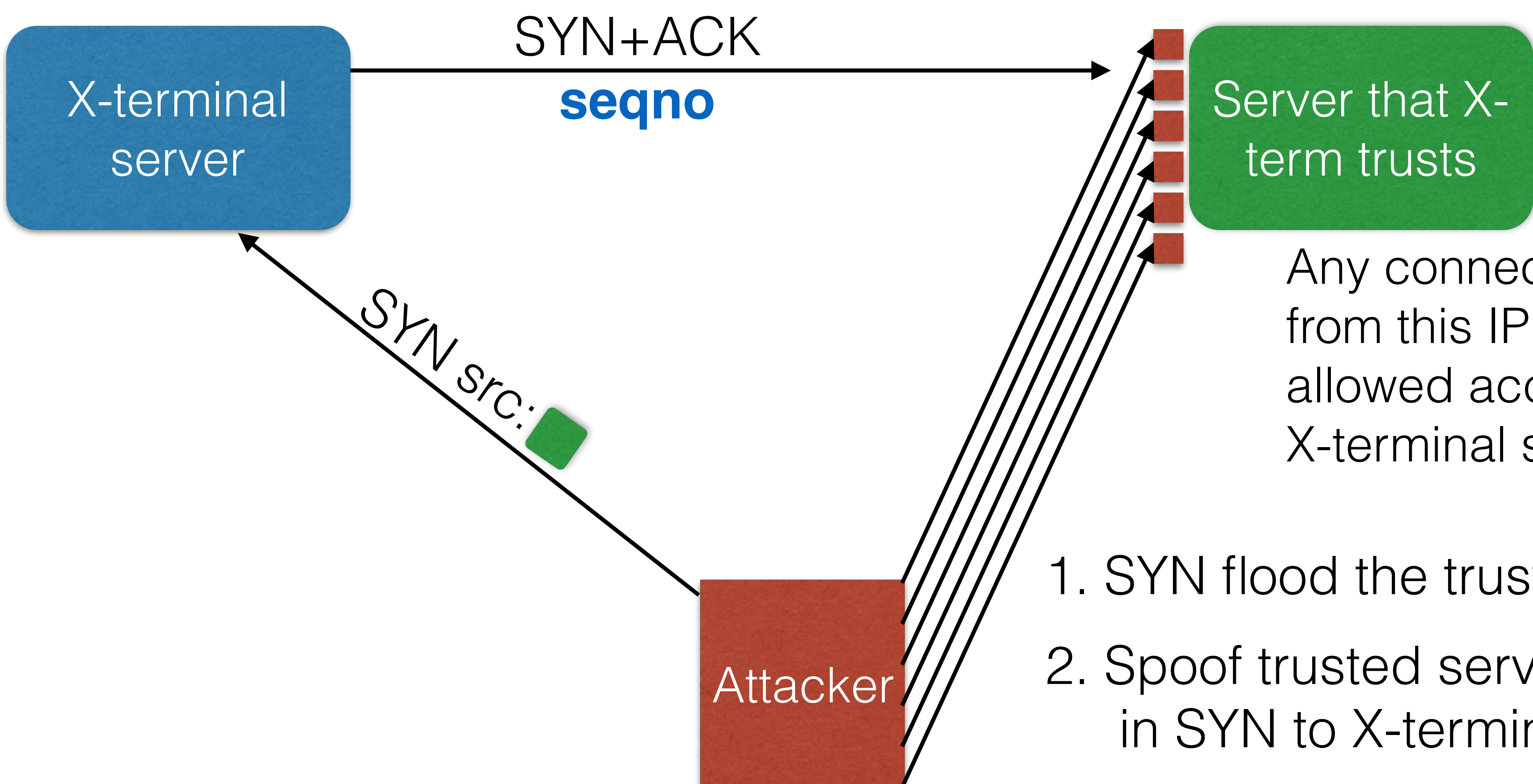

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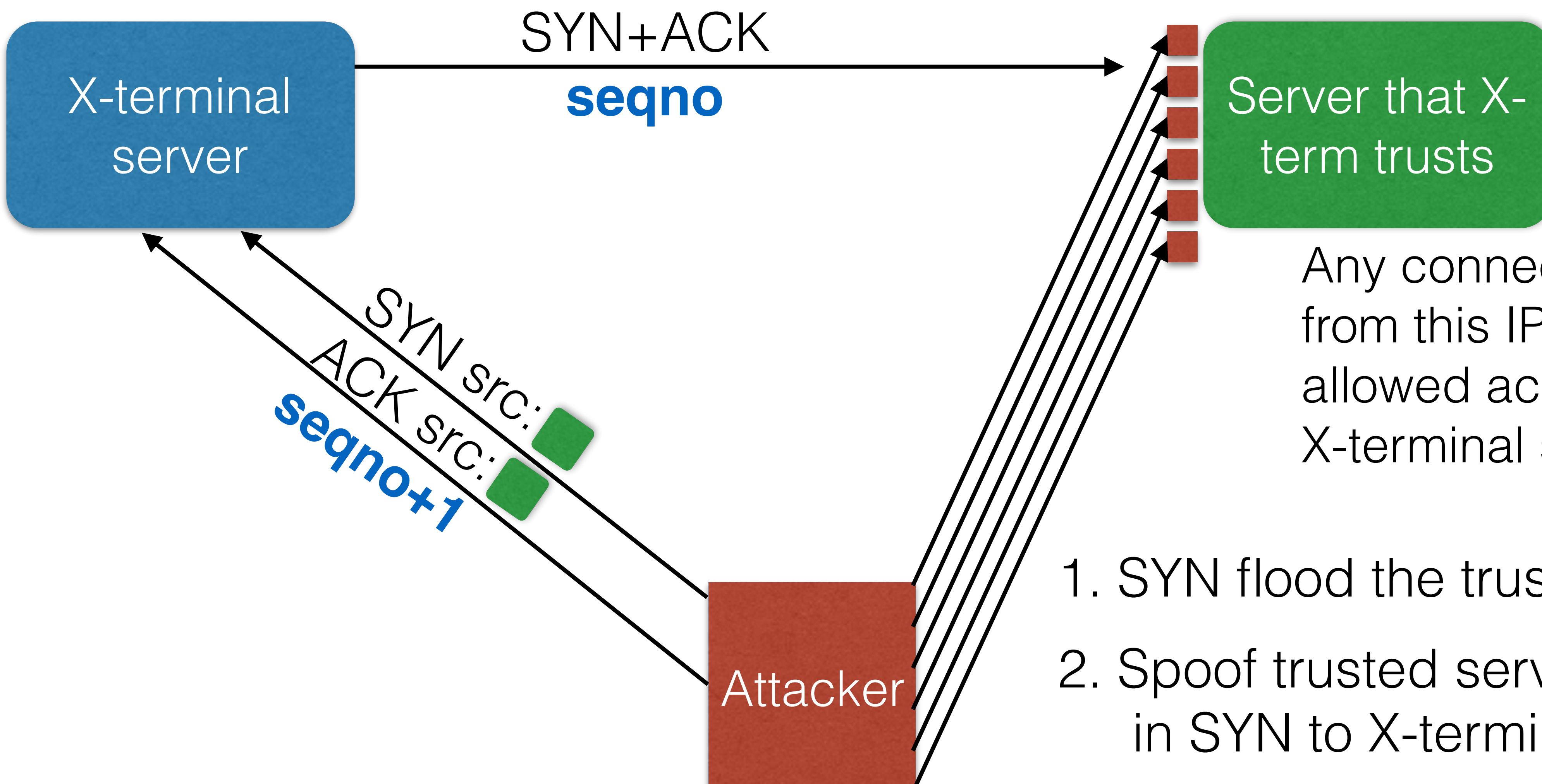

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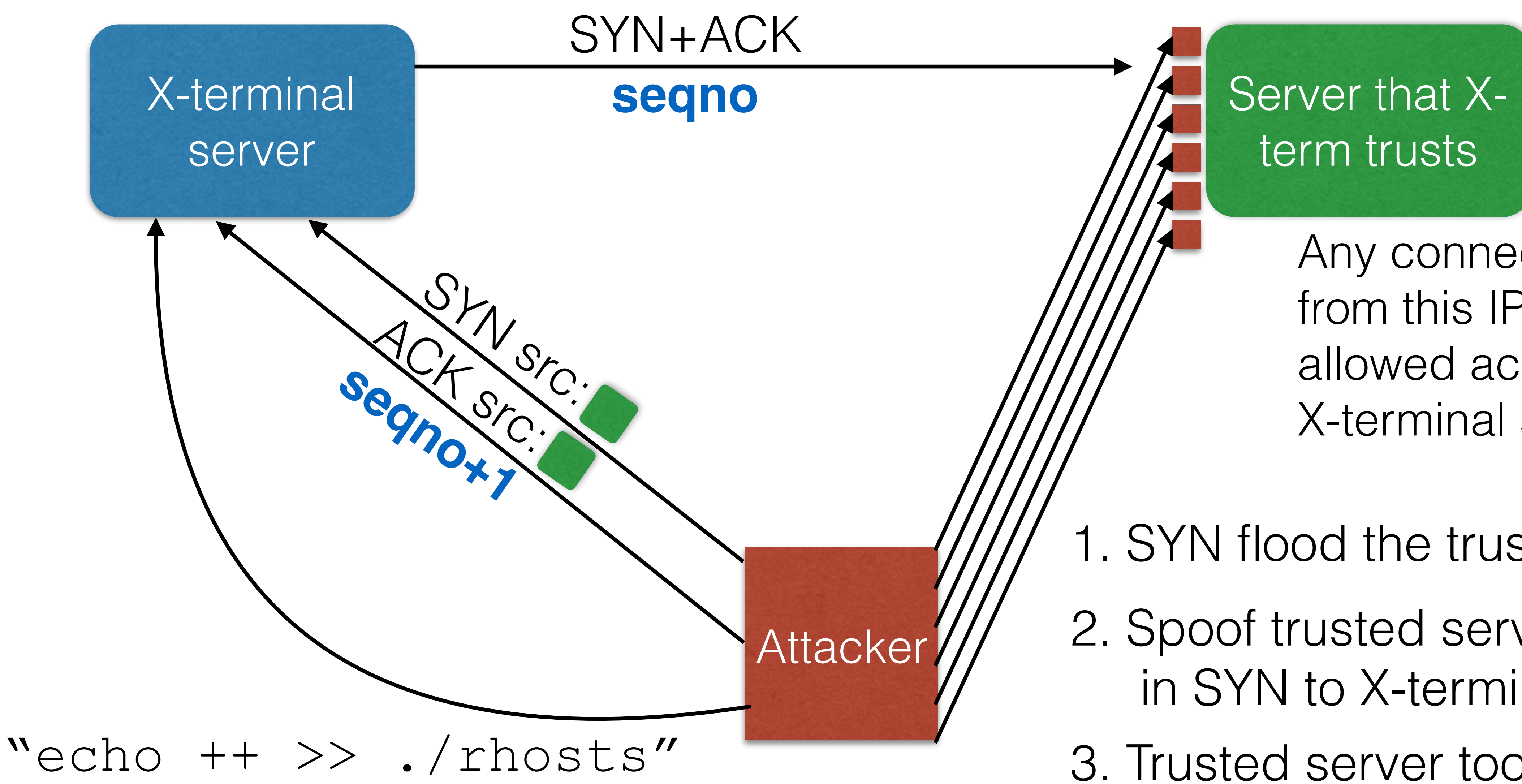

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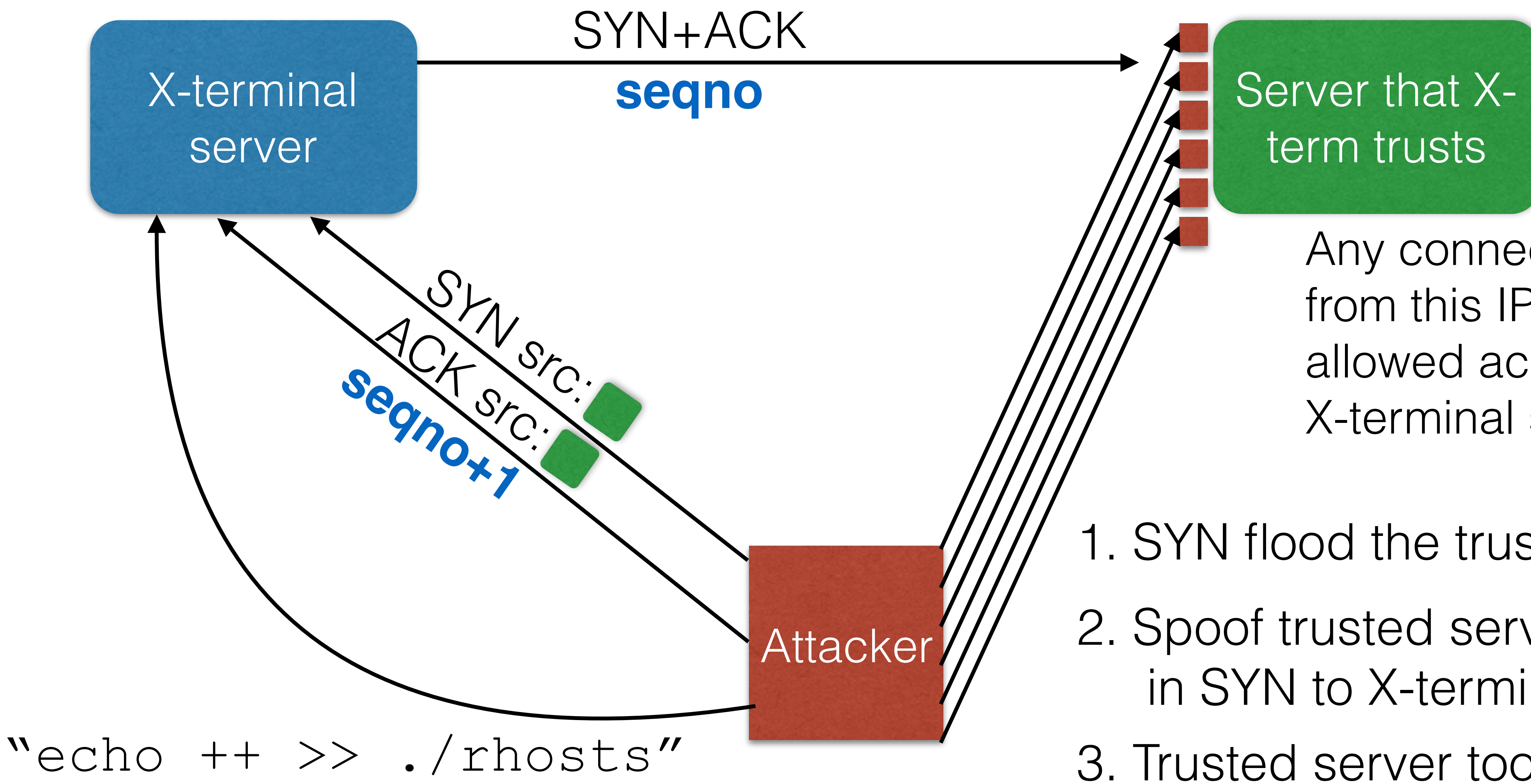

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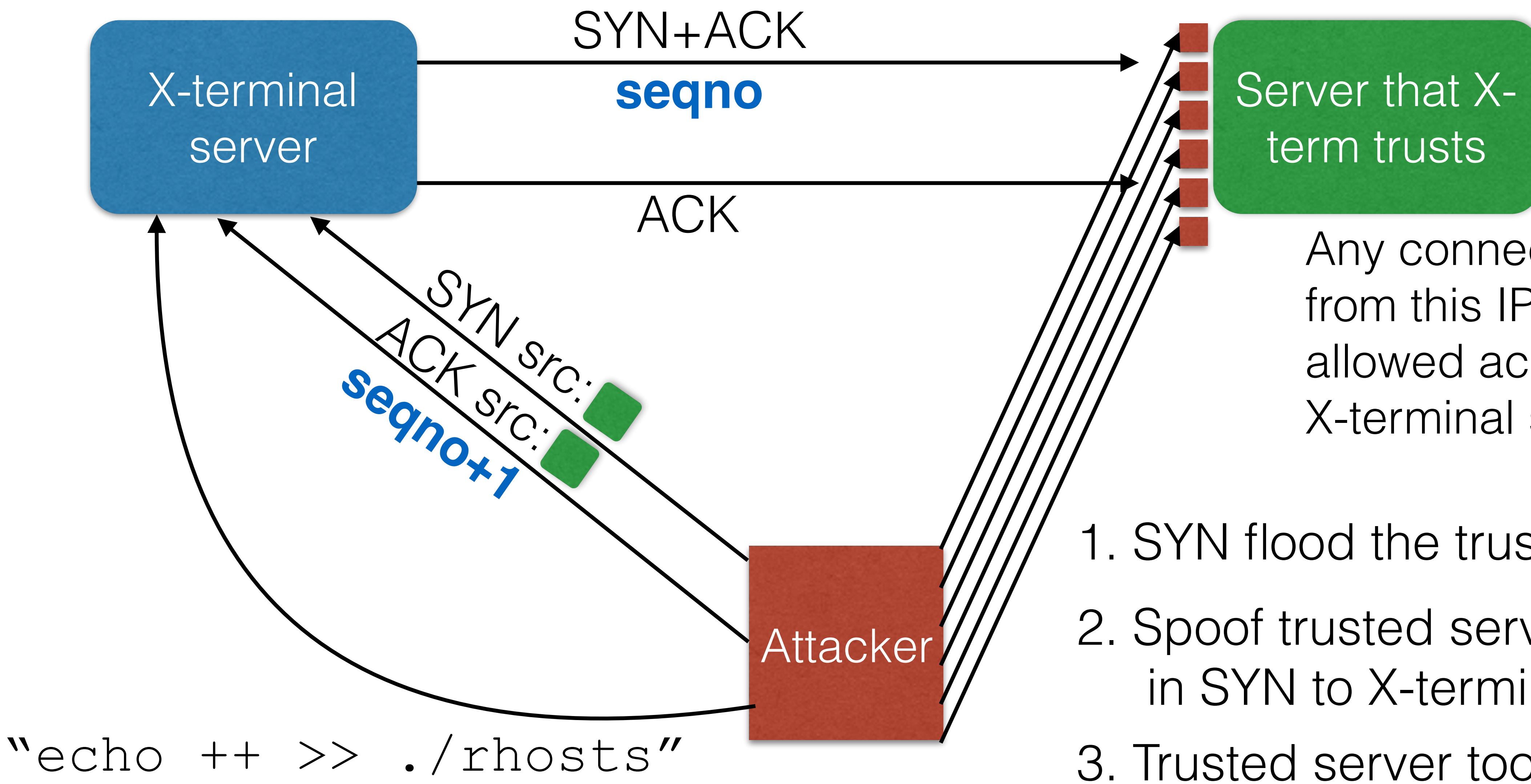

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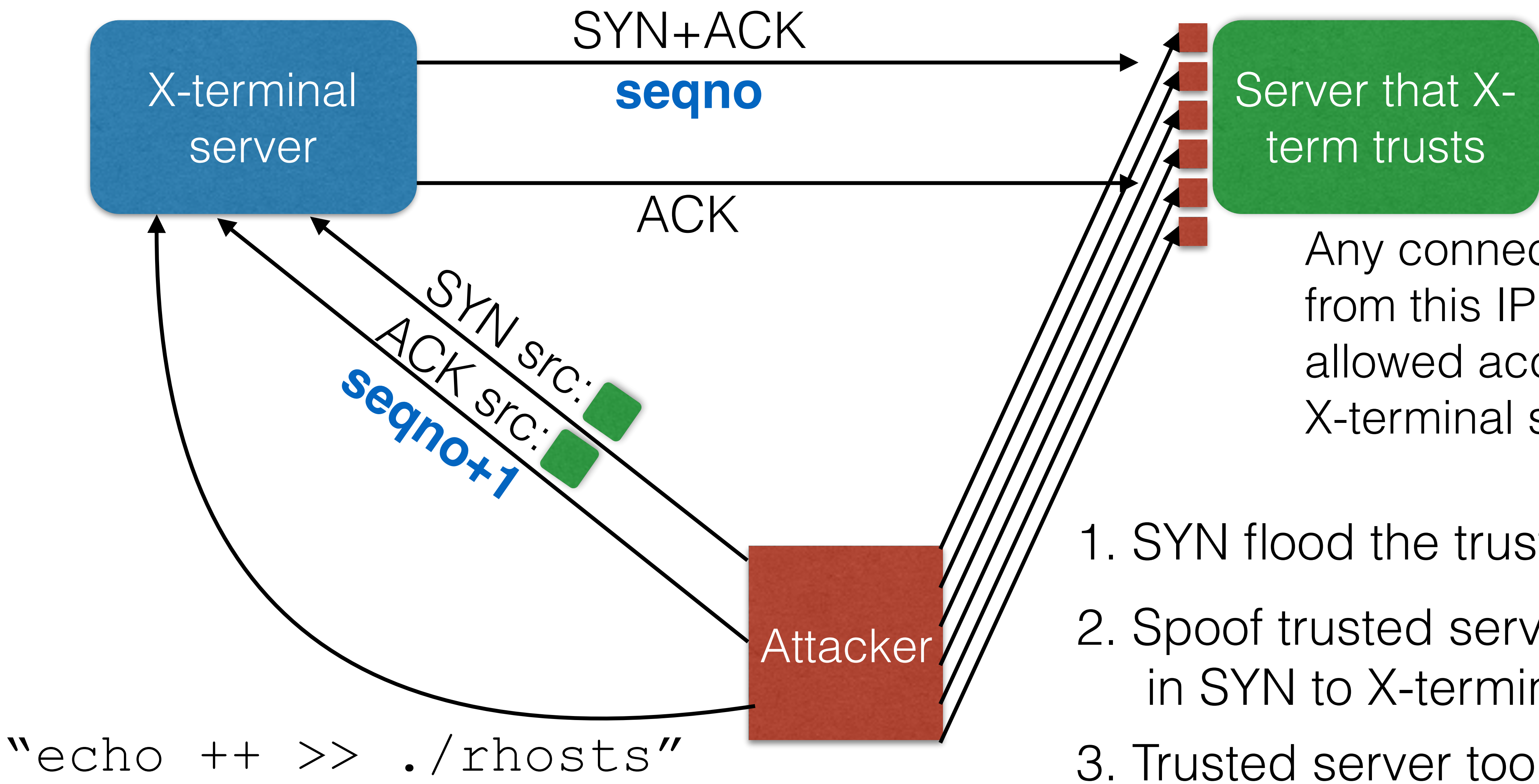

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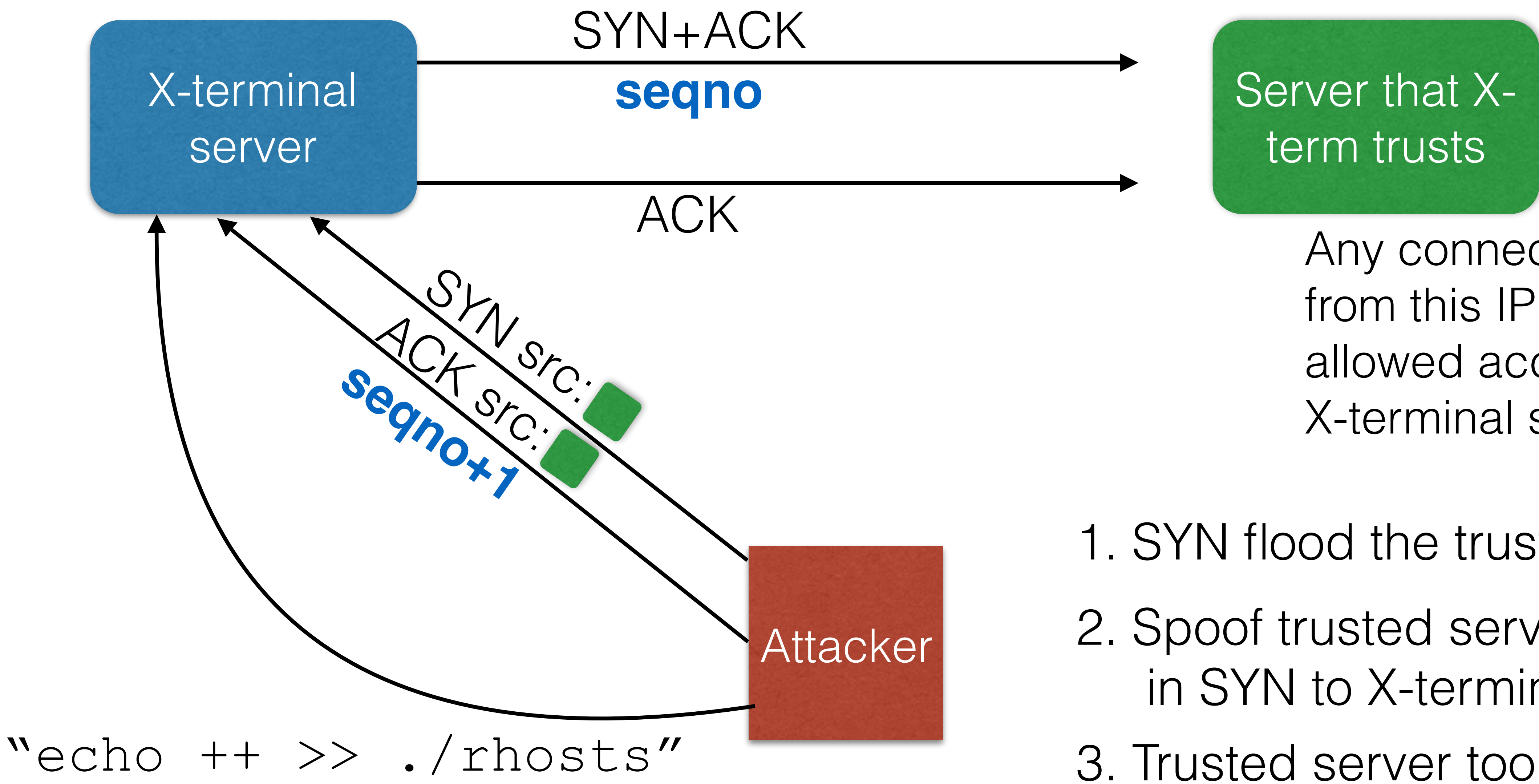

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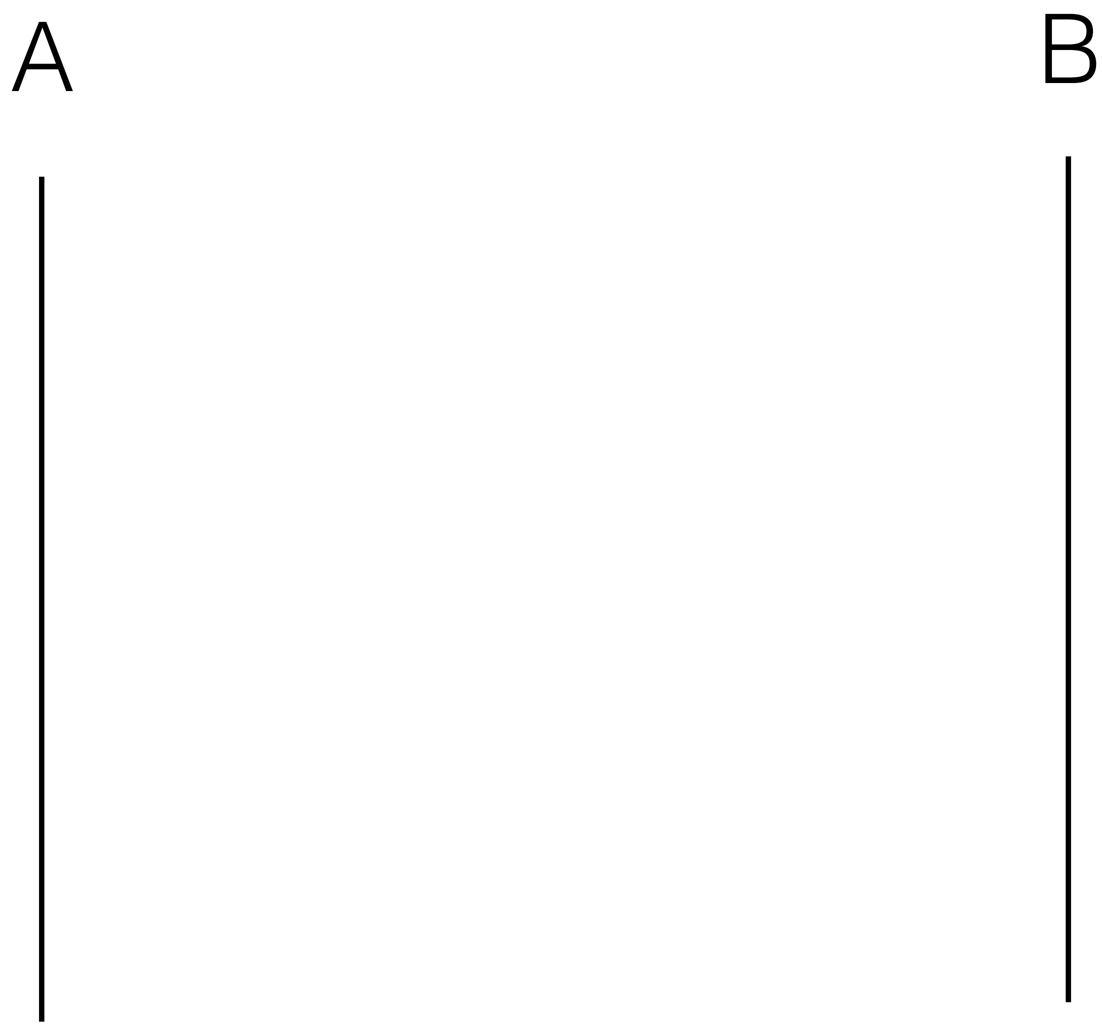
Defenses

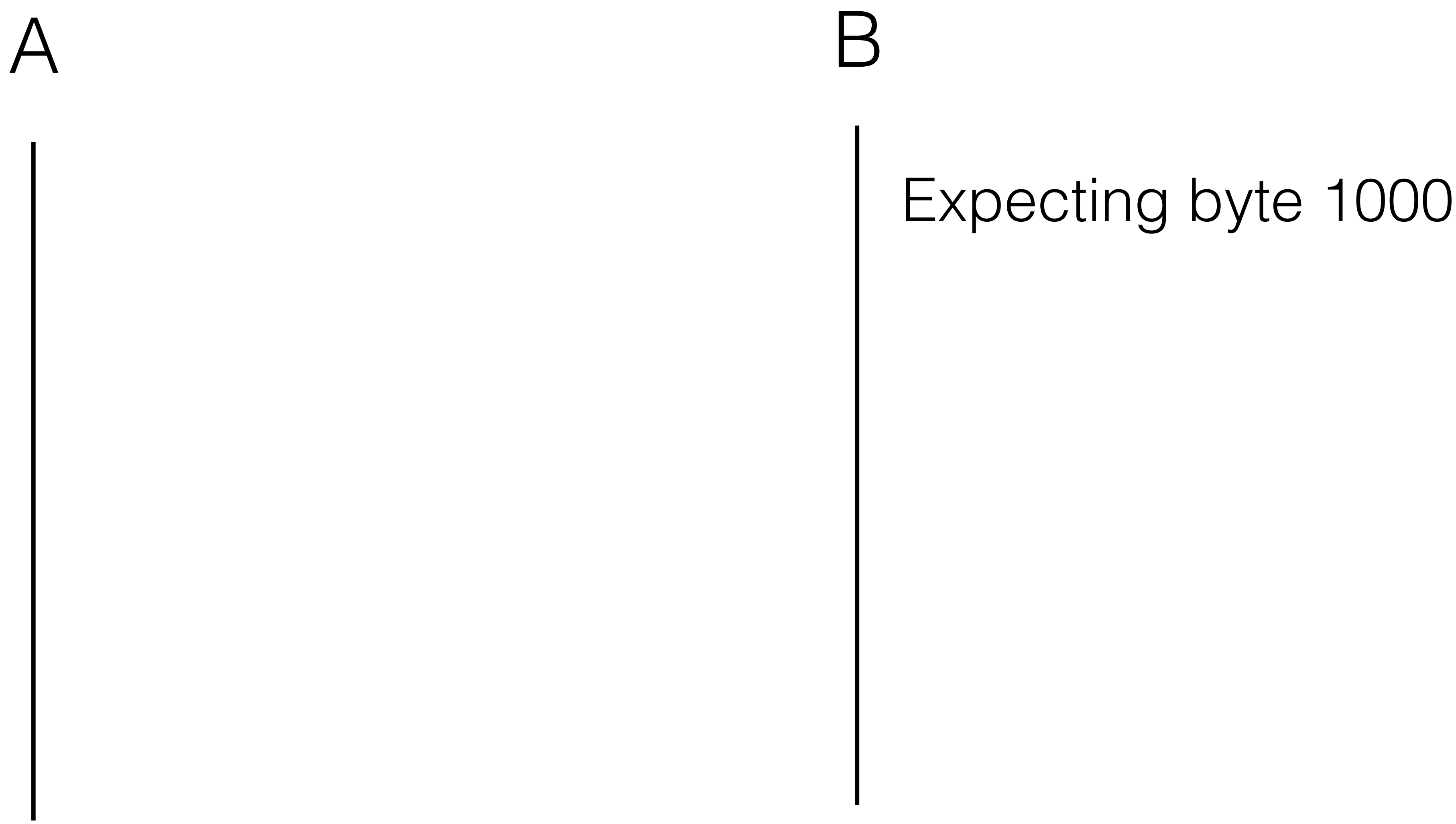
- Initial sequence number must be difficult to predict!

Opt-ack attack



TCP uses ACKs not only for reliability, but also for **congestion control:** the more ACKs come back, the faster I can send

Opt-ack attack



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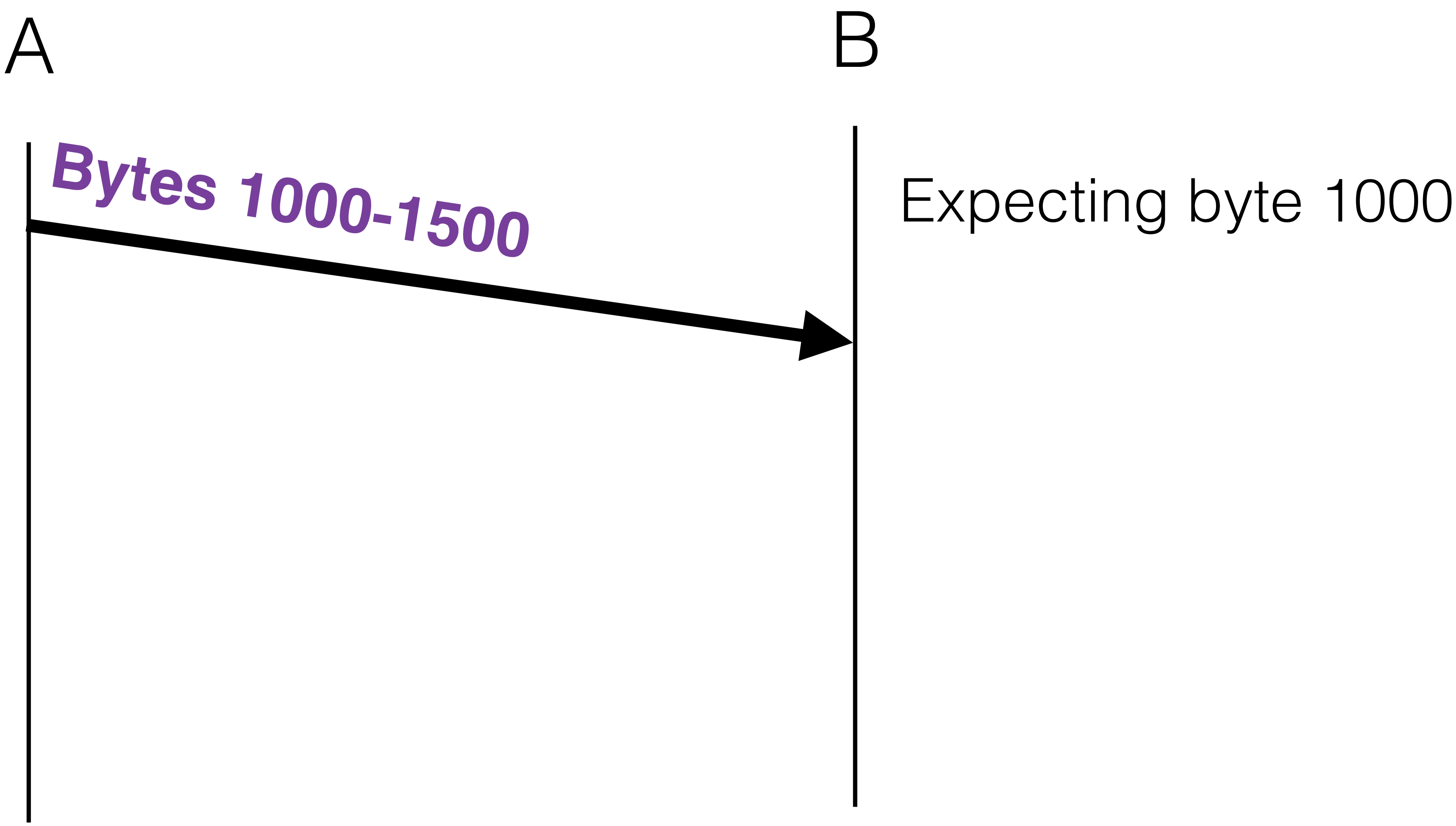

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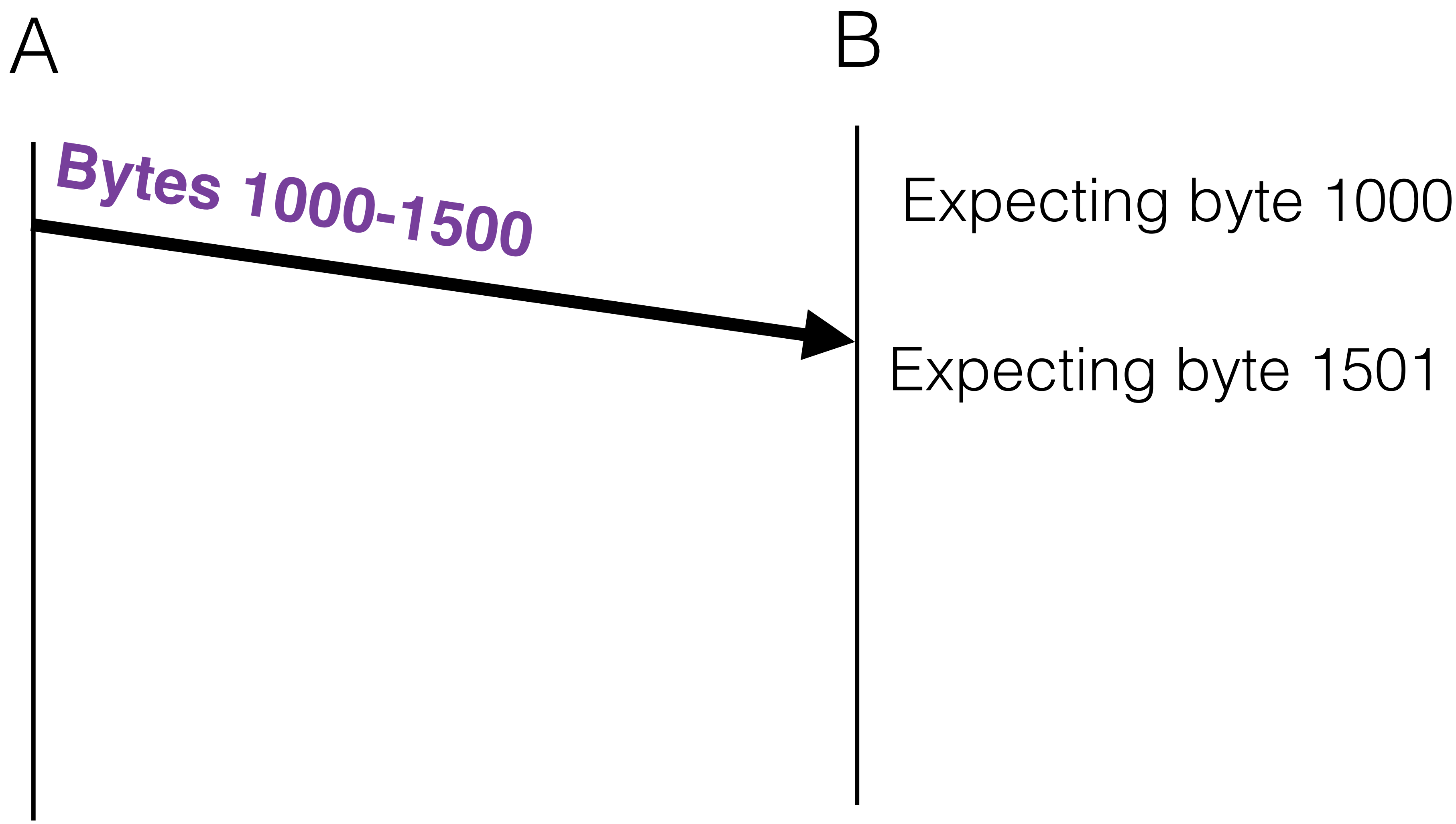

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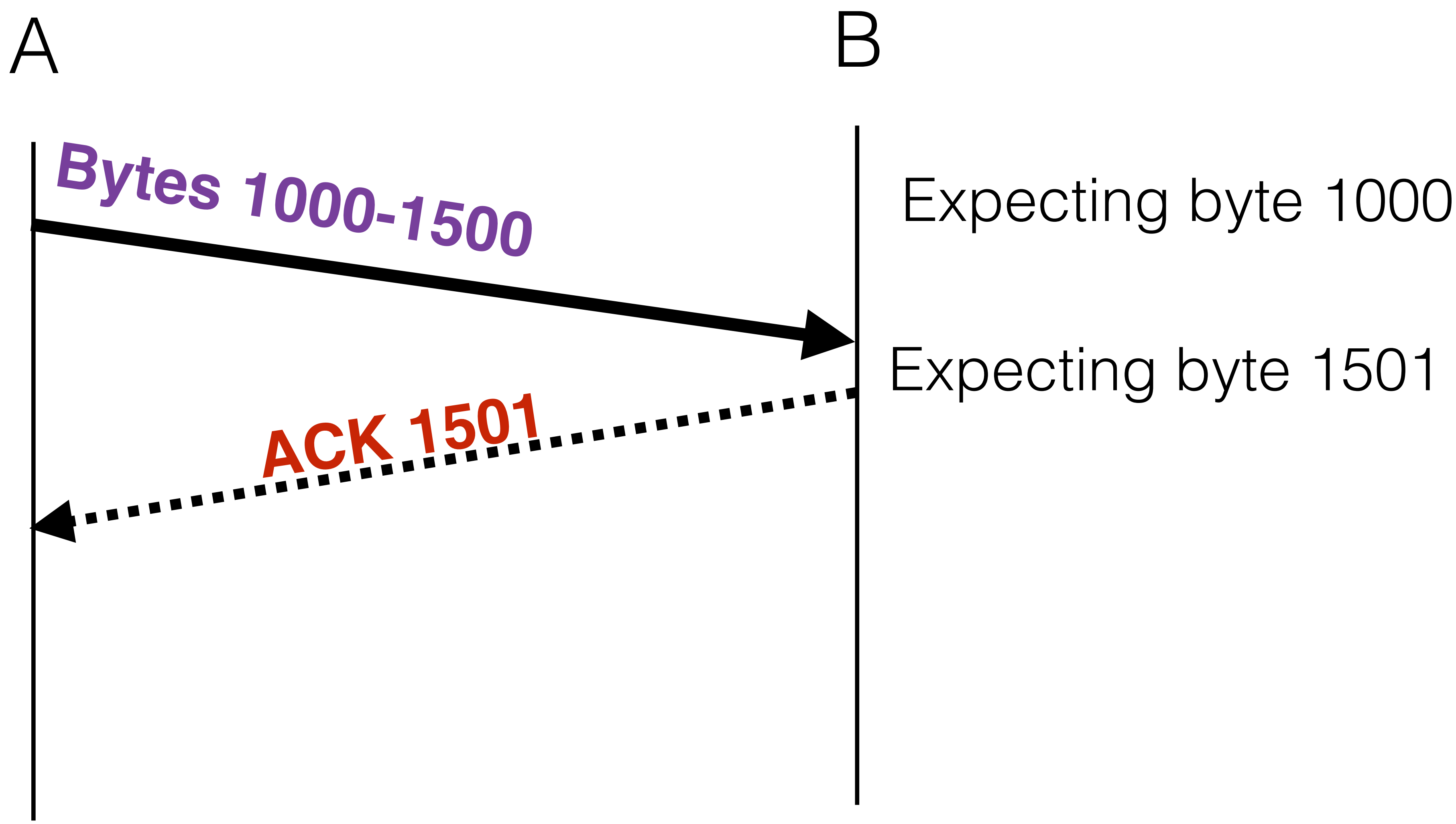

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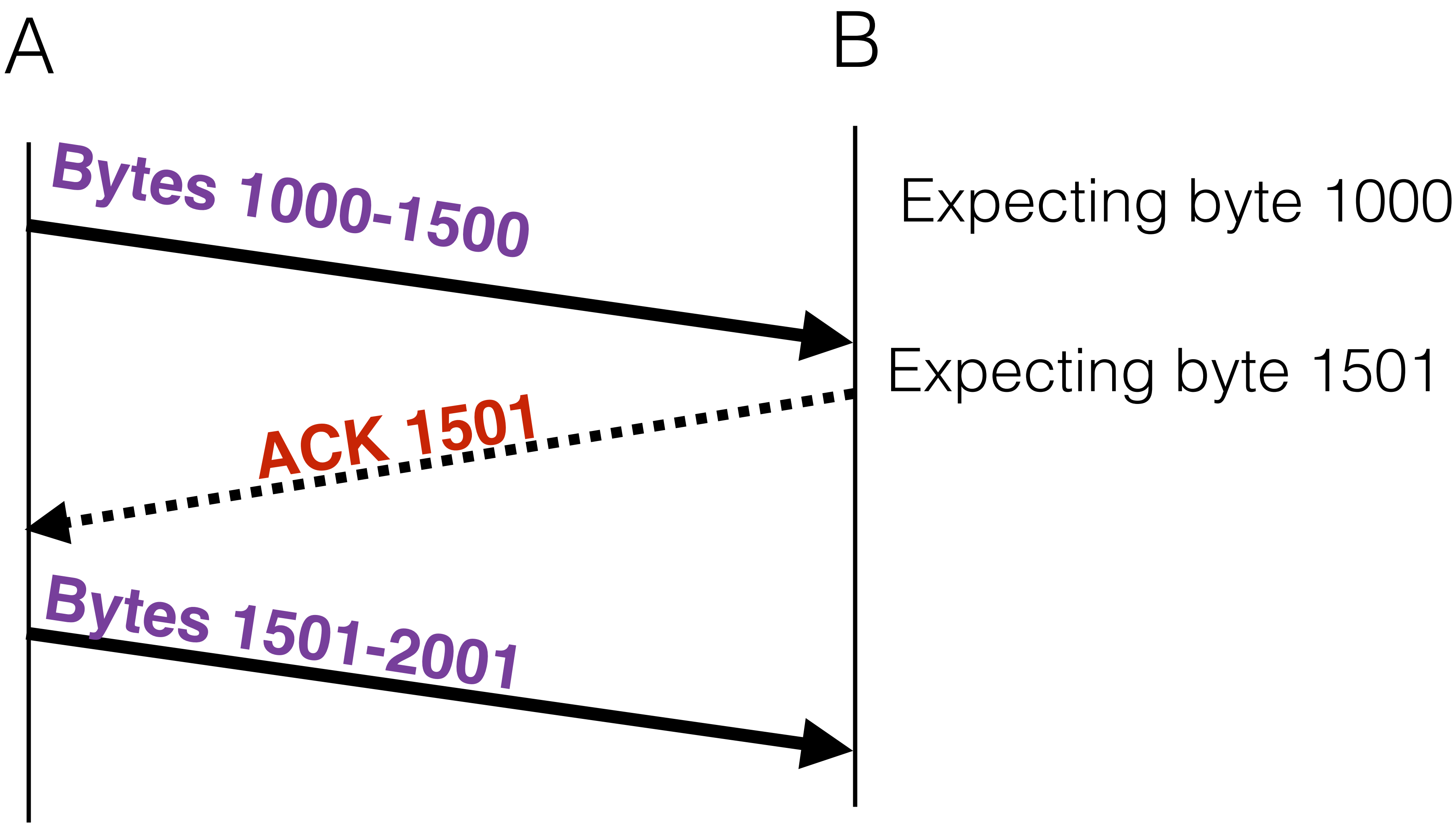

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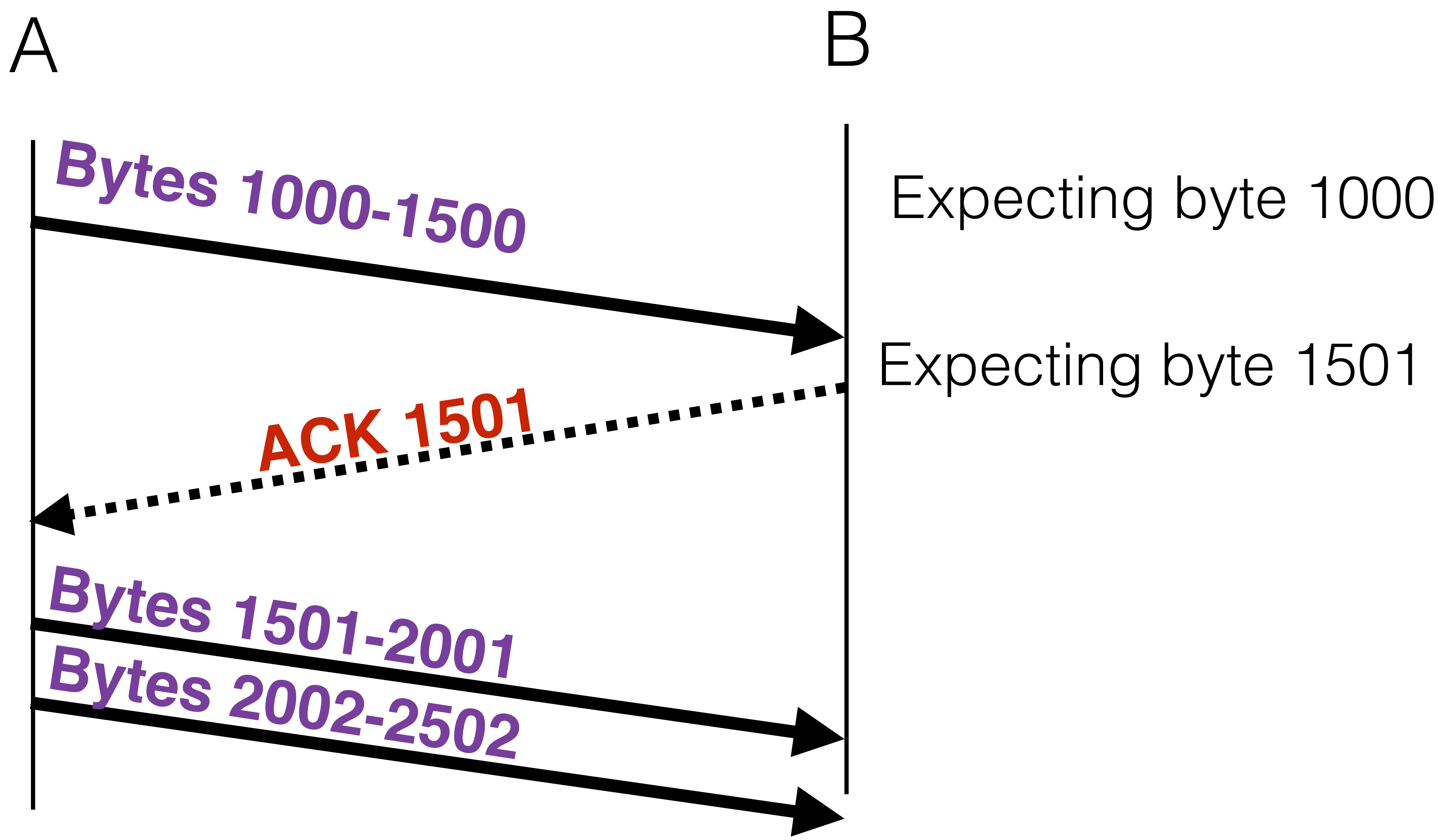

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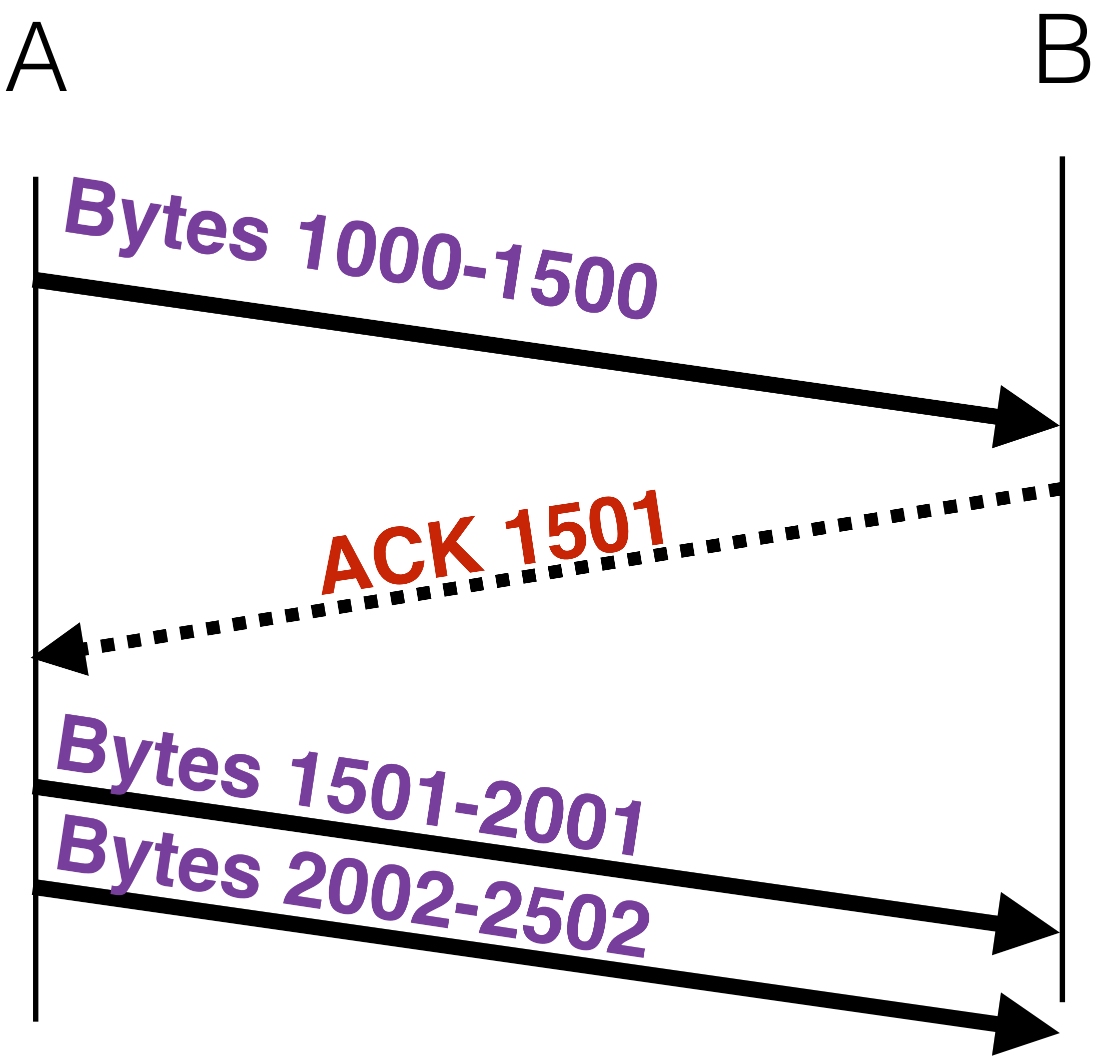

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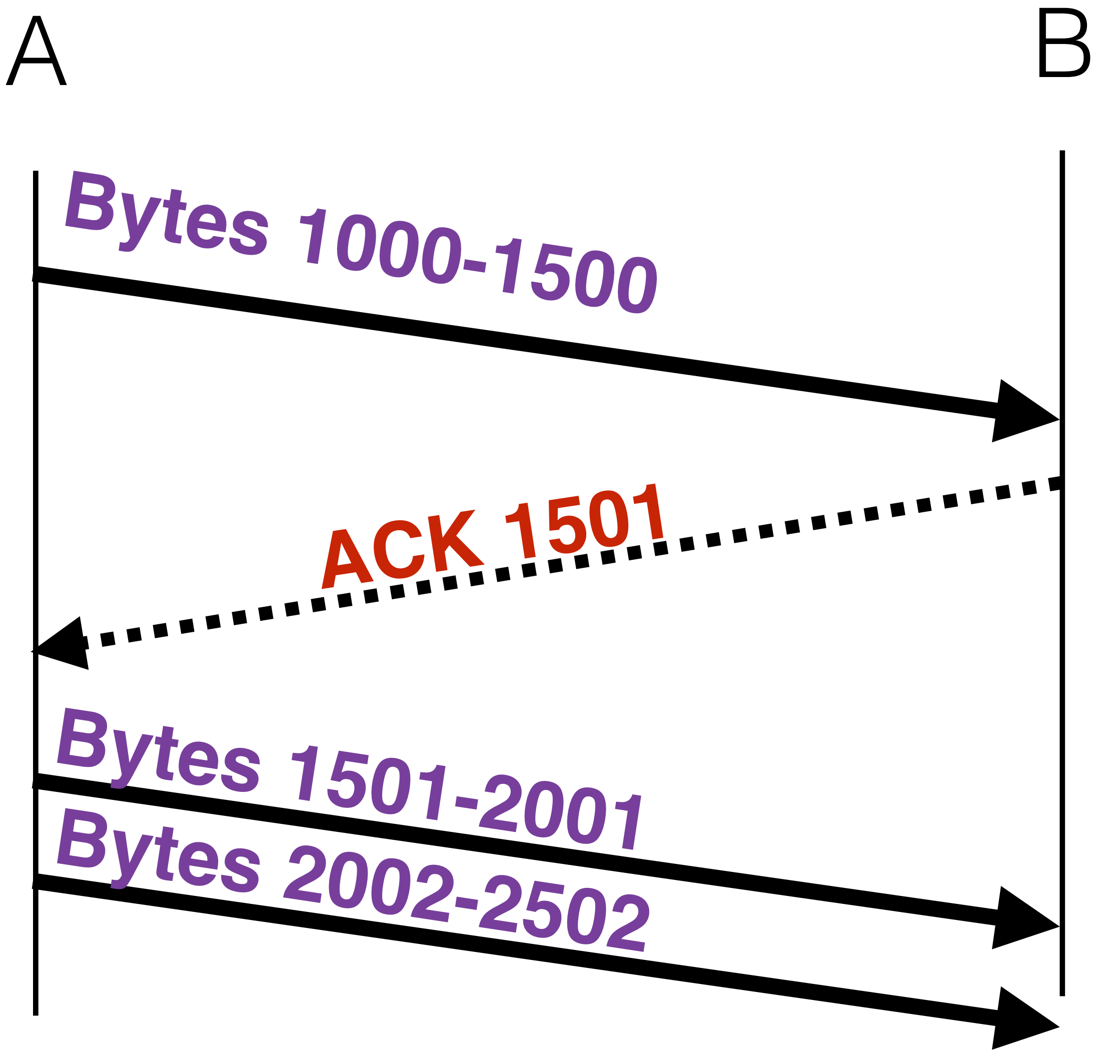
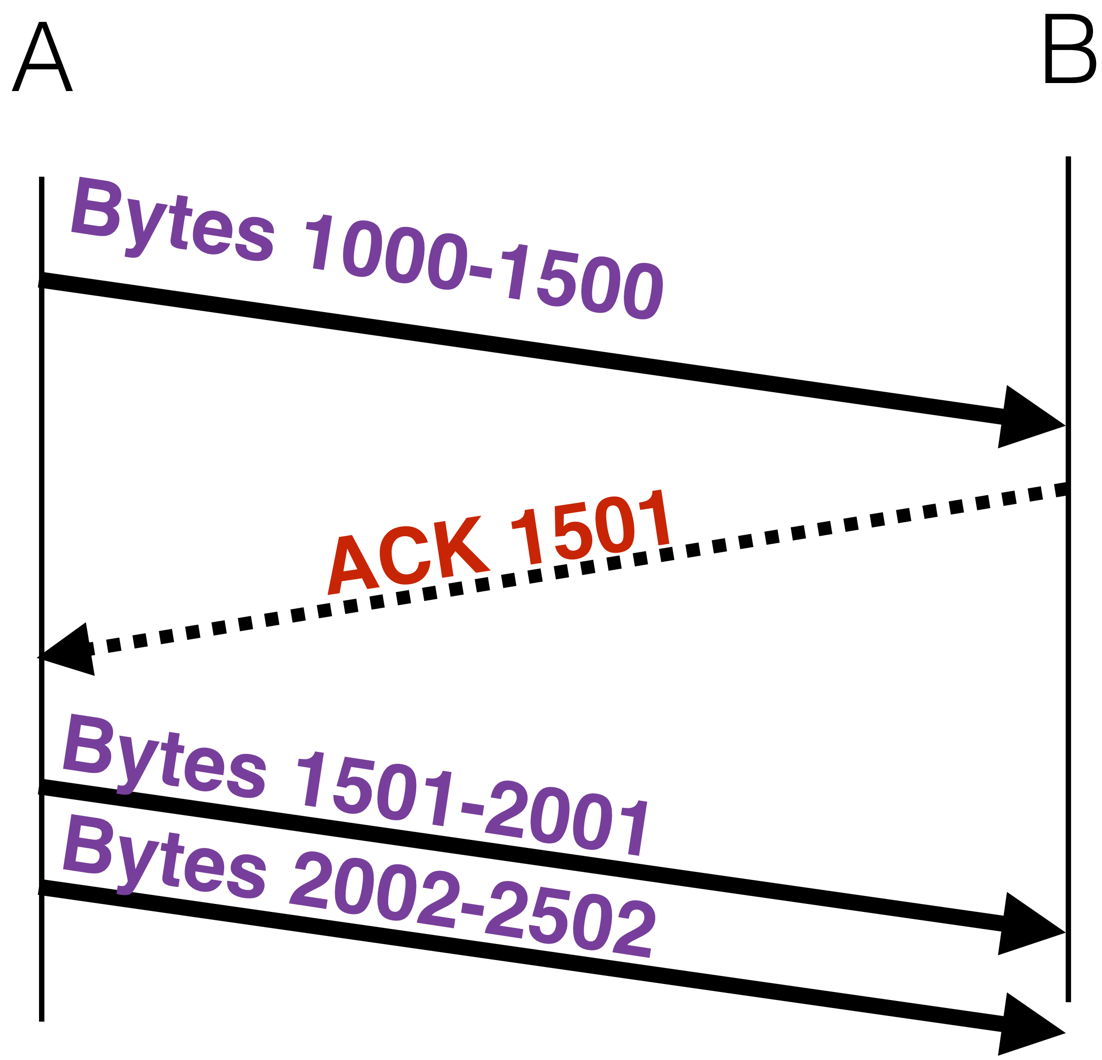


If I could convince you to send REALLY quickly, then you would effectively DoS your own network!

Opt-ack attack



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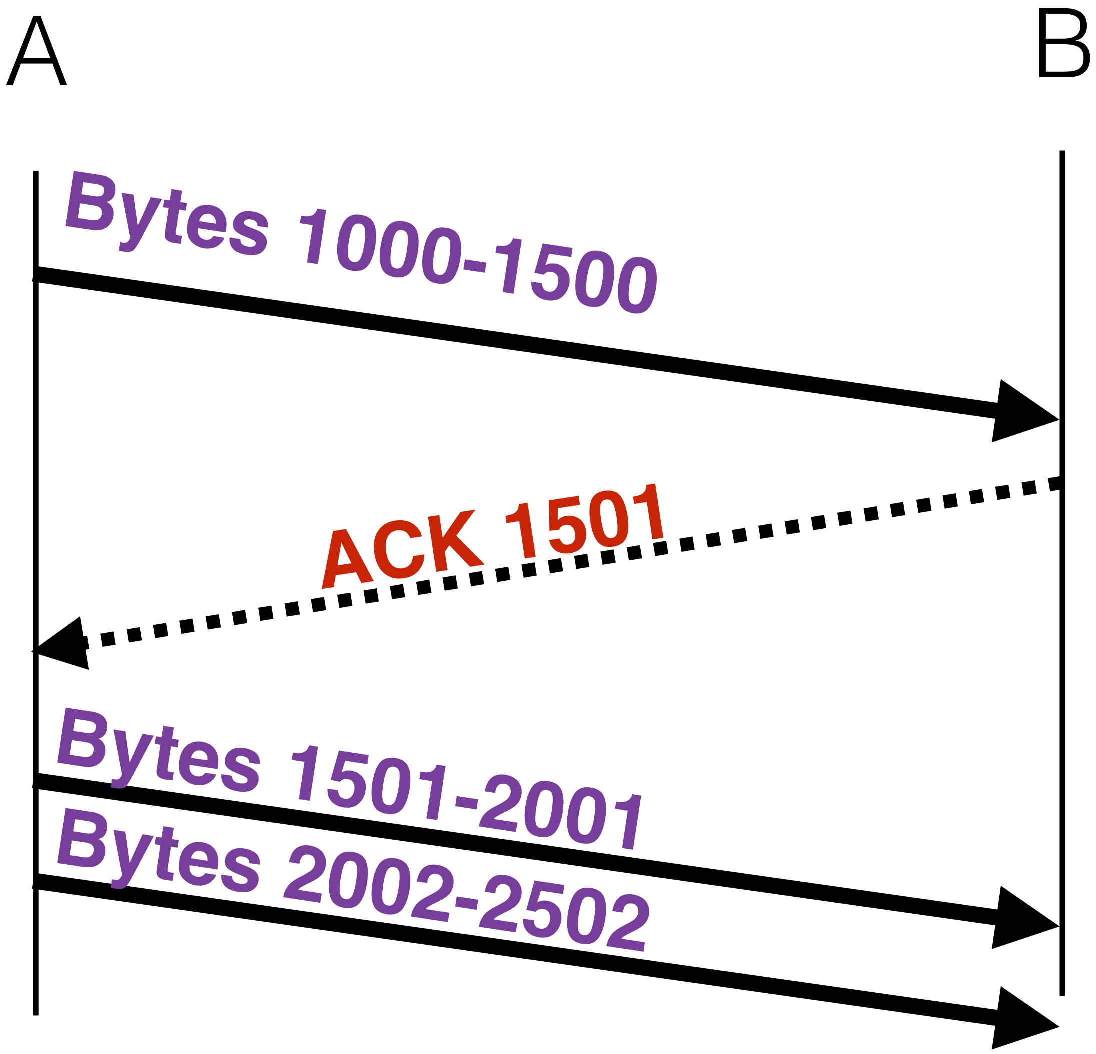

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...or do I?

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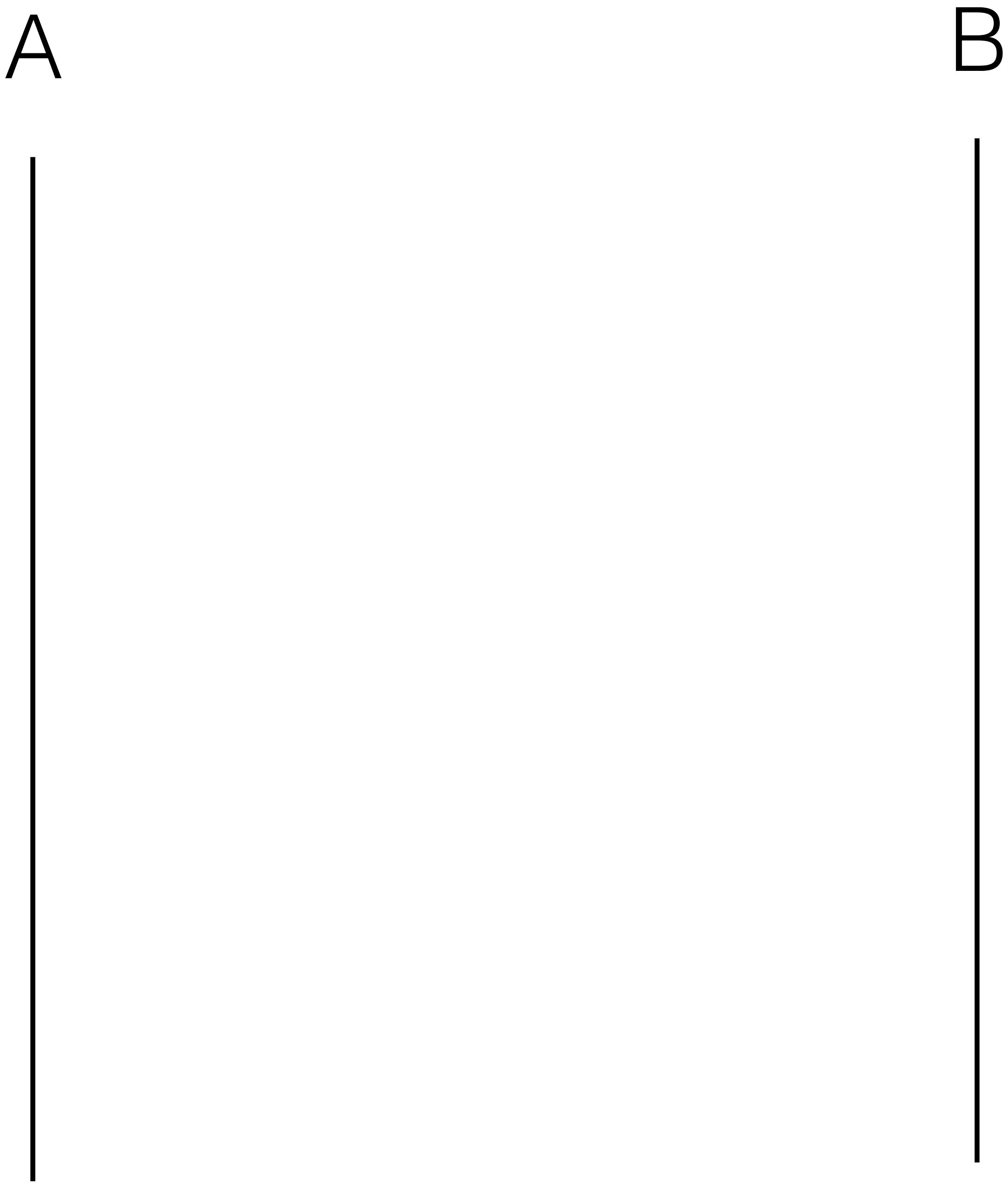

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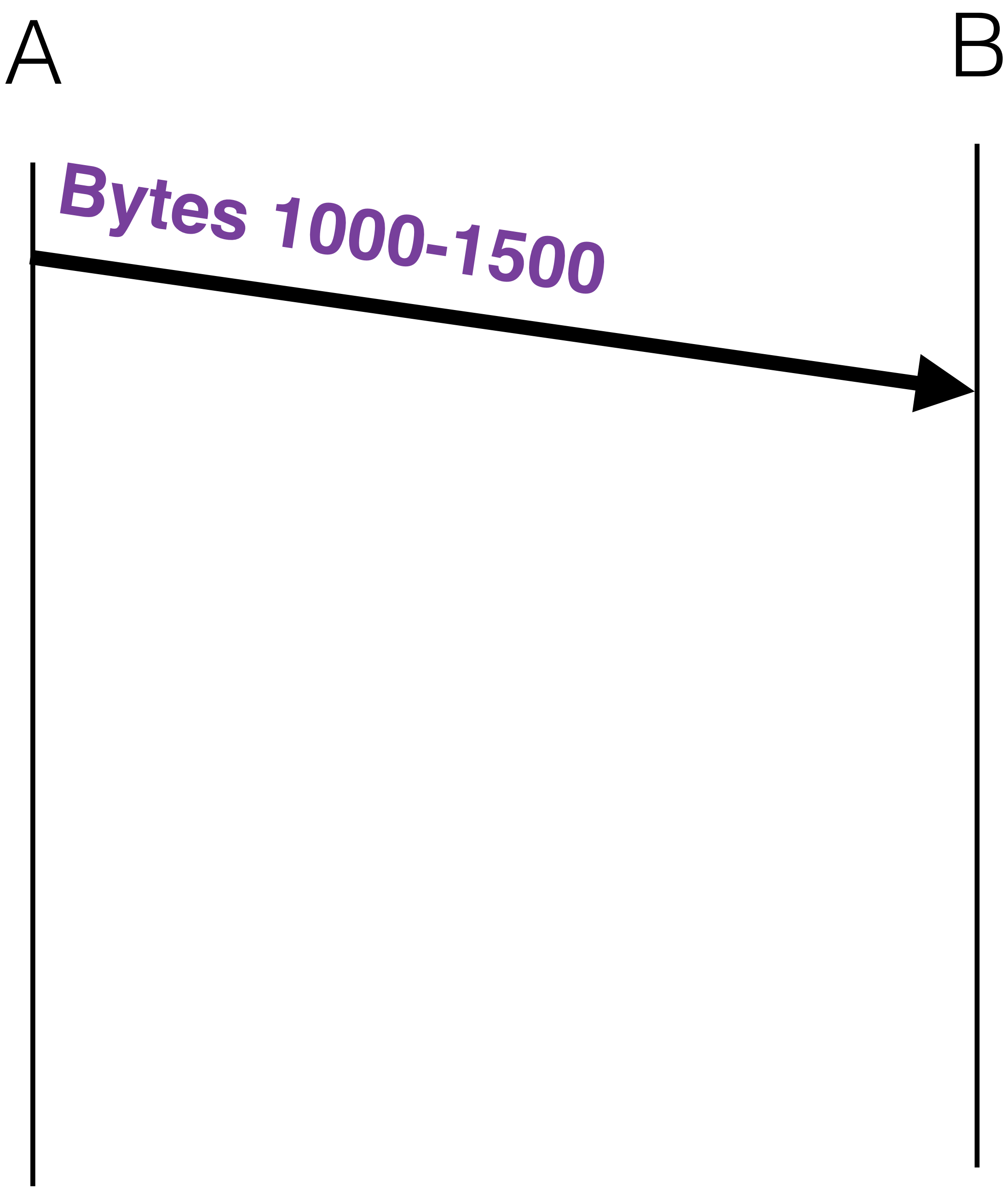

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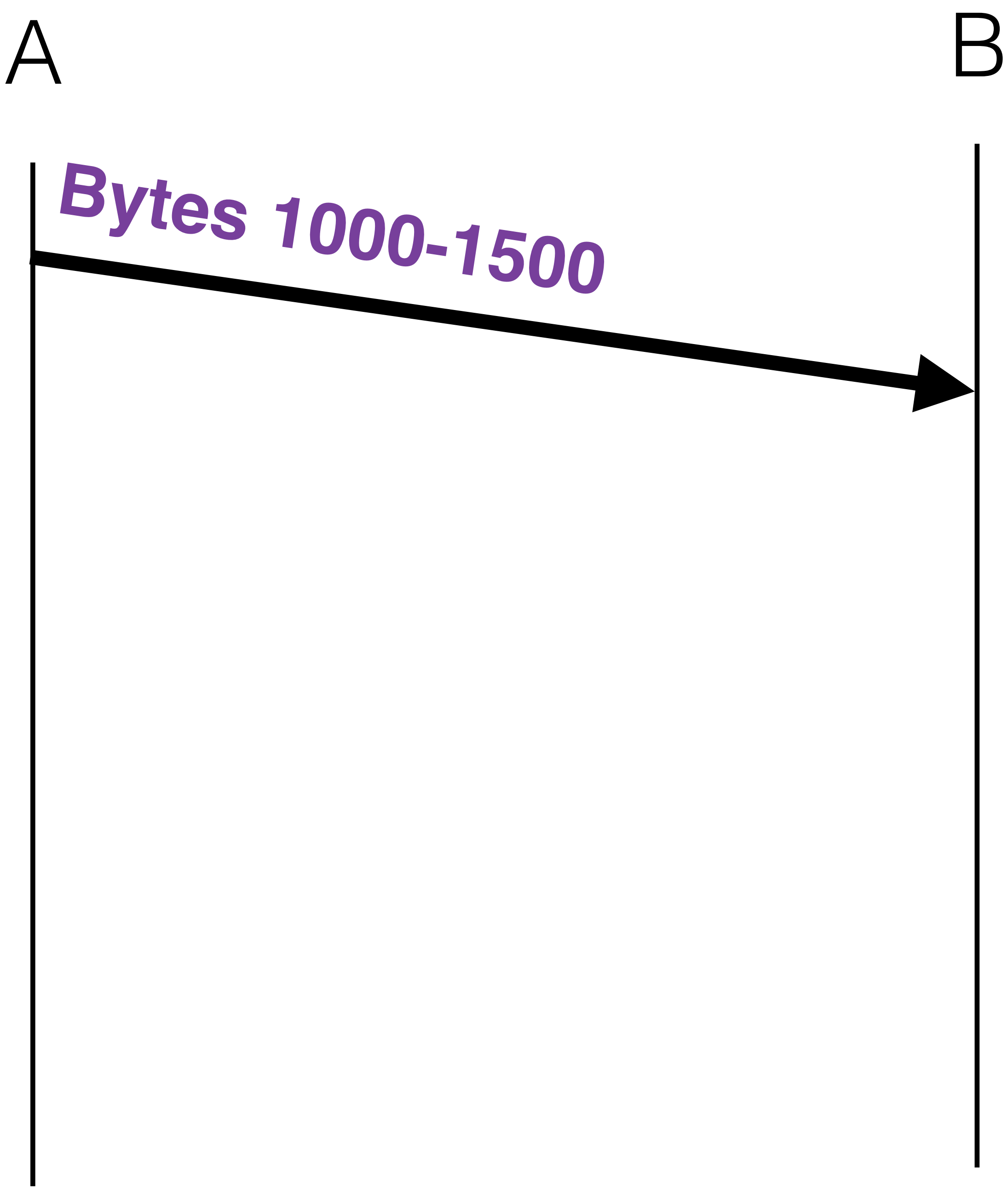

If I can predict what the last seqno will be *and* when A will send it

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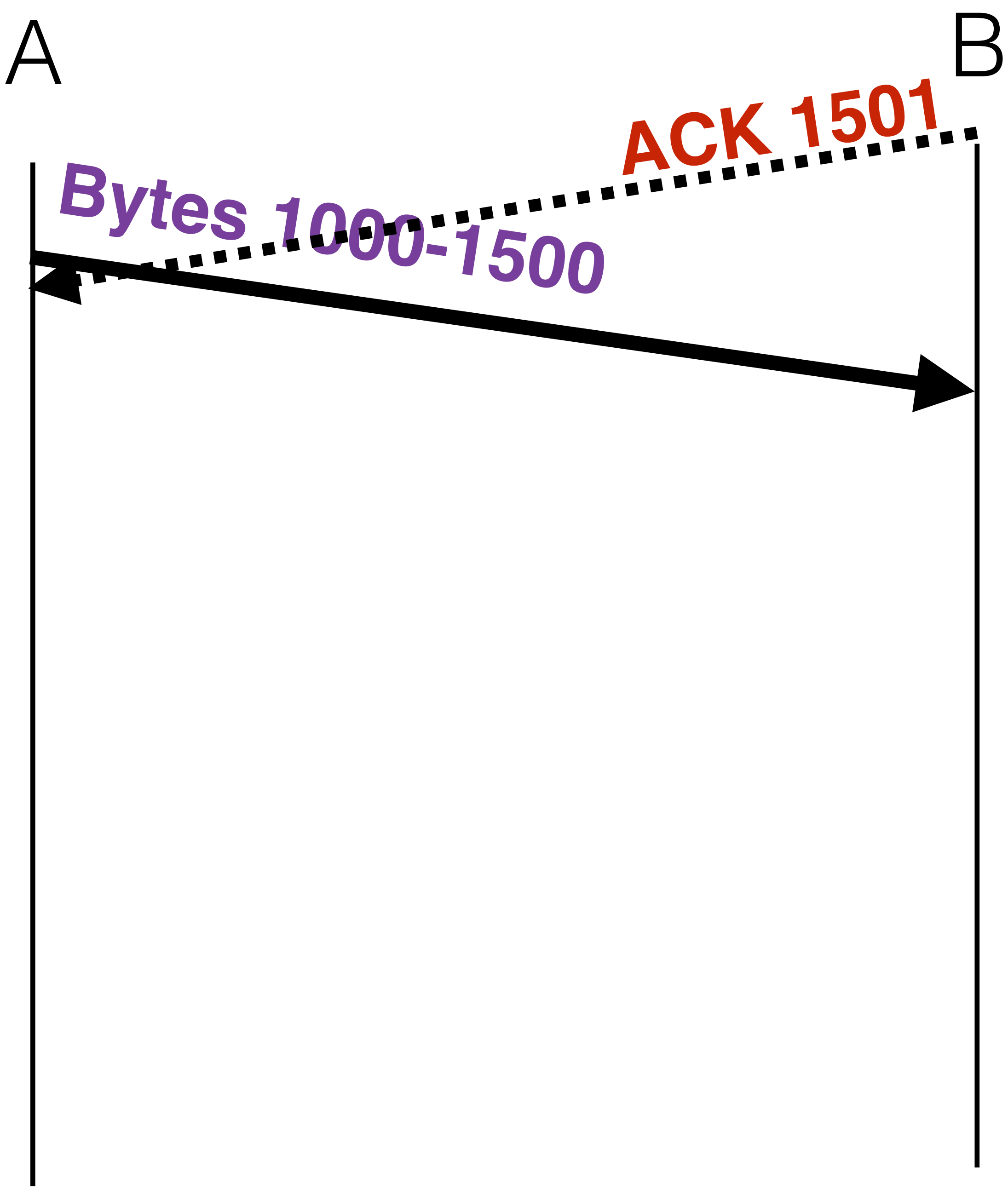

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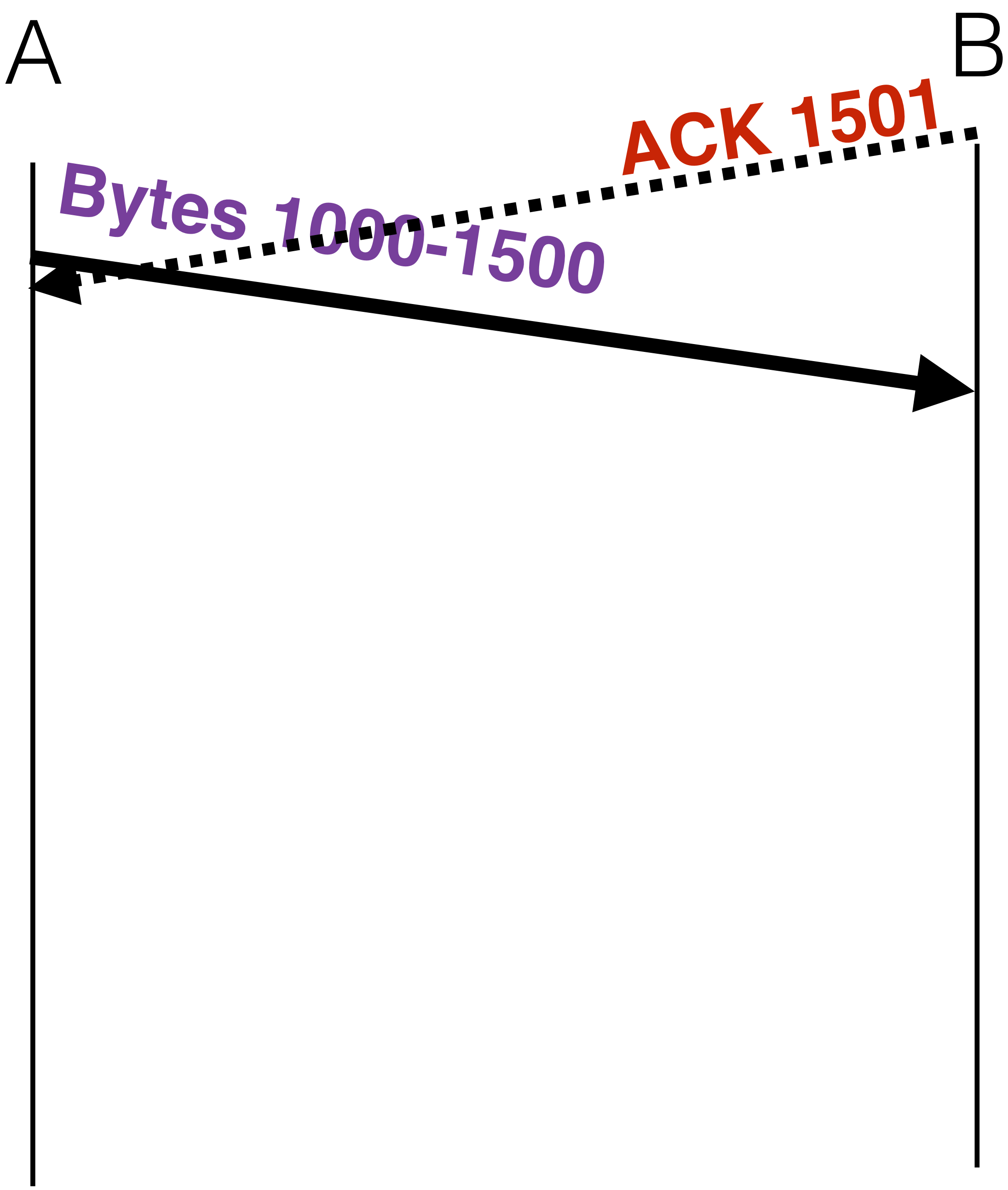

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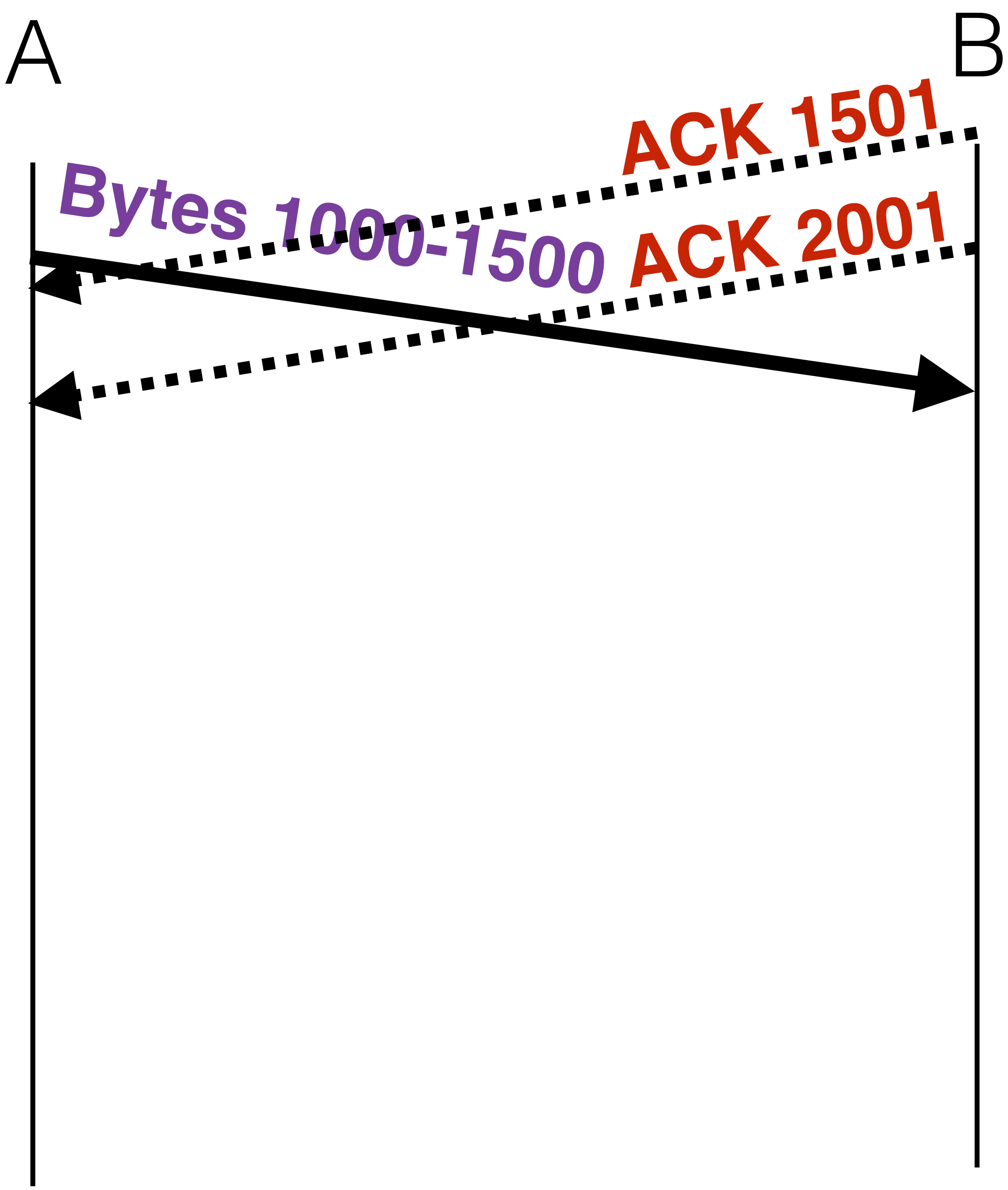

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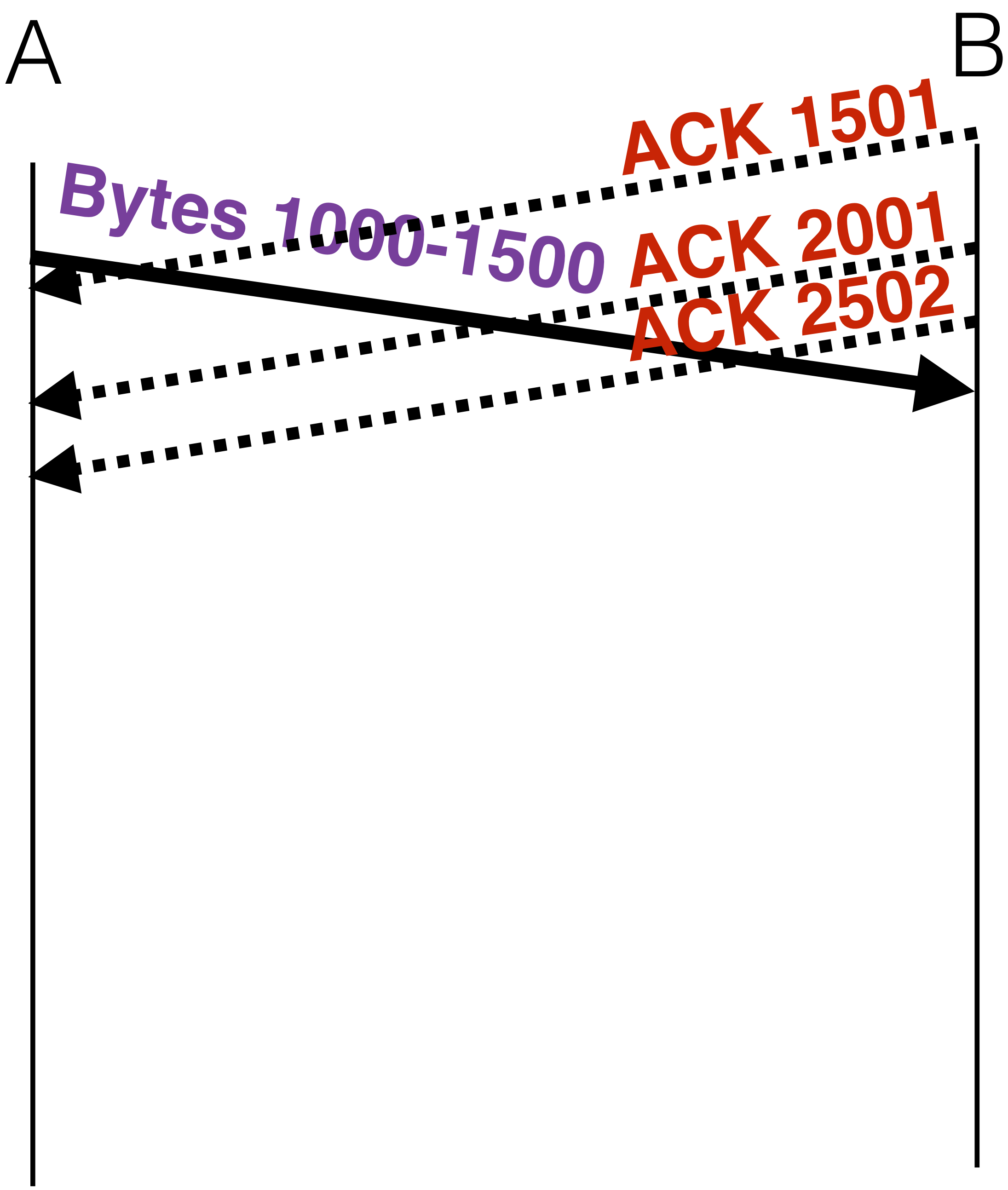

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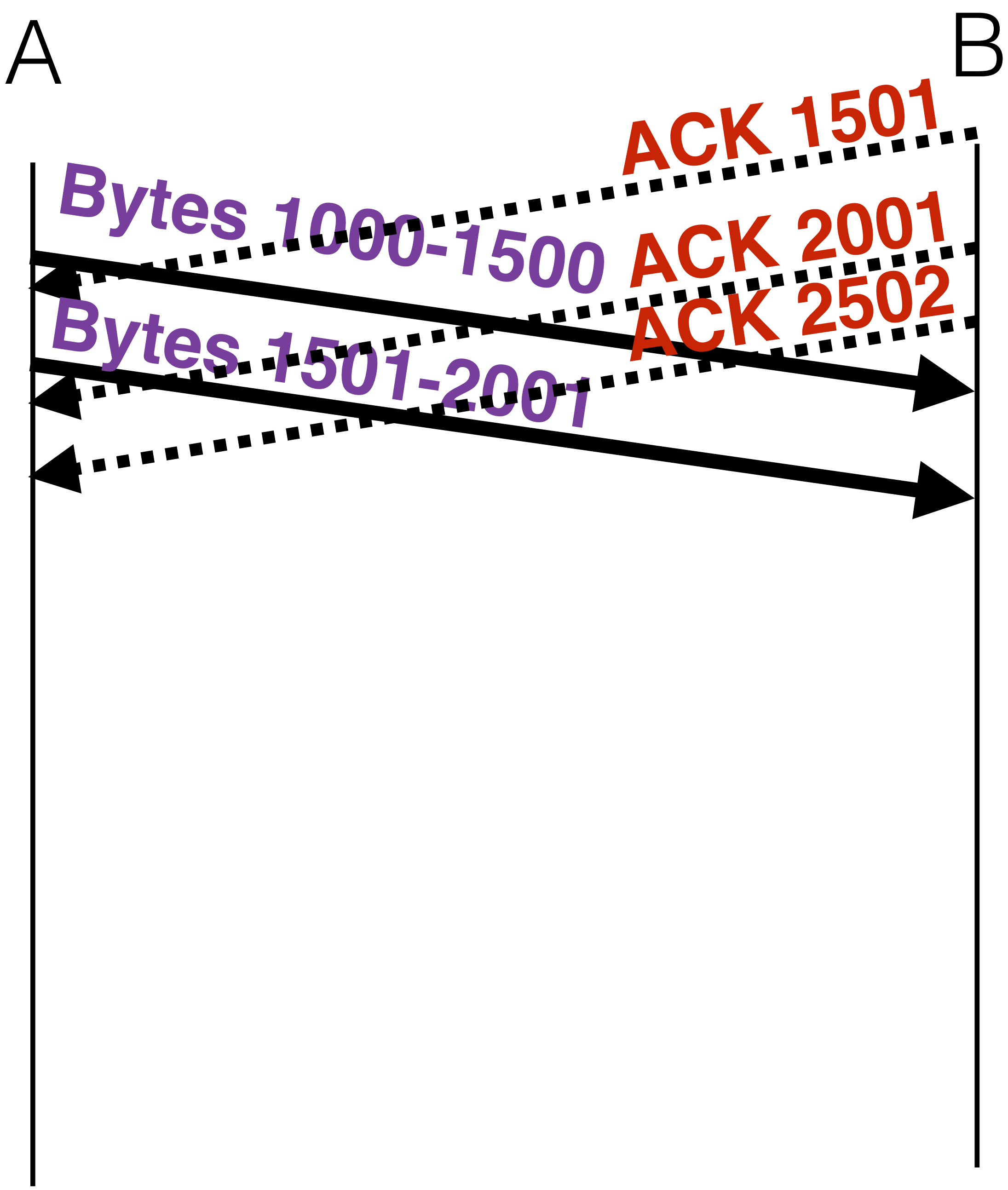

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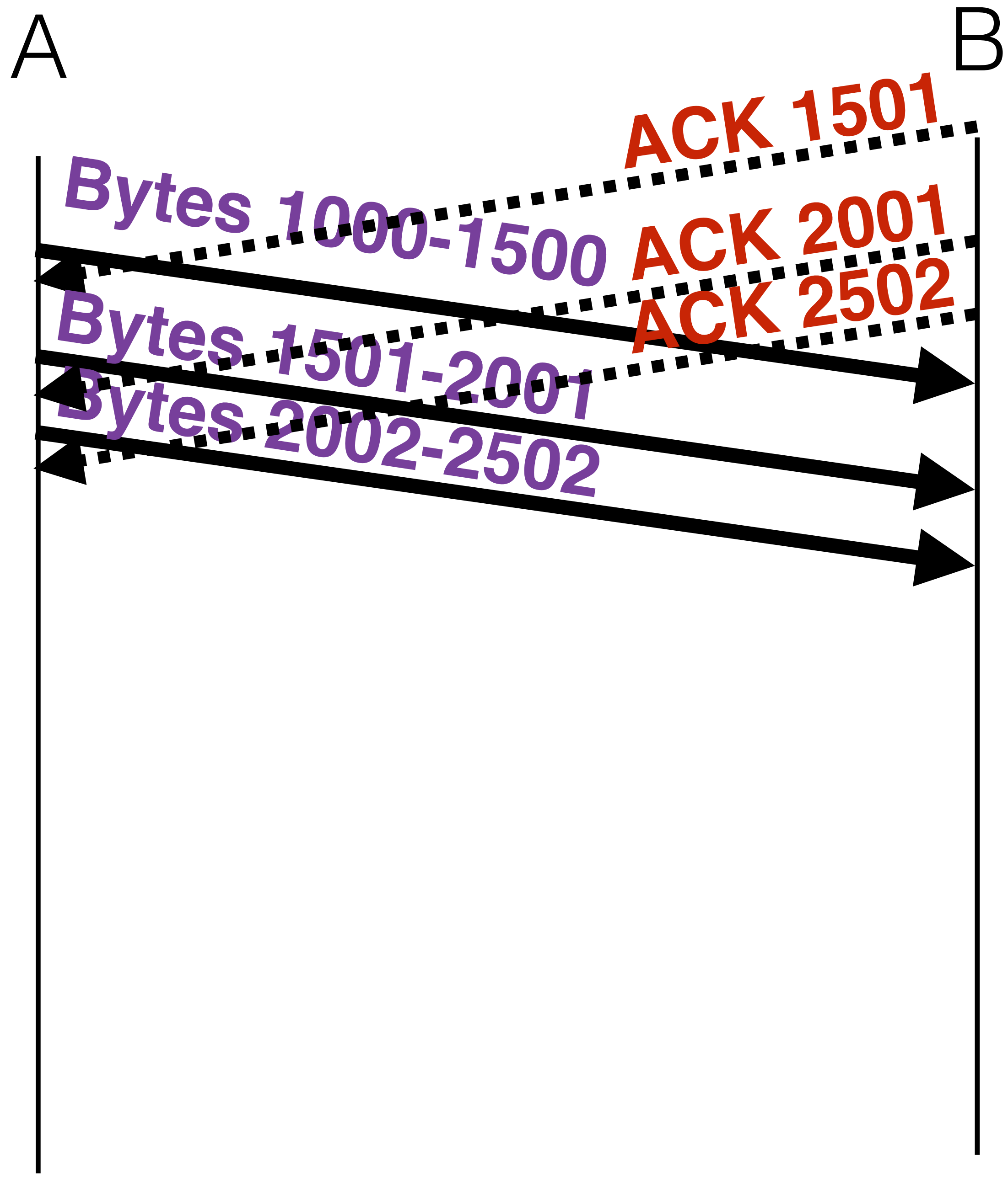

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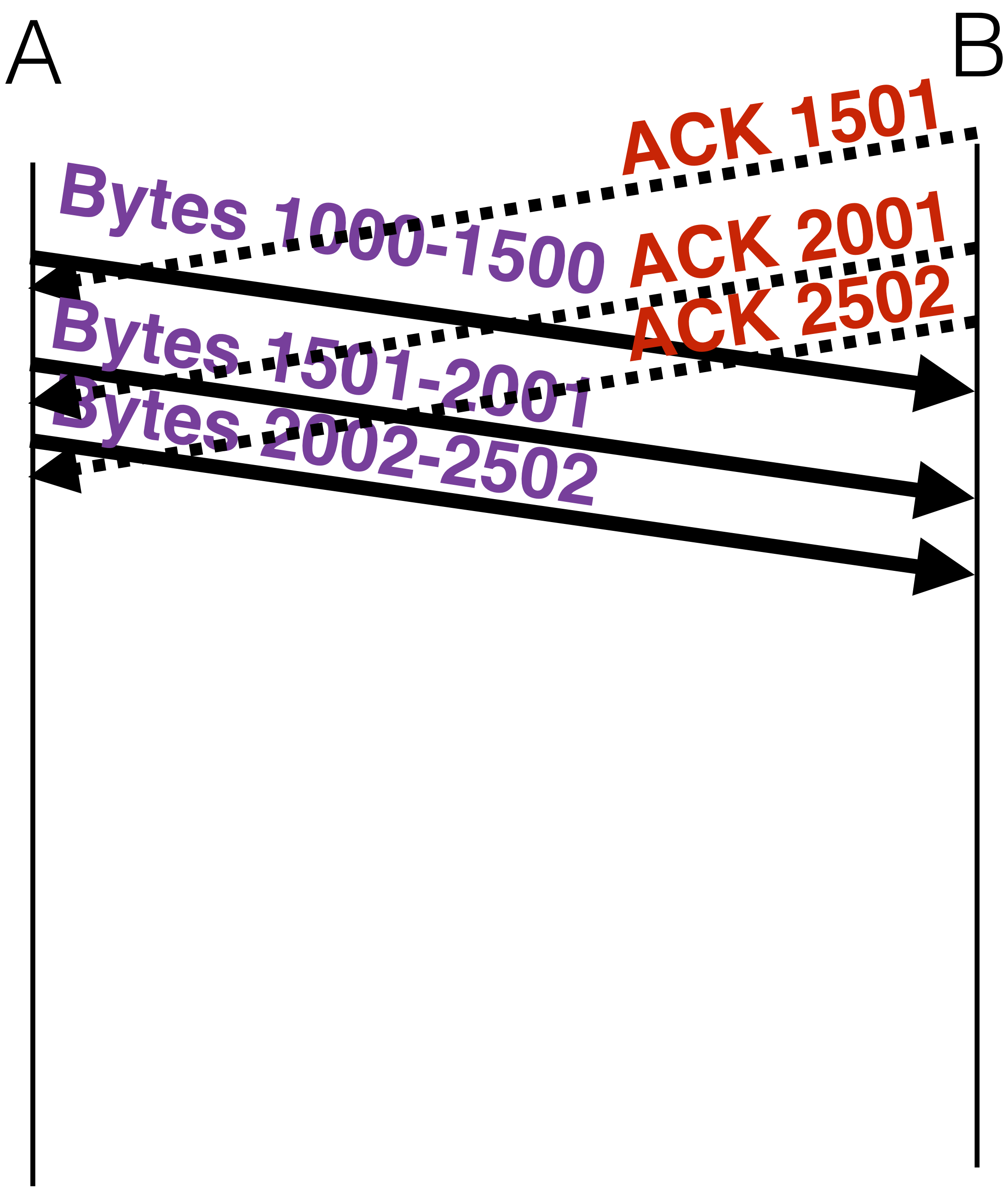

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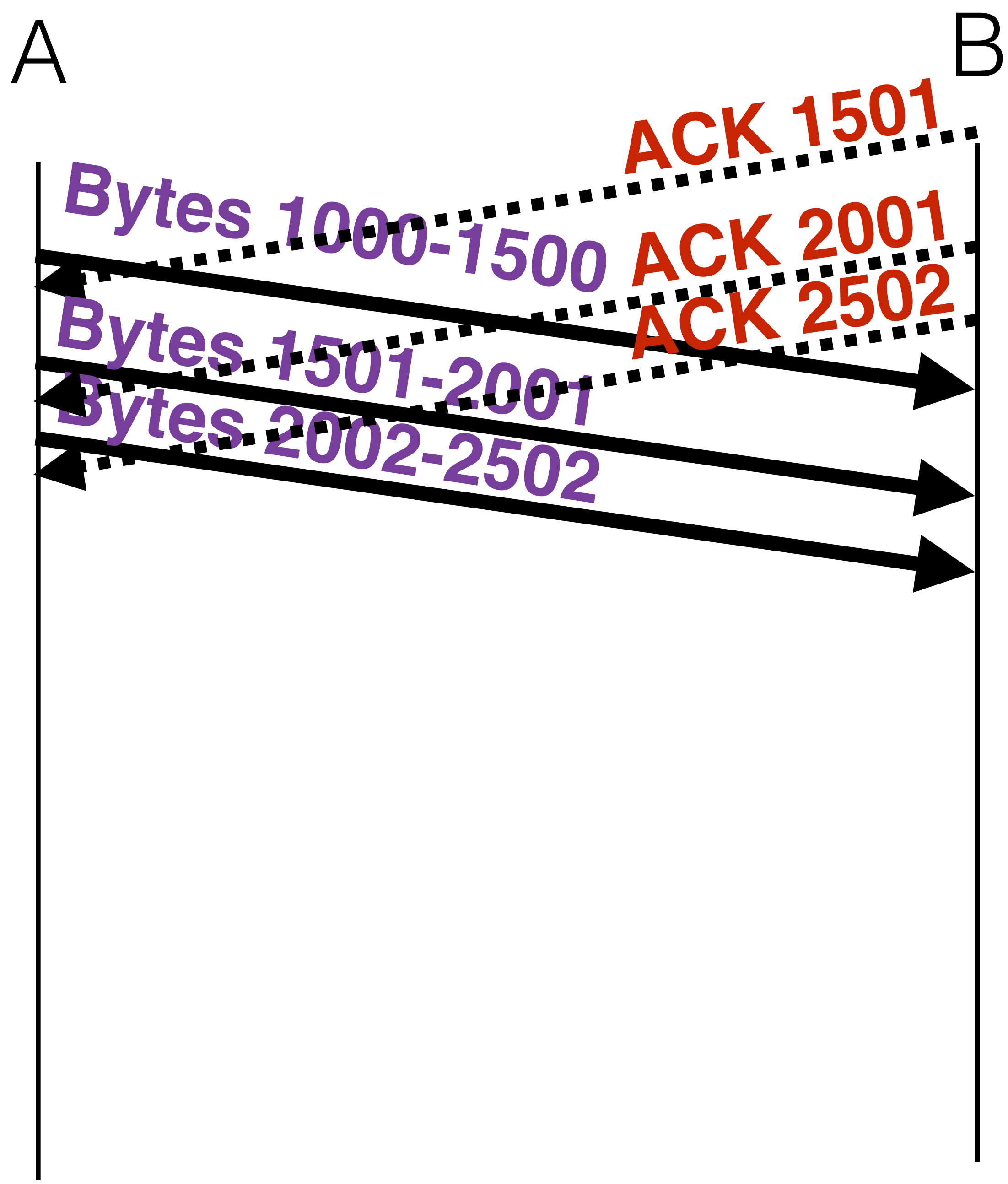

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Eventually, A’s outgoing packets will start to get dropped.

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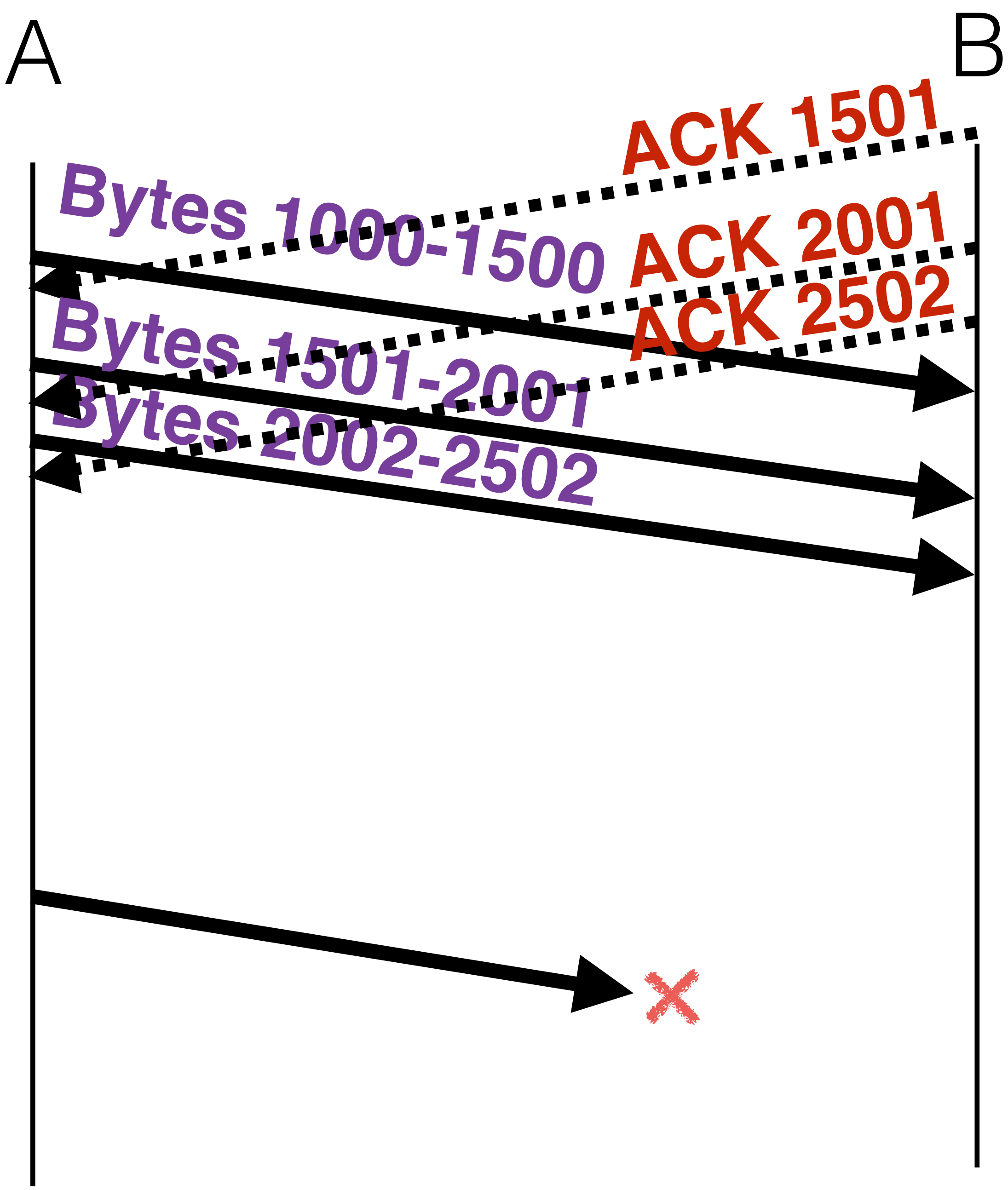

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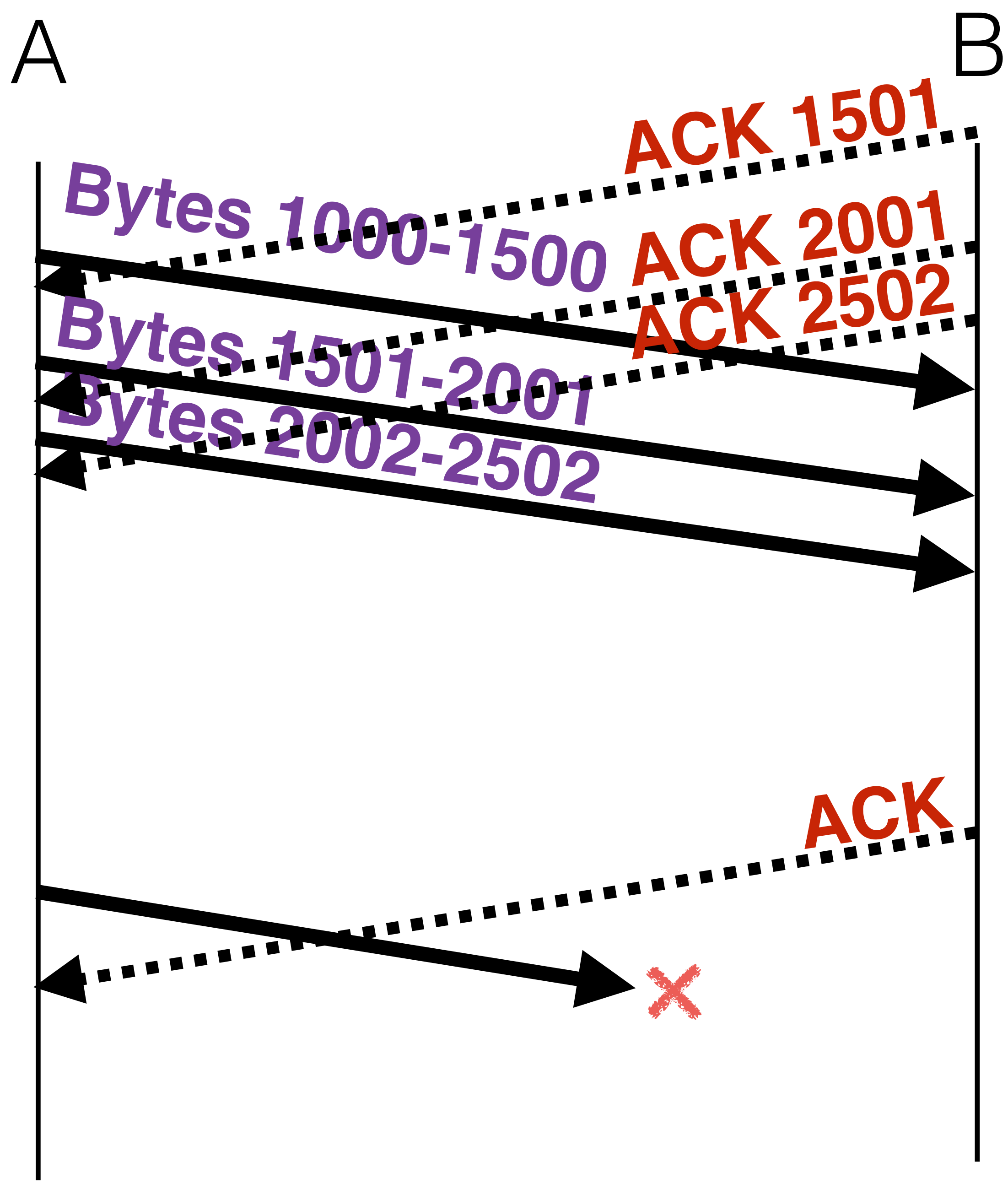

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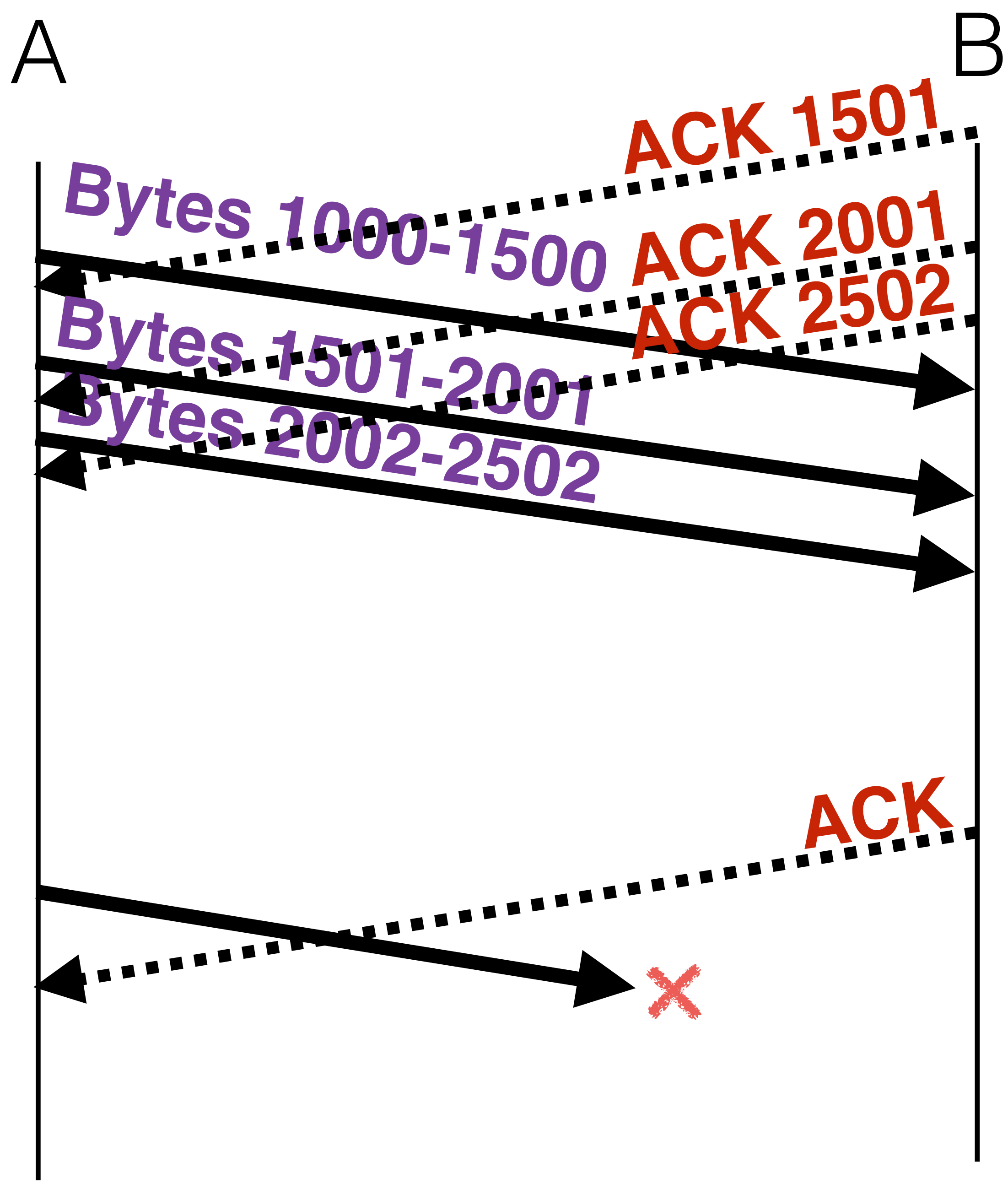

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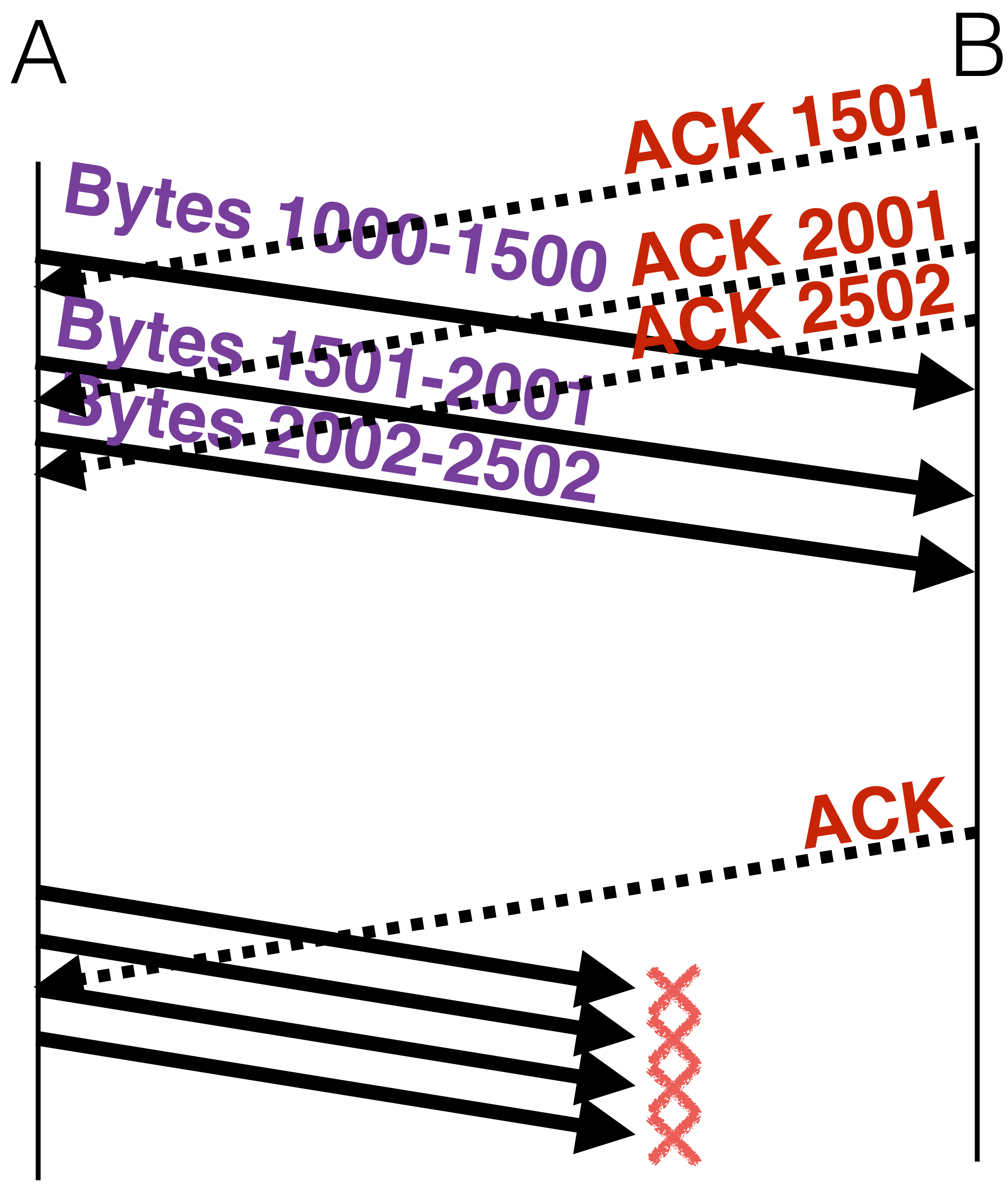

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Amplification

- The big deal with this attack is its *Amplification Factor*
  - Attacker sends *x* bytes of data, causing the victim to send many more bytes of data in response
  - Recent examples: NTP, DNSSEC

- Amplified in TCP due to cumulative ACKs
  - "ACK x" says "I've seen all bytes up to but not including x"

Opt-ack’s amplification factor

- Max bytes sent by victim per ACK:

- Max ACKs attacker can send per second:

Opt-ack's amplification factor

- Max bytes sent by victim per ACK:

$$\overbrace{\boxed{\frac{\text{Max window size}}{\text{MSS}}}}^{\text{Packets sent per ACK}} \times \overbrace{\boxed{(\underbrace{14}_{\text{Ethernet}} + \underbrace{40}_{\text{TCP/IP}} + \underbrace{\text{MSS}}_{\text{Payload}})}}^{\text{Bytes per packet}}$$

- Max ACKs attacker can send per second:

Opt-ack's amplification factor

- Max bytes sent by victim per ACK:

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- Max ACKs attacker can send per second:

$$\boxed{\frac{\text{Attacker bandwidth (bytes/sec)}}{\underbrace{(14 + 40)}_{\text{Size of ACK packet}}}}$$

Opt-ack's amplification factor

- Boils down to max window size and MSS
  - Default max window size: 65,536
  - Default MSS: 536
- Default amp factor: 65536 * (1/536 + 1/54) ~ **1336x**
- Window scaling lets you increase this by a factor of 2^14
- Window scaling amp factor: ~1336 * 2^14 ~ **22M**
- Using minimum MSS of 88: ~ **32M**

Opt-ack defenses

- Is there a way we could defend against opt-ack in a way that is still compatible with existing implementations of TCP?
- An important goal in networking is *incremental deployment*: ideally, we should be able to benefit from a system/modification when even a subset of hosts deploy it.

Opt-ack defenses

- Nonces
  - Mostly solve problem, but not incremental
- ACK alignment
  - Send ~MSS or MSS-1; make hard to keep sync'd
  - ***Breaks if routers split packet***
- Random skip
  - Sender randomly skips a segment
  - Good receiver will ask for lost packet again (Sanity check)
  - Attacker won't be able to distinguish, will ACK
  - Costs receiver 1RT of performance