NETWORKING BASICS

CMSC 8180

NOV 12 2019

WHY DOES THE INTERNET WORK?

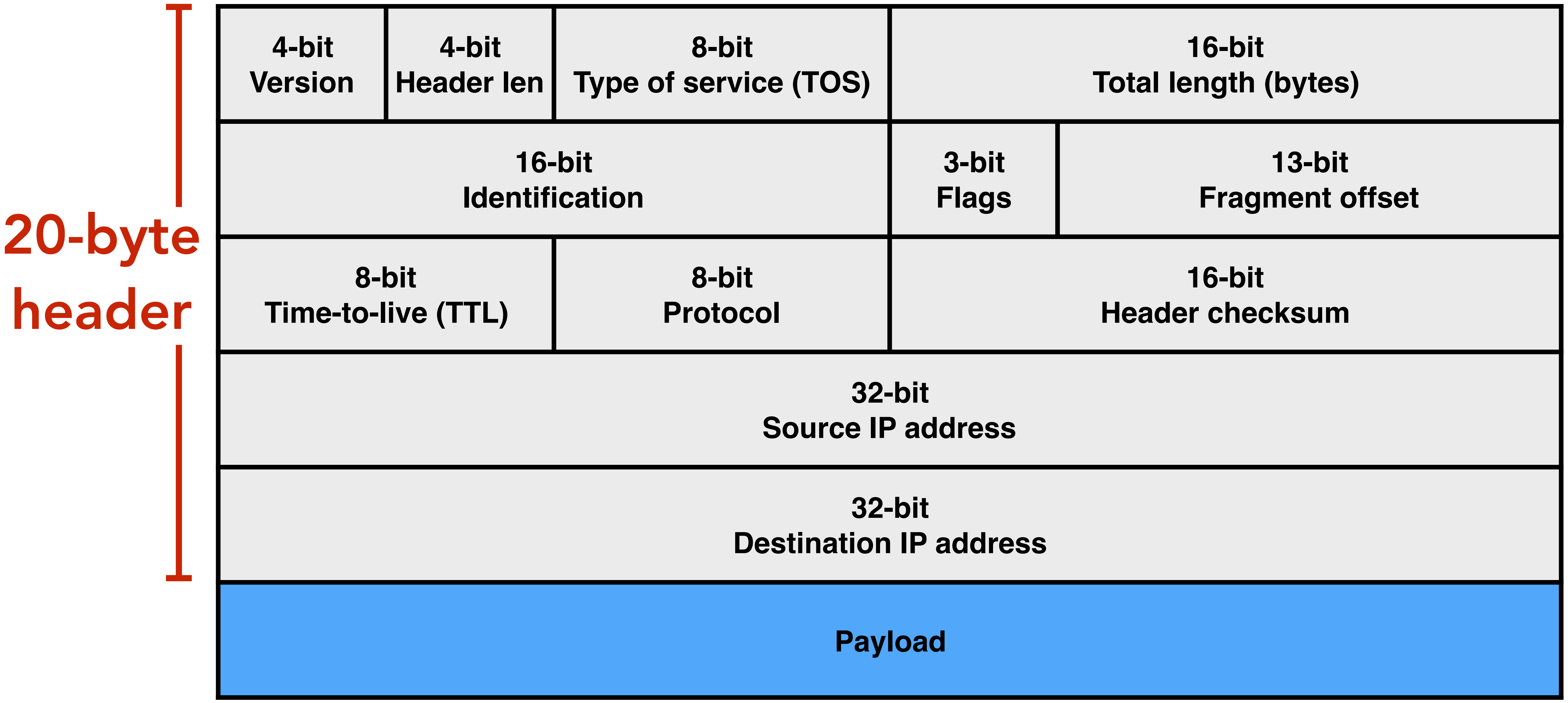
1. PROTOCOLS **Agreements on how to communicate**

Publicly standardized, esp. via Requests for Comments (RFCs)

RFC 826: ARP   RFC 103{4,5}: DNS   RFC 793: TCP

Code to the protocol and your product will work with other products

WHY DOES THE INTERNET WORK?



The payload is the "data" that IP is delivering:

May contain another protocol's header & payload, and so on

WHY DOES THE INTERNET WORK?

2. THE NETWORK IS DUMB

End-hosts are the periphery (users, devices)

Routers and **switches** are interior nodes that

- **Route** (figure out where to forward)
- **Forward** (actually send)

- Principle: the routers have no knowledge of ongoing connections through them
    - They do "destination-based" routing and forwarding
        - Given the destination in the packet, send it to the "next hop" that is best suited to help ultimately get the packet there

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Mental model: The postal system

WHY DOES THE INTERNET WORK?

3. LAYERS

- The design of the Internet is strongly partitioned into layers
  - Each layer relies on the services provided by the layer immediately below it…
  - … and provides service to the layer immediately above it

LAYERS OF THE INTERNET

PHYSICAL

Send / receive bit

Broadcasts on shared link

LAYERS OF THE INTERNET

LINK	Local send/recv	*Adds framing & destination; Still assumes shared link*
PHYSICAL	Send / receive bit	*Broadcasts on shared link*

LAYERS OF THE INTERNET

NETWORK (IP)	Global send/recv	*Adds global addresses; Requires routing*
LINK	Local send/recv	*Adds framing & destination; Still assumes shared link*
PHYSICAL	Send / receive bit	*Broadcasts on shared link*

LAYERS OF THE INTERNET

TRANSPORT (TCP,UDP)	Process send/recv	*E2E communication between processes; Adds ports/reliability*
NETWORK (IP)	Global send/recv	*Adds global addresses; Requires routing*
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LAYERS OF THE INTERNET

APPLICATION	Arbitrary	*Application-specific semantics*
TRANSPORT (TCP,UDP)	Process send/recv	*E2E communication between processes; Adds ports/reliability*
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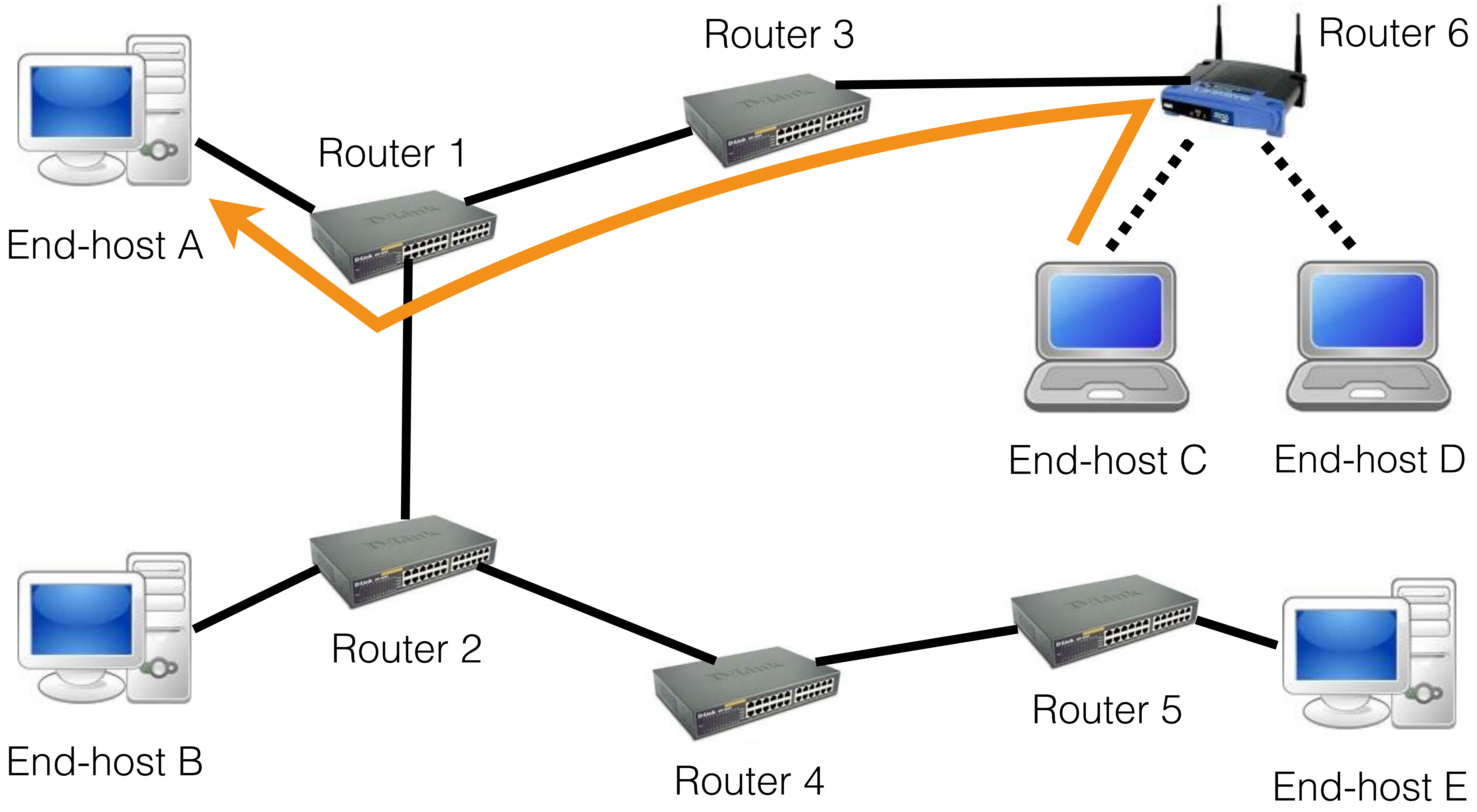
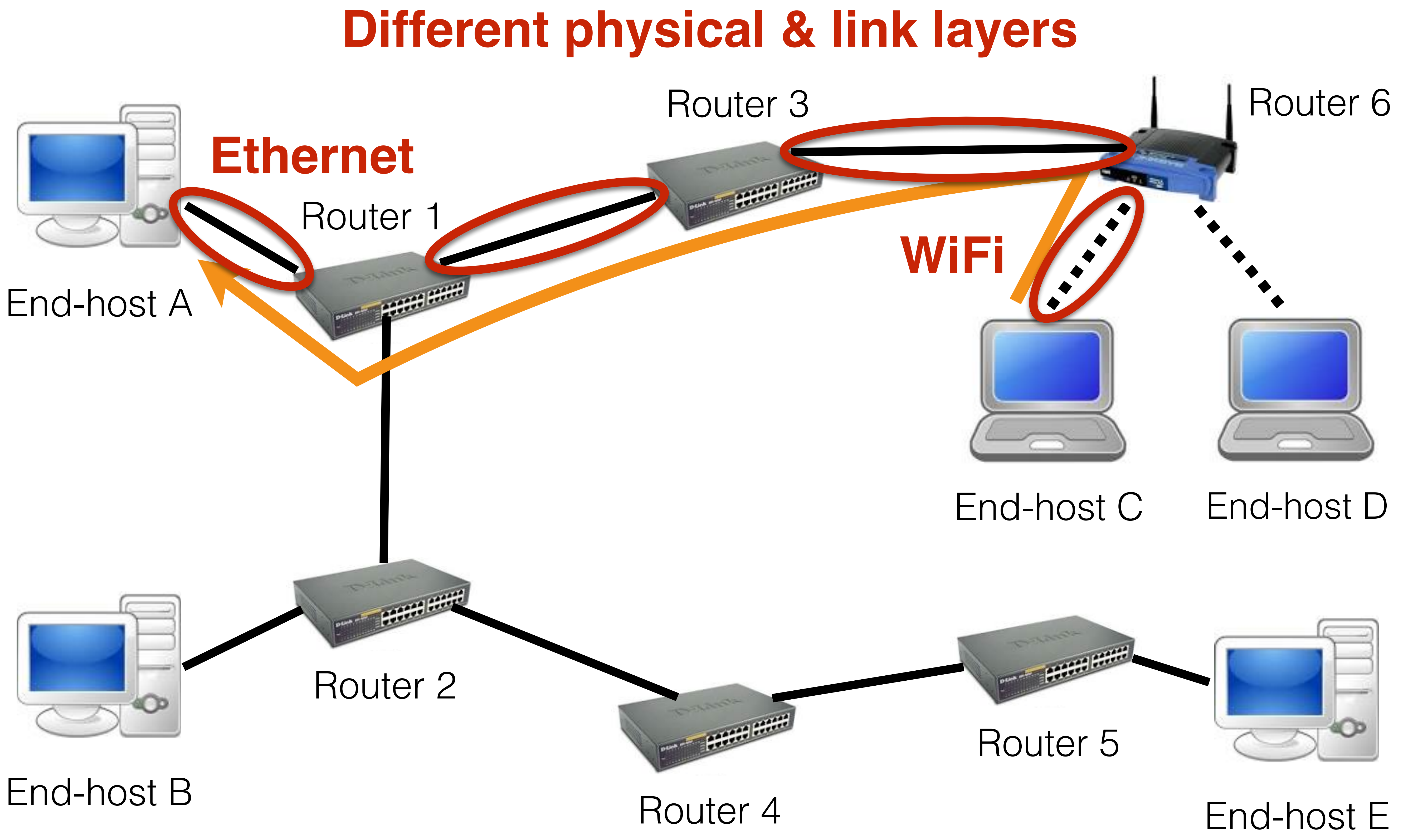
Hop-by-hop vs. end-to-end layers

Host C communicates with host A



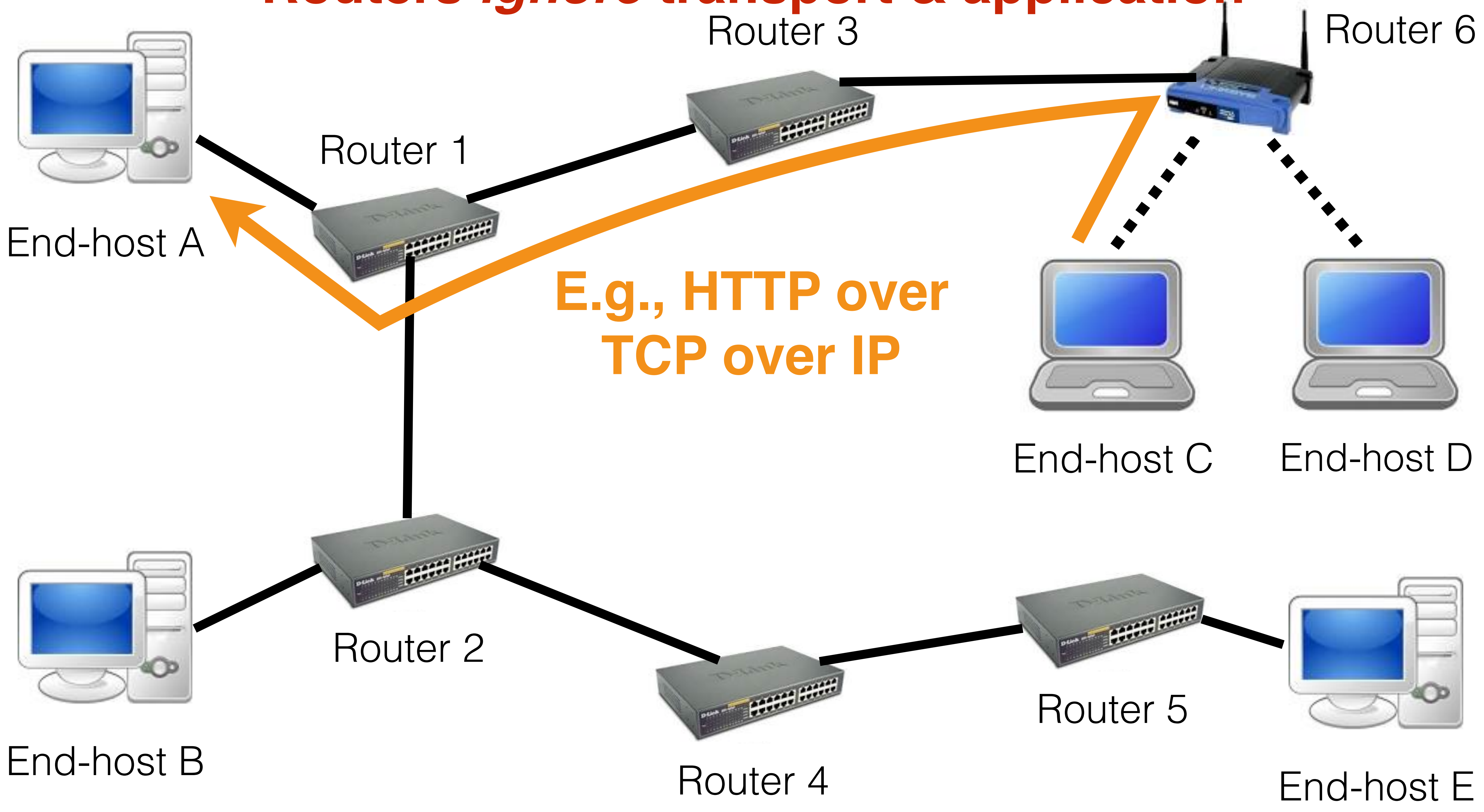
Hop-by-hop vs. end-to-end layers



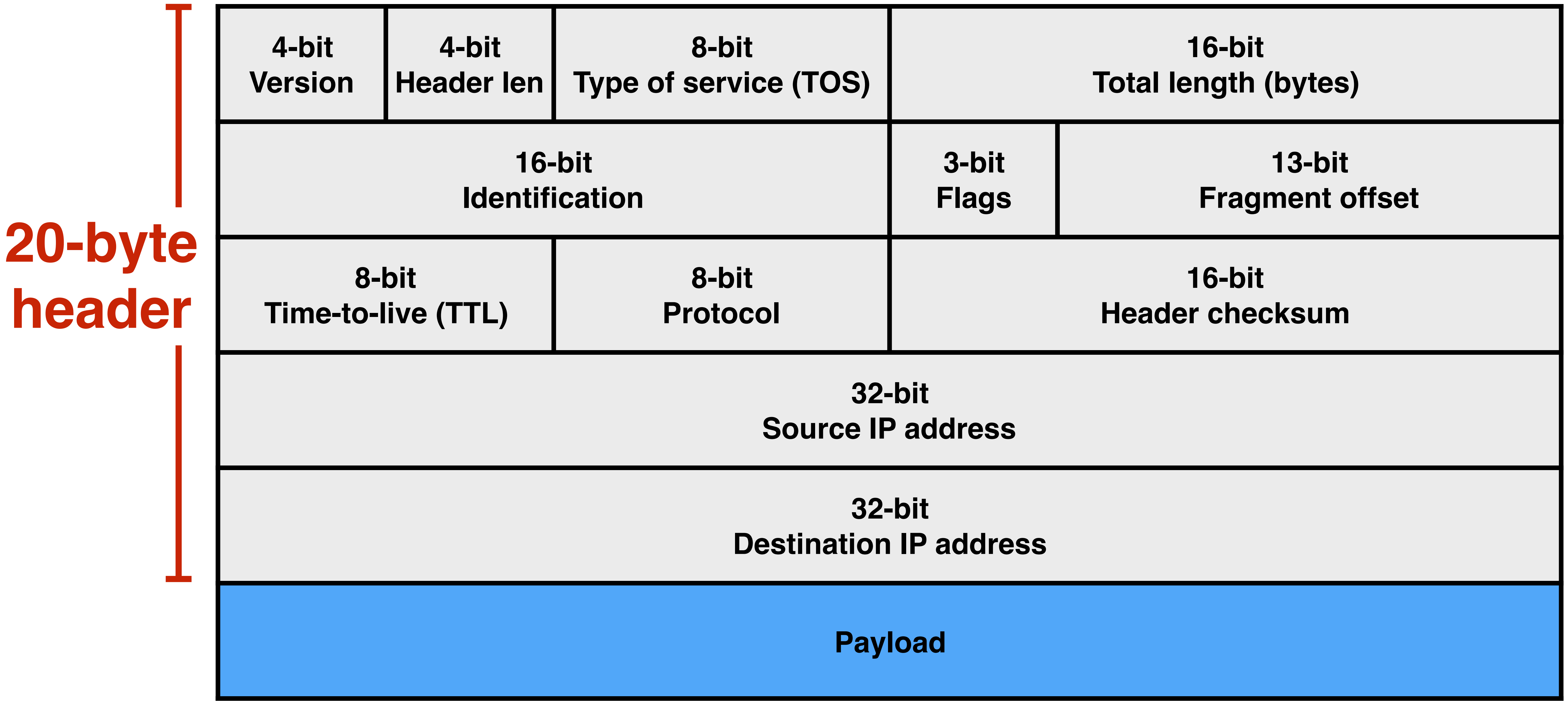
Hop-by-hop vs. end-to-end layers

Same network, transport, and application layers (3/4/7)

Routers *ignore* transport & application



IP packet “header”



IP Packet Header Fields (1)

- Version number (4 bits)
    - Indicates the version of the IP protocol
    - Necessary for knowing what fields follow
    - “4” (for IPv4) or “6” (for IPv6)

- Header length (4 bits)
    - How many 32-bit words (rows) in the header
    - Typically 5
    - Can provide IP options, too

- Type-of-service (8 bits)
    - Allow packets to be treated differently based on different needs
    - Low delay for audio, high bandwidth for bulk transfer, etc.

IP Packet Header Fields (2)

- Two IP addresses
  - Source (32 bits)
  - Destination (32 bits)

- Destination address
  - *Unique* identifier/locator for the receiving host
  - Allows each node (end-host and router) to make forwarding decisions

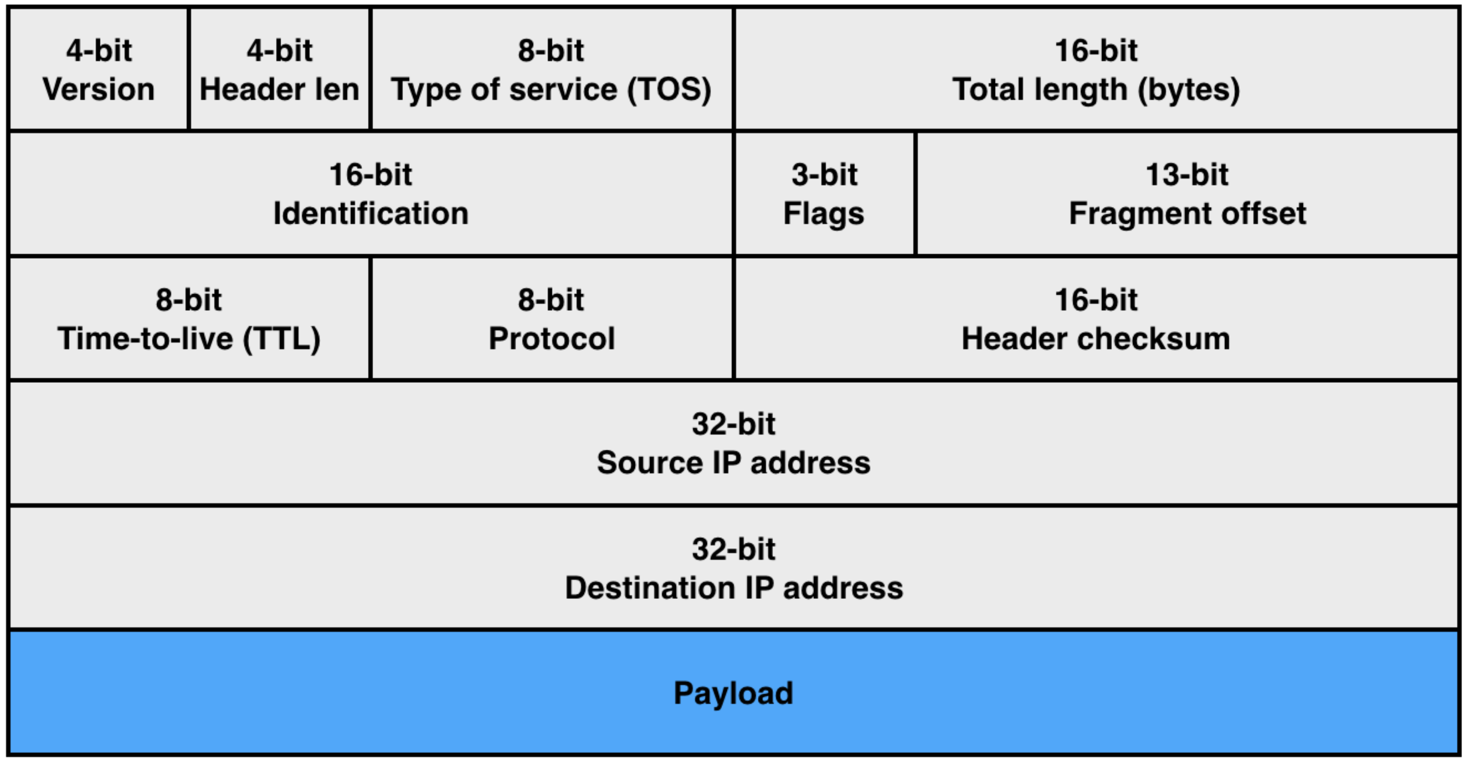
- Source address
  - Unique identifier/locator for the sending host
  - Recipient can decide whether to accept the packet
  - Allows destination to *reply* to the source

IP: “Best effort” packet delivery

- Routers inspect destination address, determine “next hop” in the forwarding table
- Best effort = “I’ll give it a try”
    - Packets may be lost
    - Packets may be corrupted
    - Packets may be delivered out of order

Fixing these is the job of the transport layer!

Attacks on IP



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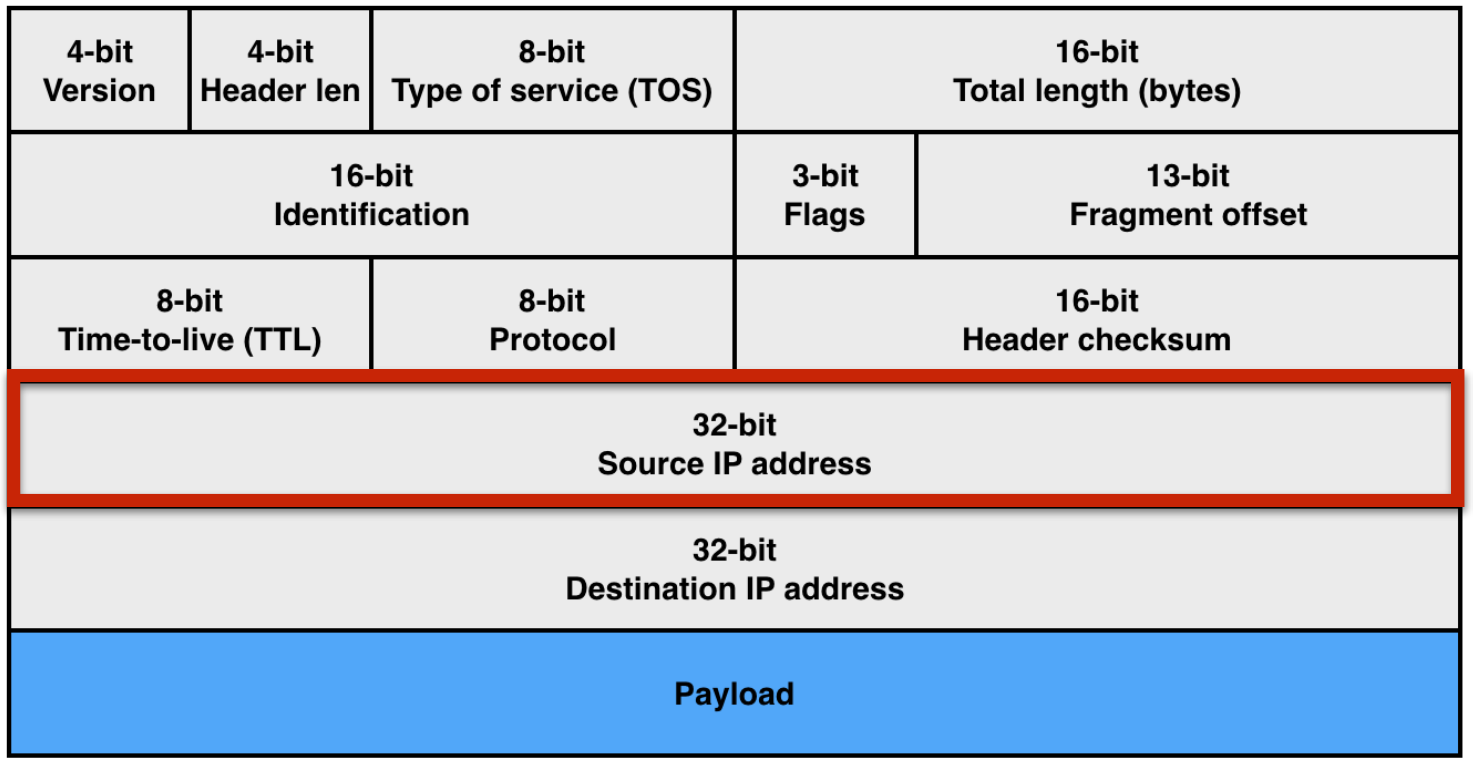
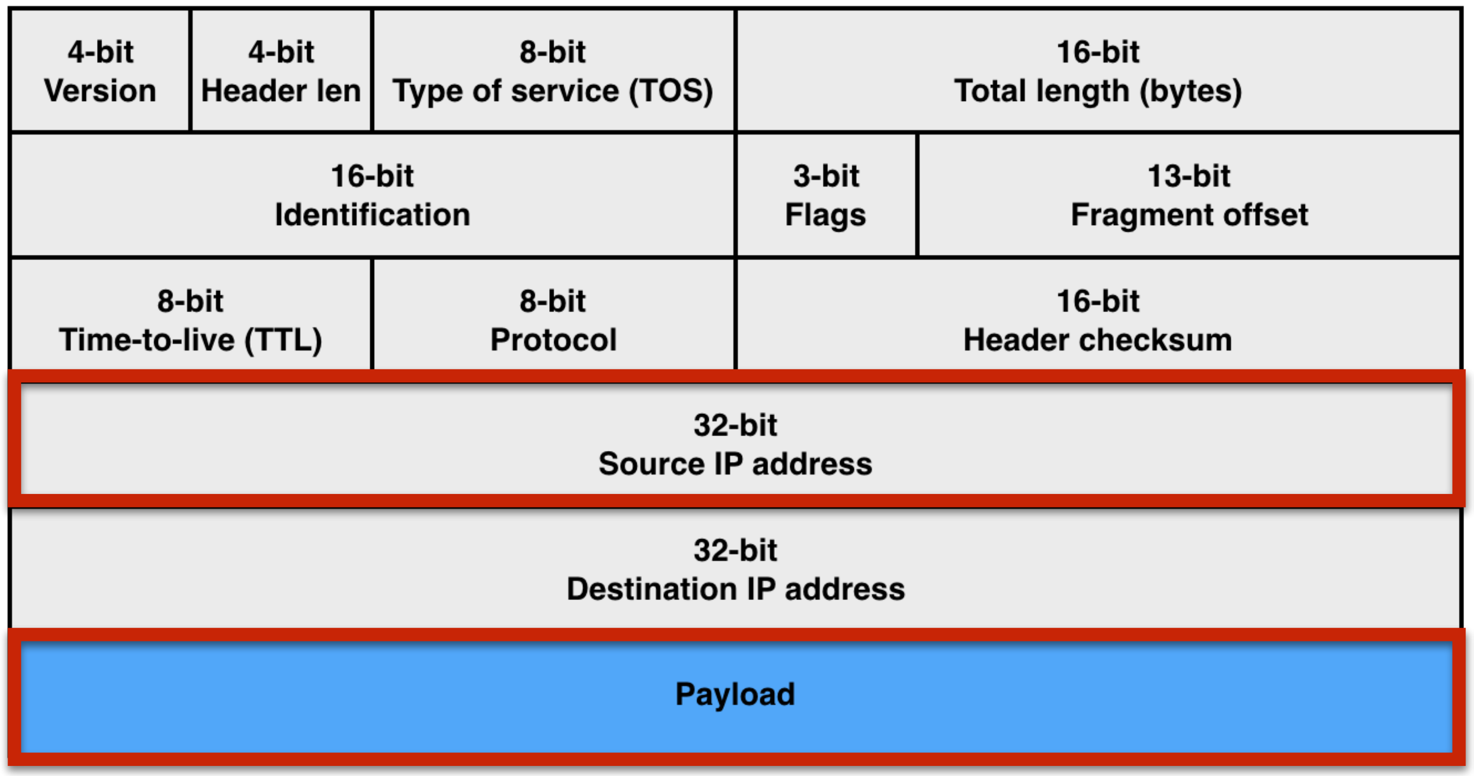


Source-spoof

There is nothing in IP that enforces that your source IP address is really “yours”

Attacks on IP



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There is nothing in IP that enforces that your source IP address is really "yours"

Eavesdrop / Tamper

IP provides no protection of the *payload* or *header*

Source-spoofing

- Why source-spoof?
  - Consider spam: send many emails from one computer
  - Easy defense: block many emails from a given (source) IP address
  - Easy countermeasure: spoof the source IP address
  - Counter-countermeasure?
- How do you know if a packet you receive has a spoofed source?

Salient network features

- Recall: The Internet operates via *destination-based routing*

- attacker: pkt (spoofed source) -> destination
  destination: pkt -> spoofed source

- In other words, the response goes to the spoofed source, *not* the attacker

Defending against source-spoofing

- How do you know if a packet you receive has a spoofed source?
    - Send a challenge packet to the (possibly spoofed) source (e.g., a difficult to guess, random nonce)
    - If the recipient can answer the challenge, then likely that the source was not spoofed

- So do you have to do this with every packet??
    - Every packet should have something that’s difficult to guess
    - Recall the query ID in the DNS queries! Easy to predict => Kaminsky attack

Source spoofing

- Why source-spoof?
  - Consider DoS attacks: generate as much traffic as possible to congest the victim's network
  - Easy defense: block all traffic from a given source near the edge of your network
  - Easy countermeasure: spoof the source address
- Challenges won't help here; the damage has been done by the time the packets reach the core of our network
- Ideally, detect such spoofing *near the source*

Egress filtering

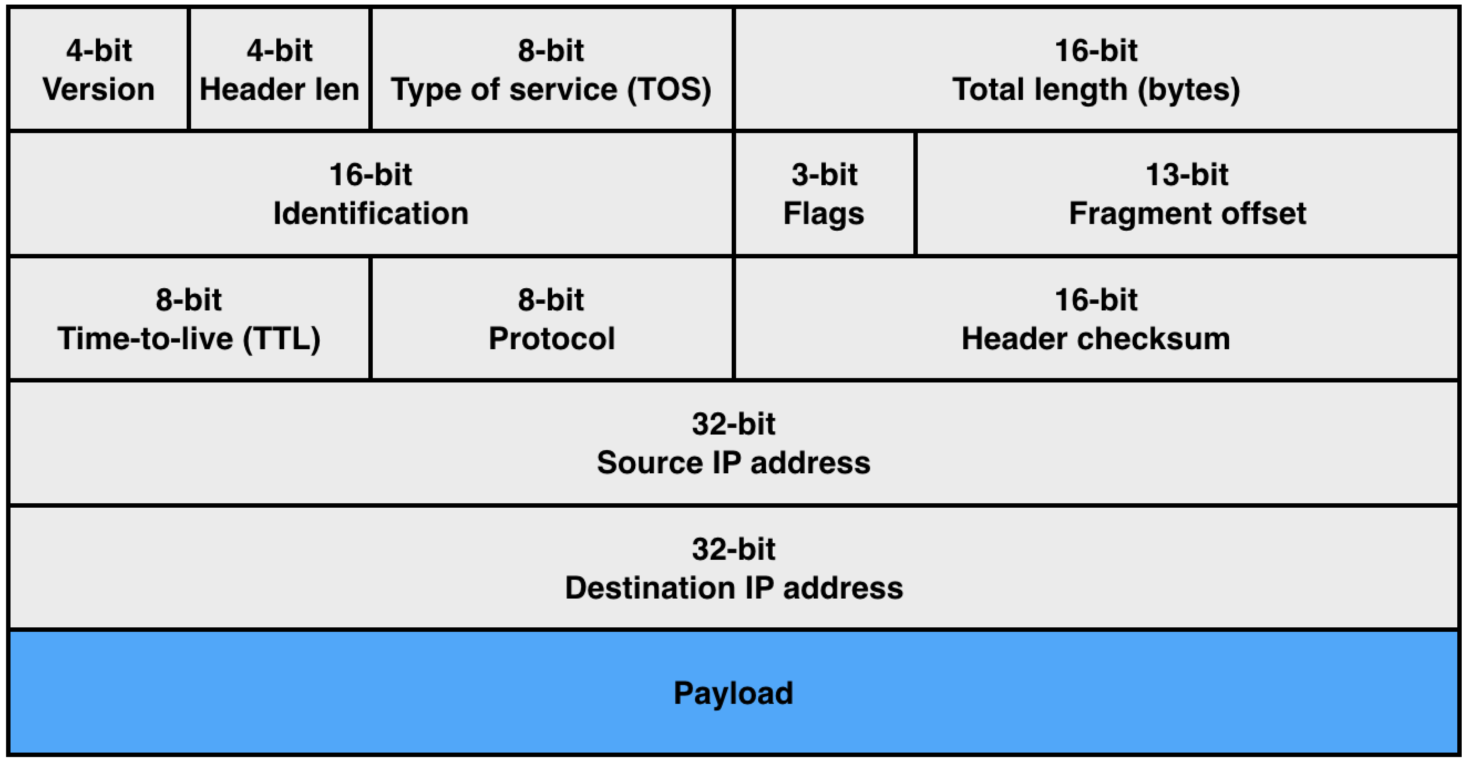
- The point (router/switch) at which traffic *enters* your network is the *ingress point*

- The point (router/switch) at which traffic *leaves* your network is the *egress point*

- You don't know who owns all IP addresses in the world, but you *do* know who in *your own network* gets what IP addresses
    - If you see a packet with a source IP address that doesn't belong to your network trying to cross your egress point, then *drop it*

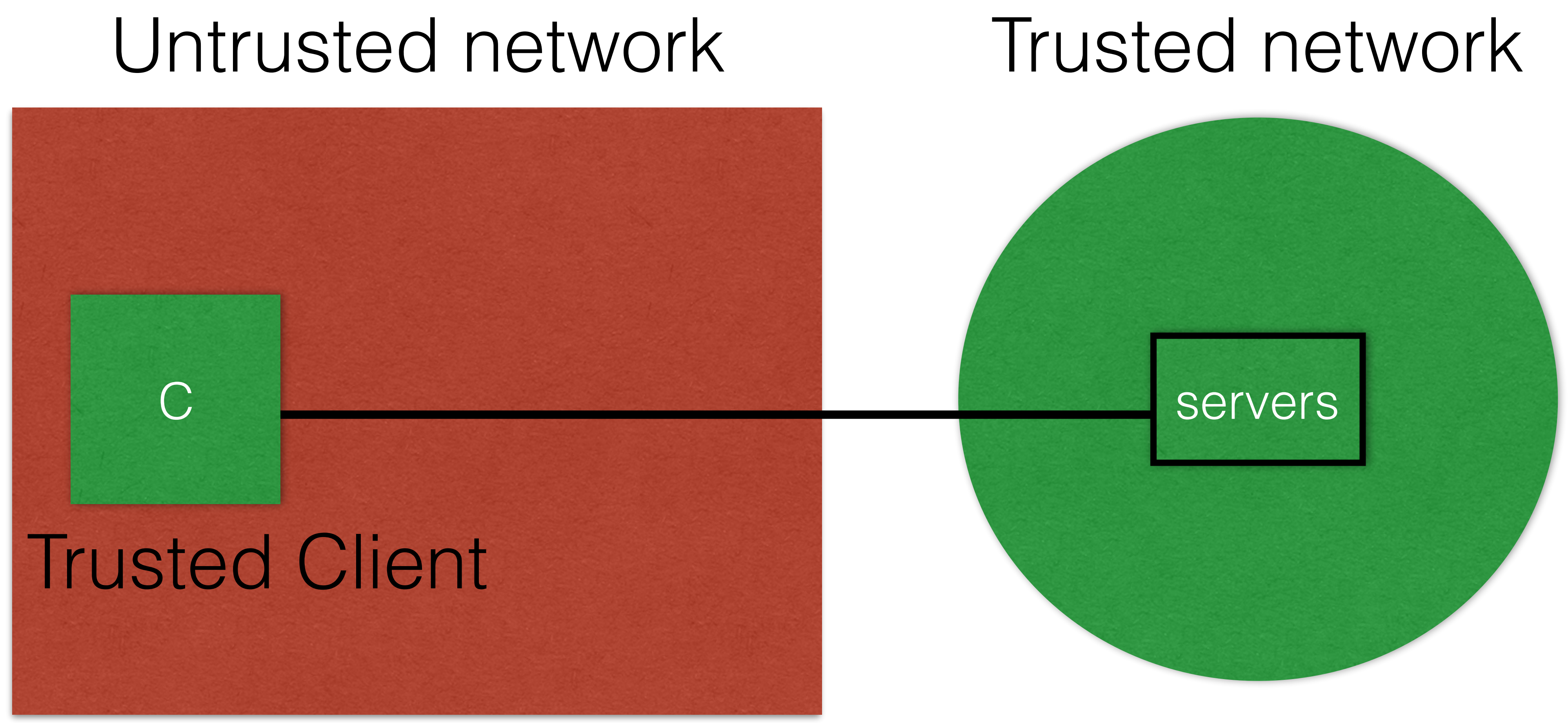
Egress filtering is not widely deployed

Eavesdropping / Tampering



- No security built into IP
- => Deploy secure IP *over IP*

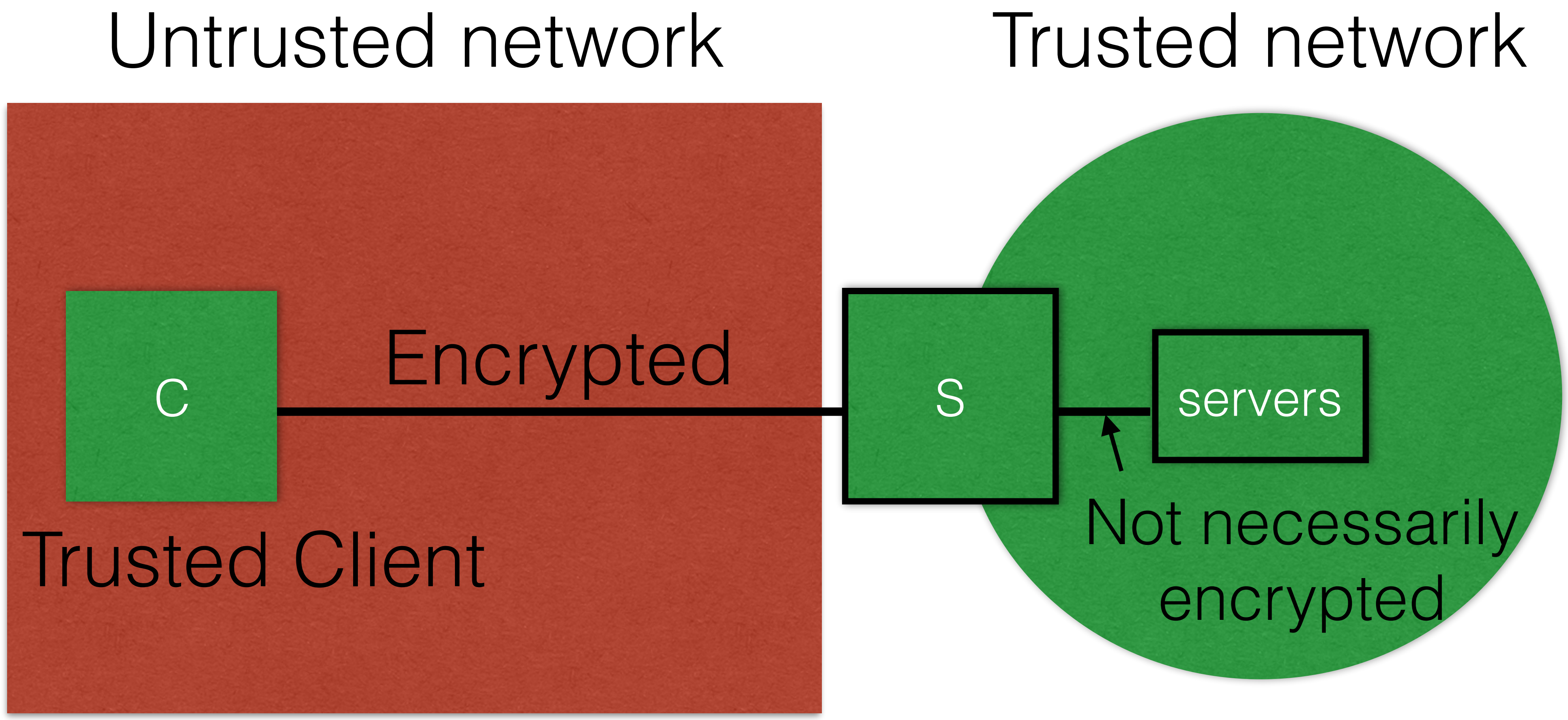
Virtual Private Networks (VPNs)



Goal: Allow the client to connect to the trusted network from within an untrusted network

Example: Connect to your company's network (for payroll, file access, etc.) while visiting a competitor's office

Virtual Private Networks (VPNs)



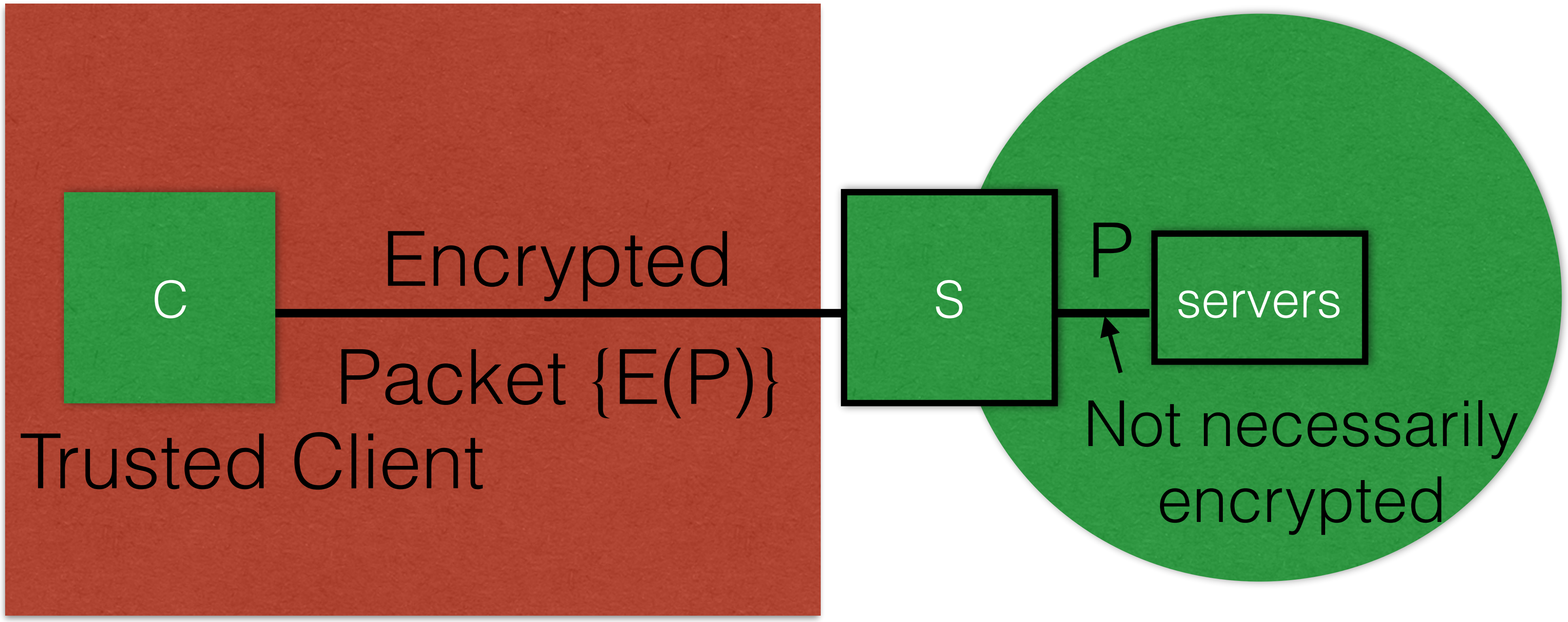
Idea: A VPN “client” and “server” together create end-to-end encryption/authentication

Predominate way of doing this: IPSec

IPSec

- Operates in a few different modes
  - Transport mode: Simply encrypt the payload but not the headers
  - Tunnel mode: Encrypt the payload *and* the headers
- But how do you encrypt the headers? How does routing work?
  - Encrypt the entire IP packet and make that the payload of another IP packet
  -

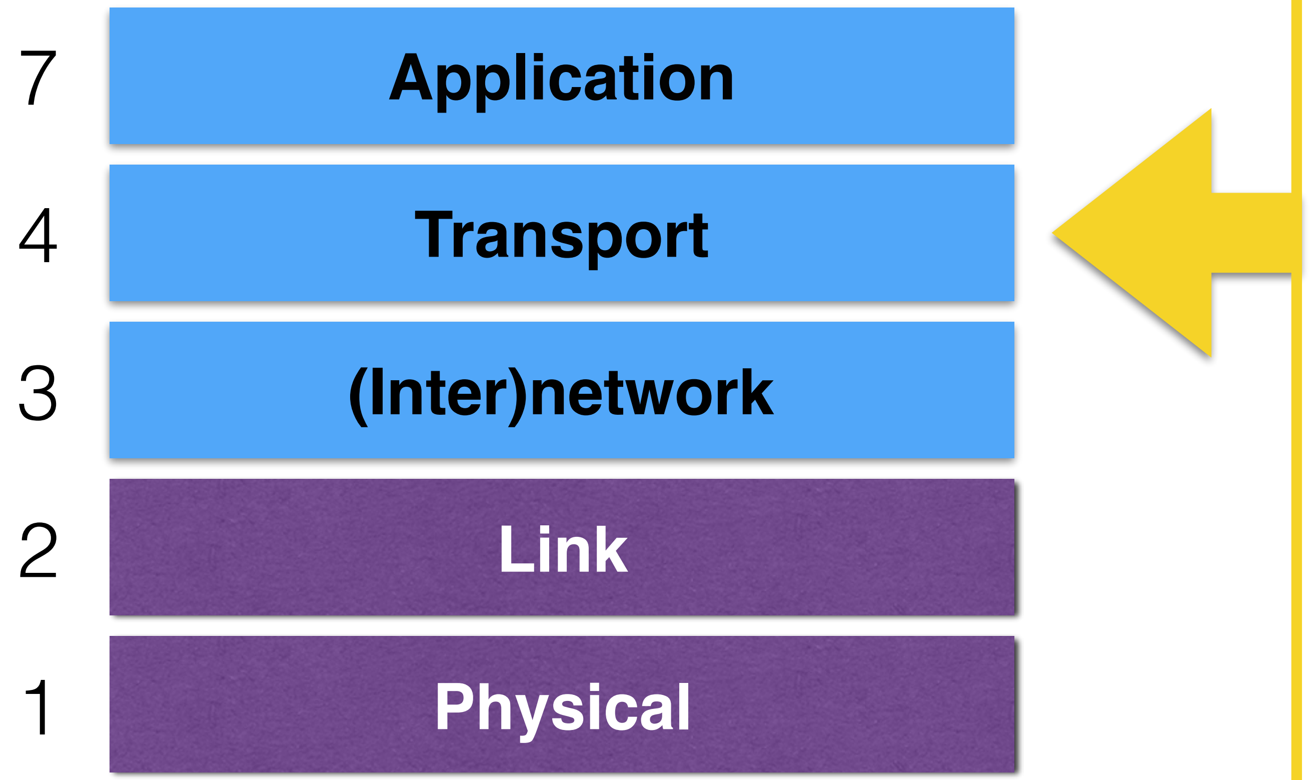
Tunnel mode



The VPN server decrypts and then sends the payload (itself a full IP packet) as if it had just received it from the network

From the client/servers' perspective:
Looks like the client is physically connected to the network!

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

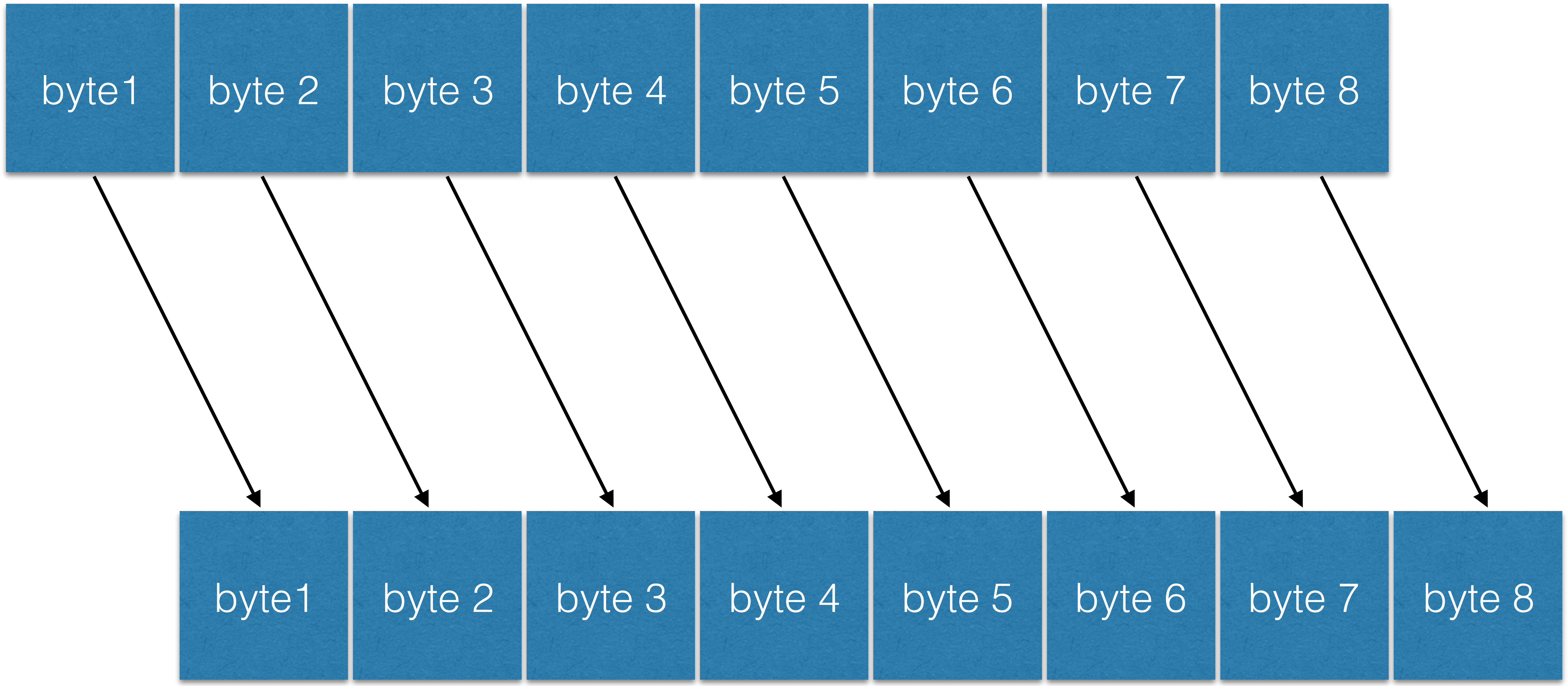
TCP’s bytestream service

- 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

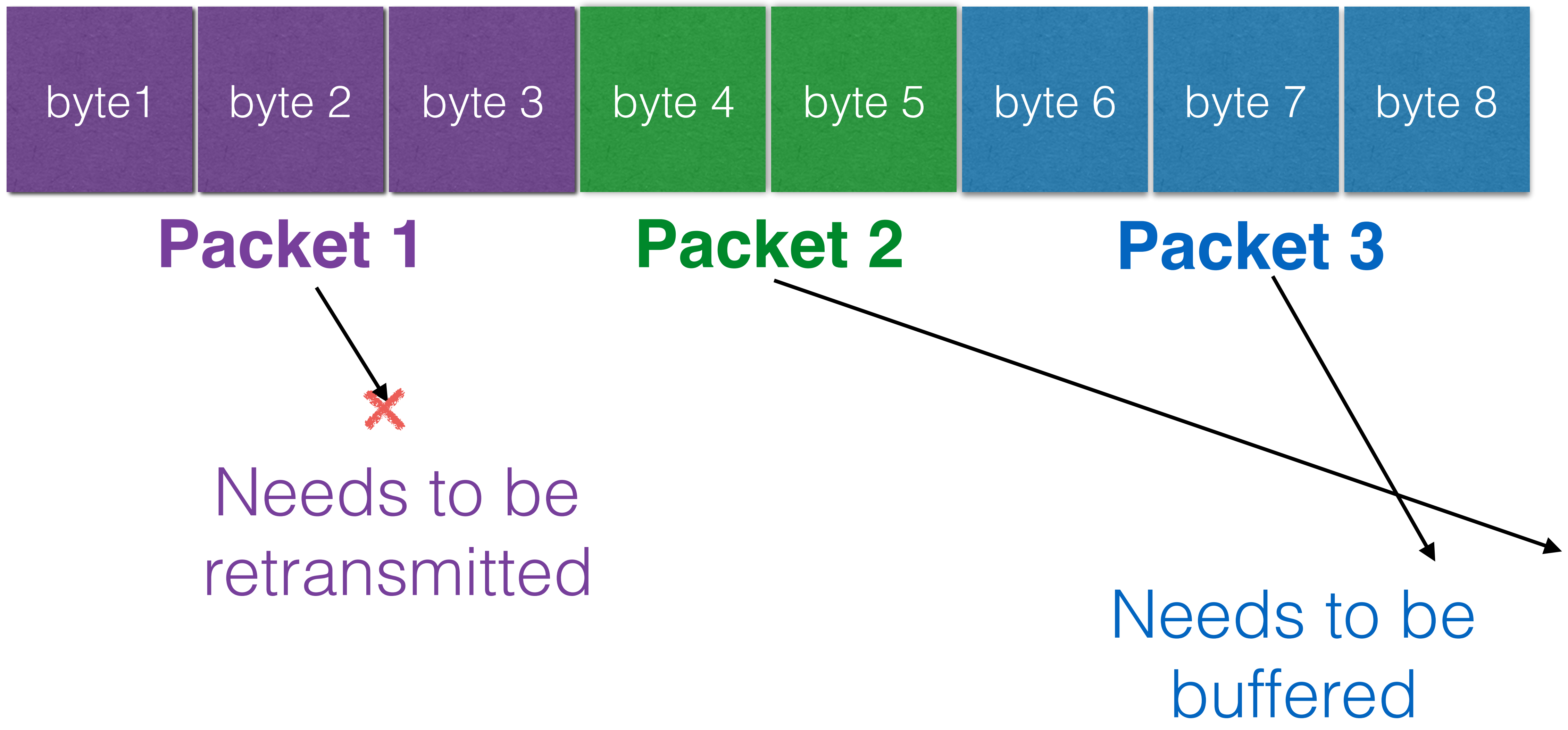
Process A on host H1



Process B on host H2

TCP bytestream service

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



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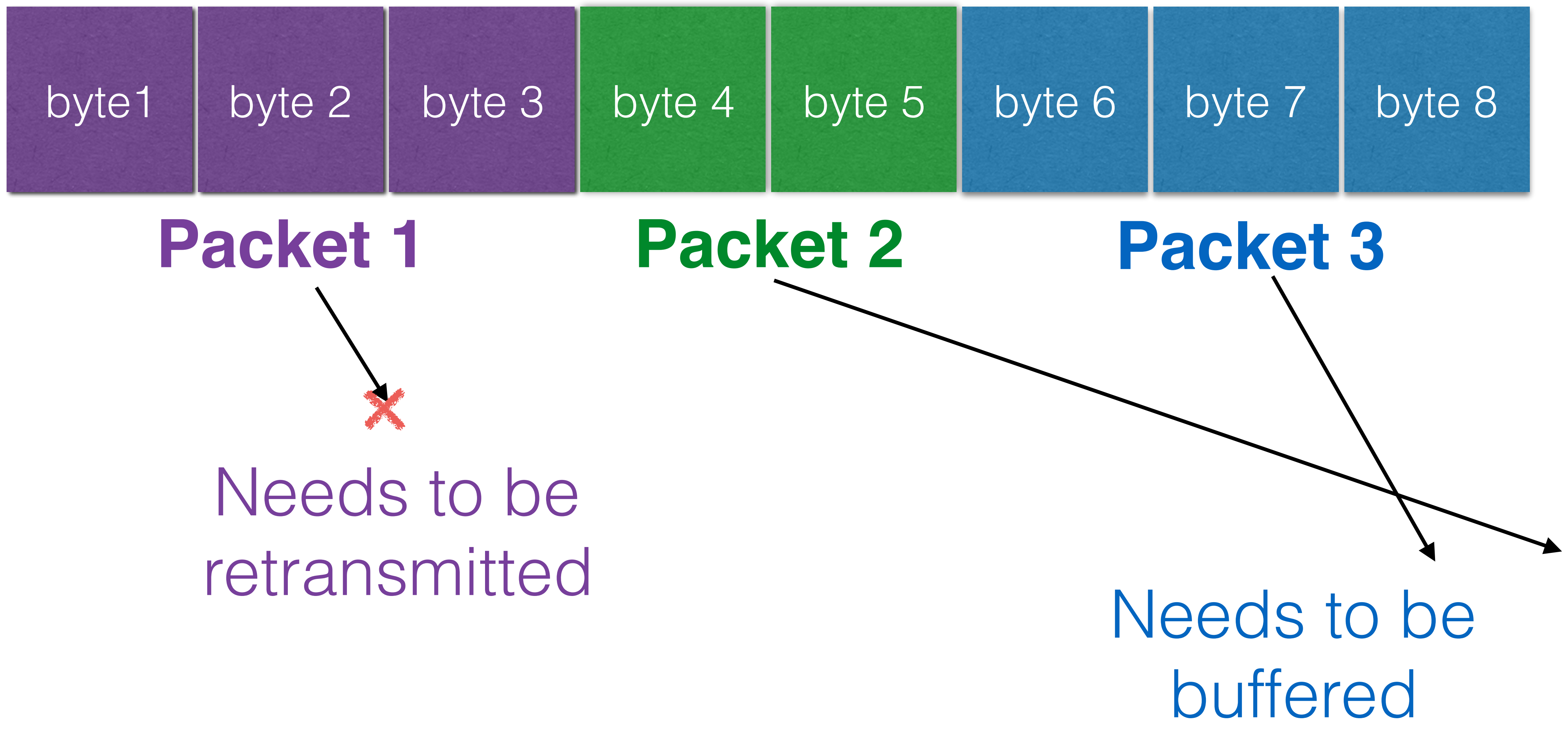
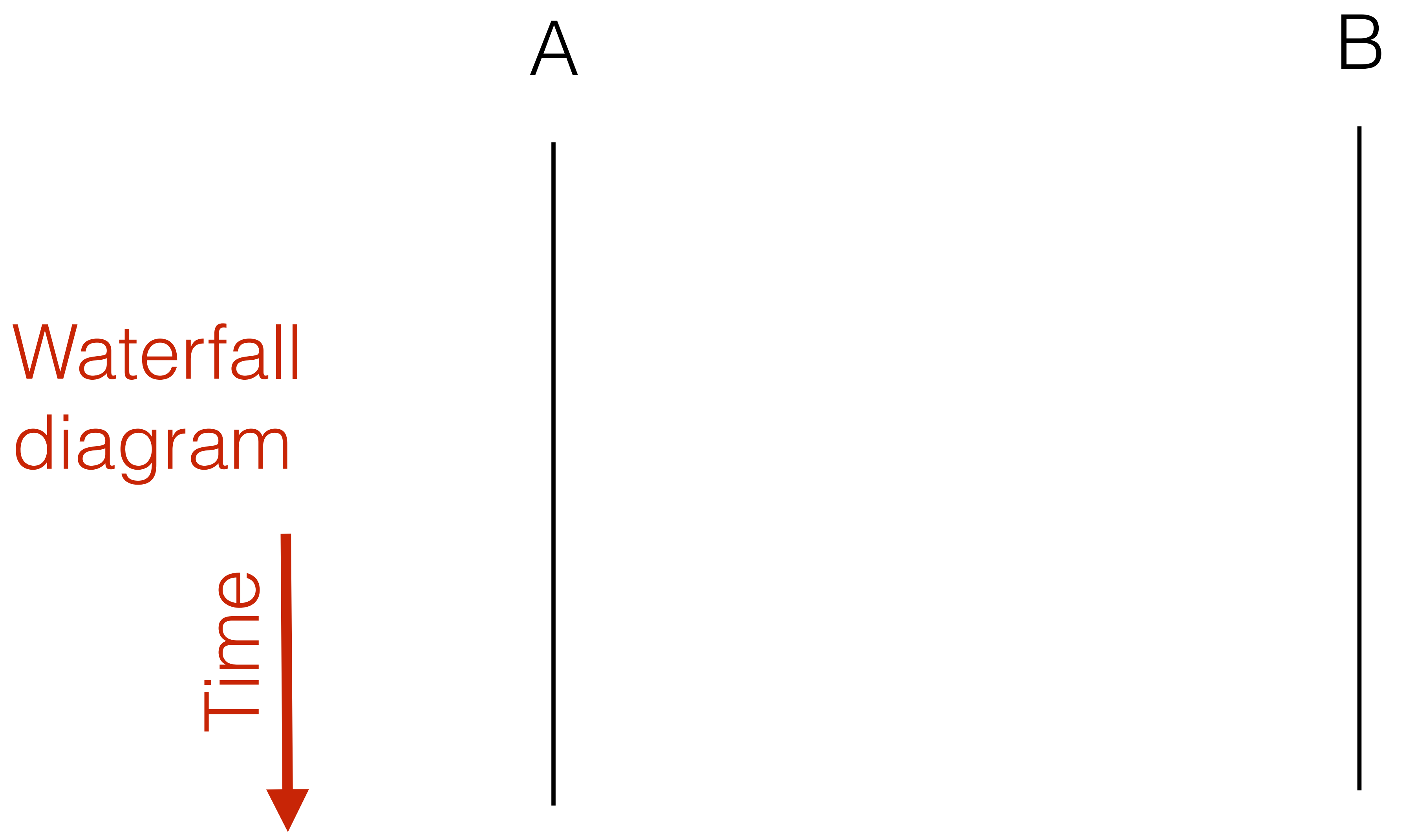


TCP's first job: achieve the abstraction while hiding the reality from the application

How does TCP achieve reliability?



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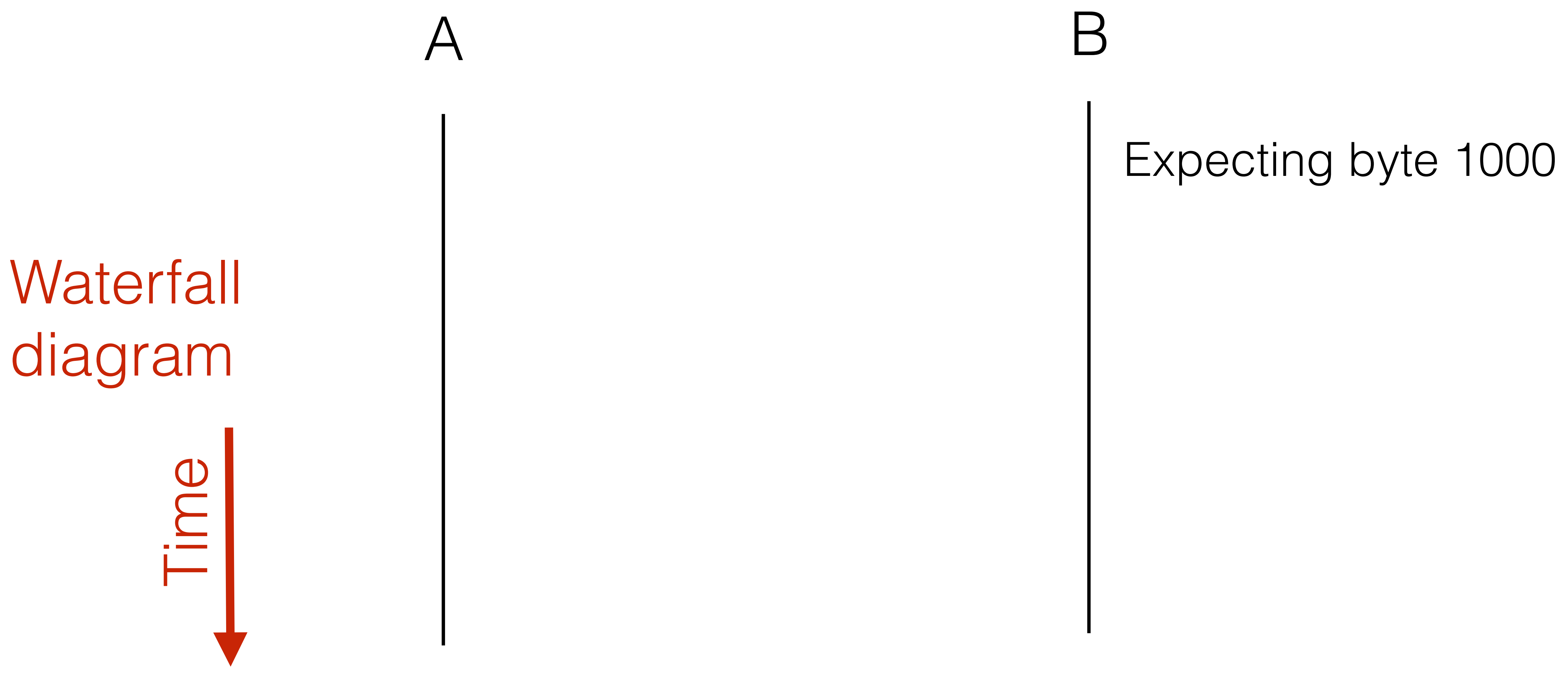

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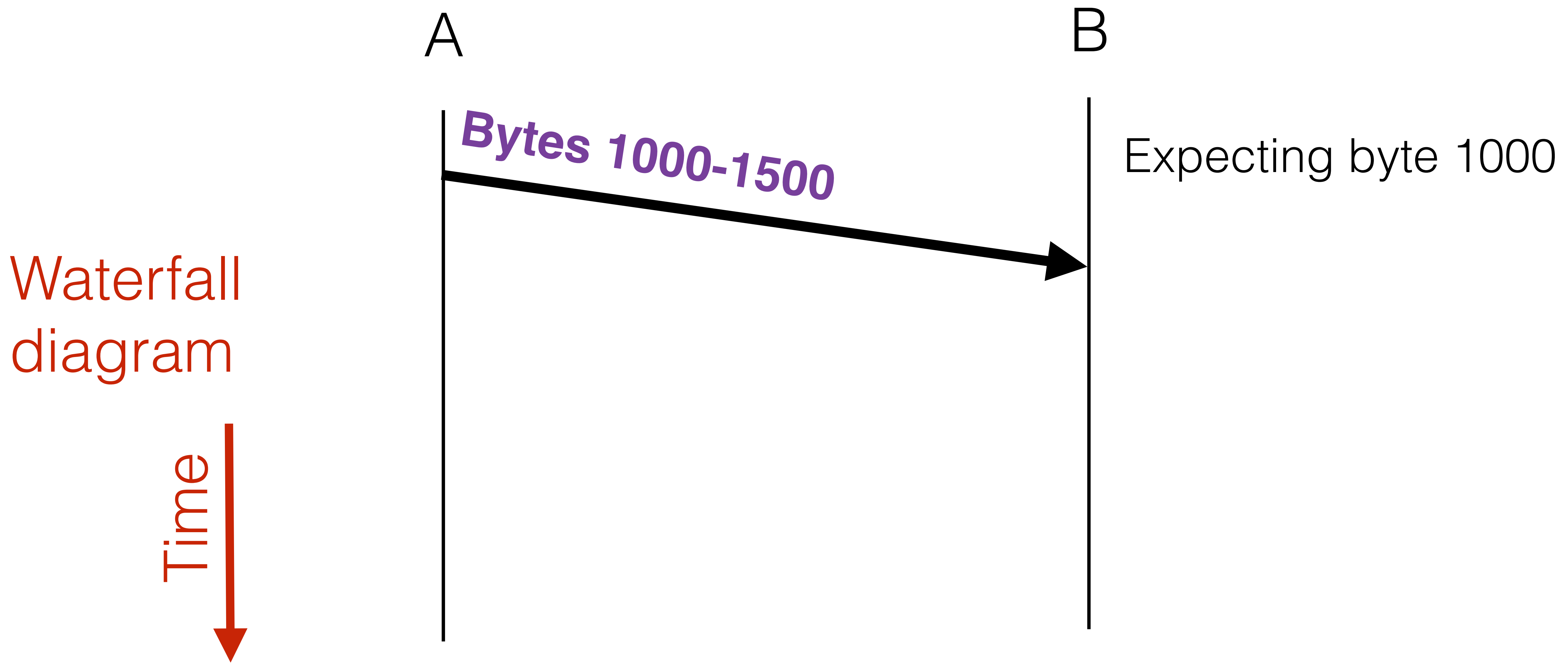

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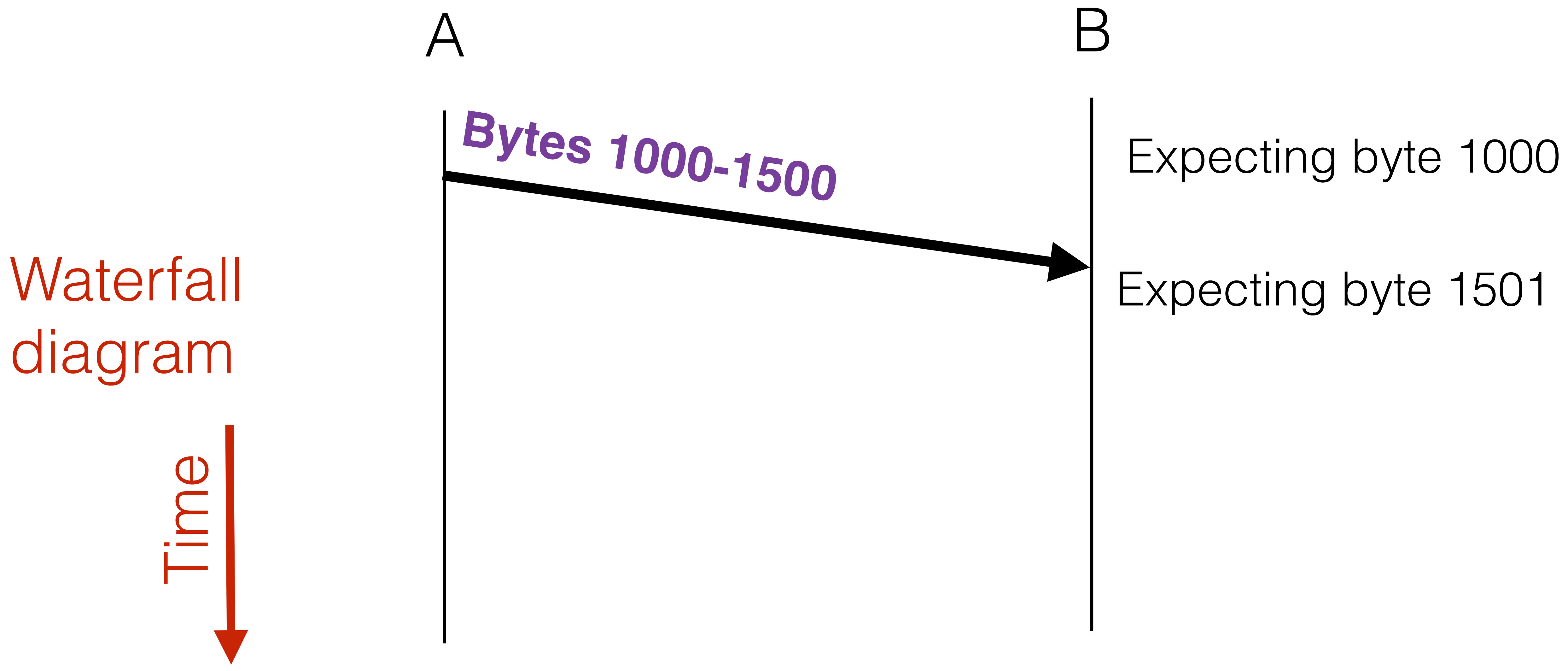

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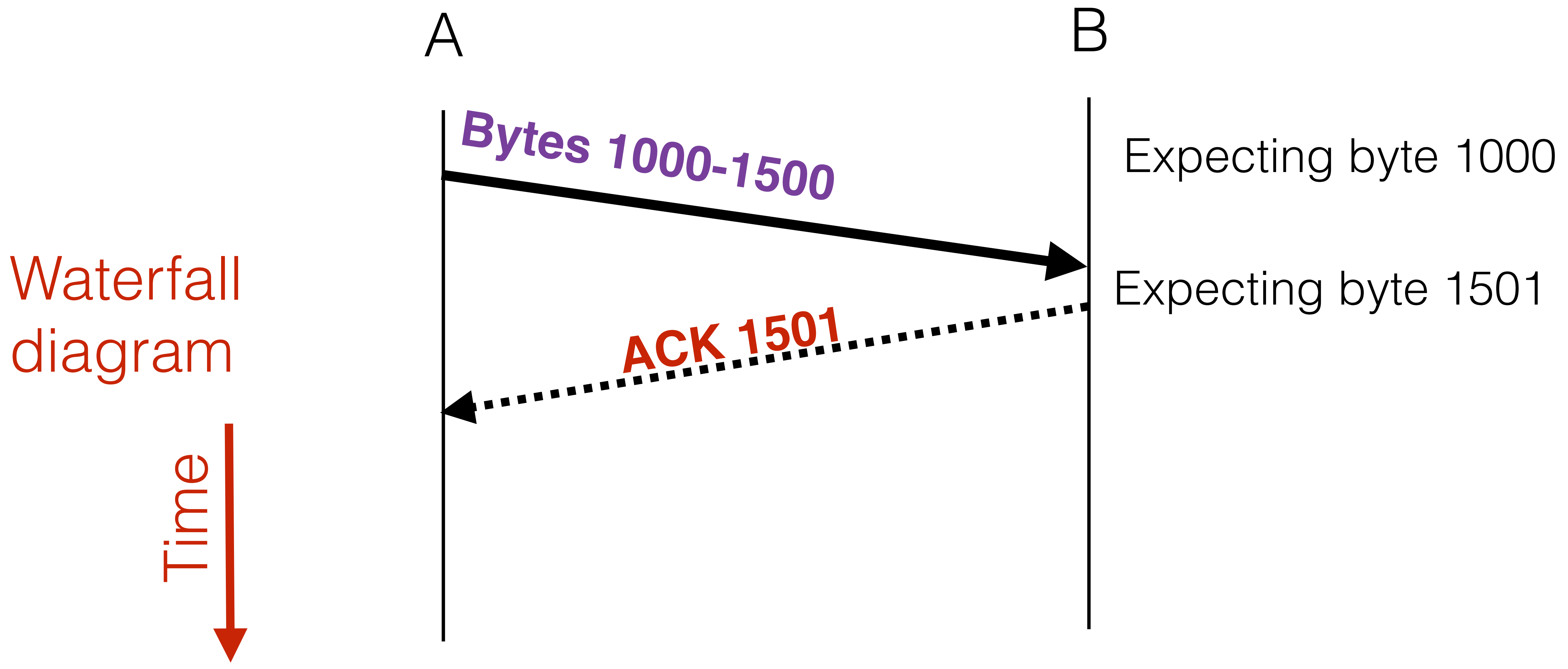

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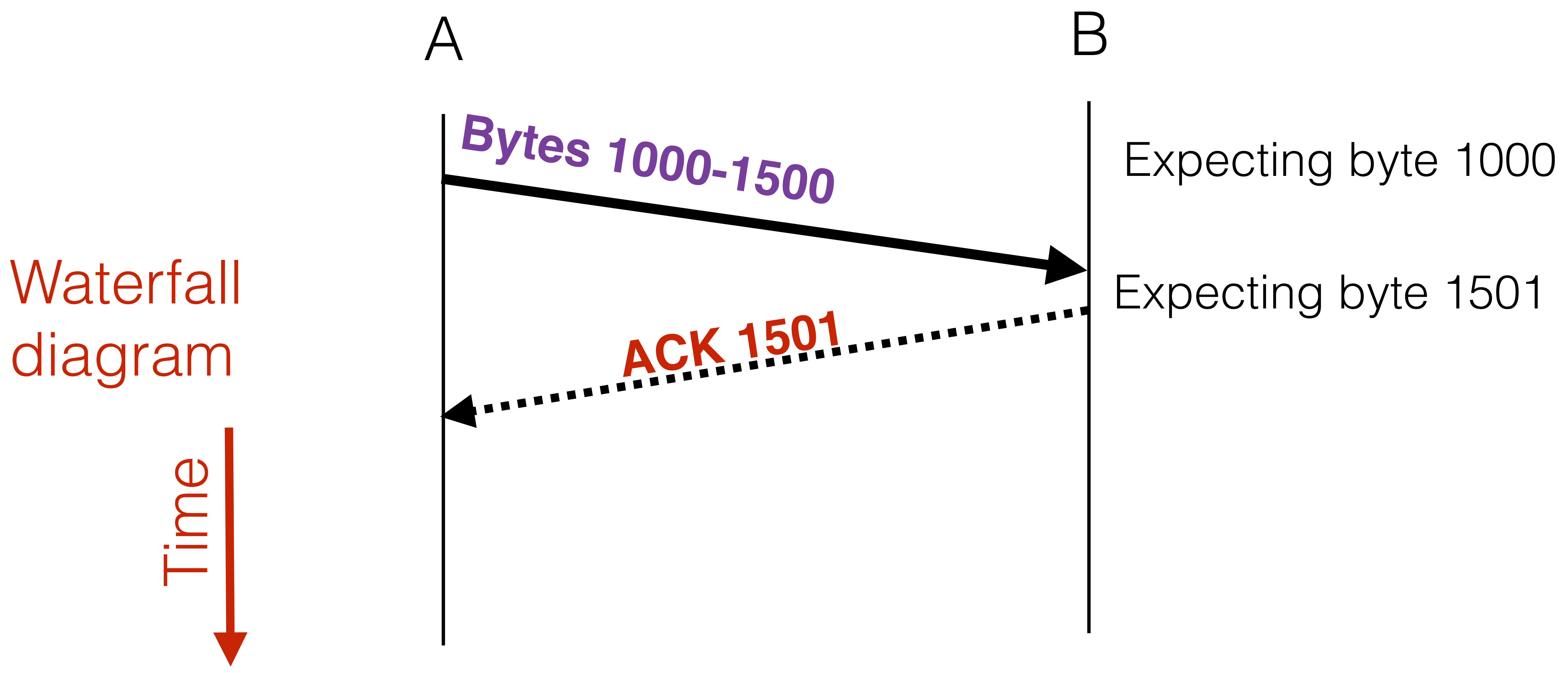

Reliability through acknowledgments
to determine whether something was received.

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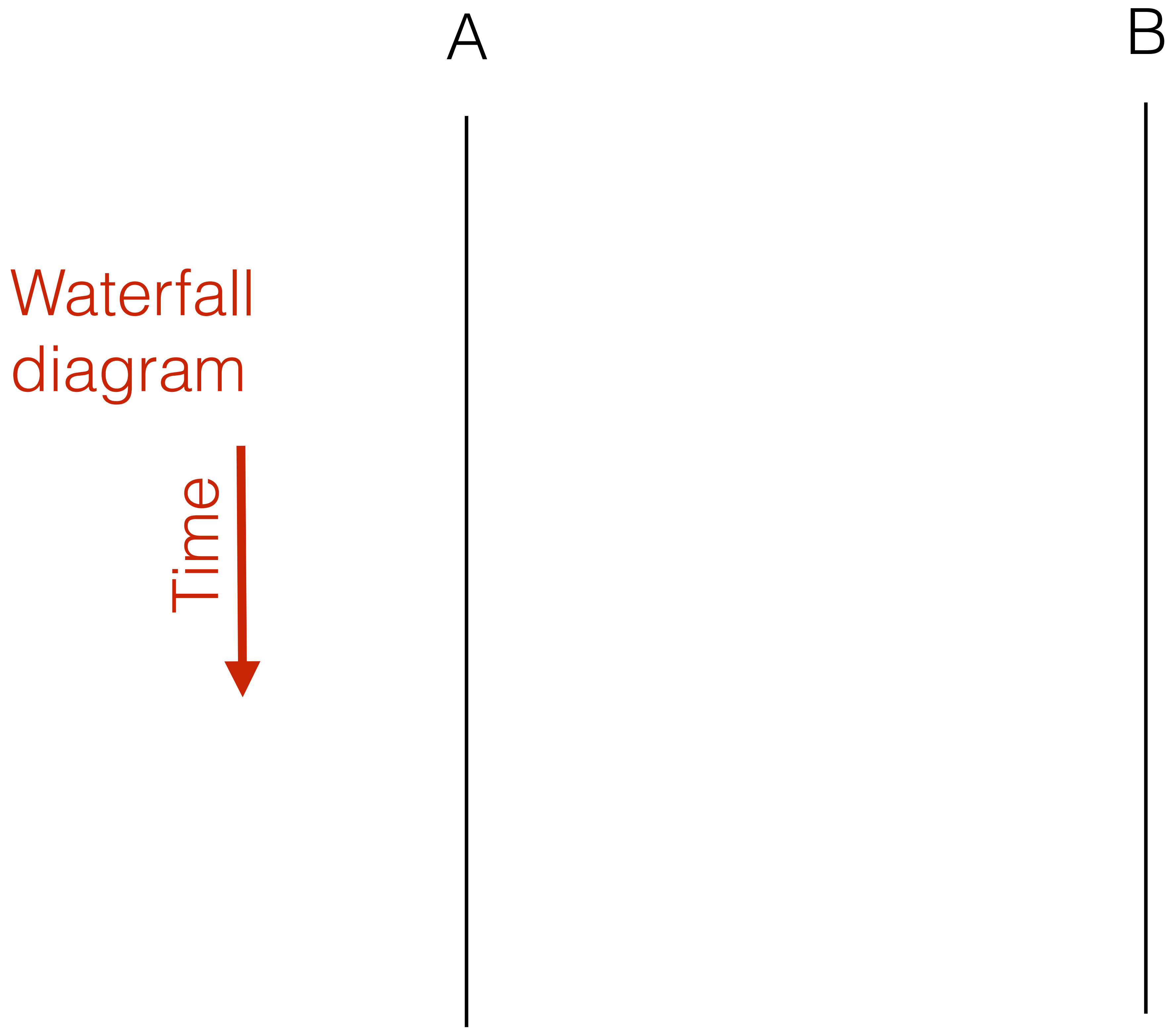

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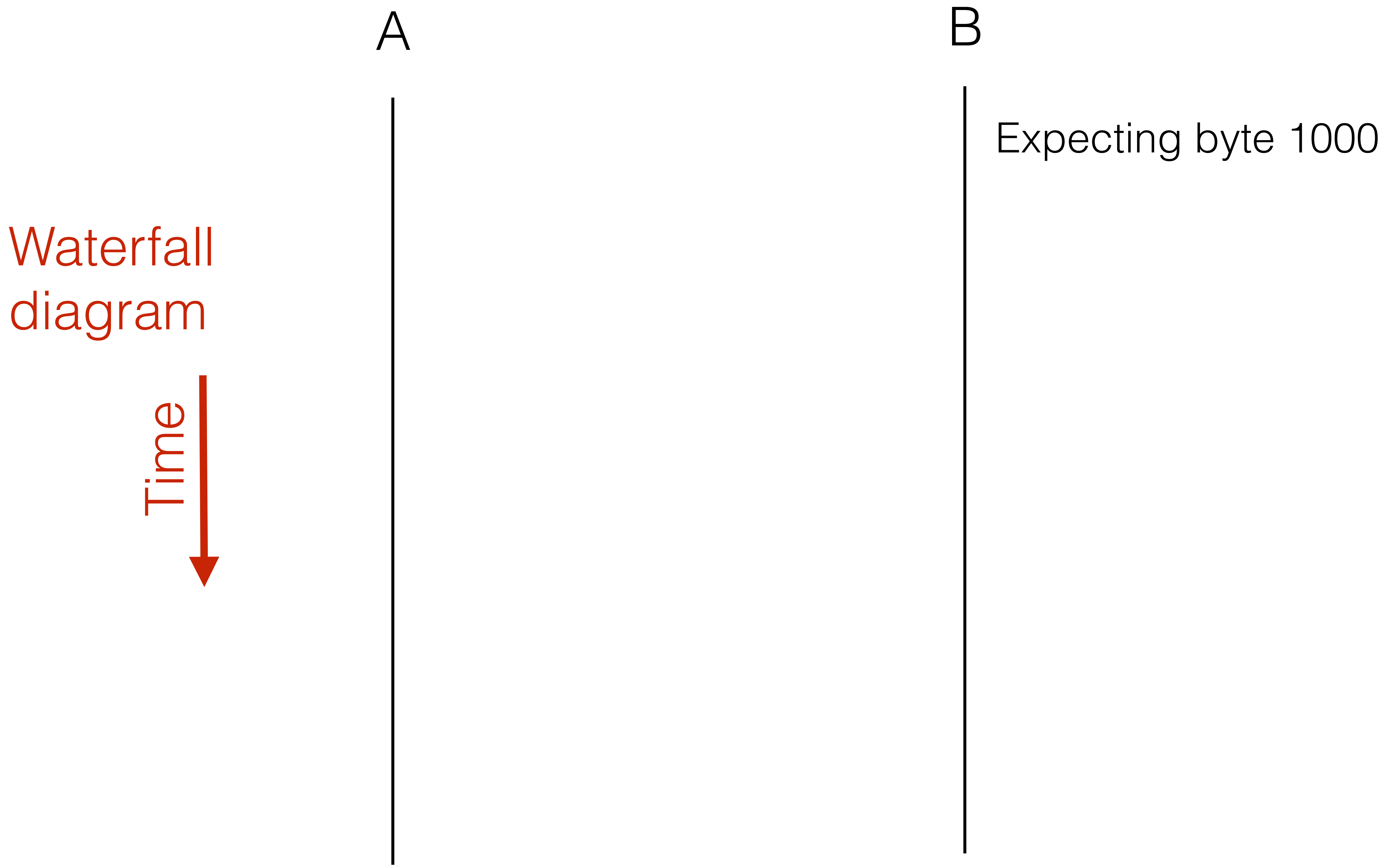

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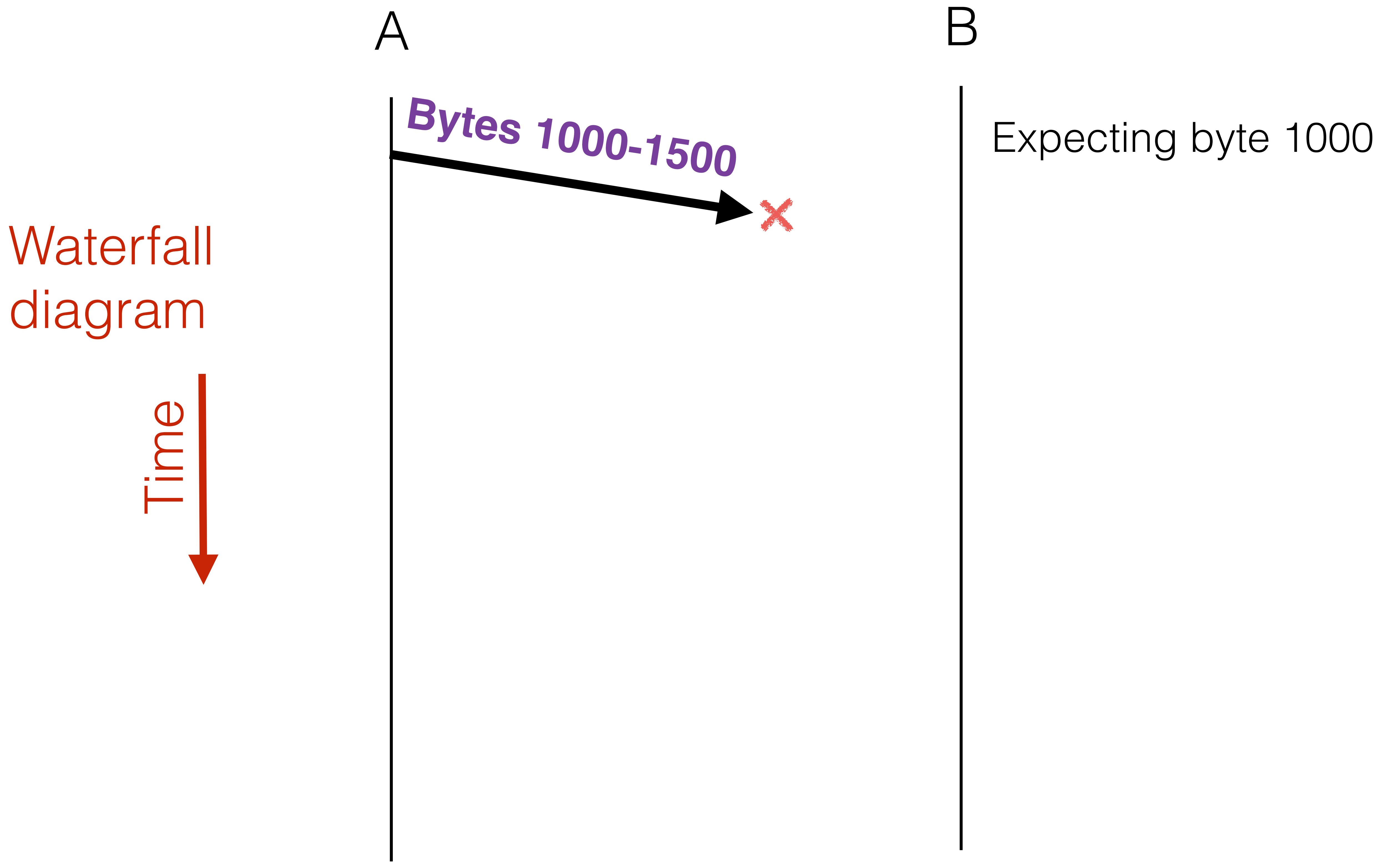

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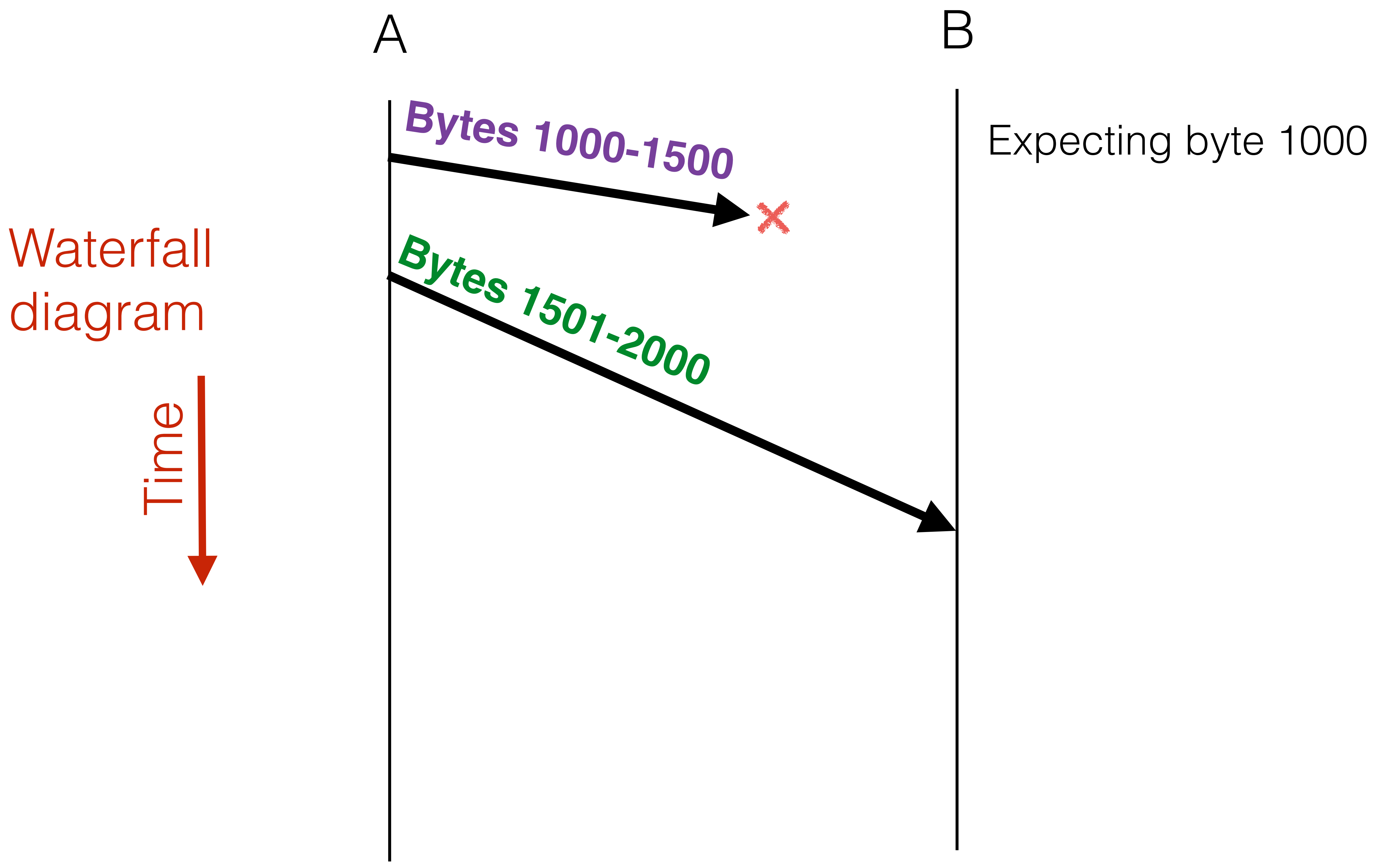

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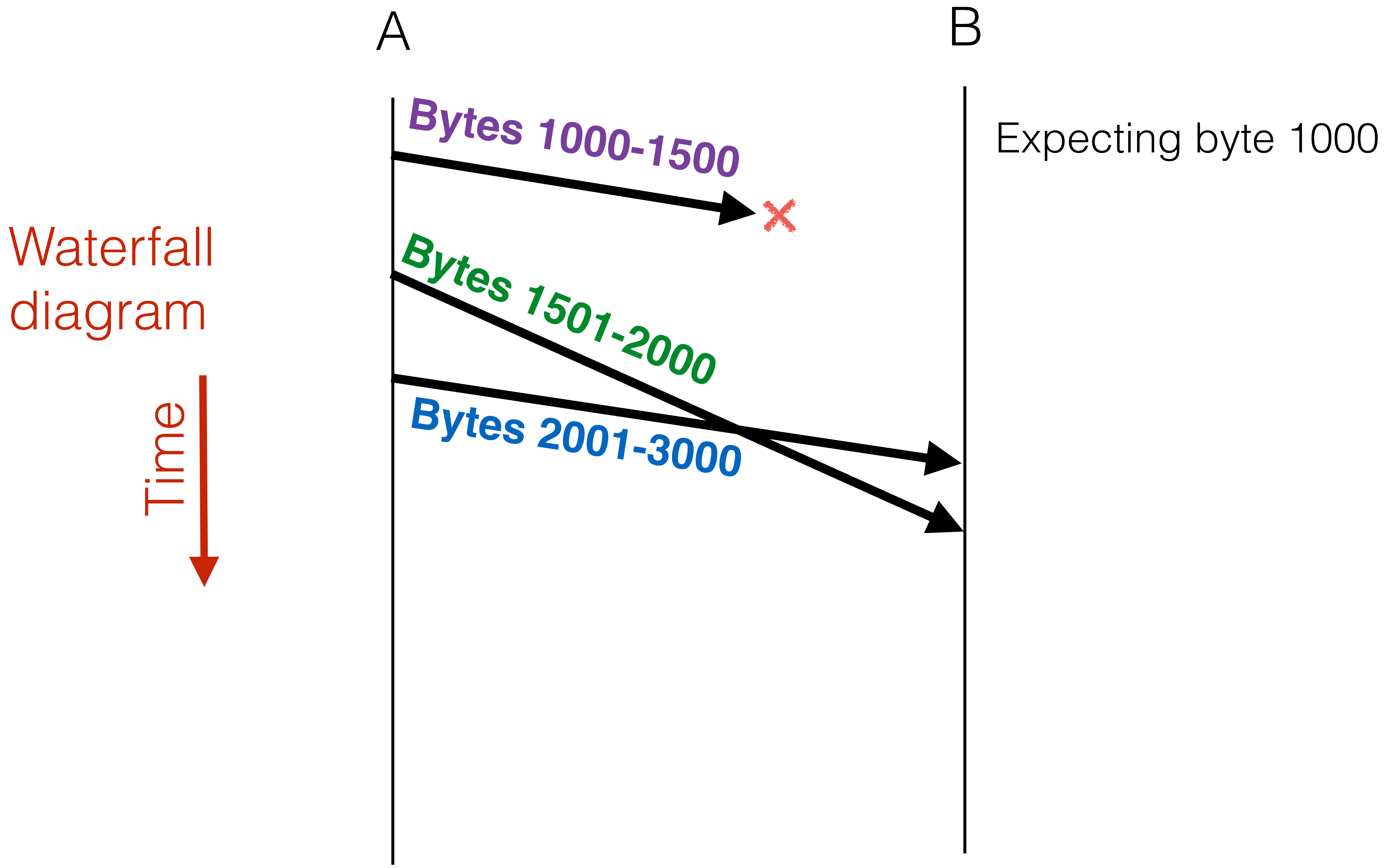

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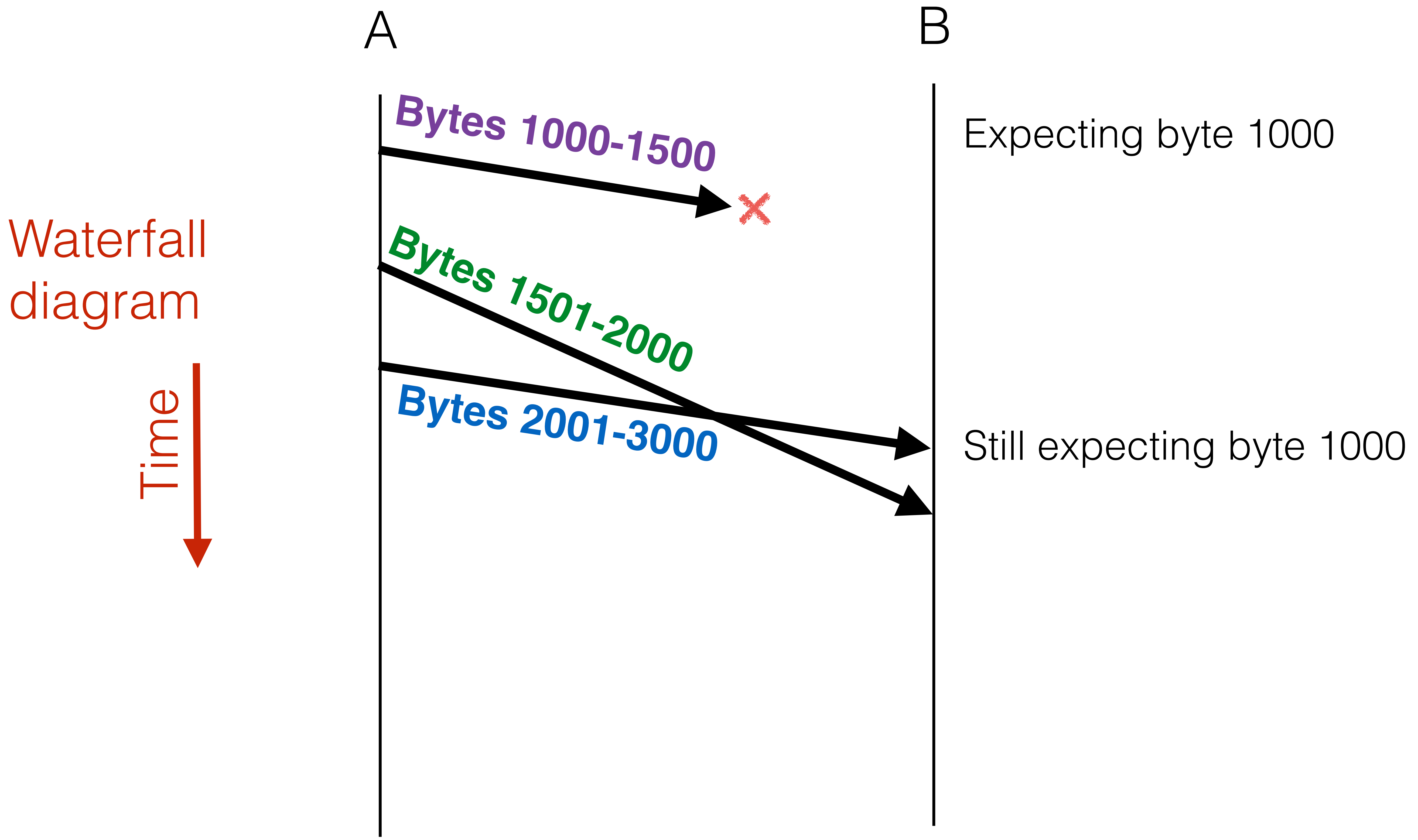

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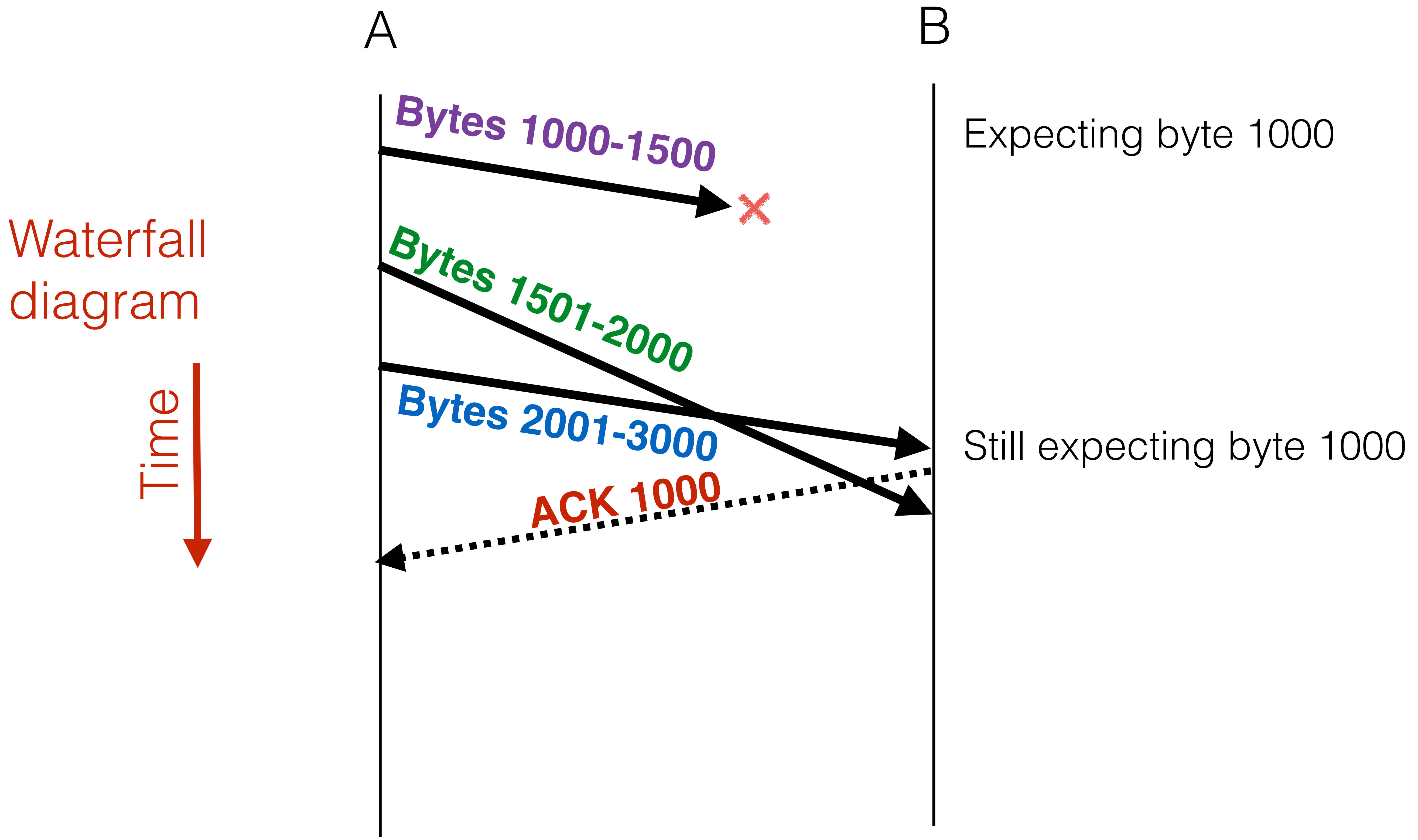

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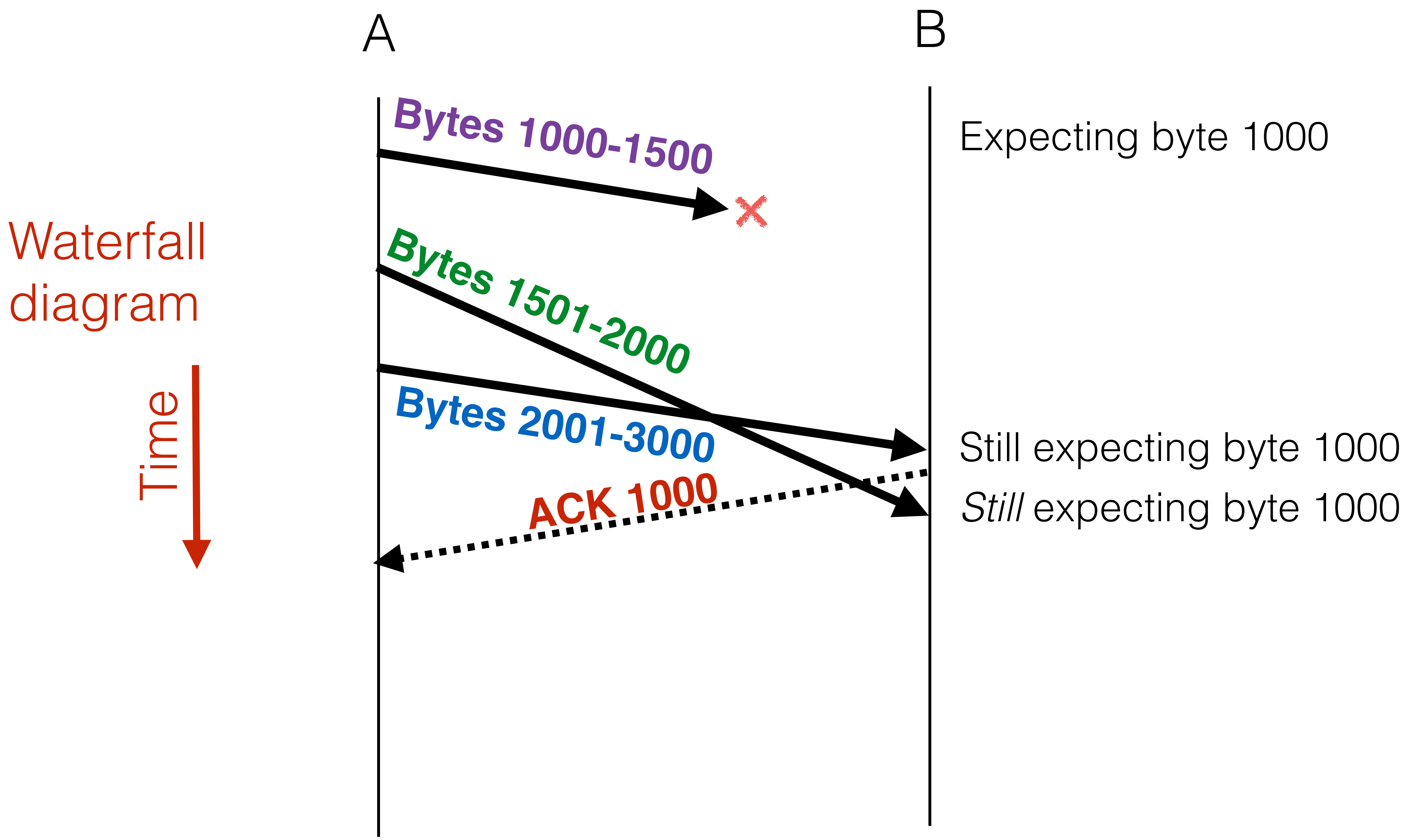

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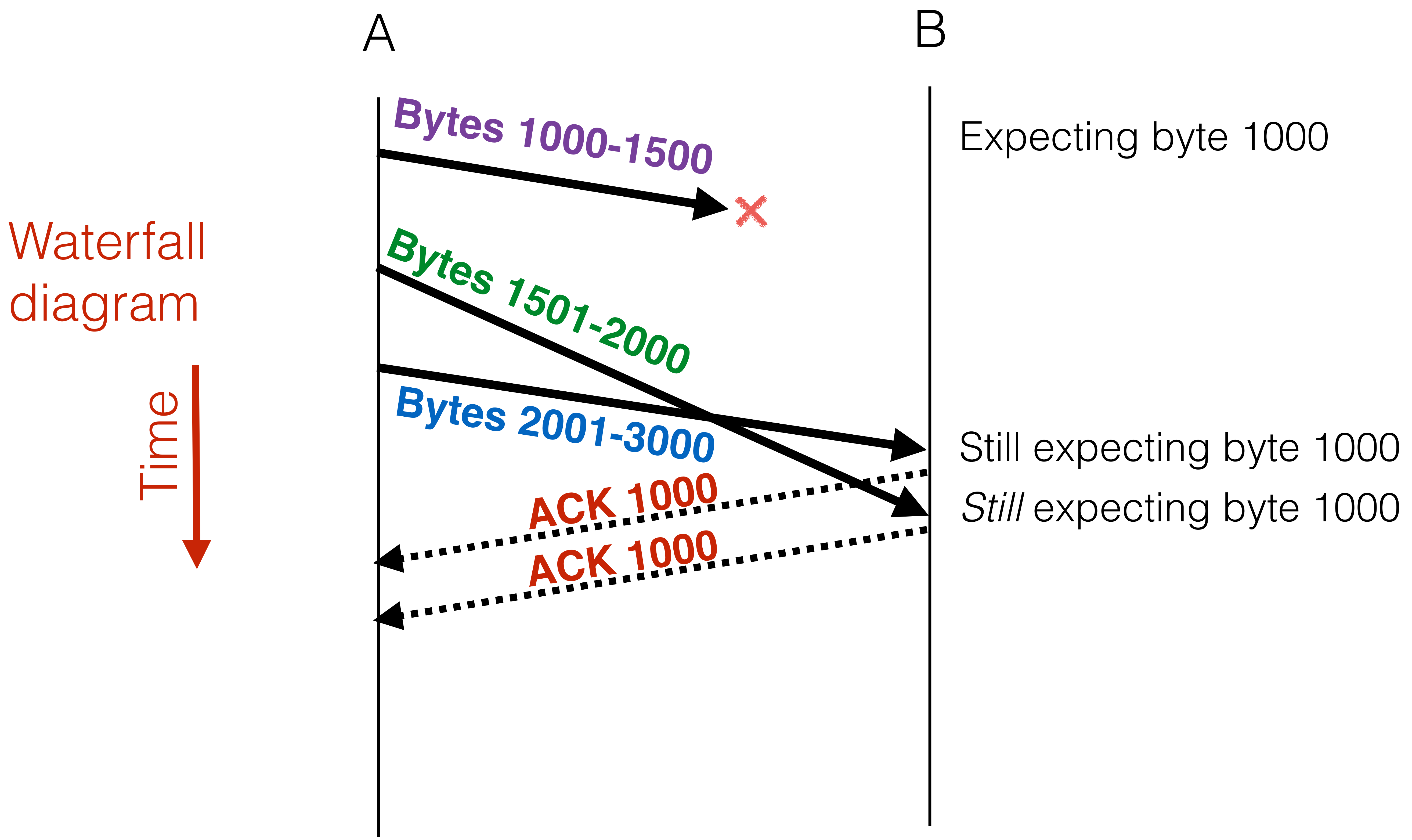

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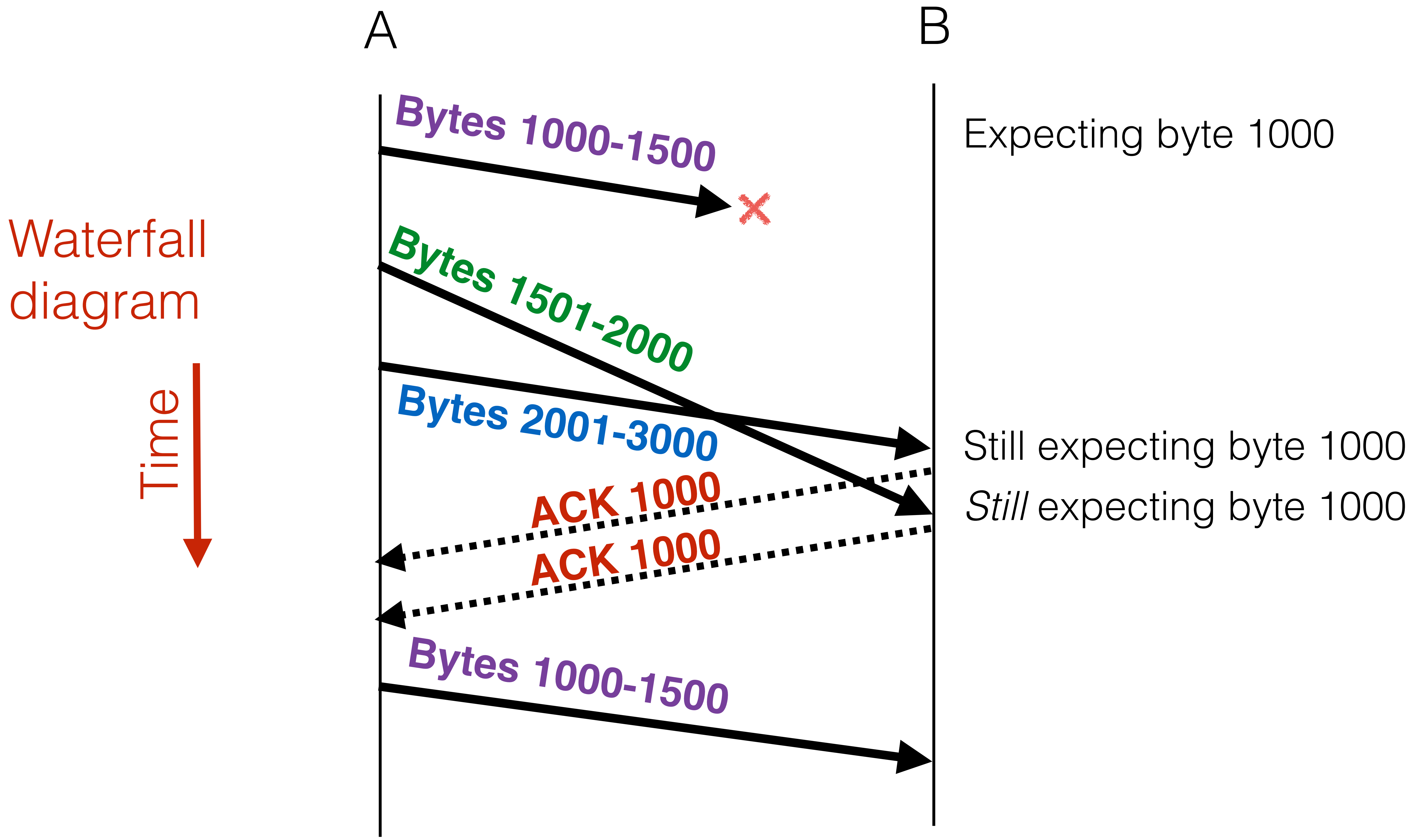

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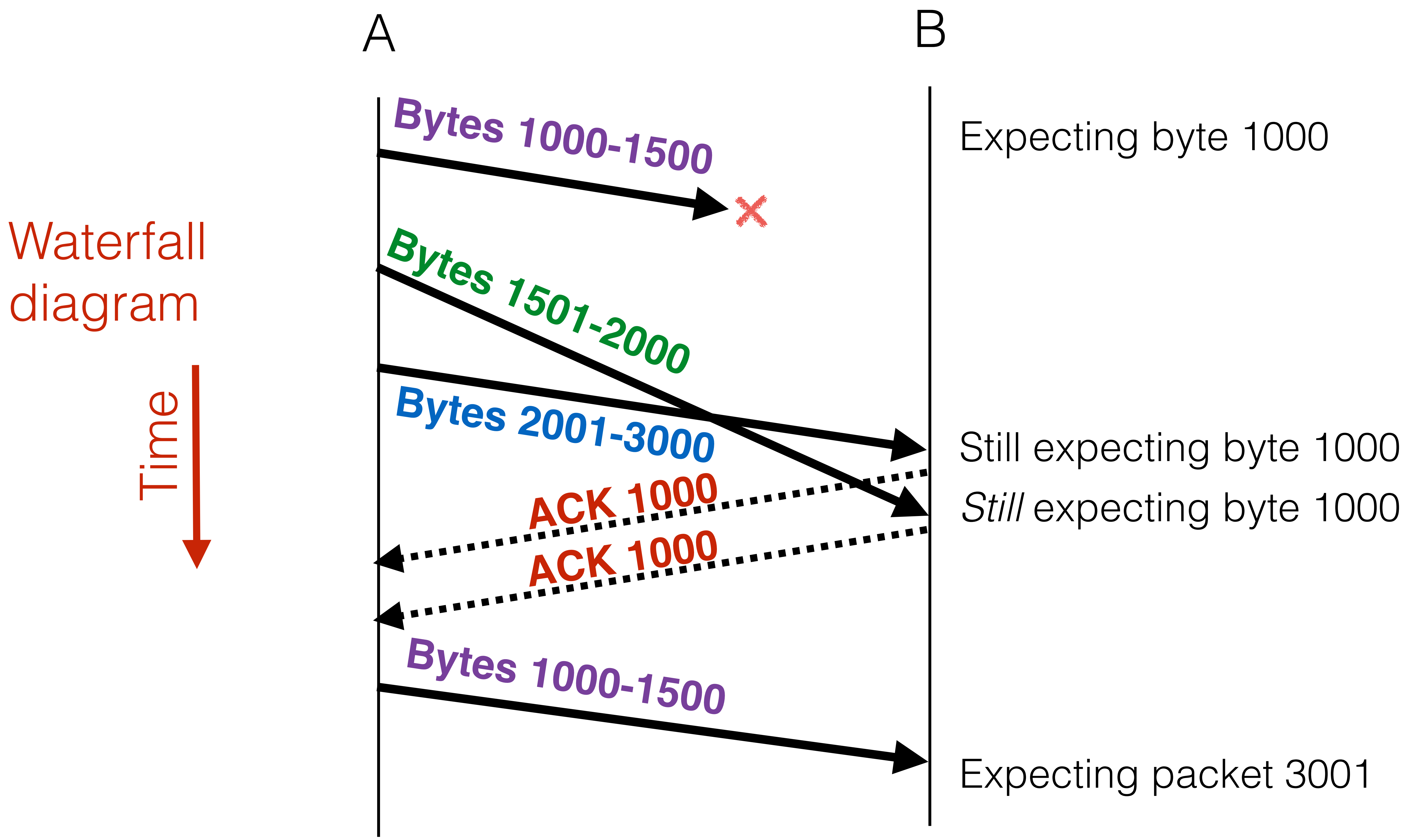

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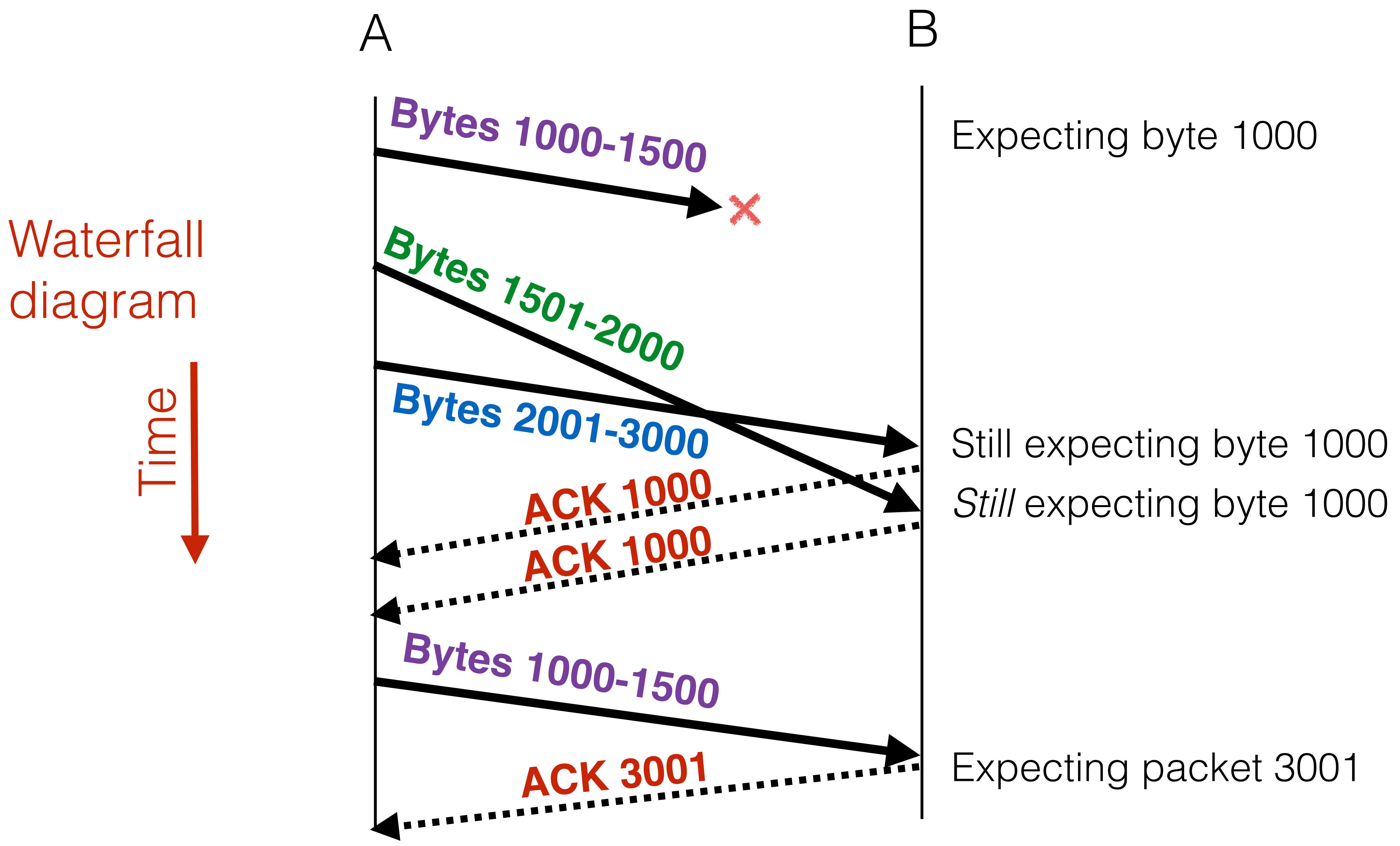

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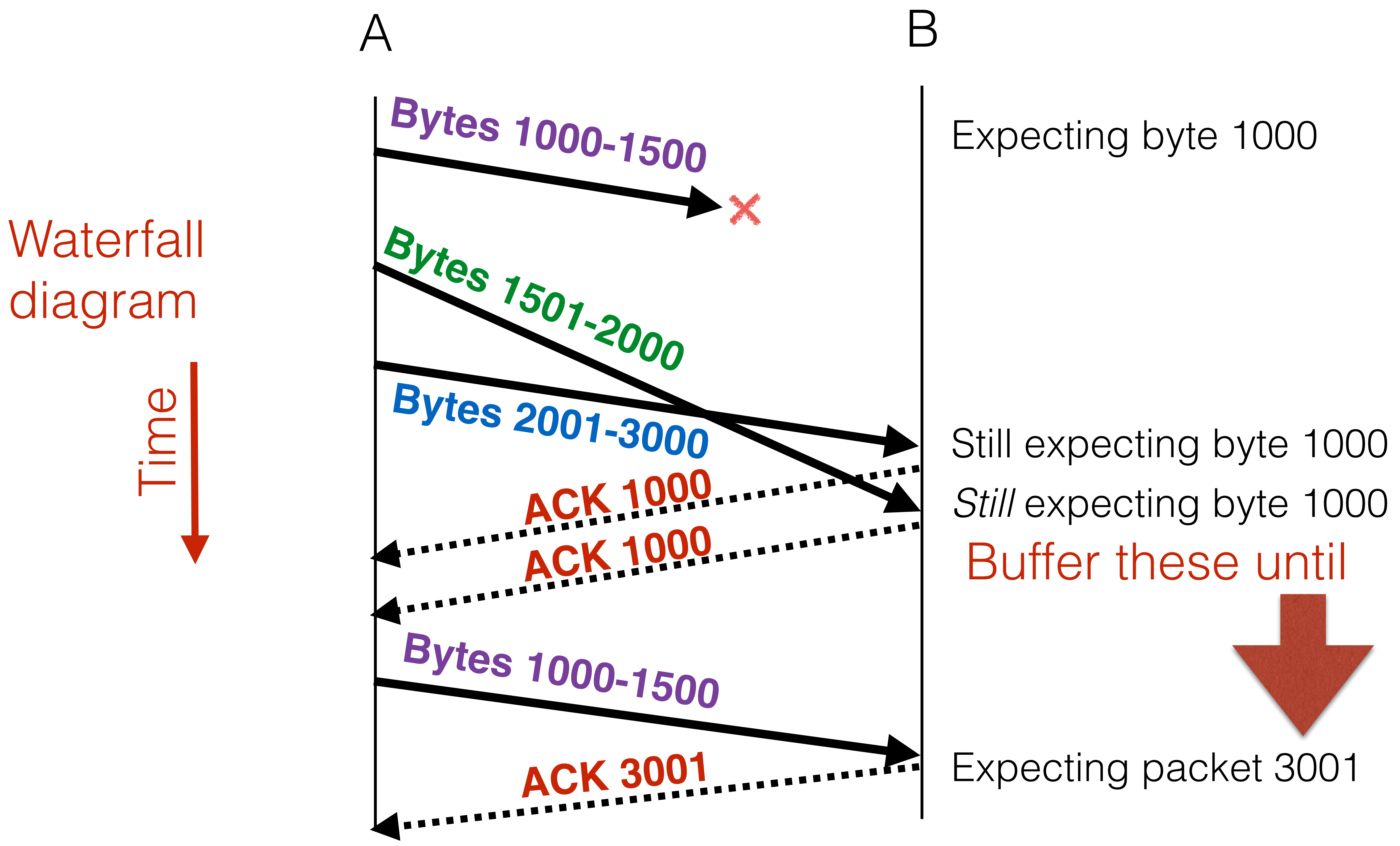
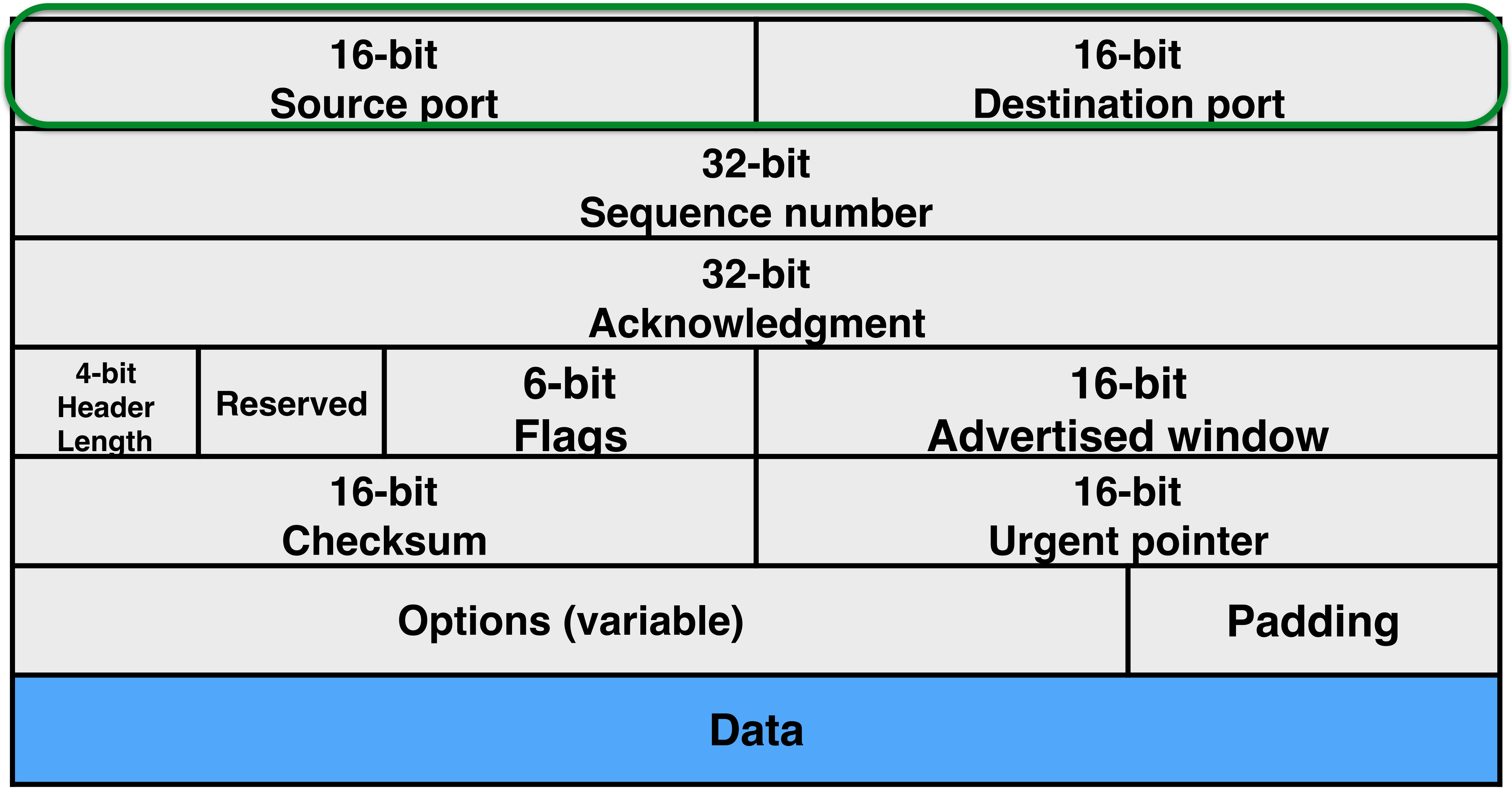


TCP congestion control

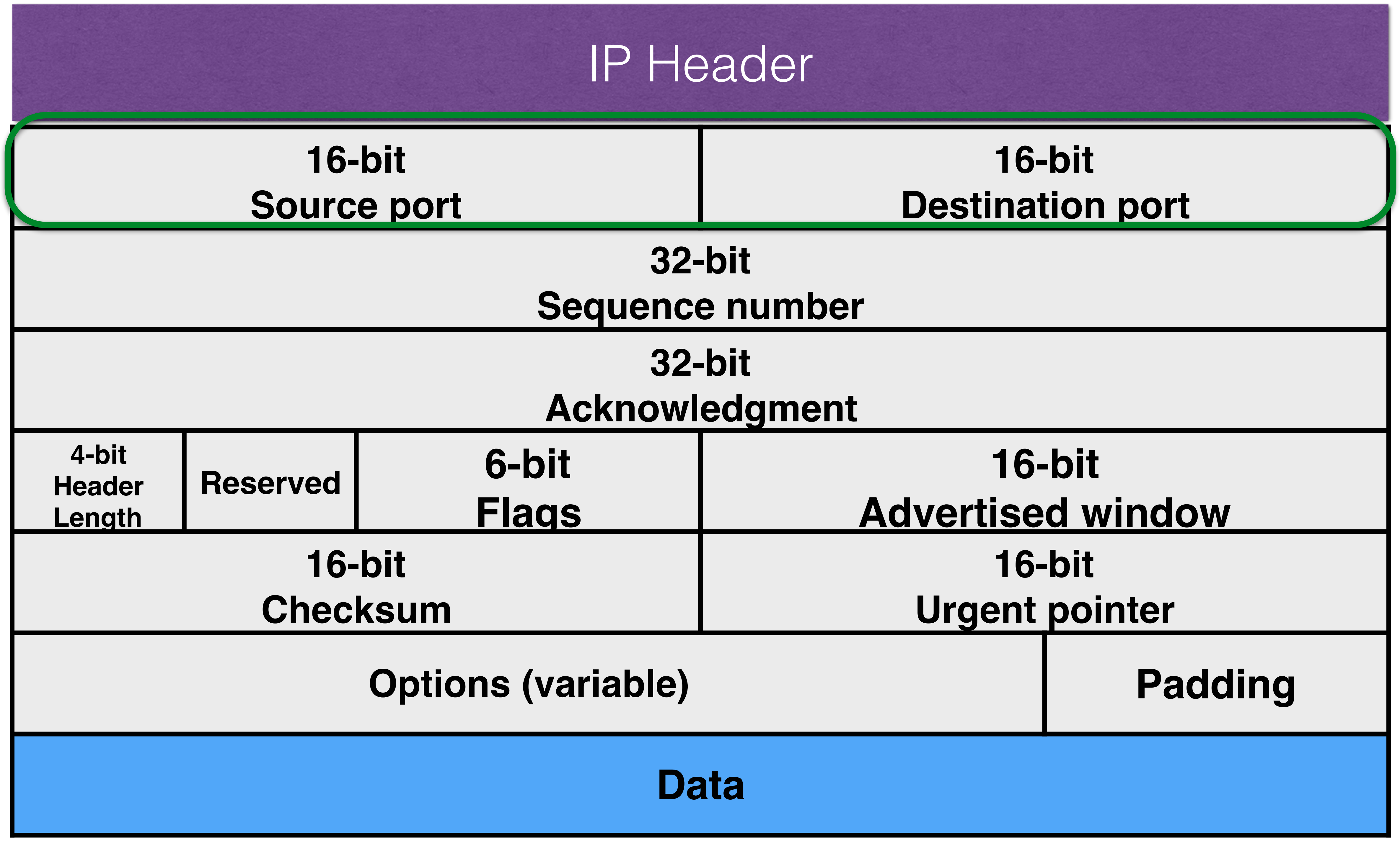
TCP's second job: don't break the network!

- 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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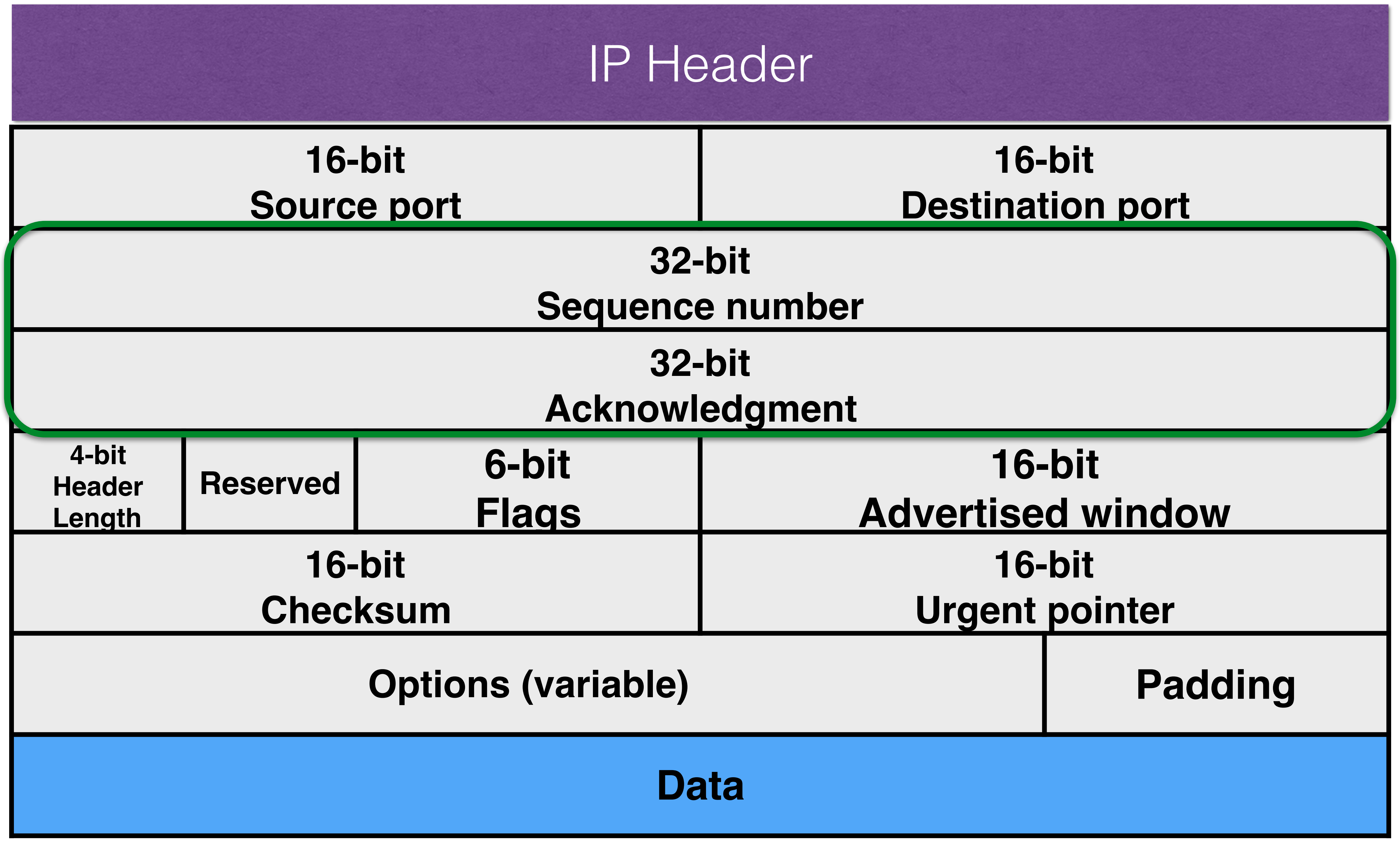
Data

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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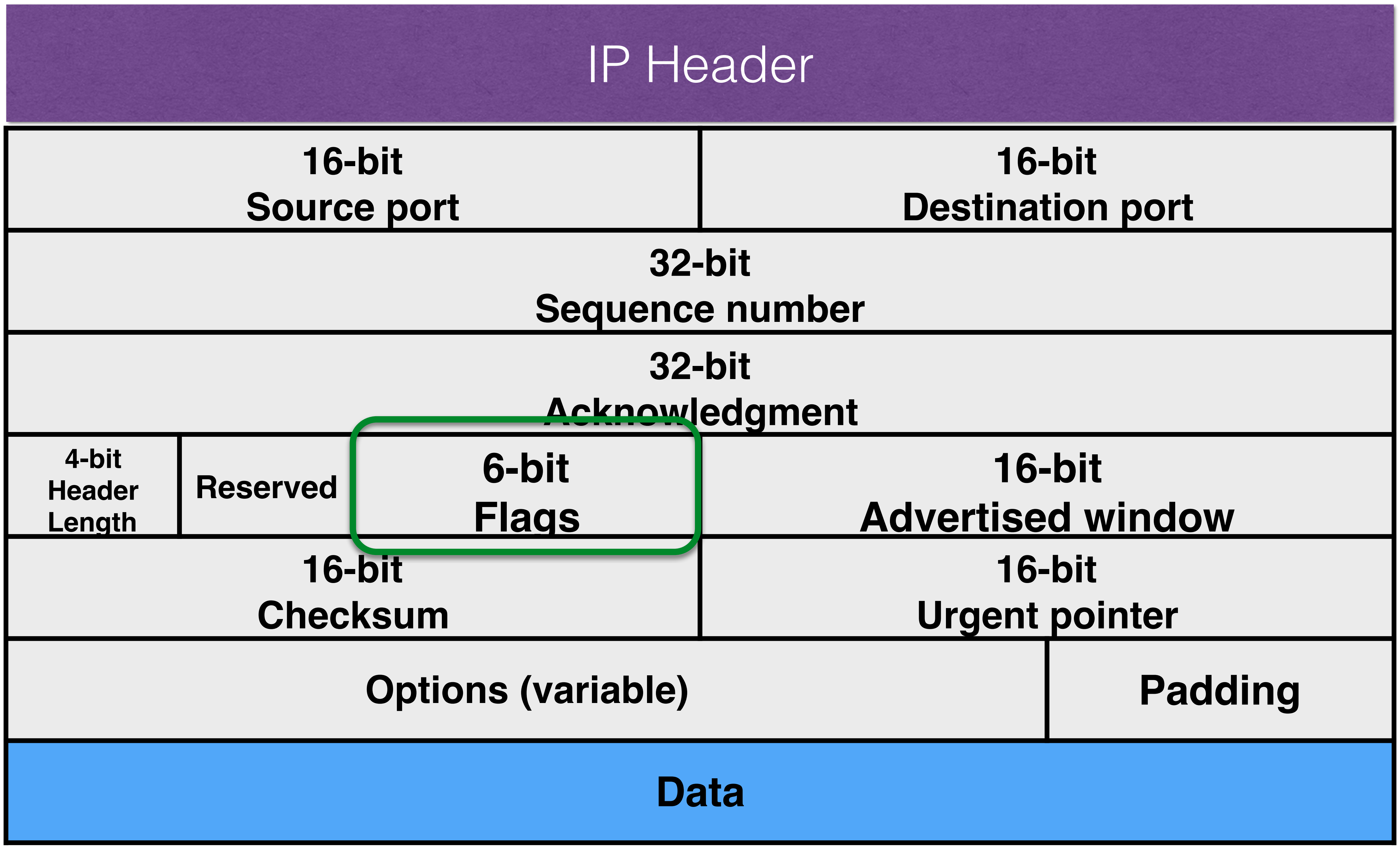
Options (variable)
Padding
Data

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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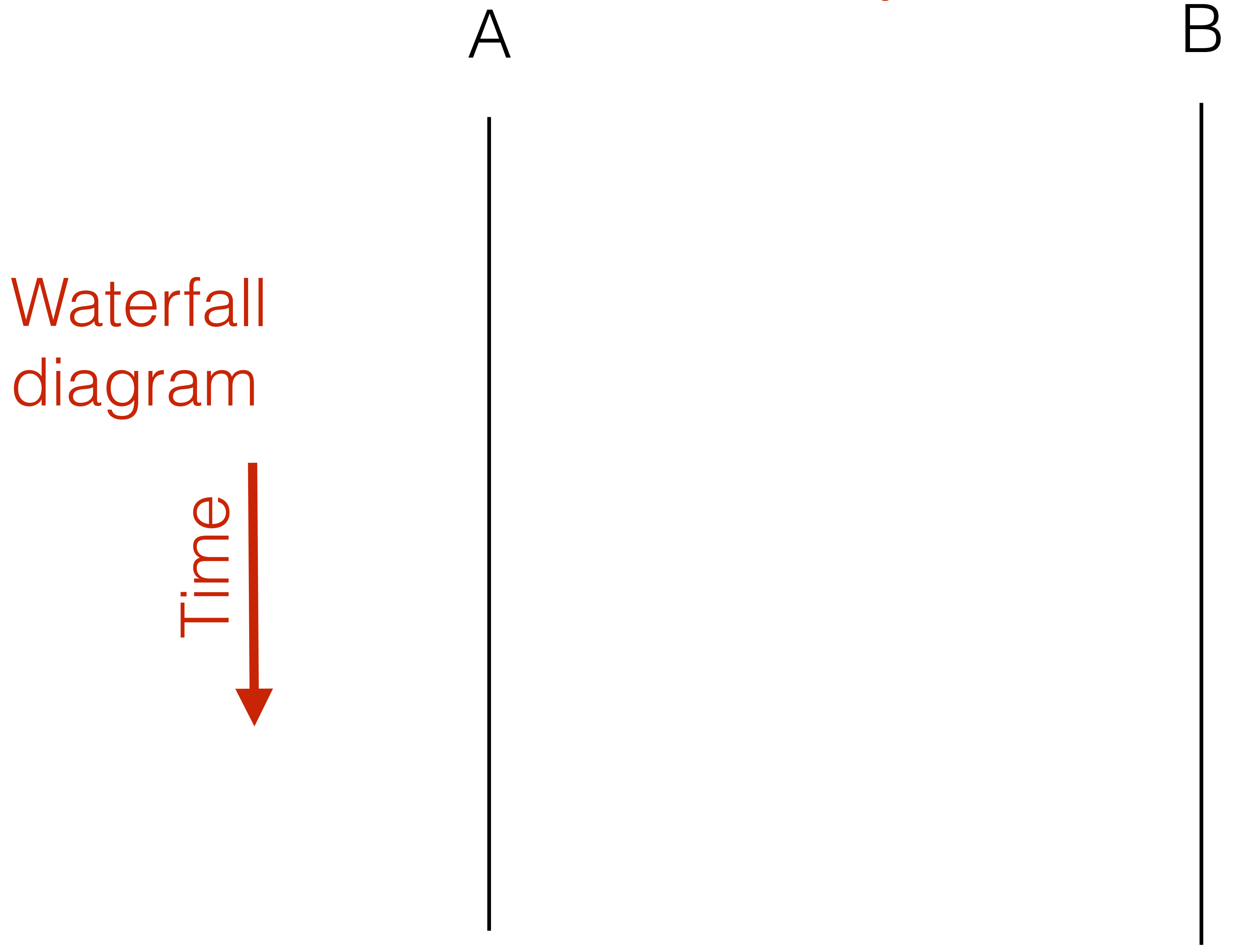
TCP flags

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

Setting up a connection

Three-way handshake



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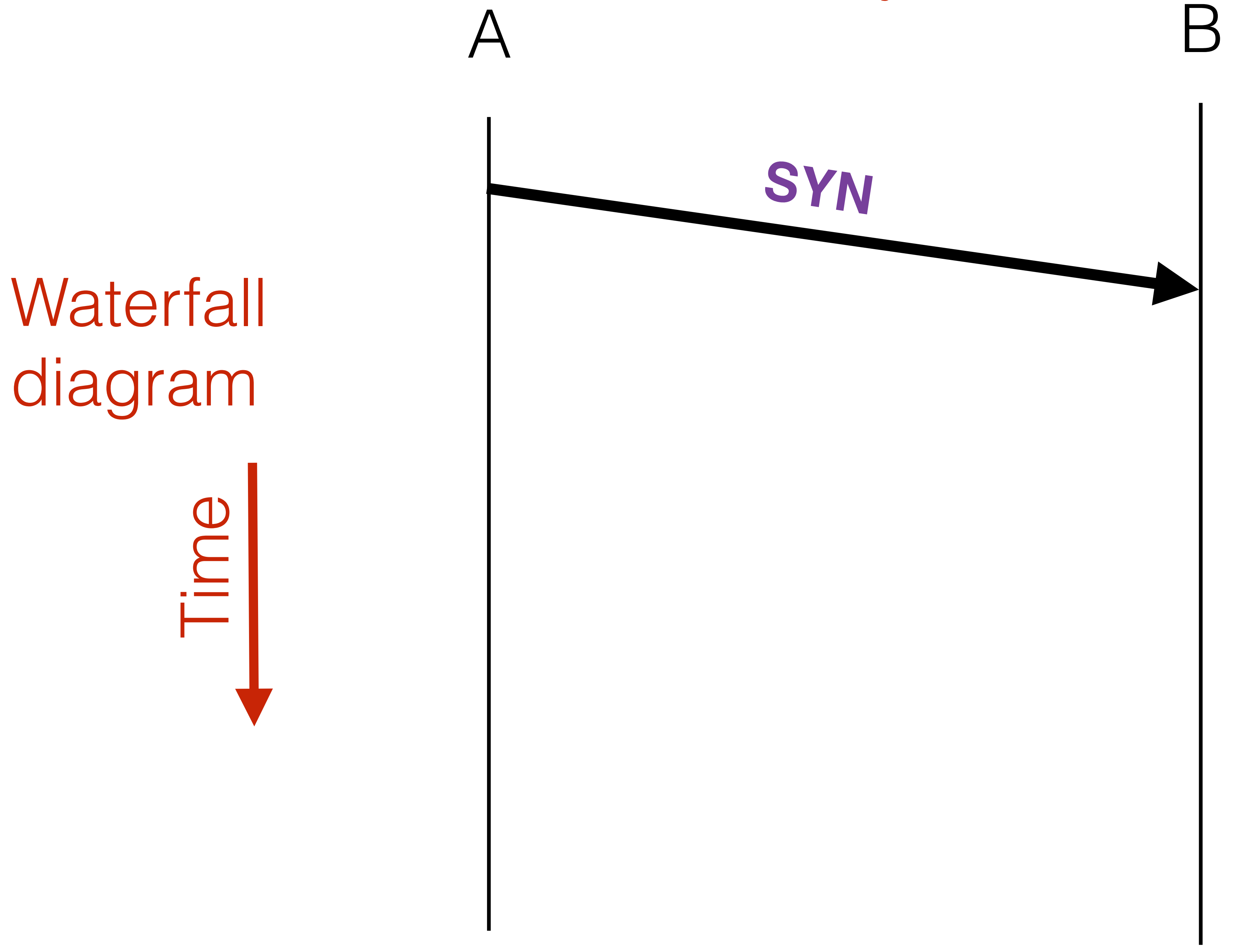

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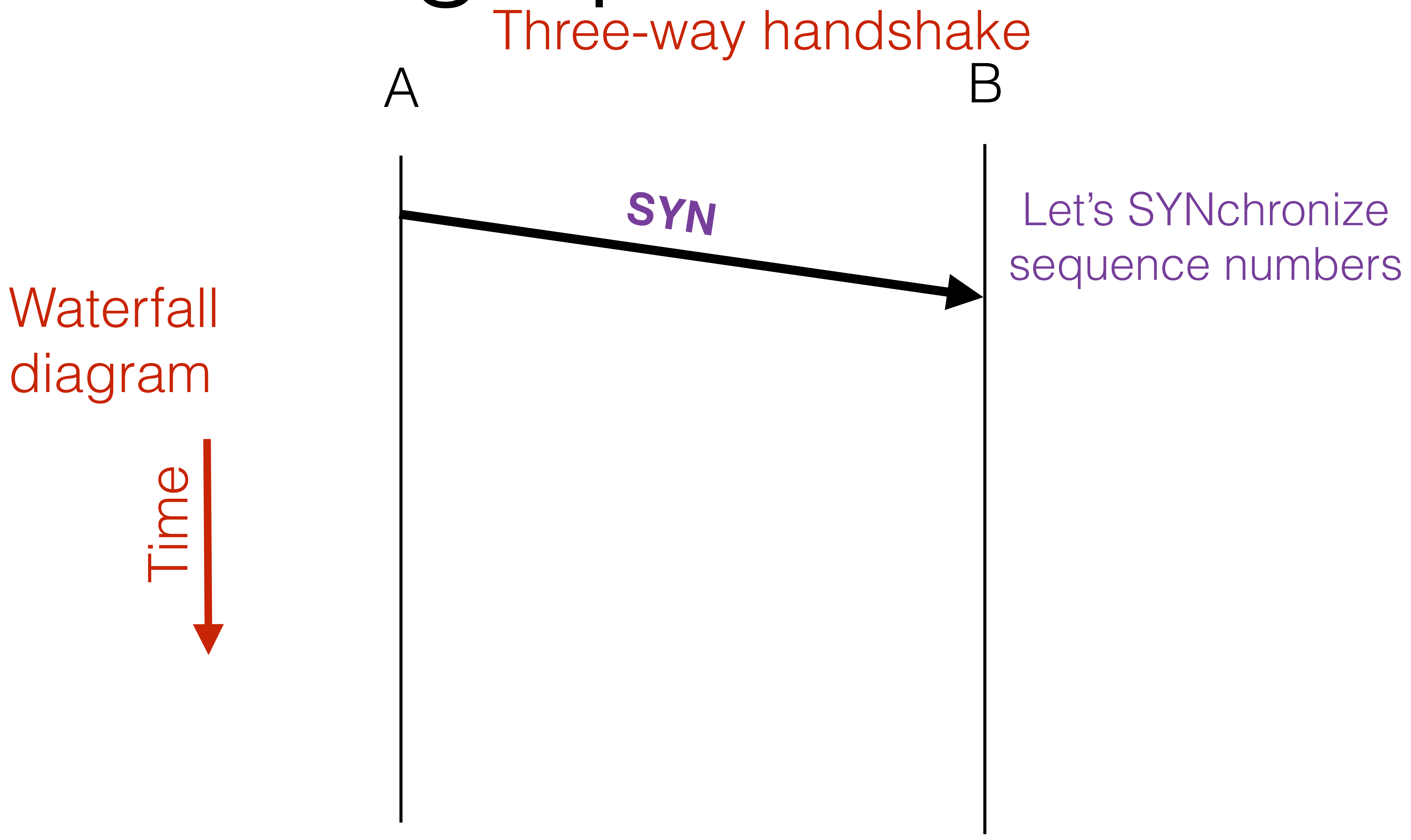

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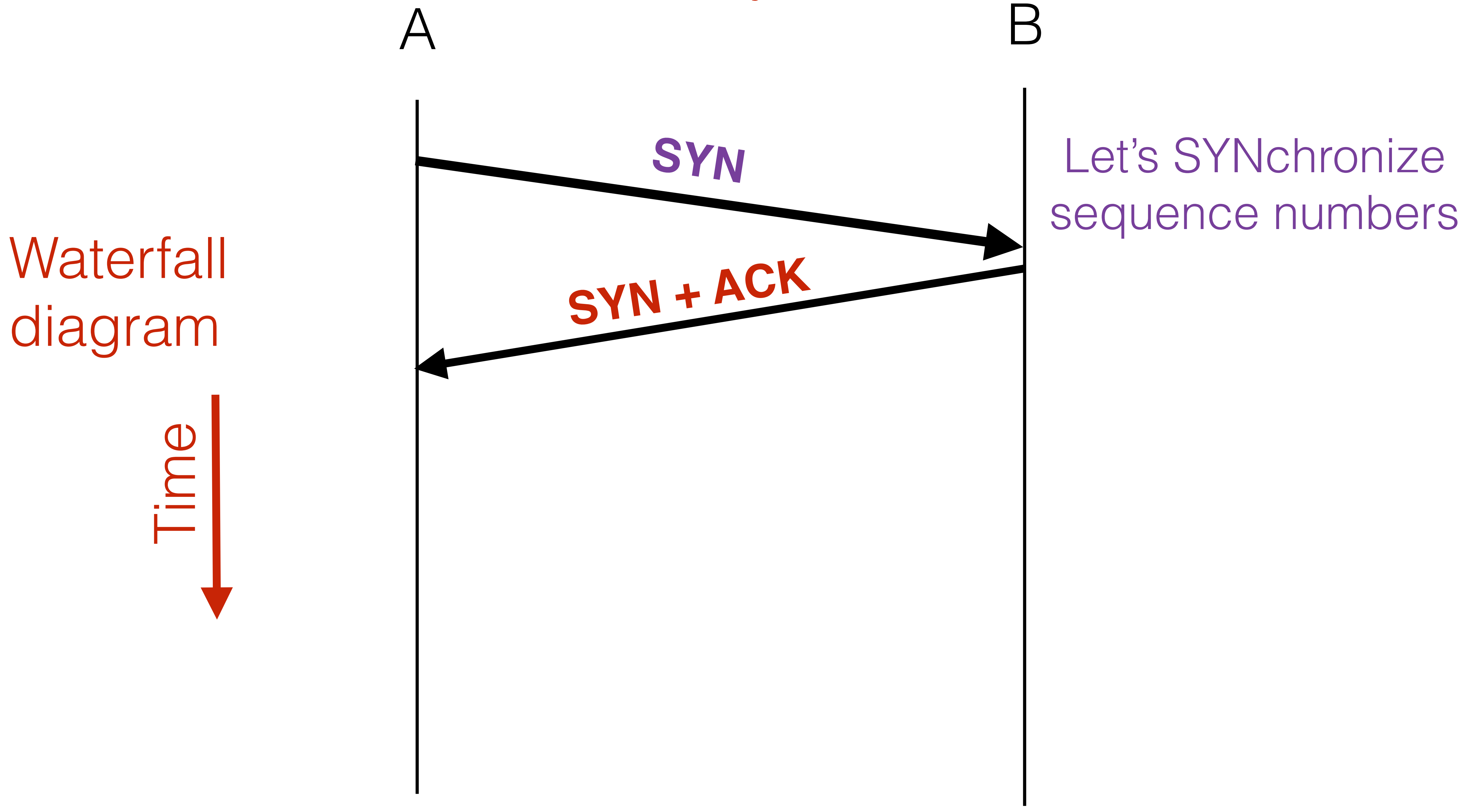

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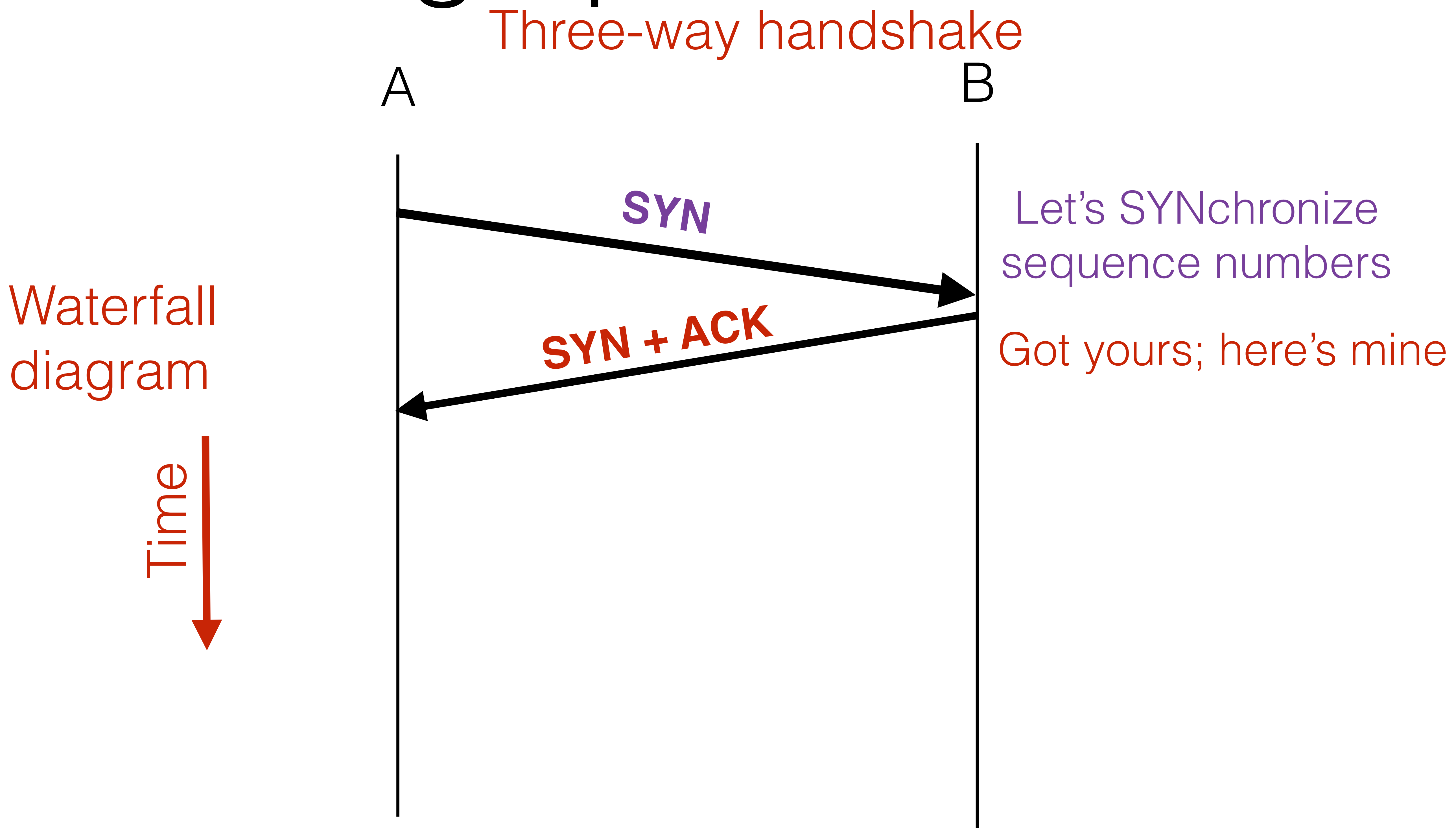

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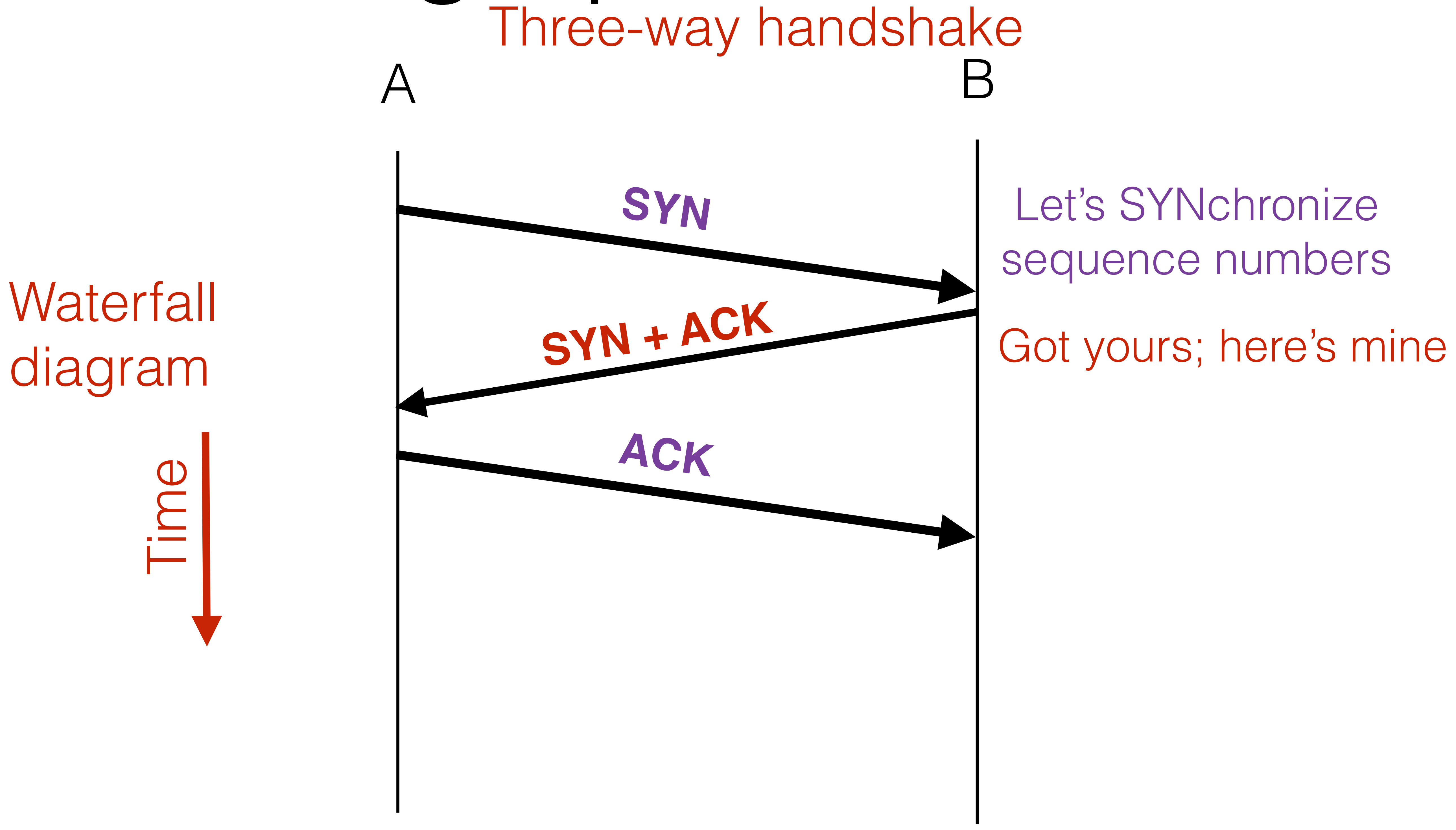
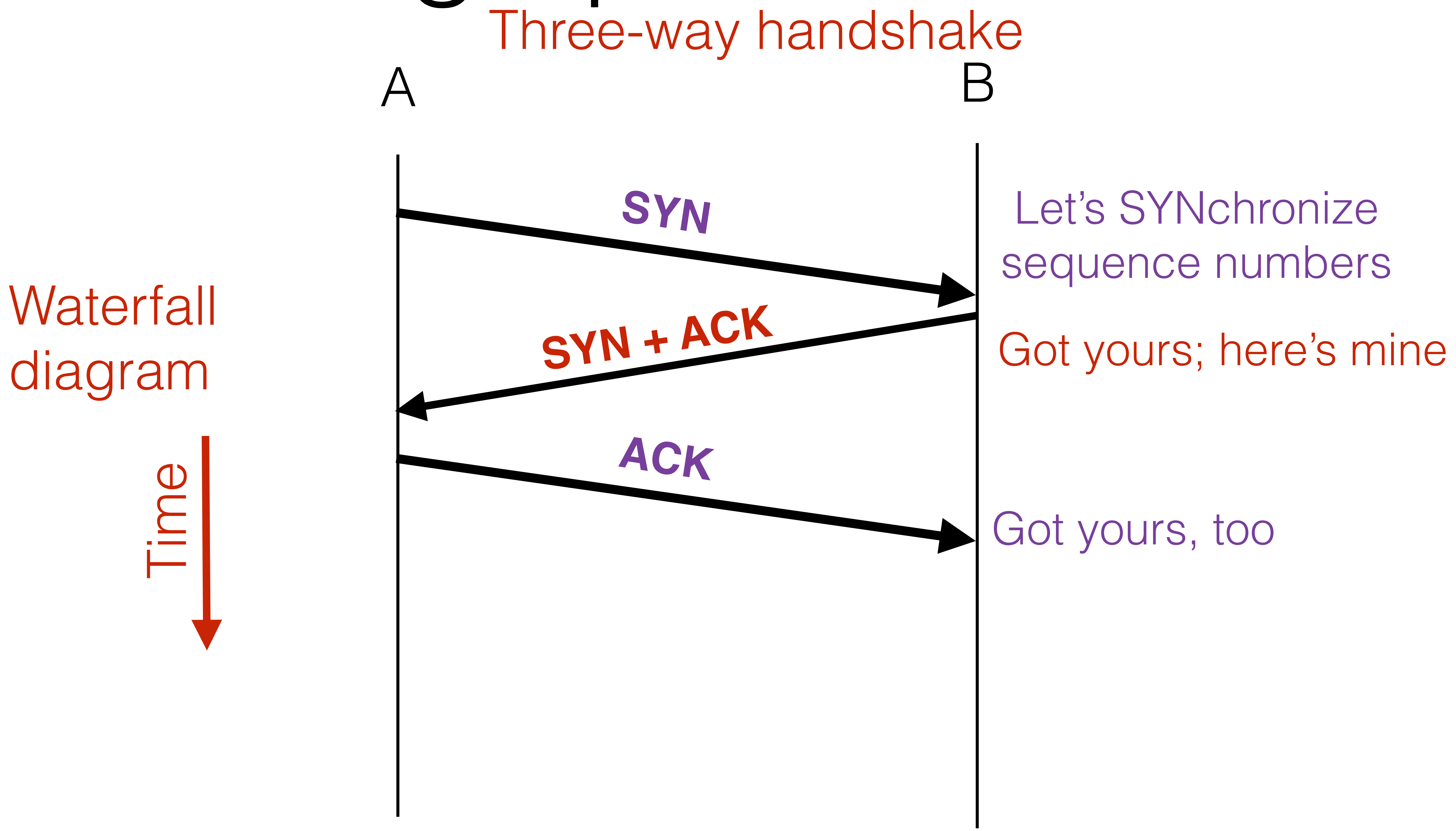


Setting up a connection



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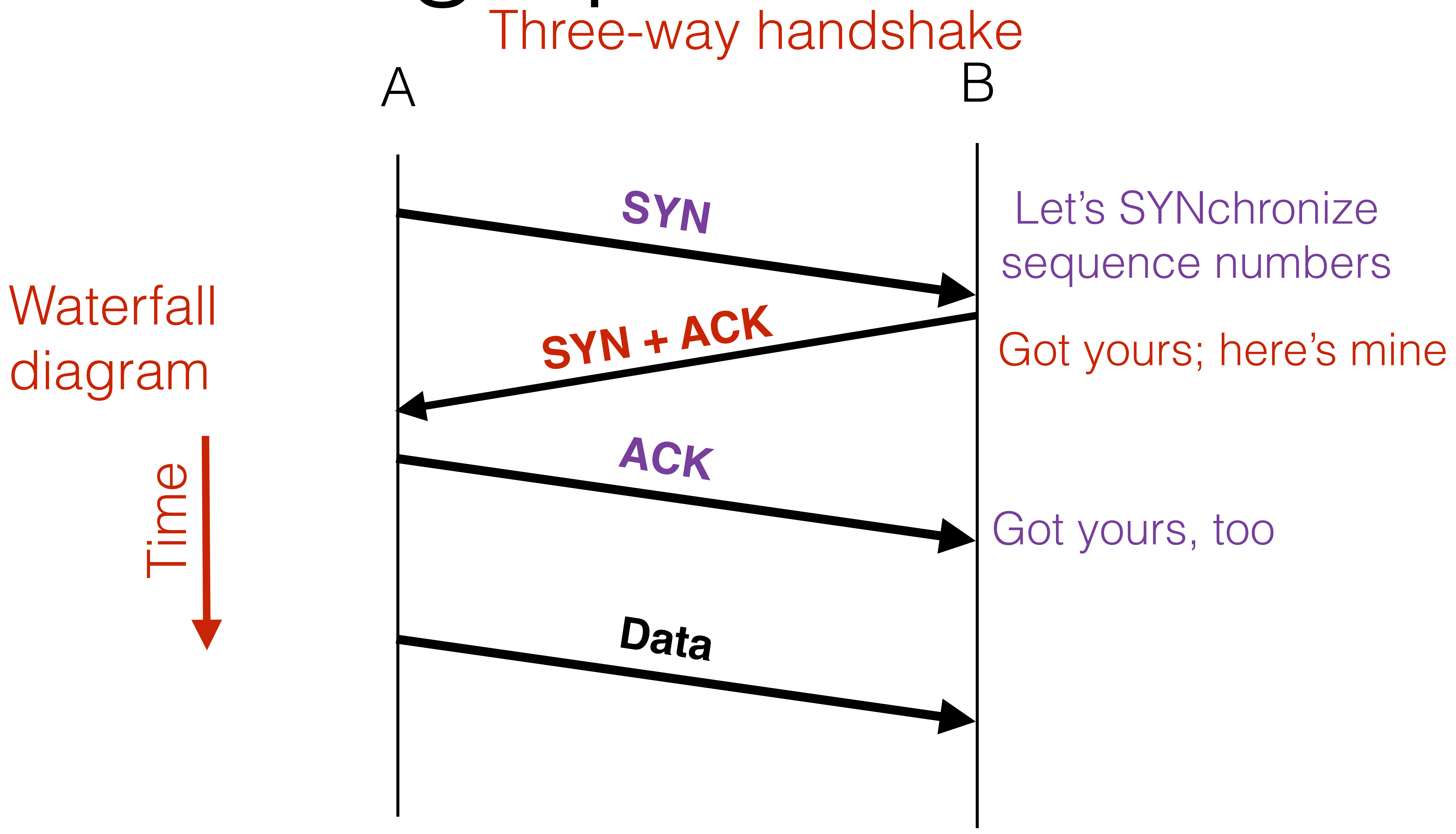
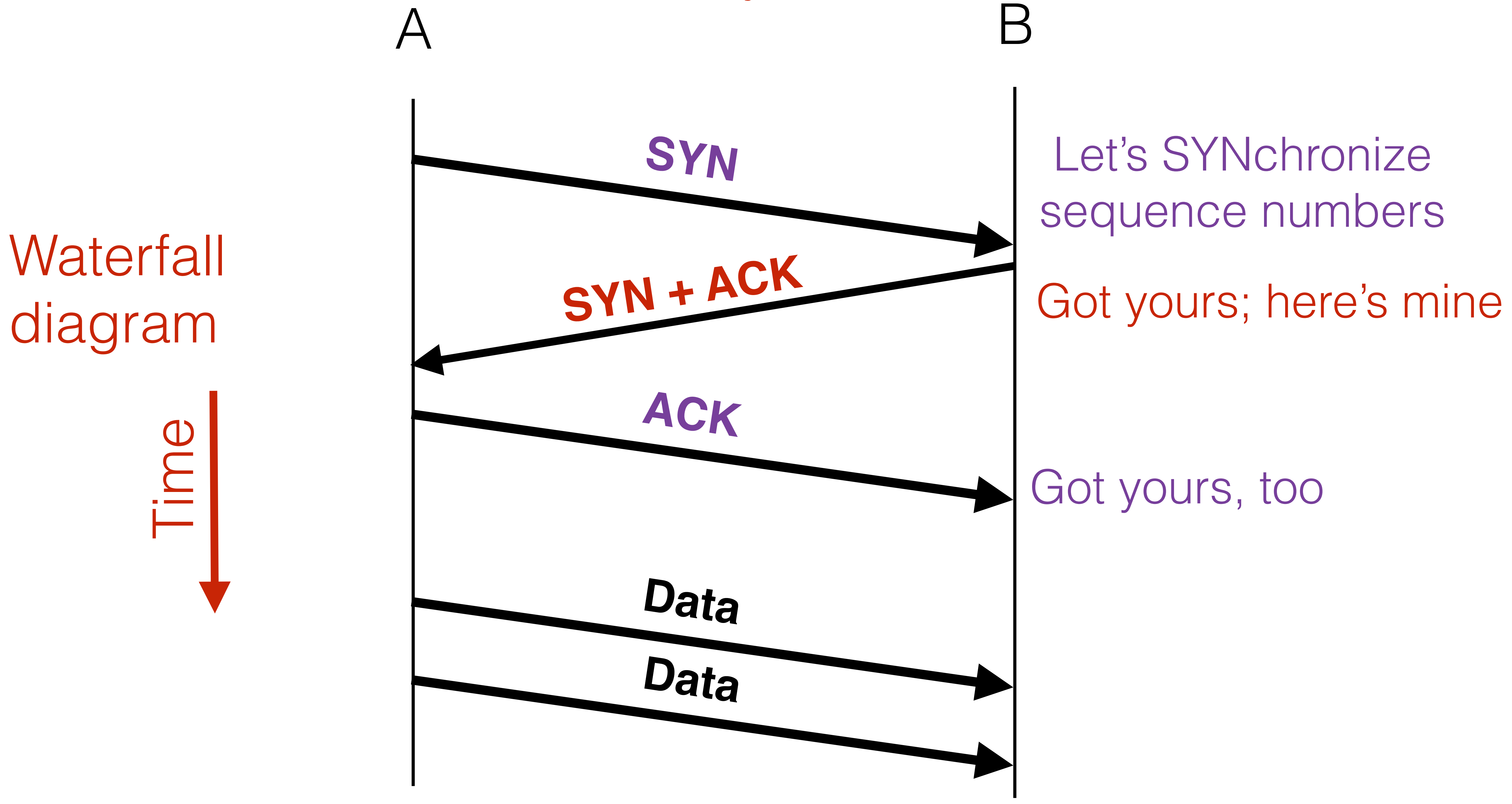


Setting up a connection

Three-way handshake



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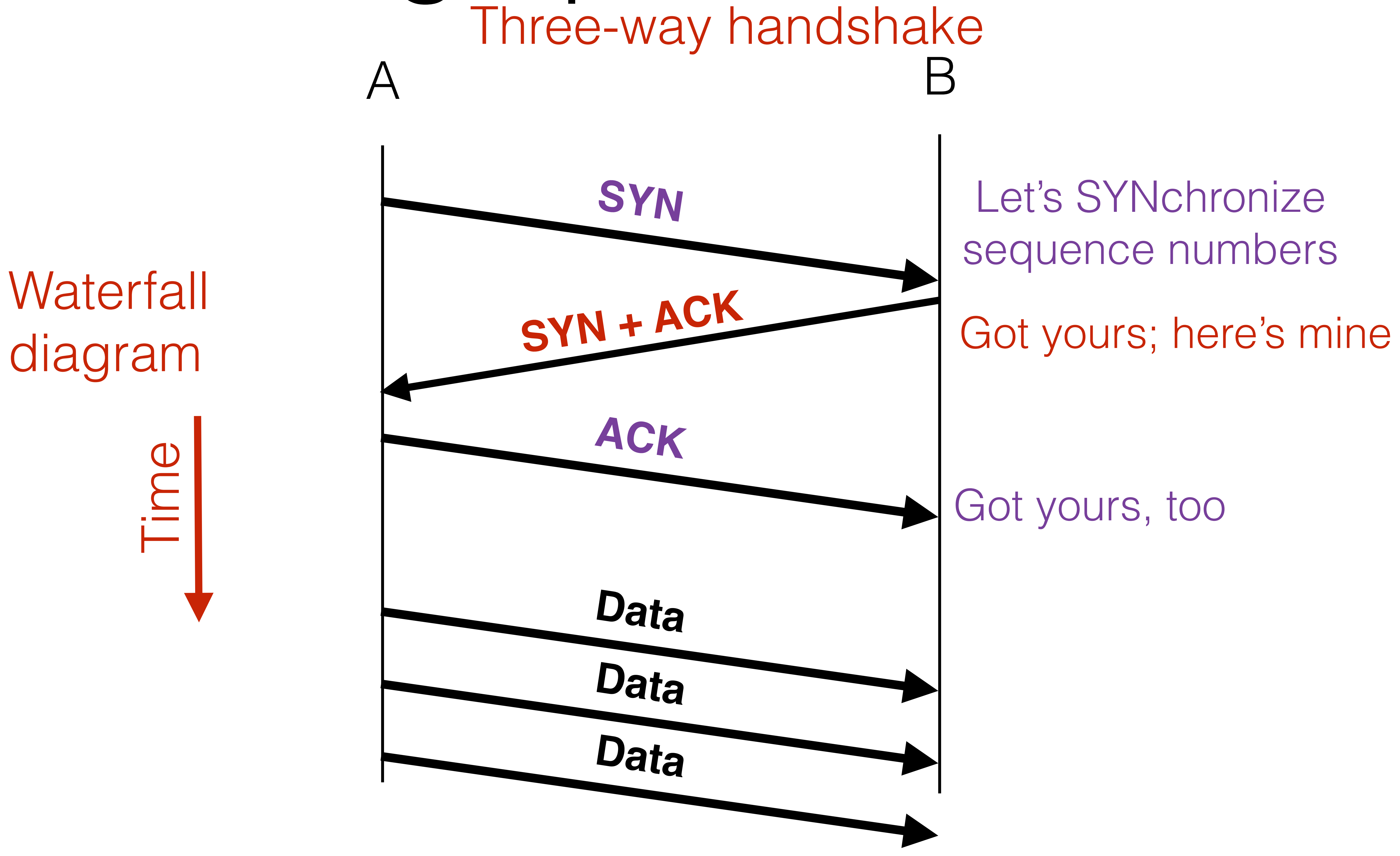
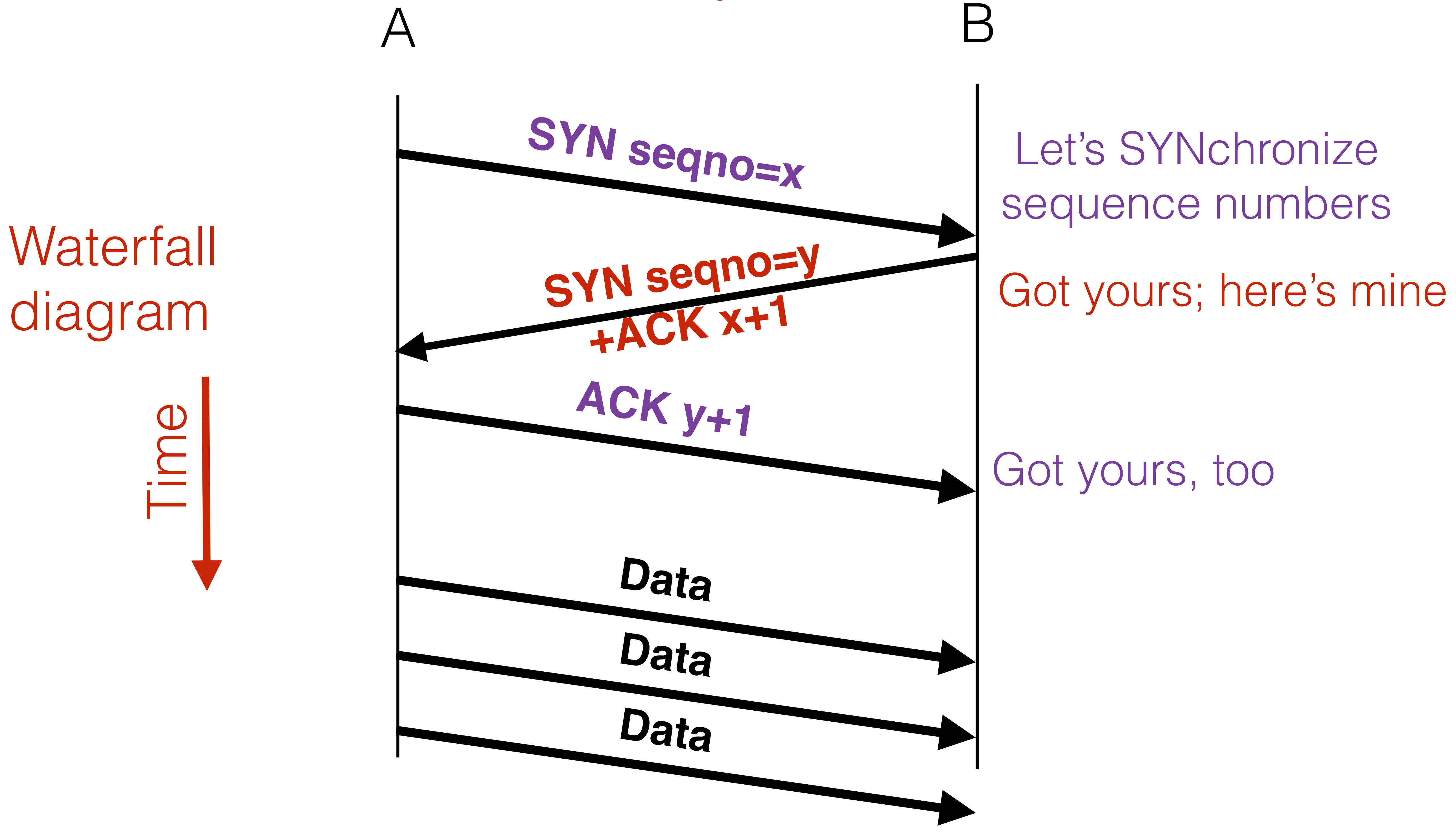


Setting up a connection

Three-way handshake



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

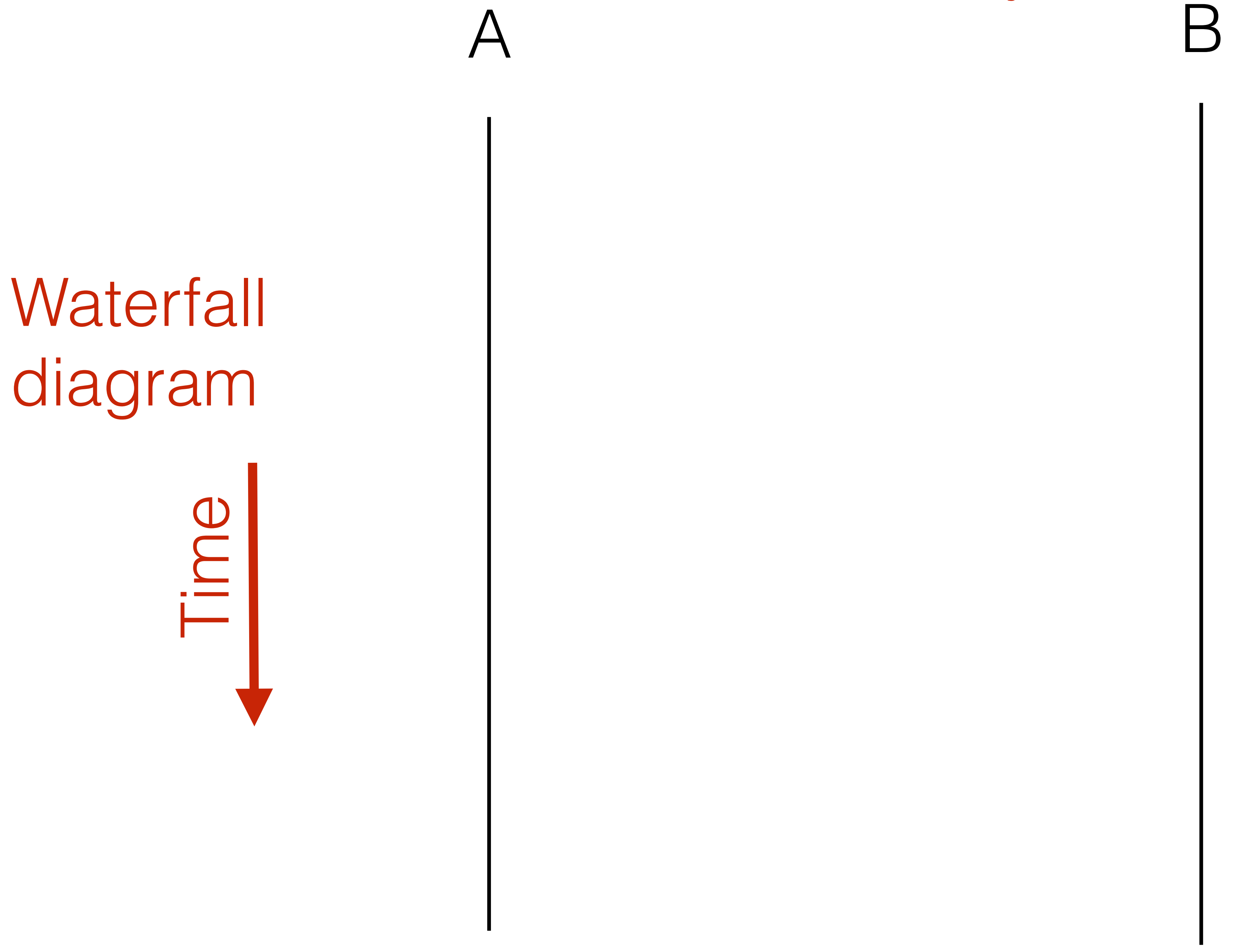
Attacks

- SYN flooding
- Injection attacks
- Opt-ack attack

SYN flooding

SYN flooding

Recall the three-way handshake:



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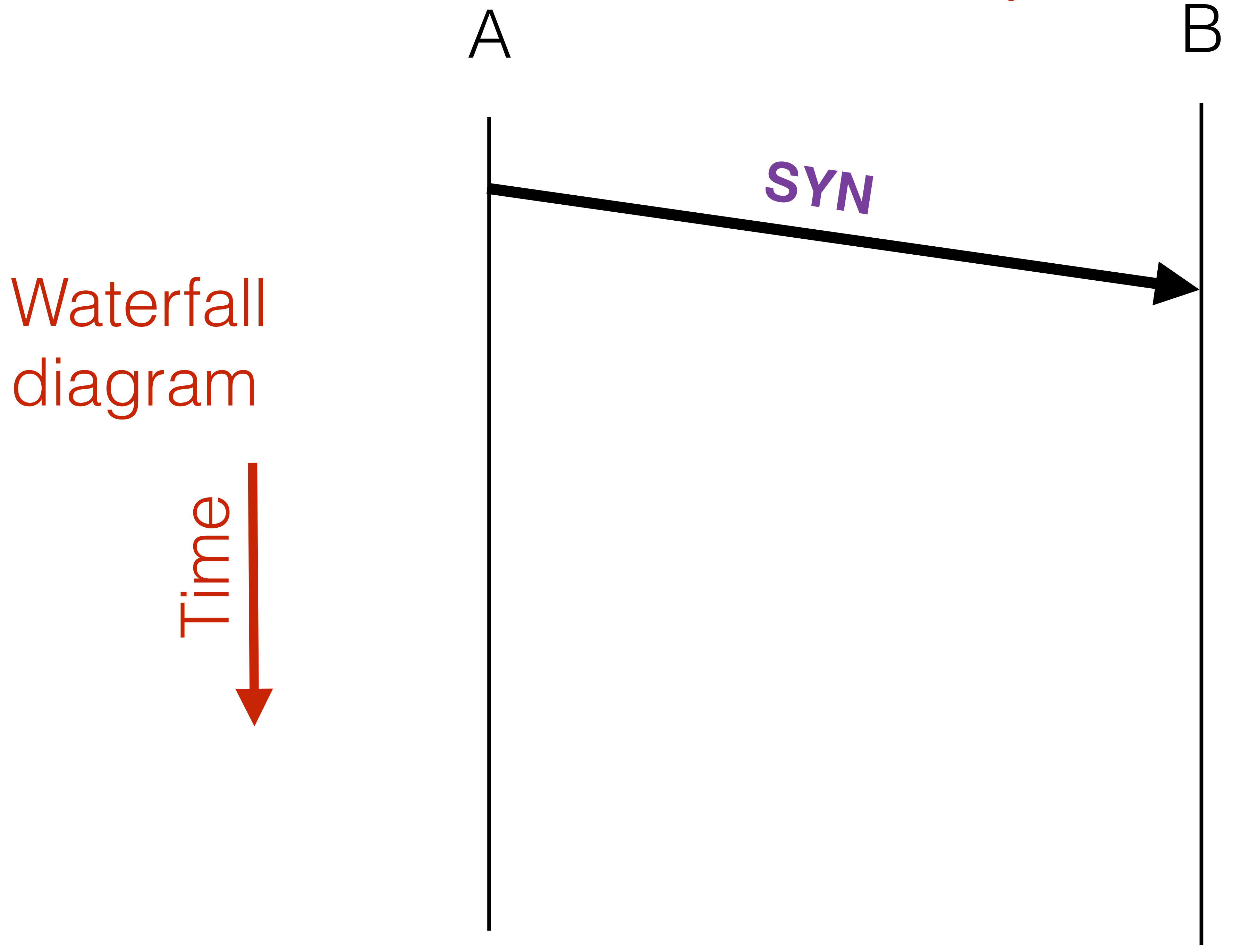

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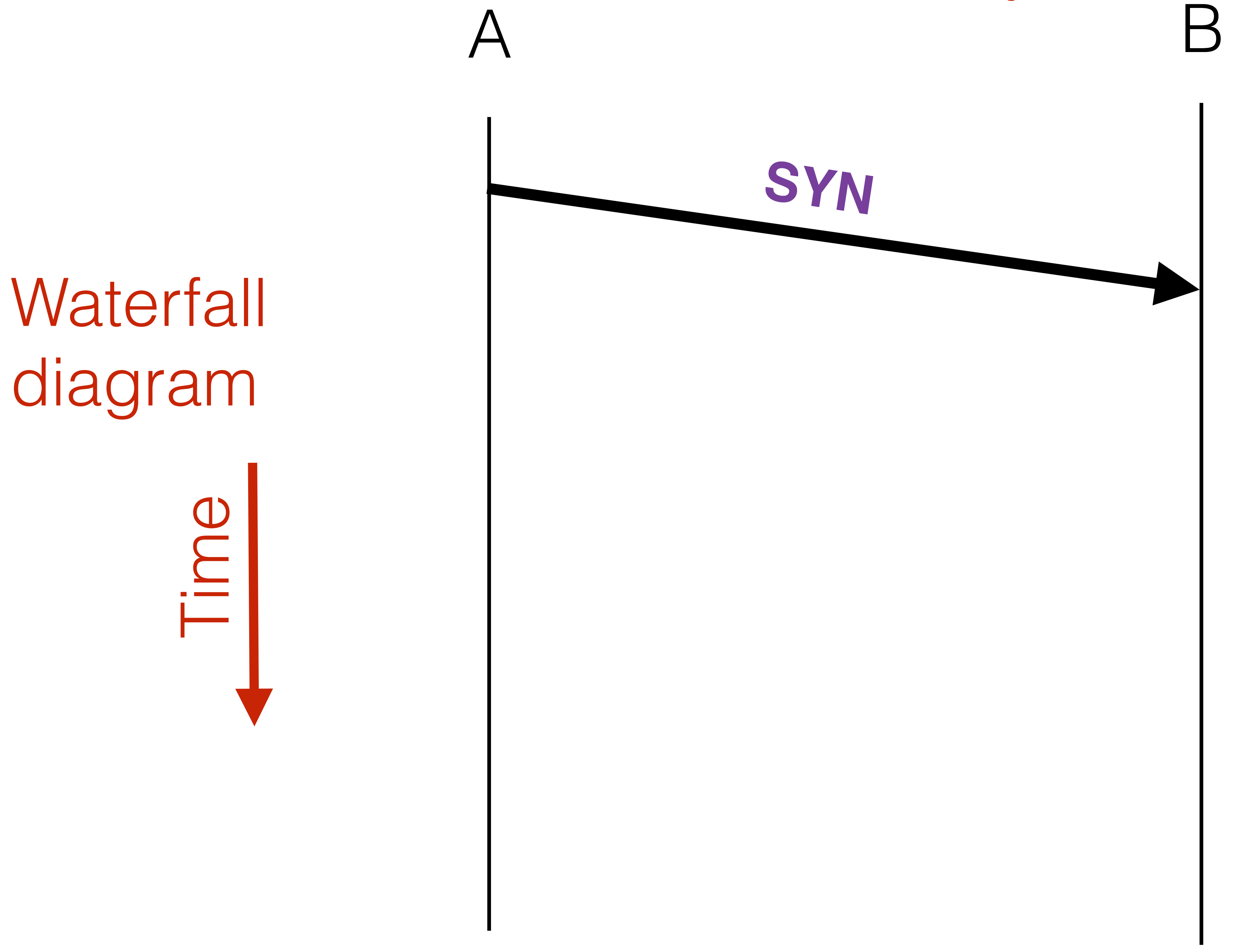

At this point, B allocates state for this new connection (incl. IP, port, maximum segment size)

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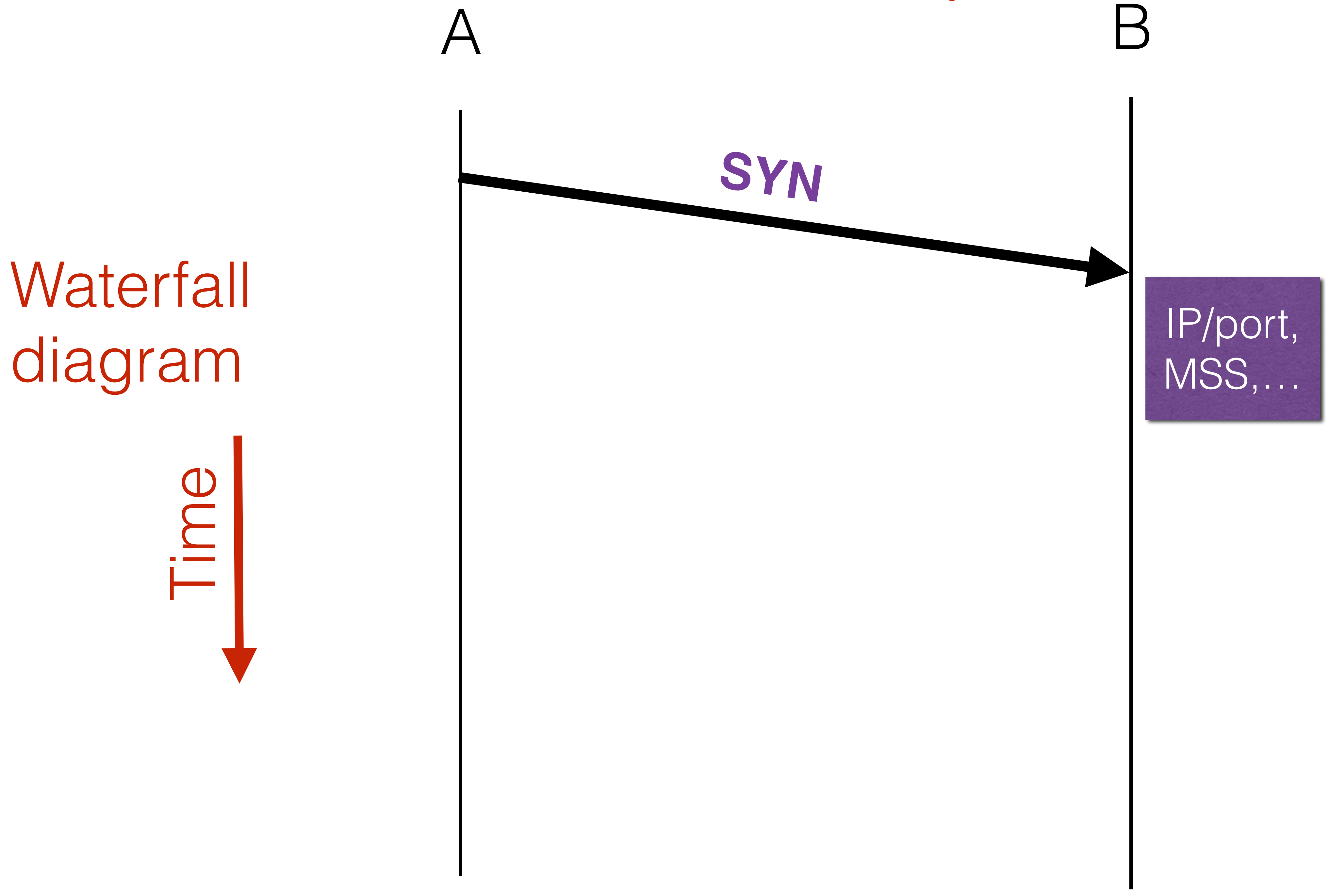

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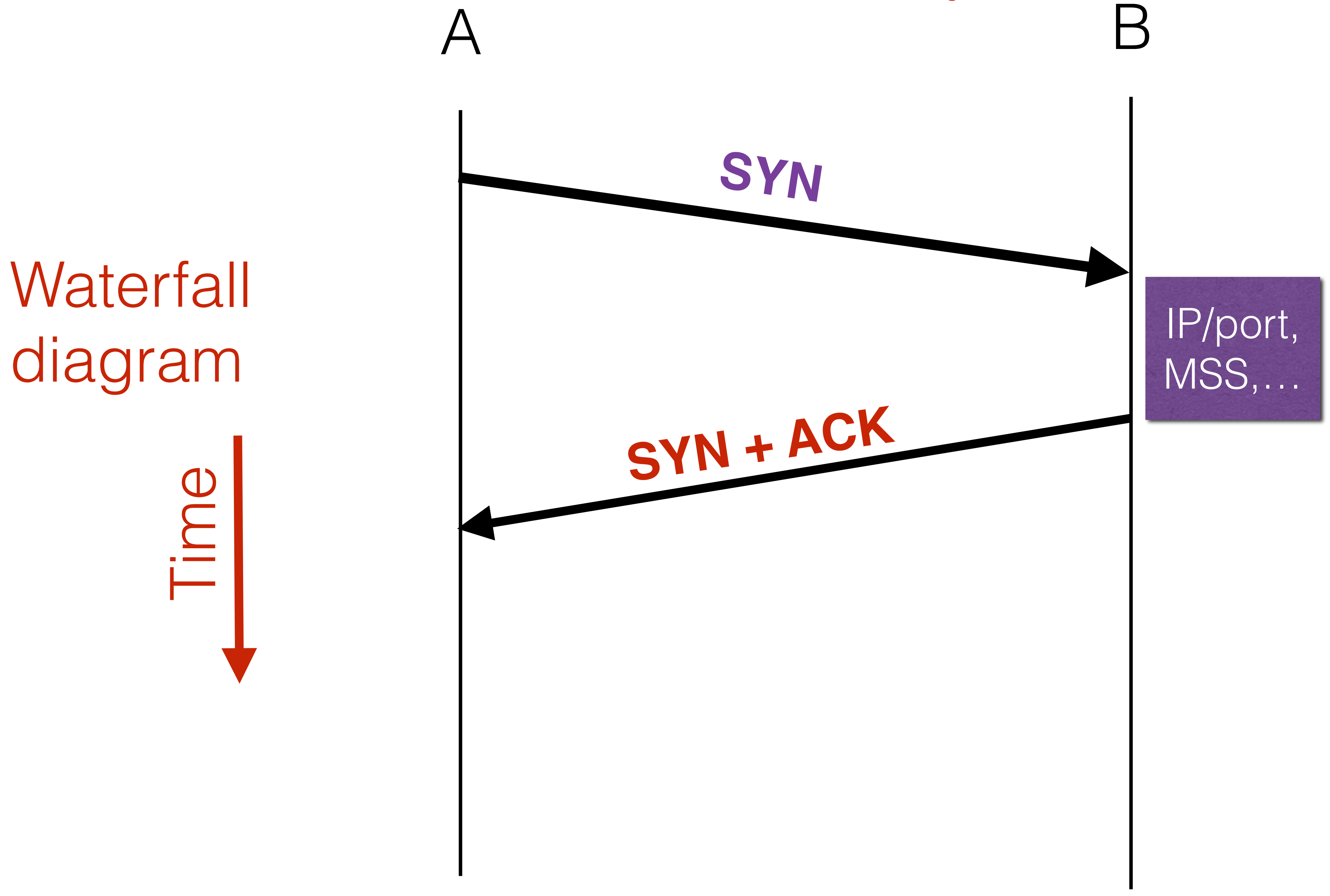

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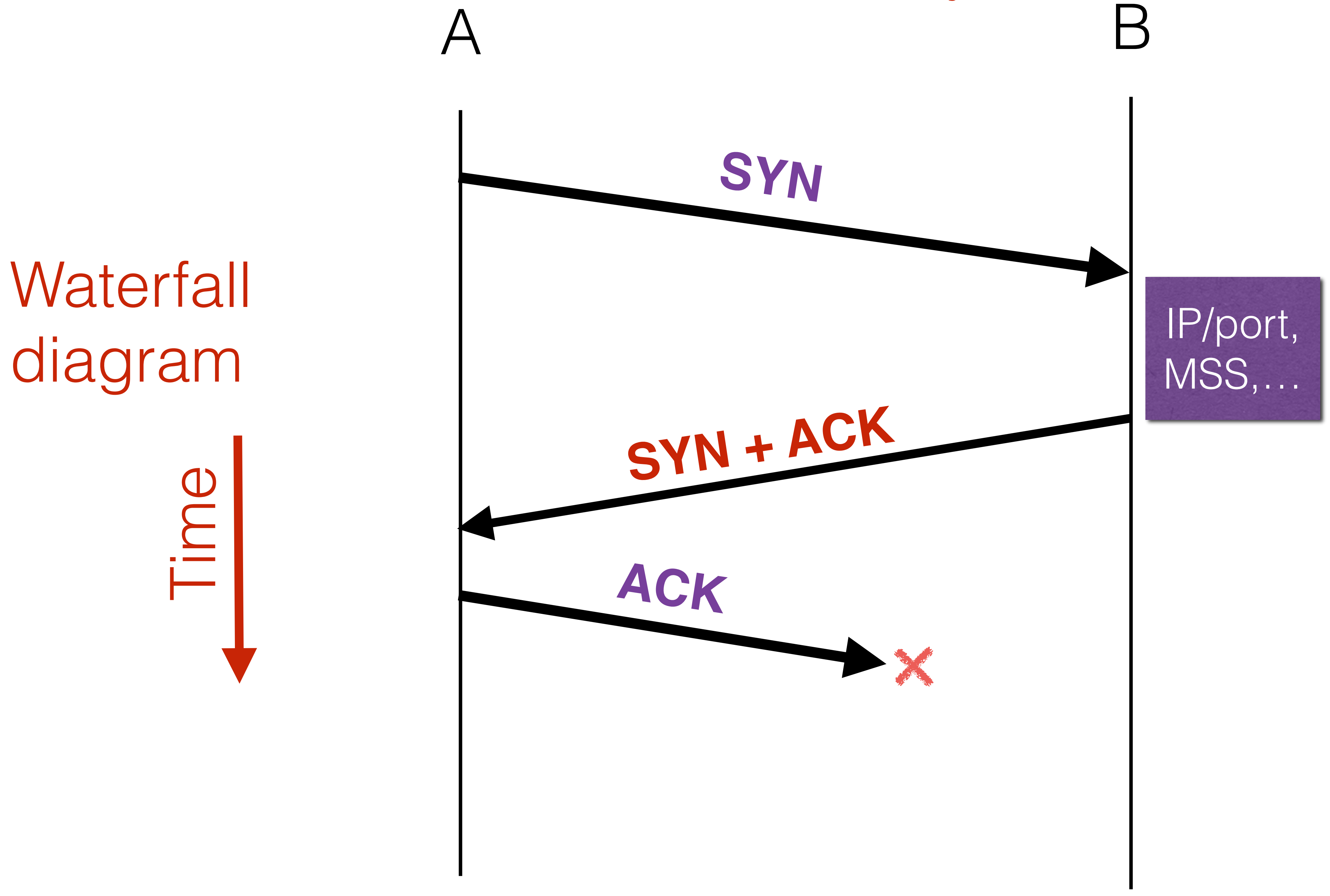

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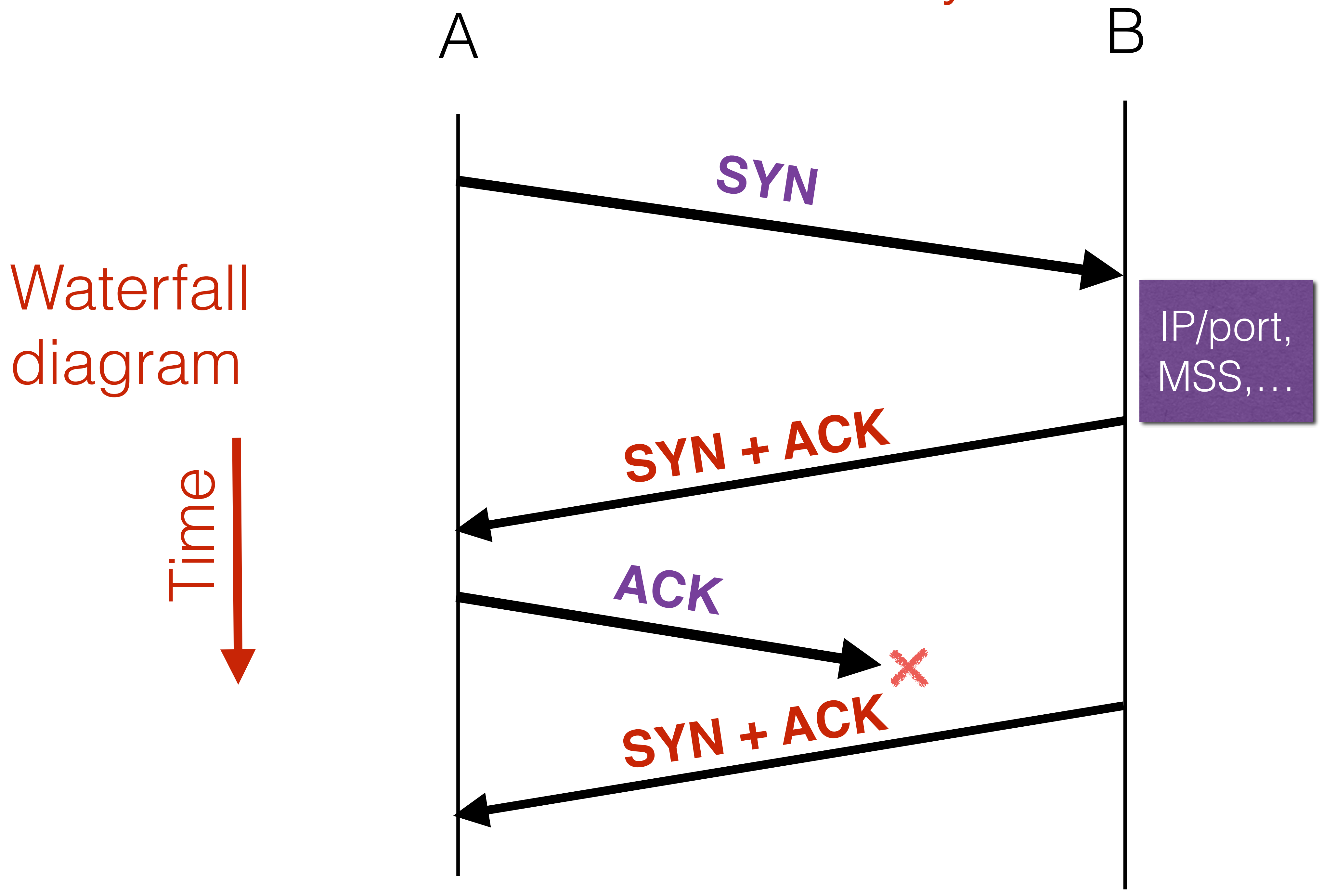

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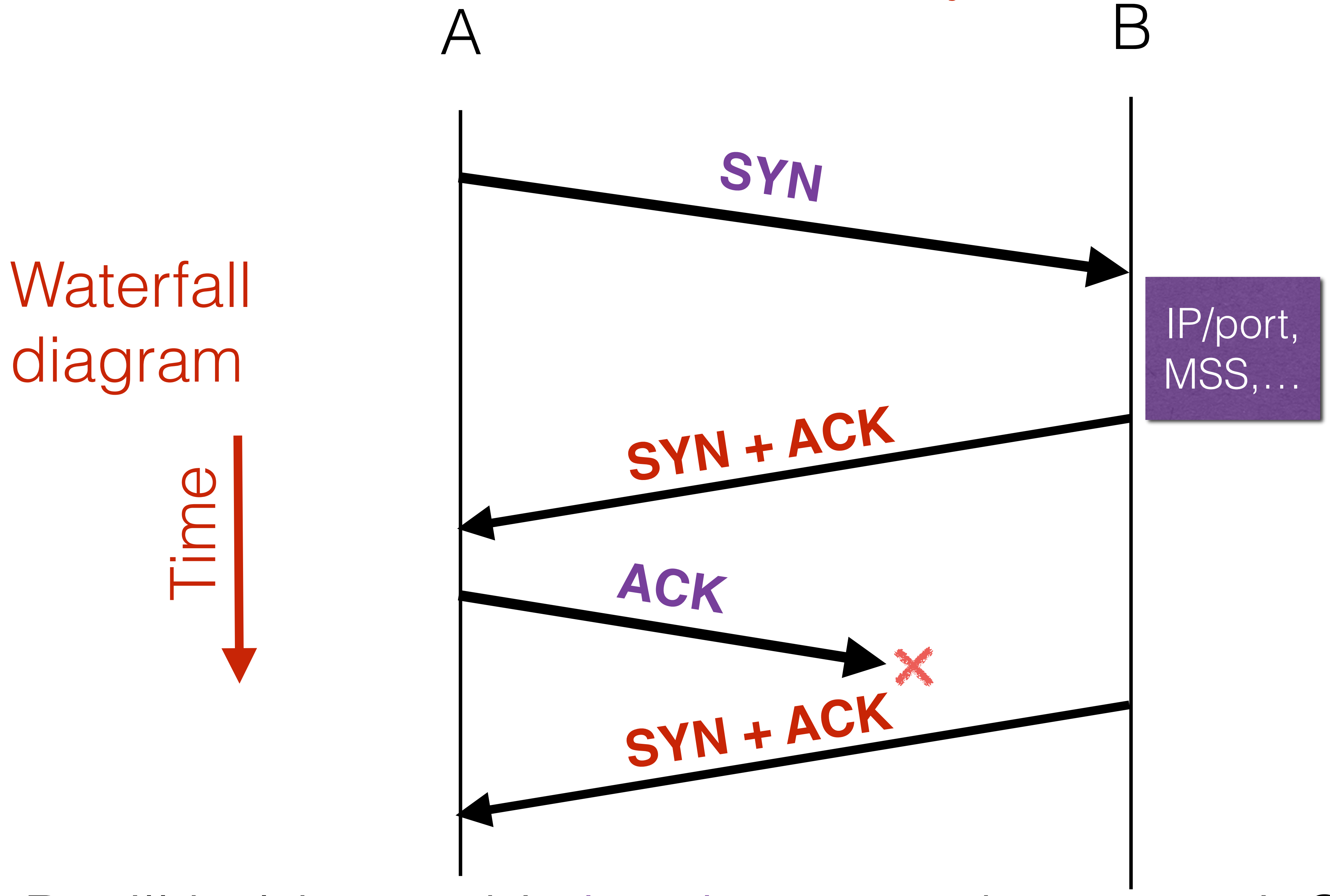
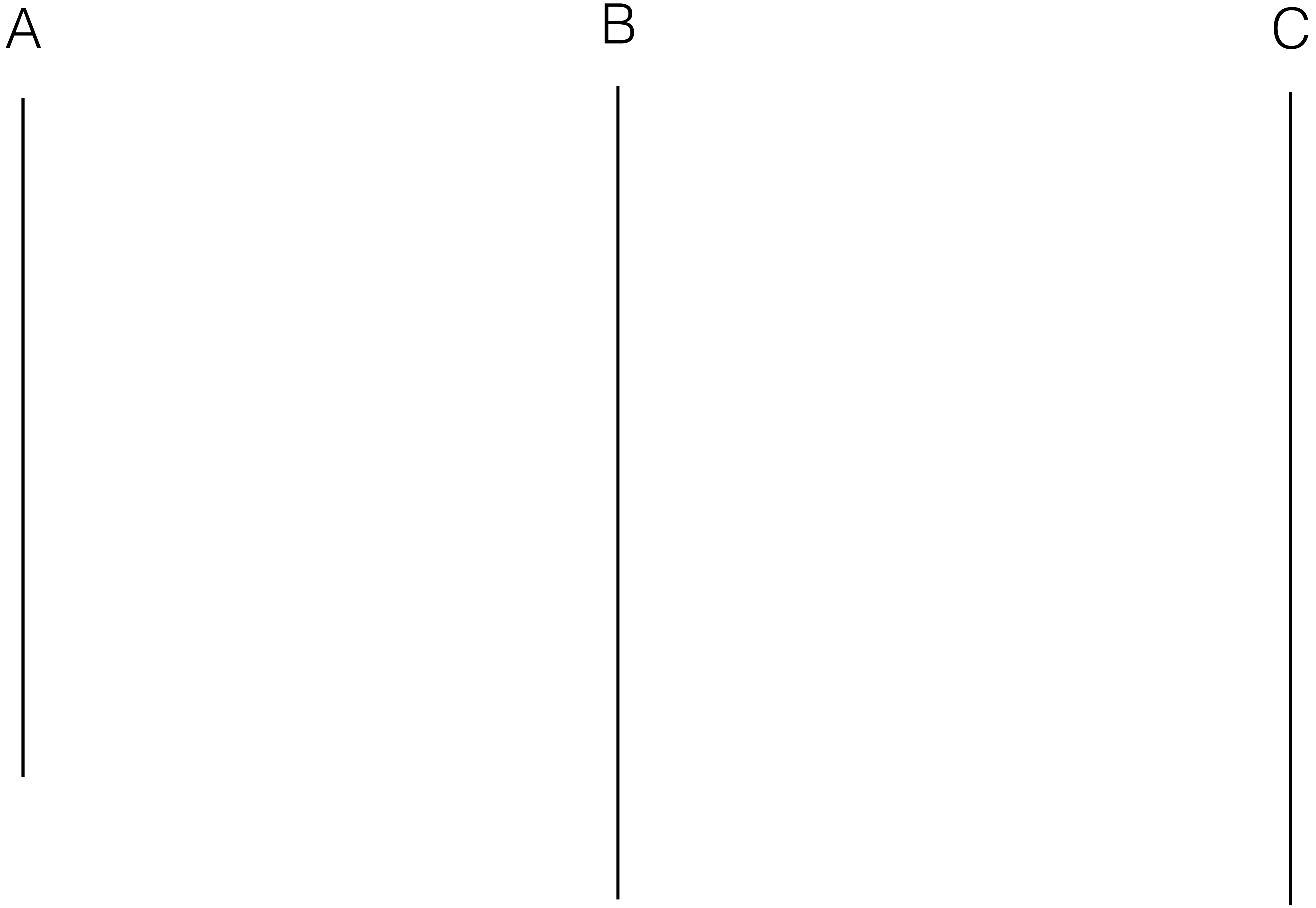


At this point, B allocates state for this new connection (incl. IP, port, maximum segment size)

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



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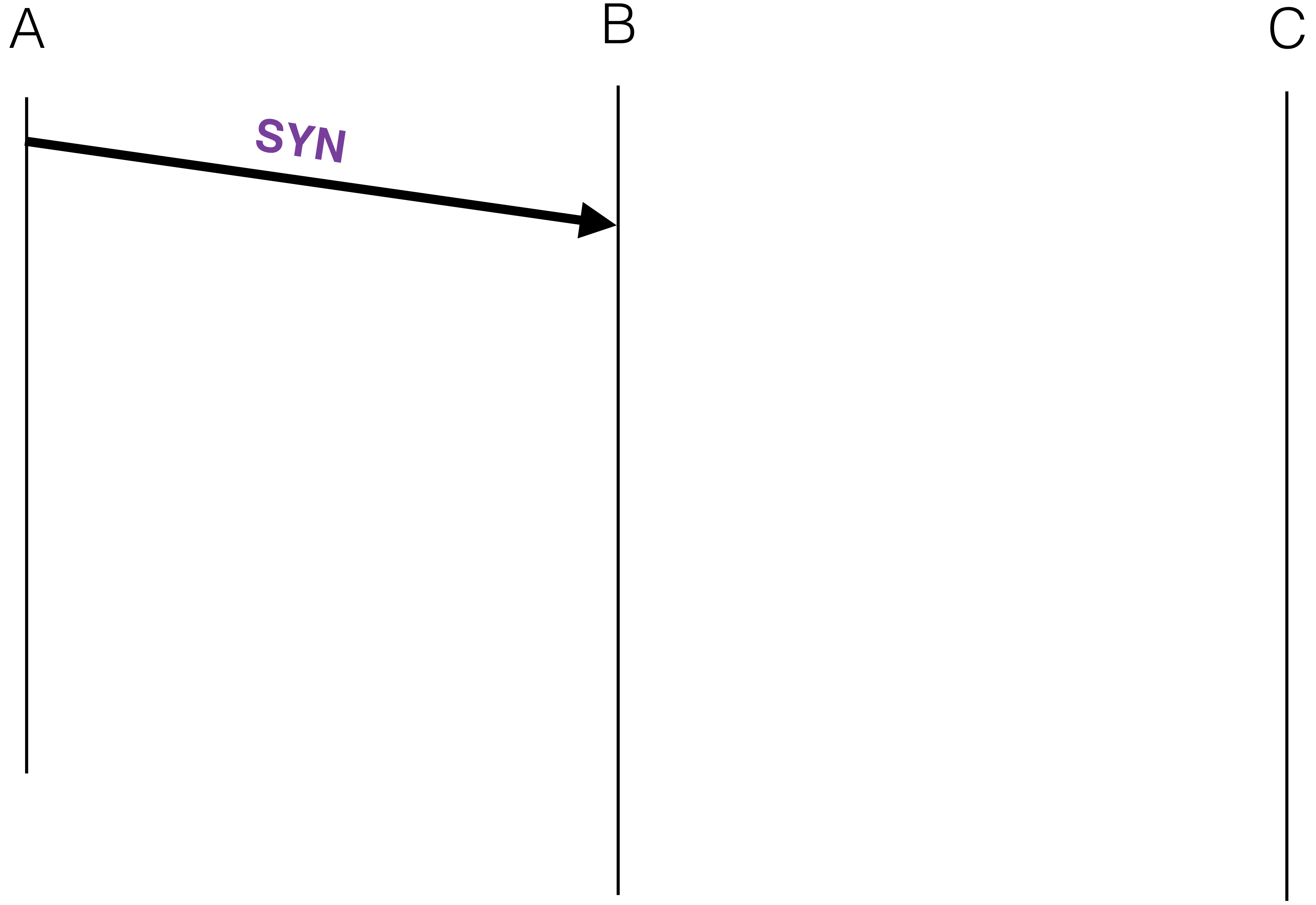

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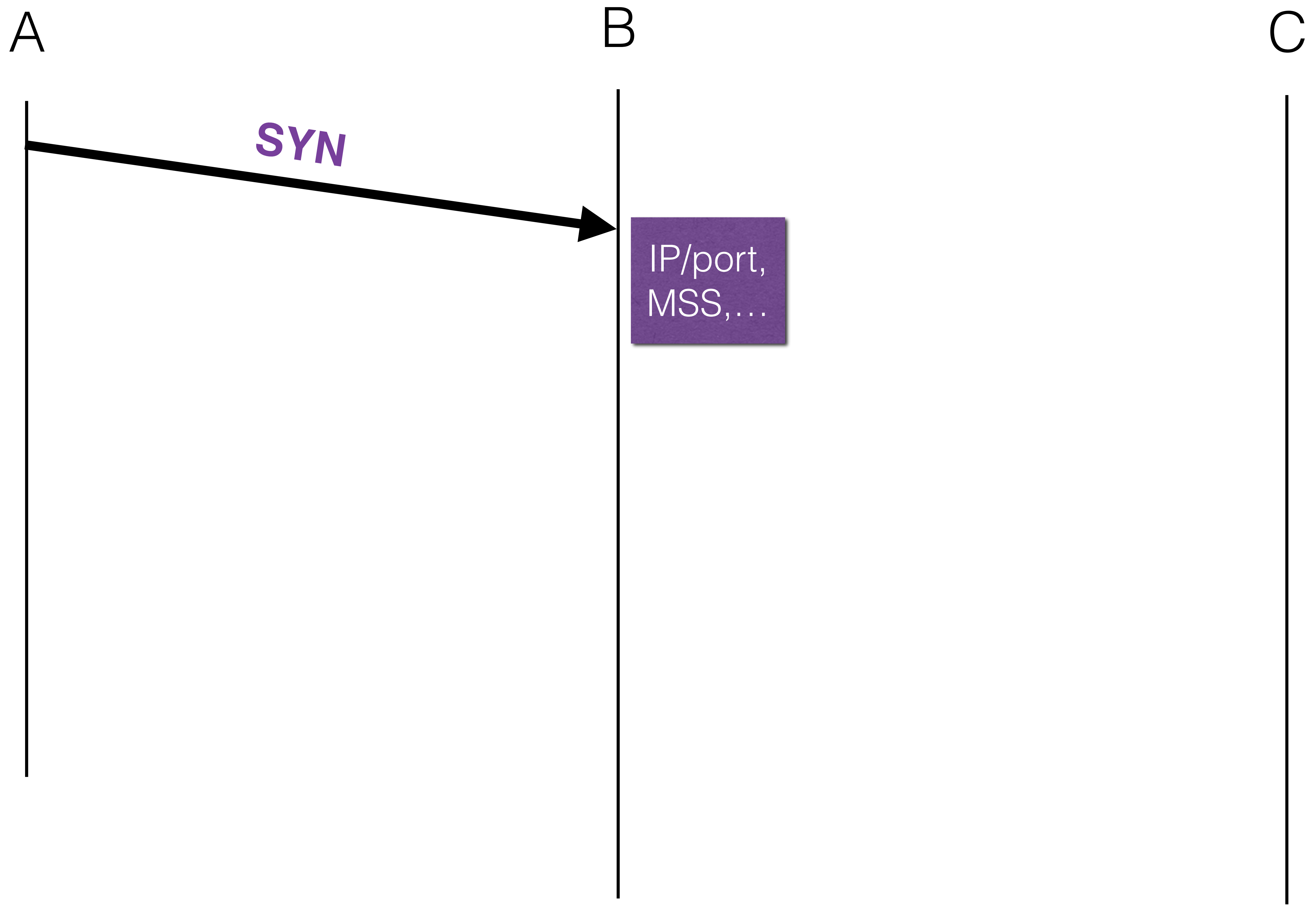

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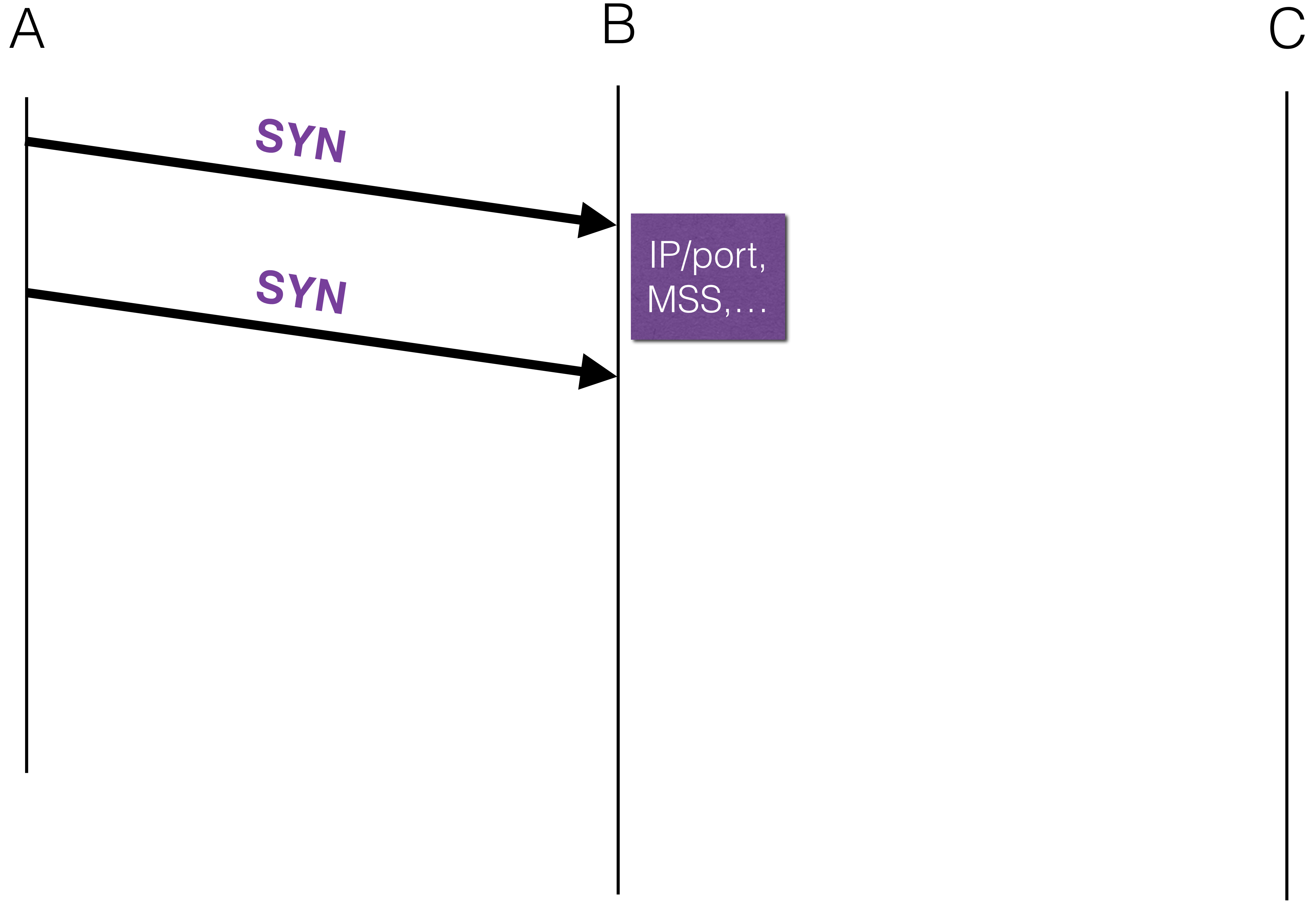

SYN flooding

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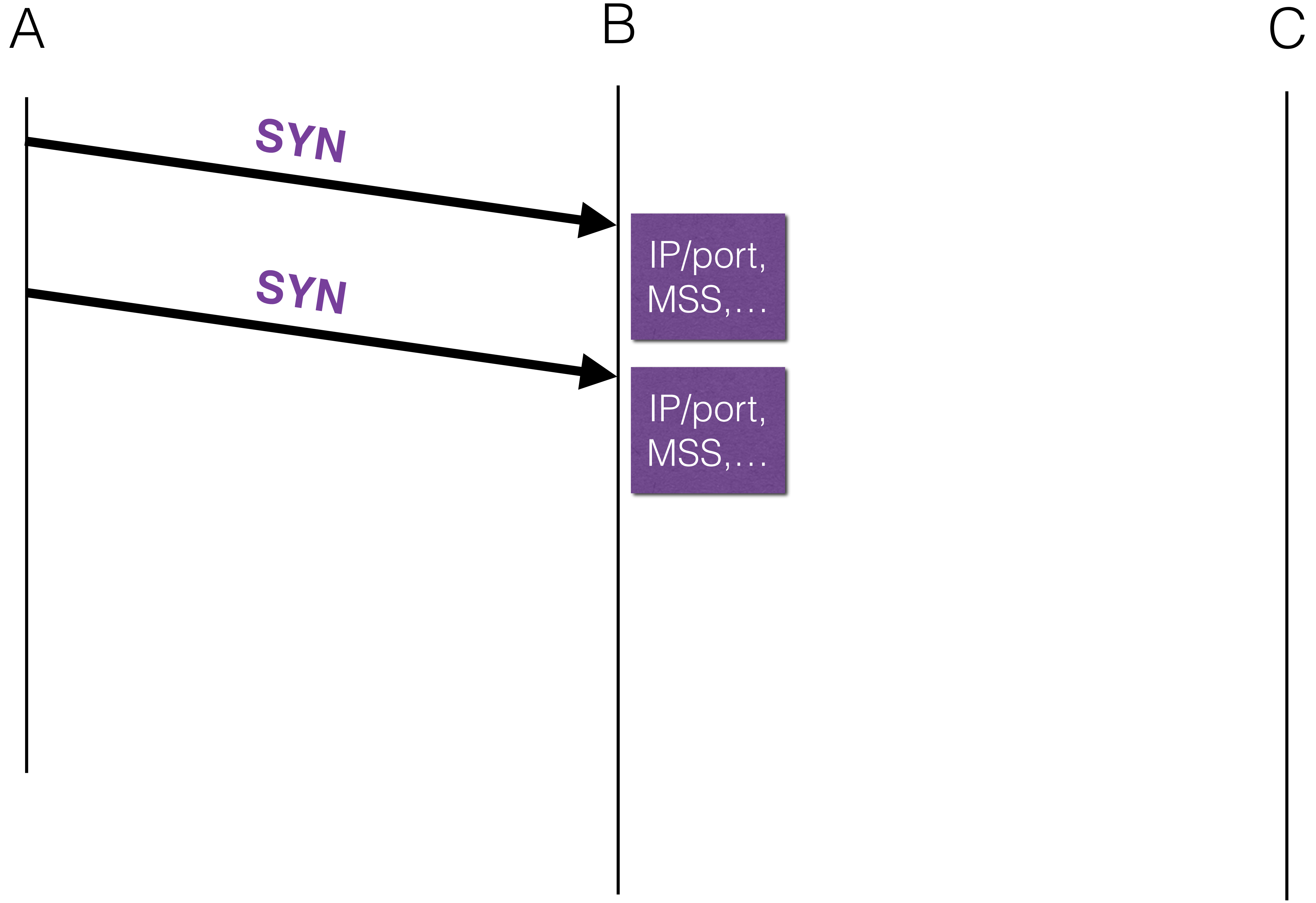

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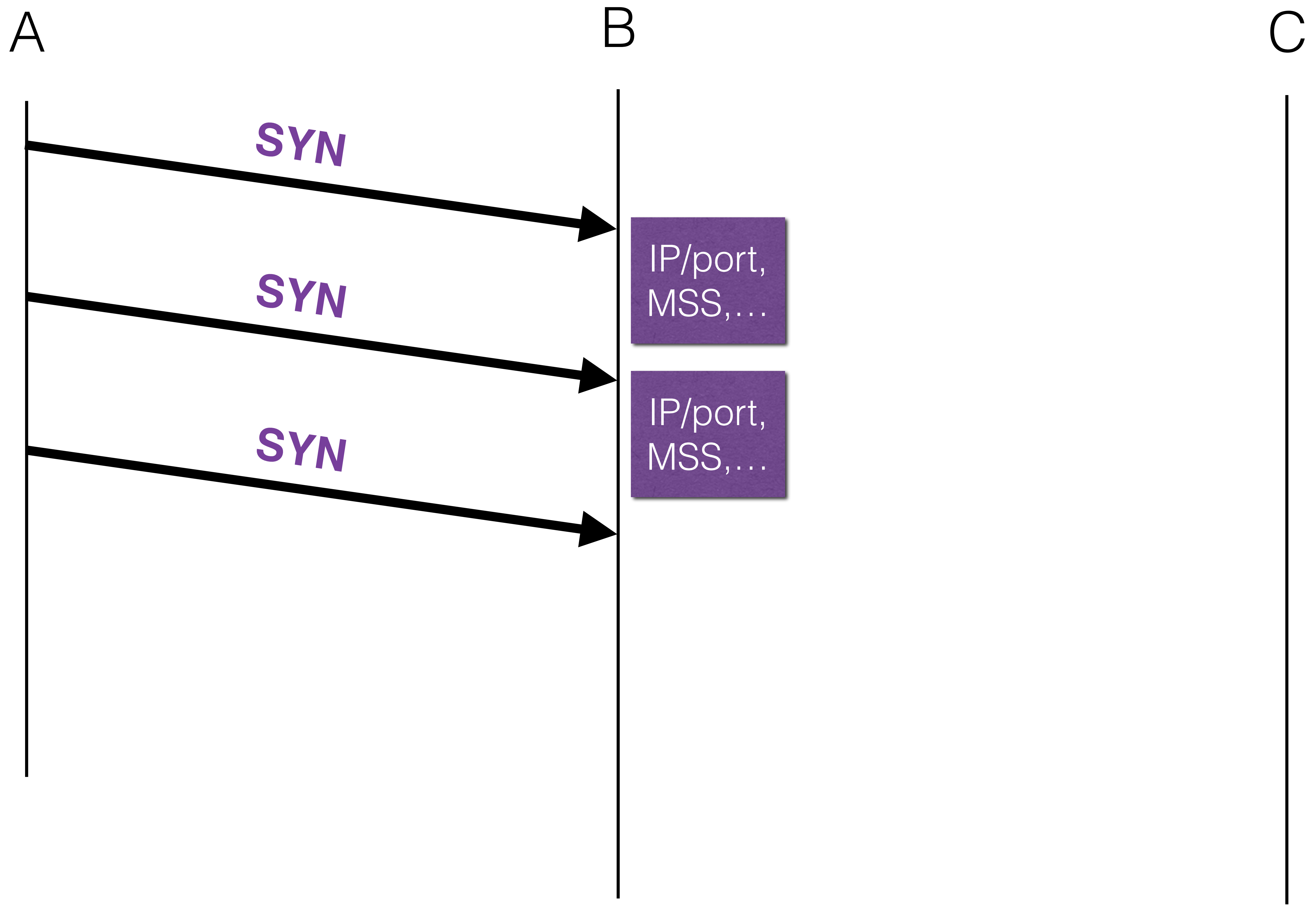

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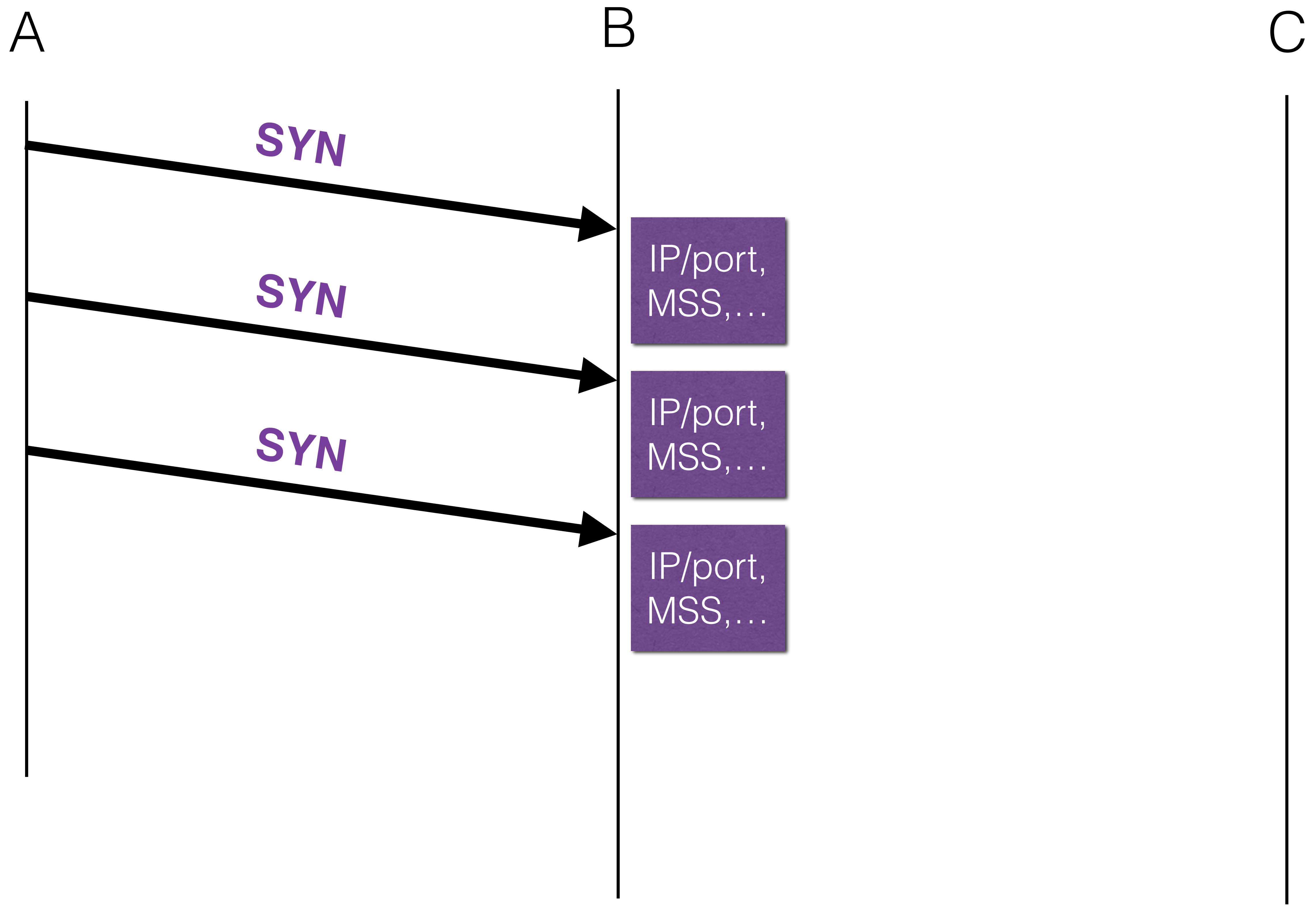

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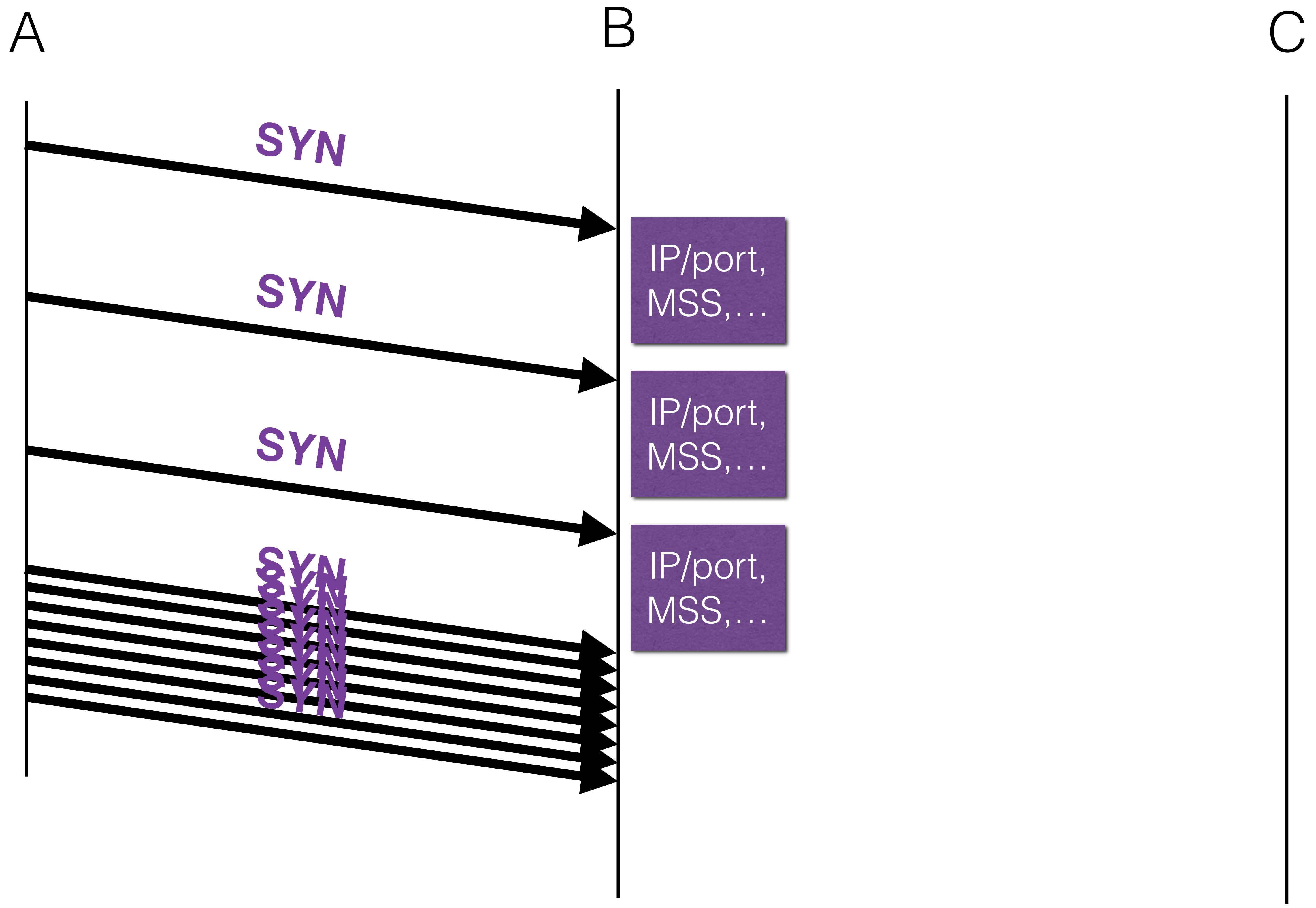

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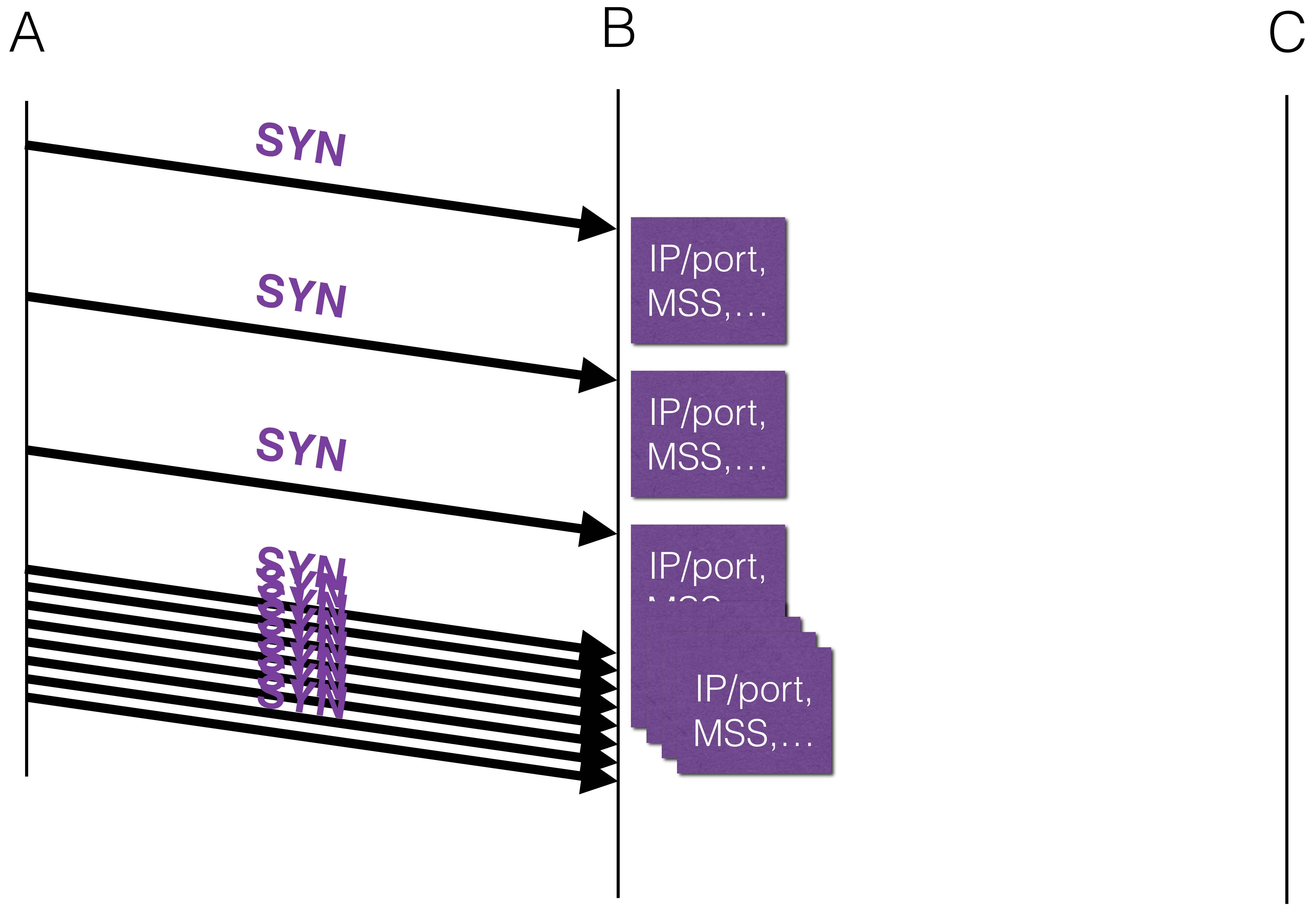

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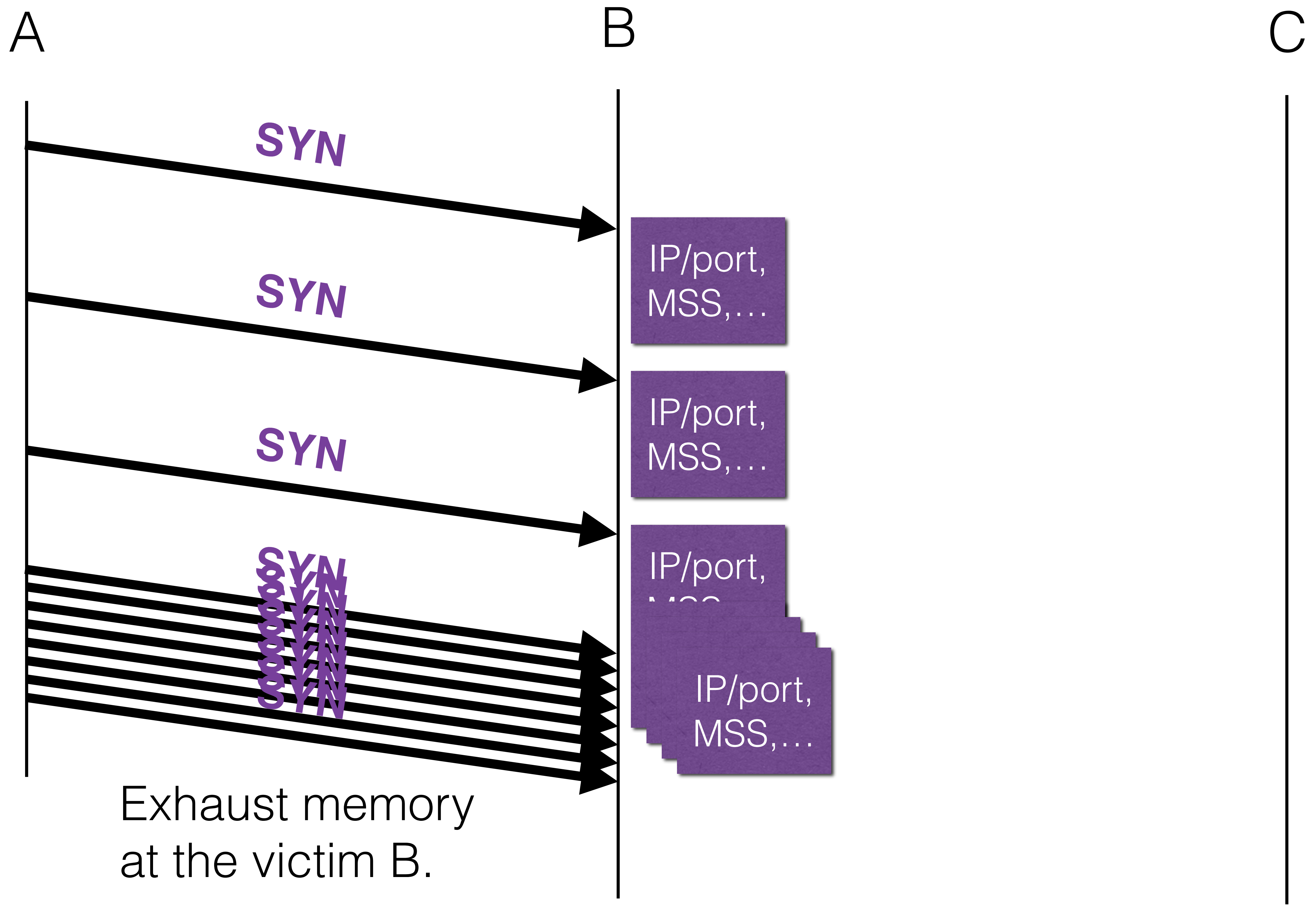
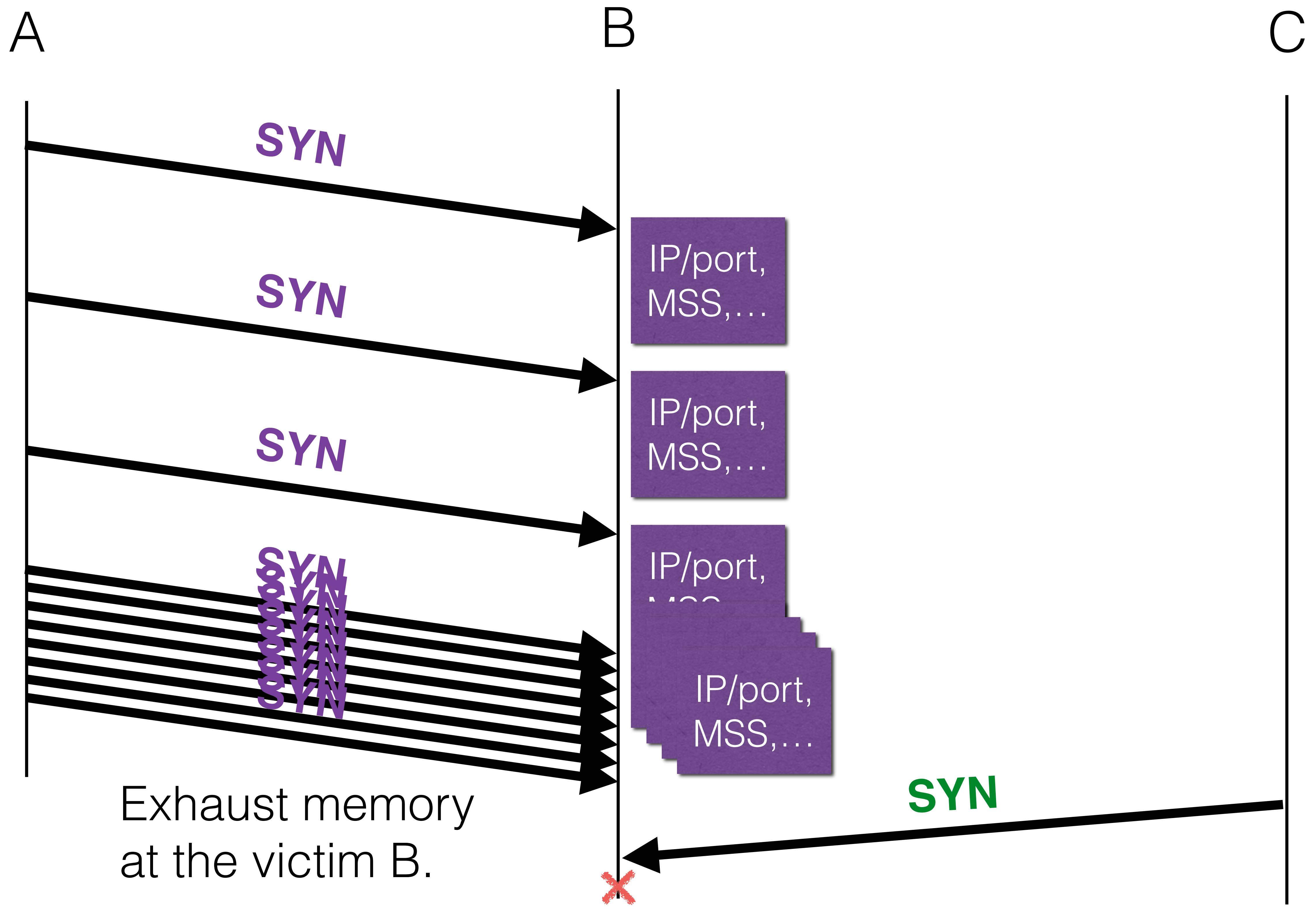


Exhaust memory at the victim B.

SYN flooding

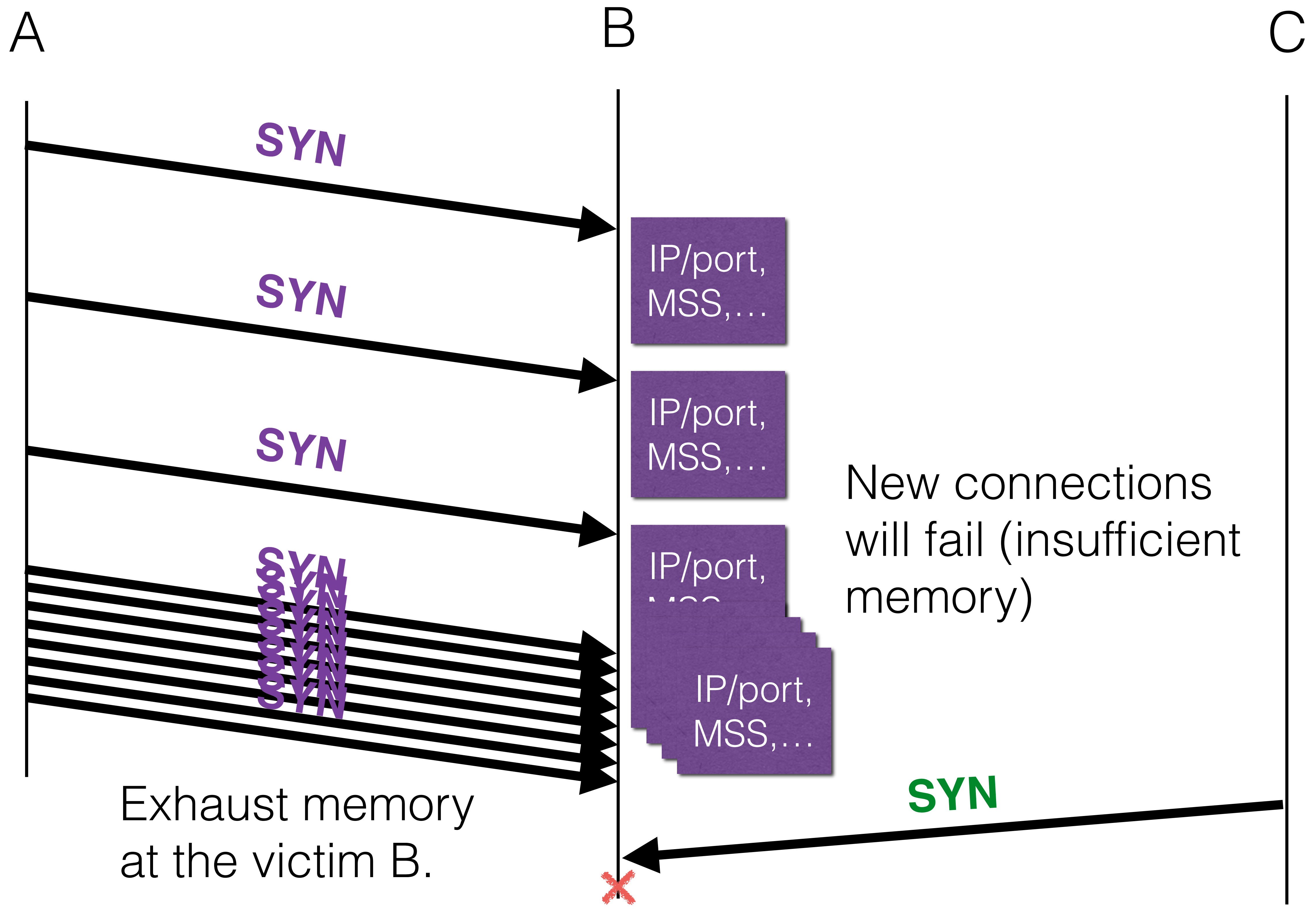
The attack



Exhaust memory
at the victim B.

SYN flooding

The attack


A
B
C
SYN
SYN
SYN
SYN
IP/port, MSS,…
IP/port, MSS,…
IP/port,
IP/port, MSS,…
New connections will fail (insufficient memory)
SYN
Exhaust memory at the victim B.

SYN flooding details

- Easy to detect many incomplete handshakes from a single IP address

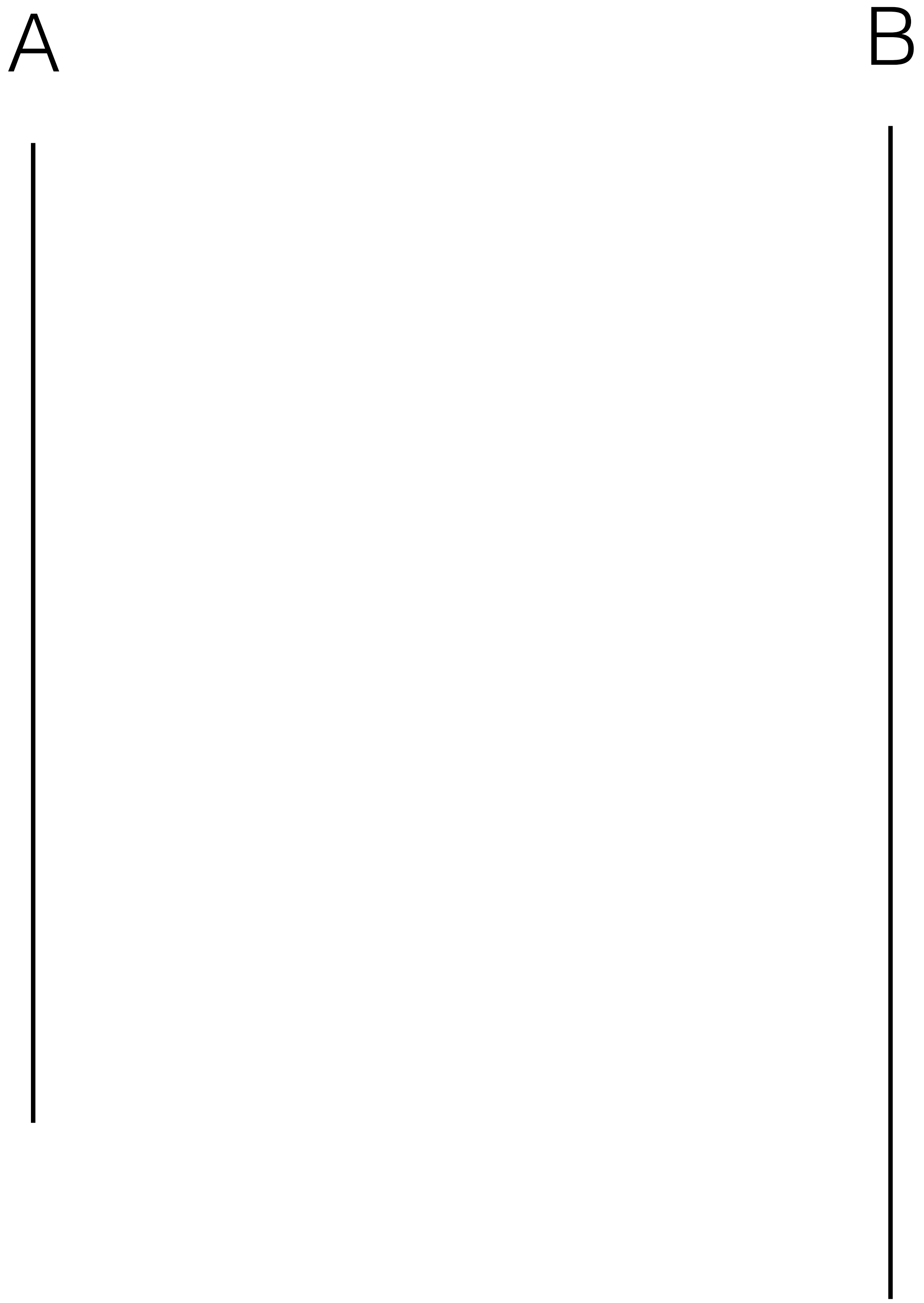
- *Spoof* the source IP address
  - It’s just a field in a header: set it to whatever you like

- 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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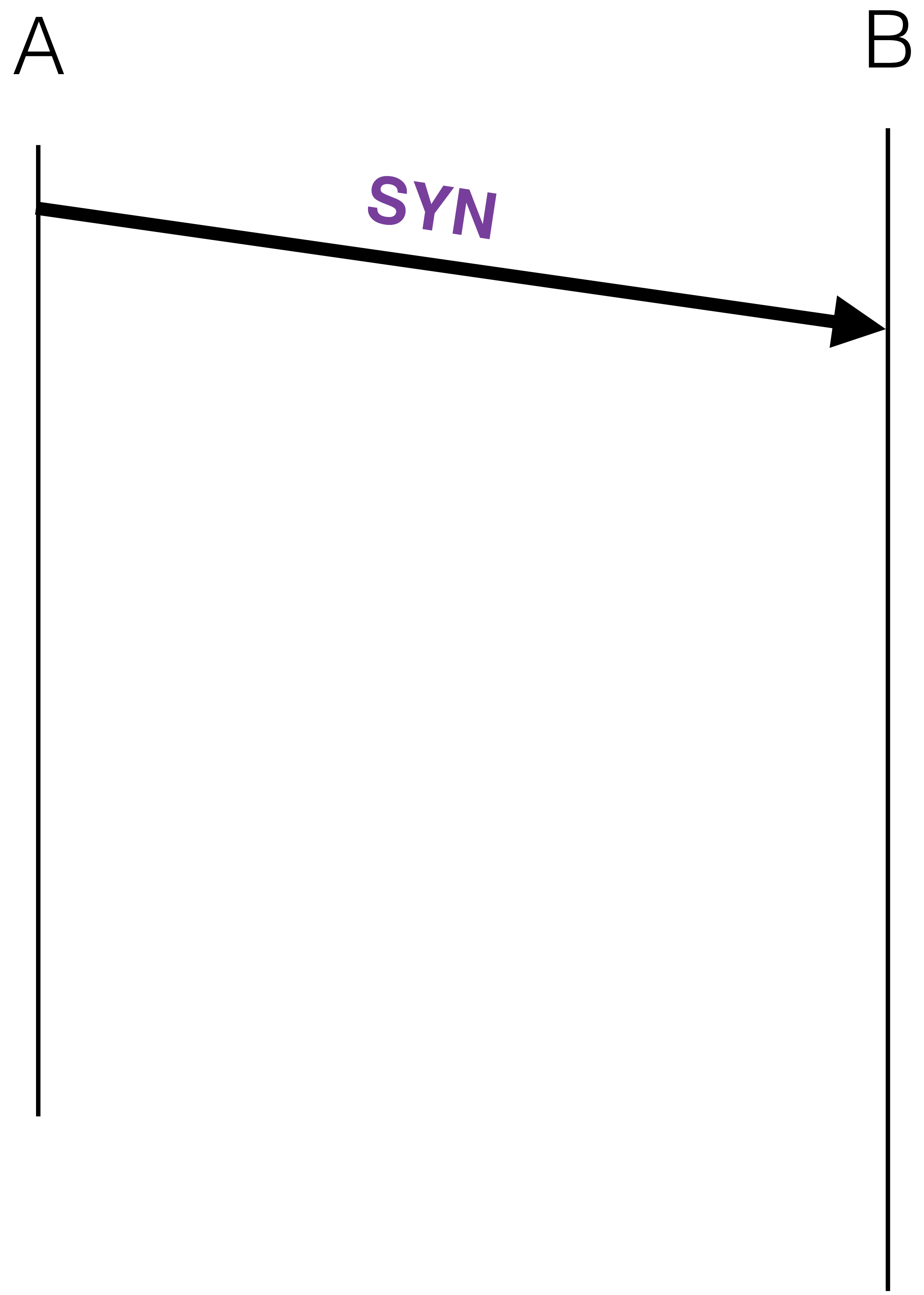

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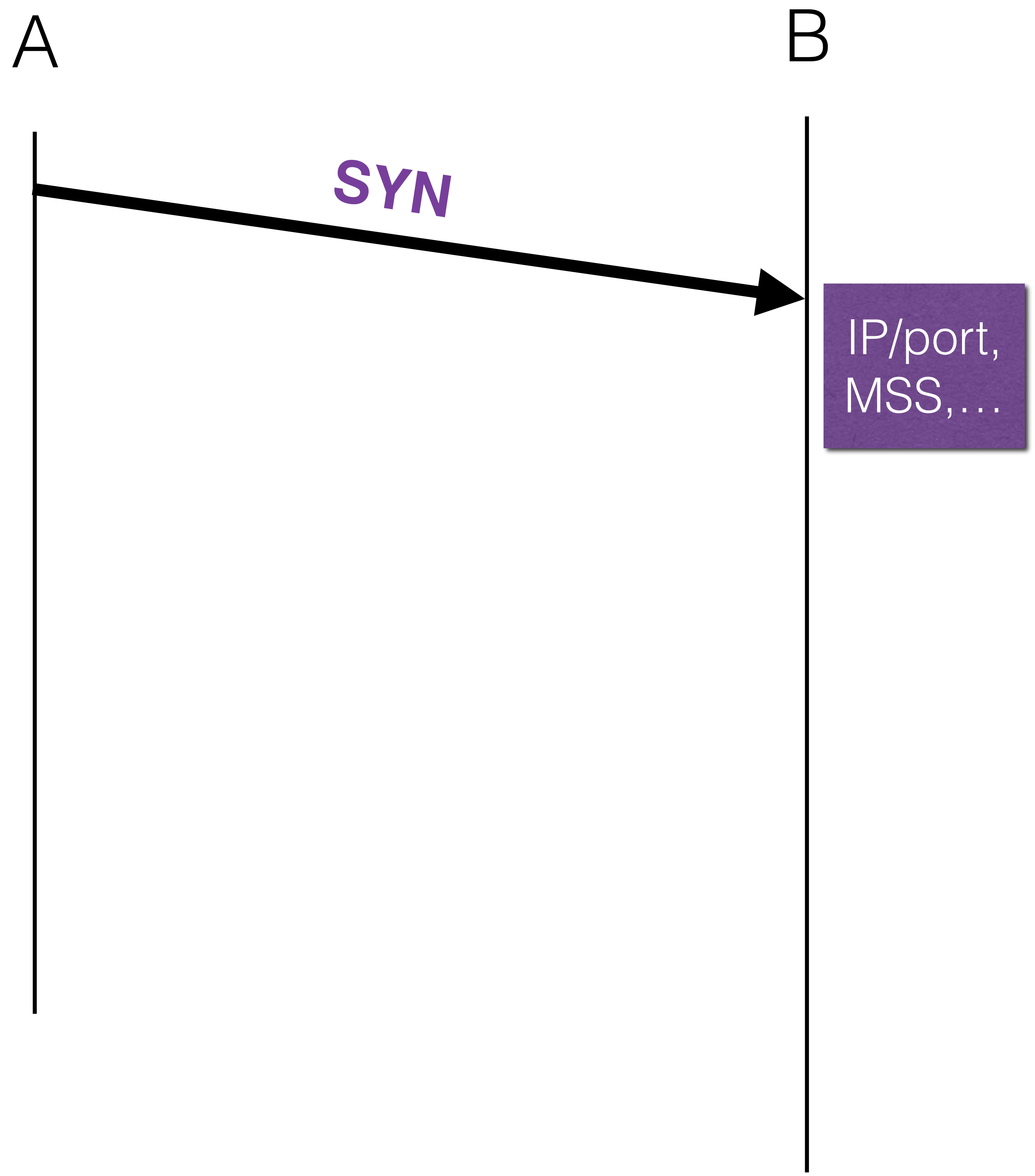

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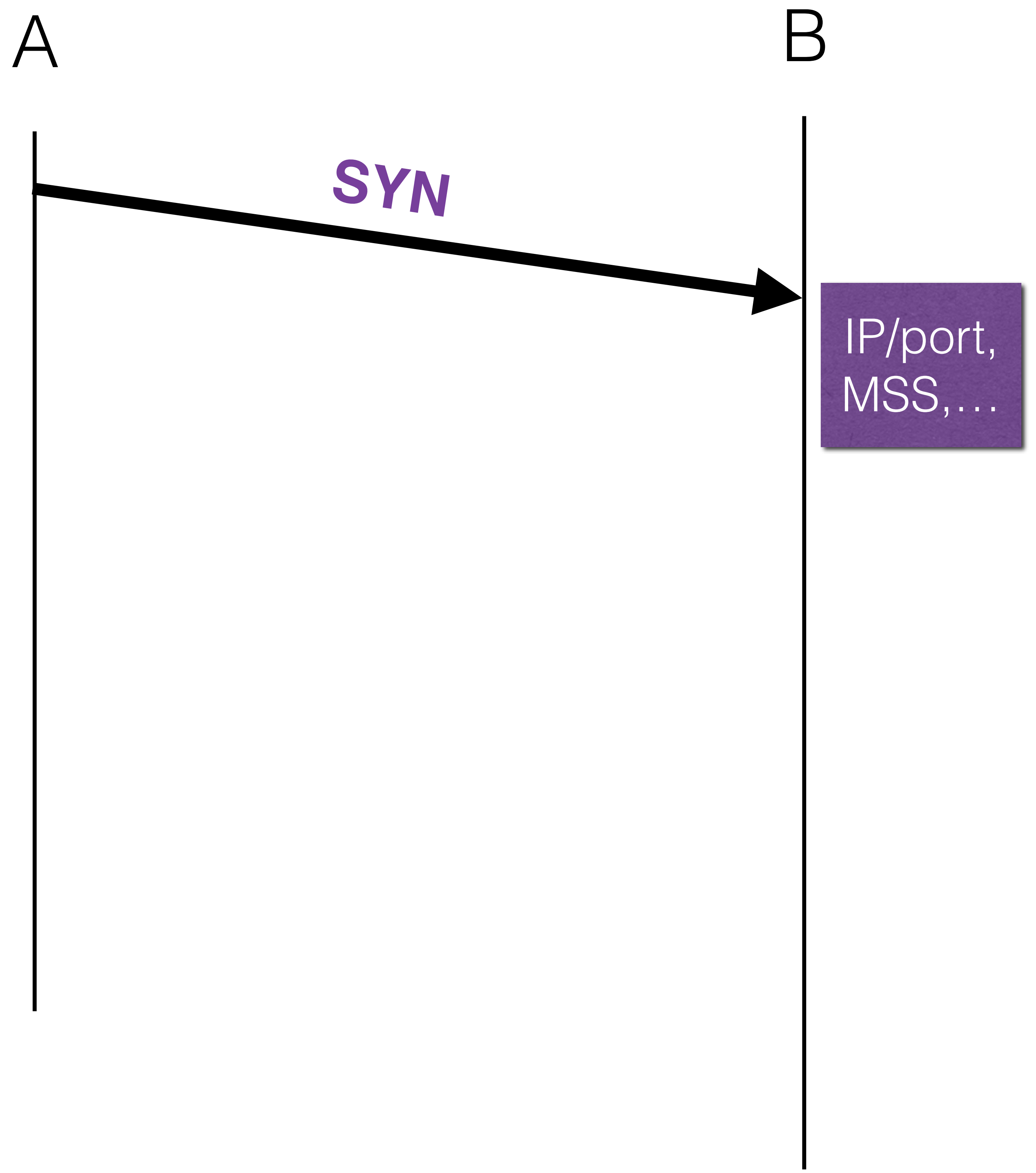
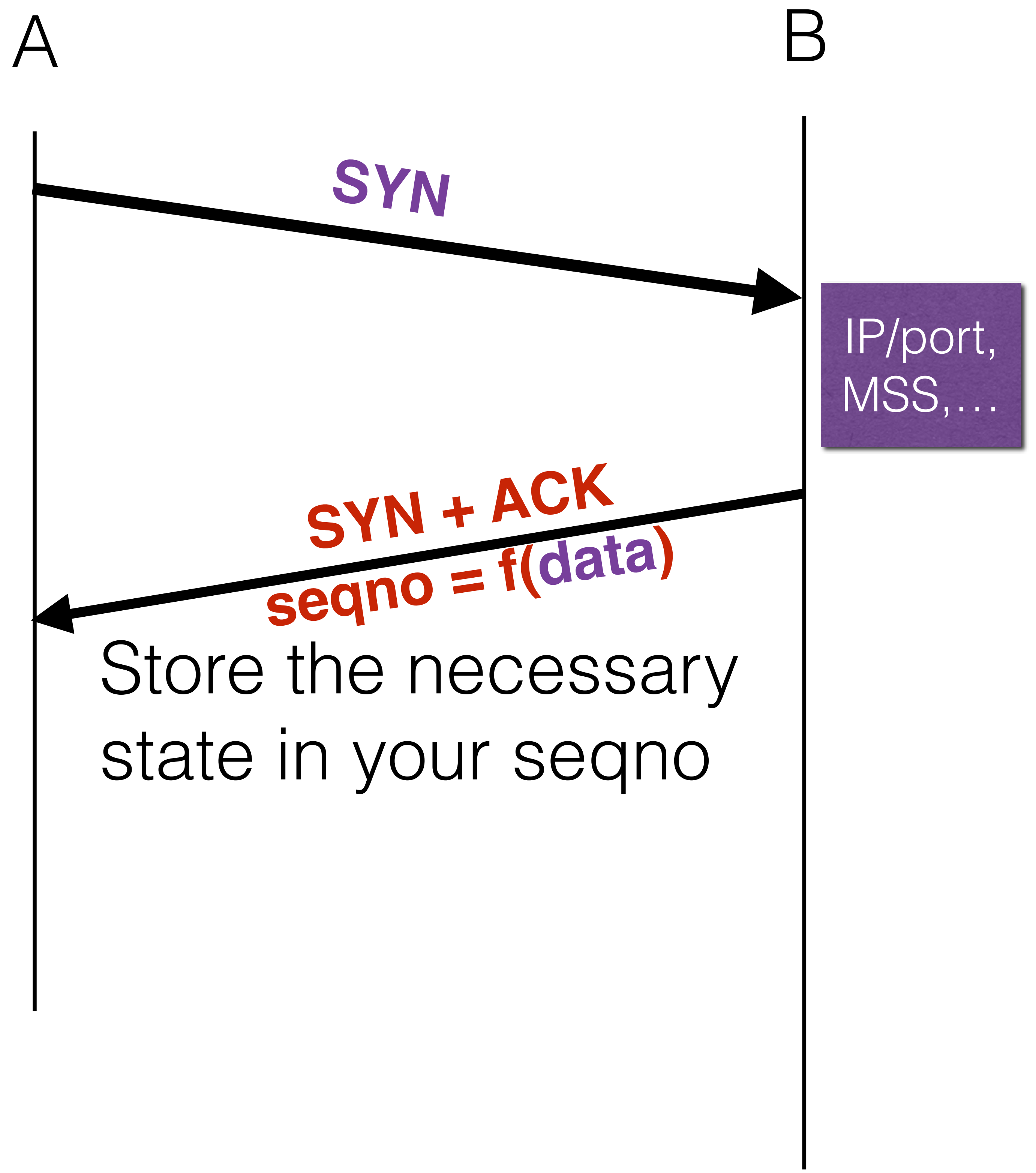


Rather than store this data, send it to the host who is initiating the connection and have him return it to you

SYN cookies

The defense



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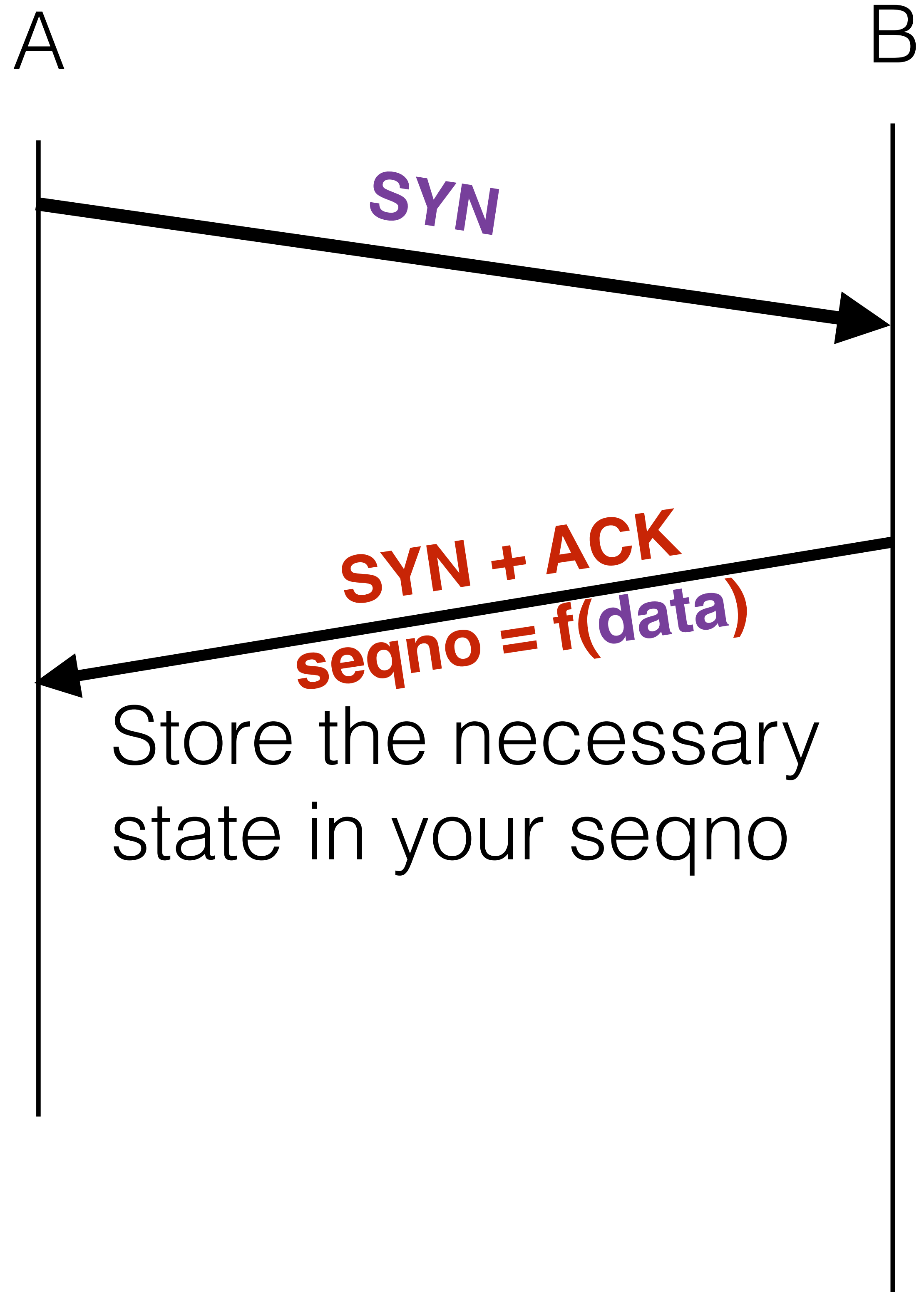

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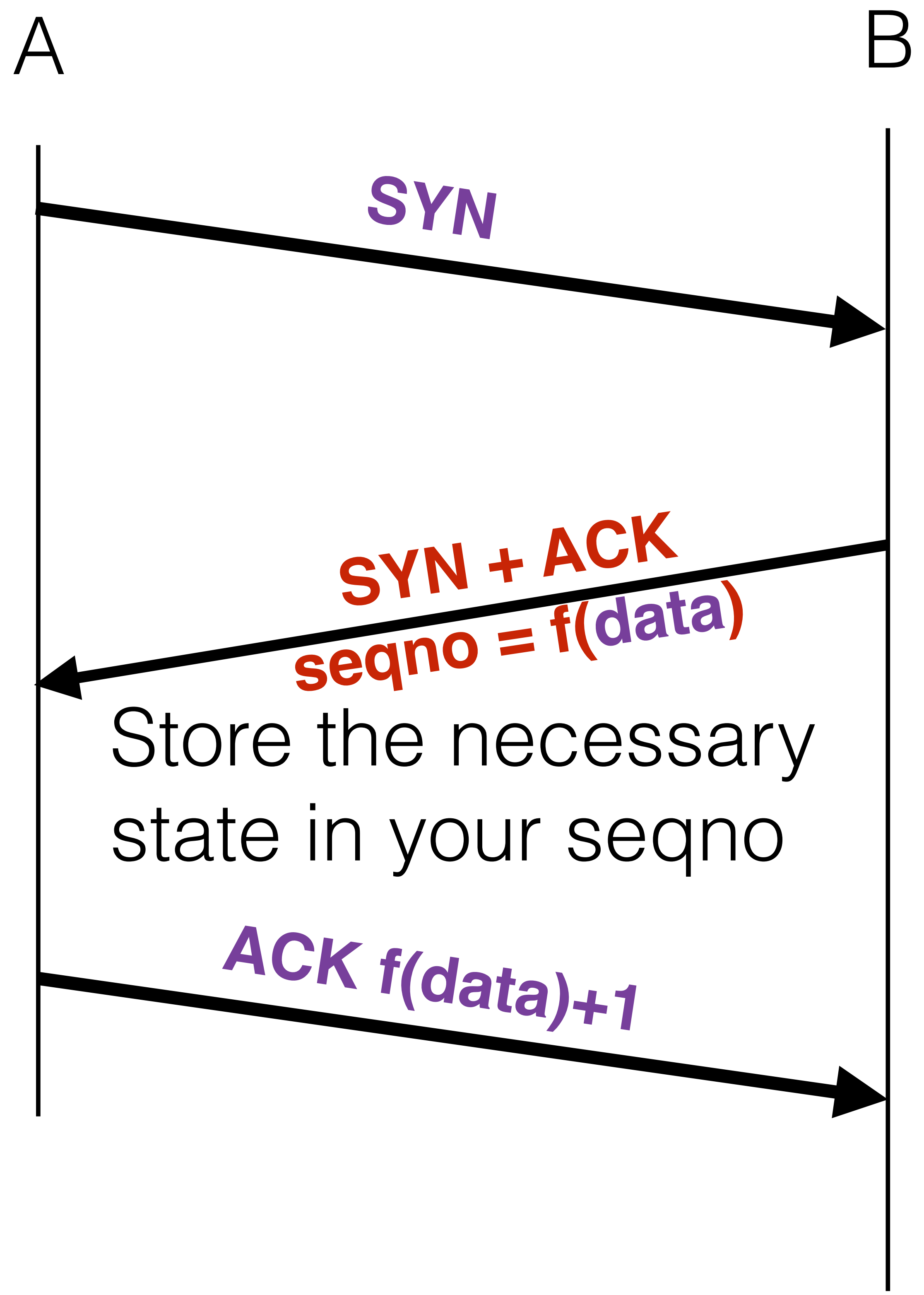

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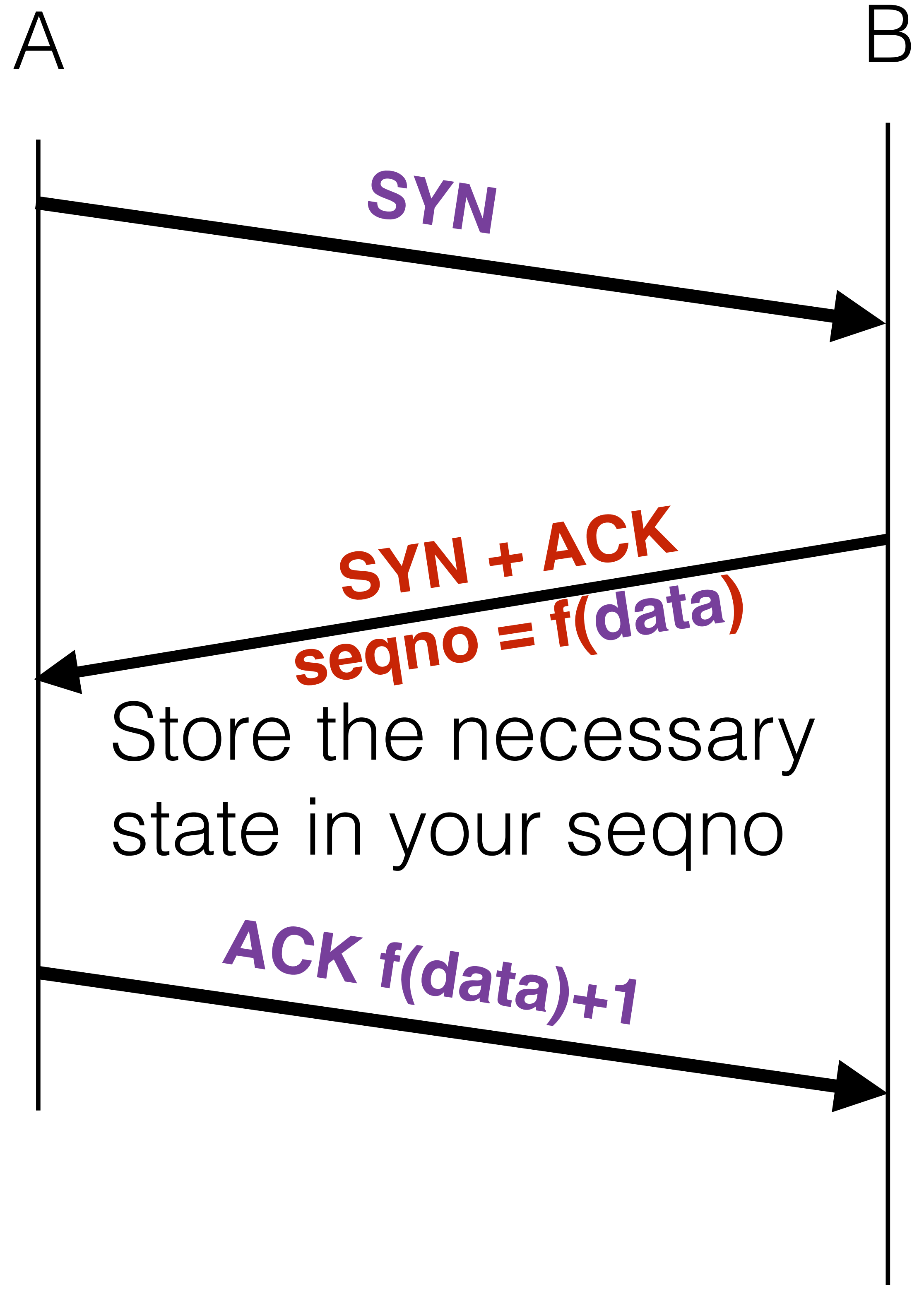

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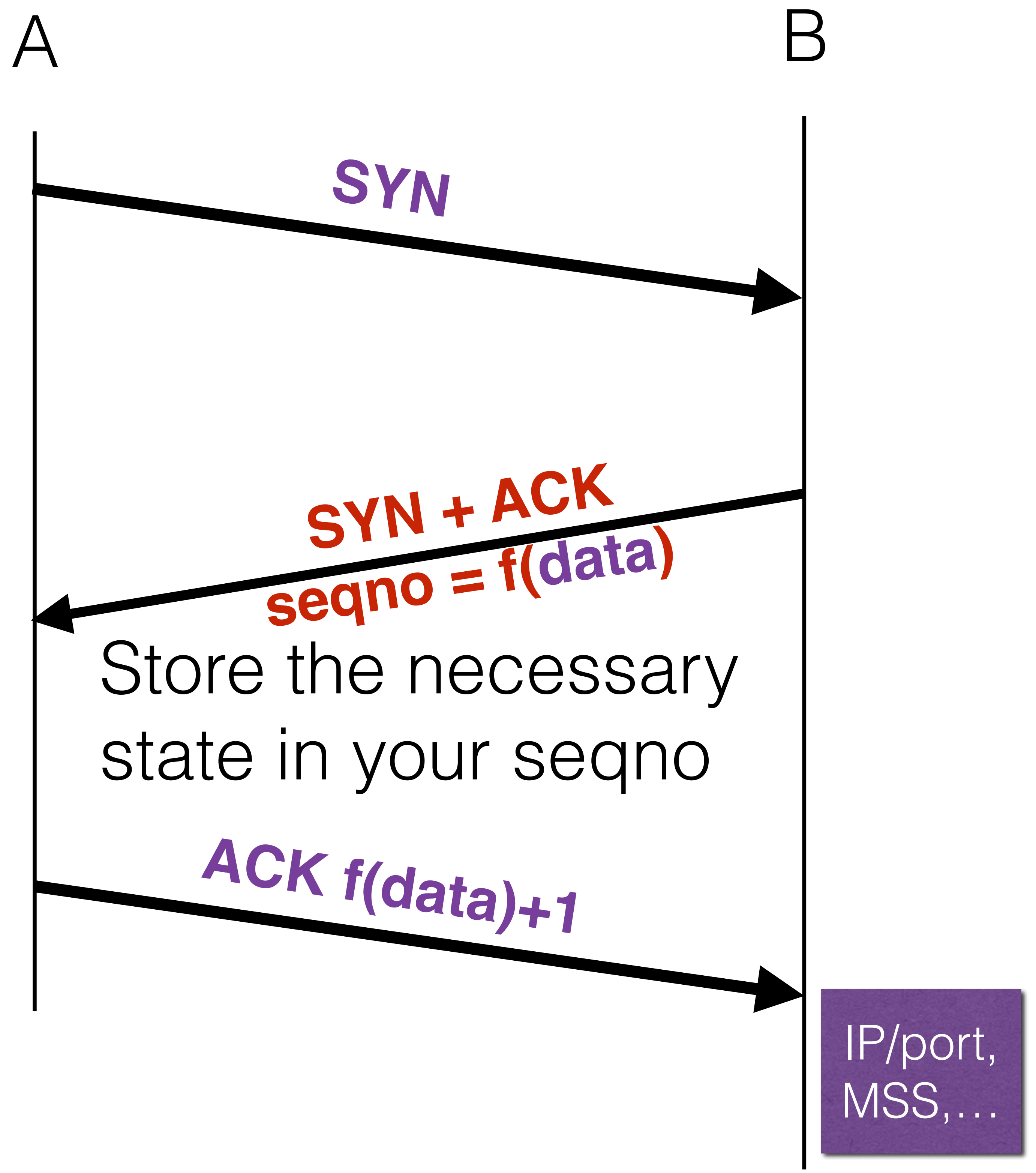
Check that f(data) is valid for this connection. Only at that point do you allocate state.

SYN cookies

The defense



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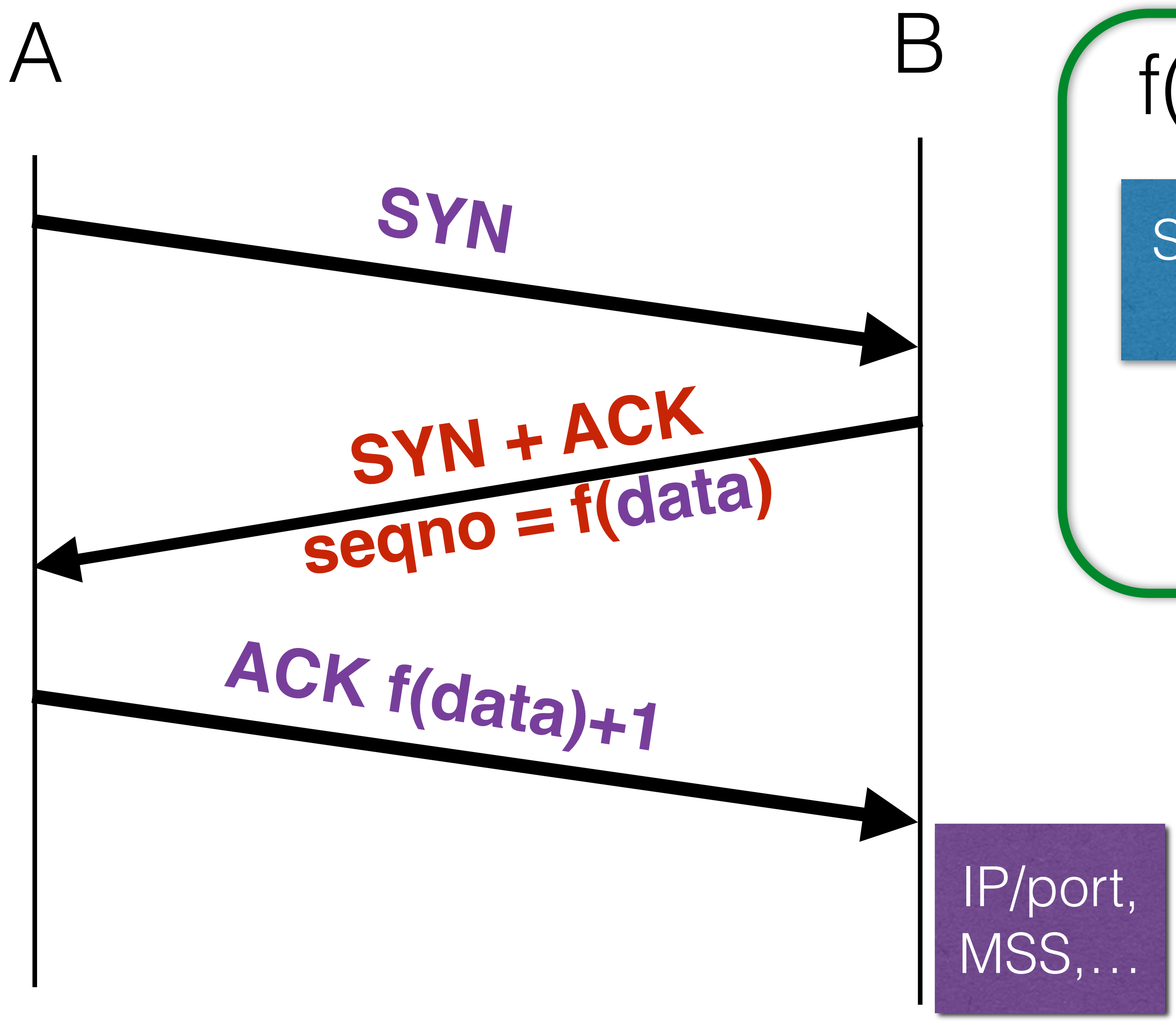
SYN cookie format



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

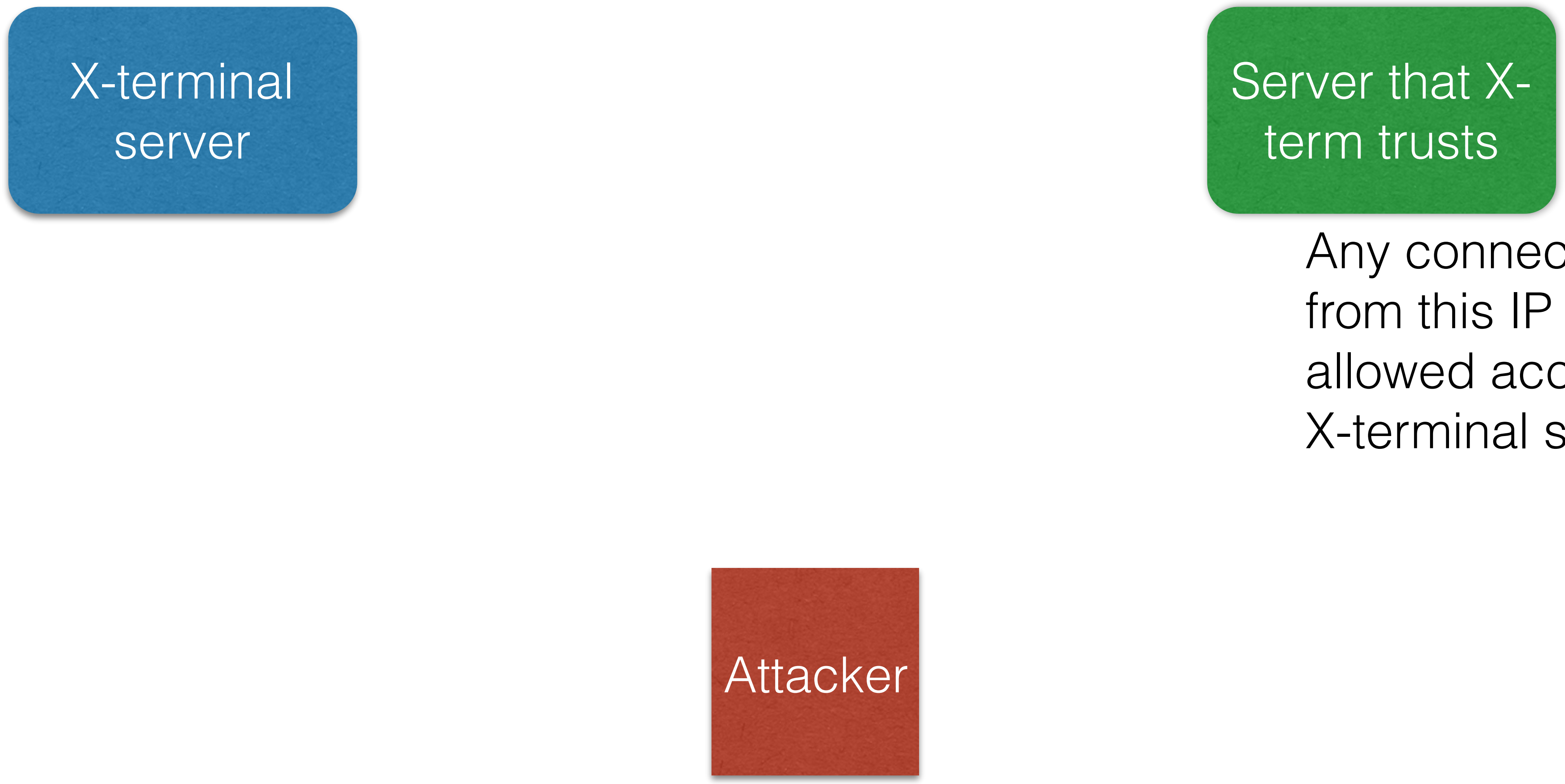
- Suppose you are on the path between src and dst; what can you do?
    - Trivial to inject packets with the correct sequence number

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

Initial sequence numbers

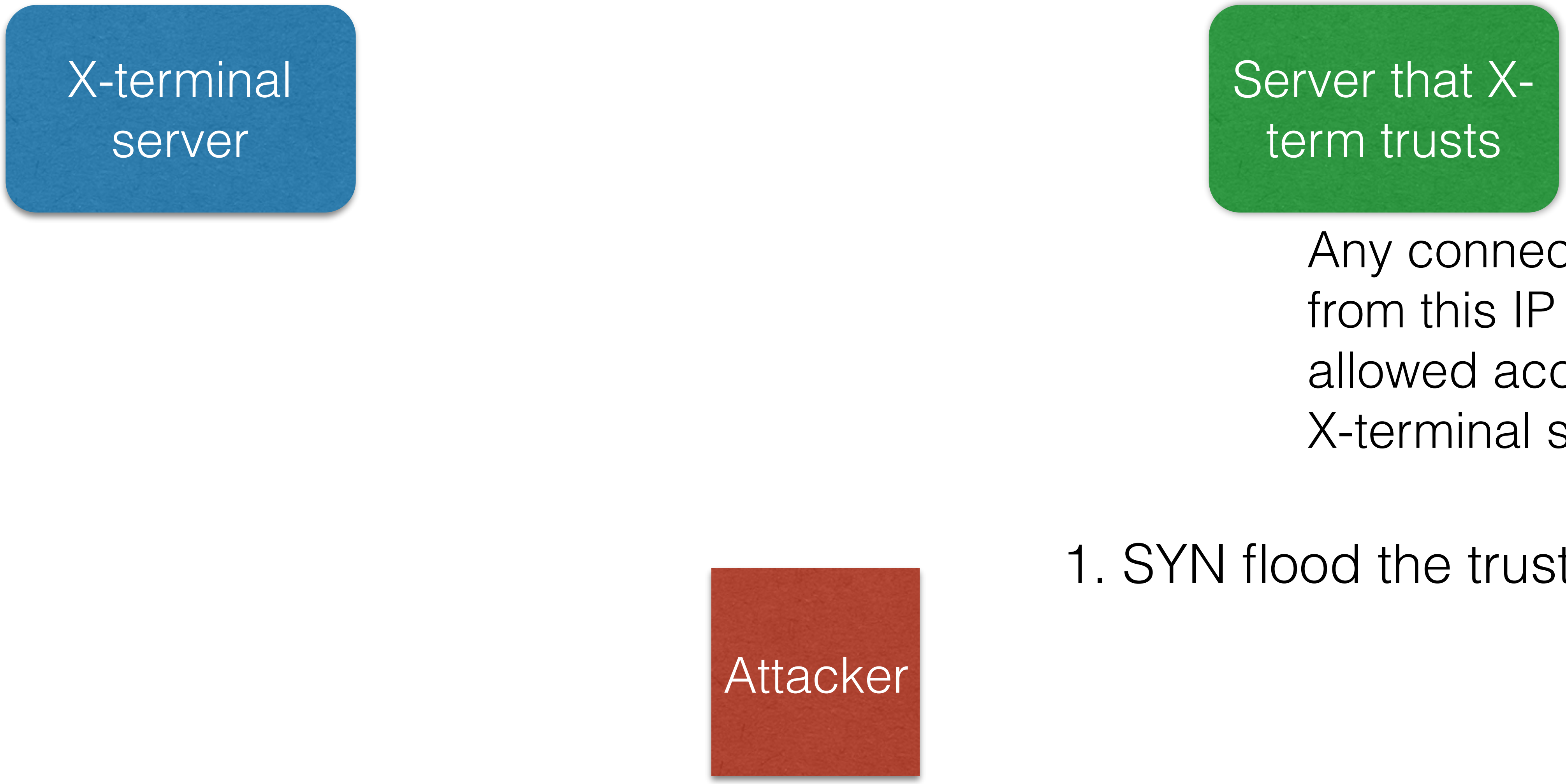
- Initial sequence numbers used to be deterministic
- What havoc can we wreak?
  - Send RSTs
  - Inject data packets into an existing connection (TCP veto attacks)
  - *Initiate and use an entire connection without ever hearing the other end*

Mitnick attack



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

Mitnick attack



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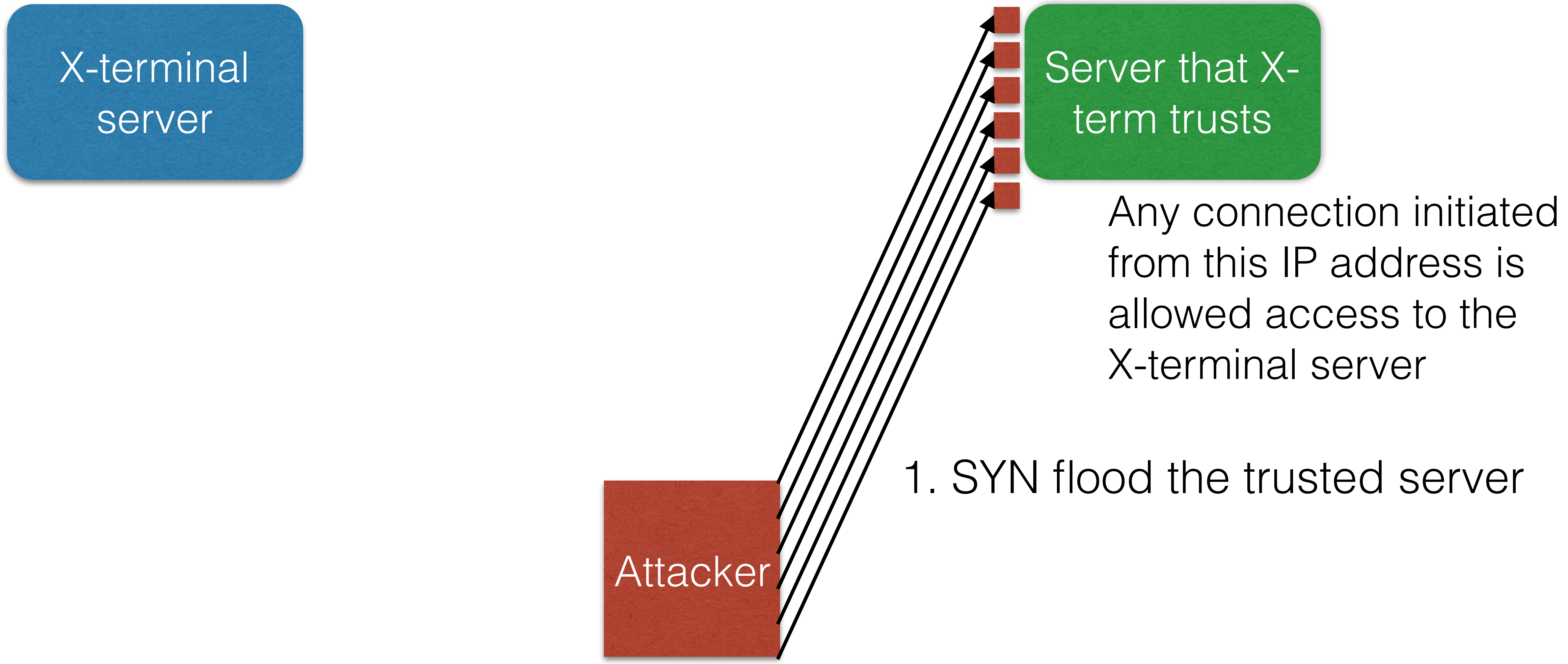
1. SYN flood the trusted server

Mitnick attack



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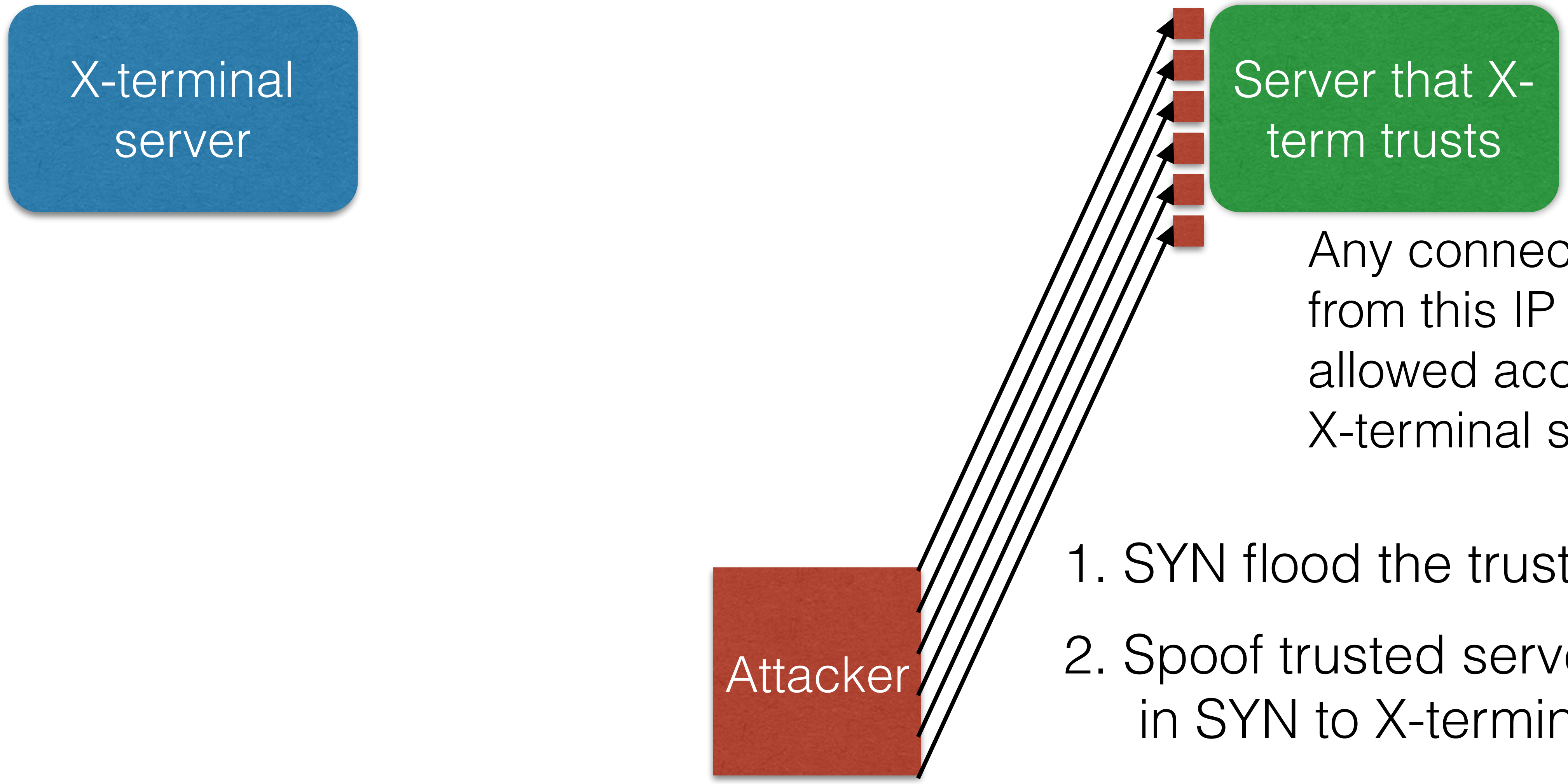

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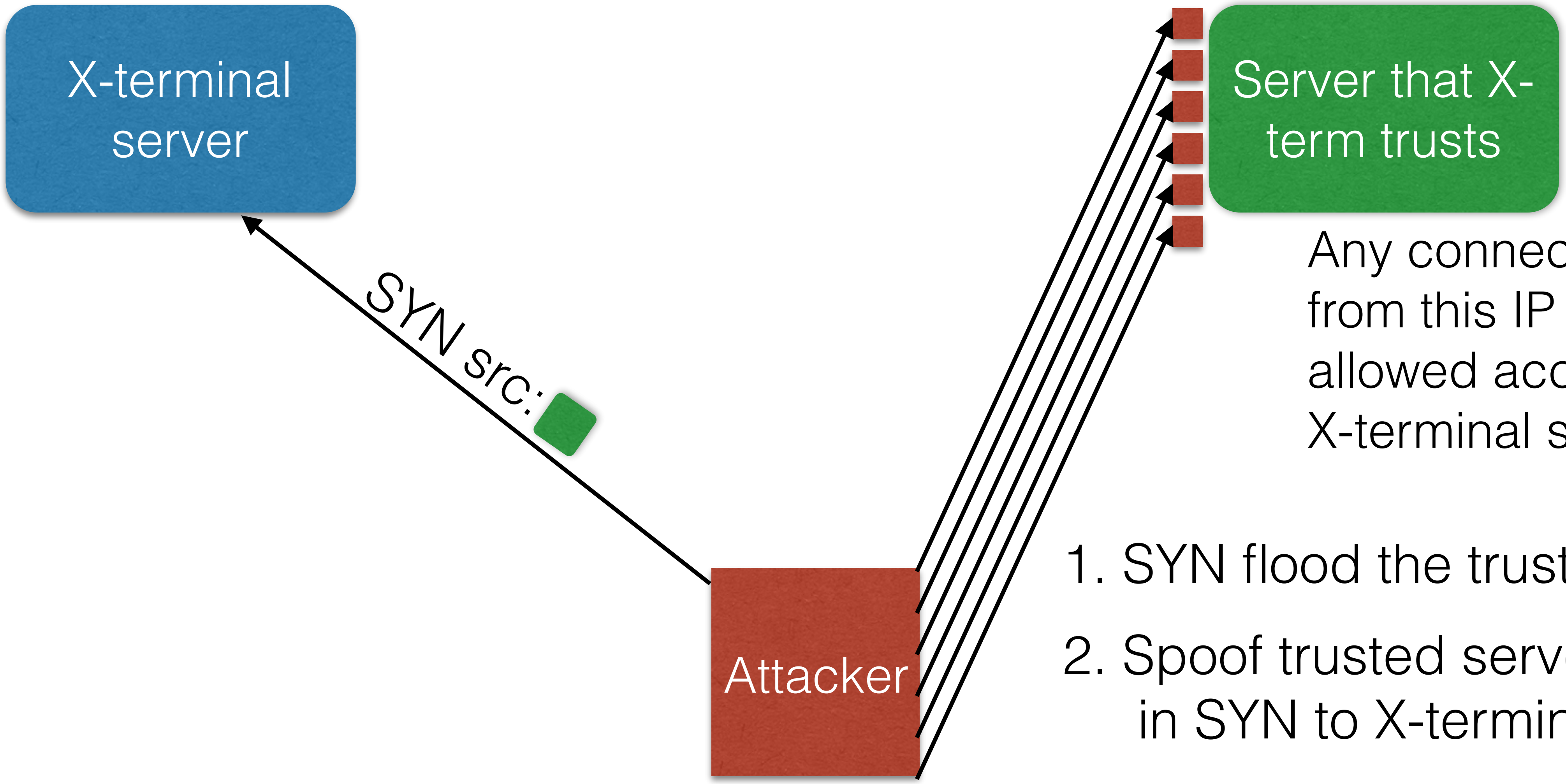

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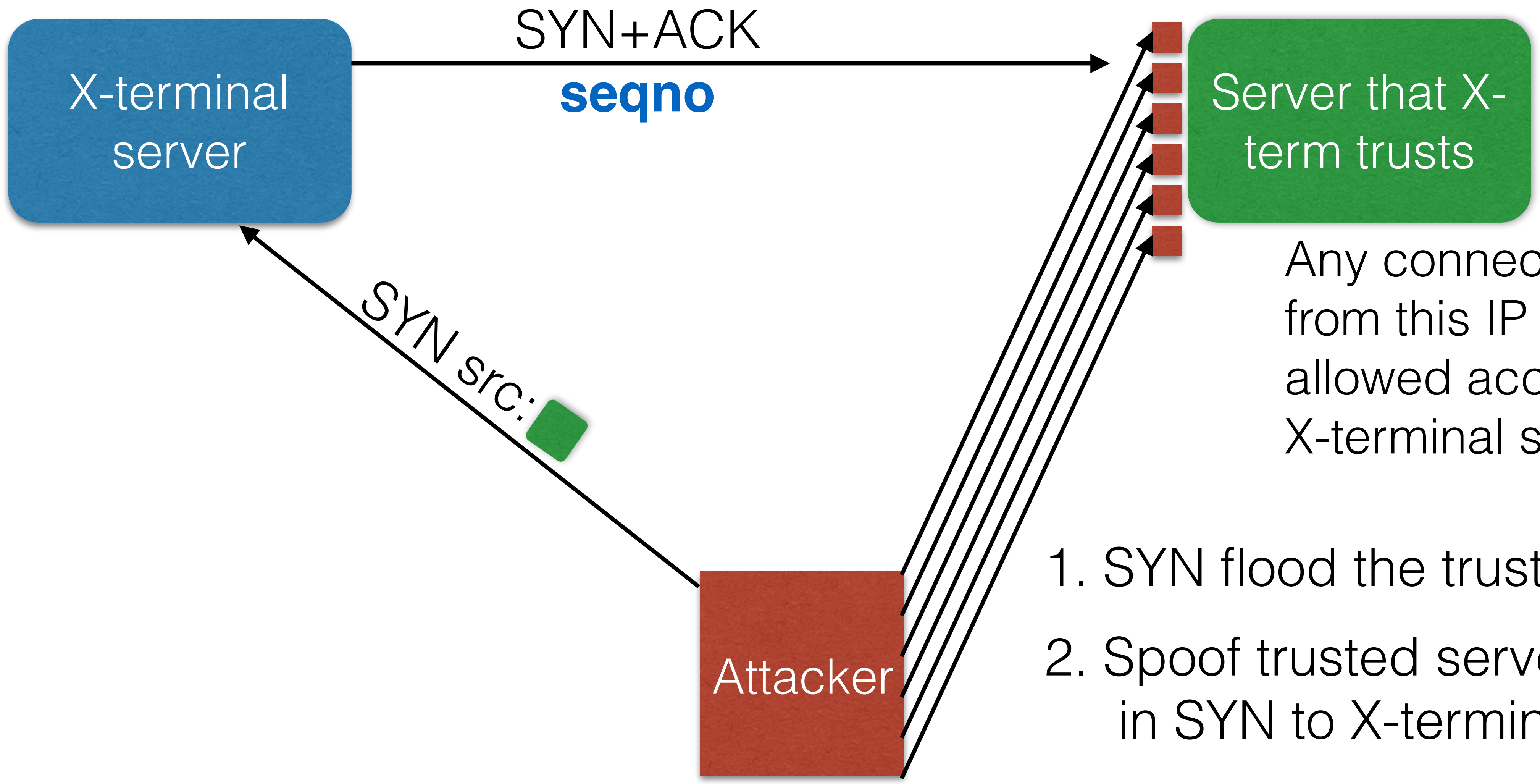

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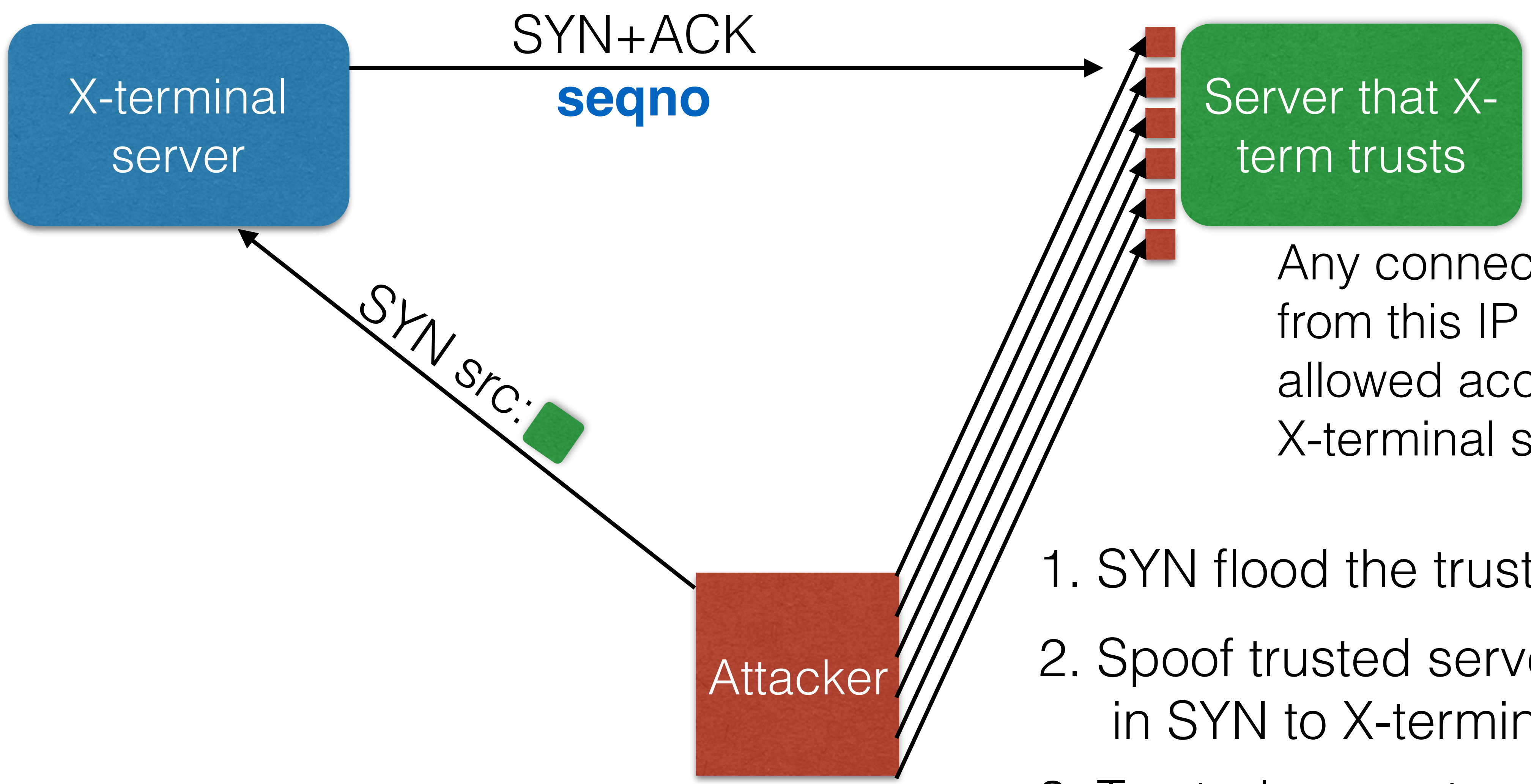

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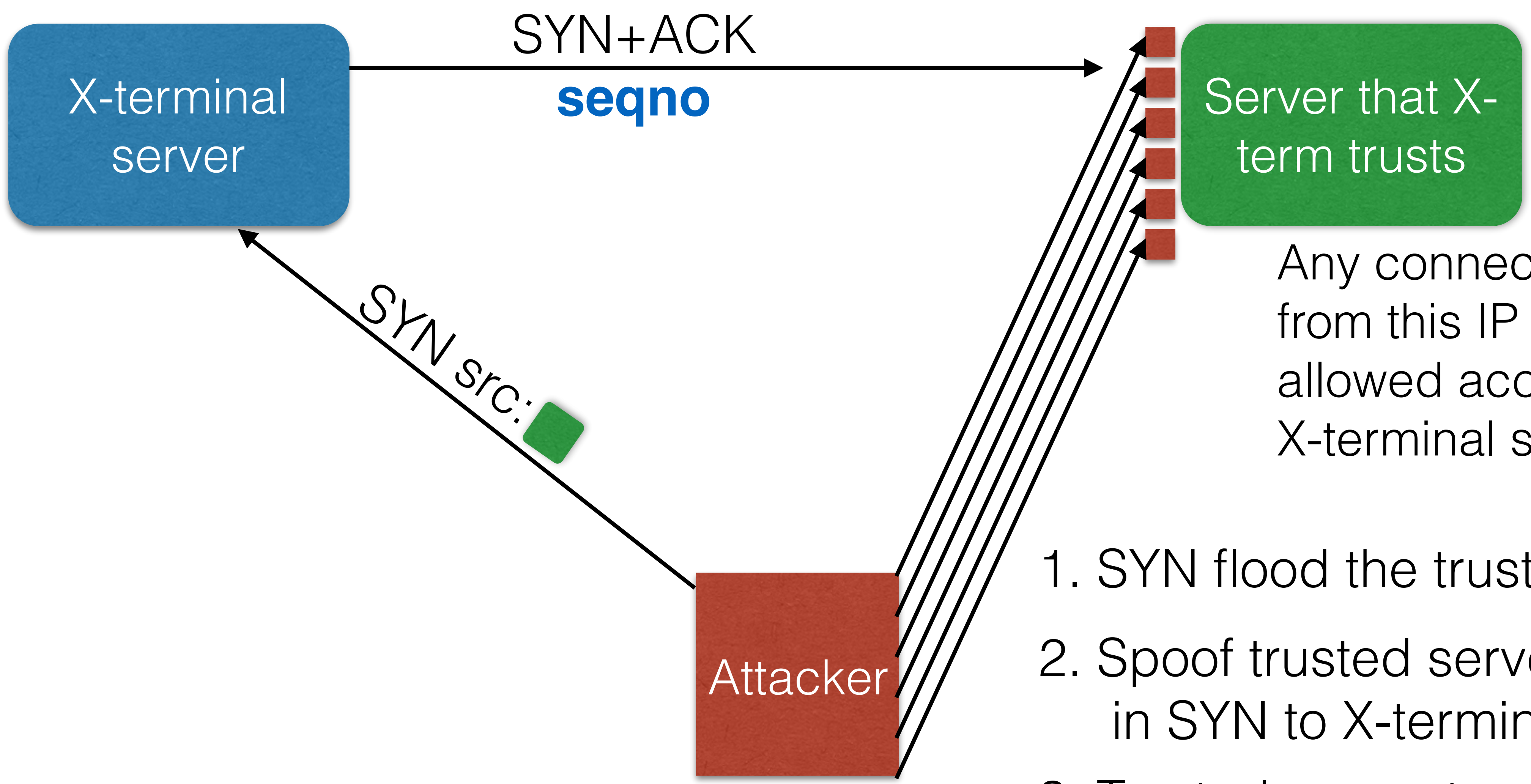
2. Spoof trusted server's IP addr in SYN to X-terminal
3. Trusted server too busy to RST

Mitnick attack



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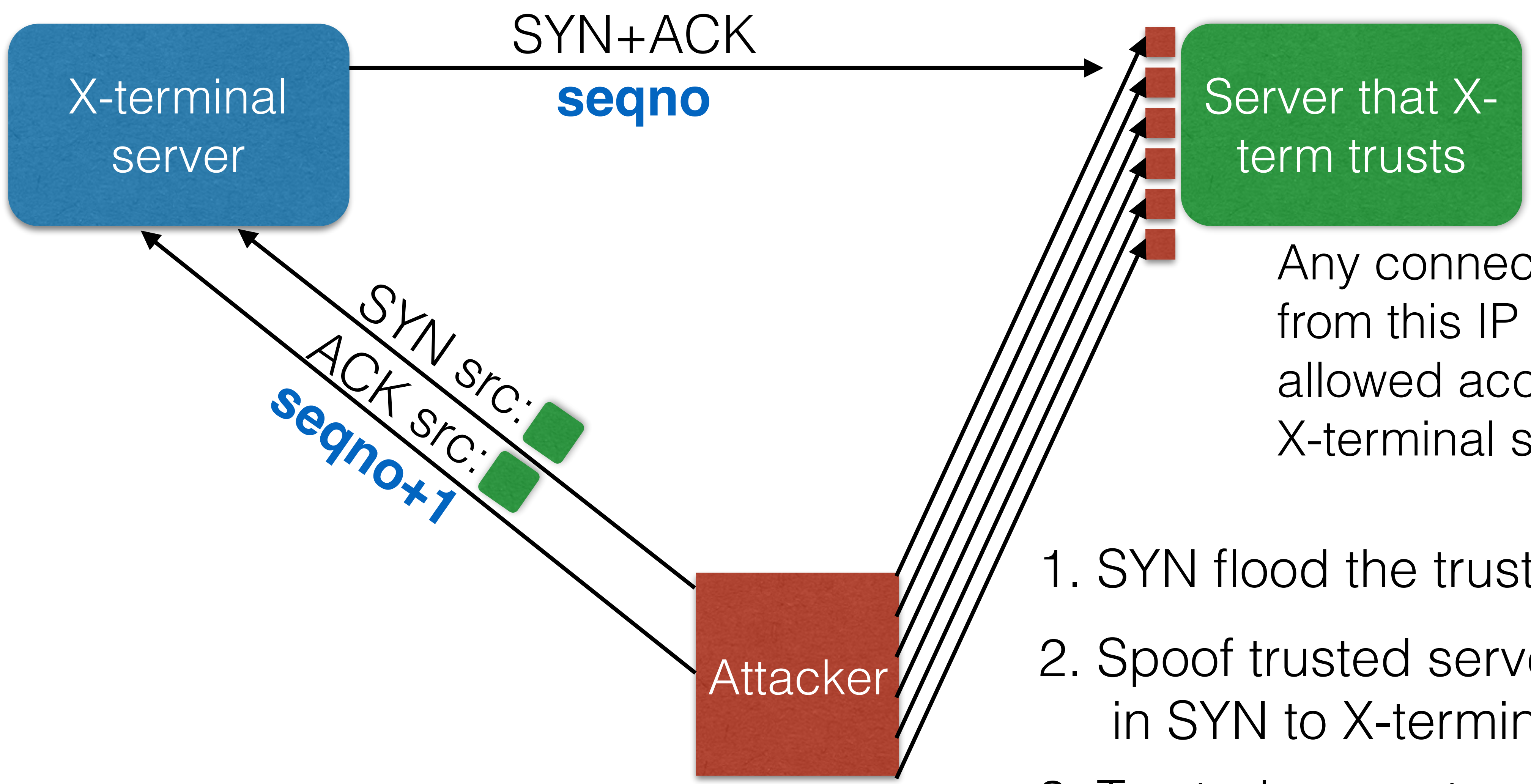
4. ACK with the guessed **seqno**

Mitnick attack



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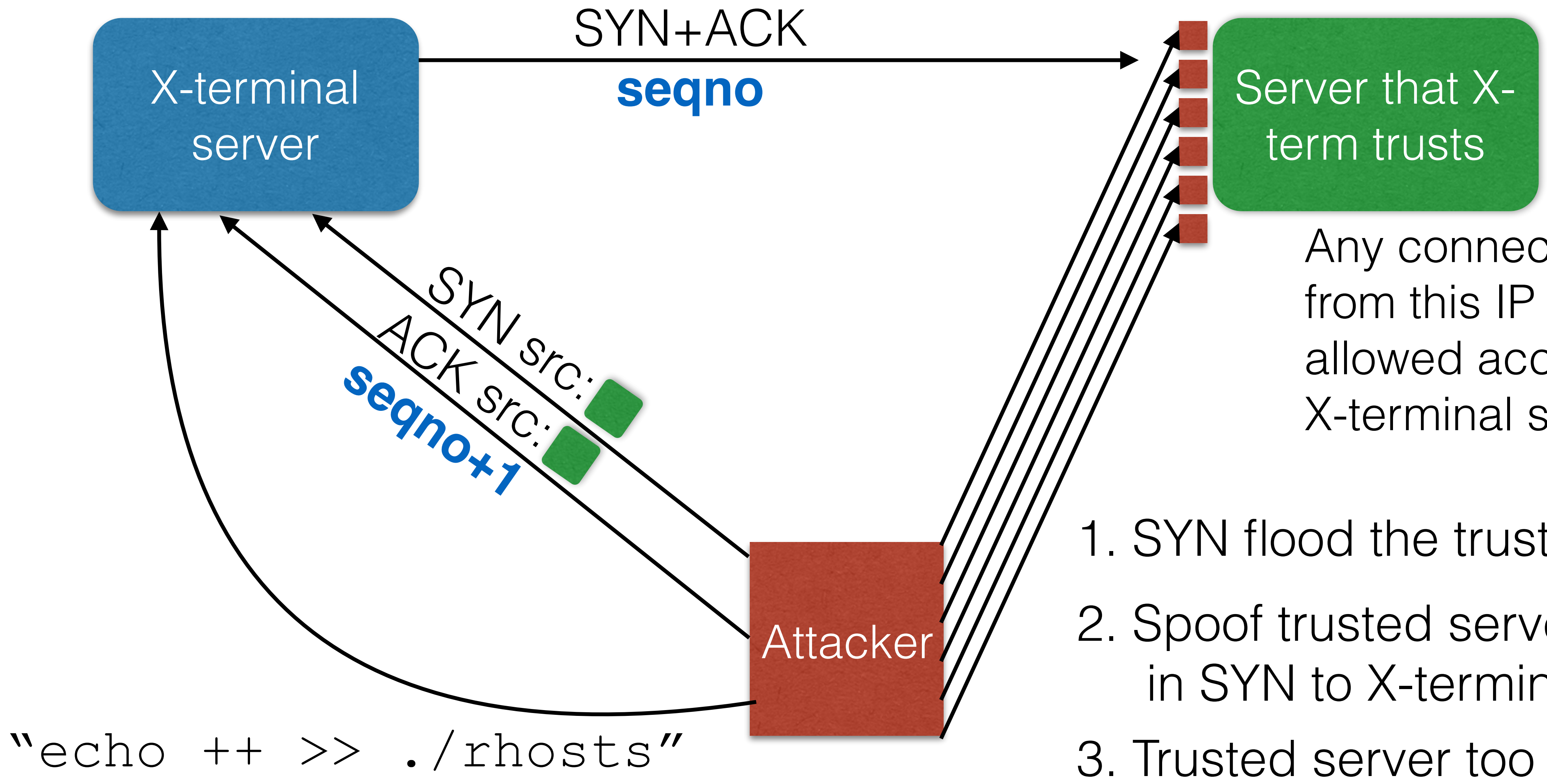

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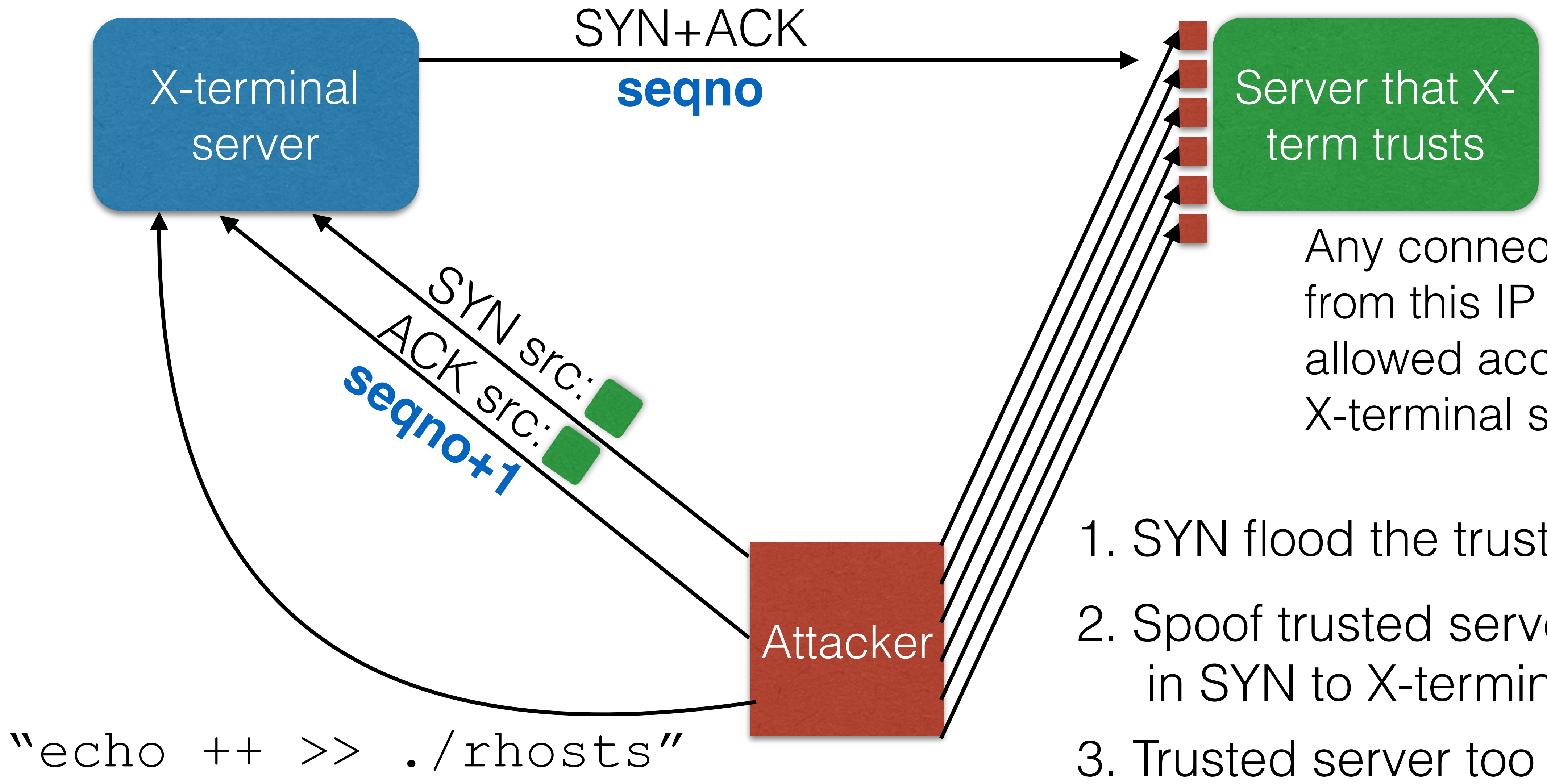

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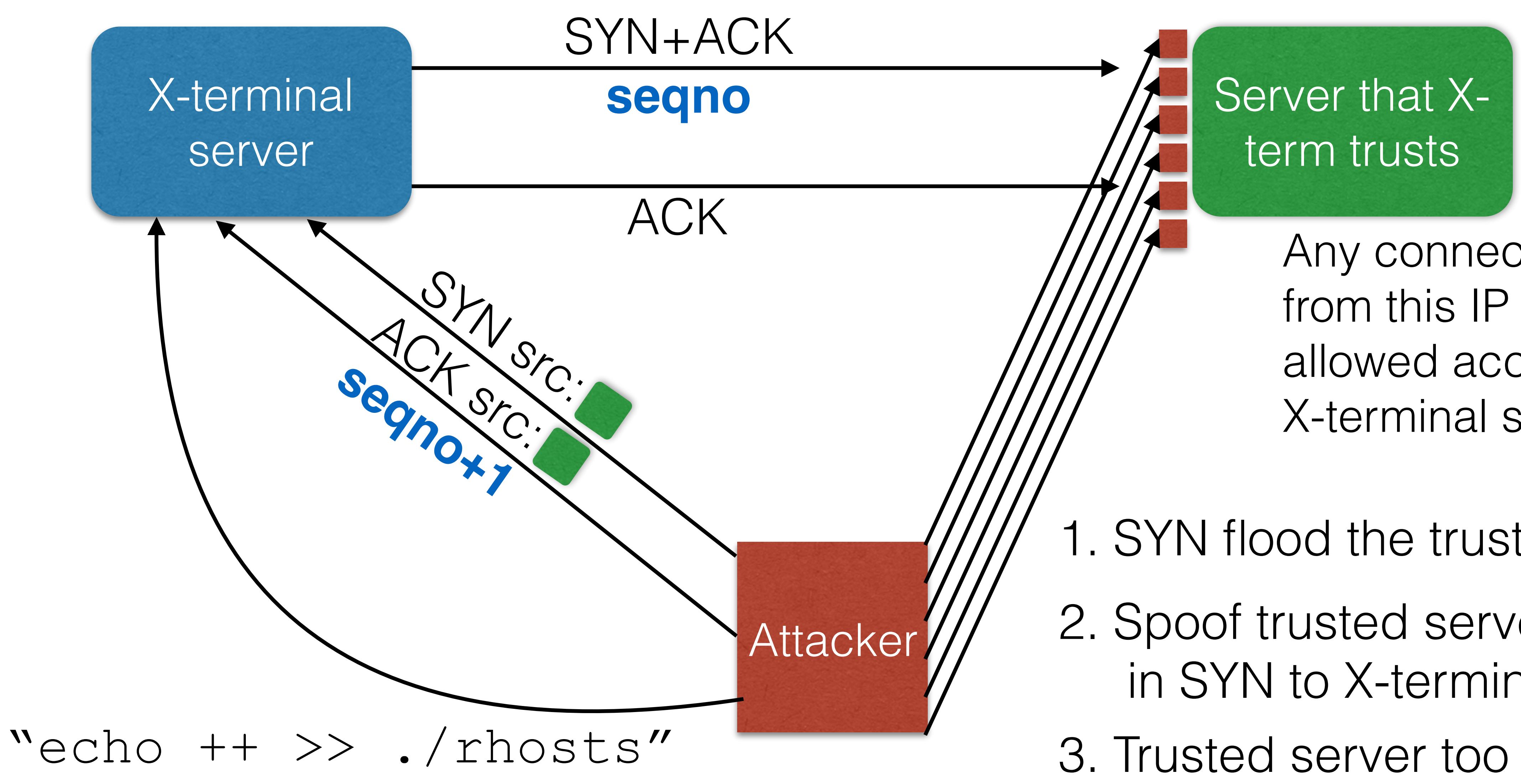

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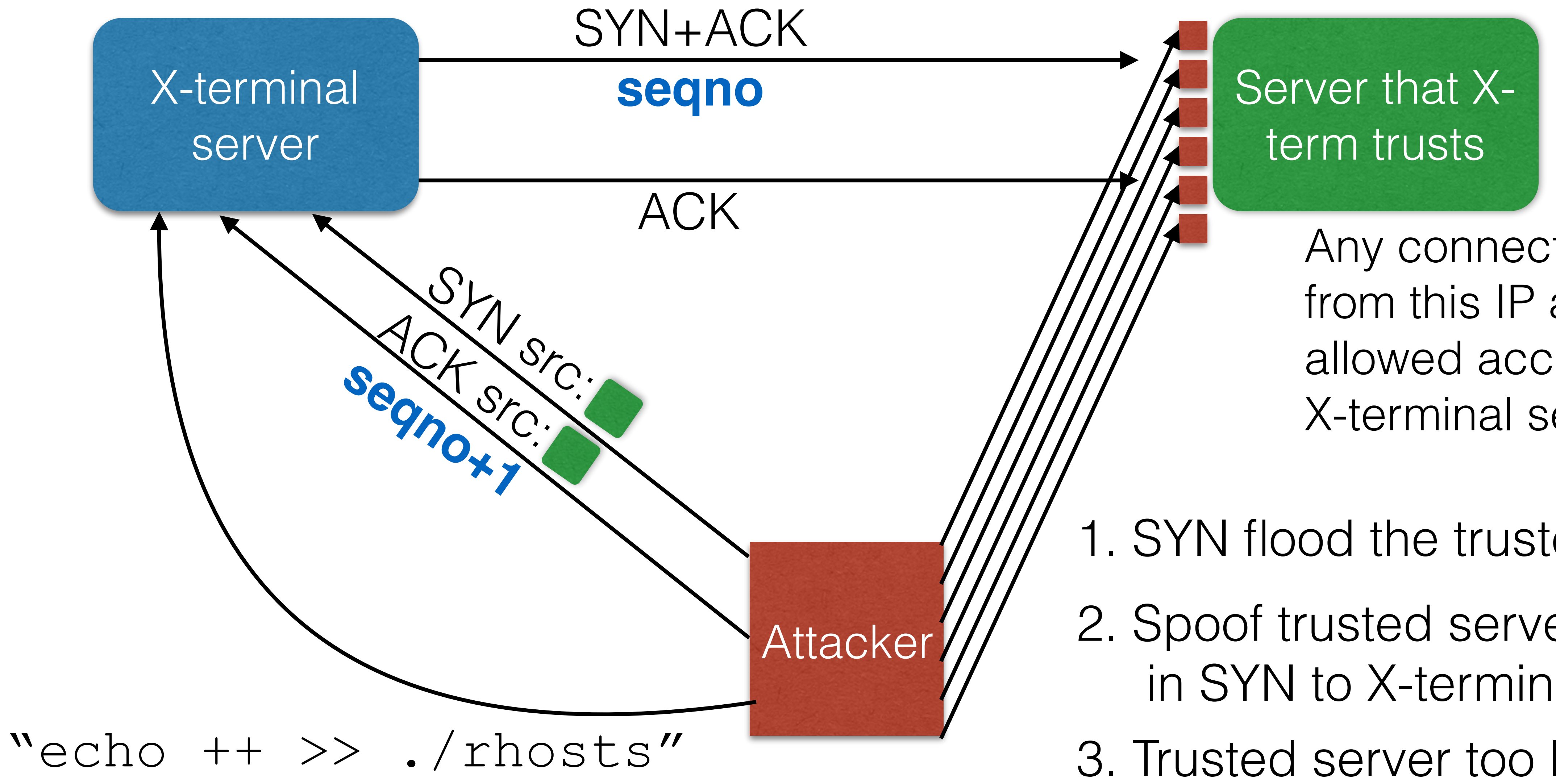

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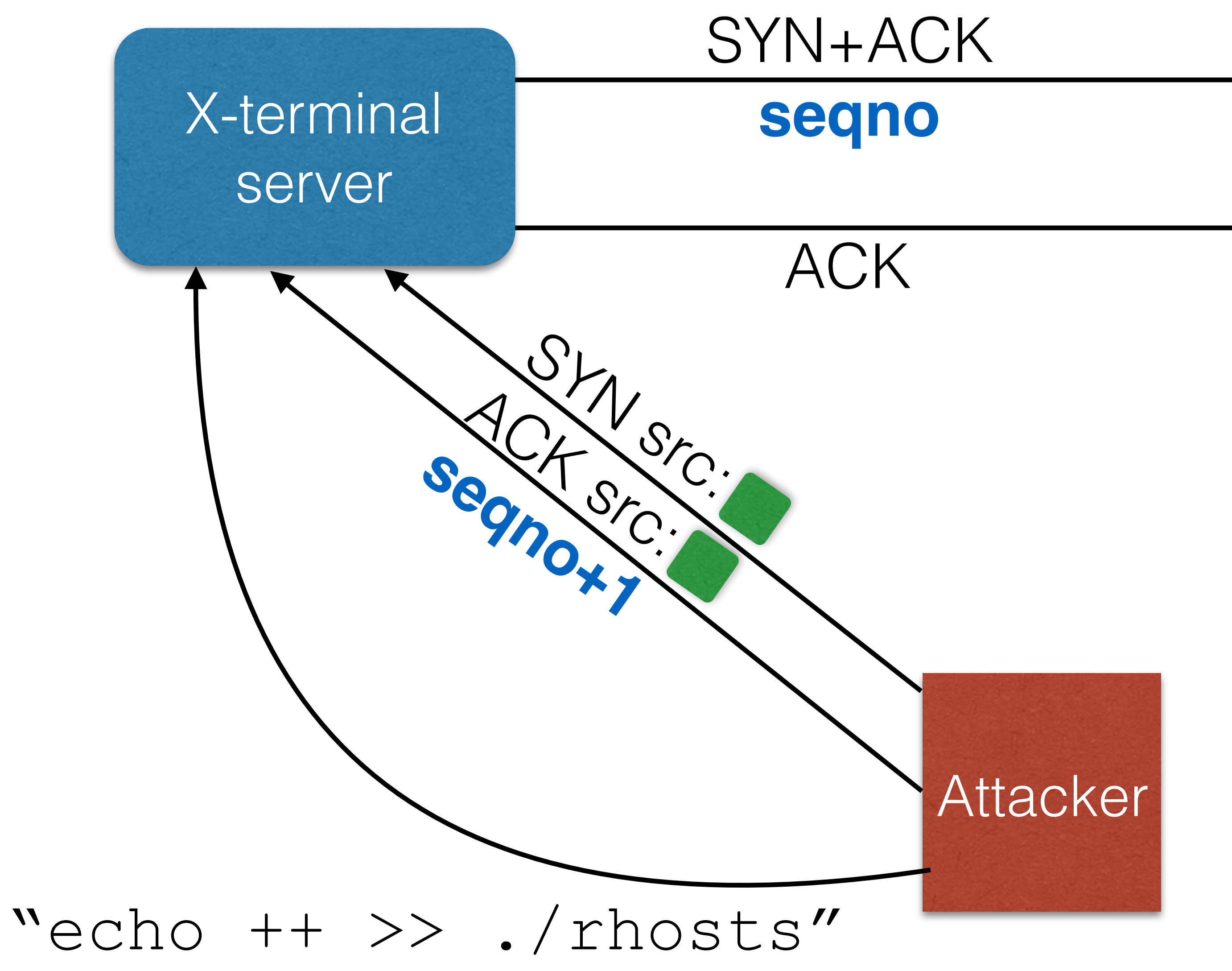
6. RSTs to trusted server (cleanup)

Mitnick attack



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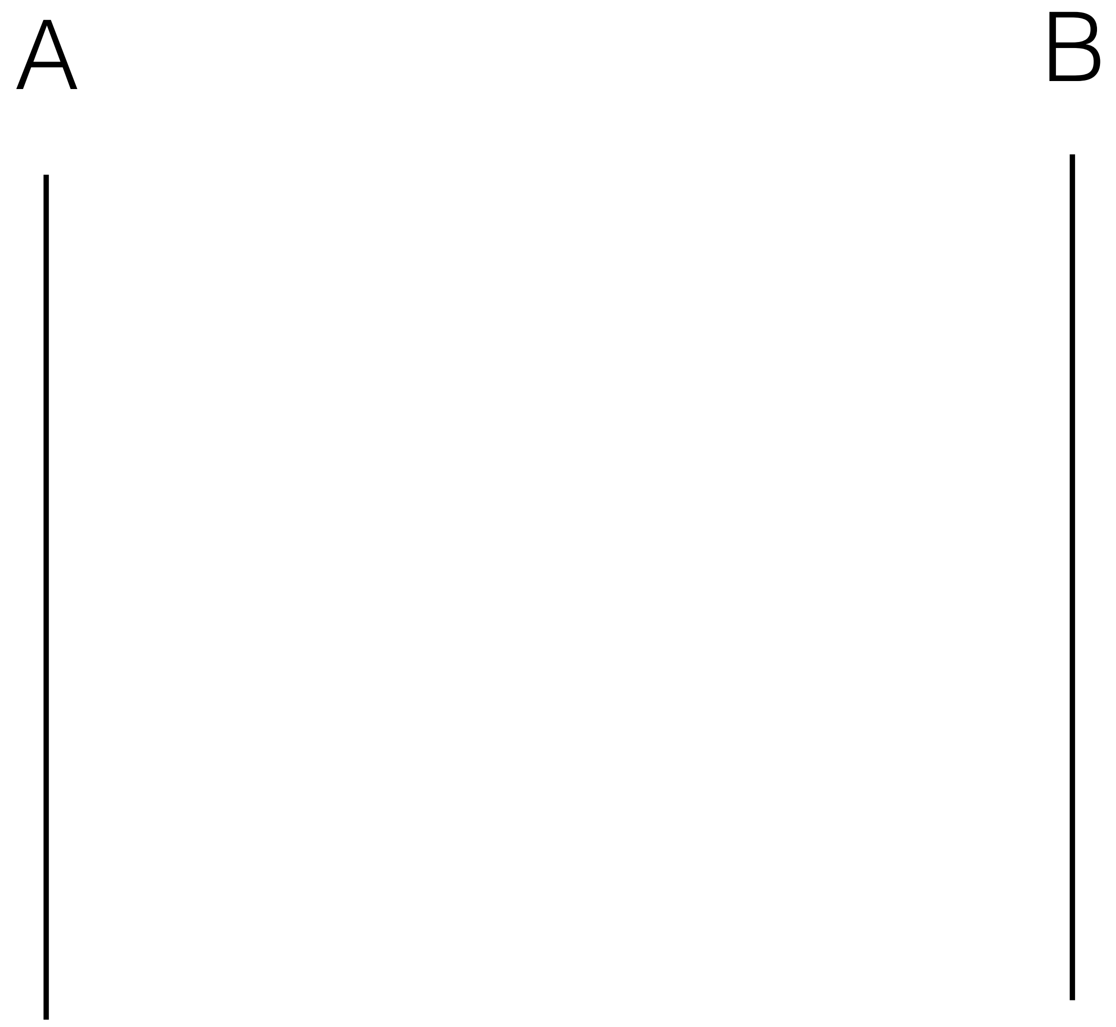
Defenses

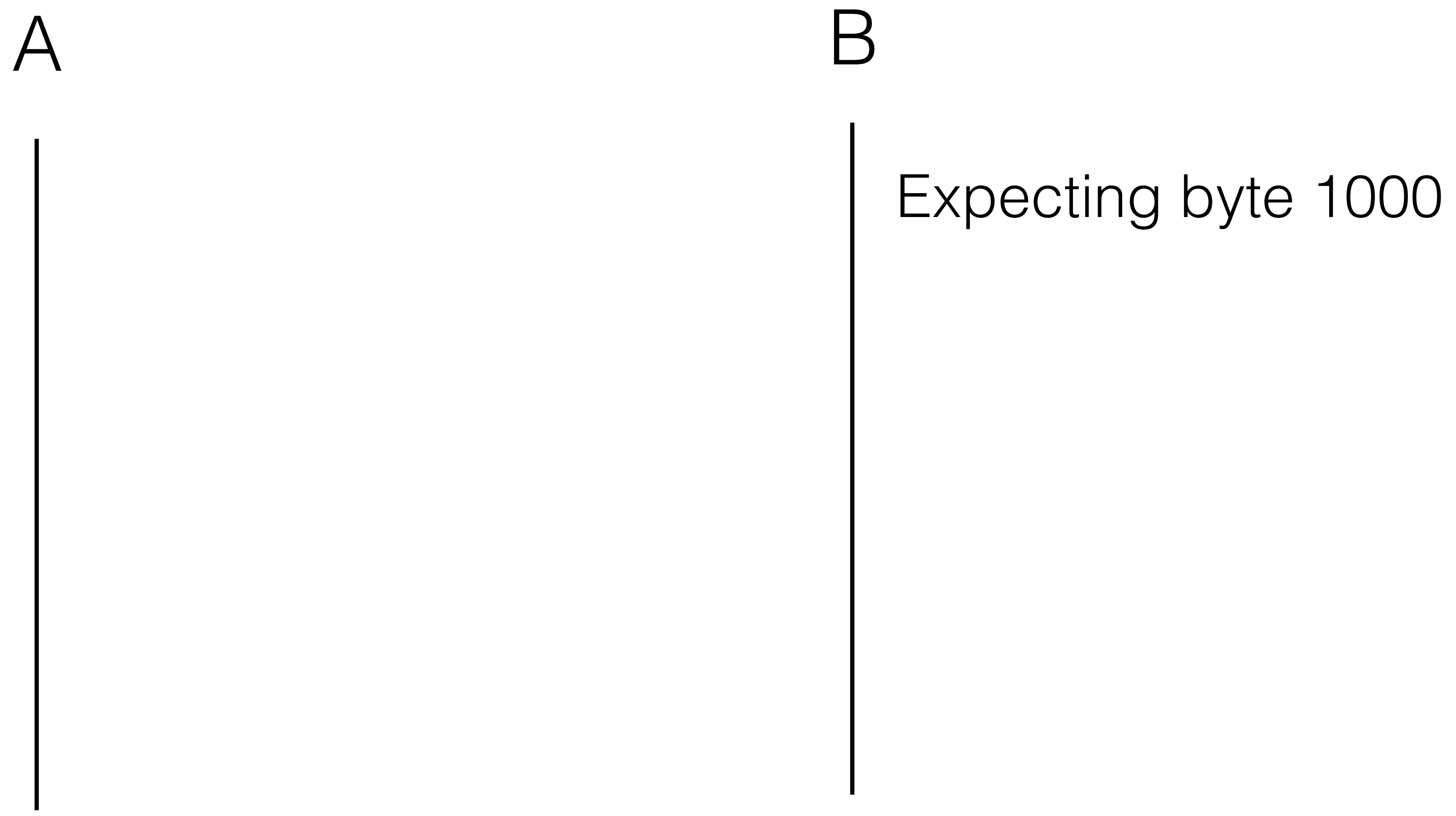
- Initial sequence number must be difficult to predict!

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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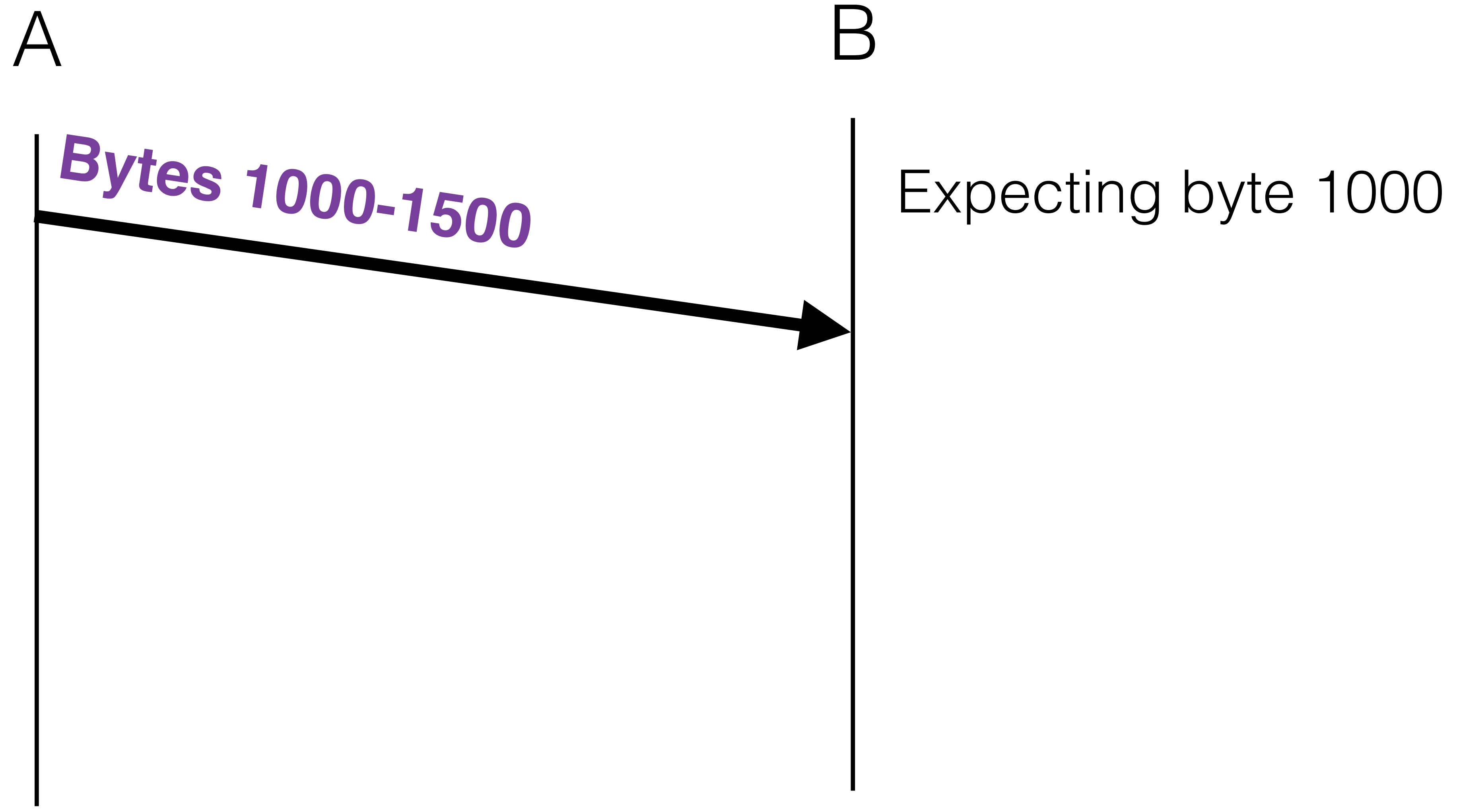

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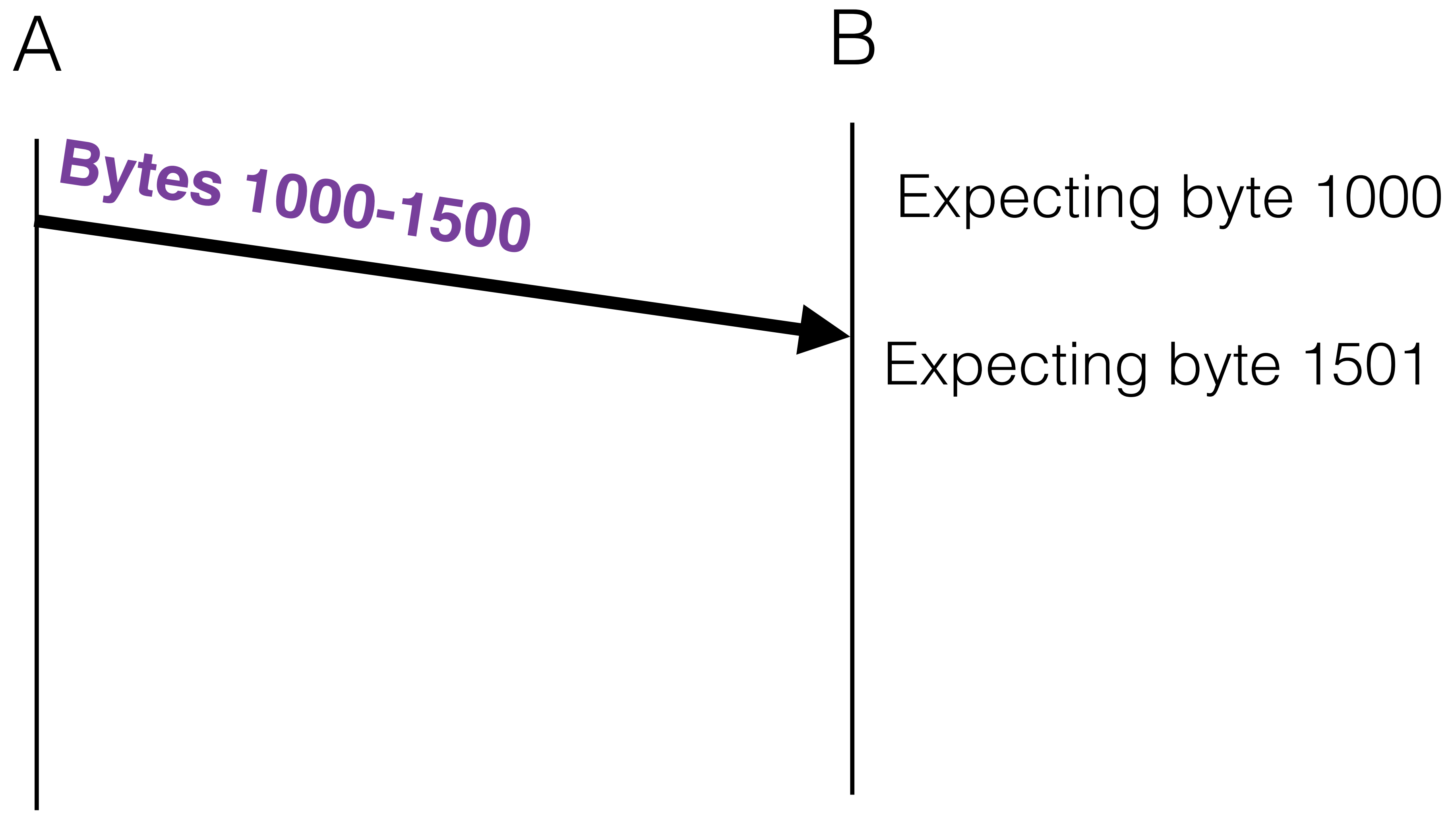

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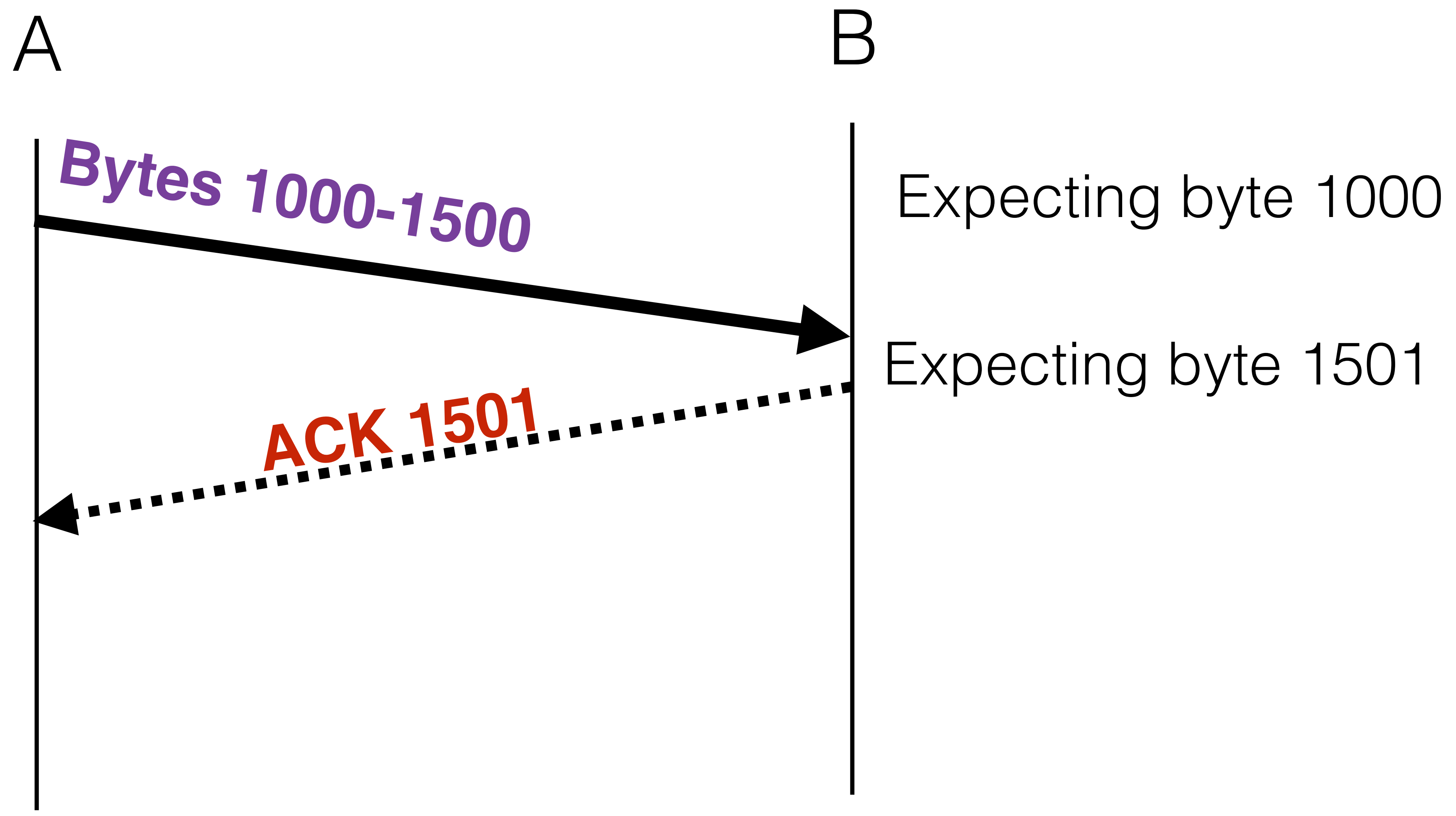

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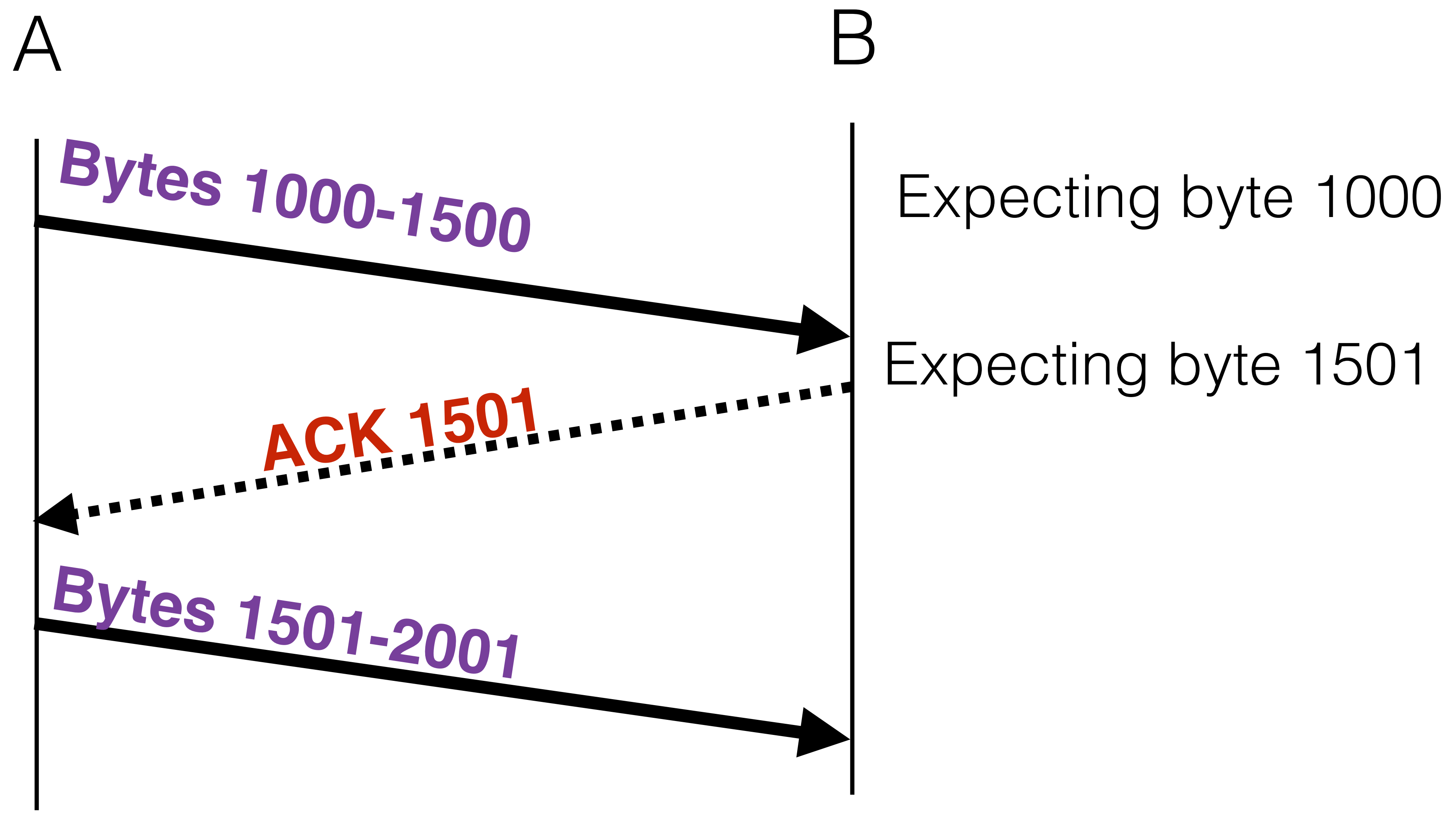

TCP uses ACKs not only for reliability, but also for **congestion control:** the more ACKs come back, the faster I can send

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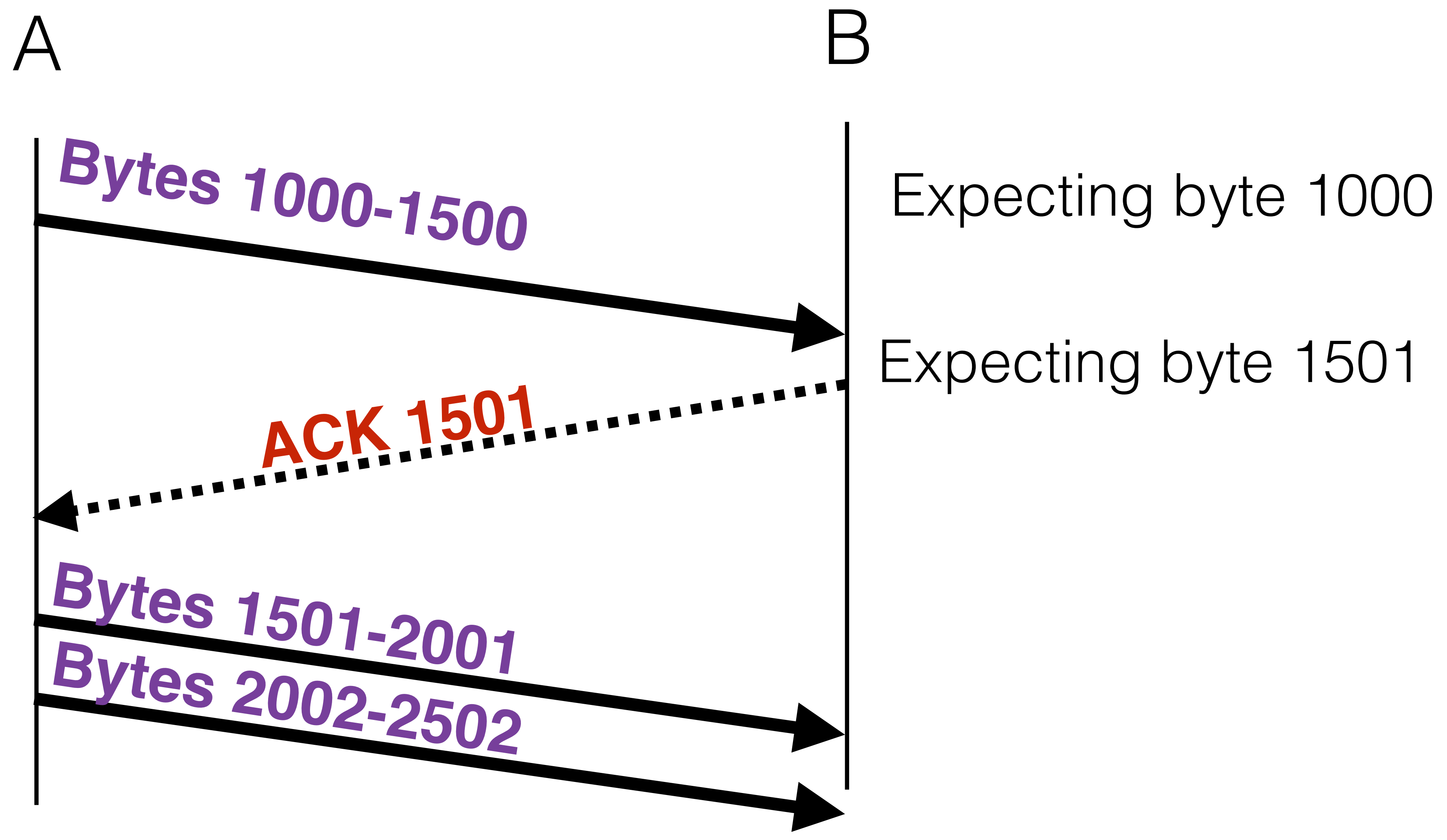

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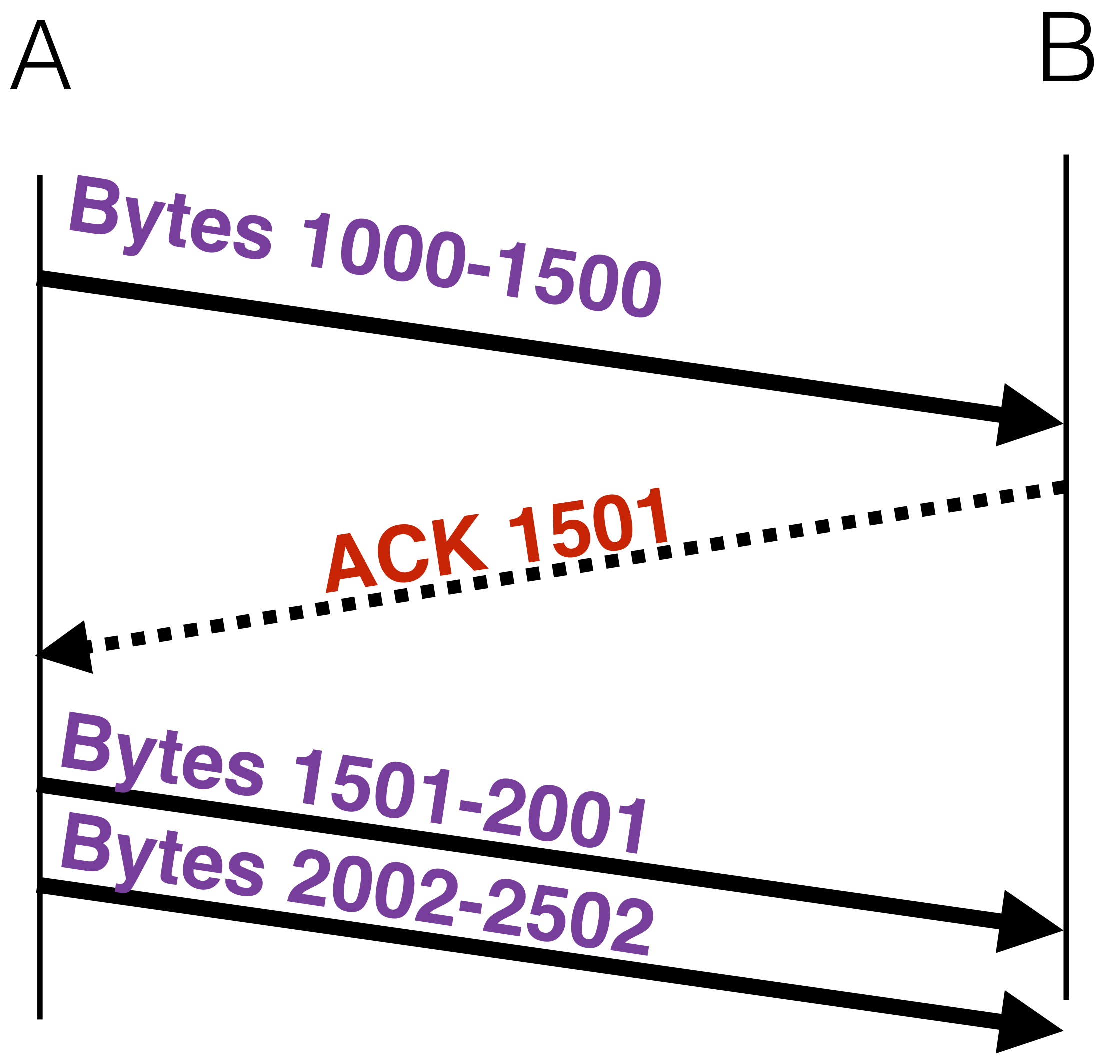

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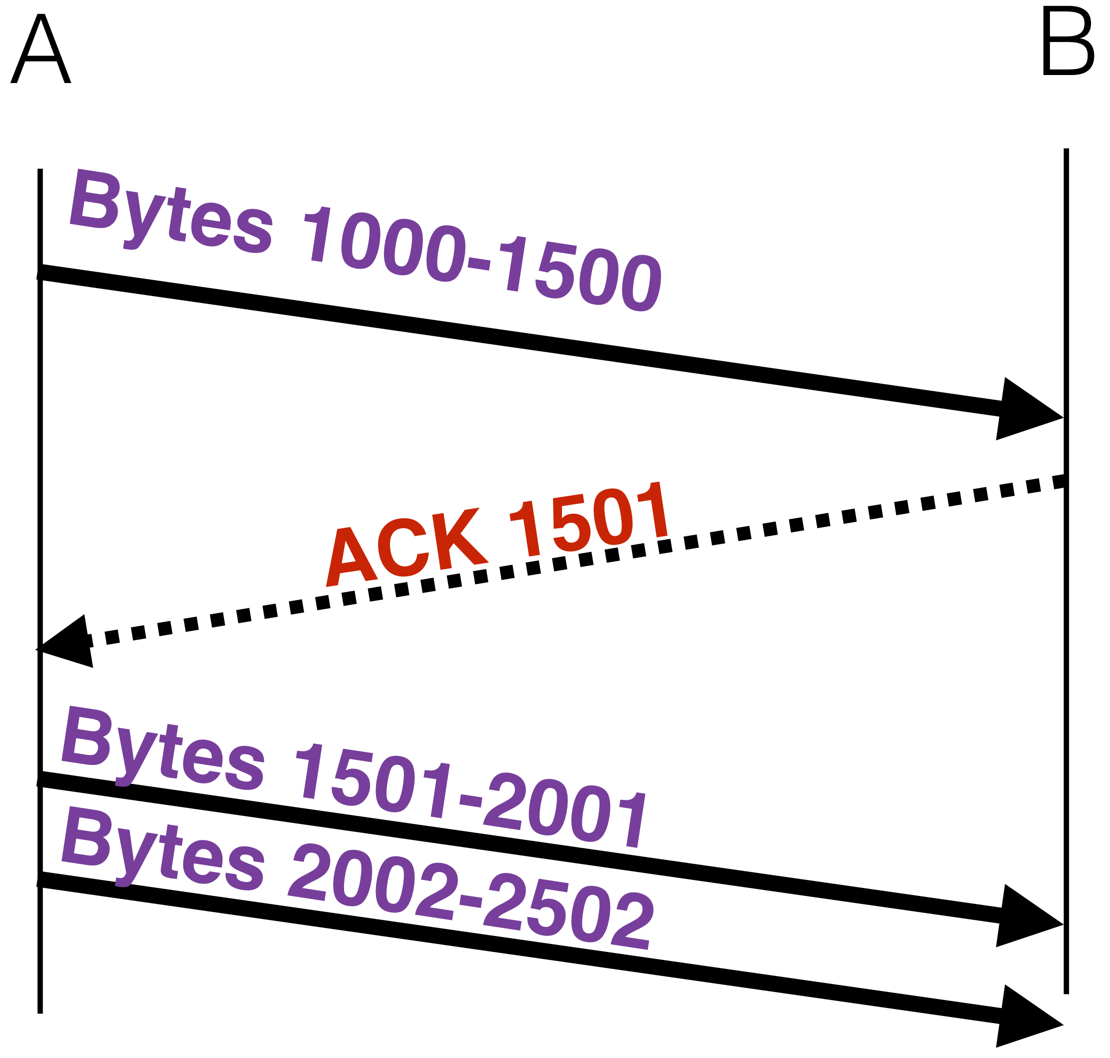

If I could convince you to send REALLY quickly, then you would effectively DoS your own network!

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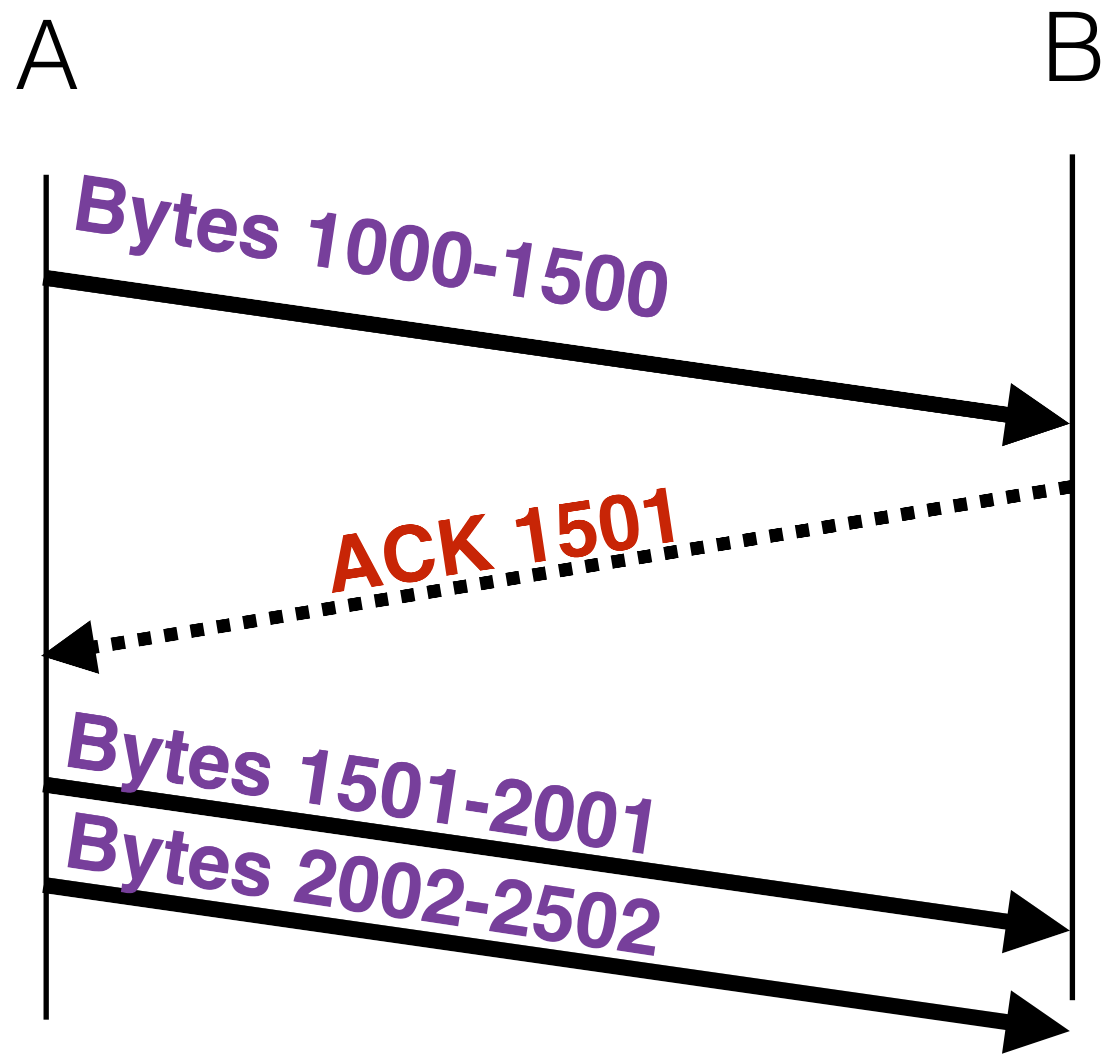

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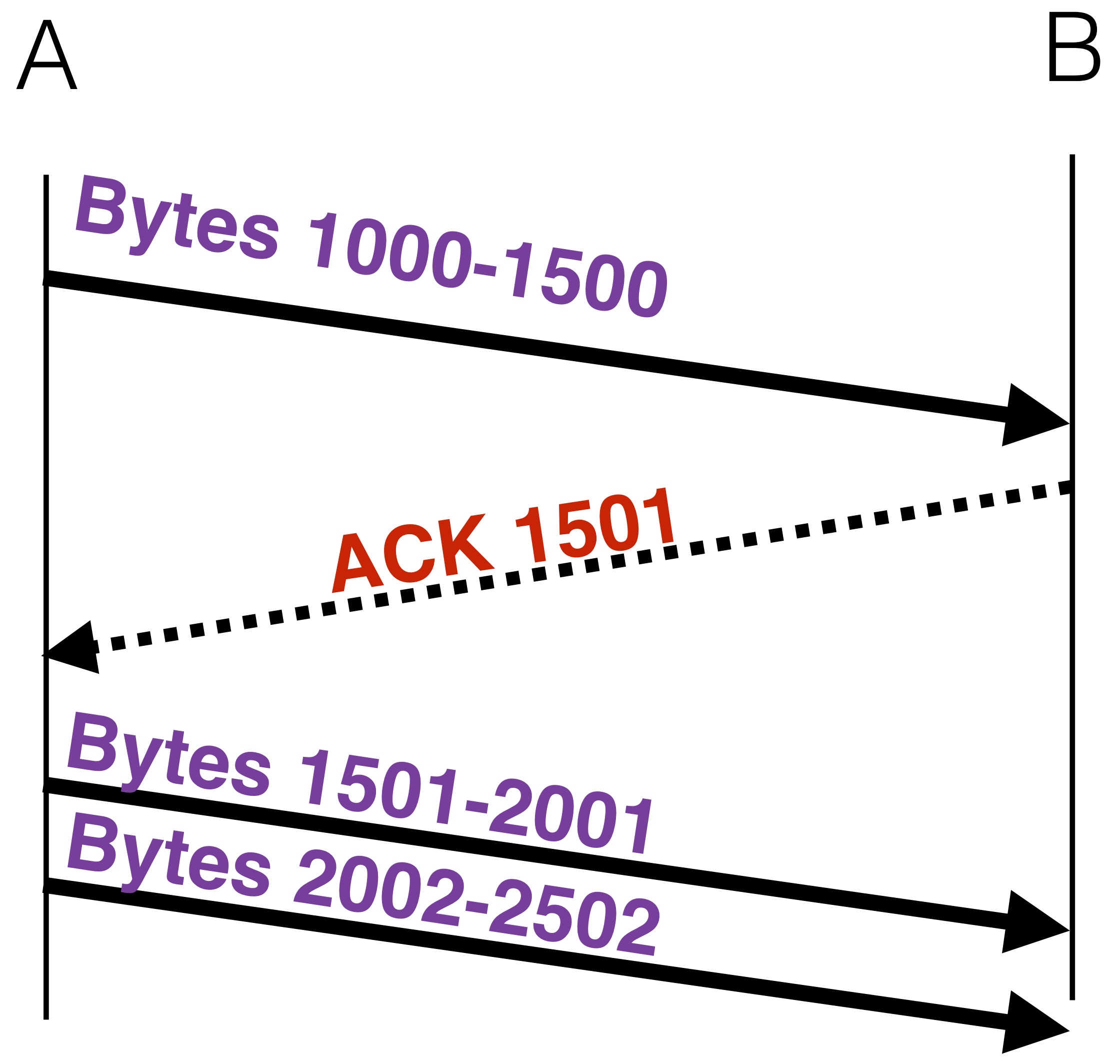

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...or do I?

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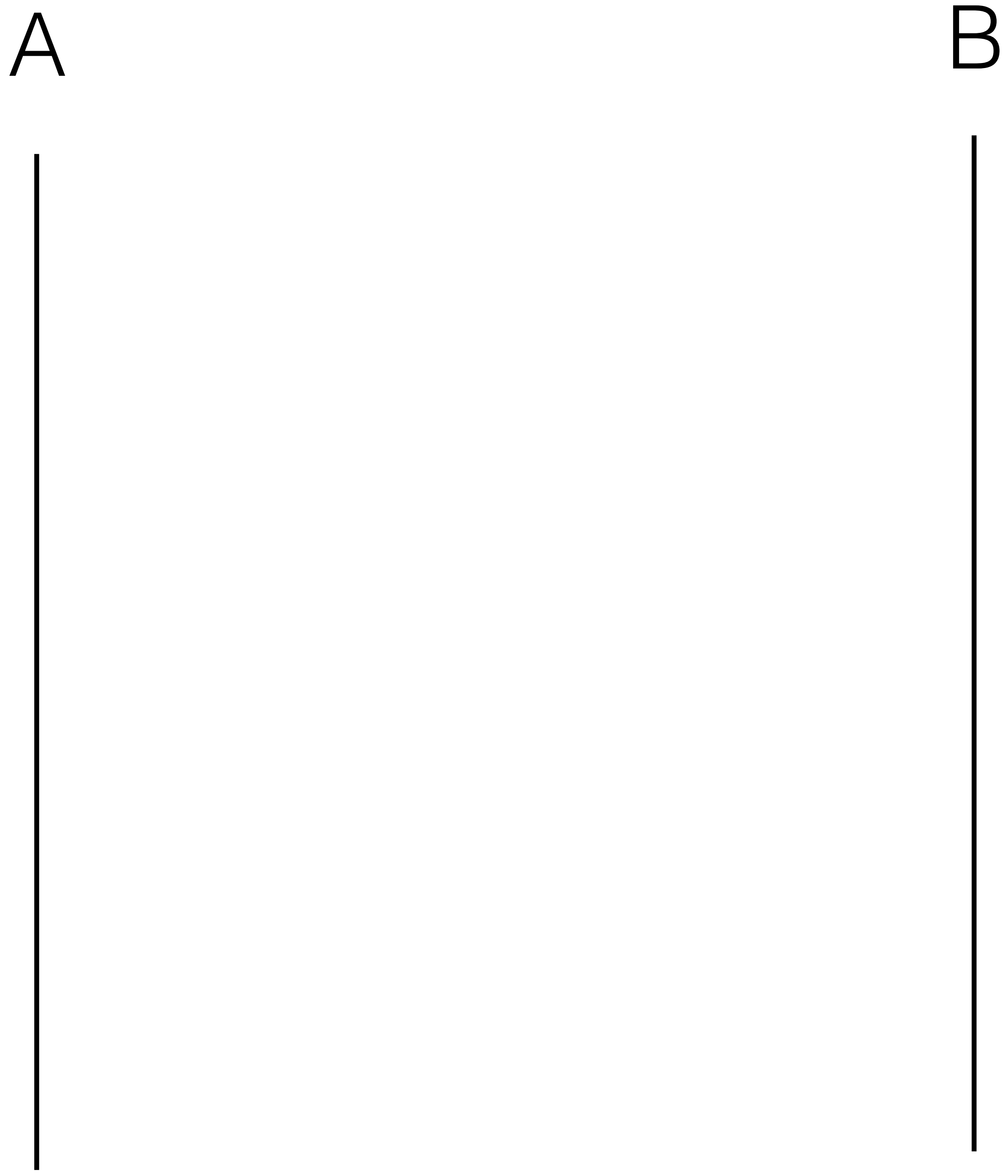

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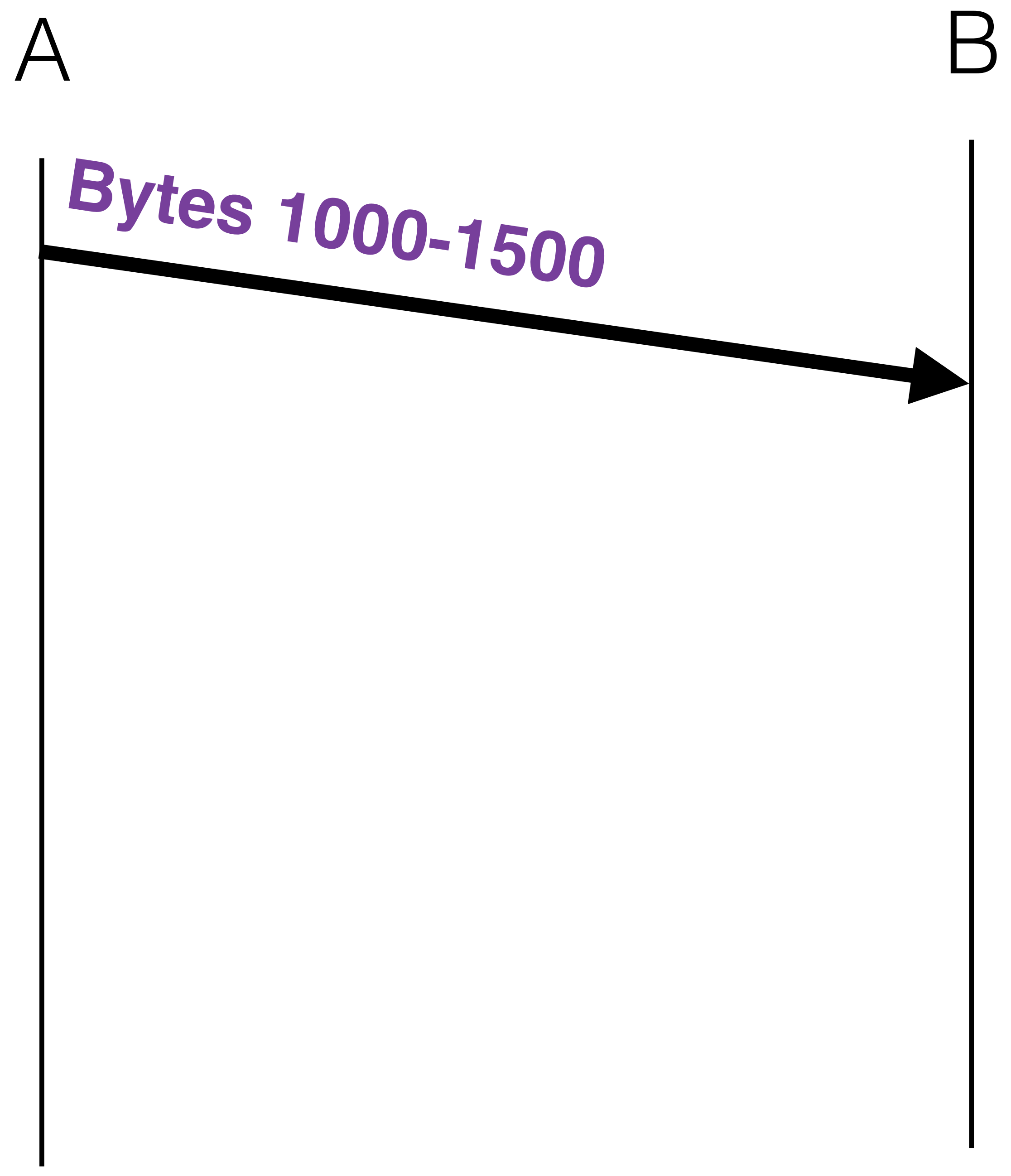

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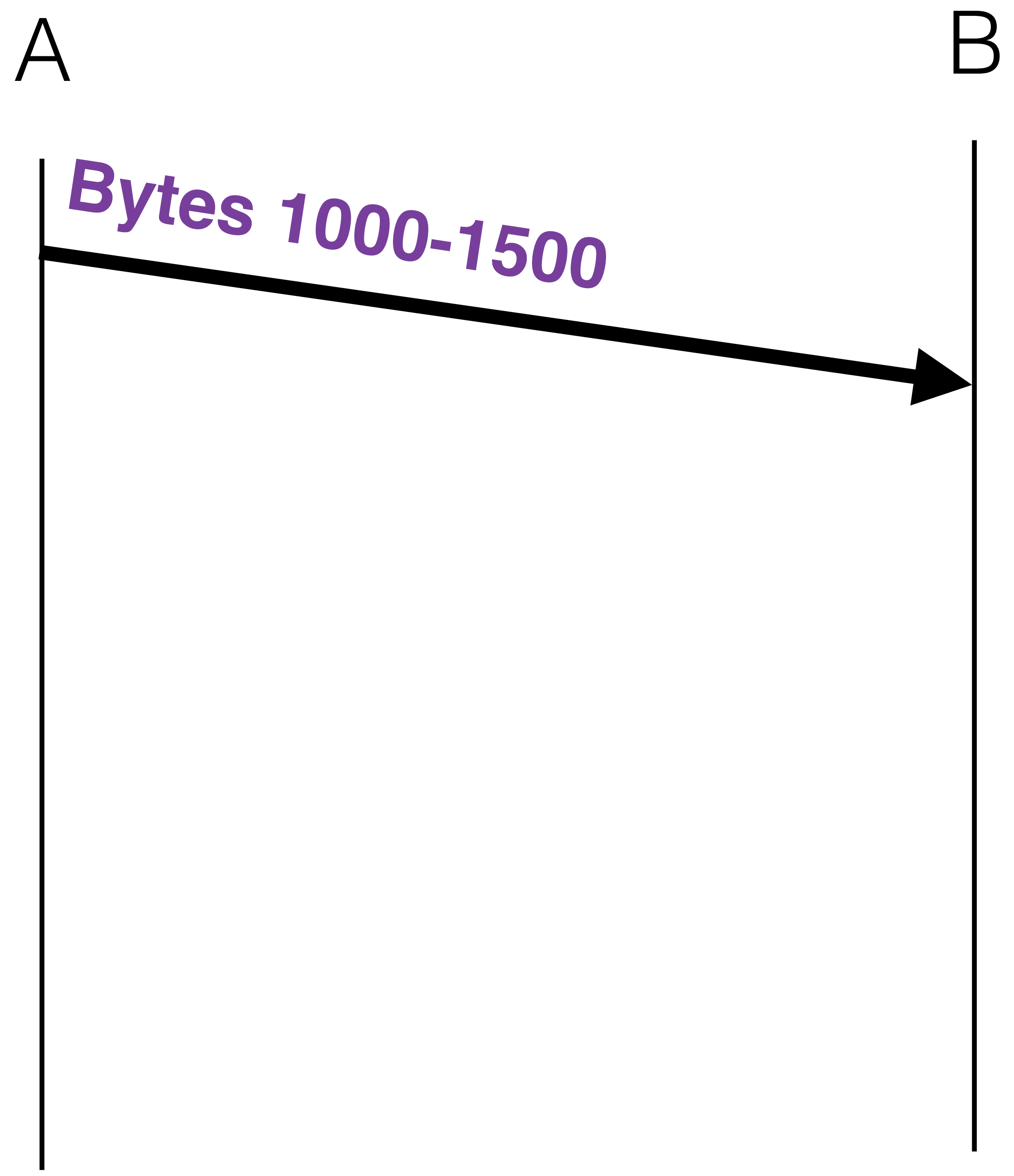

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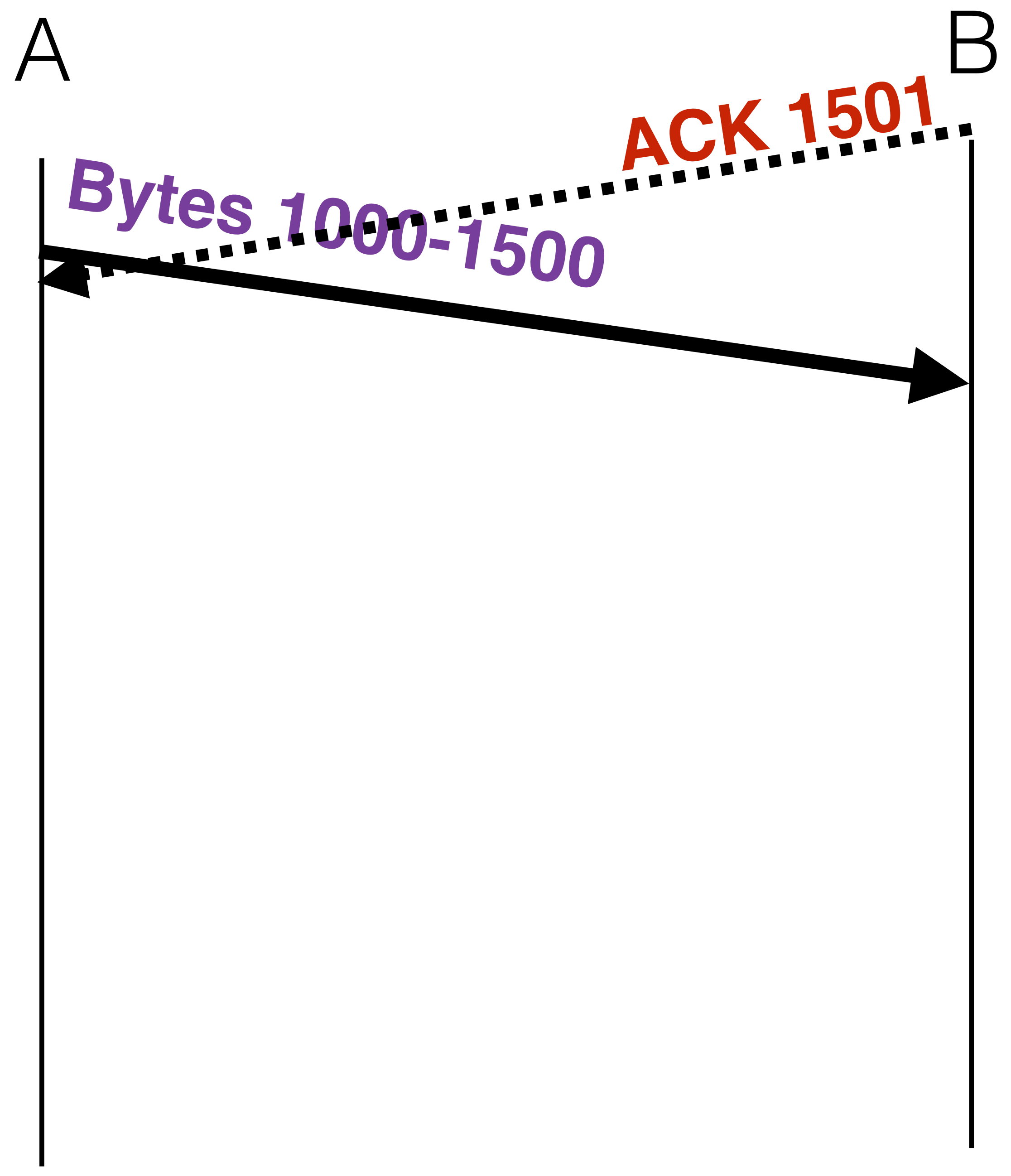

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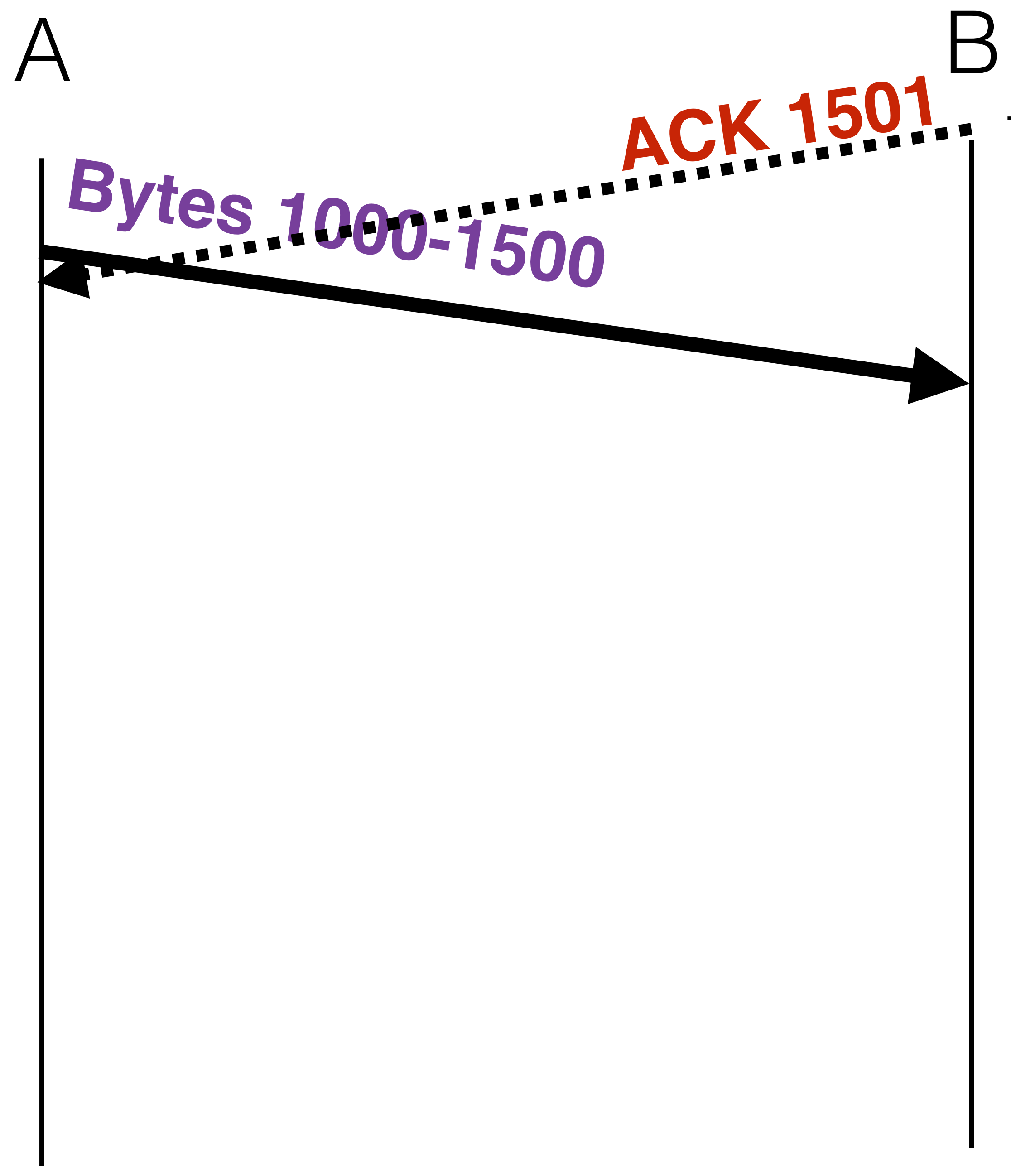

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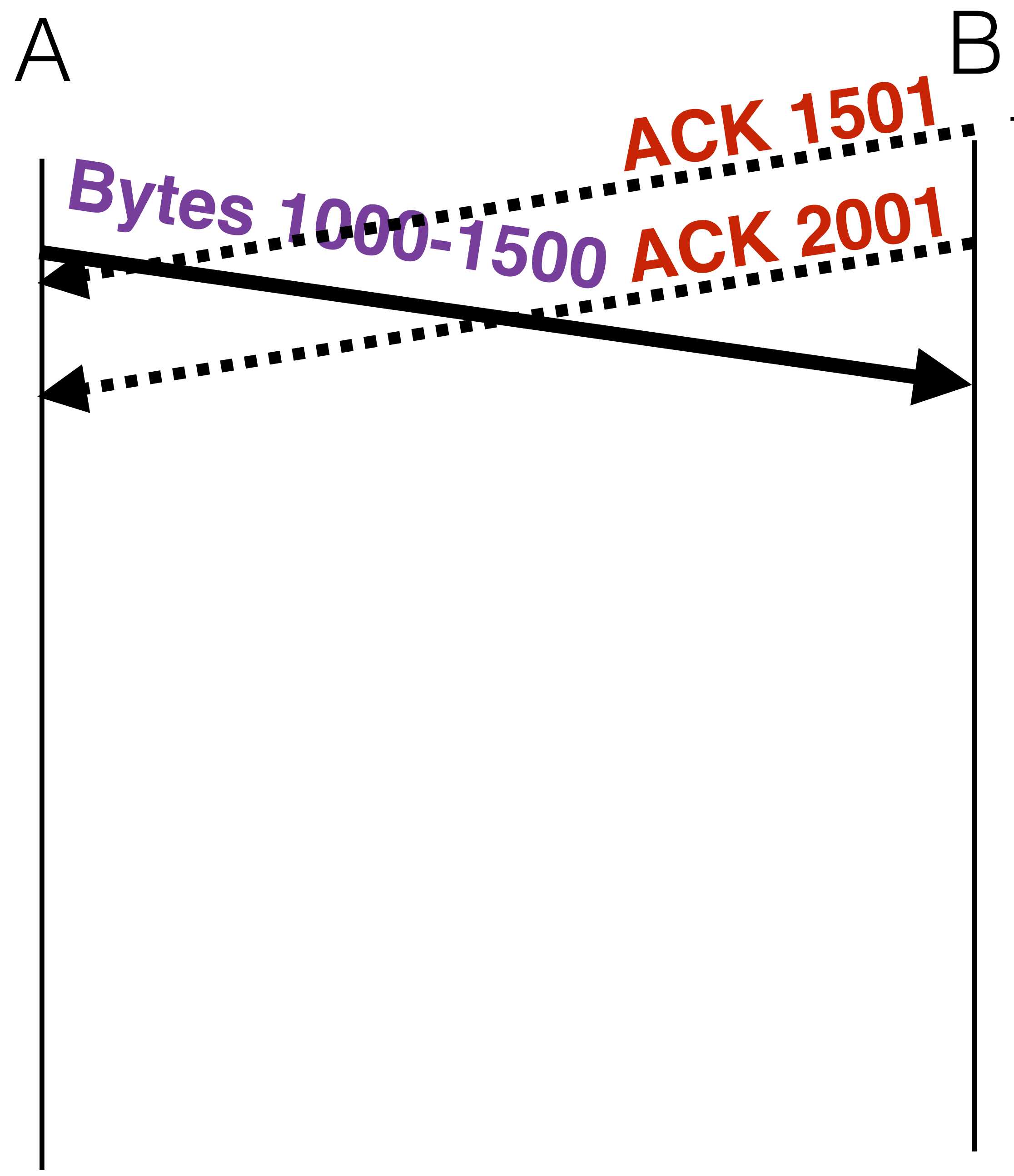

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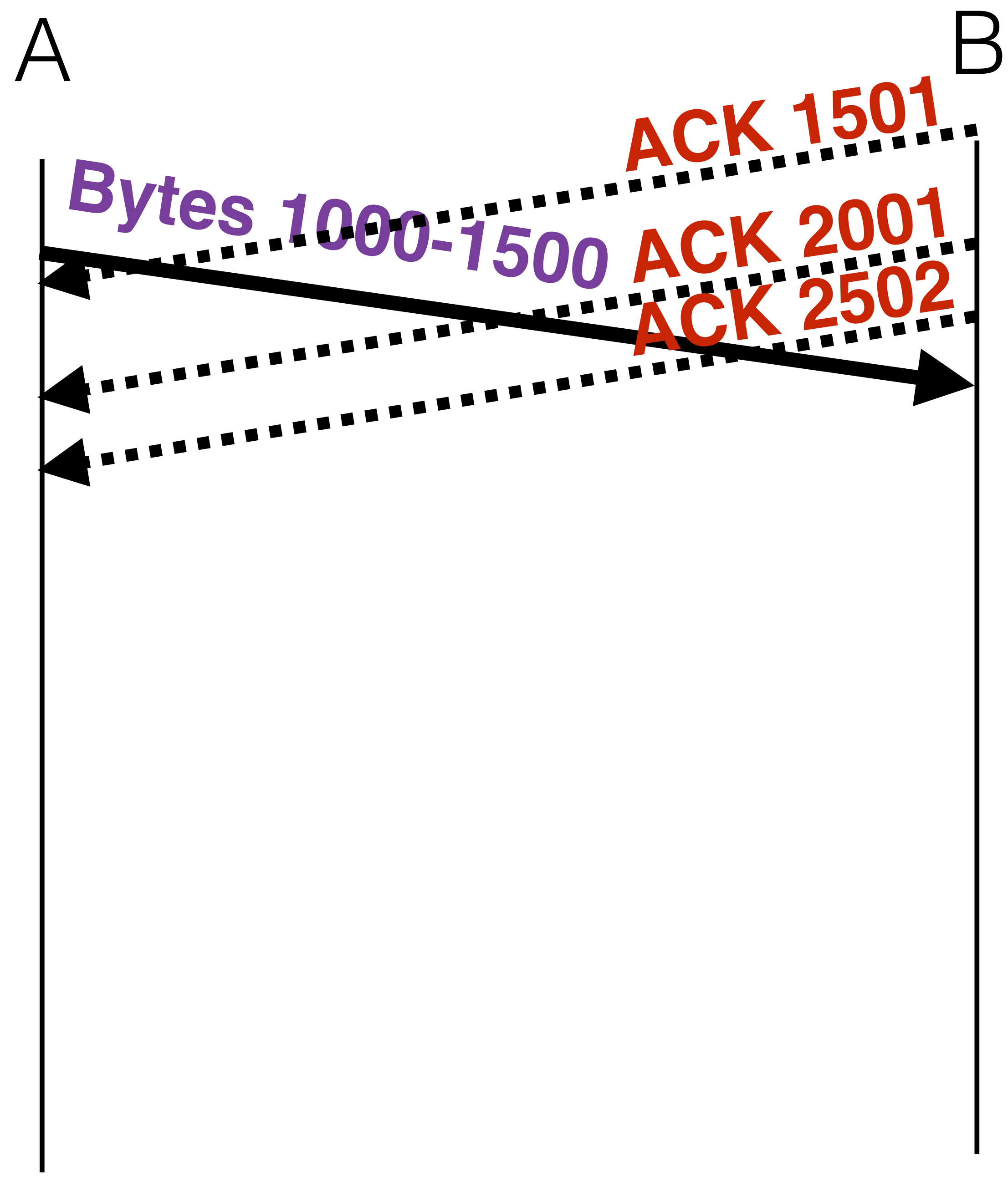

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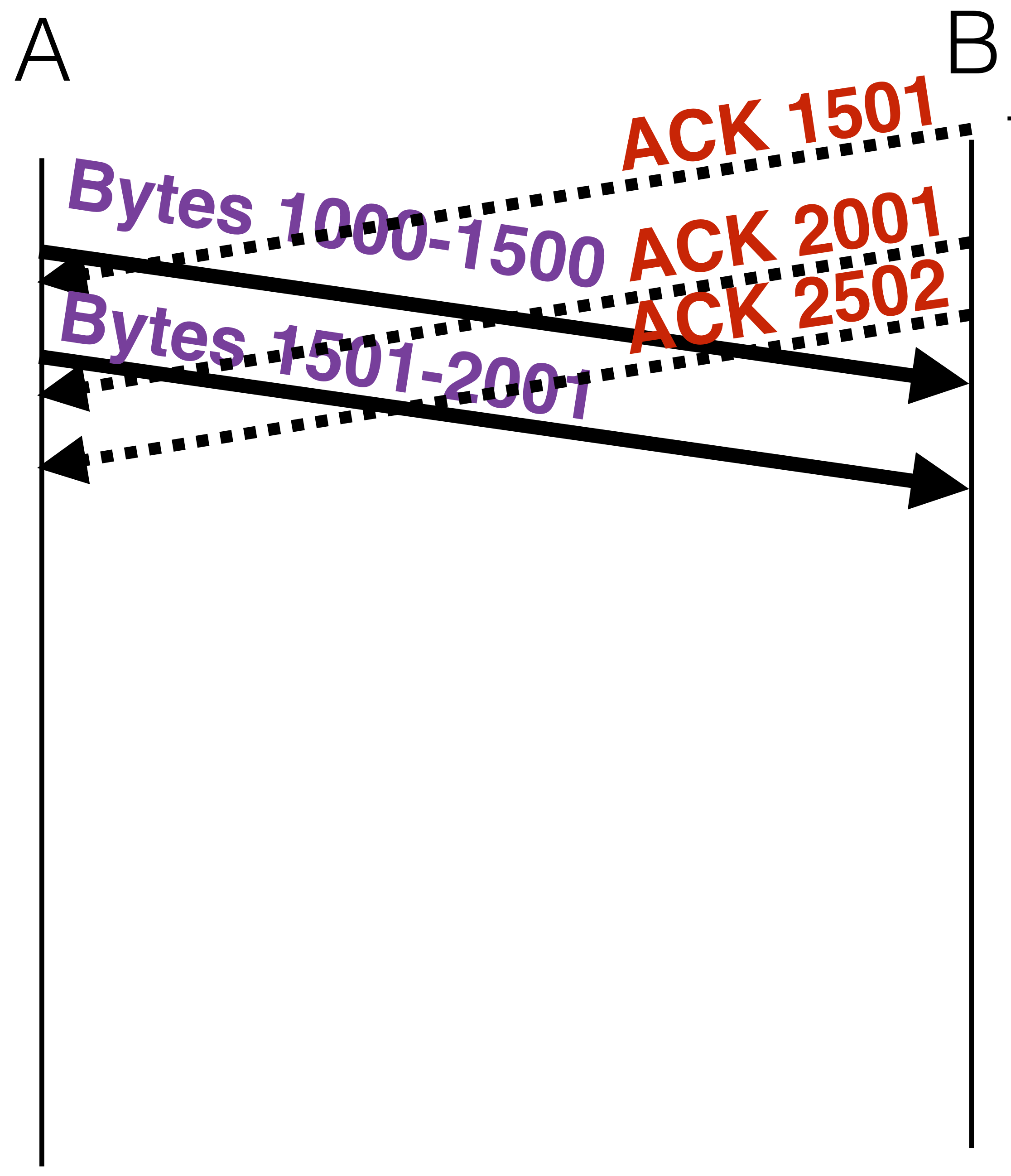

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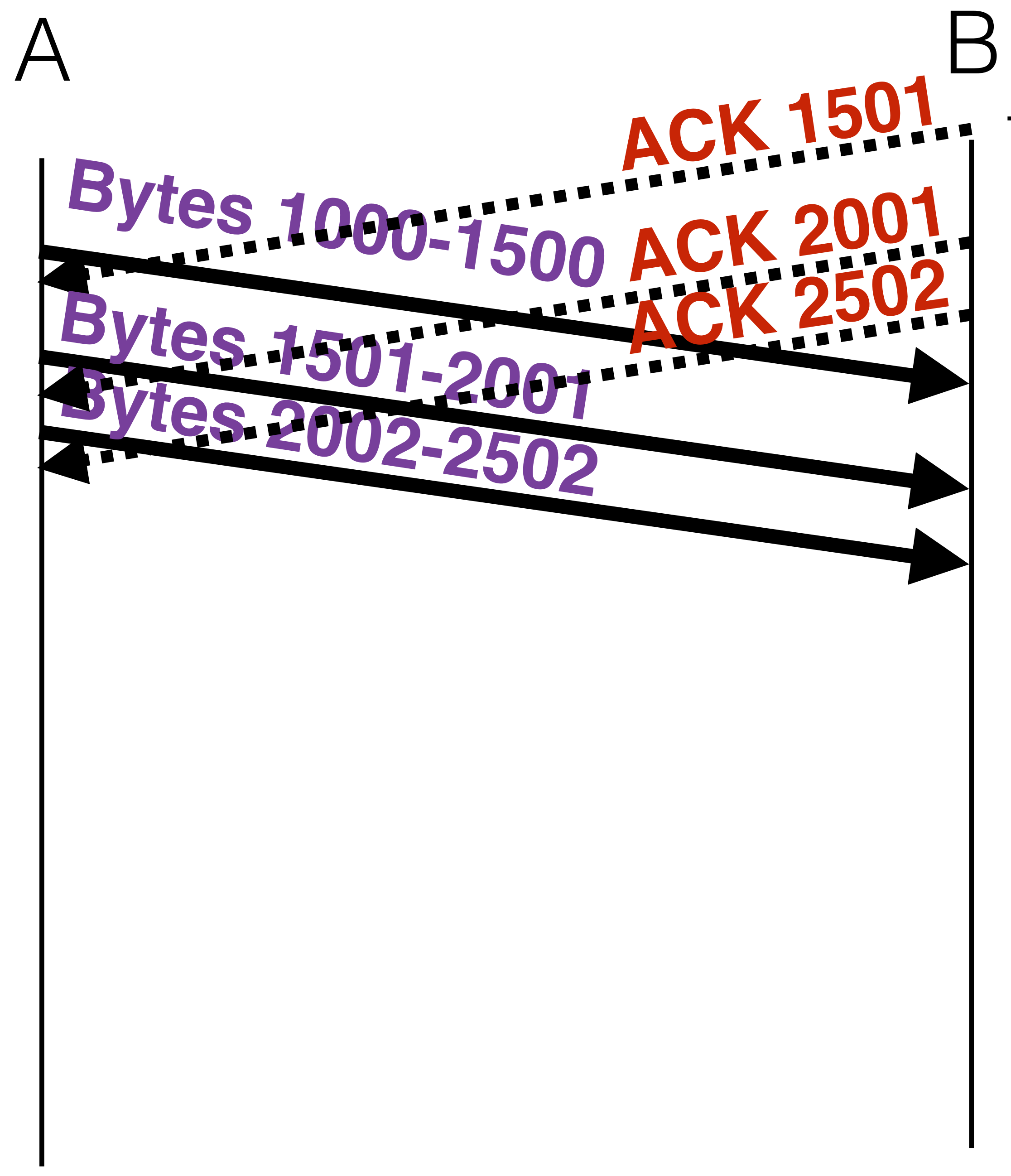

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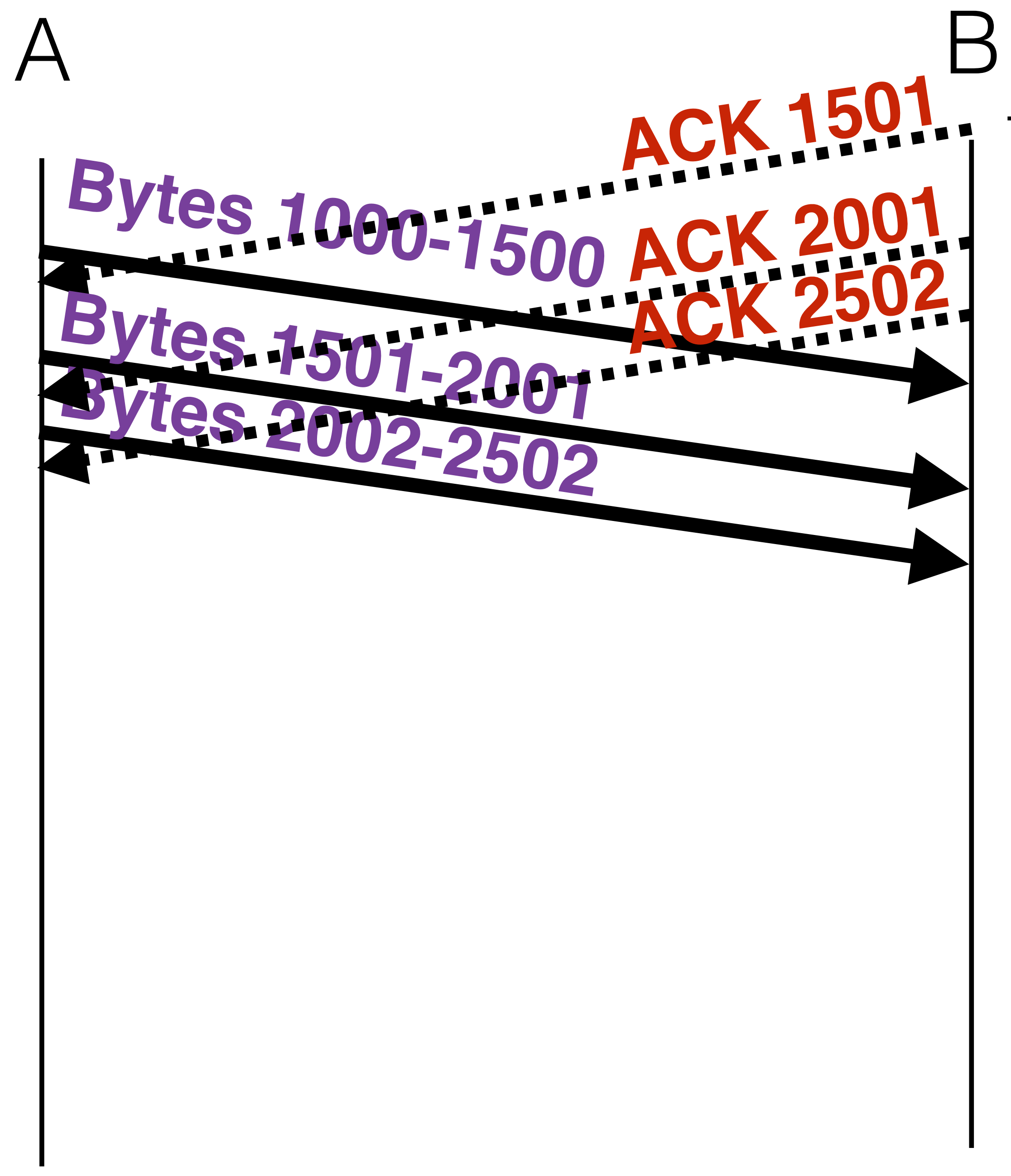

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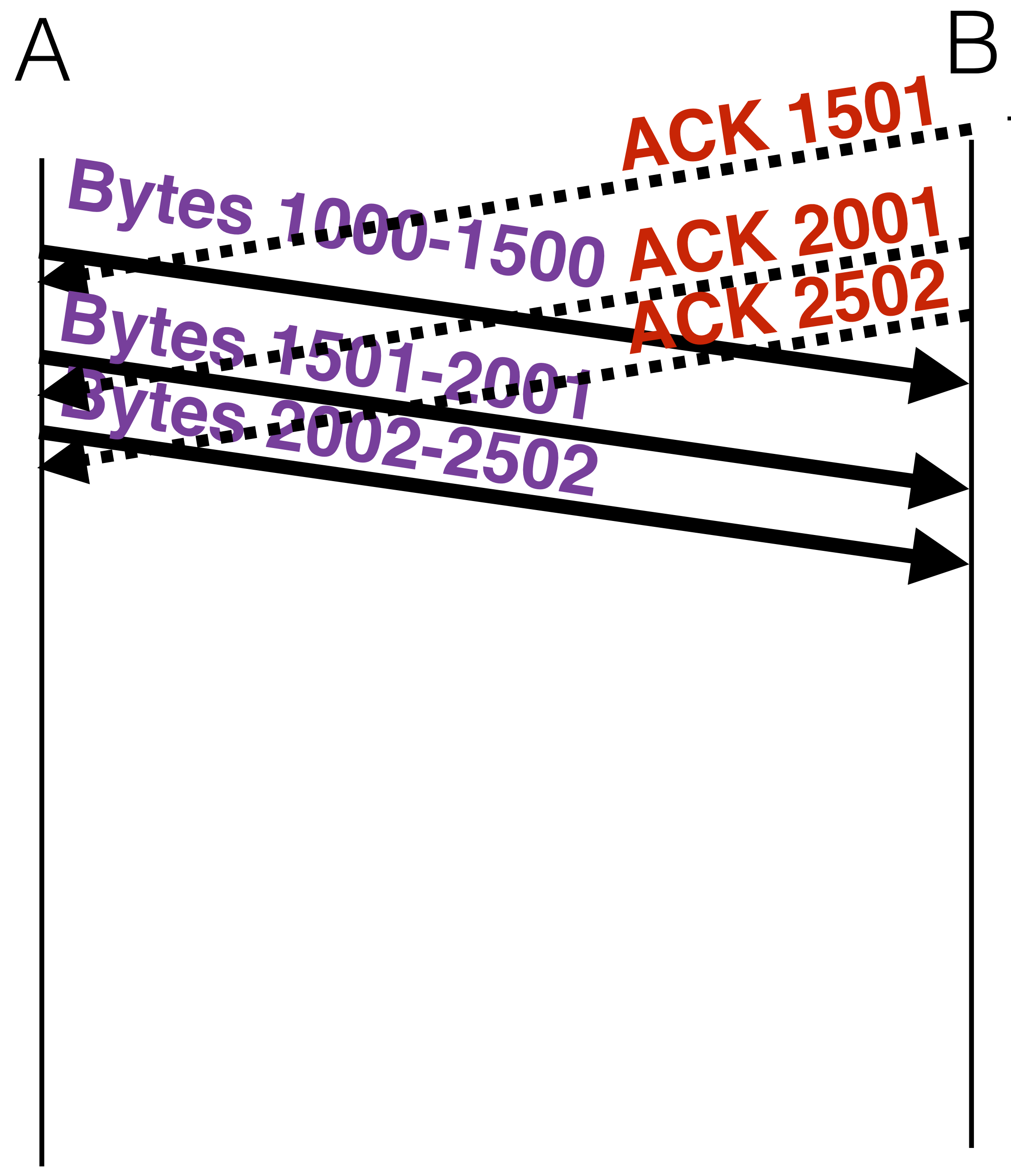

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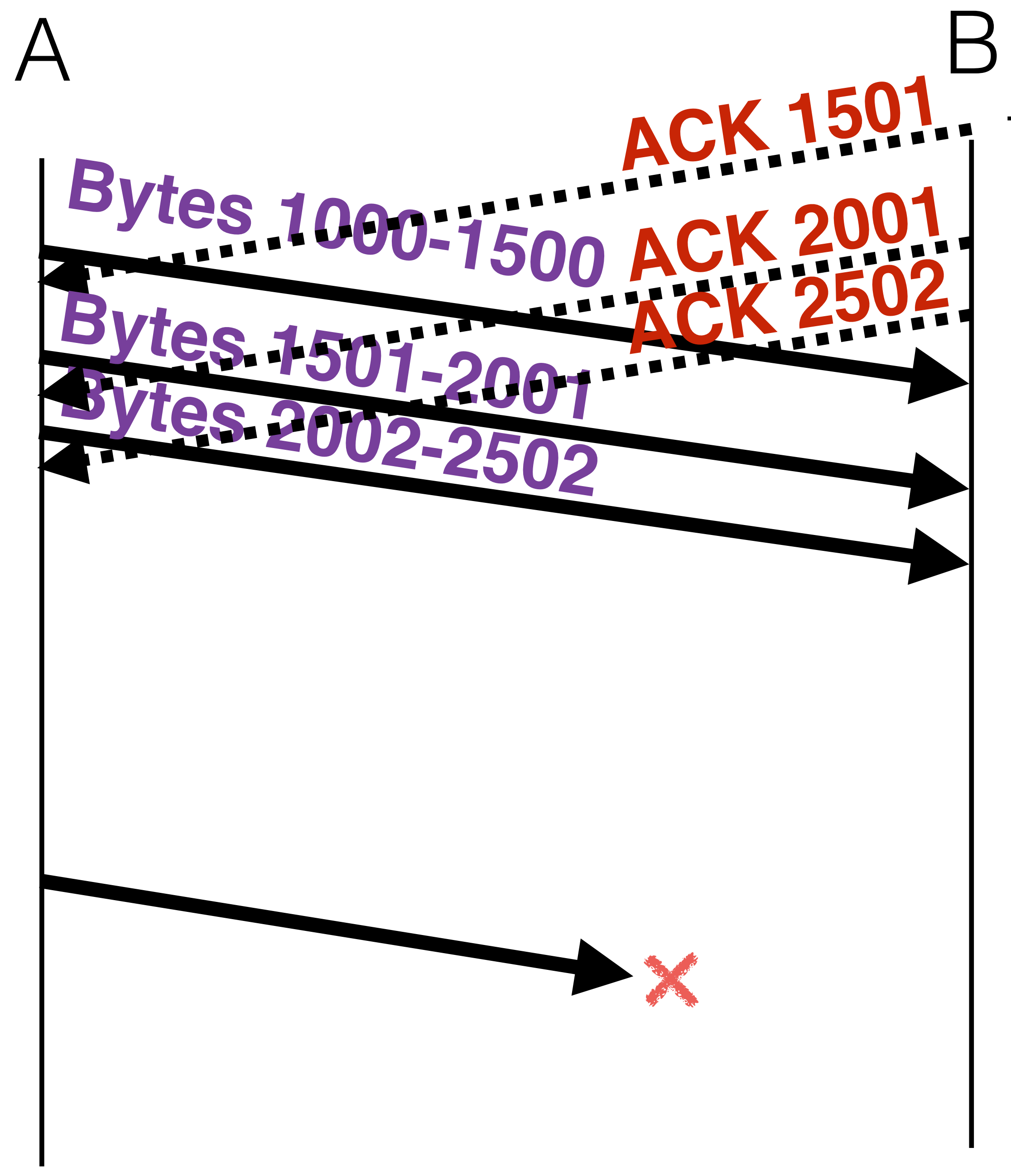

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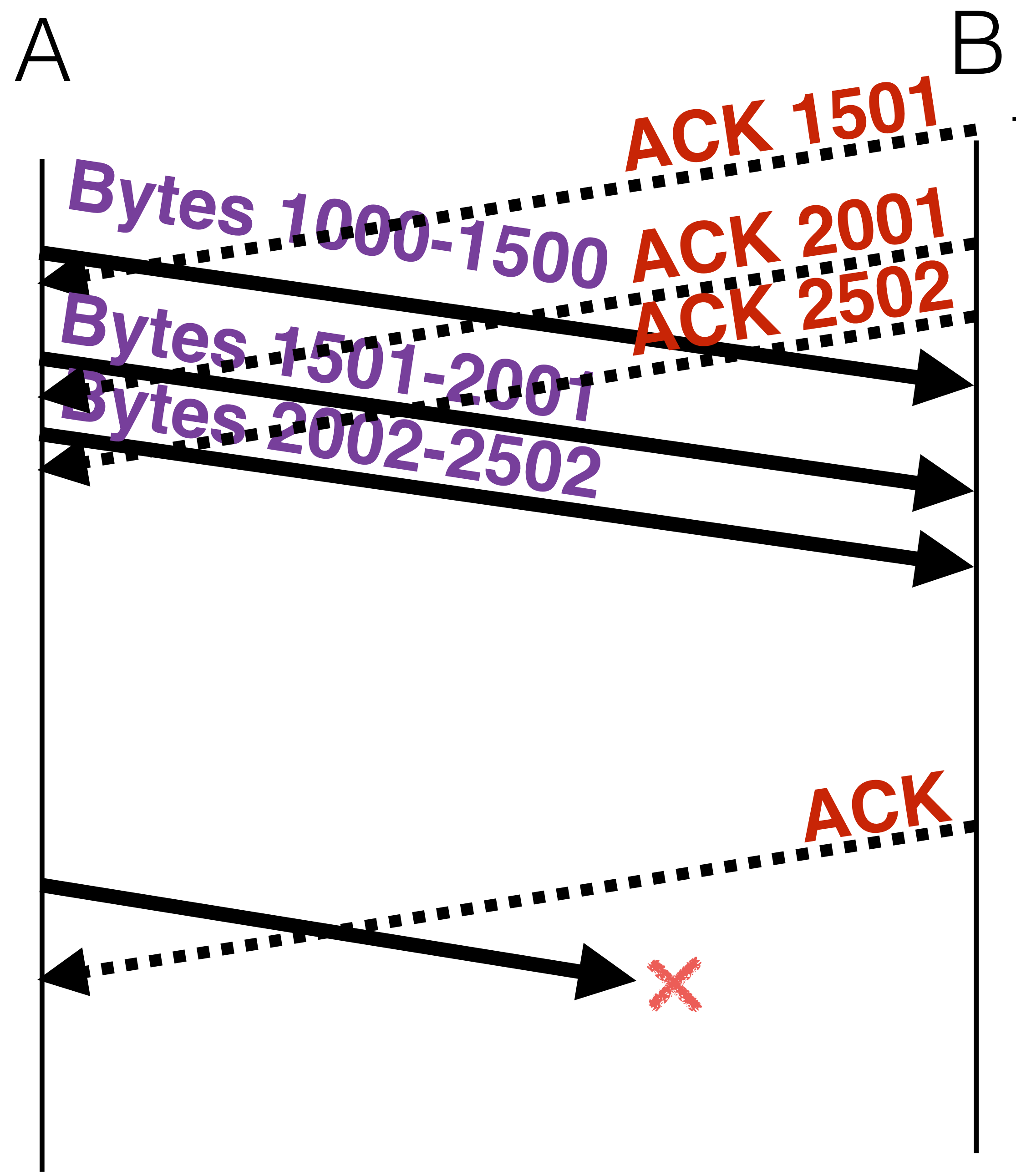

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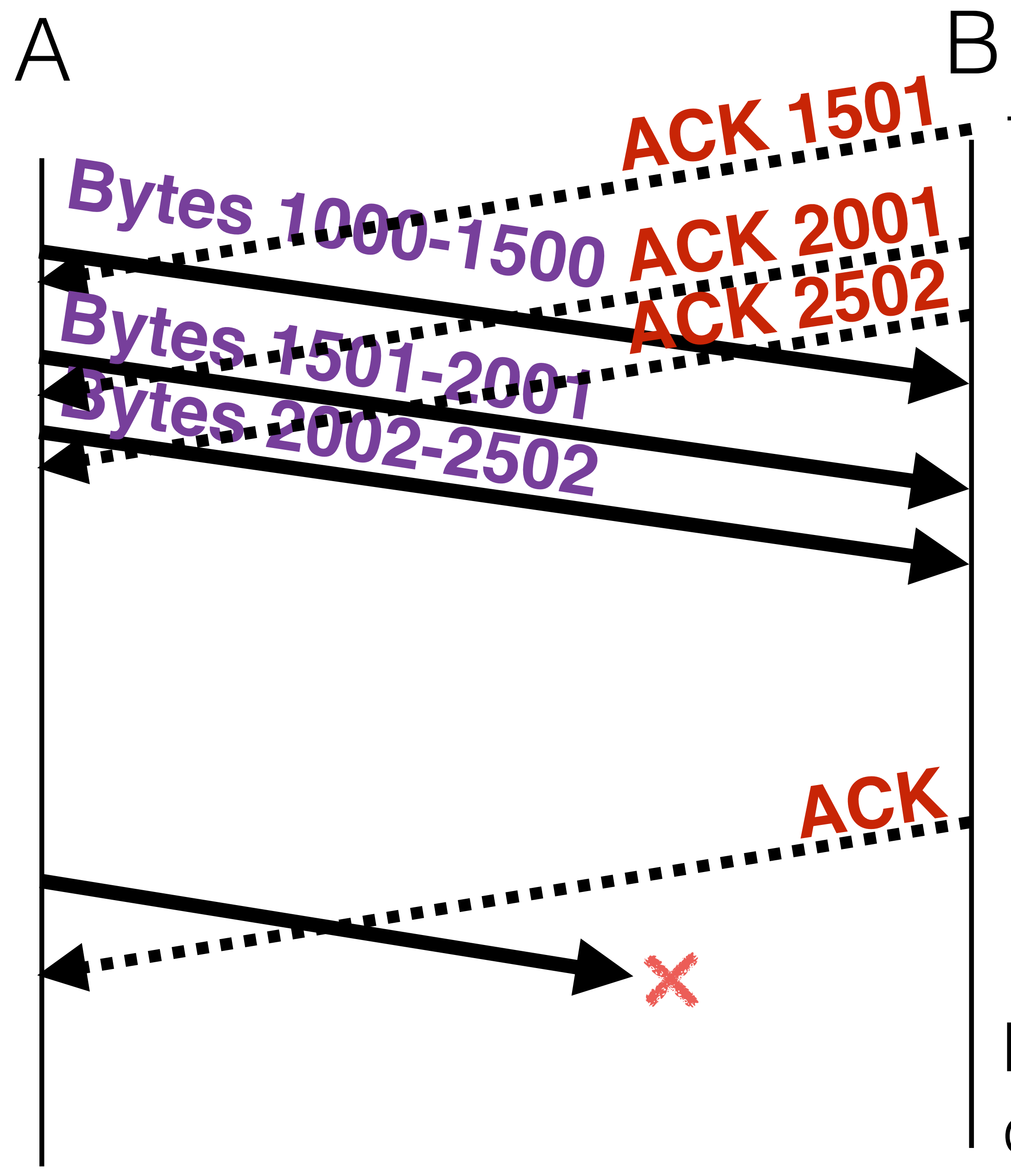

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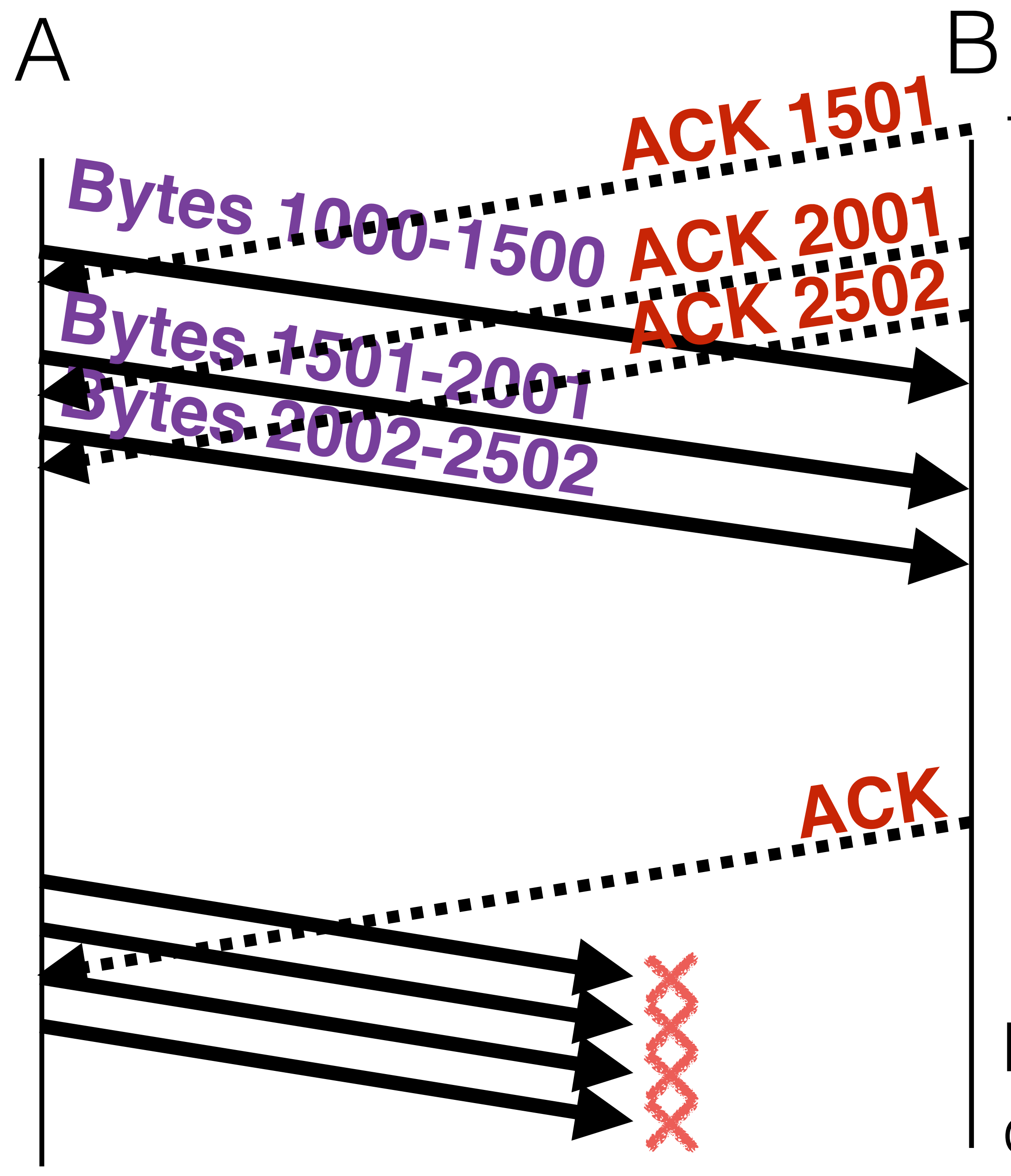

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Amplification

- 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:

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

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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?

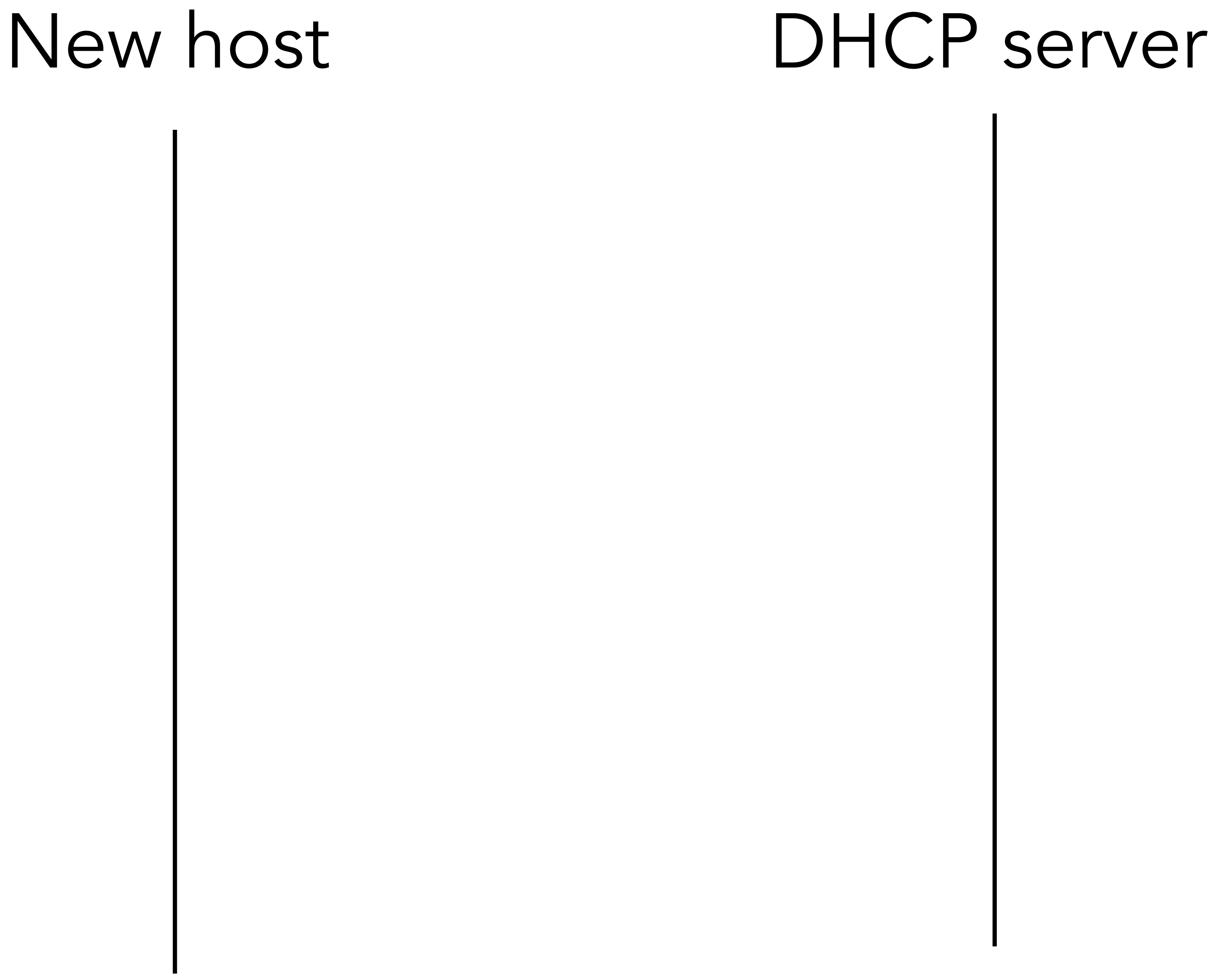
- An important goal in networking is *incremental deployment*: ideally, we should be able to benefit from a system/modification when even a subset of hosts deploy it.

NAMING

- IP addresses allow global connectivity
- But they're pretty useless for humans!
  - Can't be expected to pick their own IP address
  - Can't be expected to remember another's IP address
- **DHCP** : Setting IP addresses
- **DNS** : Mapping a memorable name to a routable IP address

DHCP

DYNAMIC HOST CONFIGURATION PROTOCOL



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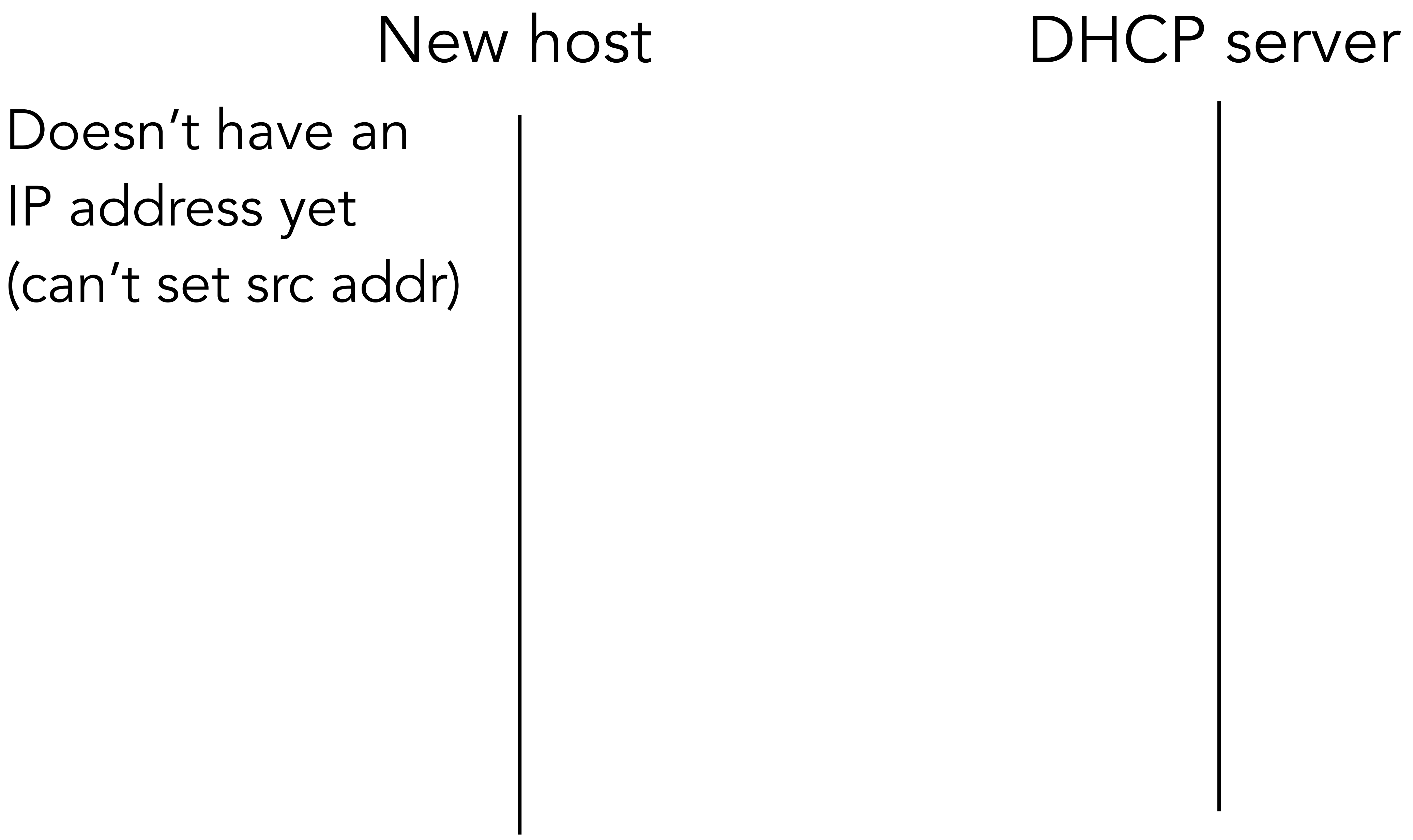

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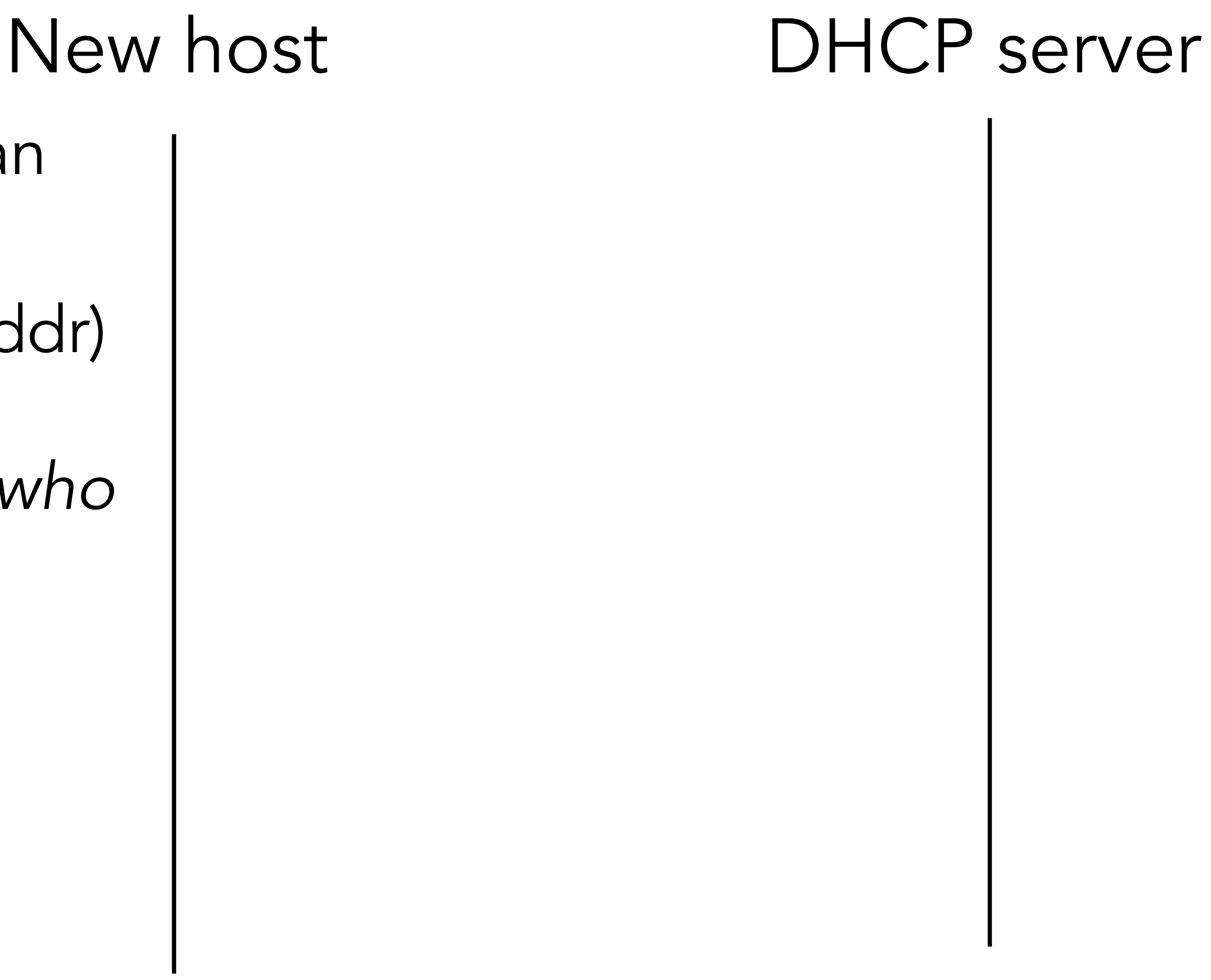

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Doesn't know *who* to ask for one

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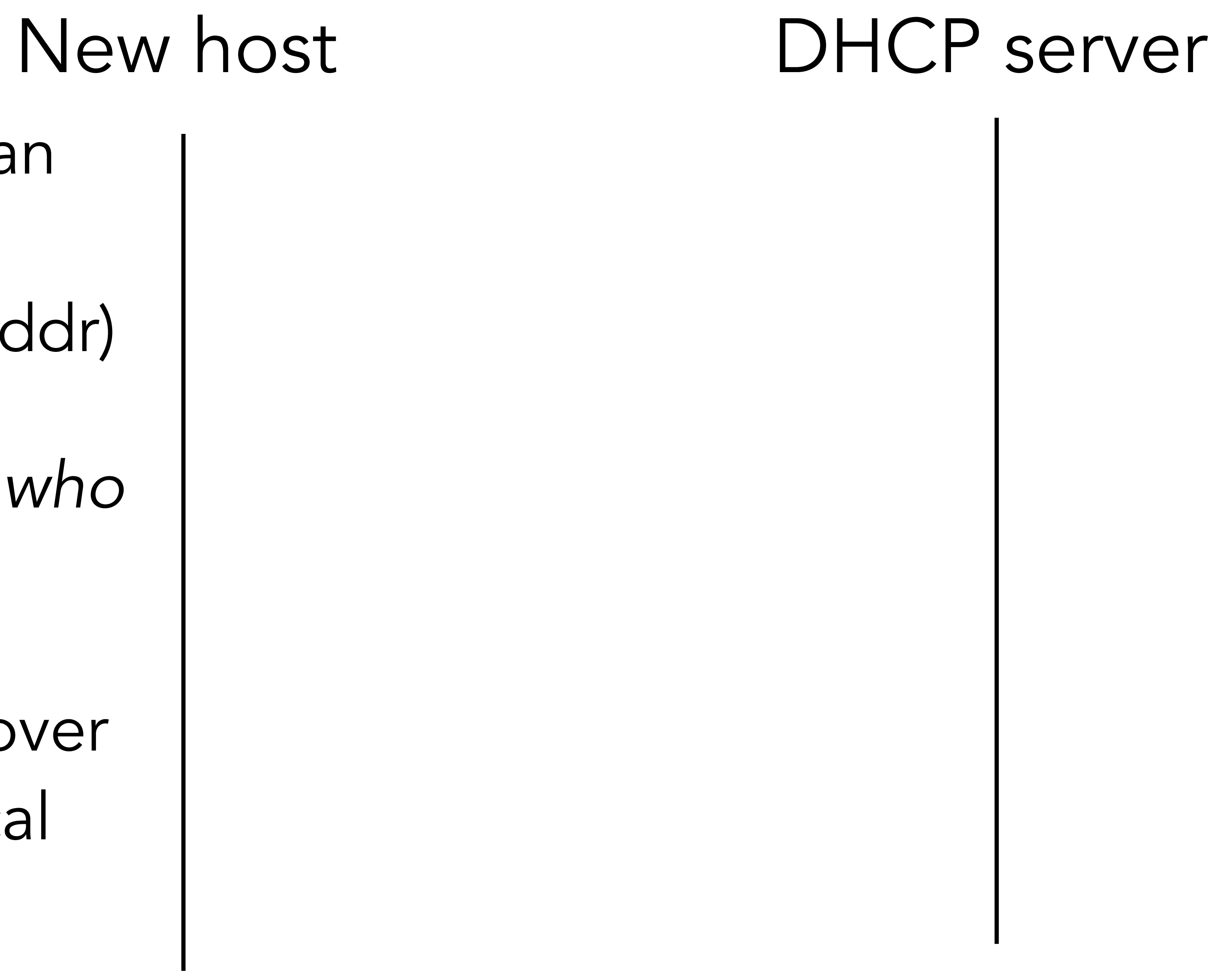

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Solution: Discover one on the local subnet

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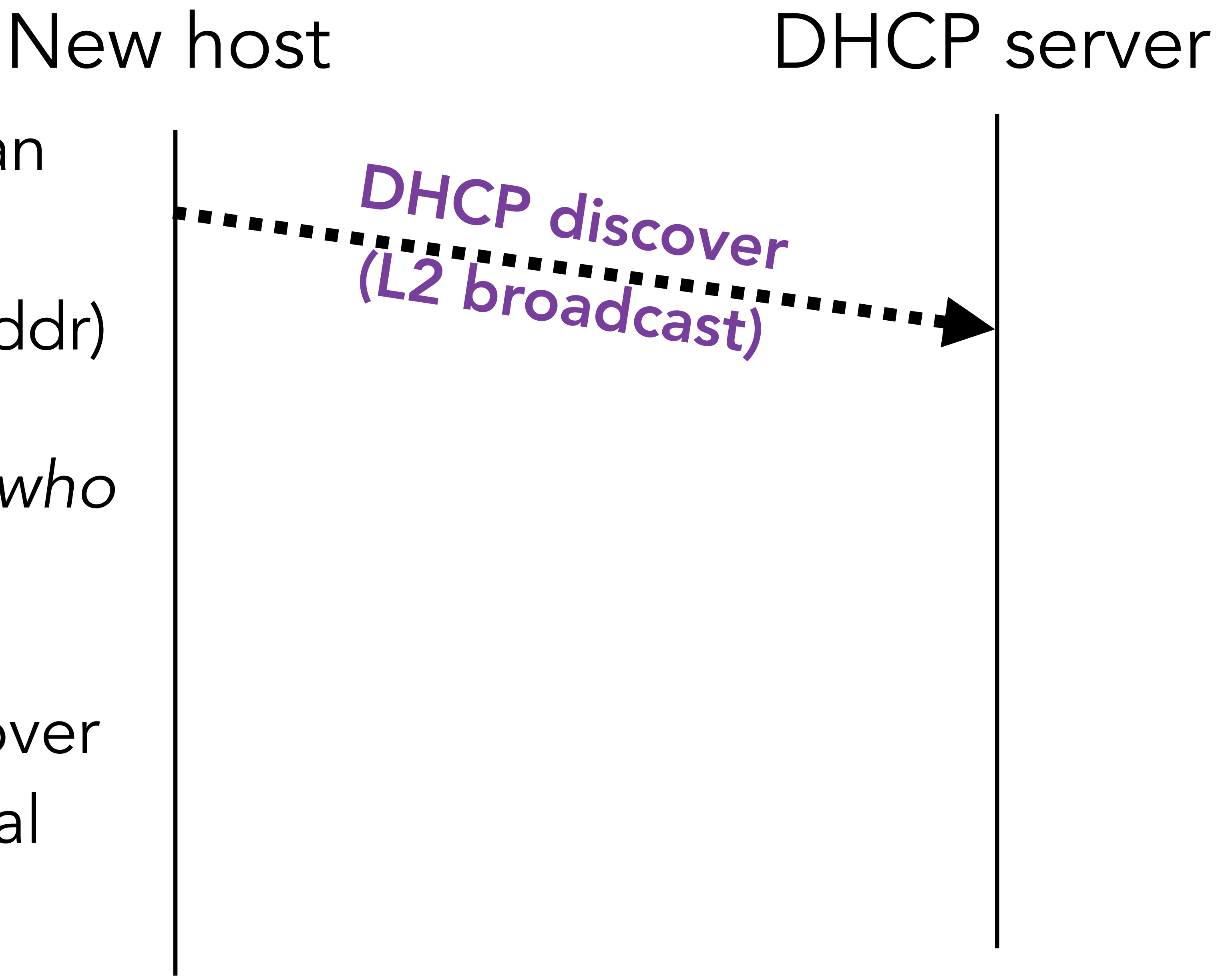

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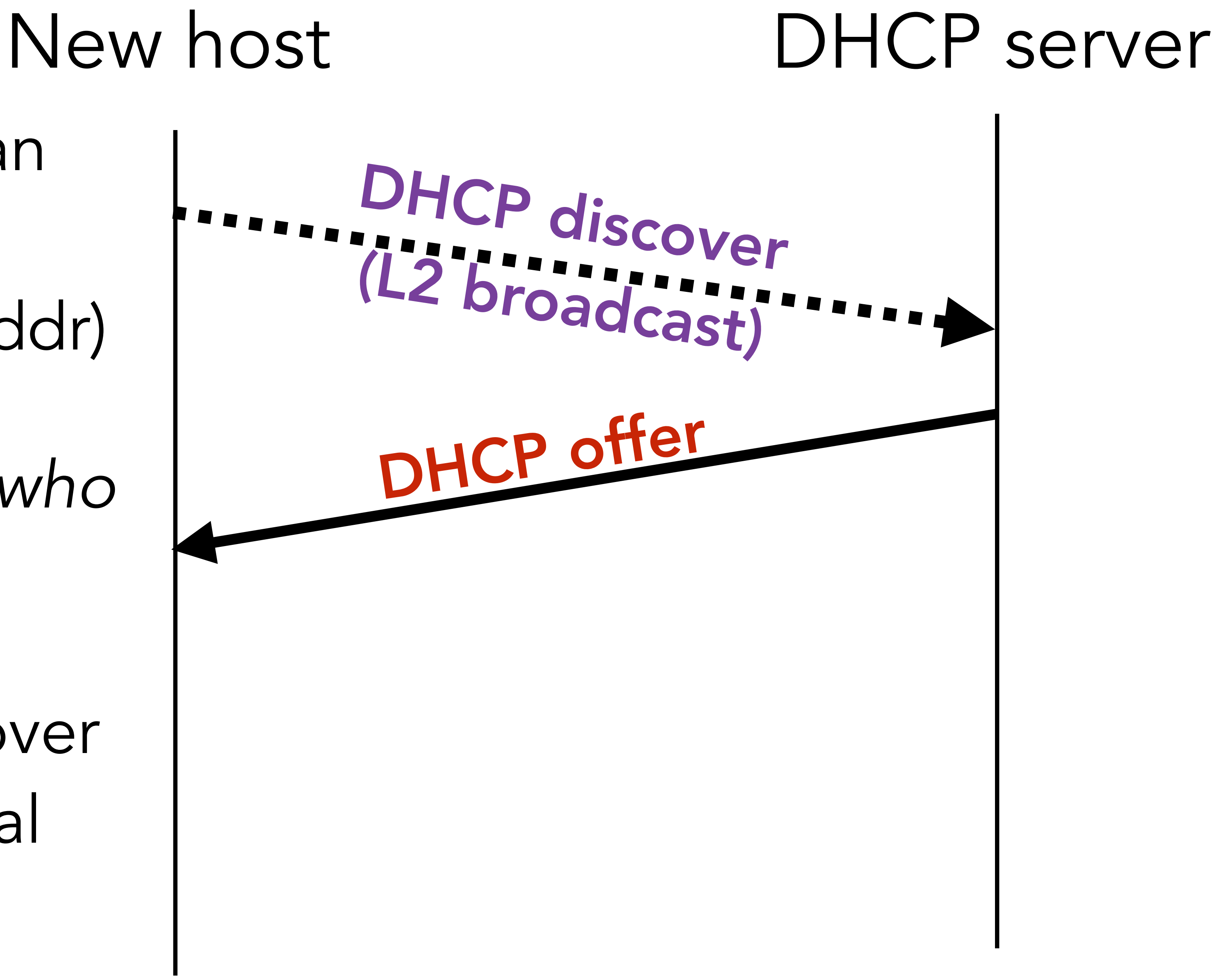

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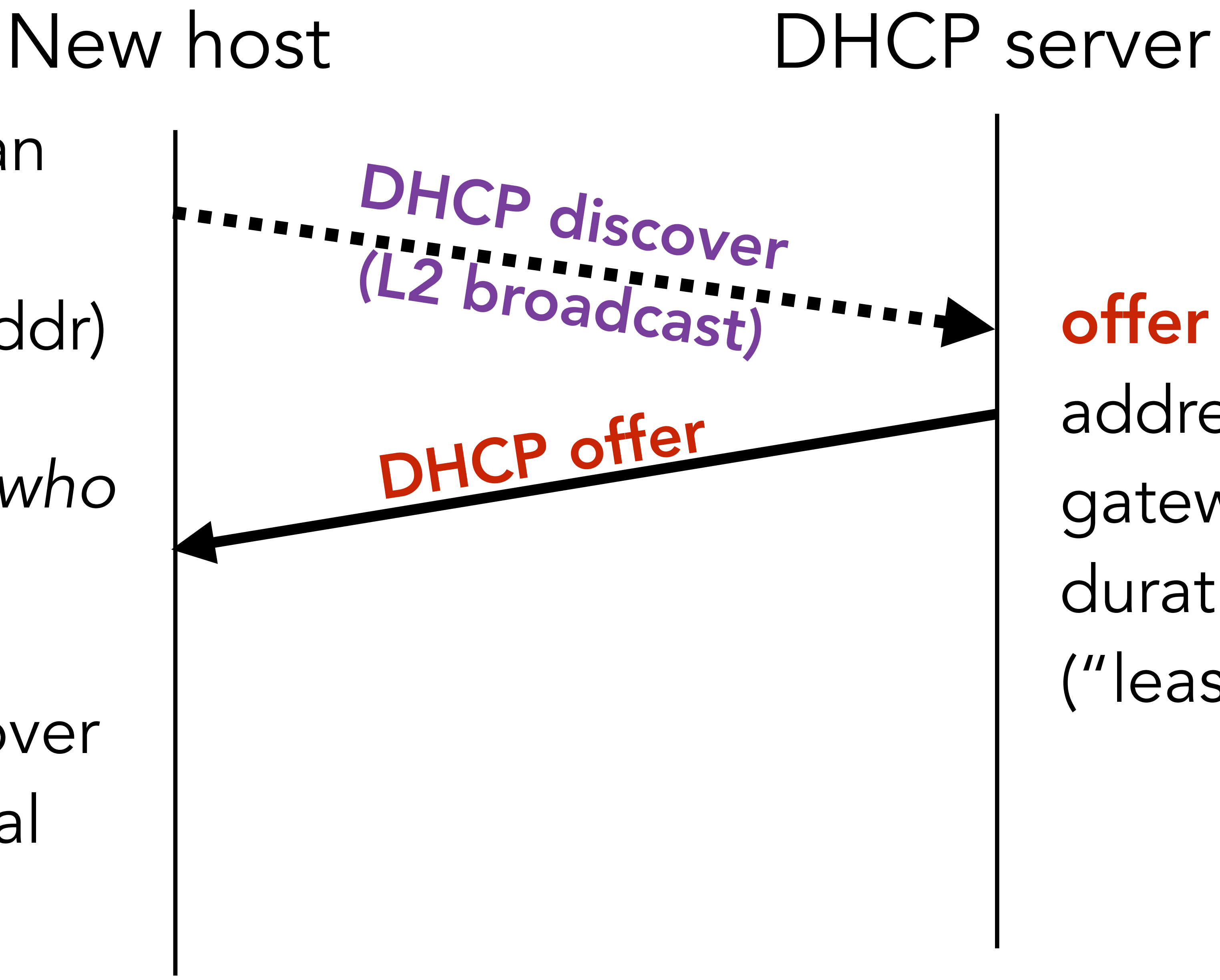

offer includes: IP address, DNS server, gateway router, and duration of this offer (“lease” time)

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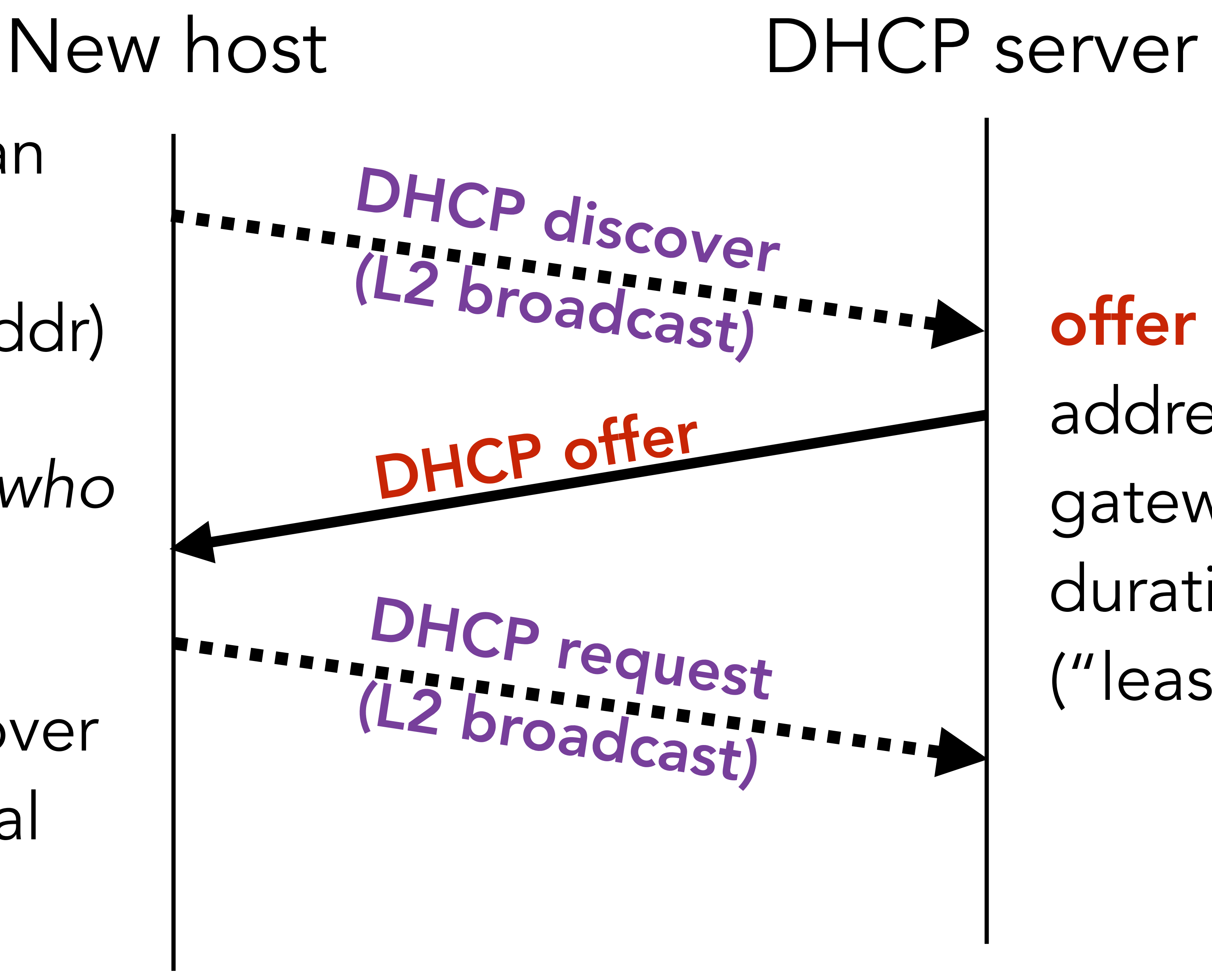

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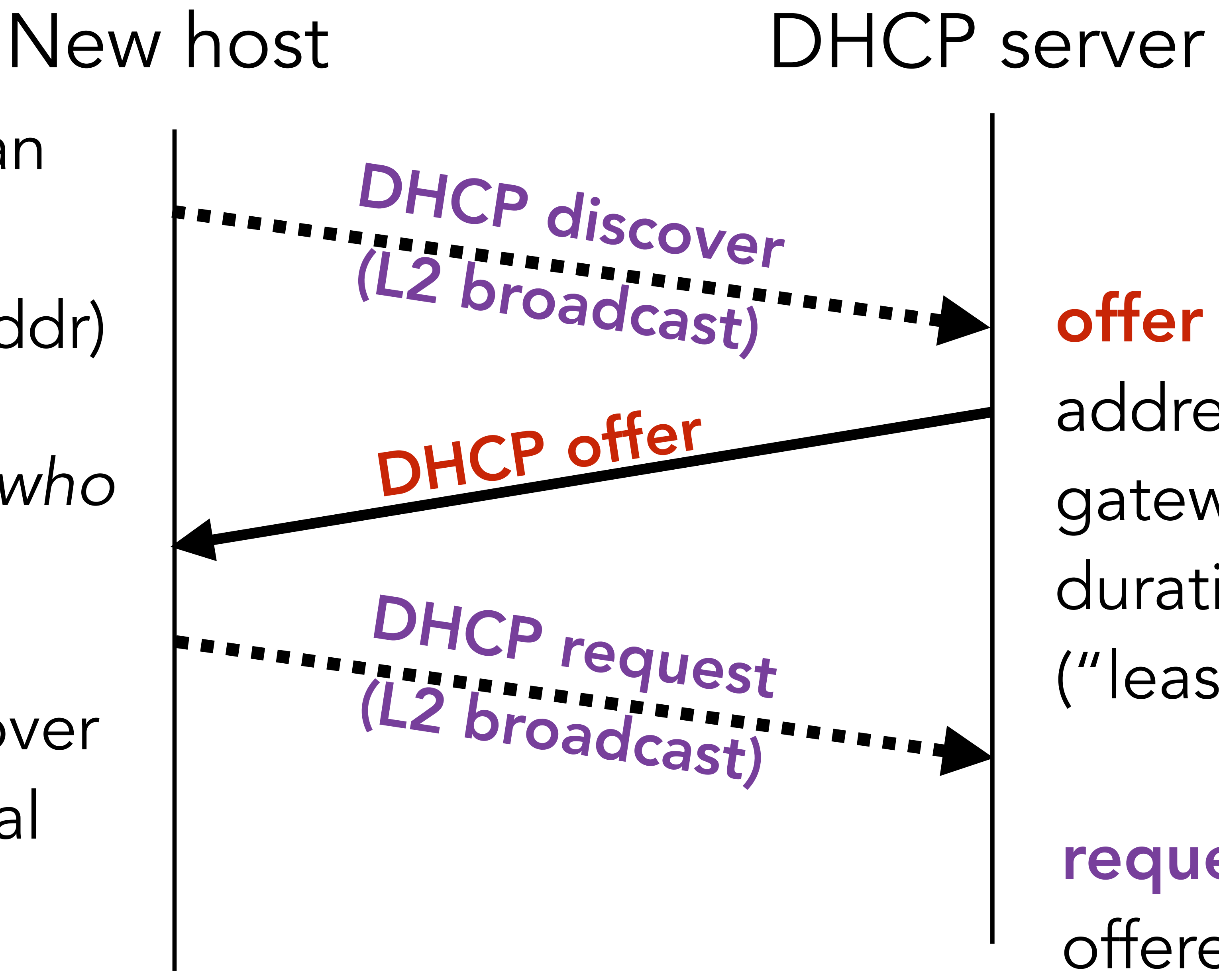

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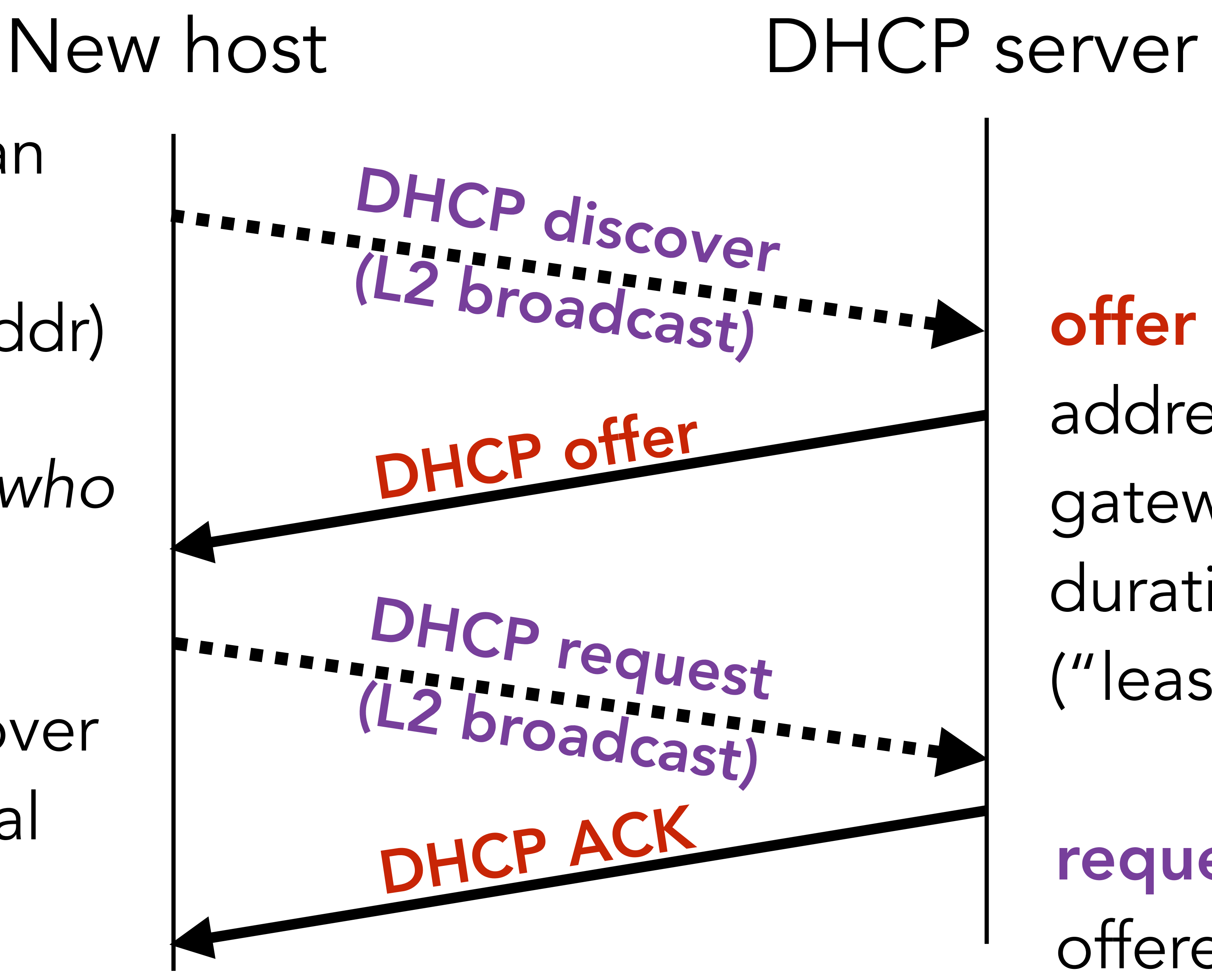

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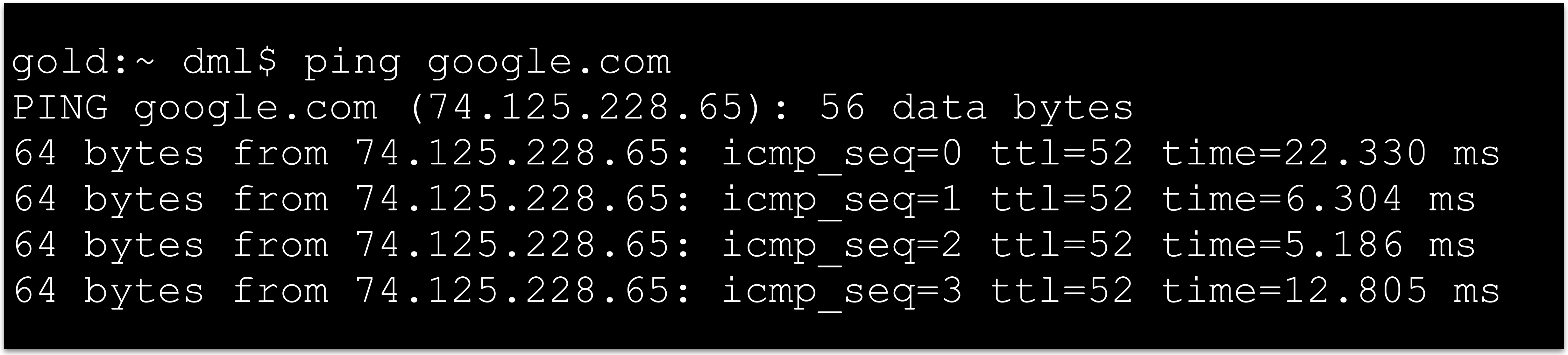
request asks for the offered IP address

DHCP ATTACKS

- Requests are broadcast: attackers on the same subnet can hear new host’s request
- Race the *actual* DHCP server to replace:
  - DNS server
    - Redirect any of a host’s lookups (“what IP address should I use when trying to connect to google.com?”) to a machine of the attacker’s choice
  - Gateway
    - The gateway is where the host sends all of its outgoing traffic (so that the host doesn’t have to figure out routes himself)
    - Modify the gateway to intercept all of a user’s traffic
    - Then relay it to the gateway (MITM)
    - How could the user detect this?

HOSTNAMES AND IP ADDRESSES



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PING google.com (74.125.228.65): 56 data bytes
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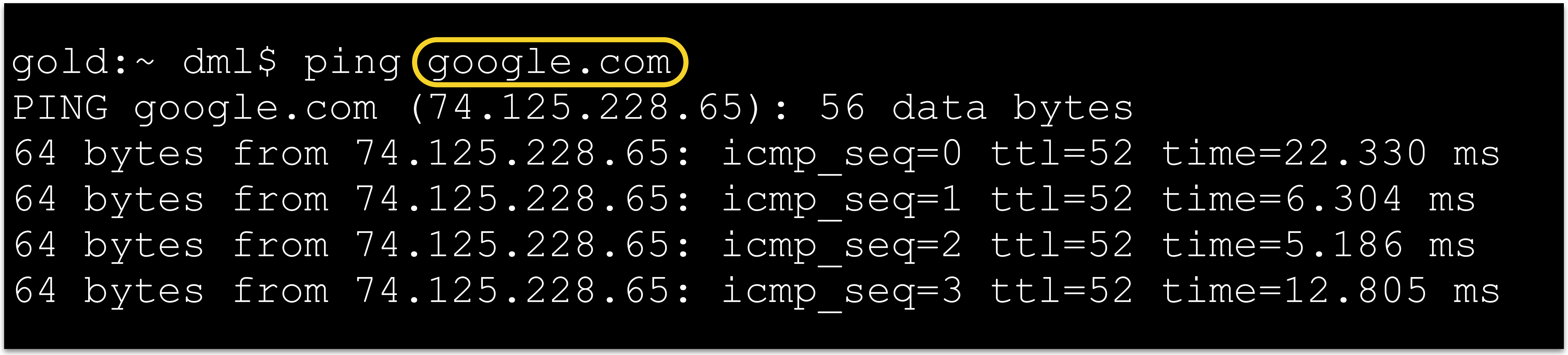

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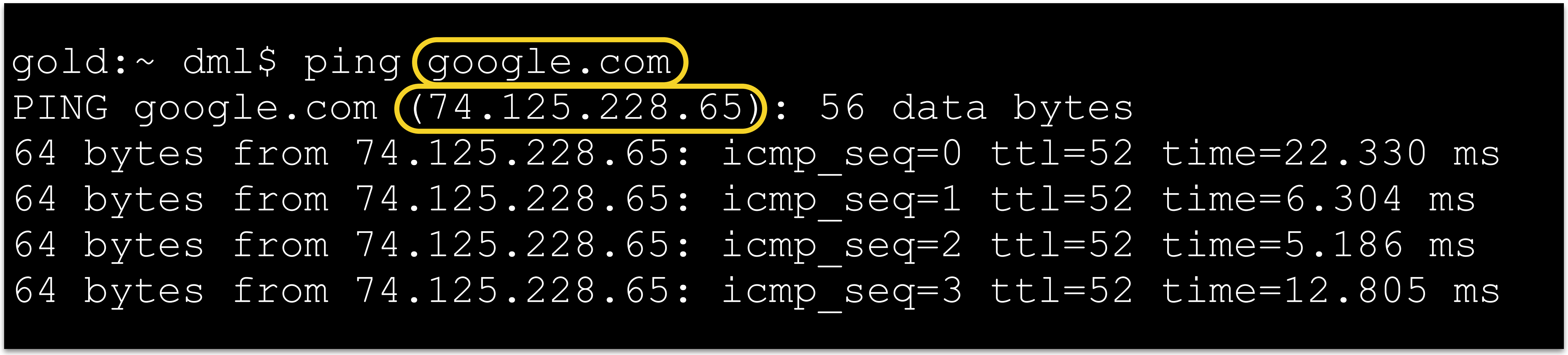

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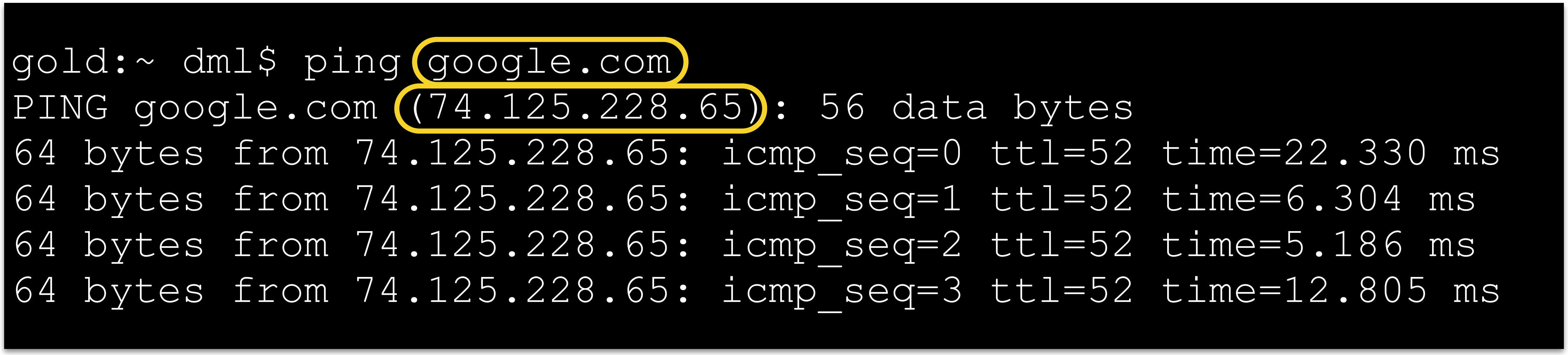

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google.com is easy to remember, but not routable

74.125.228.65 is routable

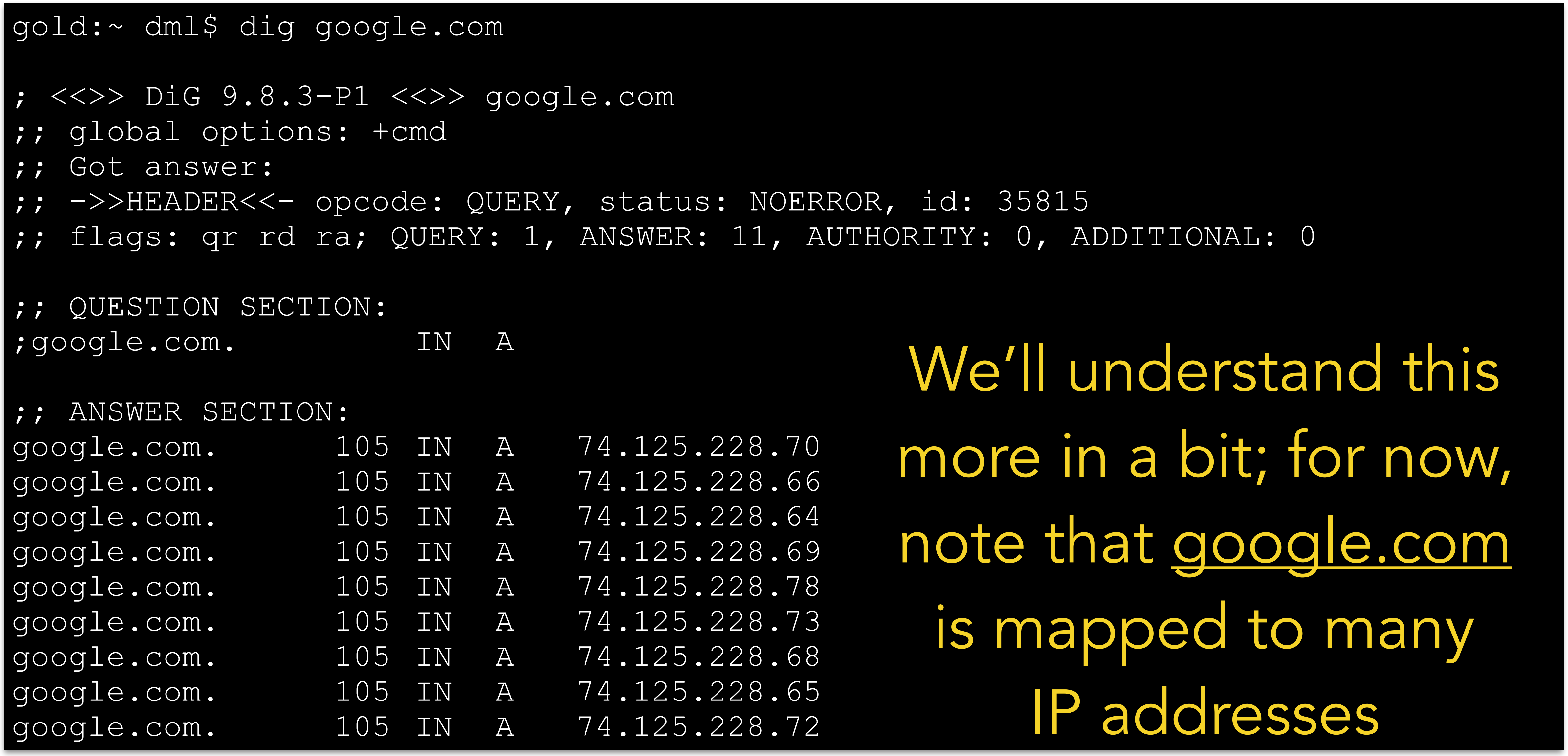
Name resolution:

The process of mapping from one to the other

TERMINOLOGY

- www.cs.umd.edu = "**domain name**"
  - www.cs.umd.edu is a "subdomain" of cs.umd.edu

- Domain names can map to a set of IP addresses



```
gold:~ dml$ dig google.com

; <<>> DiG 9.8.3-P1 <<>> google.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 35815
;; flags: qr rd ra; QUERY: 1, ANSWER: 11, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;google.com.            IN   A

;; ANSWER SECTION:
google.com.        105  IN   A    74.125.228.70
google.com.        105  IN   A    74.125.228.66
google.com.        105  IN   A    74.125.228.64
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google.com.        105  IN   A    74.125.228.78
google.com.        105  IN   A    74.125.228.73
google.com.        105  IN   A    74.125.228.68
google.com.        105  IN   A    74.125.228.65
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We'll understand this more in a bit; for now, note that google.com is mapped to many IP addresses

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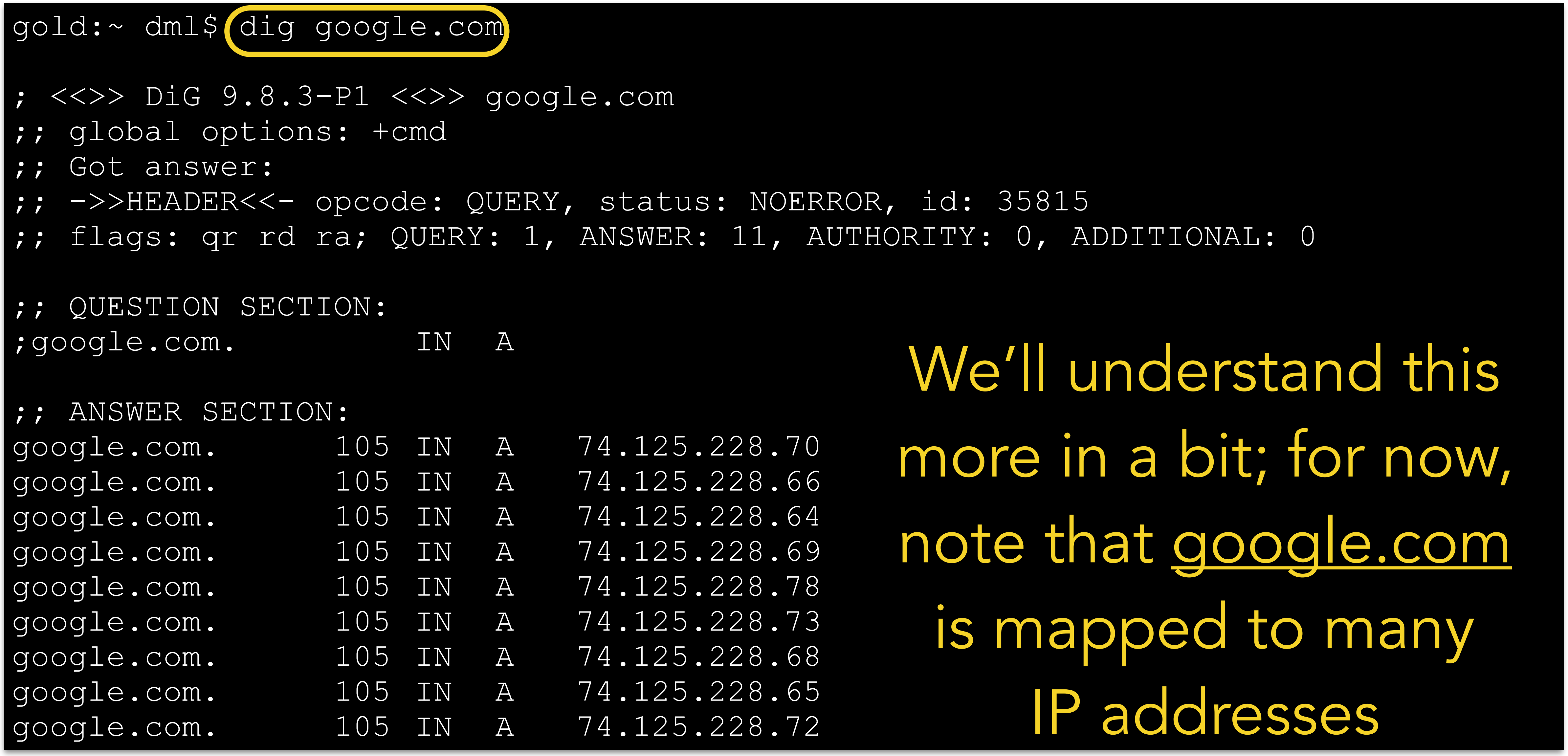

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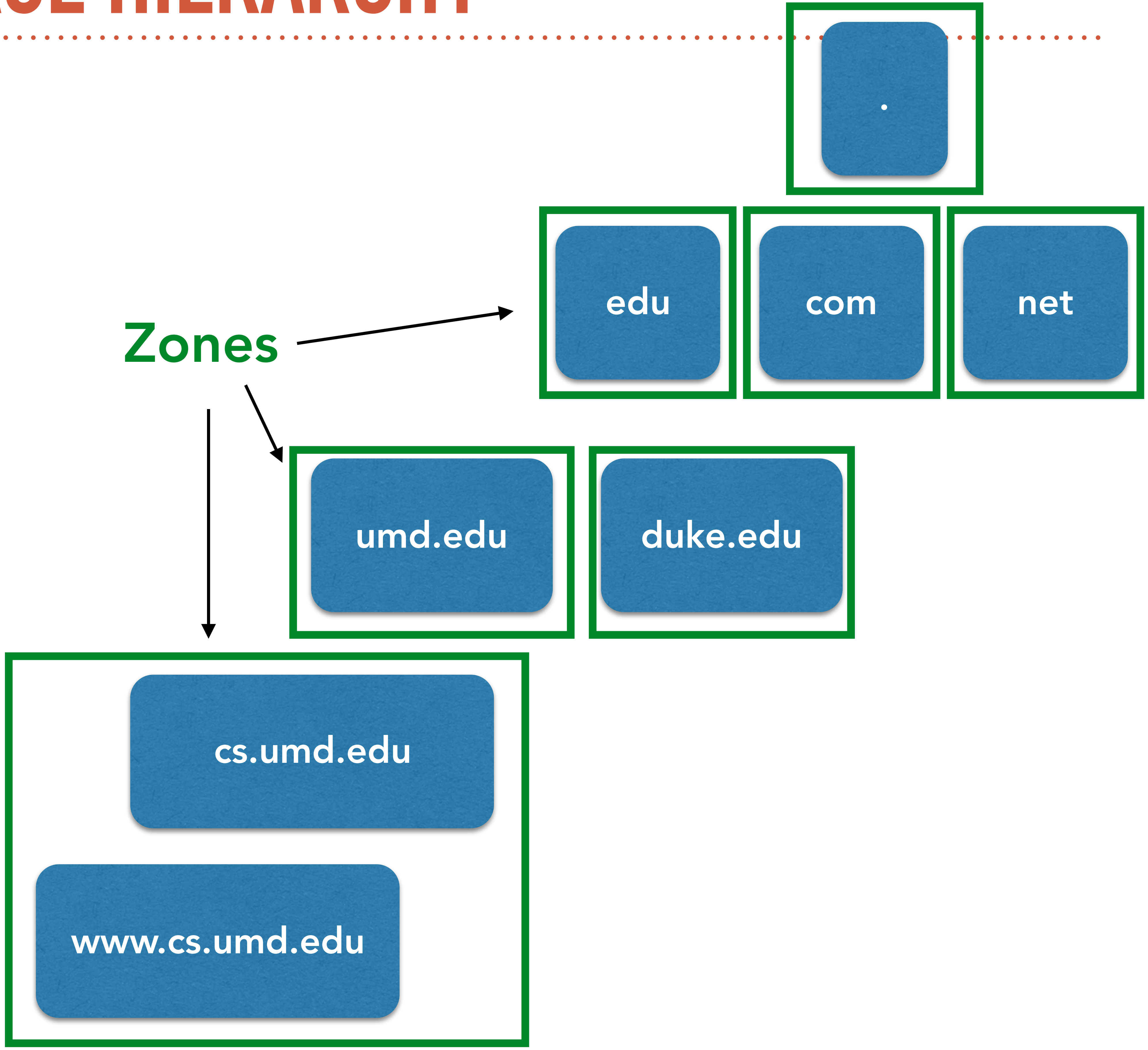
TERMINOLOGY

- “**zone**” = a portion of the DNS namespace, divided up for administrative reasons
  - Think of it like a collection of hostname/IP address pairs that happen to be lumped together
    - www.google.com, mail.google.com, dev.google.com, …
- Subdomains do not need to be in the same zone
  - Allows the owner of one zone (umd.edu) to delegate responsibility to another (cs.umd.edu)

NAMESPACE HIERARCHY



TERMINOLOGY

- "**Nameserver**" = A piece of code that answers queries of the form "What is the IP address for foo.bar.com?"
  - Every zone must run ≥2 nameservers
  - Several very common nameserver implementations: BIND, PowerDNS (more popular in Europe)
- "**Authoritative nameserver**":
  - Every zone has to maintain a file that maps IP addresses and hostnames ("www.cs.umd.edu is 128.8.127.3")
  - One of the name servers in the zone has the *master* copy of this file. It is the authority on the mapping.

TERMINOLOGY

- "**Resolver**" - while name servers *answer* queries, resolvers *ask* queries.
- Every OS has a resolver. Typically small and pretty dumb. All it typically does it forward the query to a local…
- "**Recursive nameserver**" - a nameserver which will do the heavy lifting, issuing queries on behalf of the client resolver until an authoritative answer returns.
- Prevalence
  - There is almost always a *local* (private) recursive name server
  - But very rare for name servers to support recursive queries otherwise

TERMINOLOGY

- "**Record**" (or "resource record") = usually think of it as a mapping between hostname and IP address
- But more generally, it can map virtually anything to virtually anything
- Many record types:
  - (**A**)ddress records (IP <-> hostname)
  - Mail server (**MX**, mail exchanger)
  - SOA (start of authority, to delineate different zones)
  - Others for DNSSEC to be able to share keys
- Records are the unit of information

TERMINOLOGY

Nameservers within a zone must be able to give:

- **Authoritative answers (A)** for hostnames in that zone
  - The umd.edu zone's nameservers must be able to tell us what the IP address for umd.edu is

"A" record: umd.edu = 54.84.241.99

54.84.241.99 is a valid IP address for umd.edu

TERMINOLOGY

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54.84.241.99 is a valid IP address for umd.edu

- Pointers to **name servers (NS)** who host zones in its subdomains
  - The umd.edu zone’s nameservers must be able to tell us what the name and IP address of the cs.umd.edu zone’s nameservers

“NS” record: cs.umd.edu = ipa01.cs.umd.edu.

Ask ipa01.cs.umd.edu for all cs.umd.edu subdomains

DNS

Domain Name Service at a very high level

What is an IP address for cs.umd.edu?

DNS

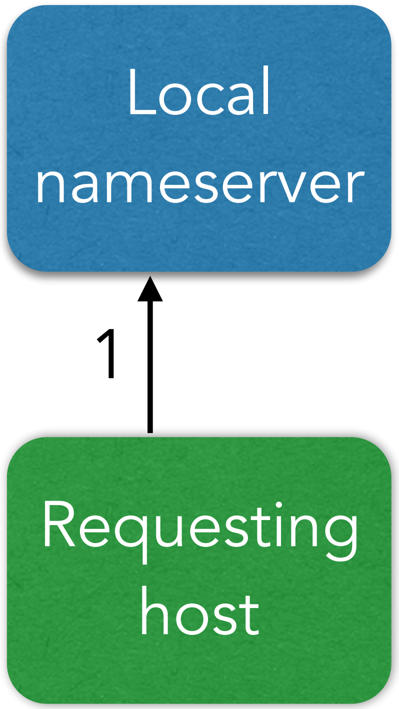
Domain Name Service at a very high level

Local nameserver
Requesting host

What is an IP address for cs.umd.edu?

DNS

Domain Name Service at a very high level



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DNS

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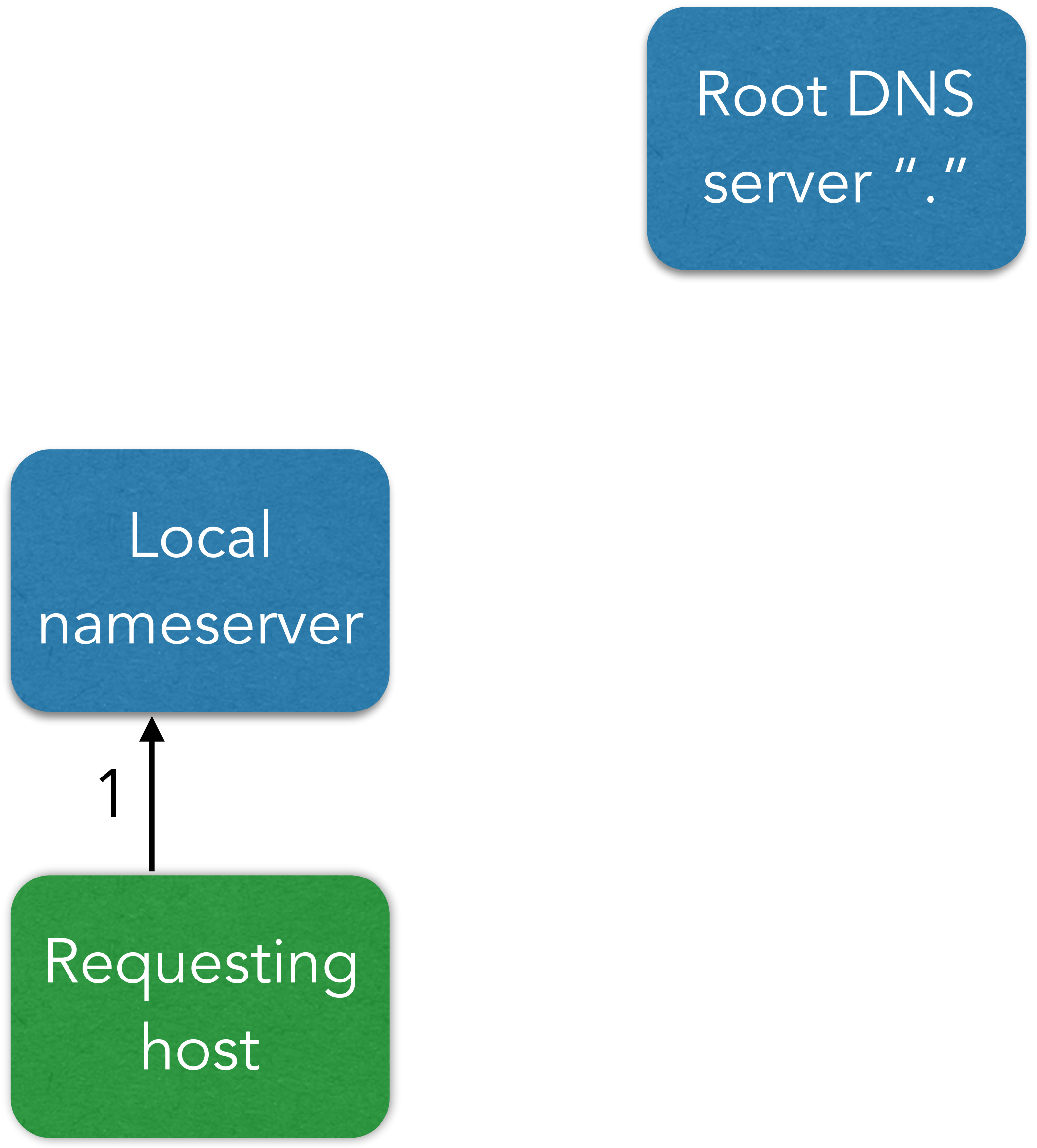

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DNS

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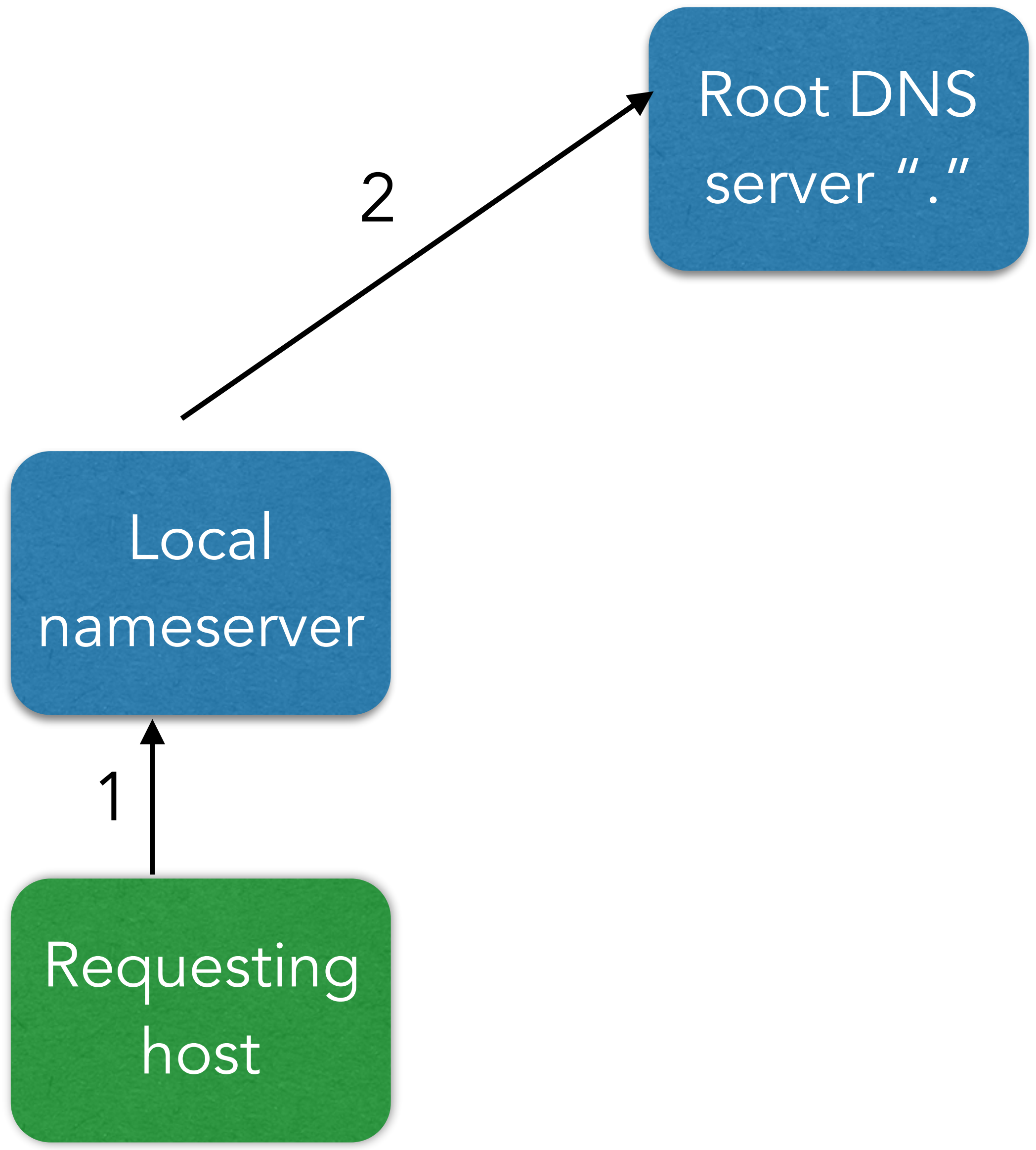

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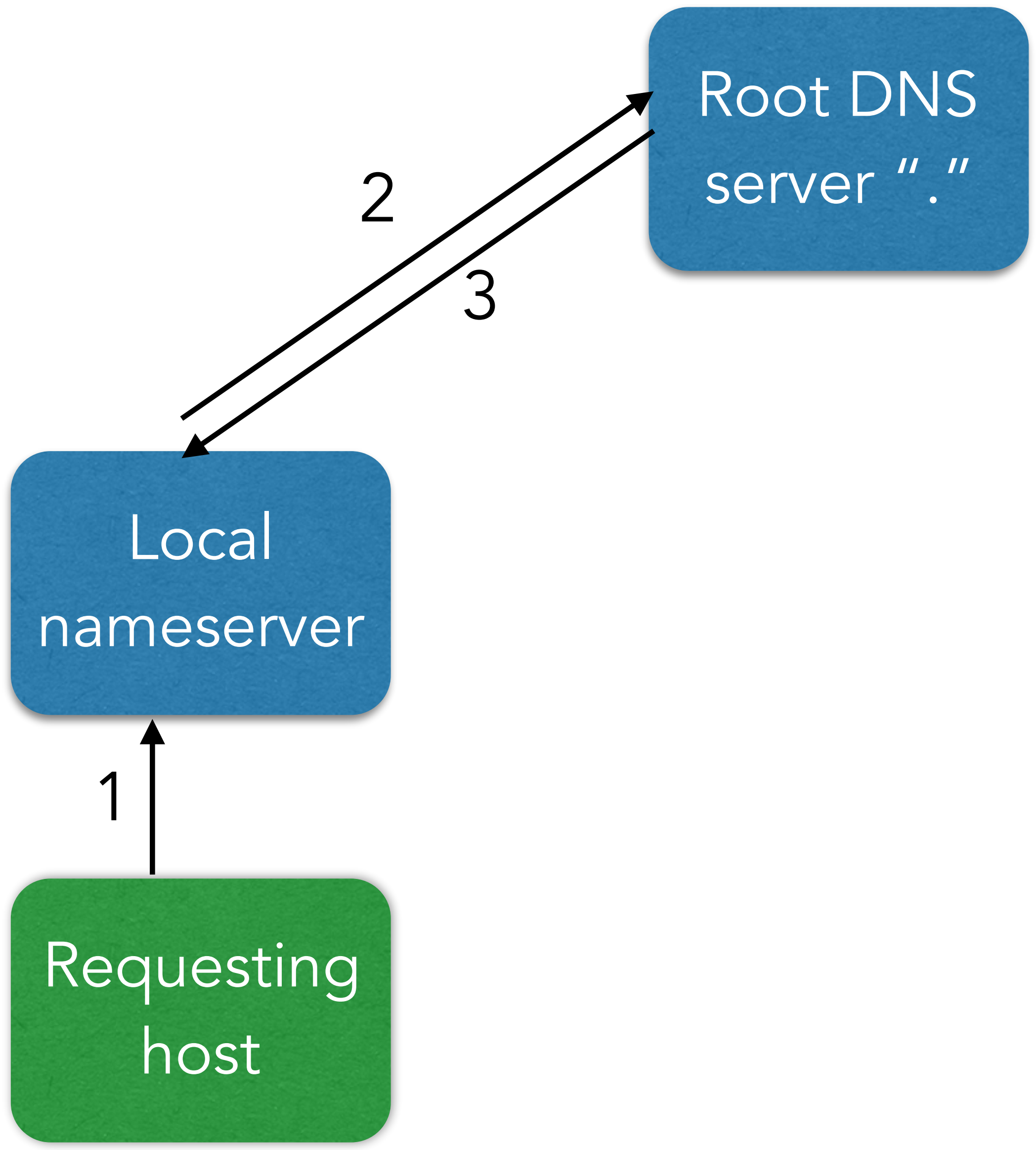

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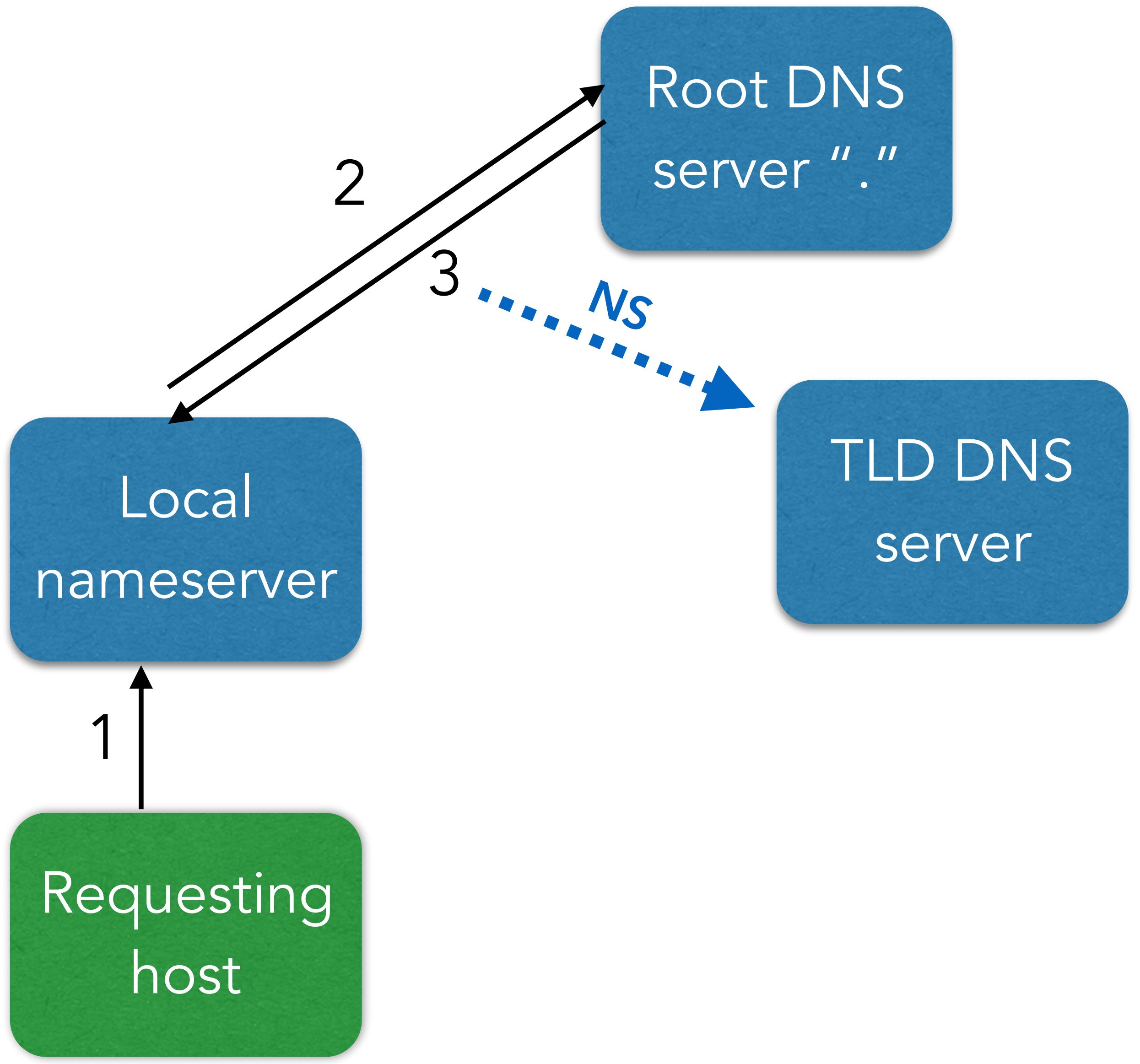

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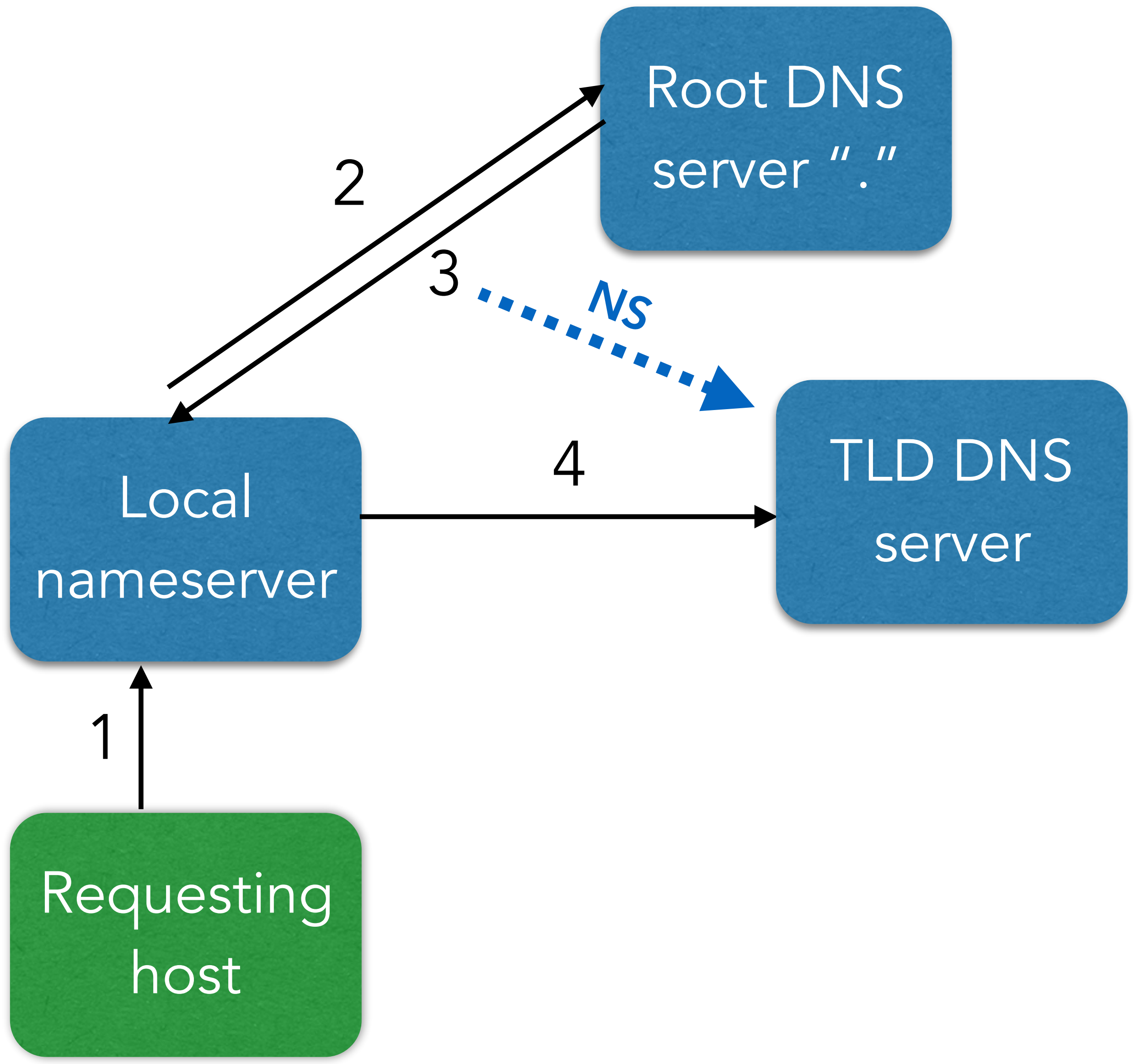

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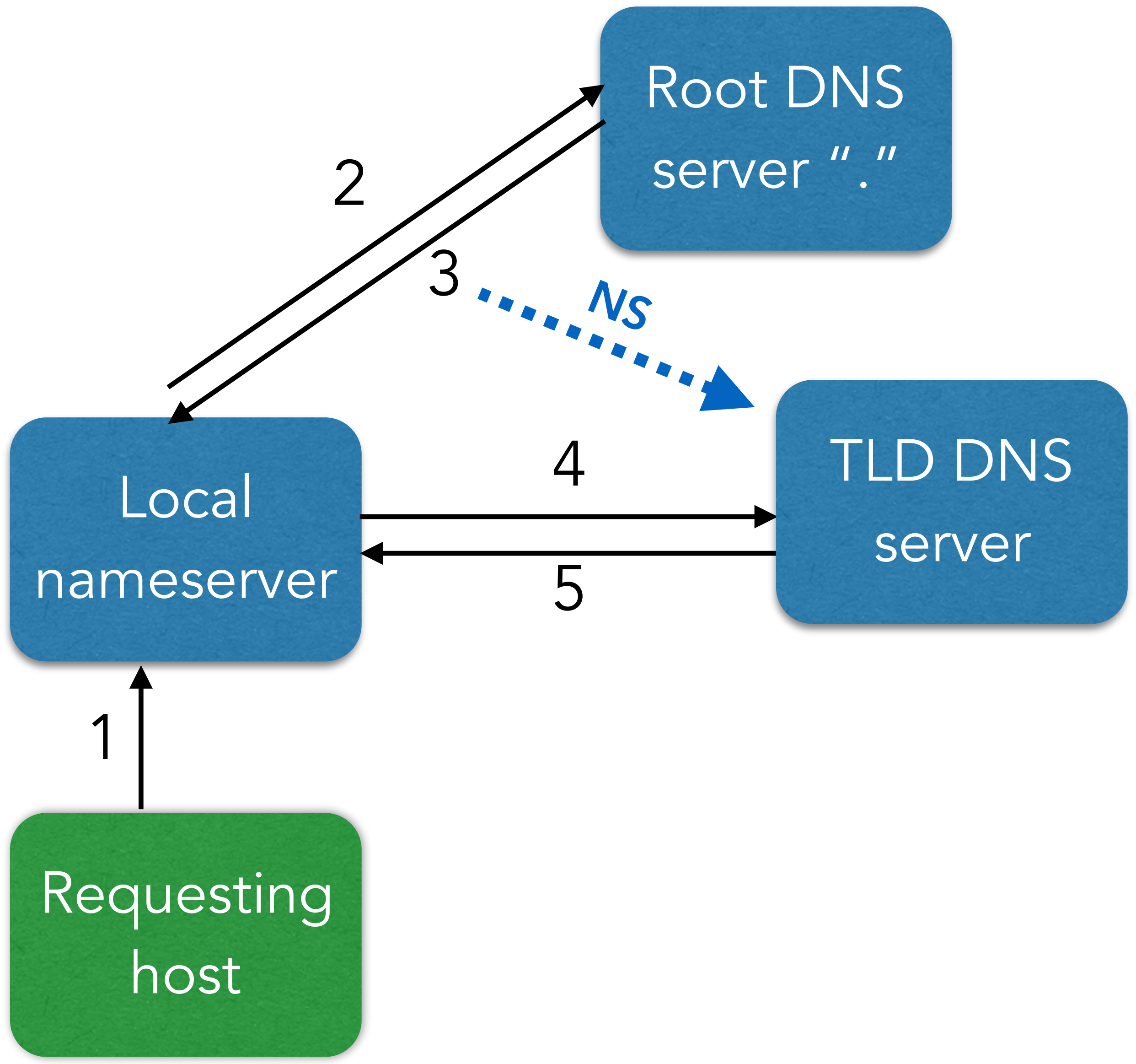

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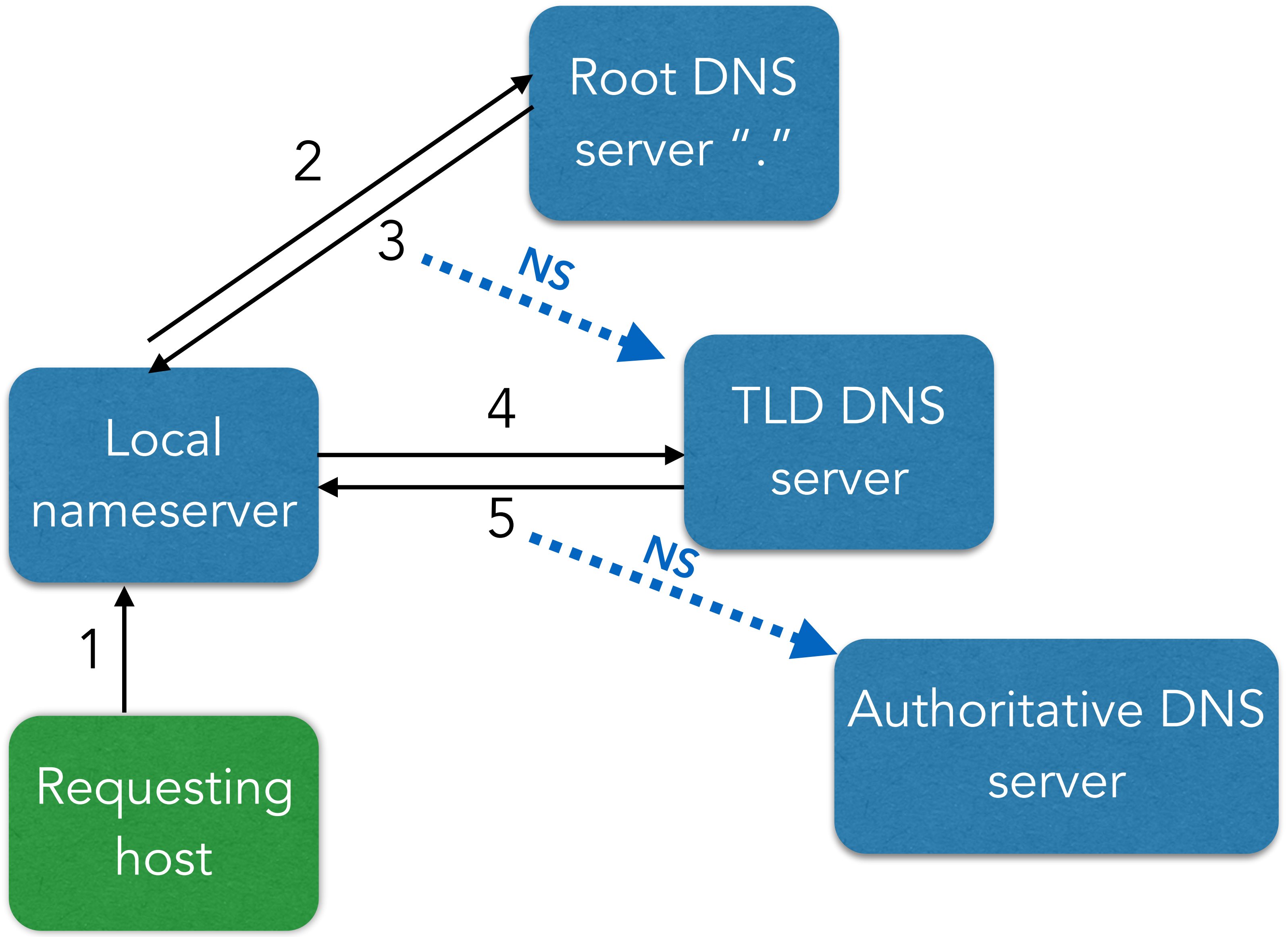

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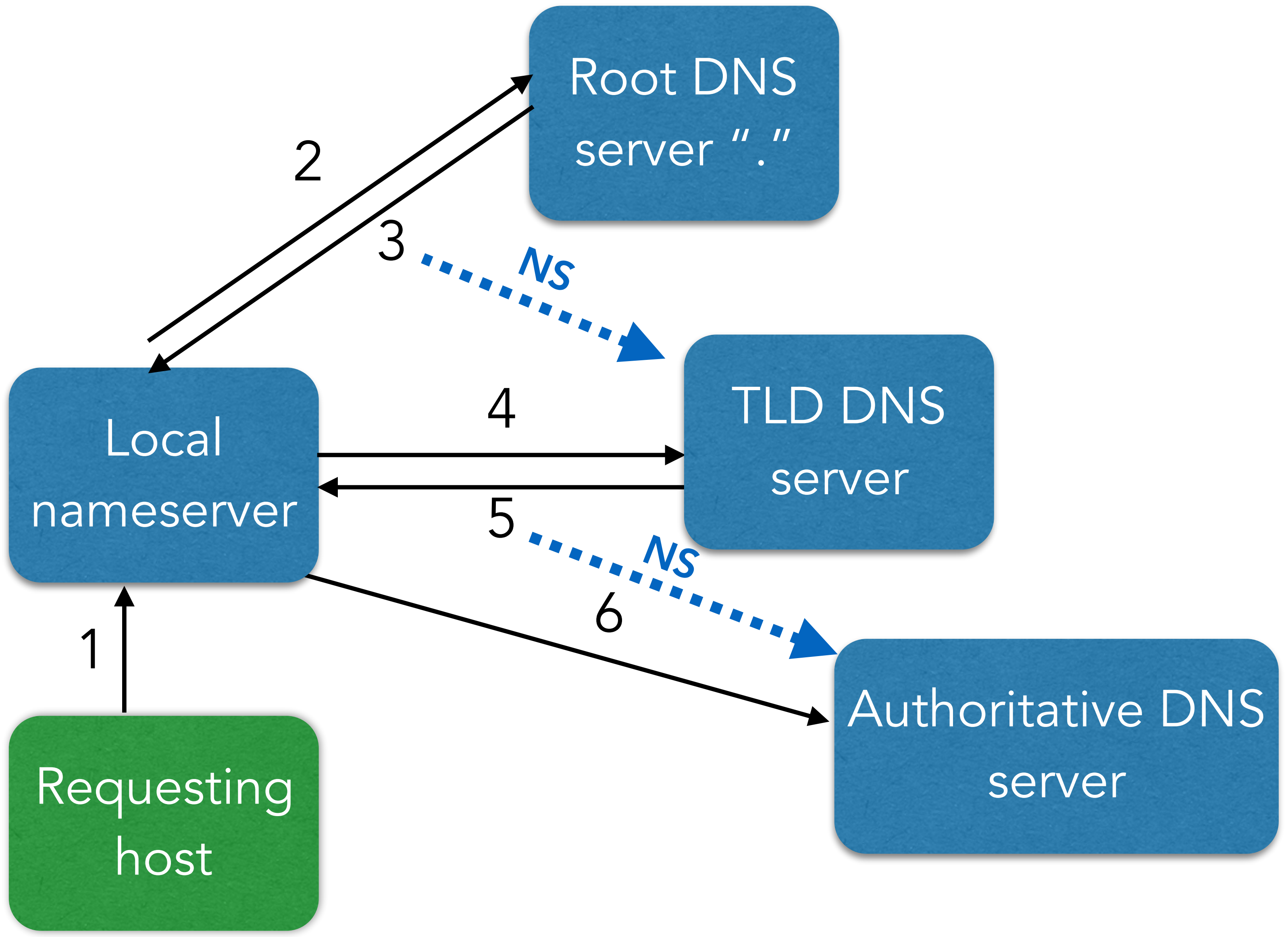

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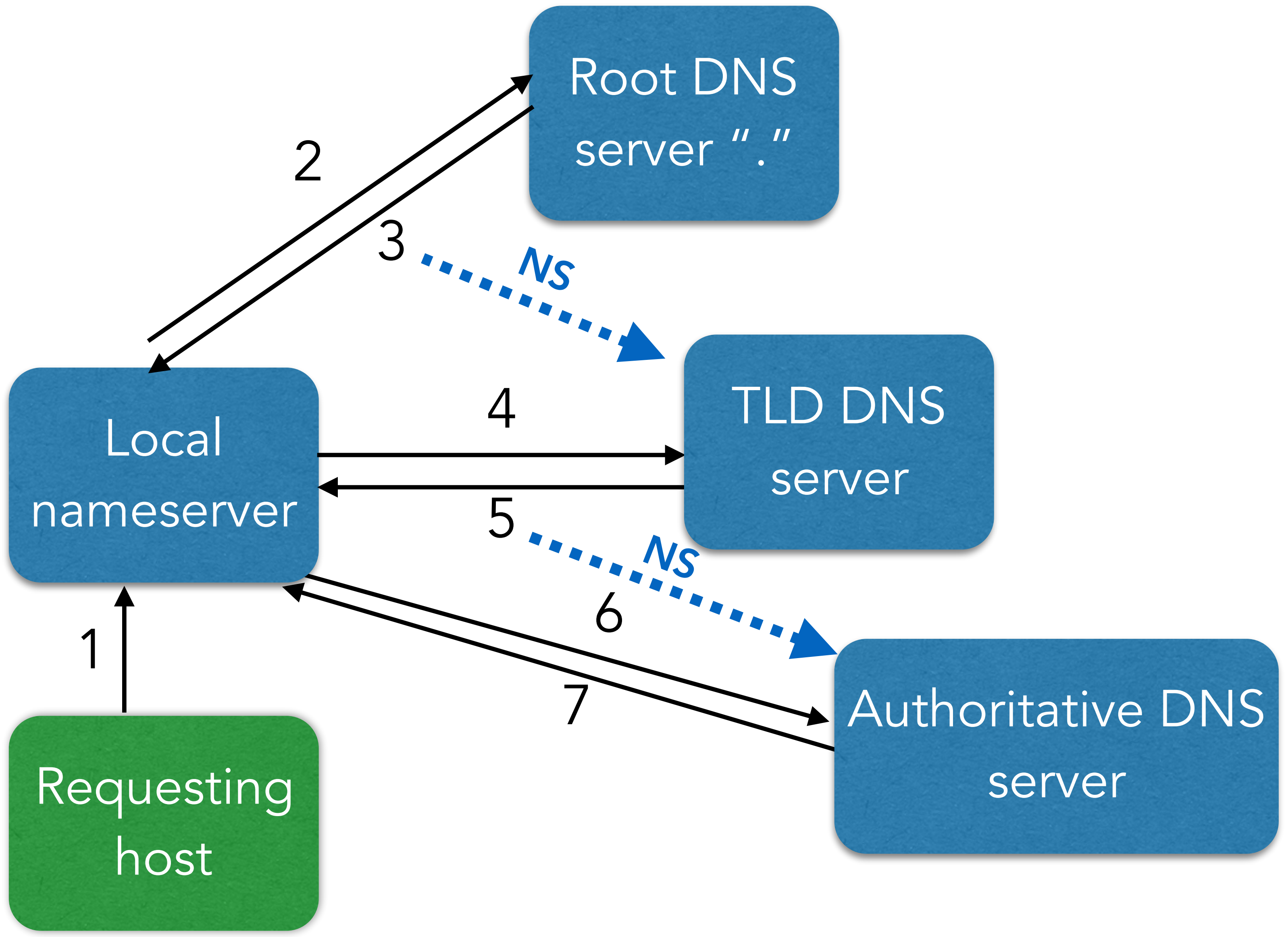

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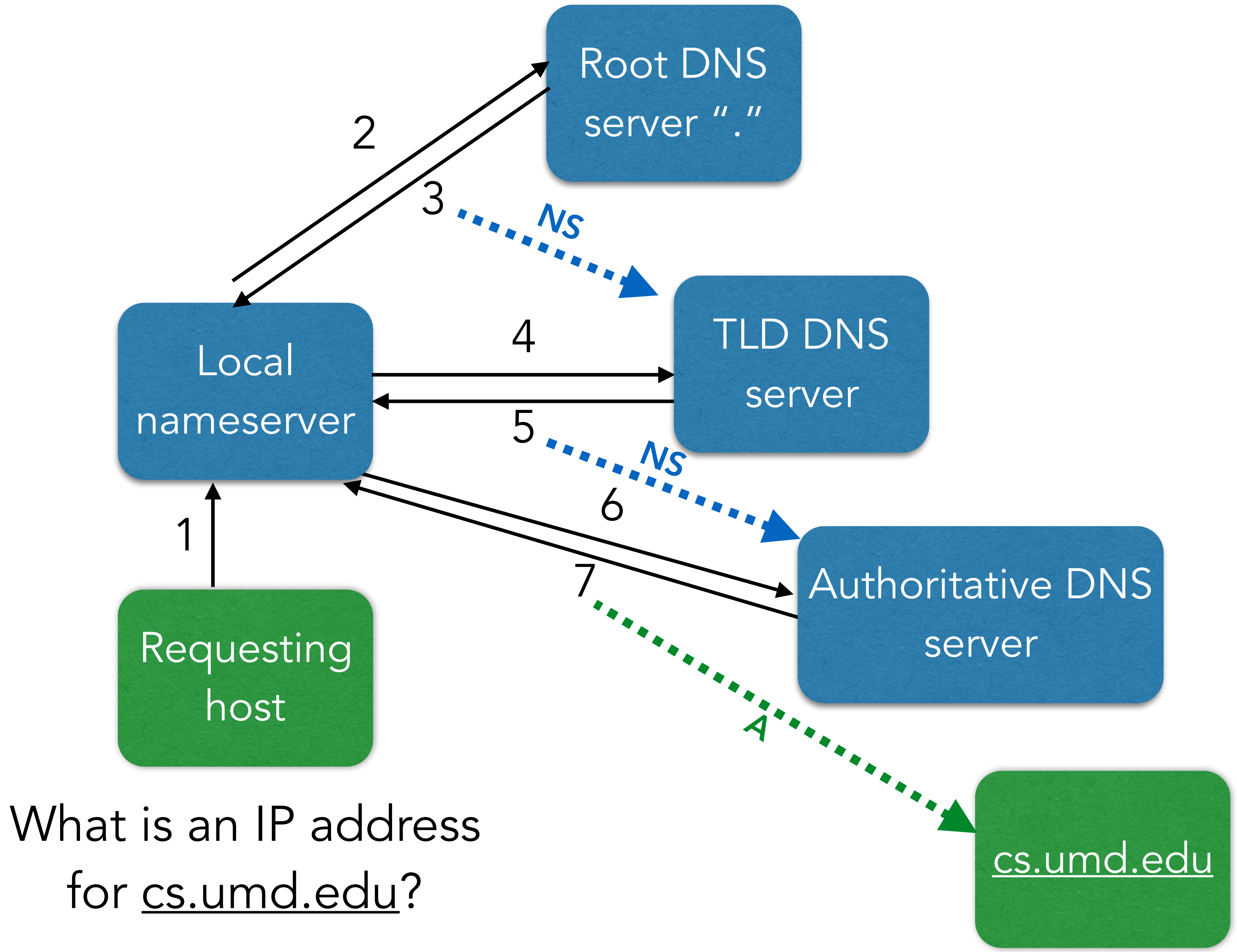

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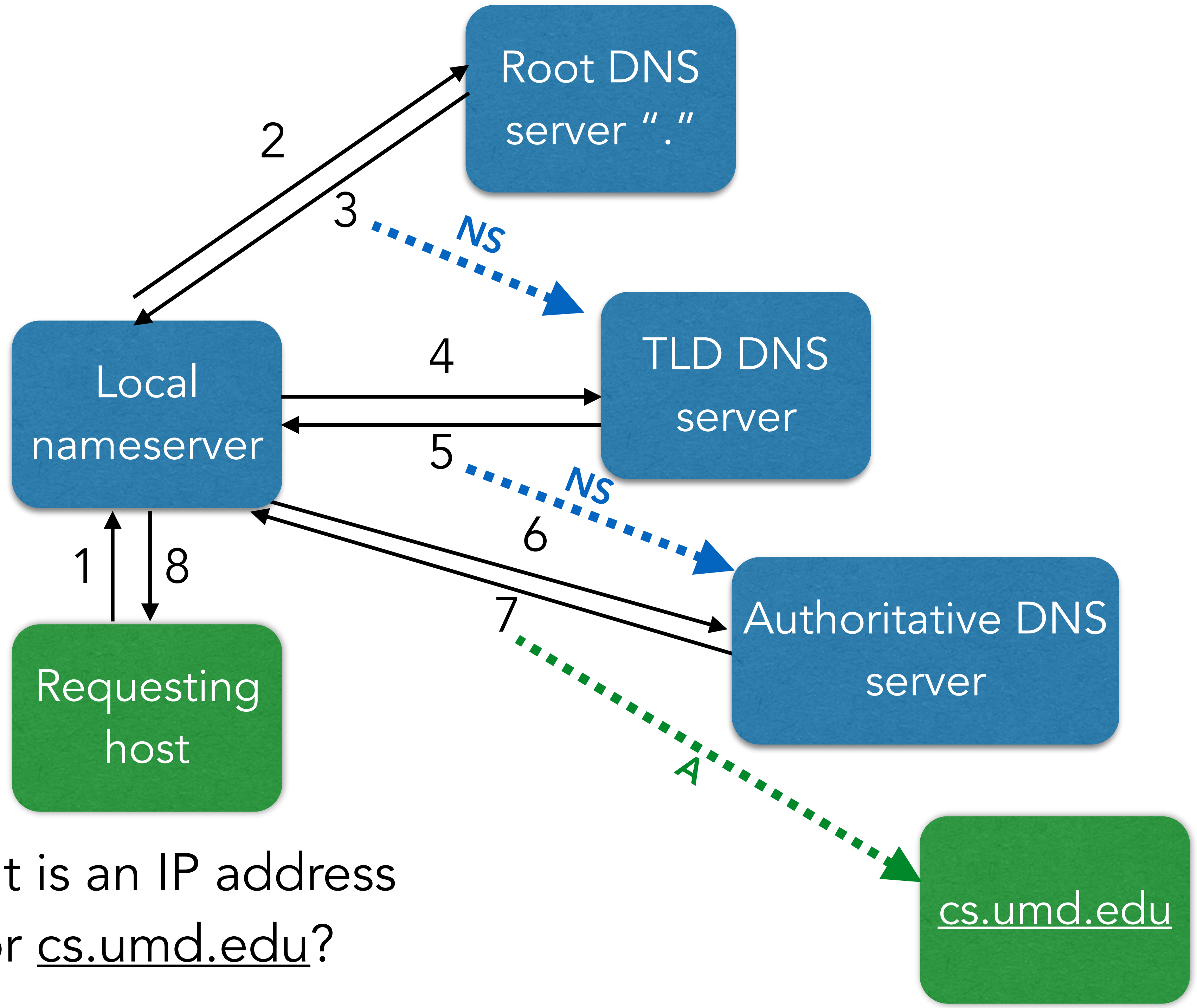

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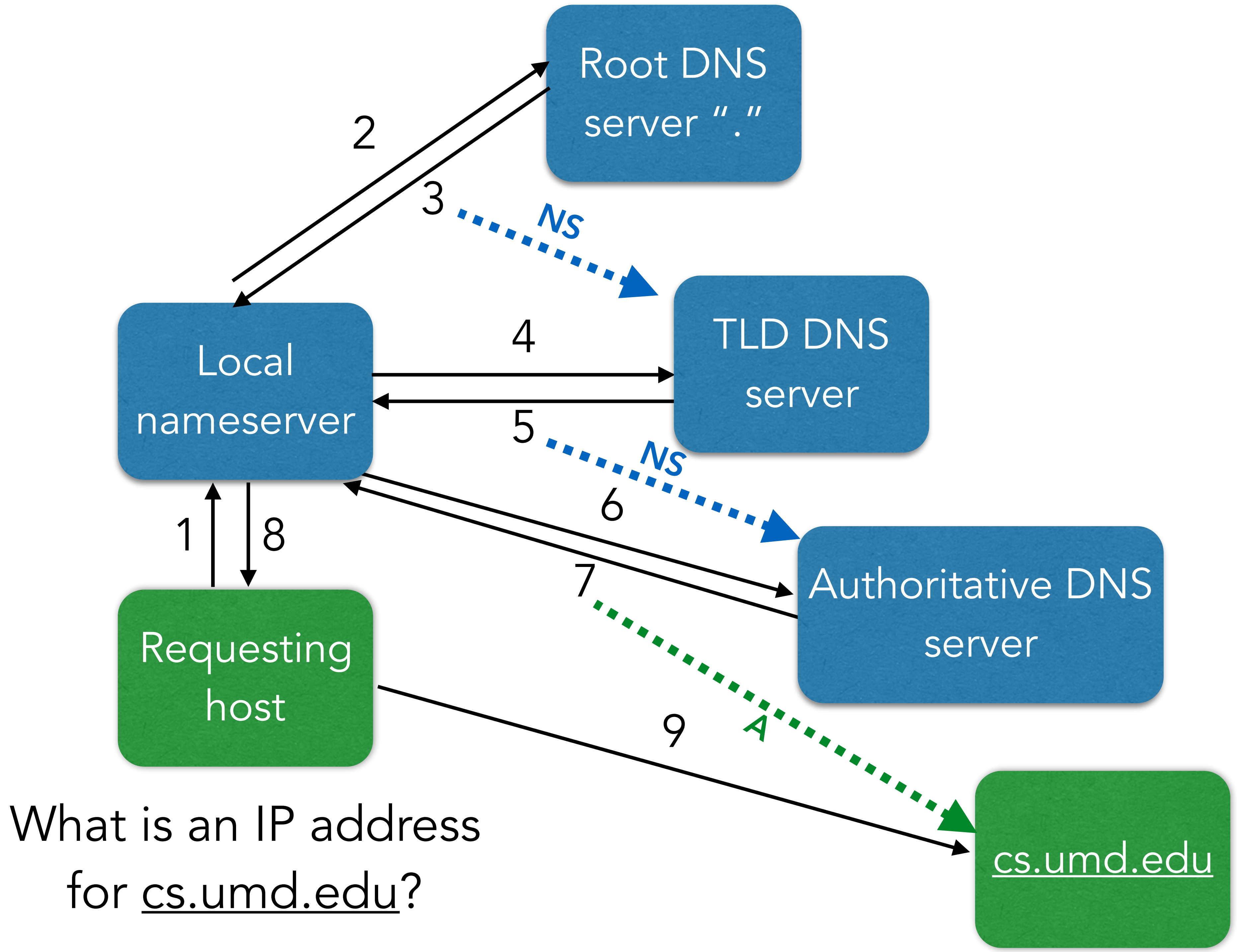

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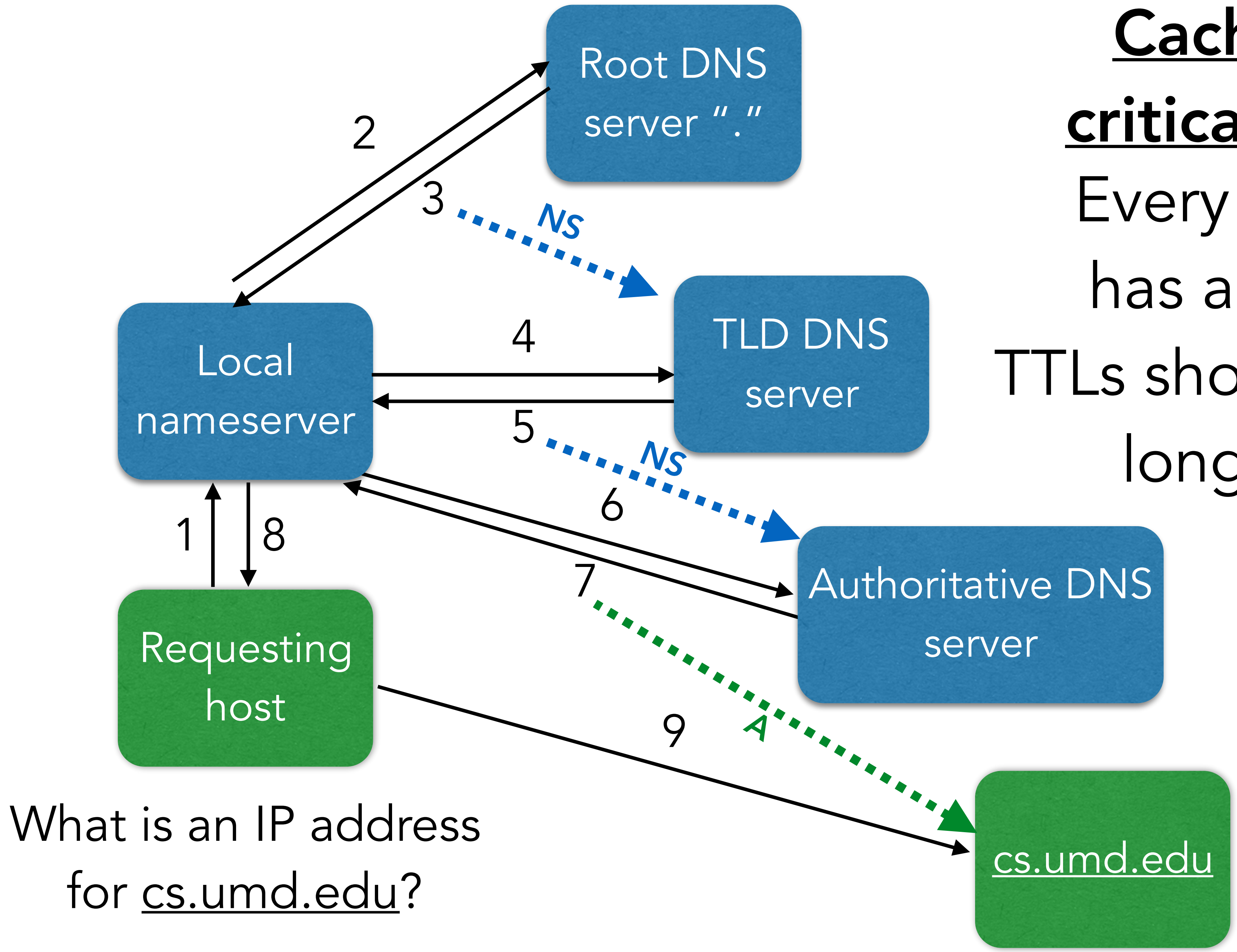


What is an IP address for cs.umd.edu?

Caching responses is critical to DNS's success

Every response (3,5,7,8) has a time-to-live (TTL). TTLs should be reasonably long (days), but some are minutes.

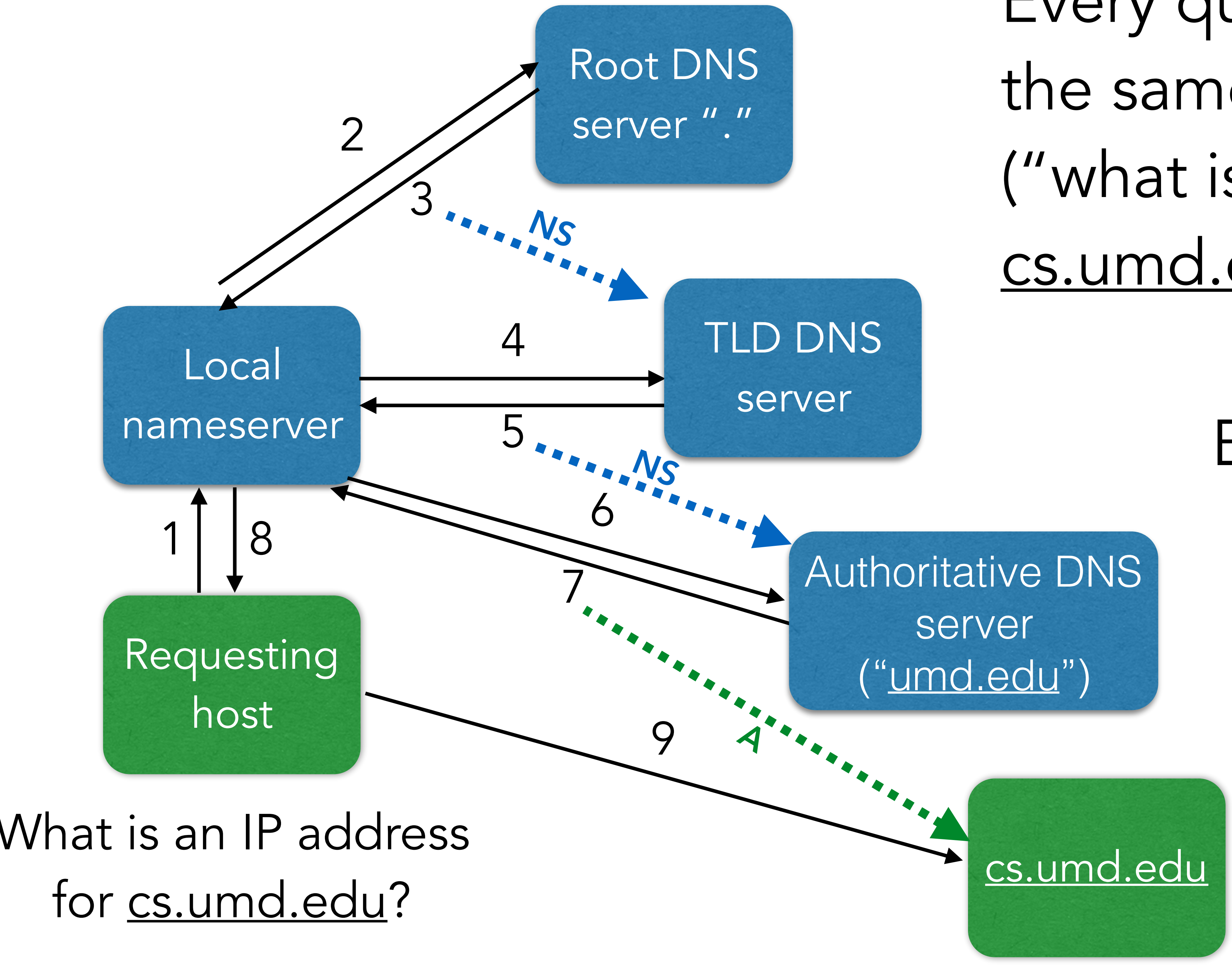
HOW DO THEY KNOW THESE IP ADDRESSES?

- Local DNS server: host learned this via DHCP
- A parent knows its children: part of the registration process
- Root nameserver: *hardcoded* into the local DNS server (and every DNS server)
  - 13 root servers (logically): A-root, B-root, …, M-root
  - These IP addresses change *very* infrequently
  - **UMD runs D-root.**
    - IP address changed beginning of 2013!!
    - For the most part, the change-over went alright, but Lots of weird things happened — ask me some time.

CACHING

- Central to DNS’s success
- Also central to attacks
- “Cache poisoning”: filling a victim’s cache with false information

QUERIES



Every query (2,4,6) has the same request in it ("what is the IP address for cs.umd.edu?")

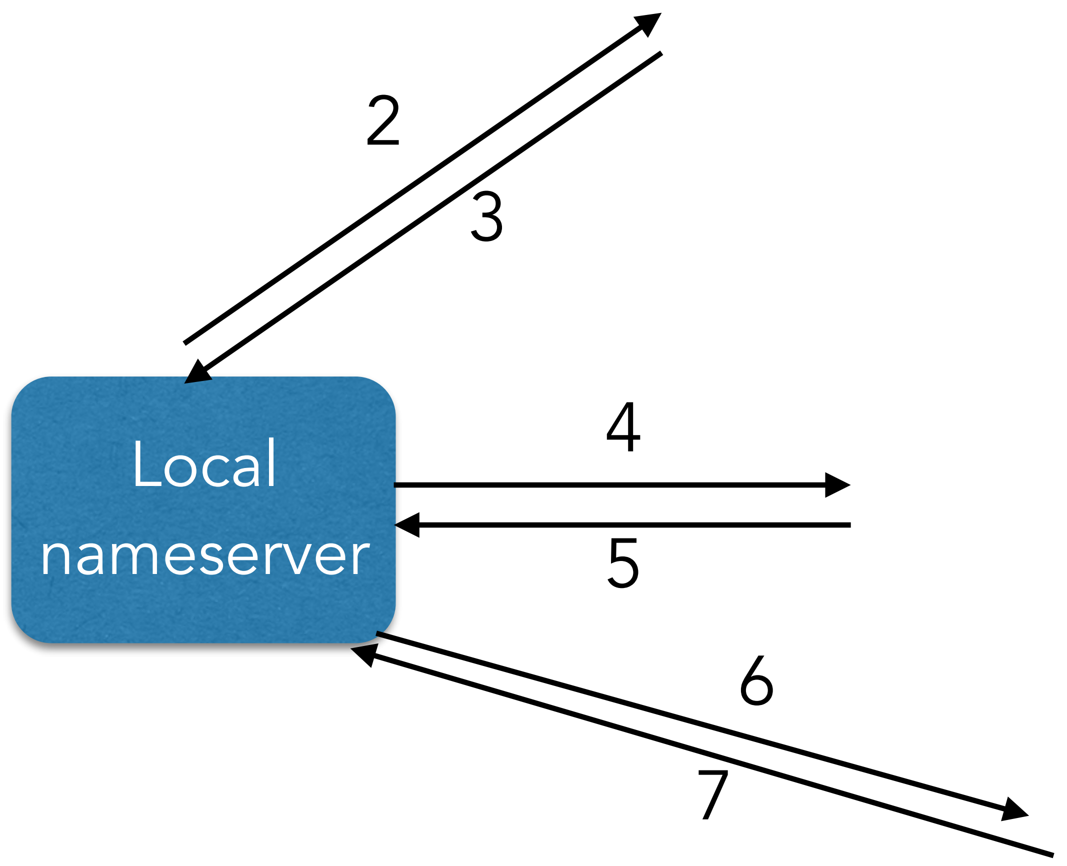
But **different**:

- dst IP (port = 53)
- query ID

WHAT'S IN A RESPONSE?

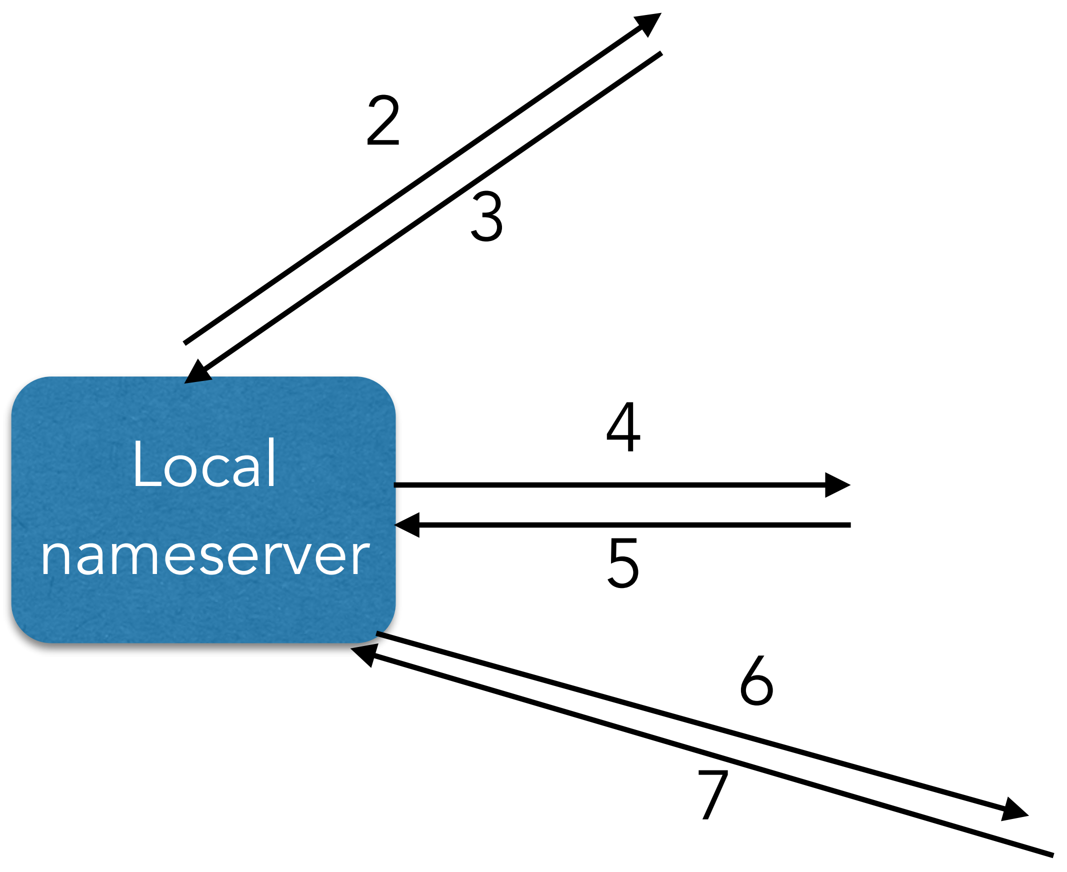
- Many things, but for the attacks we're concerned with…
- A record: gives "the authoritative response for the IP address of this hostname"
- NS record: describes "this is the name of the nameserver who should know more about how to answer this query than I do"
    - Often also contains "glue" records (IP addresses of those name servers to avoid chicken and egg problems)
    - Resolver will generally cache all of this information

QUERY IDS



- The local resolver has a lot of incoming/outgoing queries at any point in time.
- To determine which response maps to which queries, it uses a *query ID*
- Query ID: 16-bit field in the DNS header
  - Requester sets it to whatever it wants
  - Responder must provide the same value in its response

QUERY IDS



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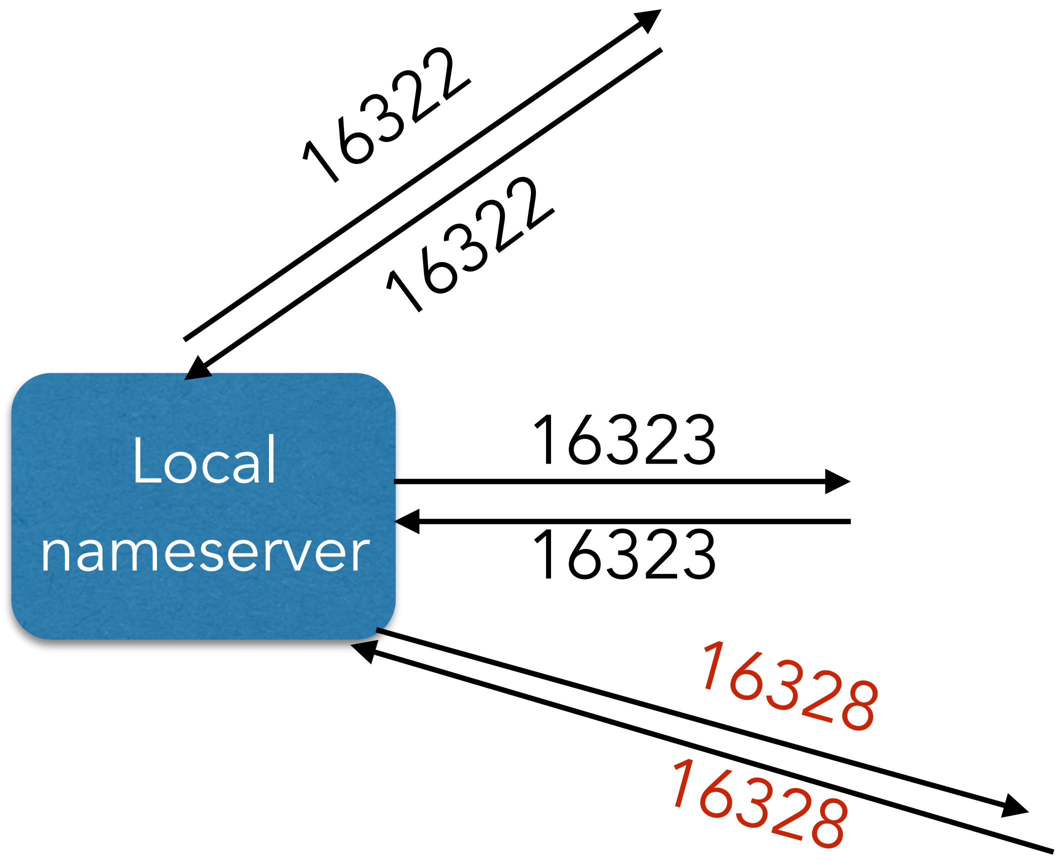
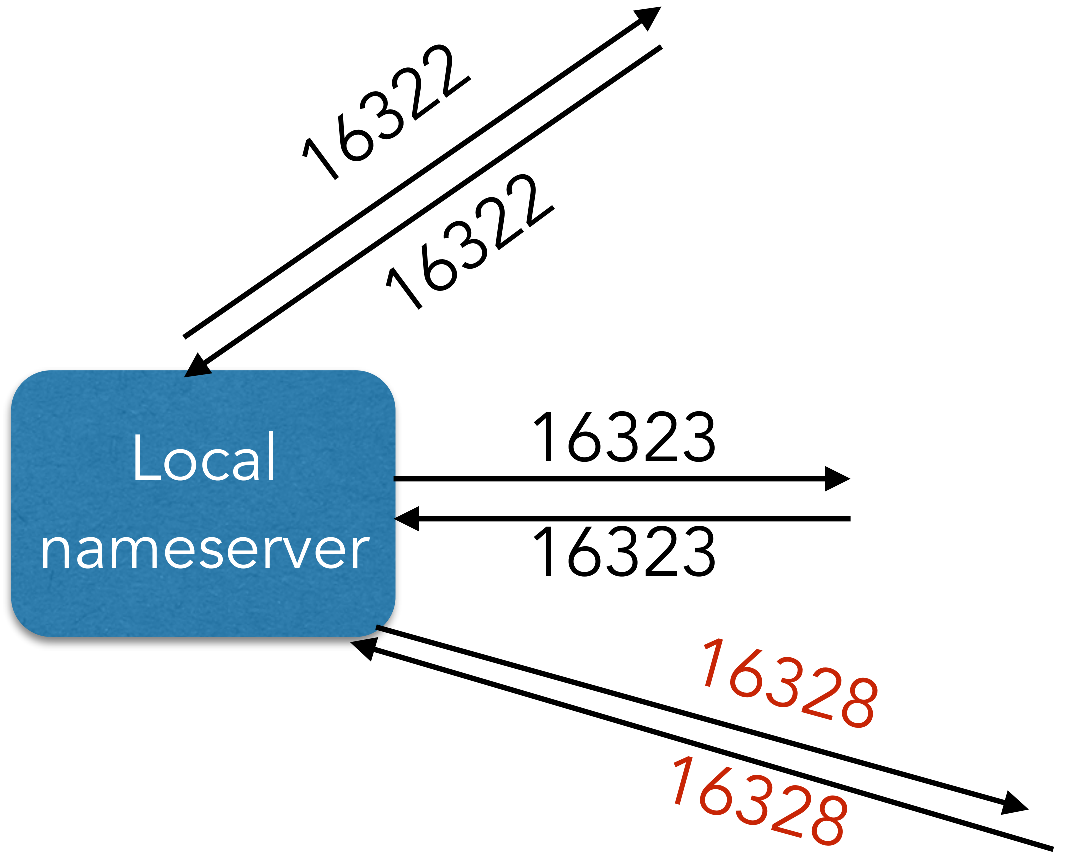
How would you implement query IDs at a resolver?

QUERY IDS USED TO INCREMENT



- Global query ID value
- Map outstanding query ID to local state of who to respond to (the client)
- Basically:
  new Packet(queryID++)

QUERY IDS USED TO INCREMENT



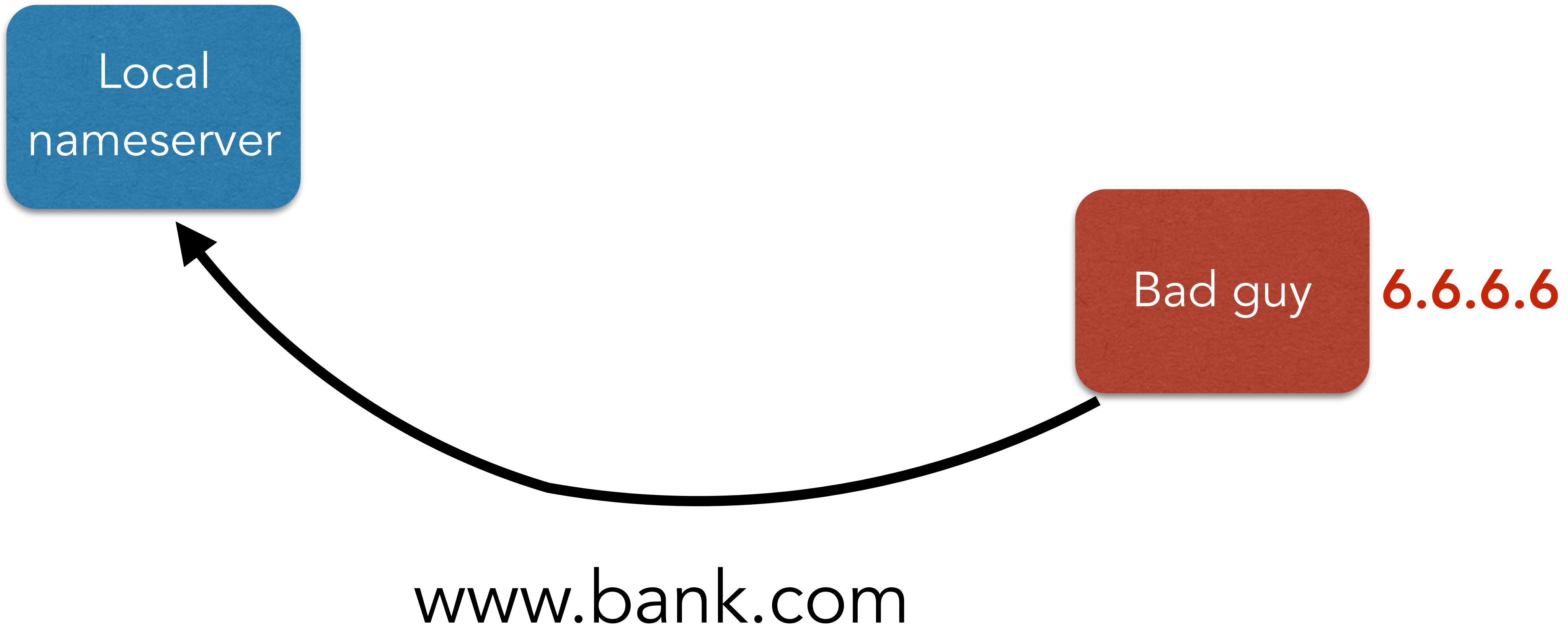
- Global query ID value
- Map outstanding query ID to local state of who to respond to (the client)
- Basically:
  new Packet(queryID++)

How would you attack this?

CACHE POISONING

Local nameserver
Bad guy
6.6.6.6

CACHE POISONING



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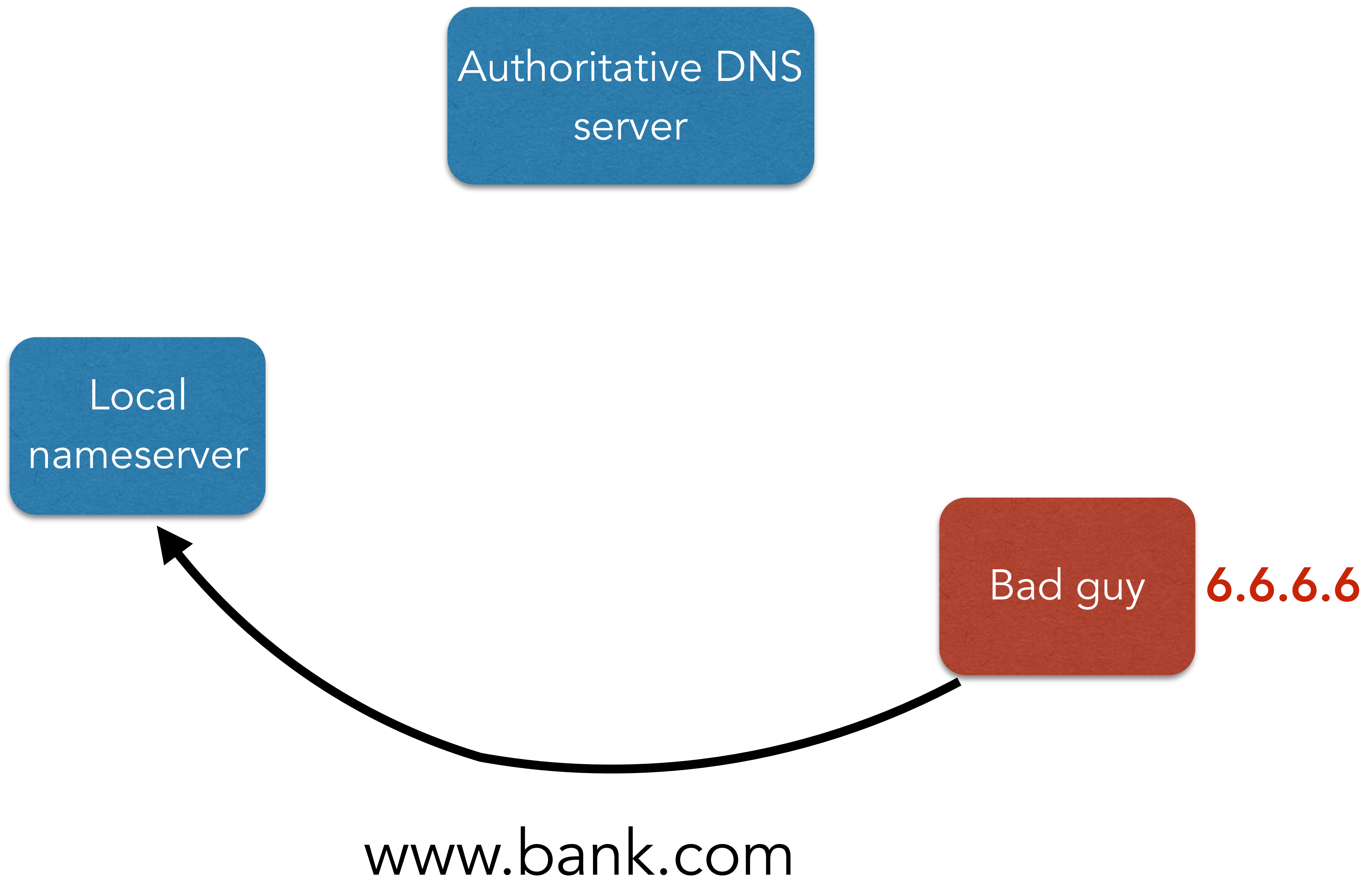

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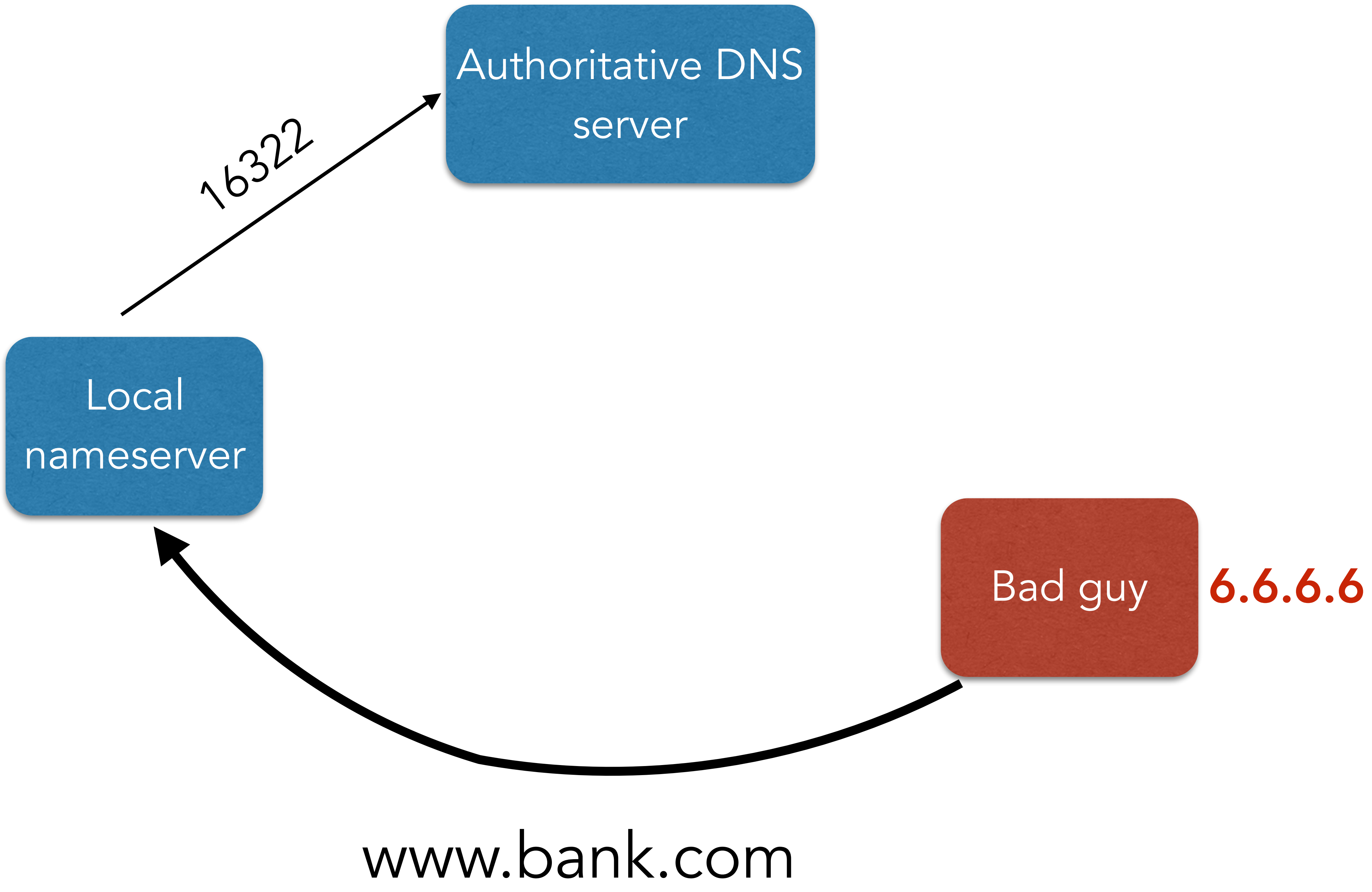

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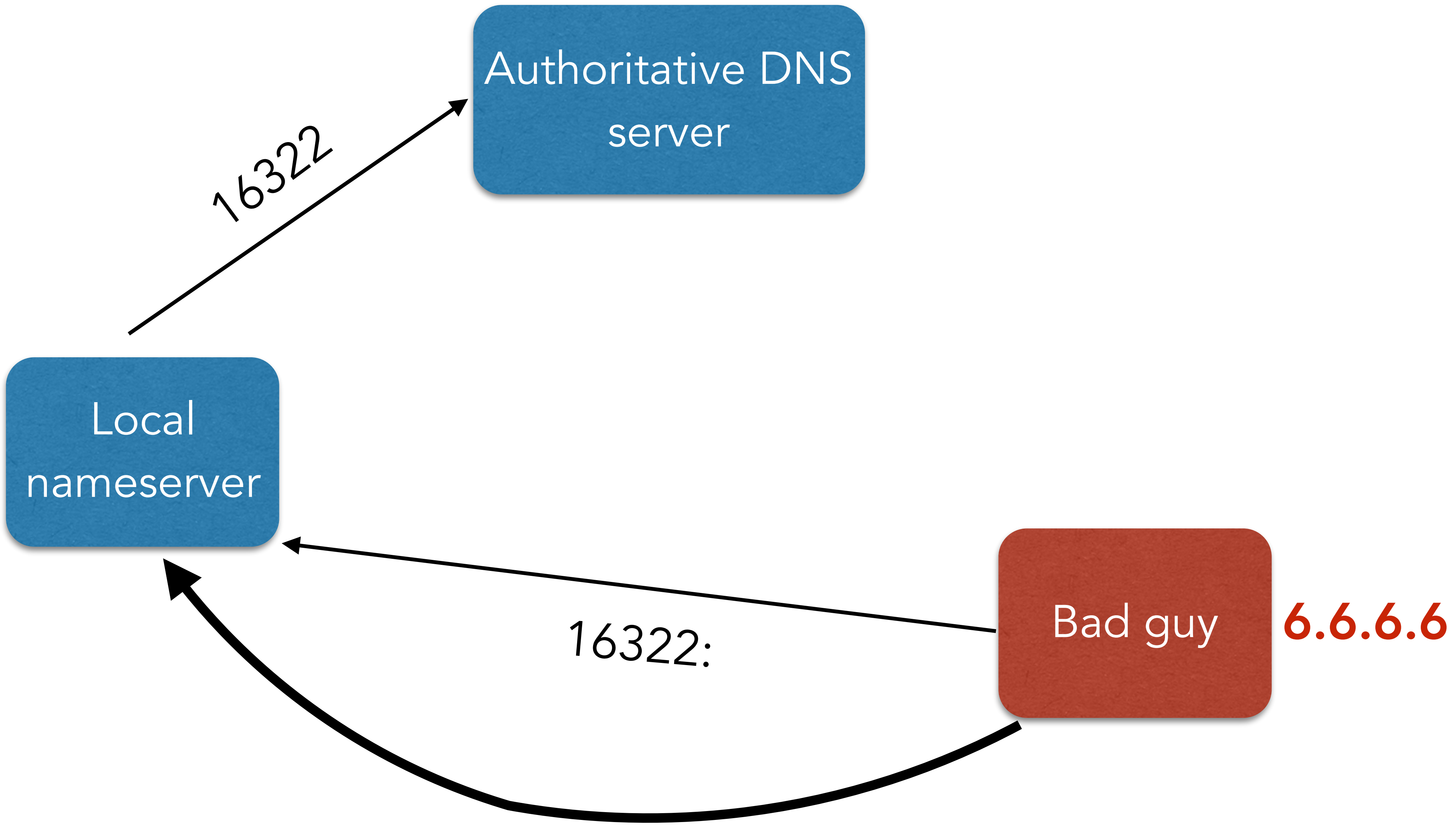
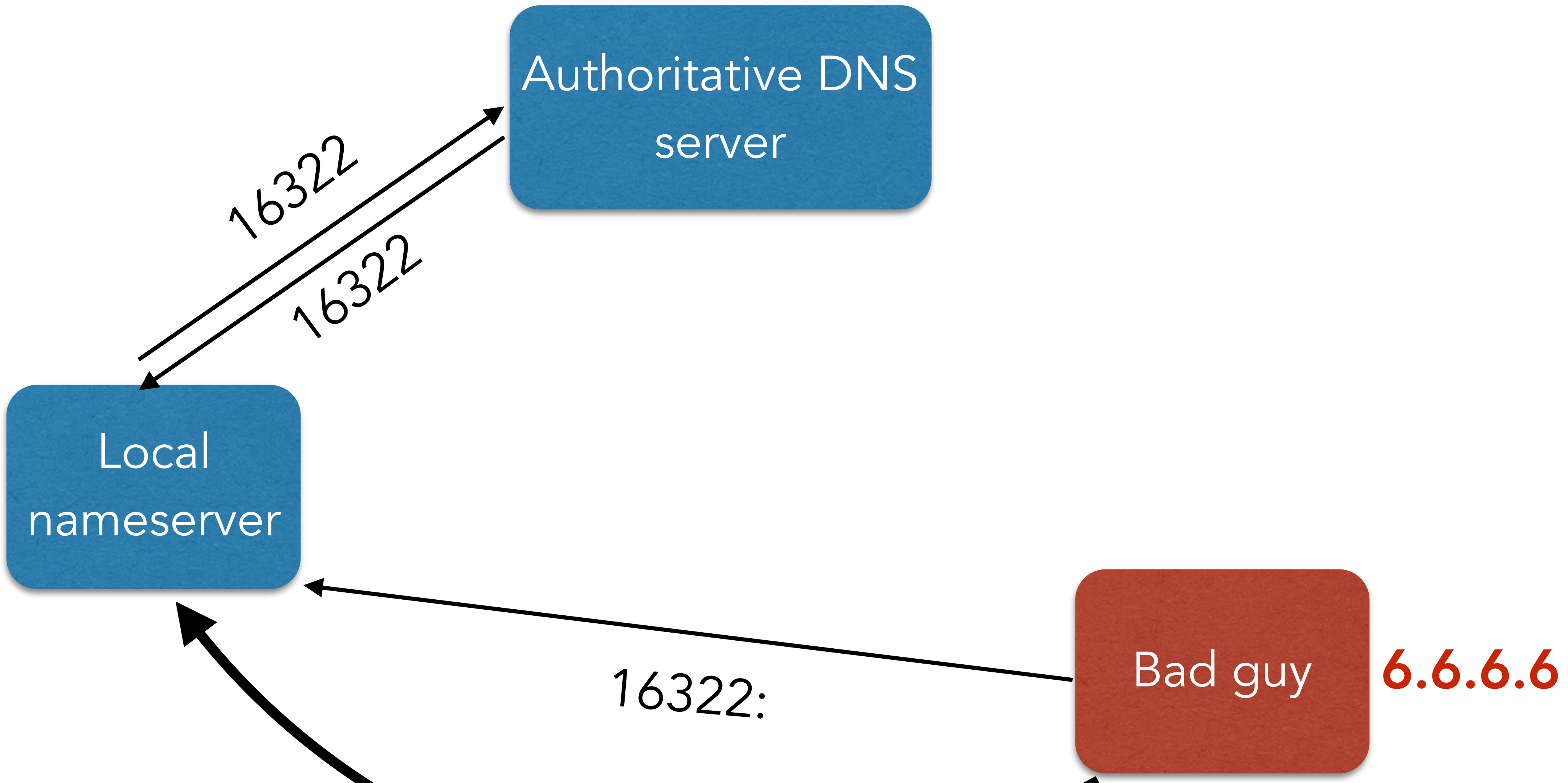


www.bank.com

CACHE POISONING



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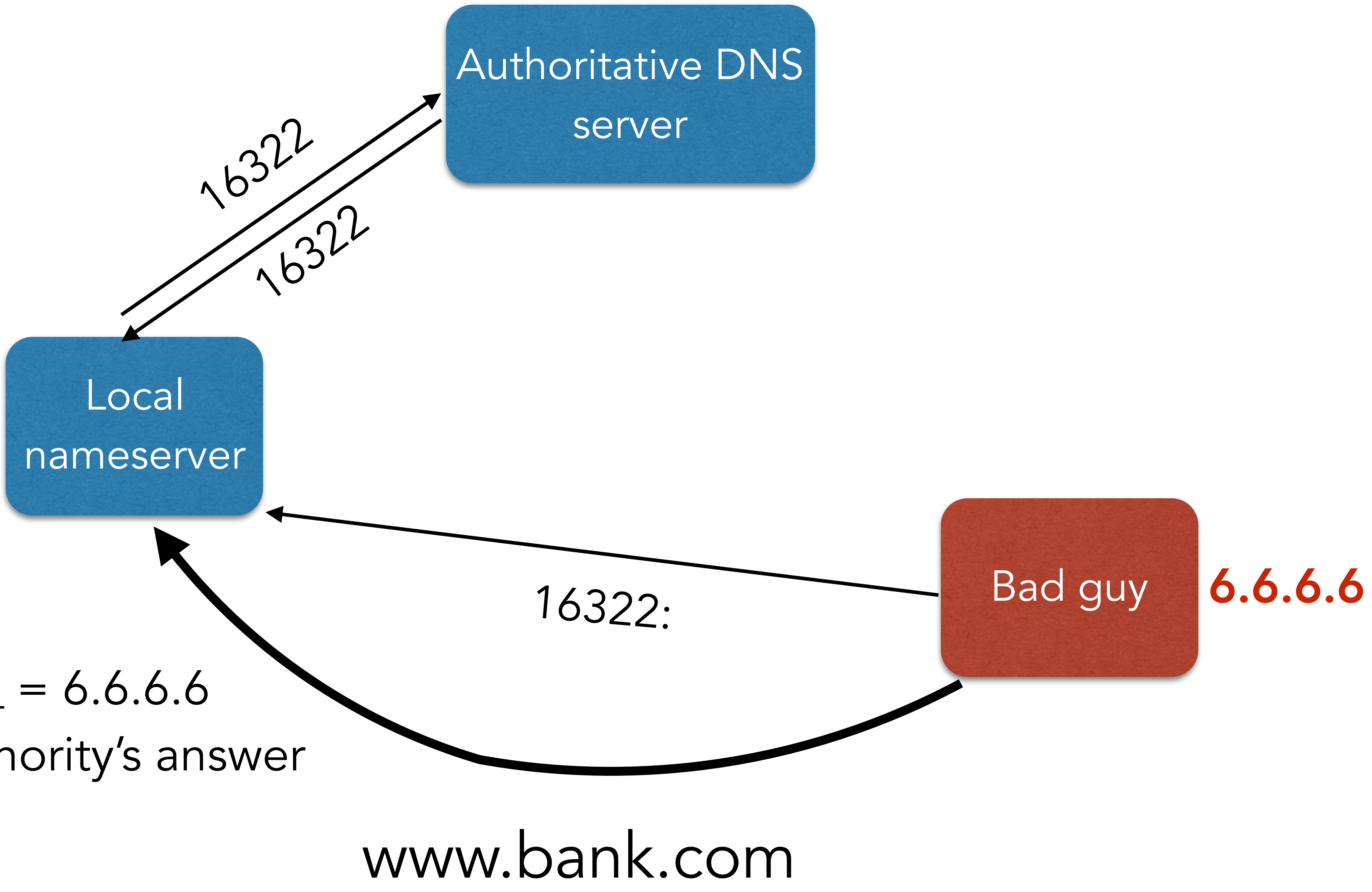
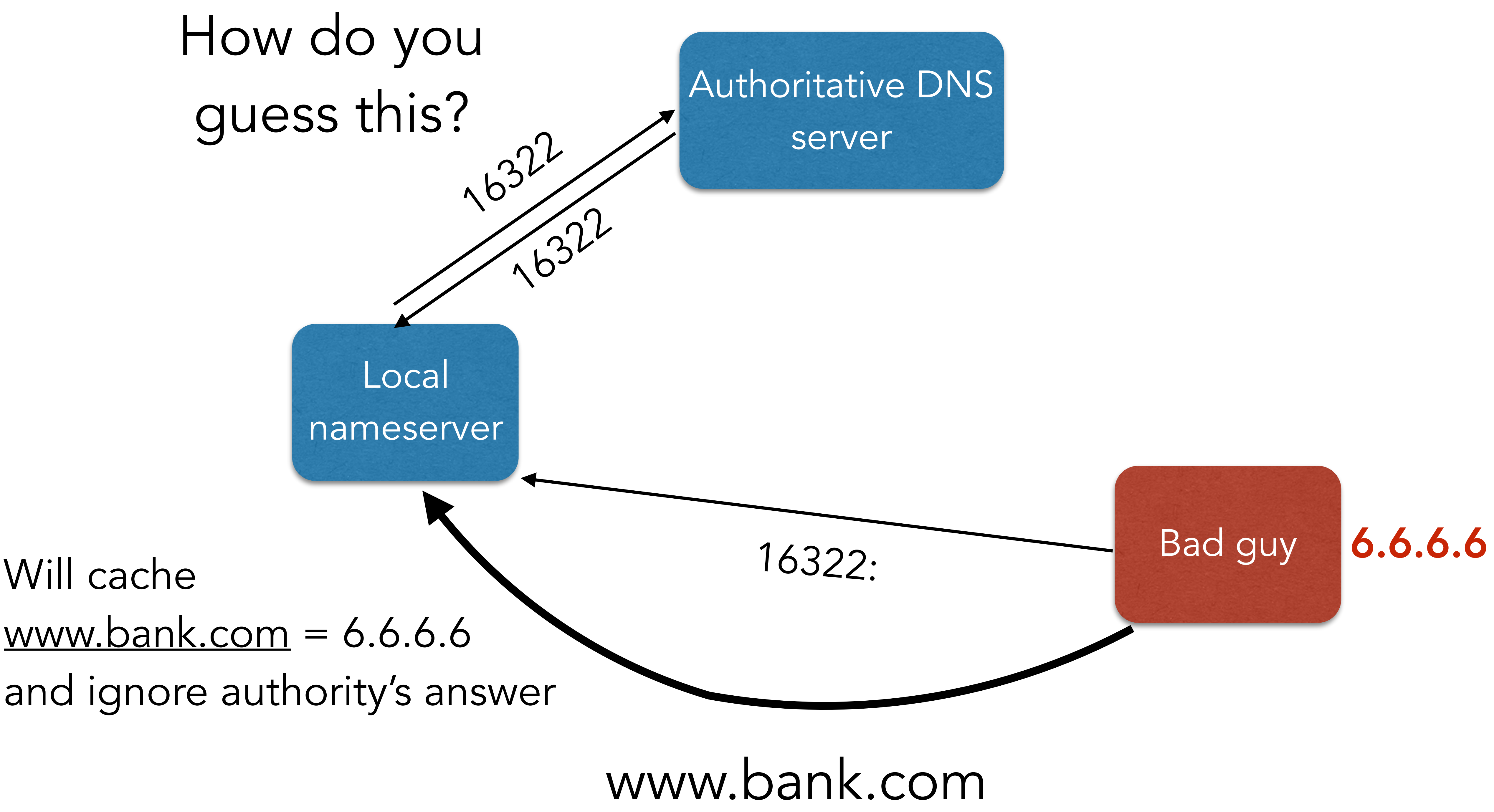


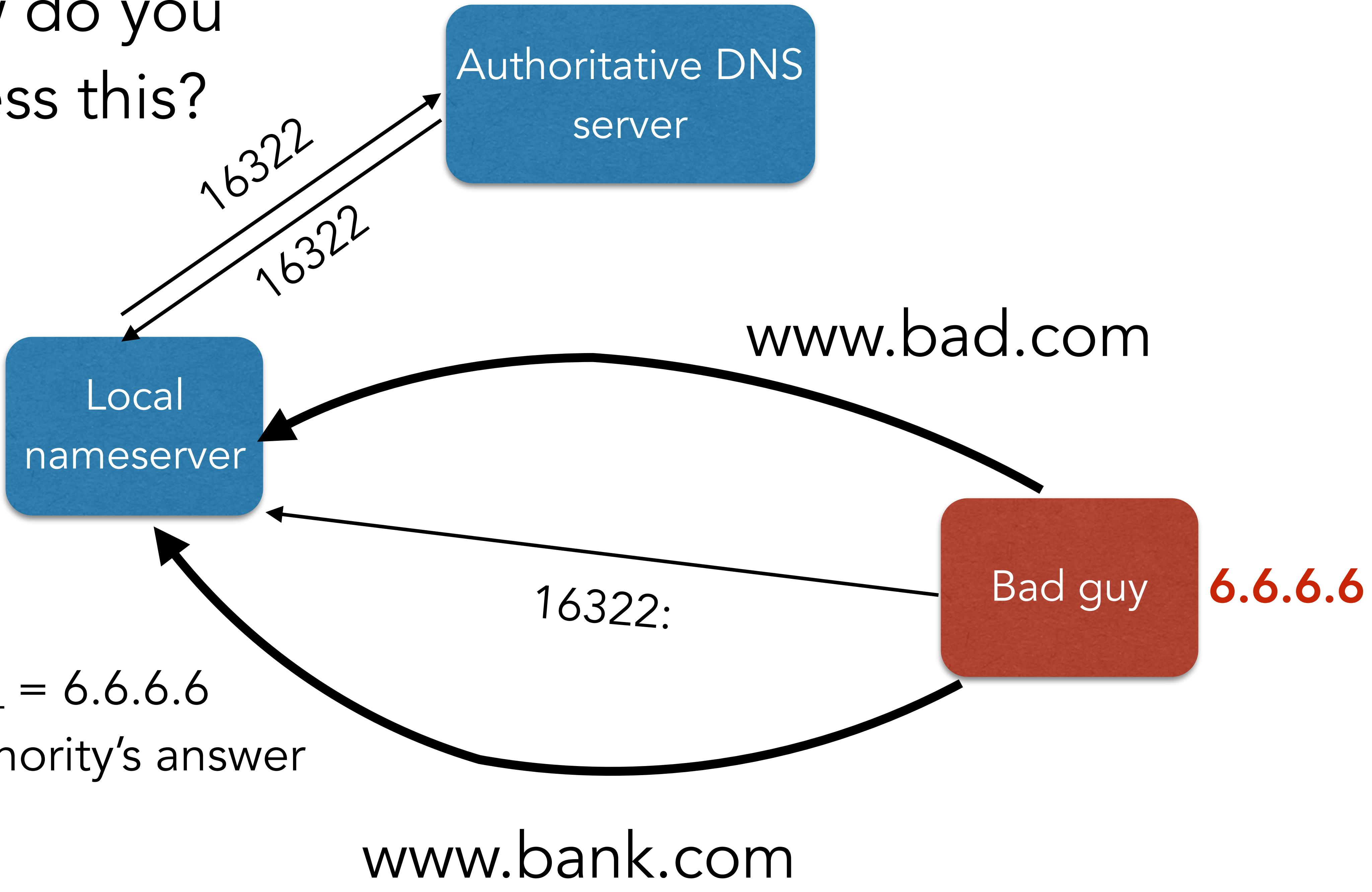
Will cache
www.bank.com = 6.6.6.6
and ignore authority's answer

CACHE POISONING



CACHE POISONING

How do you guess this?



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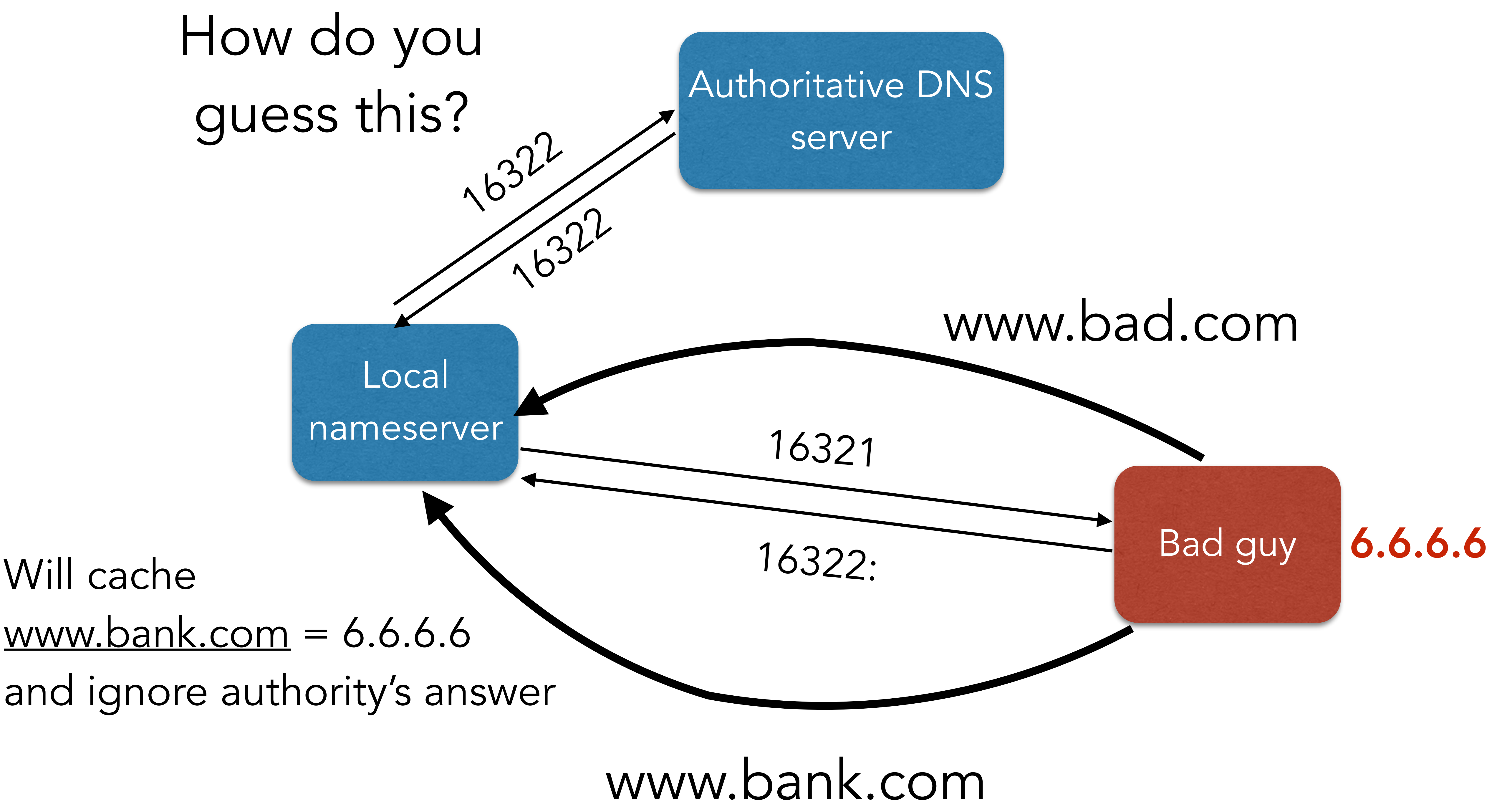

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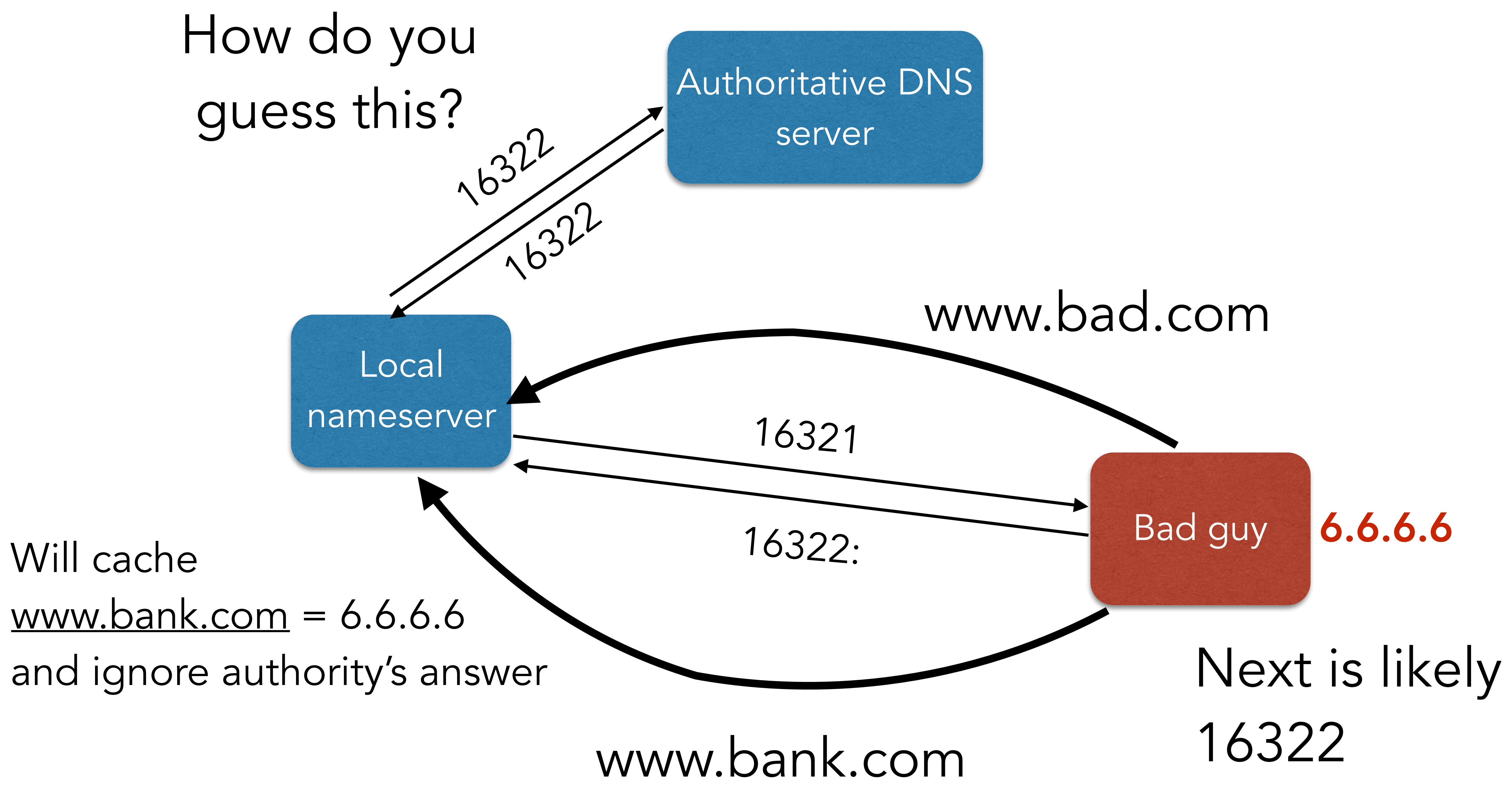
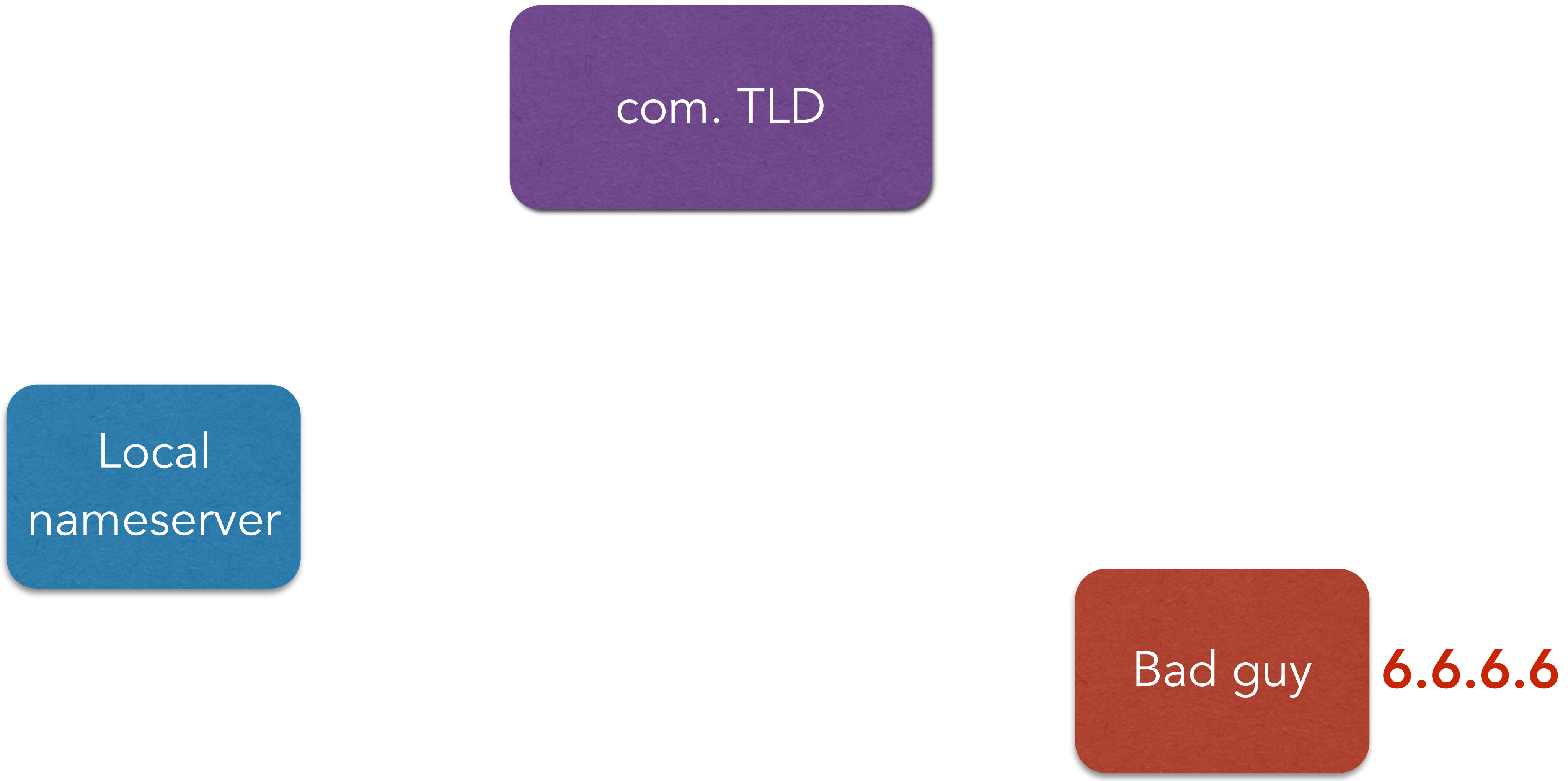


DETAILS OF GETTING THE ATTACK TO WORK

- Must guess query ID: ask for it, and go from there
  - Partial fix: randomize query IDs
  - Problem: small space
  - Attack: issue a Lot of query IDs
- Must guess source port number
  - Typically constant for a given server (often always 53)
- The answer must not already be in the cache
  - It will avoid issuing a query in the first place

CACHE POISONING

Can we do more harm than a single record?



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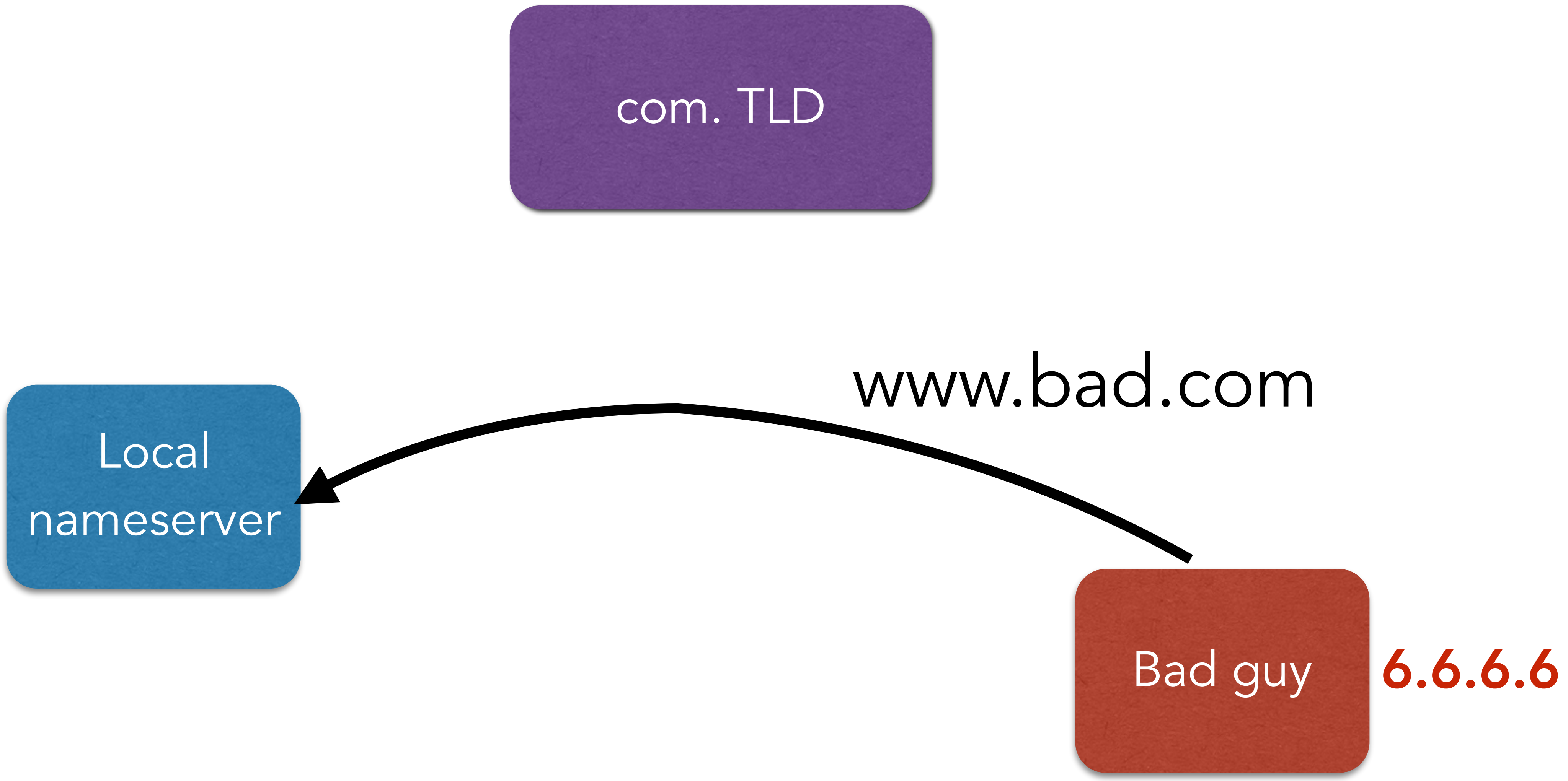

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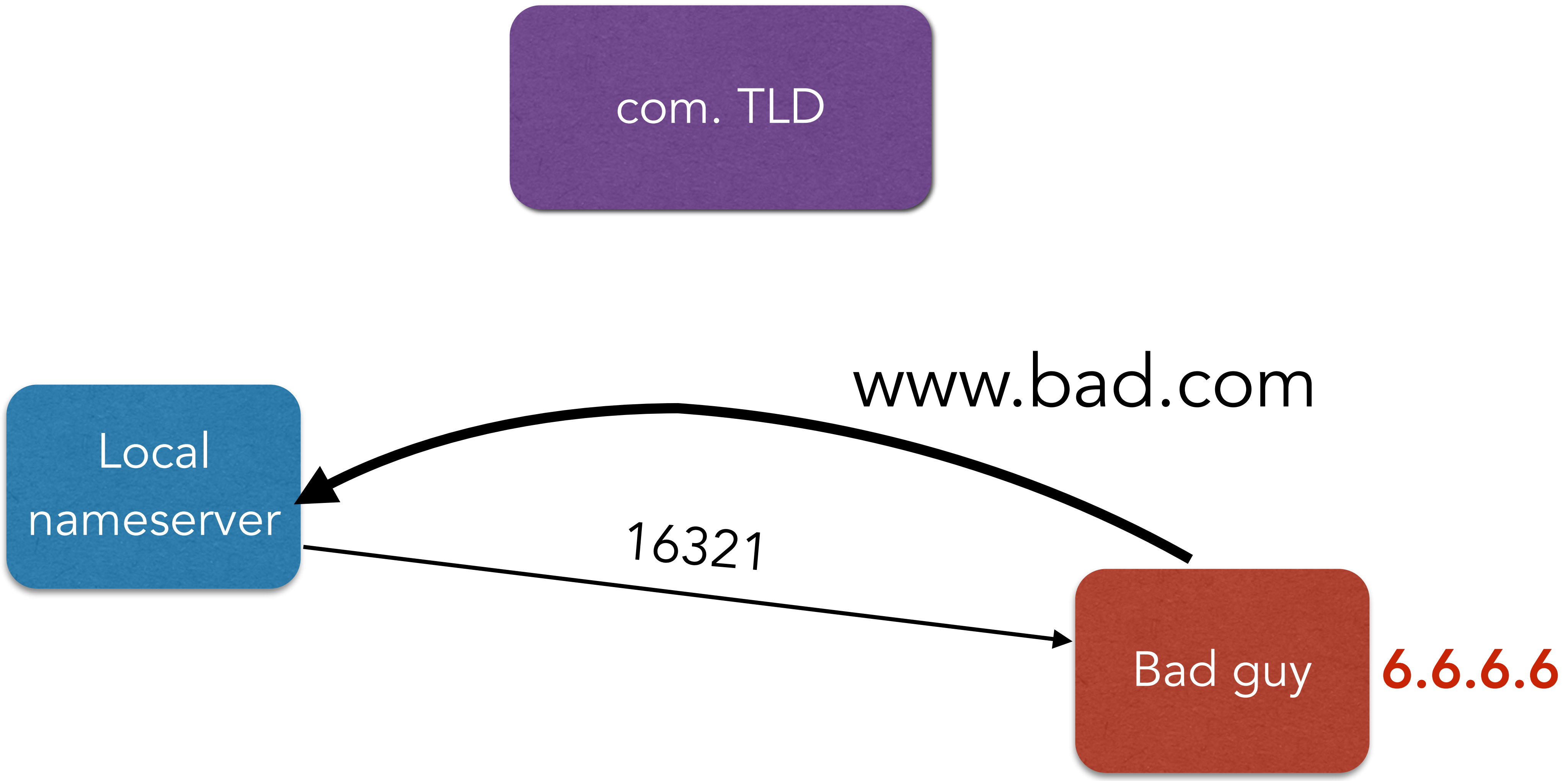

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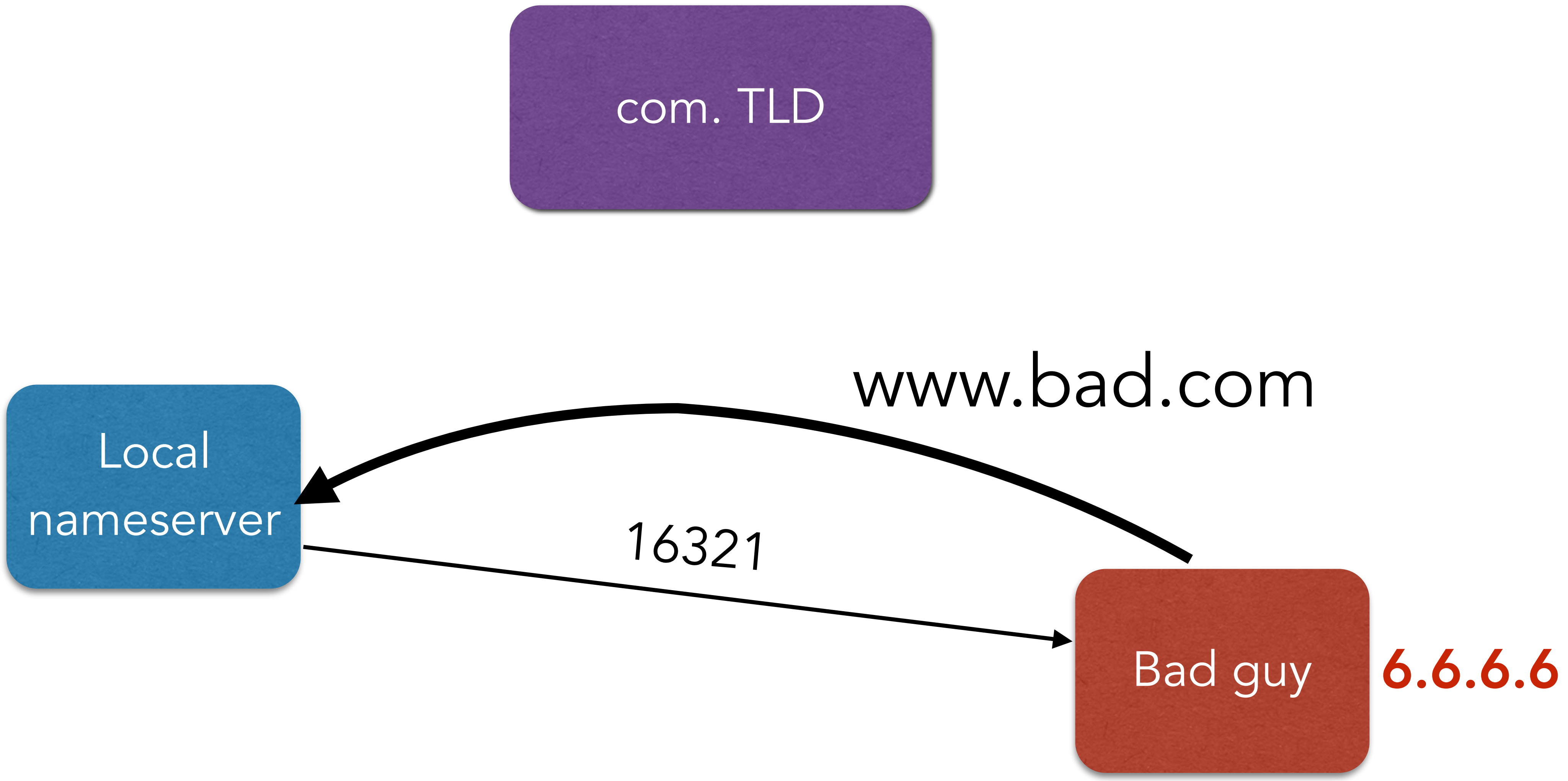

Next is likely 16322

CACHE POISONING

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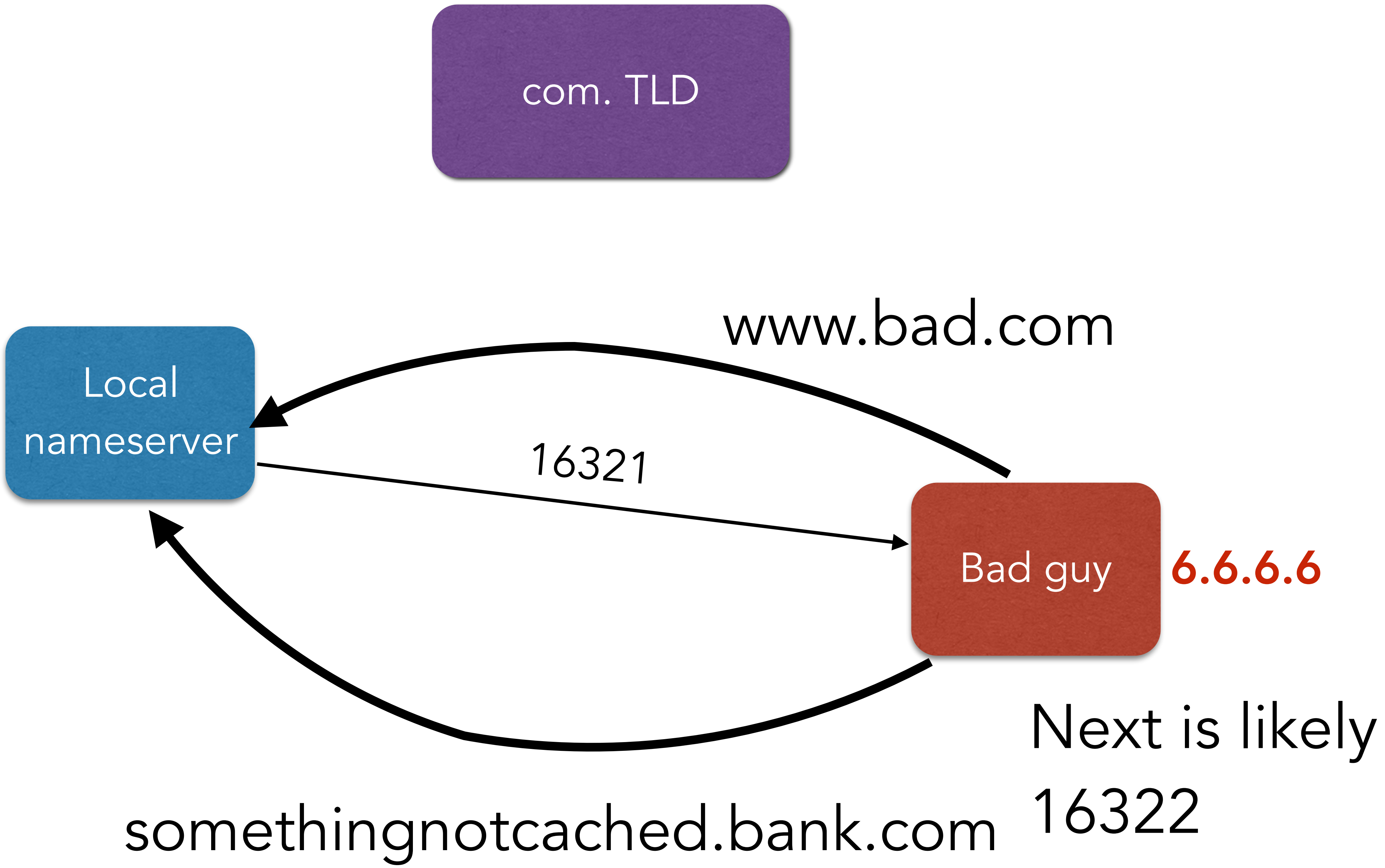

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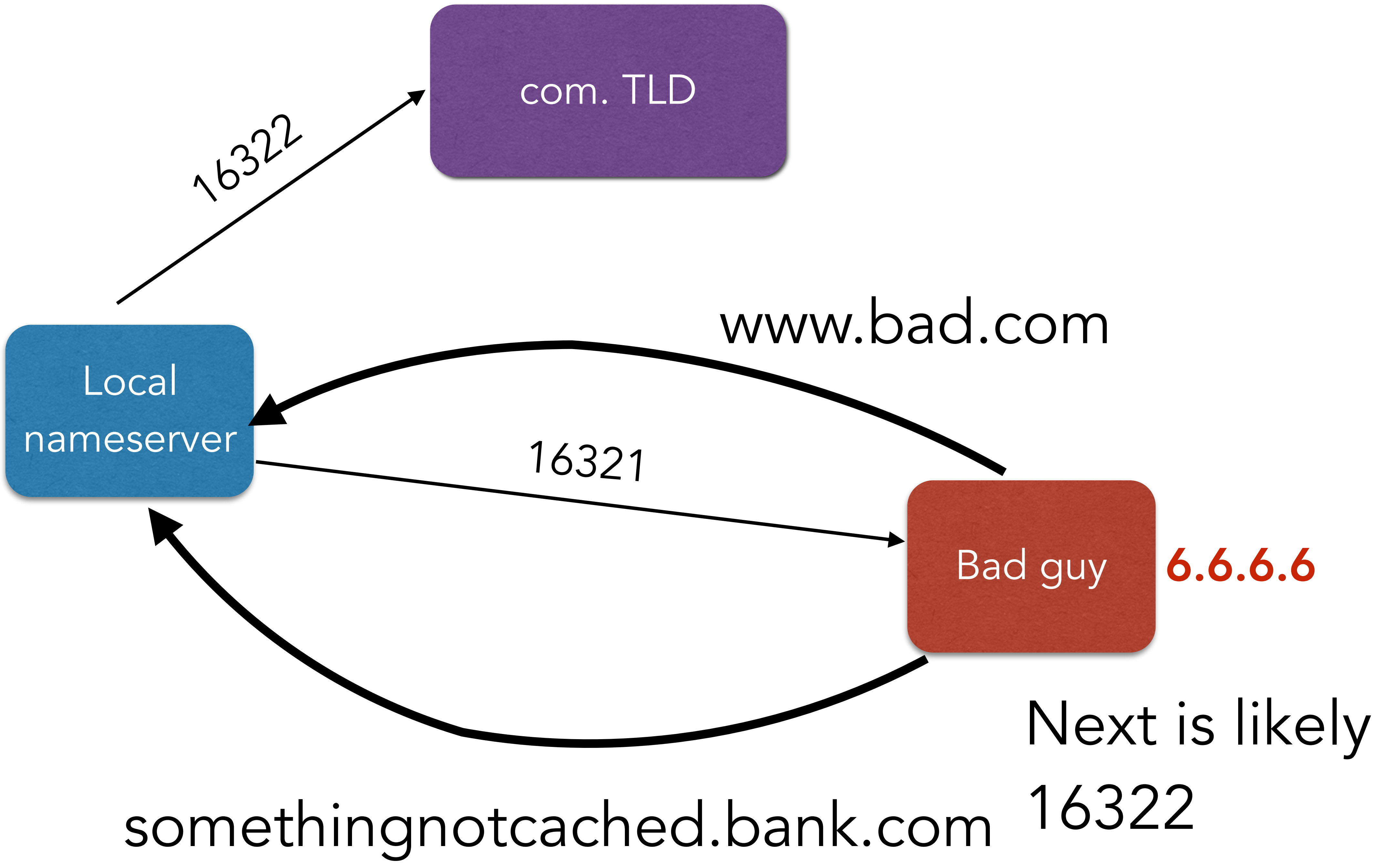

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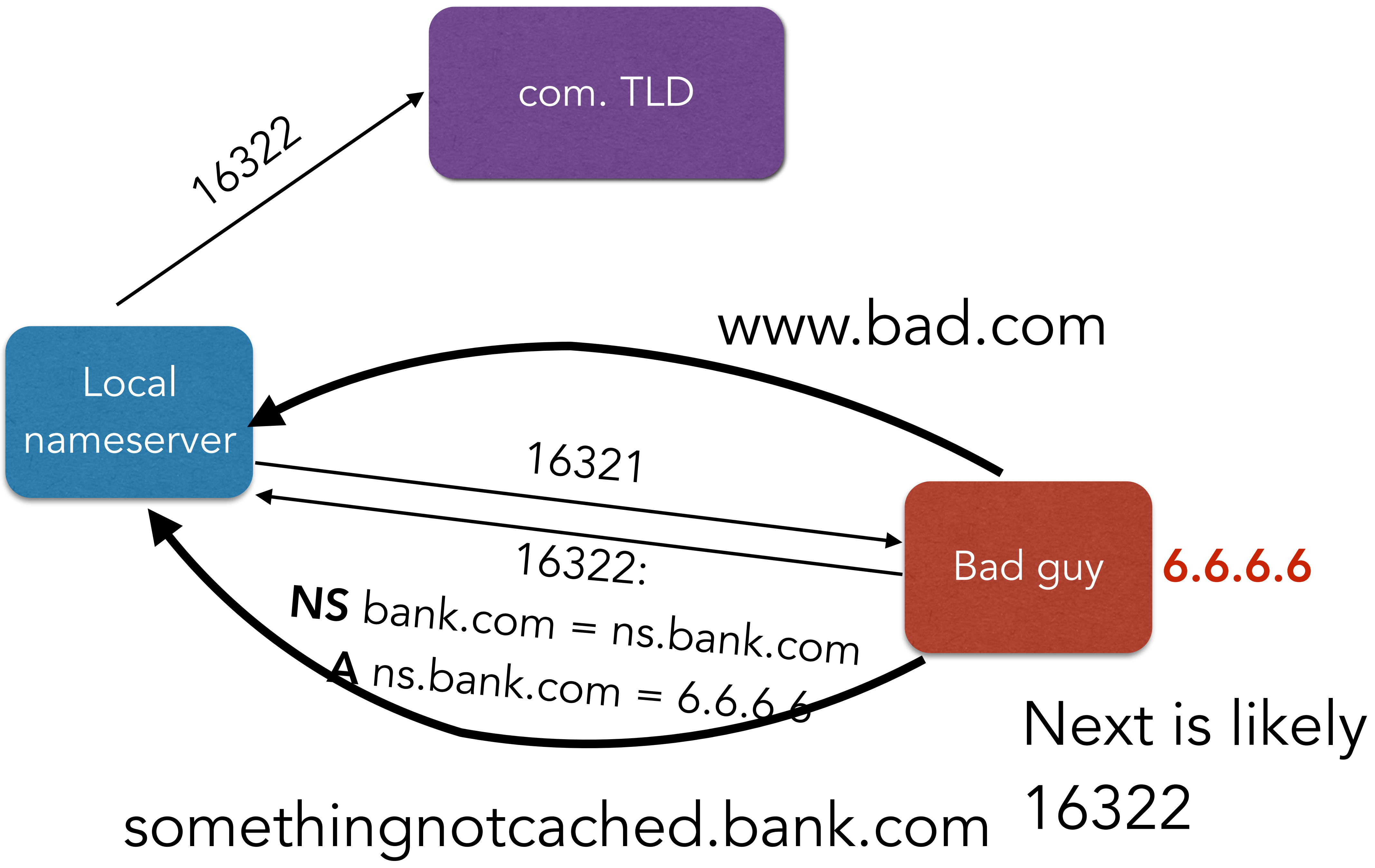

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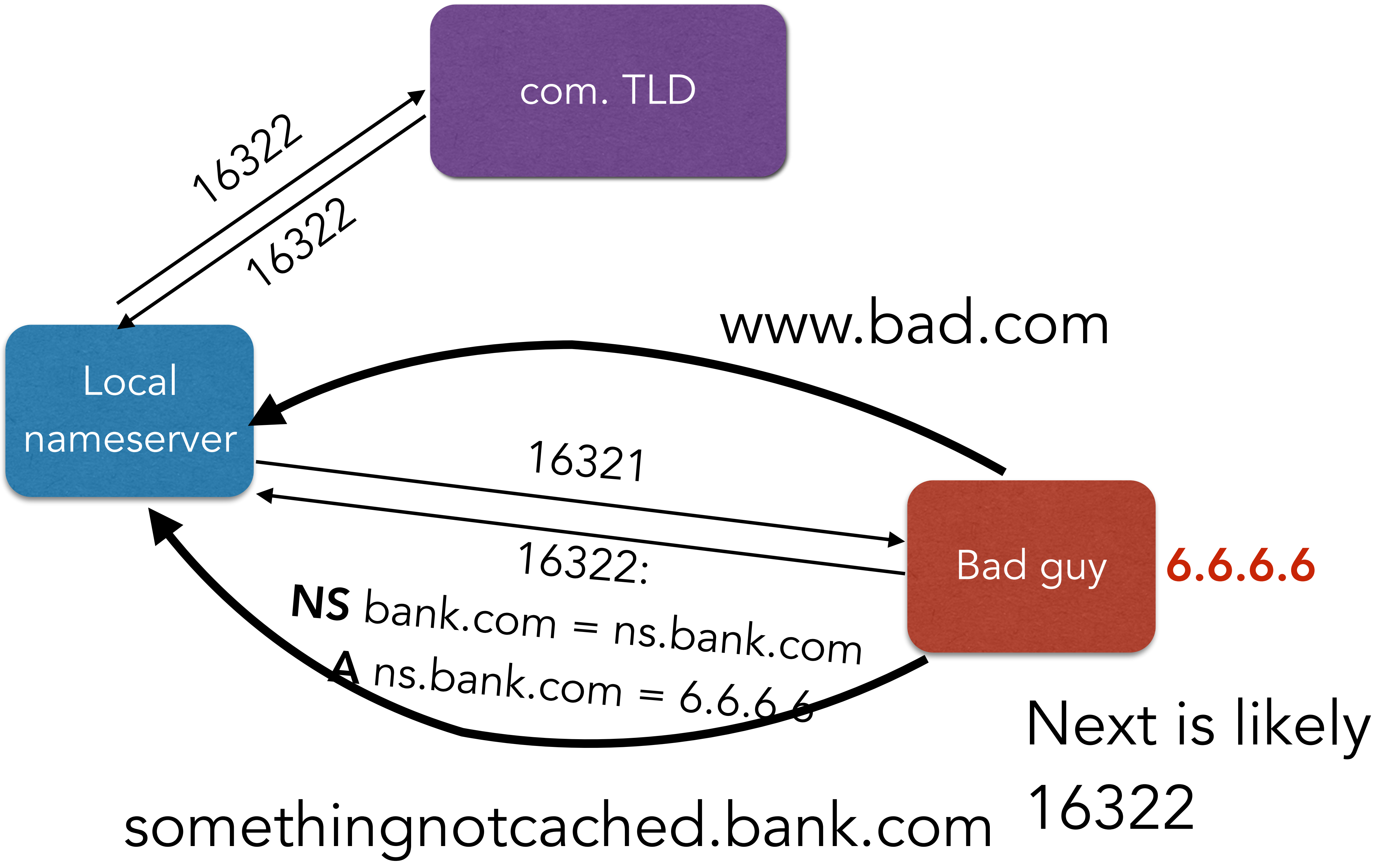

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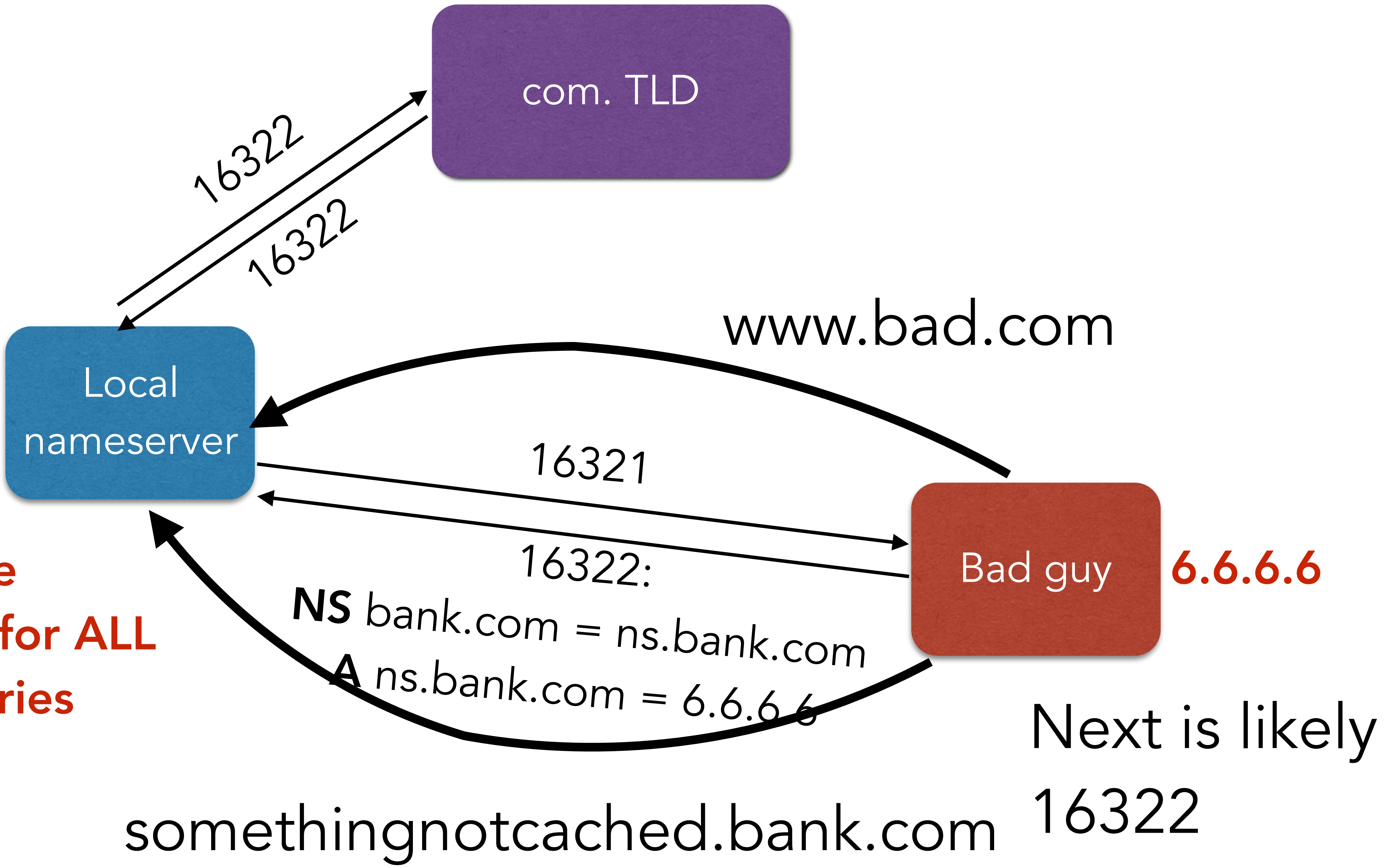
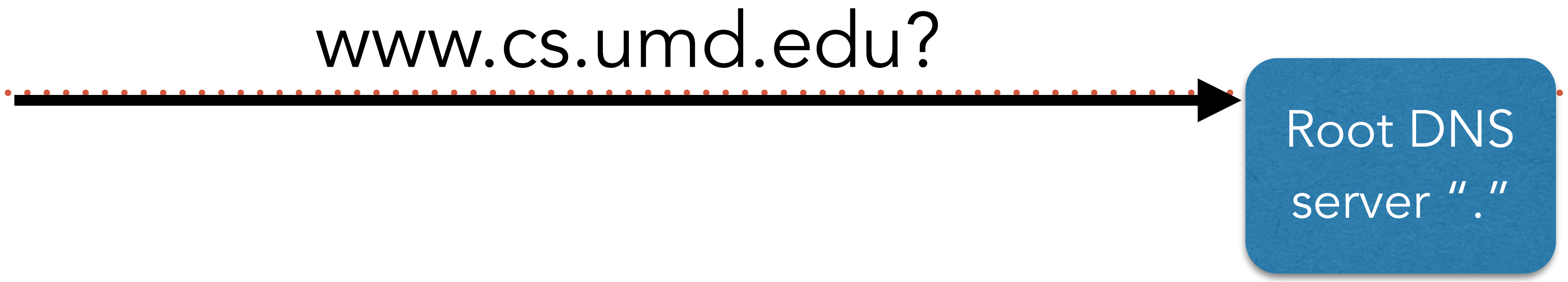


Will cache "the person to ask for ALL bank.com queries is 6.6.6.6"

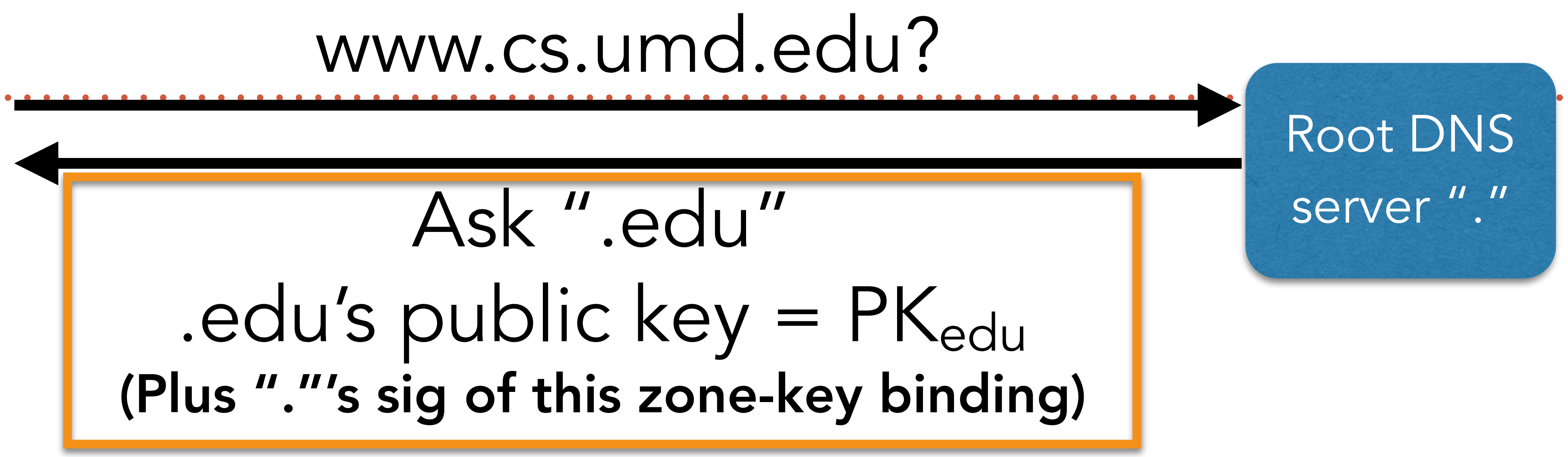
SOLUTIONS?

- Randomizing query ID?
  - Not sufficient alone: only 16 bits of entropy
- Randomize source port, as well
  - There's no reason for it stay constant
  - Gets us another 16 bits of entropy
- DNSSEC?

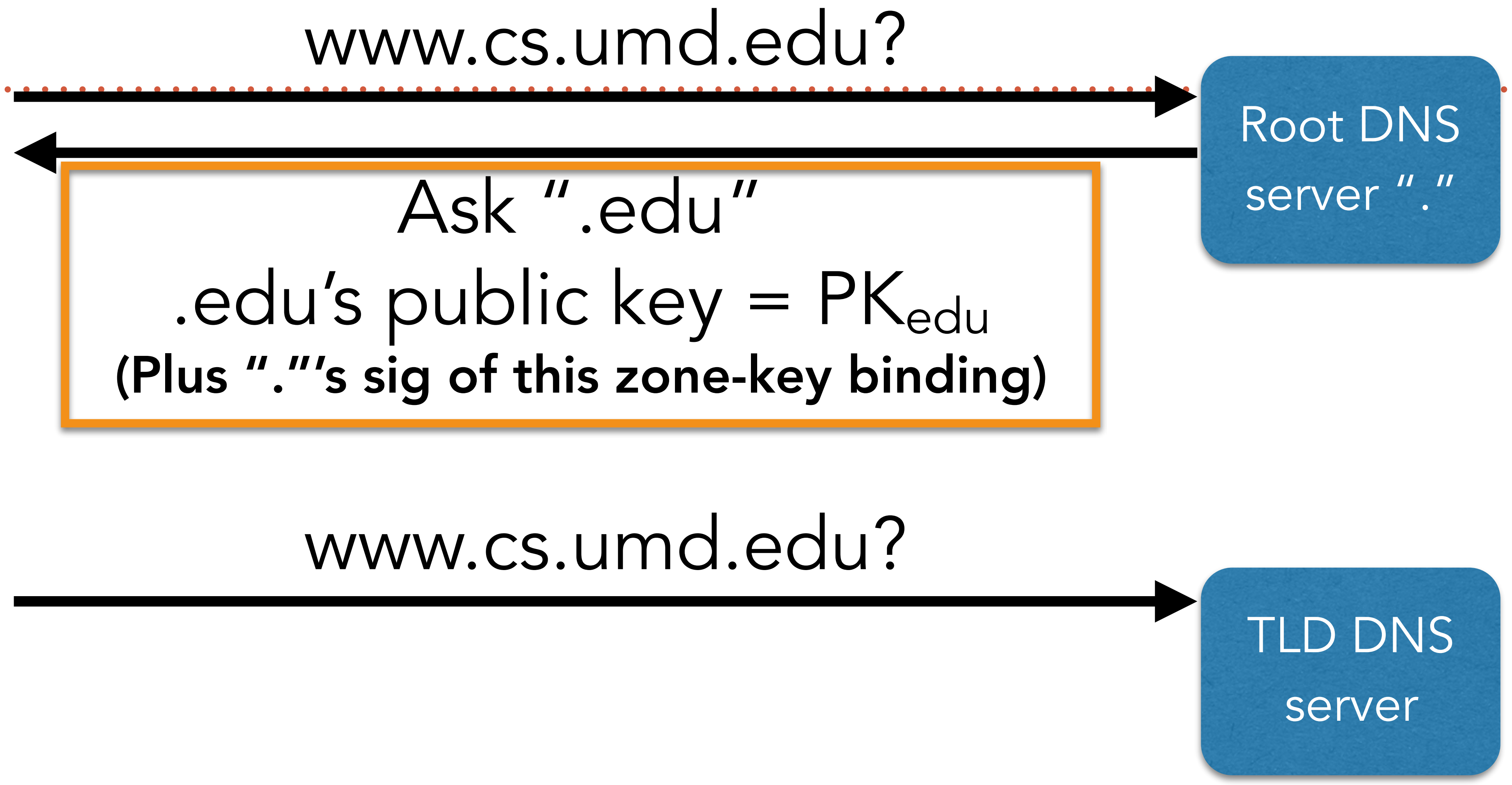
DNSSEC



DNSSEC


www.cs.umd.edu?
Root DNS server "."
Ask ".edu"
.edu's public key = PK_{edu}
(Plus "."'s sig of this zone-key binding)

DNSSEC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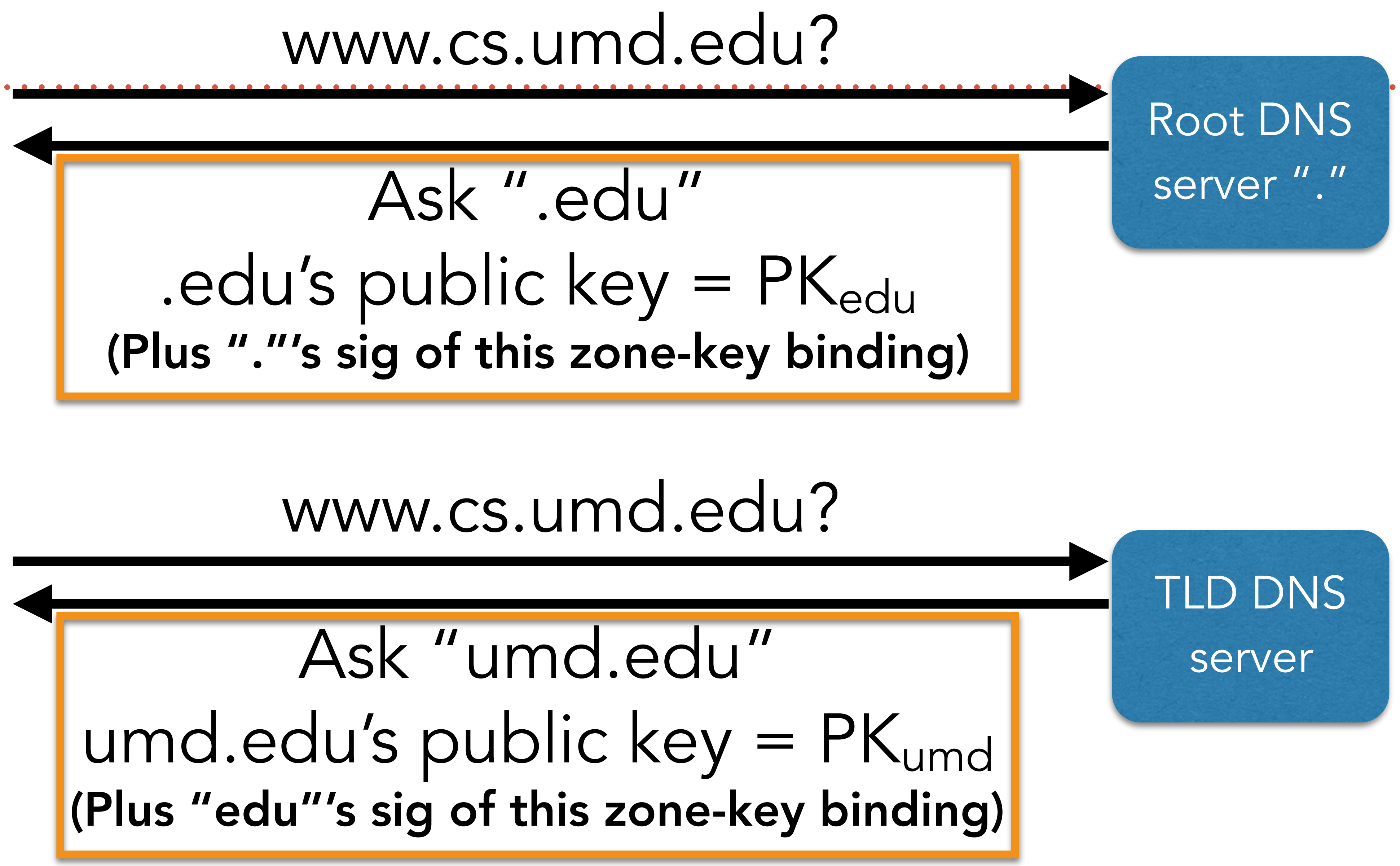
www.cs.umd.edu?
TLD DNS server

DNSSEC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www.cs.umd.edu?
TLD DNS server
Ask "umd.edu"
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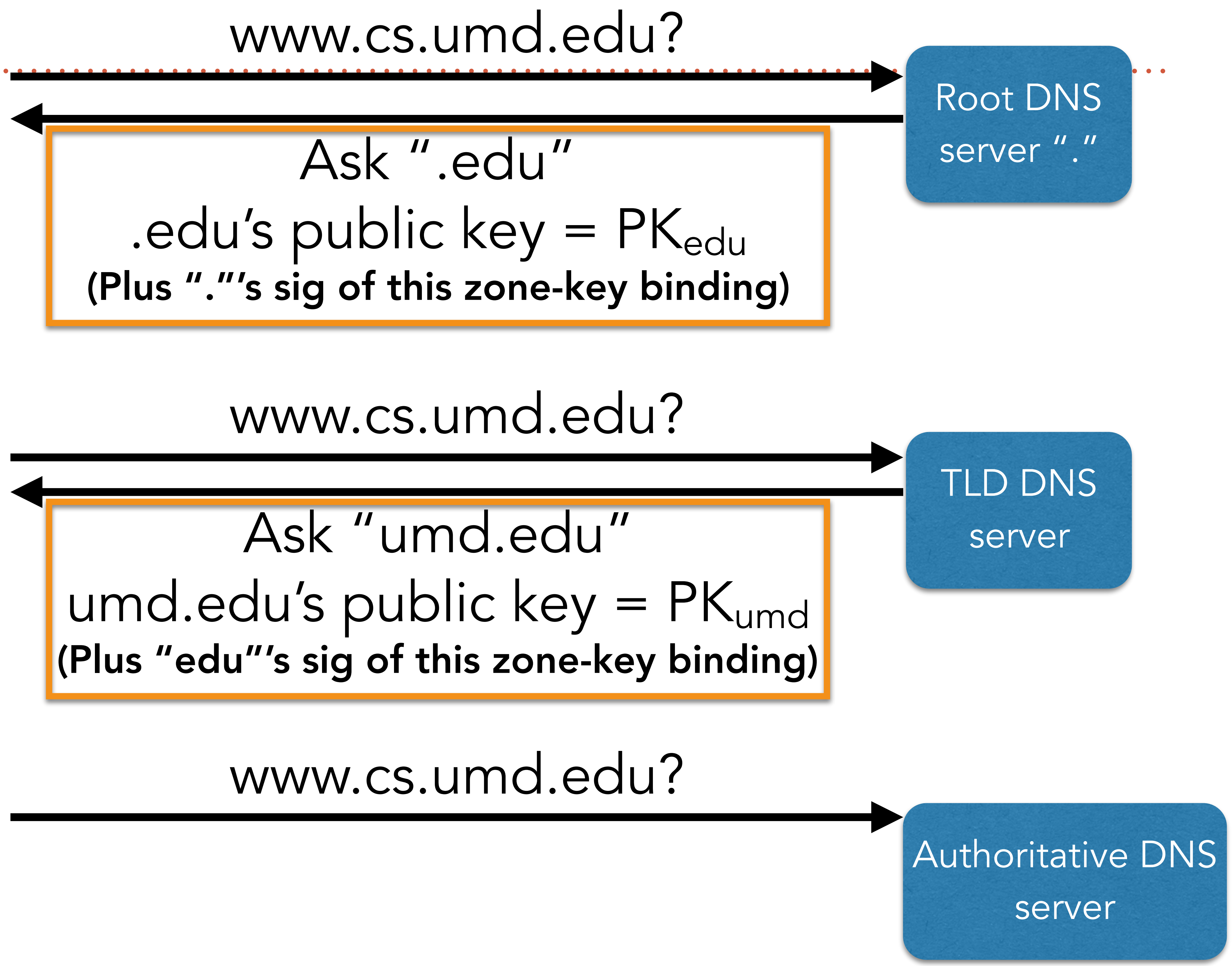
(Plus "edu"'s sig of this zone-key binding)

DNSSEC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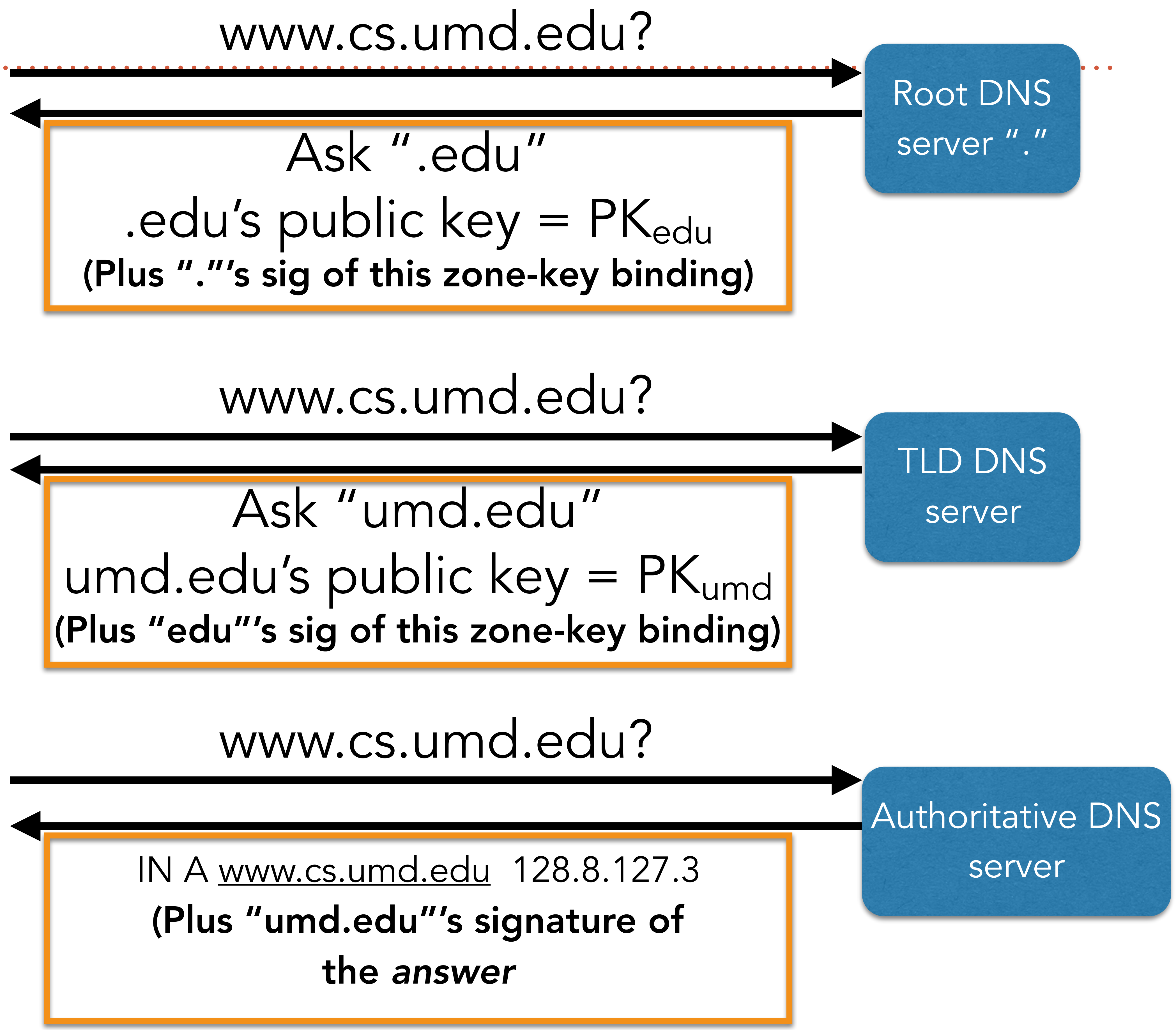
Root DNS server "."
Ask ".edu"
.edu's public key = PK_{edu}
(Plus "."'s sig of this zone-key binding)
www.cs.umd.edu?
TLD DNS server
Ask "umd.edu"
umd.edu's public key = PK_{umd}
(Plus "edu"'s sig of this zone-key binding)
www.cs.umd.edu?
Authoritative DNS server

DNSSEC



www.cs.umd.edu?

Ask ".edu"
.edu's public key = PK_{edu}
(Plus "."'s sig of this zone-key binding)

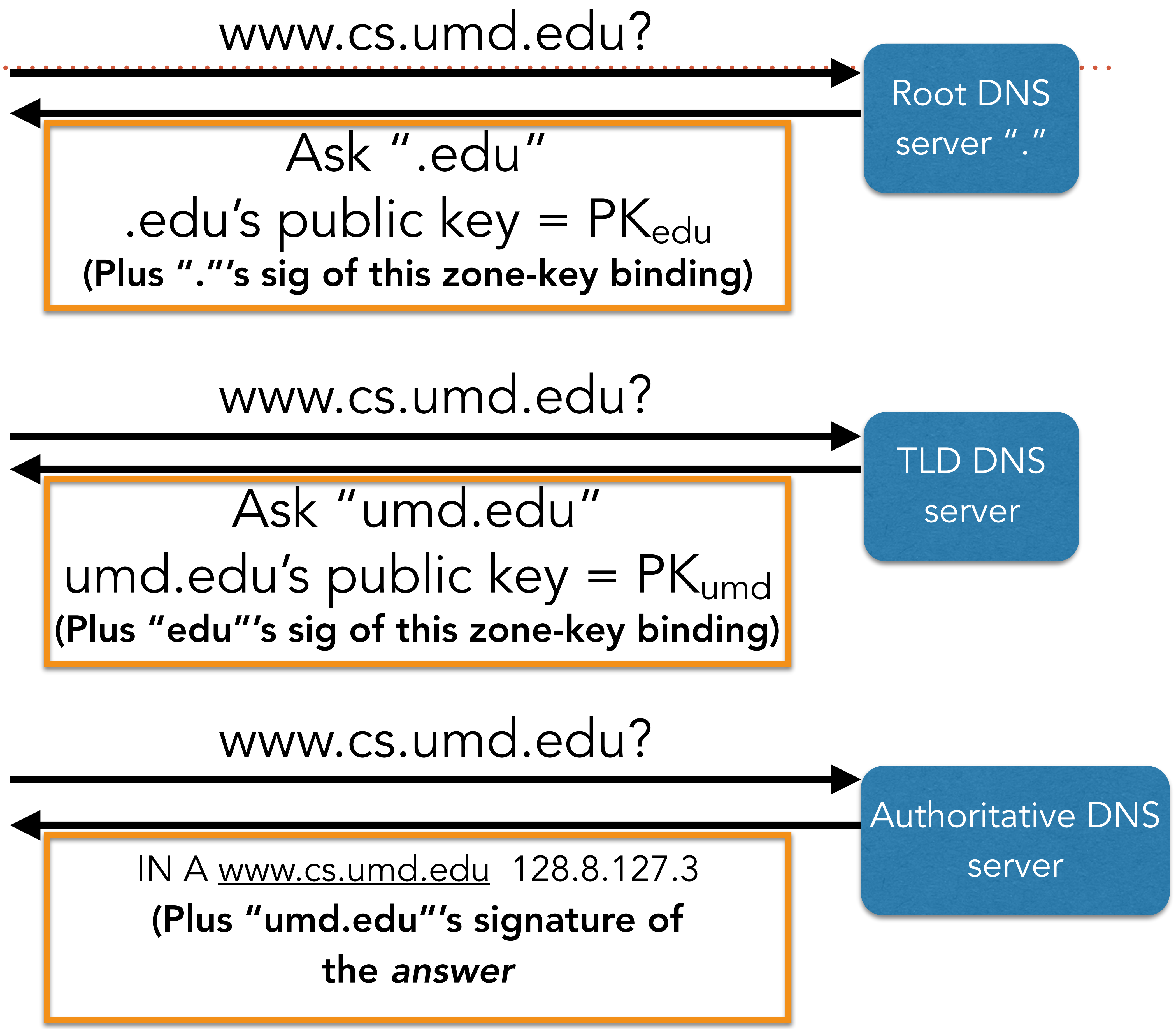
www.cs.umd.edu?

Ask "umd.edu"
umd.edu's public key = PK_{umd}
(Plus "edu"'s sig of this zone-key binding)

www.cs.umd.edu?

IN A www.cs.umd.edu 128.8.127.3
(Plus "umd.edu"'s signature of the *answer*

DNSSEC



Ask ".edu"
.edu's public key = PK$_{edu}$
(Plus "."'s sig of this zone-key binding)

Ask "umd.edu"
umd.edu's public key = PK$_{umd}$
(Plus "edu"'s sig of this zone-key binding)

IN A www.cs.umd.edu 128.8.127.3
(Plus "umd.edu"'s signature of the *answer*

Only the authoritative answer is signed

PROPERTIES OF DNSSEC

- If everyone has deployed it, and if you know the root's keys, then prevents spoofed responses
  - Very similar to PKIs in this sense
- But unlike PKIs, we still want authenticity despite the fact that not everyone has deployed DNSSEC
  - What if someone replies back without DNSSEC?
  - Ignore = secure but you can't connect to a lot of hosts
  - Accept = can connect but insecure
- Back to our notion of incremental deployment
  - DNSSEC is not all that useful incrementally