Network Attacks, Con't

CS 161: Computer Security

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http://inst.eecs.berkeley.edu/~cs161/

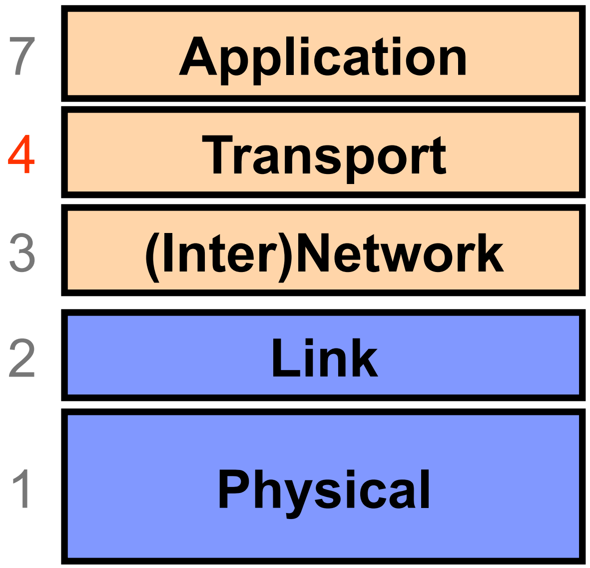
March 14, 2017

The Transport Layer: TCP

"Best Effort" is Lame! What to do?

- It's the job of our Transport (layer 4) protocols to build data delivery services that our apps need out of IP's modest layer-3 service

Layer 4: Transport Layer



End-to-end communication between processes

Different services provided:

TCP = reliable *byte stream*

UDP = unreliable *datagrams*

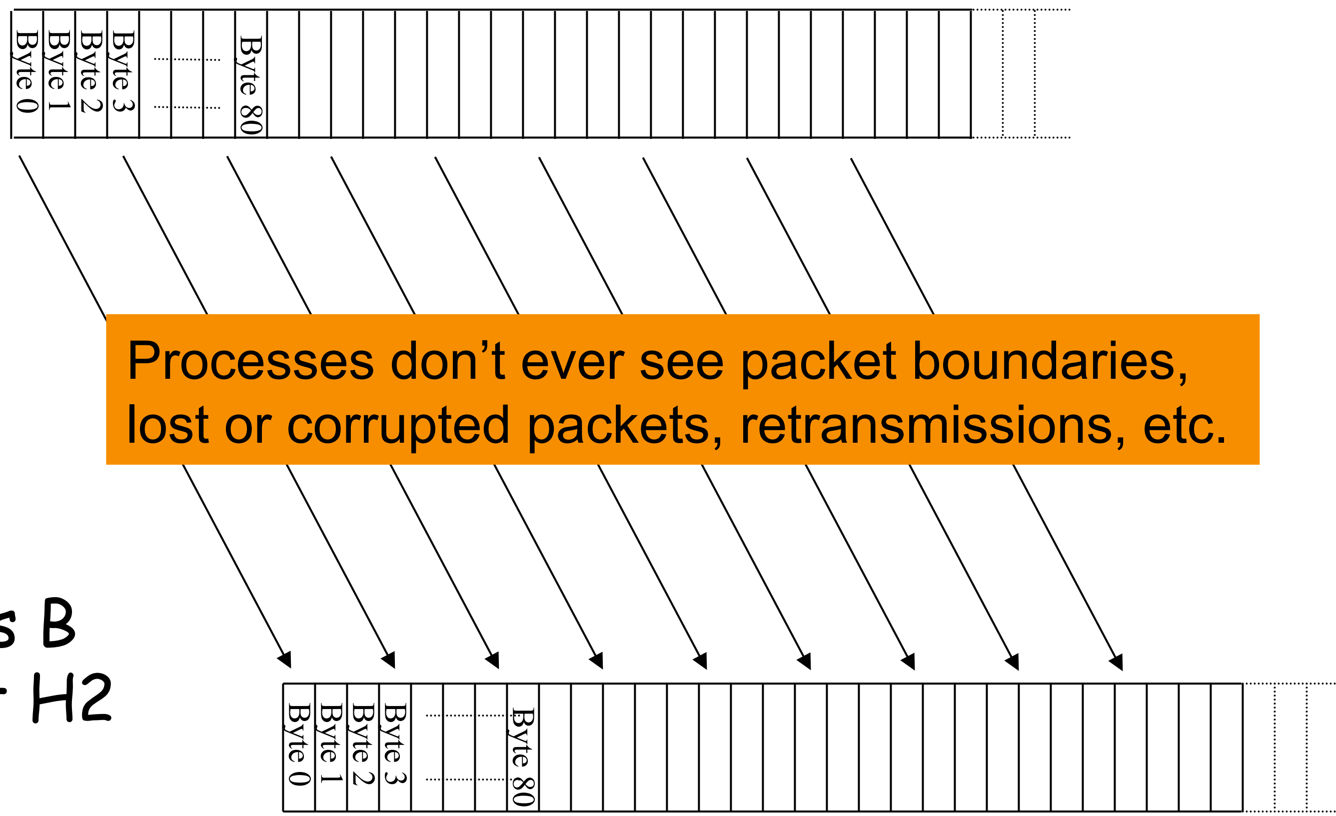
(Datagram = single packet message)

"Best Effort" is Lame! What to do?

- It's the job of our Transport (layer 4) protocols to build data delivery services that our apps need out of IP's modest layer-3 service
- #1 workhorse: TCP (Transmission Control Protocol)
- Service provided by TCP:
  - Connection oriented (explicit set-up / tear-down)
    - End hosts (processes) can have multiple concurrent long-lived communication
  - **Reliable**, in-order, *byte-stream* delivery
    - Robust detection & retransmission of lost data

TCP “Bytestream” Service

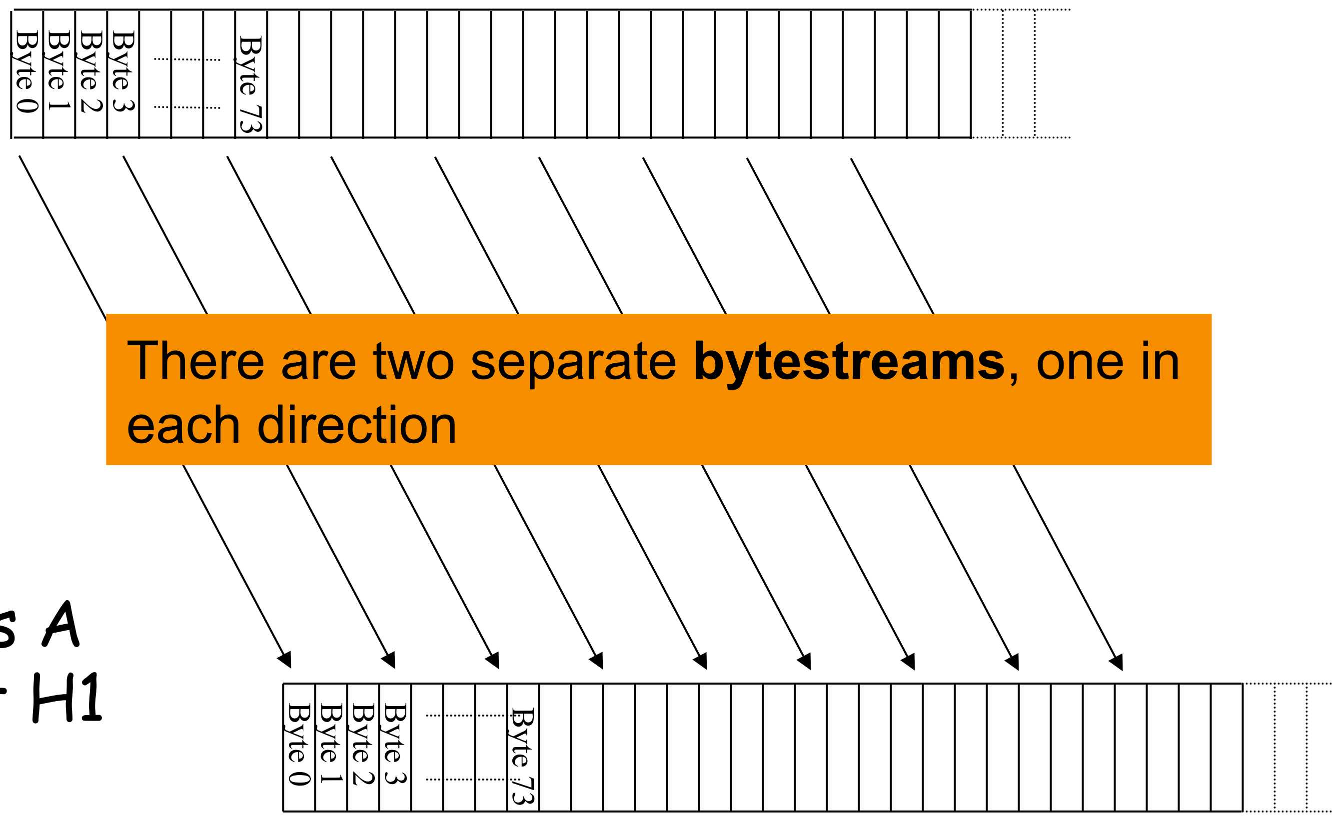
Process A on host H1



Process B
on host H2

Bidirectional communication:

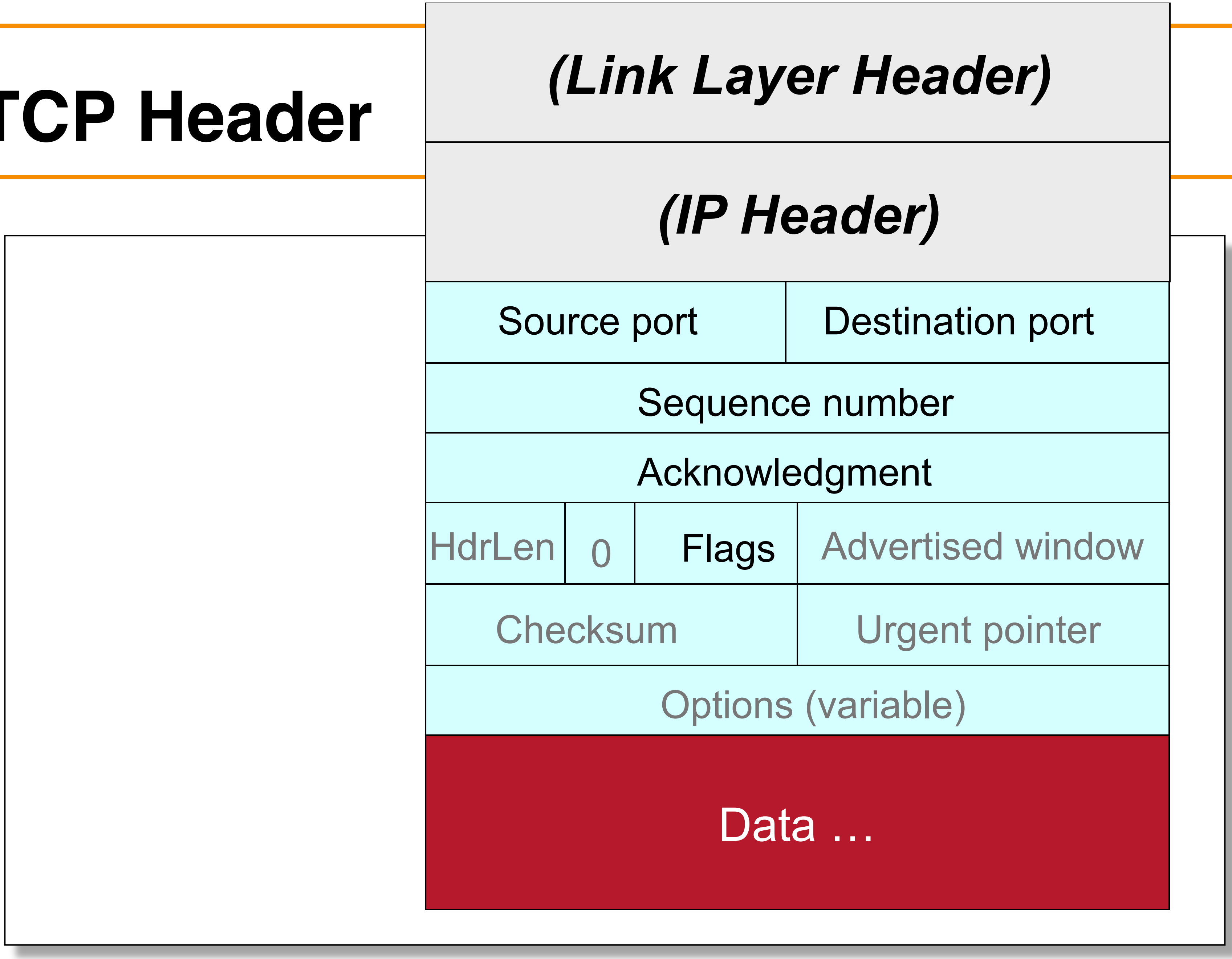
Process B on host H2



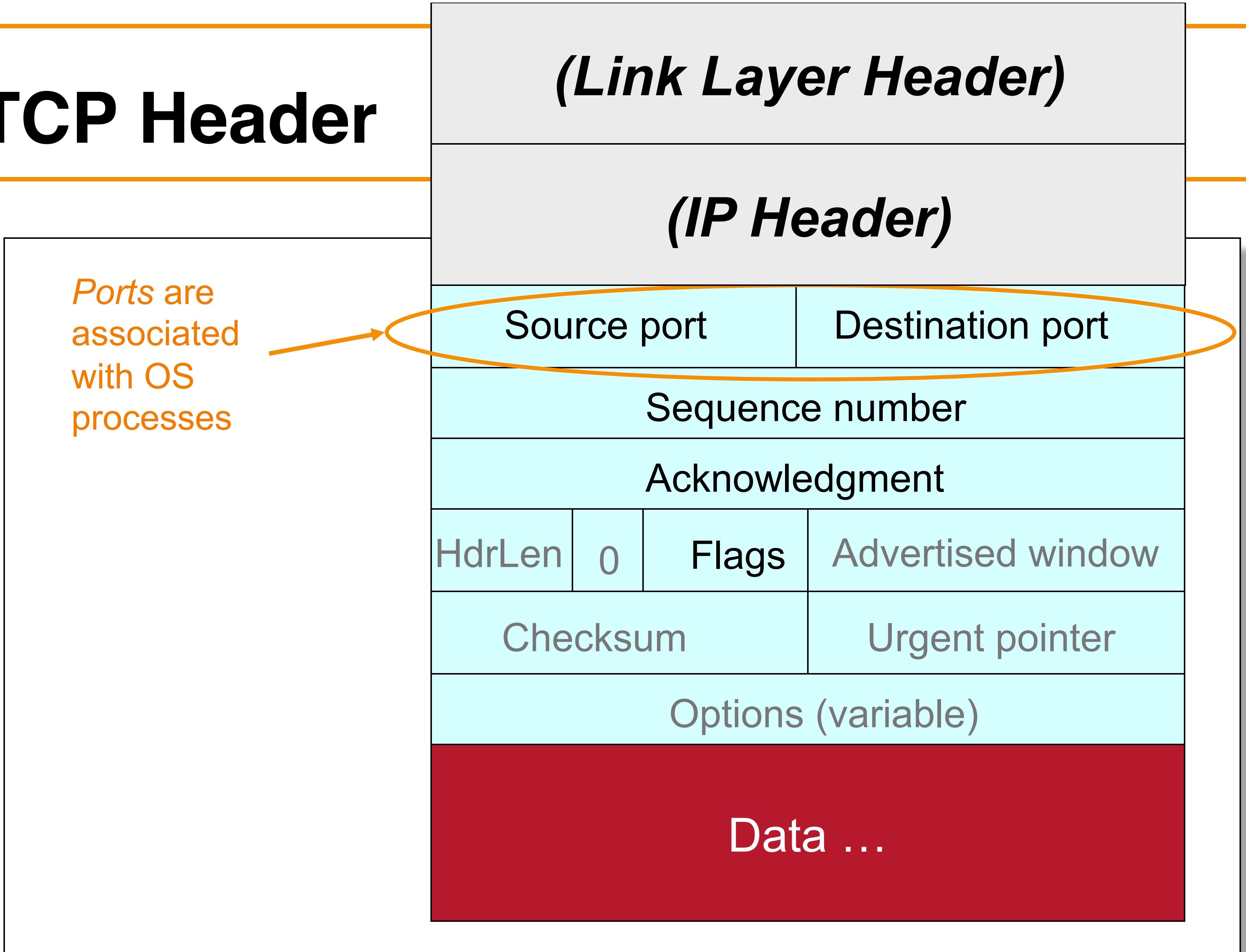
There are two separate **bytestreams**, one in each direction

Process A
on host H1

TCP Header


(Link Layer Header)
(IP Header)
Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data …

TCP Header



Ports are associated with OS processes
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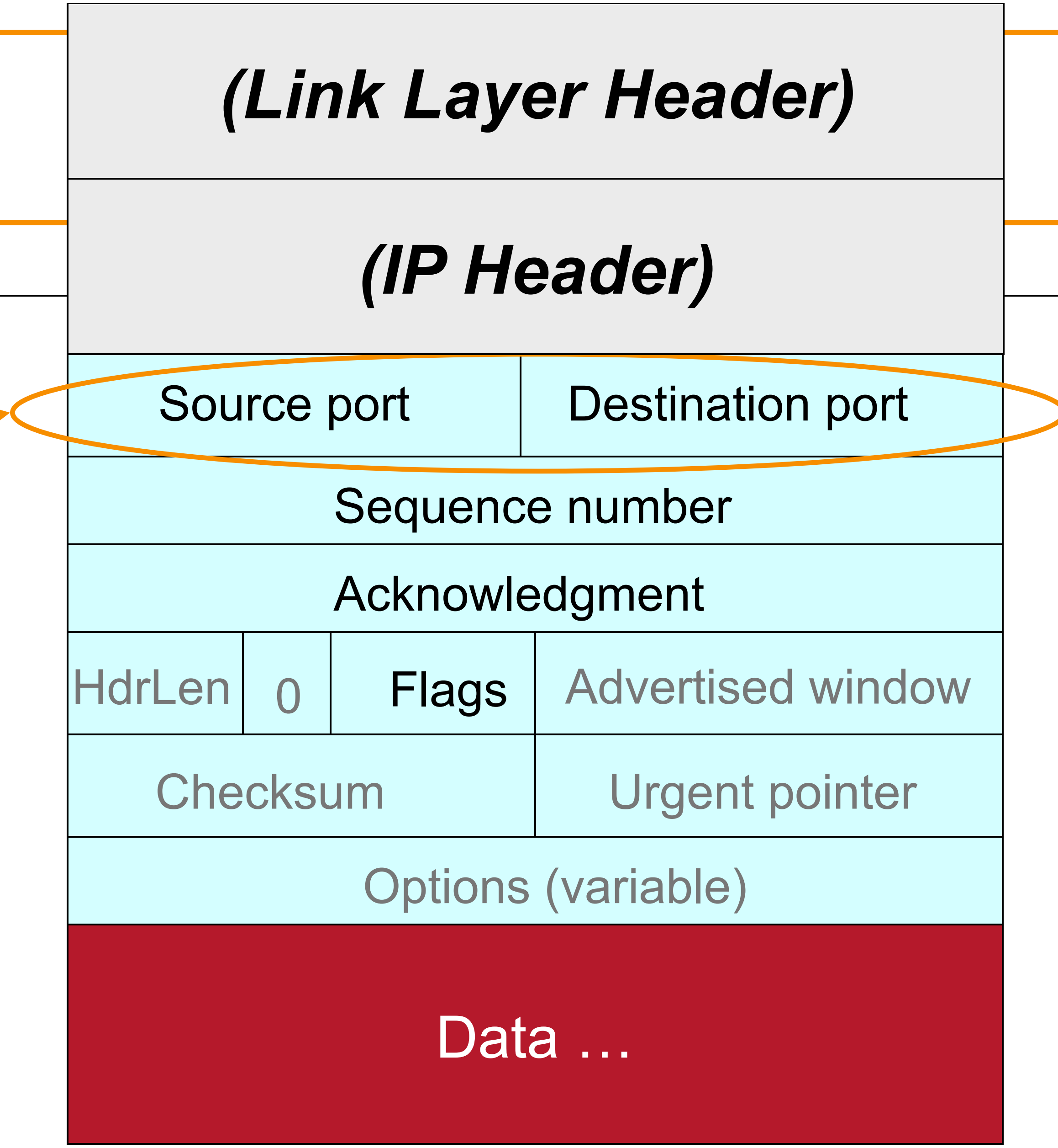
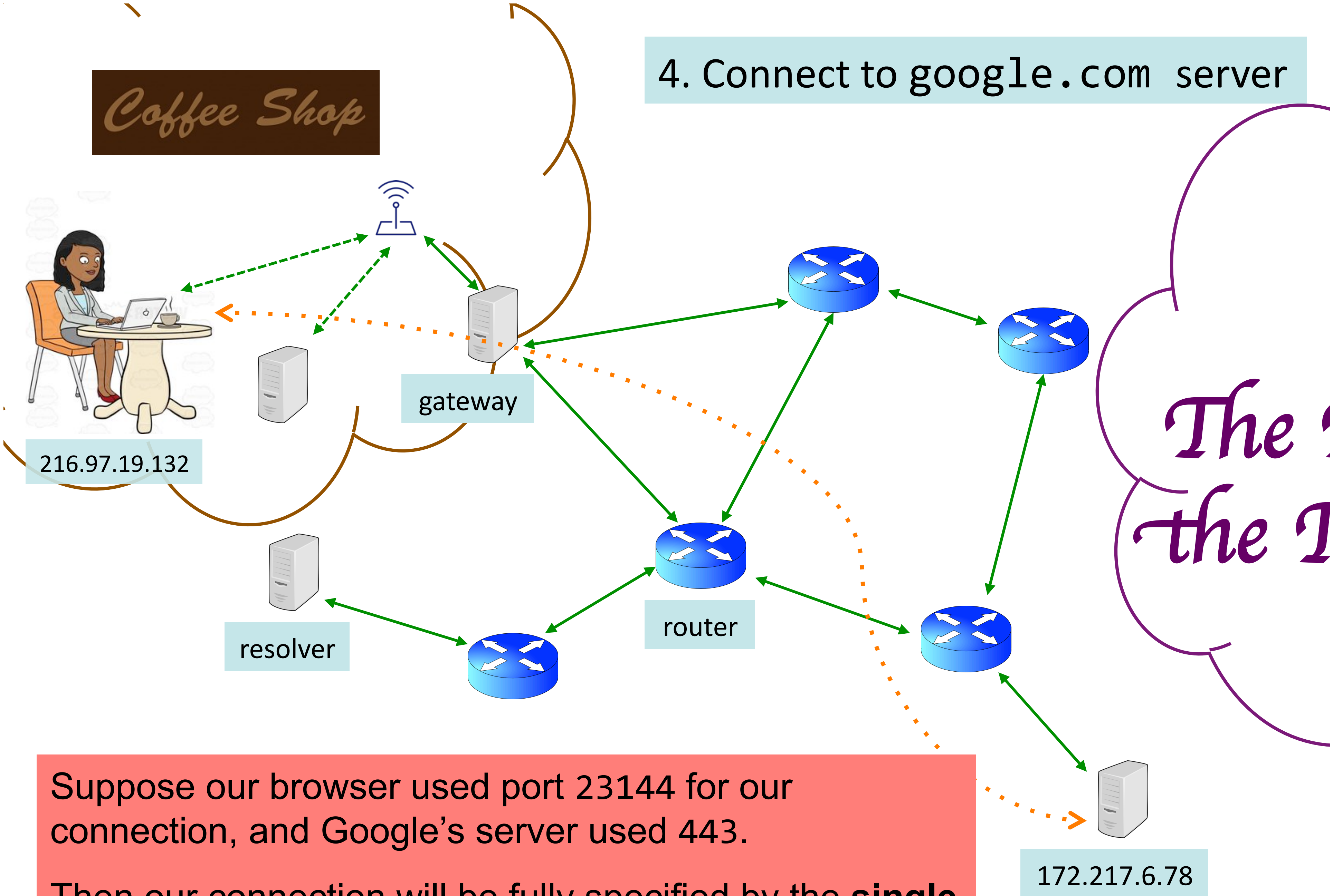
TCP Header

Ports are associated with OS processes



IP source & destination addresses plus TCP source and destination ports uniquely identifies a (bidirectional) TCP connection

4. Connect to `google.com` server



Suppose our browser used port 23144 for our connection, and Google's server used 443.

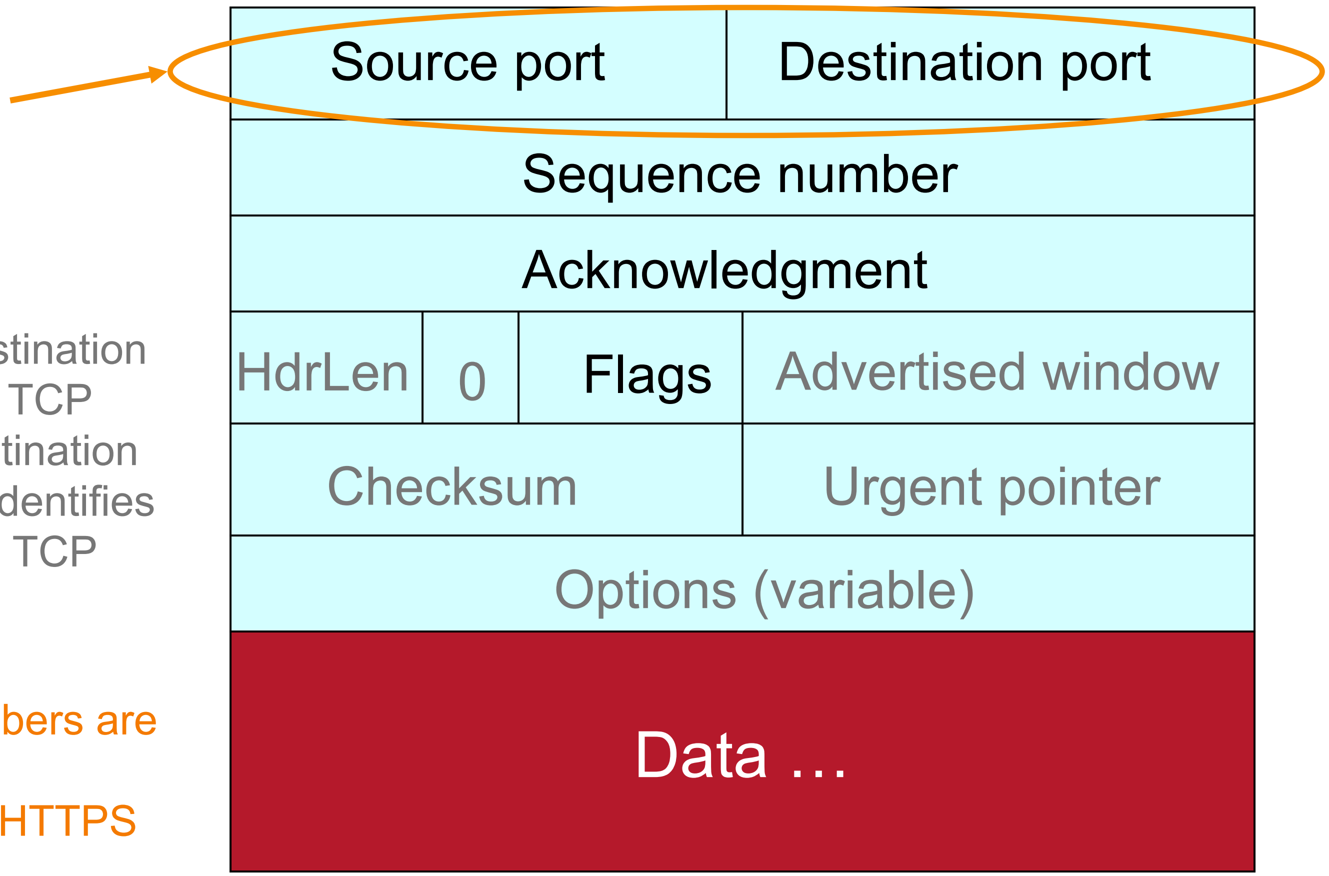
Then our connection will be fully specified by the **single** tuple <`216.97.19.132`, `23144`, `172.217.6.78`, `443`>

TCP Header

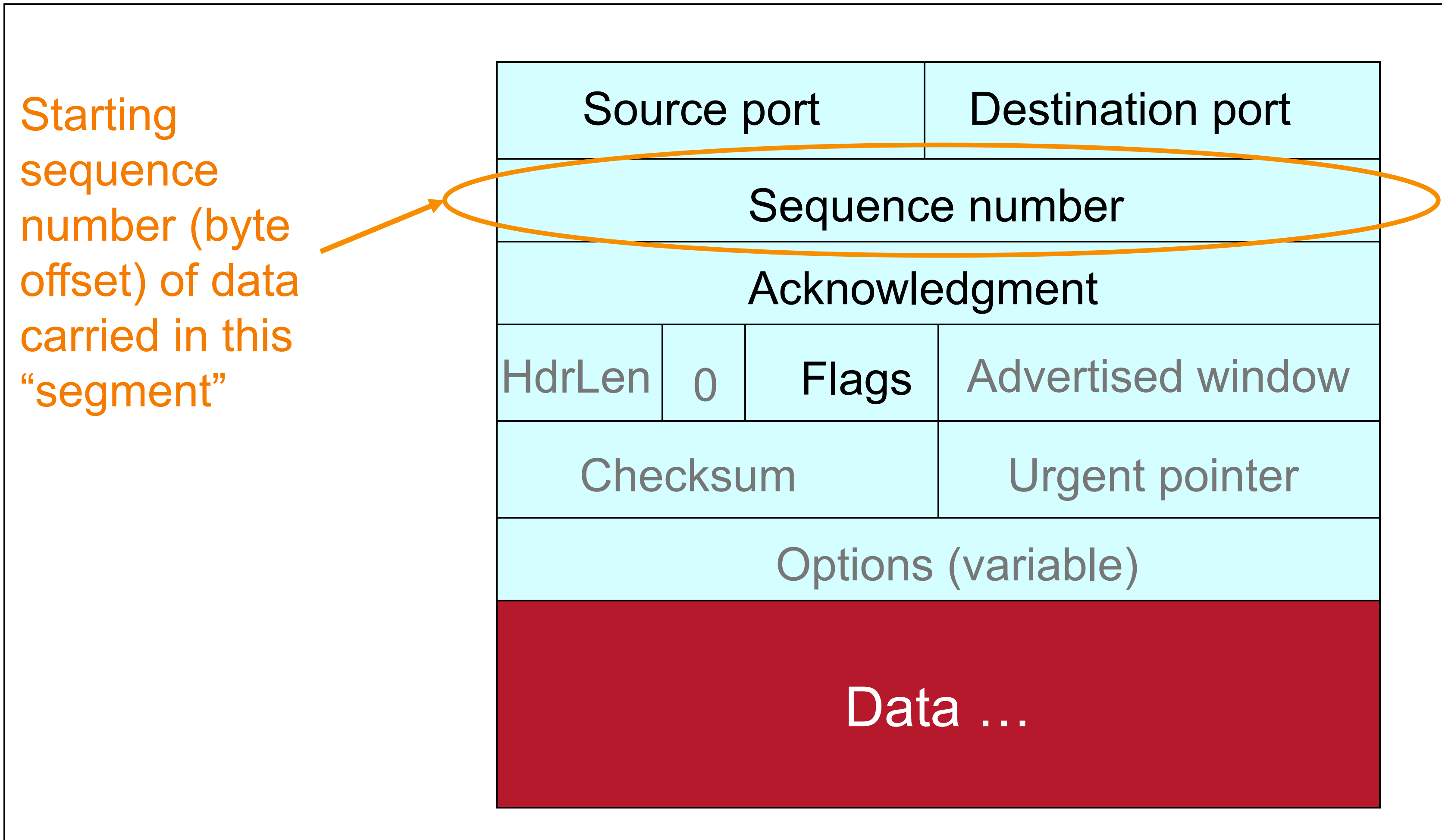
Ports are associated with OS processes

IP source & destination addresses plus TCP source and destination ports uniquely identifies a (bidirectional) TCP connection

Some port numbers are "well known"
e.g. port 443 = HTTPS



TCP Header



Starting sequence number (byte offset) of data carried in this "segment"
Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data …

TCP Header

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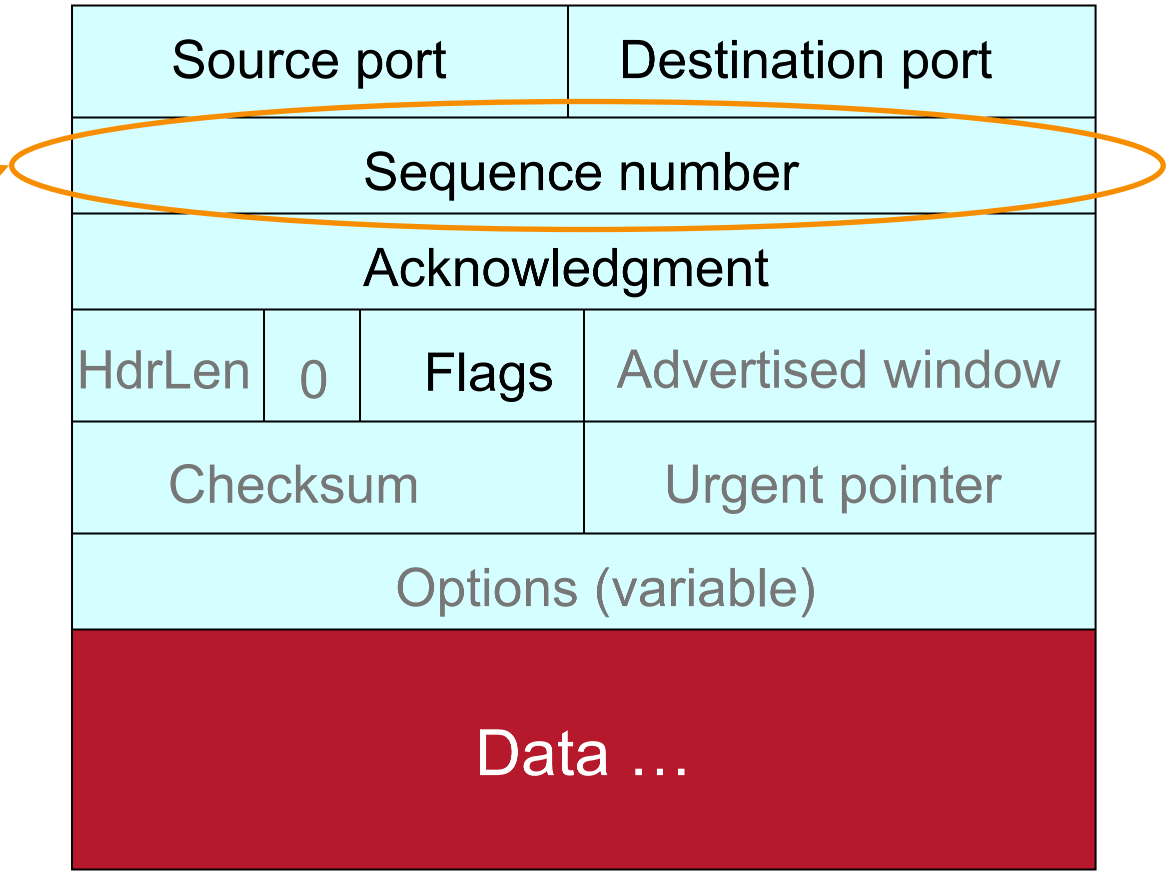
Byte streams numbered independently in each direction



TCP Header

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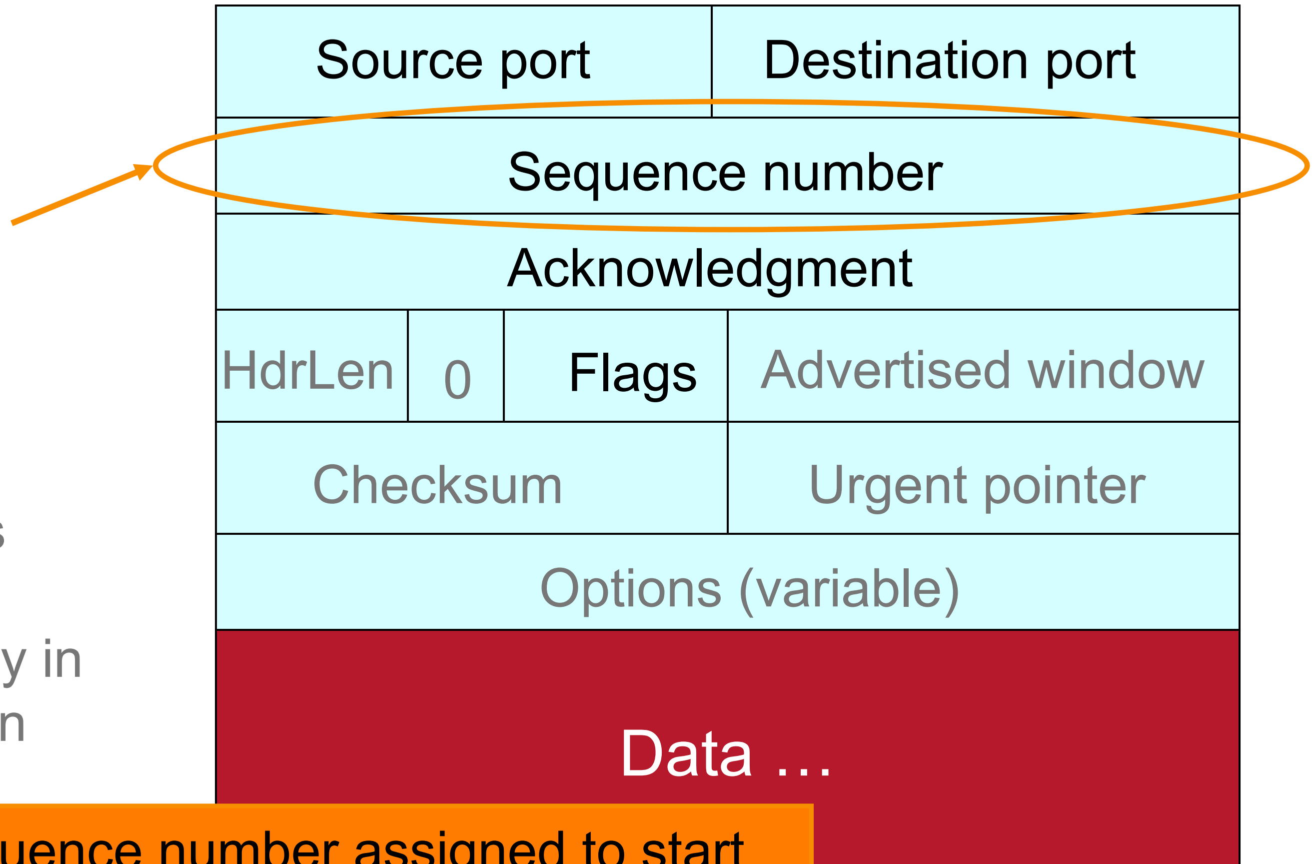


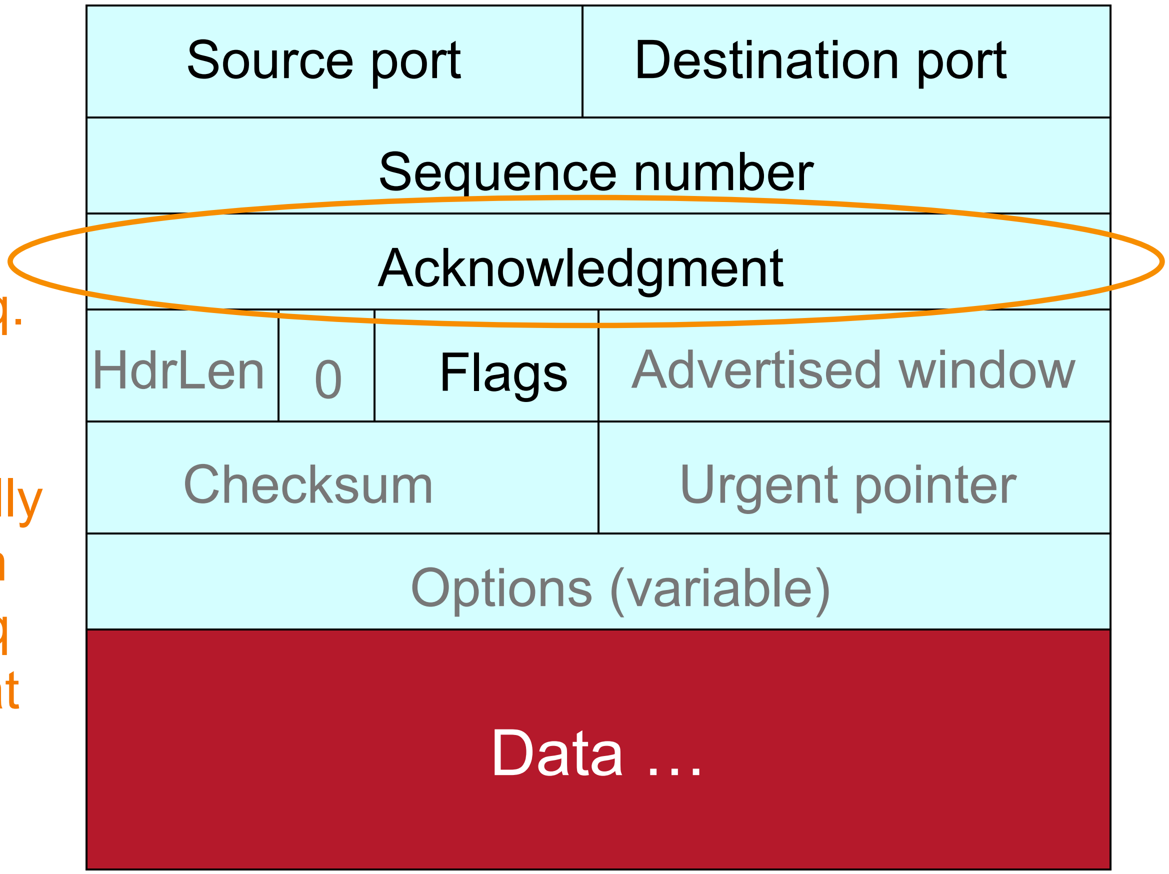
Byte streams numbered independently in each direction

Sequence number assigned to start of byte stream is picked when connection begins; **doesn’t** start at 0

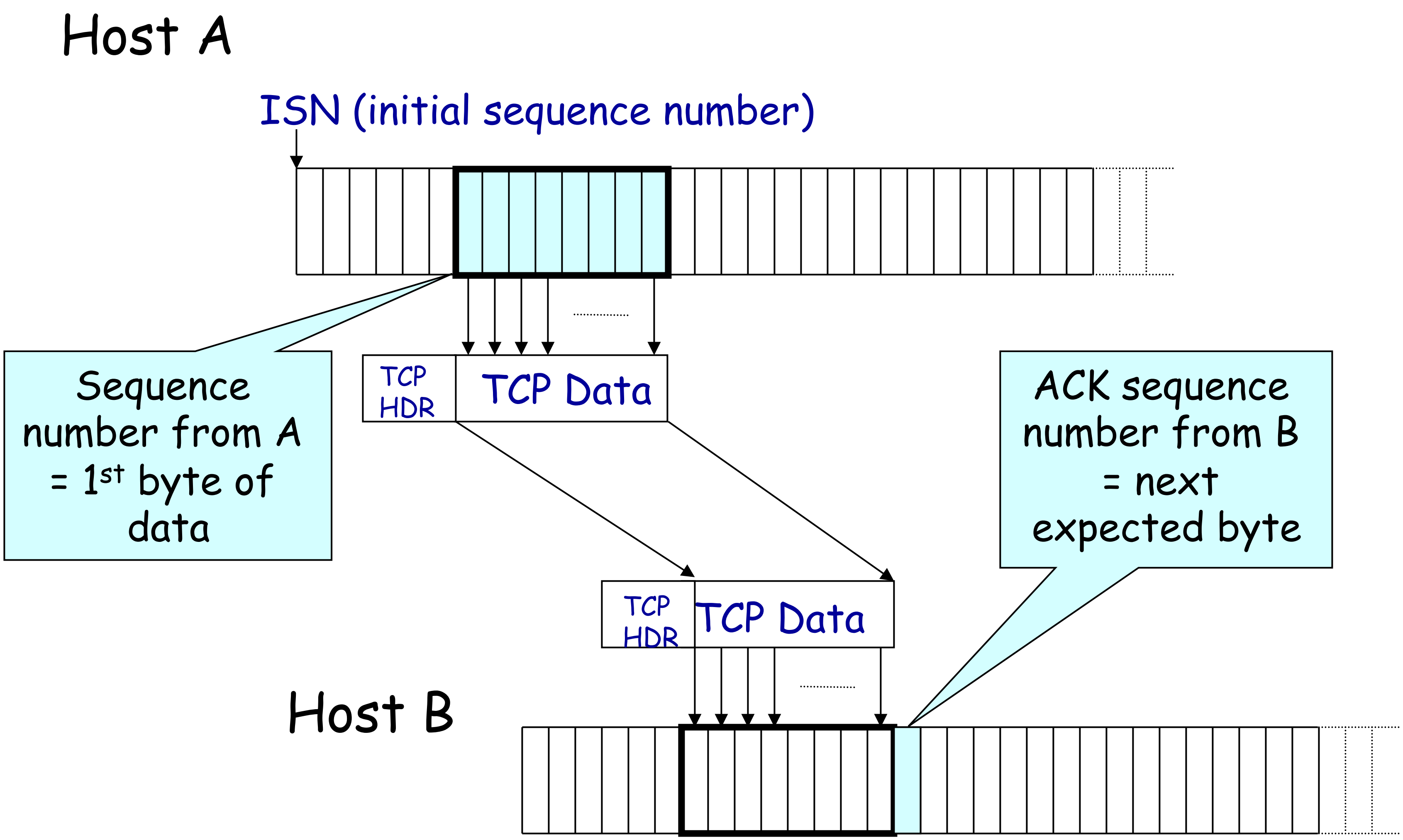
TCP Header

Acknowledgment gives seq # **just beyond** highest seq. received **in order**.

If sender successfully sends **N** bytestream bytes starting at seq **S** then "ack" for that will be **S+N**.



Sequence Numbers

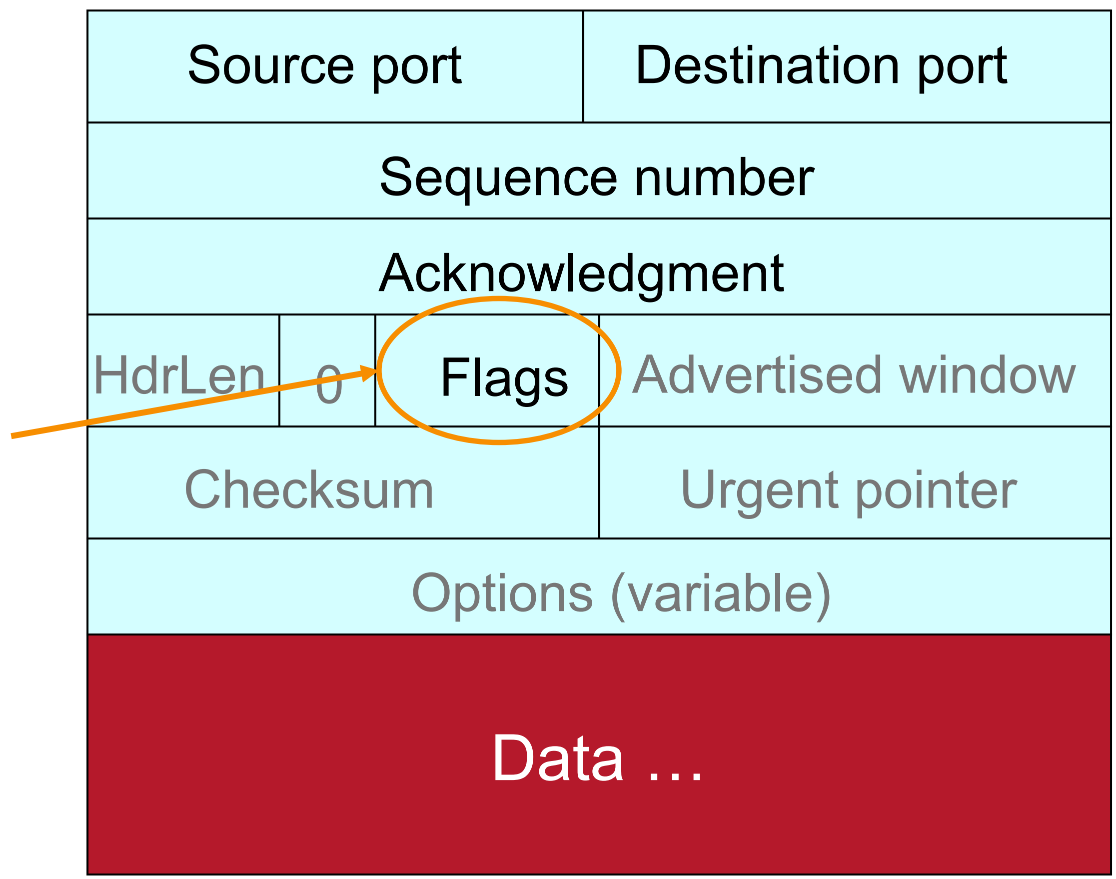


TCP Header

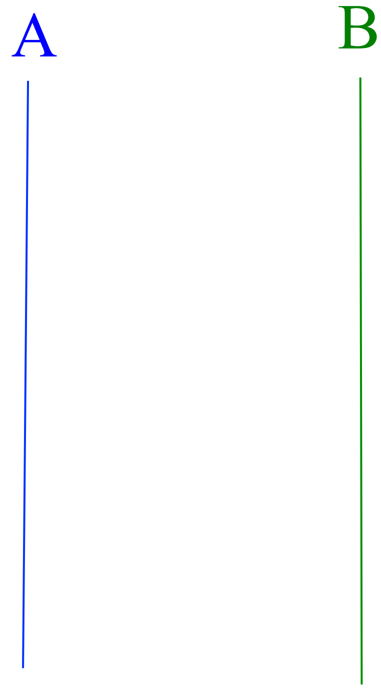
Uses include:

acknowledging data (“**ACK**”)

setting up (“**SYN**”) and closing connections (“**FIN**” and “**RST**”)

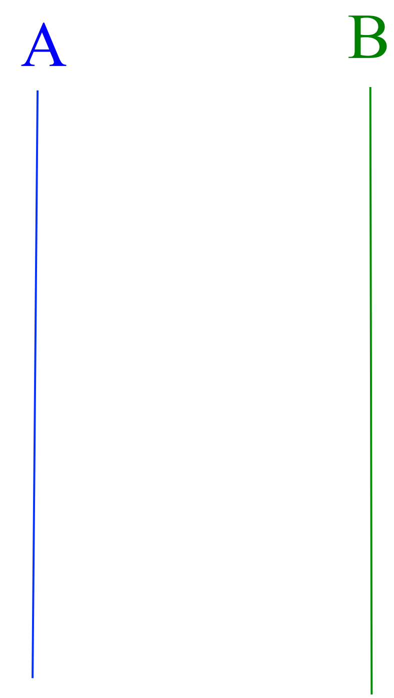


Establishing a TCP Connection



- *Three-way handshake* to establish connection

Establishing a TCP Connection

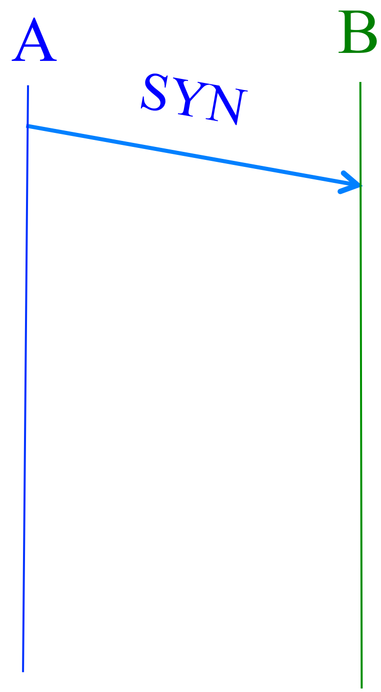


Each host tells its *Initial Sequence Number* (ISN) to the other host.

(Spec says to pick based on a clock)

- *Three-way handshake* to establish connection

Establishing a TCP Connection



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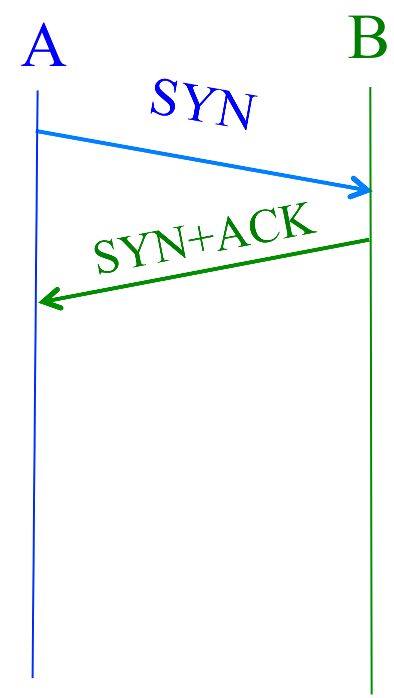

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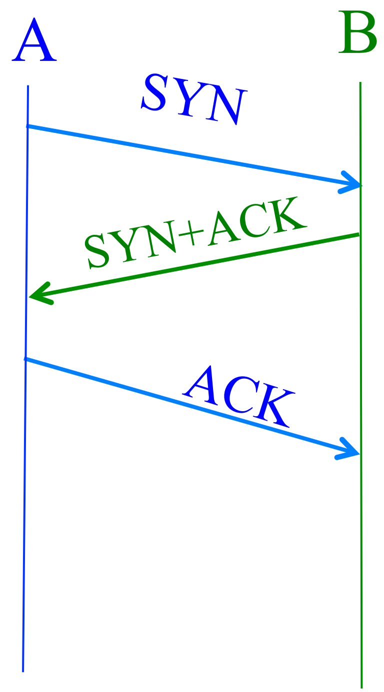

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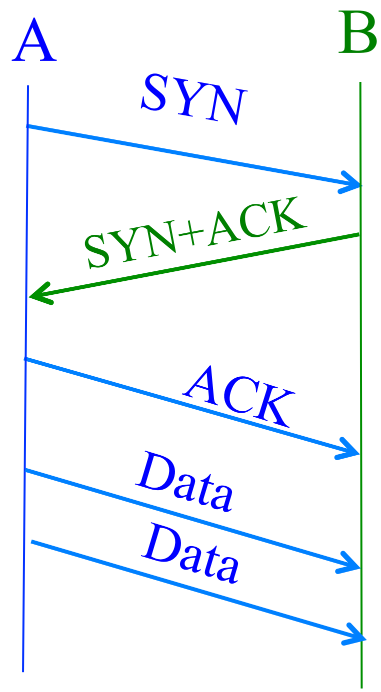

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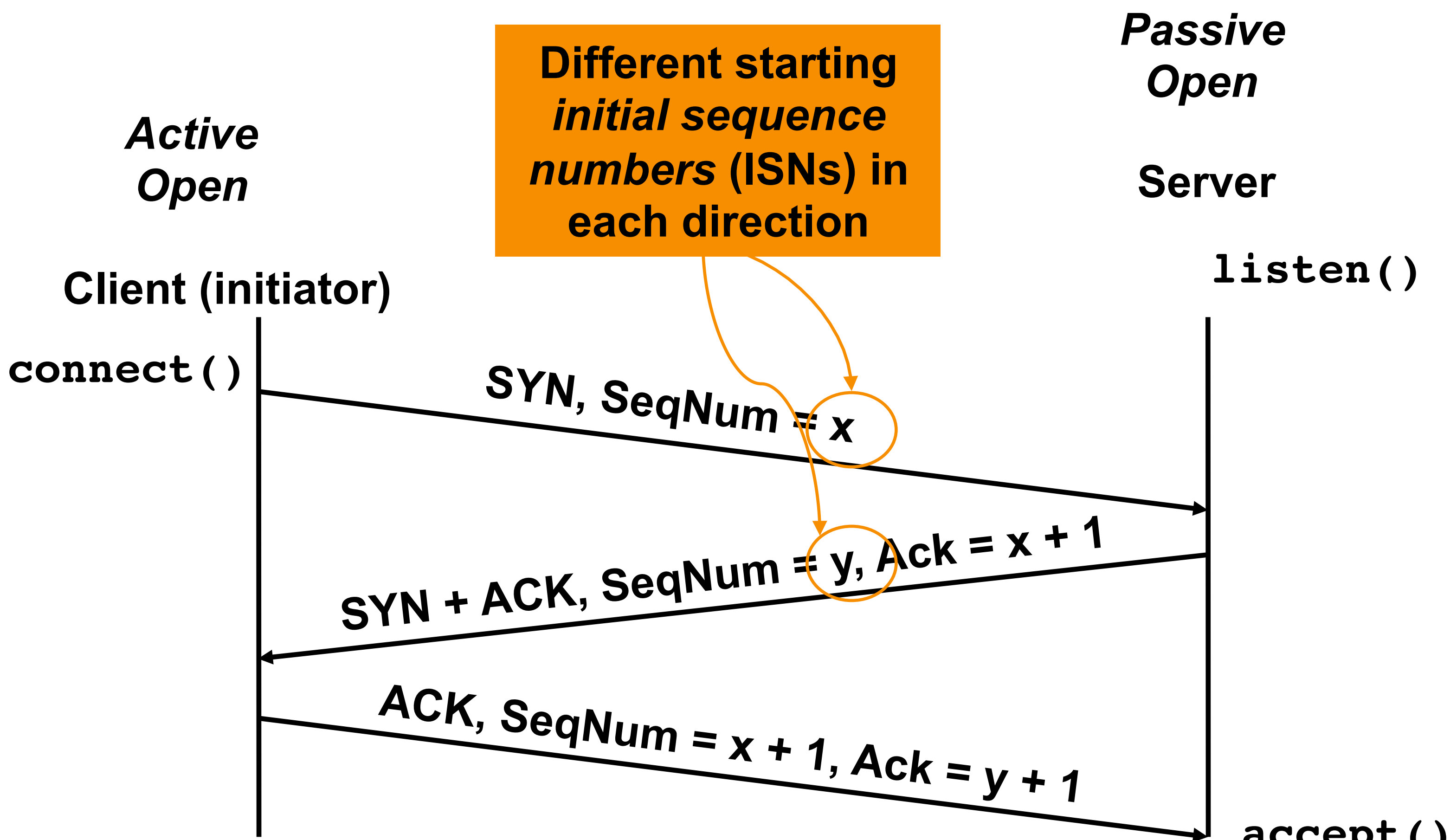
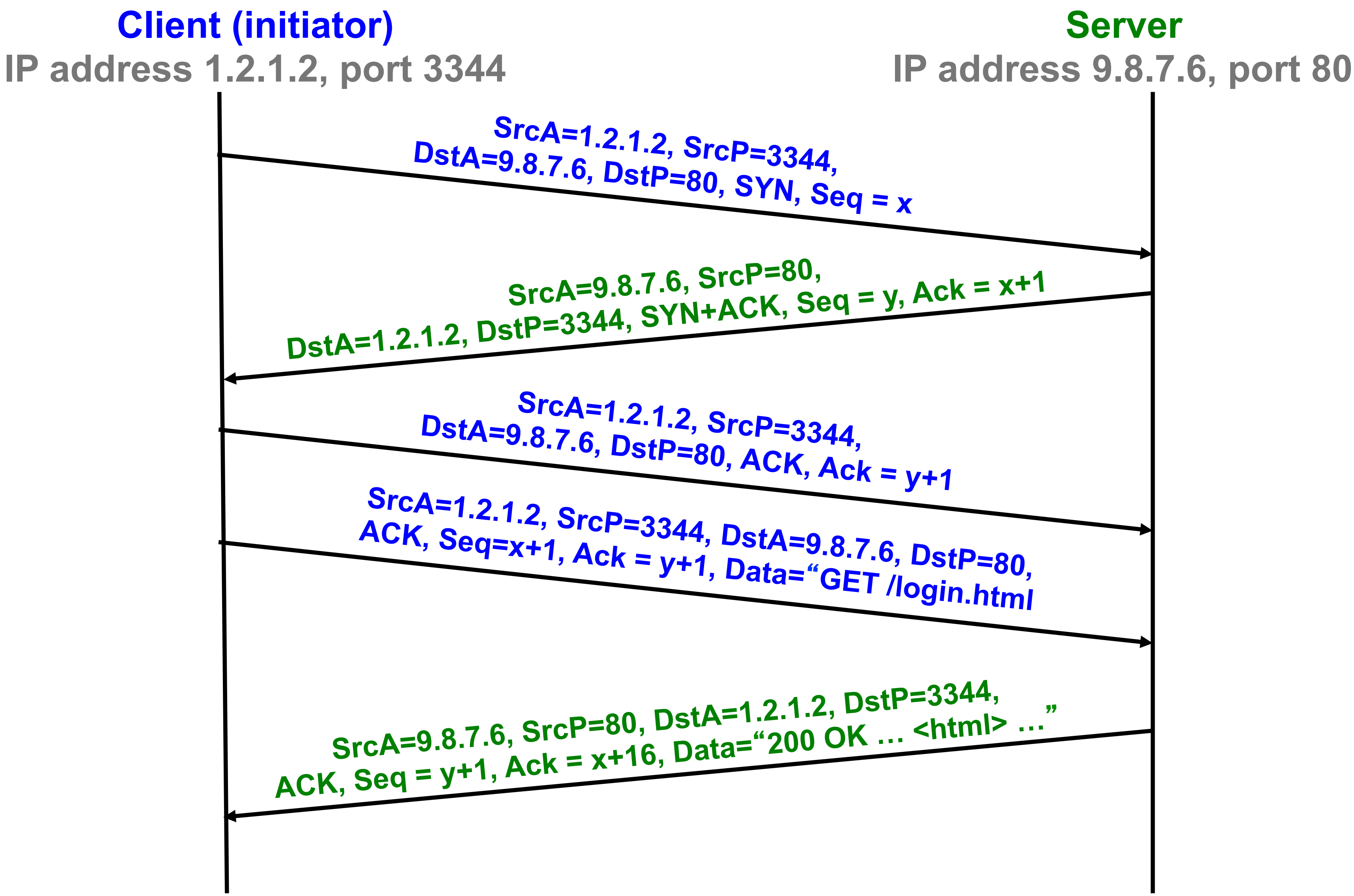
Timing Diagram: 3-Way Handshaking

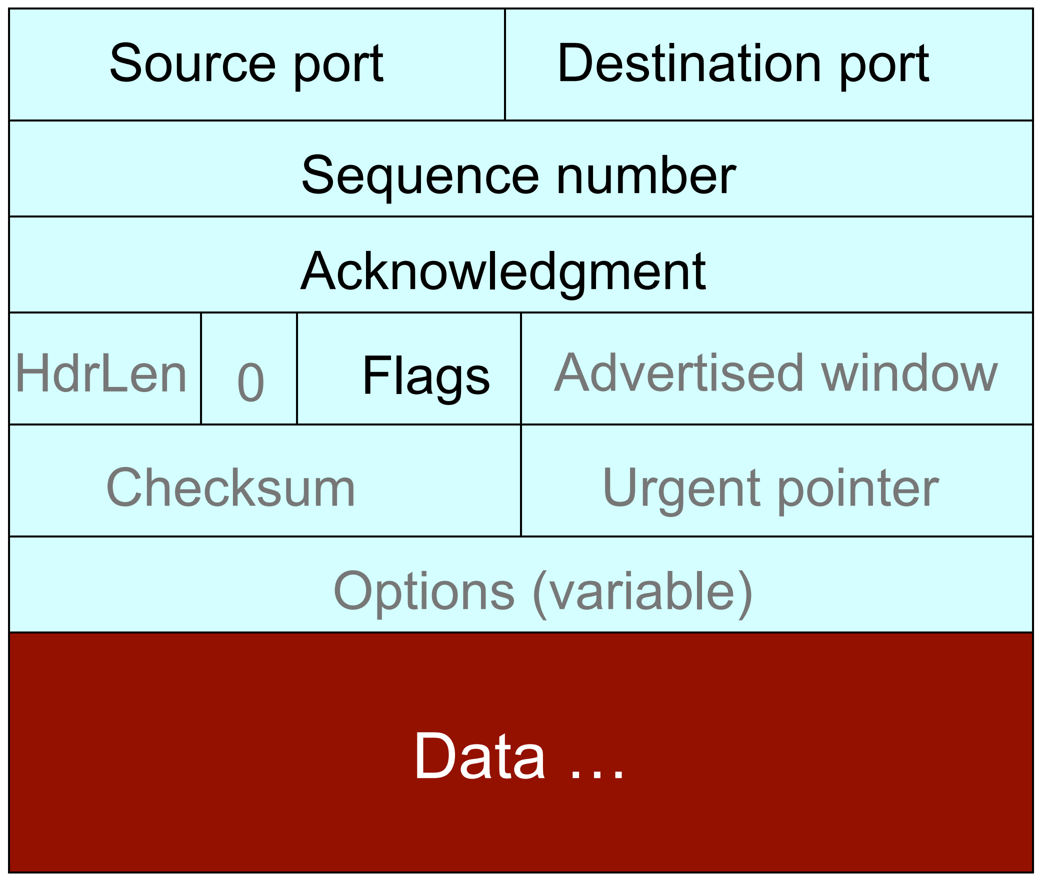


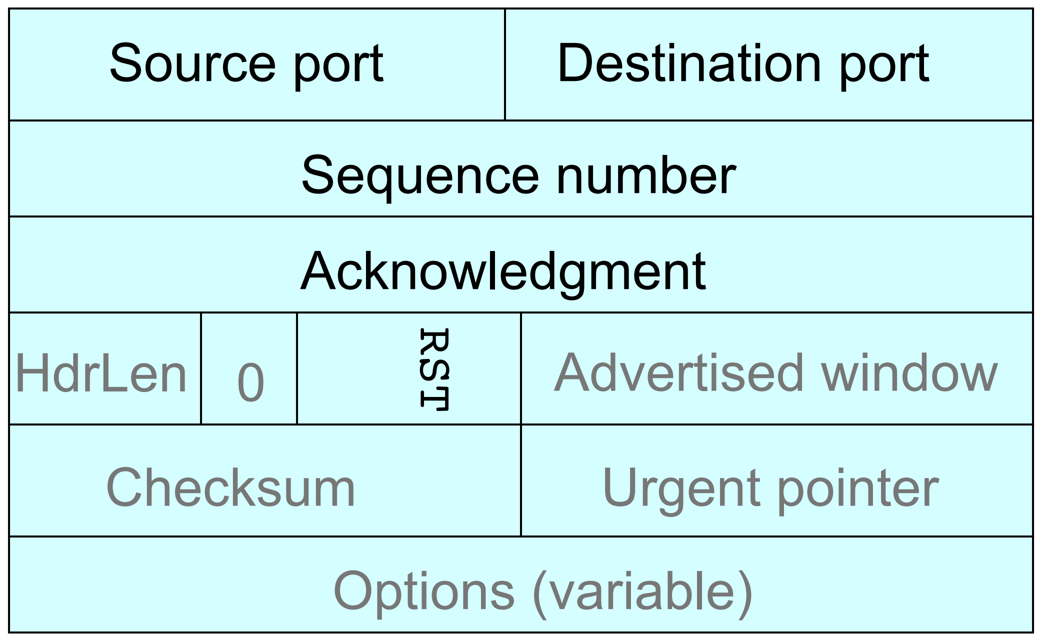
TCP Conn. Setup & Data Exchange



TCP Threat: Disruption

- Normally, TCP finishes ("closes") a connection by each side sending a `FIN` control message
  - Reliably delivered, since other side must ack
- But: if a TCP endpoint finds unable to continue (process dies; info from other "peer" is inconsistent), it abruptly terminates by sending a **RST** control message
  - Unilateral
  - Takes effect immediately (no ack needed)
  - Only accepted by peer if has correct* sequence number


Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data …


Source port
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Sequence number
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HdrLen
0
RST
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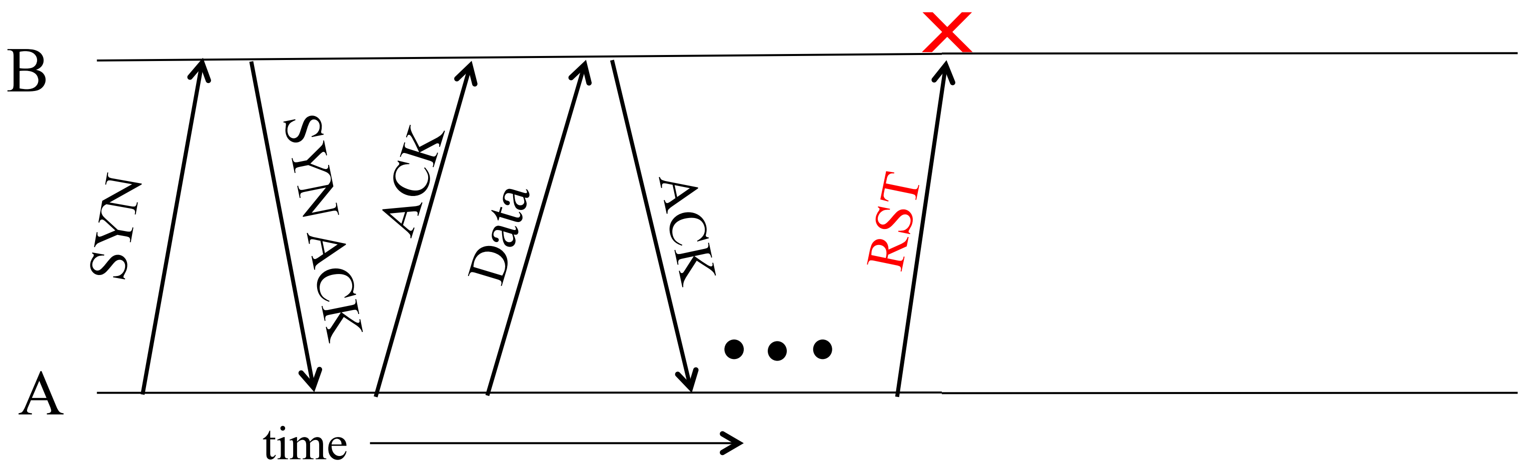
Options (variable)

Abrupt Termination



- A sends a TCP packet with RESET (**RST**) flag to B
  - E.g., because app. process on A crashed
  - (Could instead be that B sends a RST to A)
- Assuming that the sequence numbers in the **RST** fit with what B expects, That's It:
  - B's user-level process receives: `ECONNRESET`
  - No further communication on connection is possible

TCP Threat: Disruption

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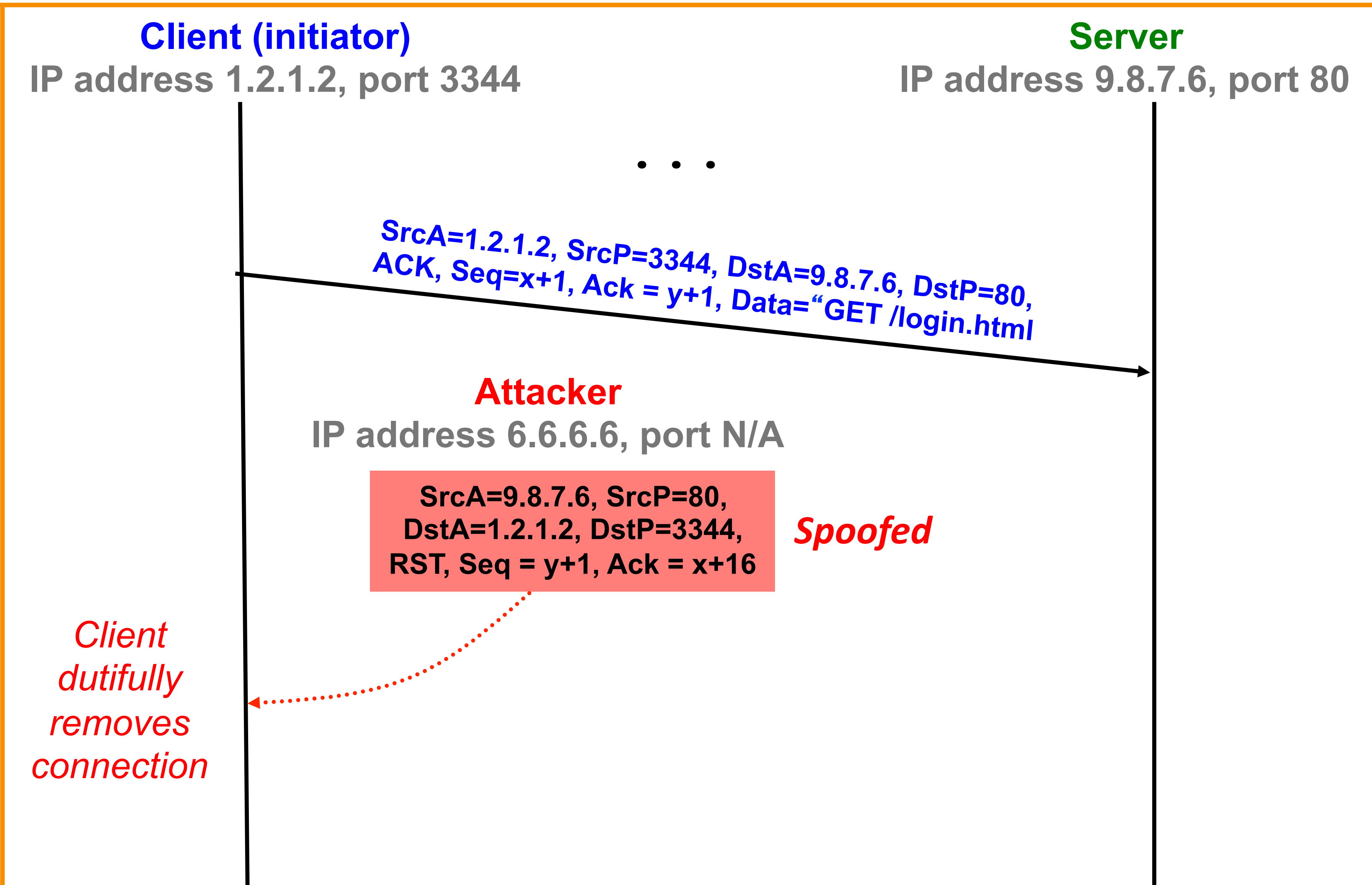
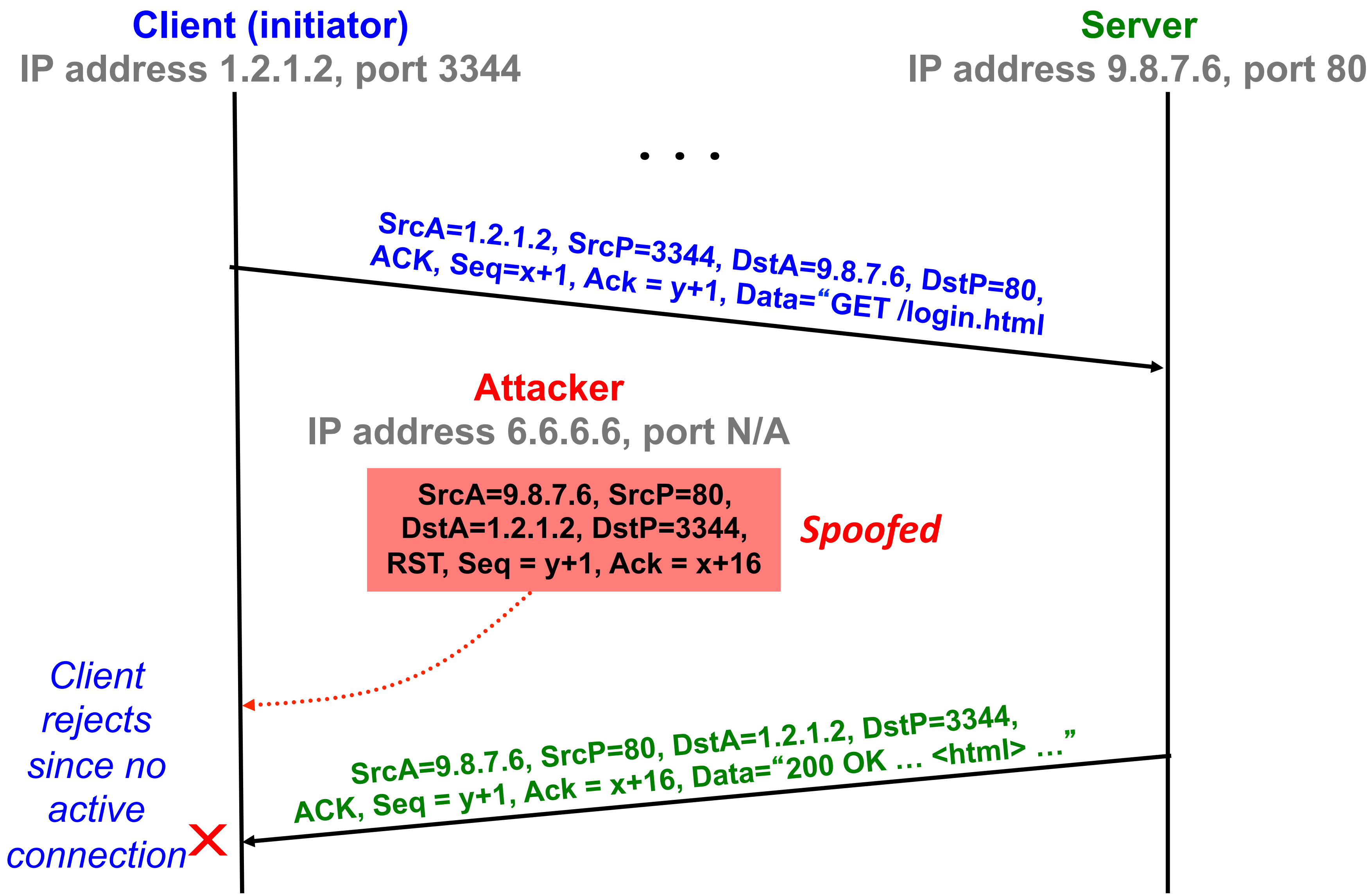
- So: if attacker knows ports & sequence numbers, can disrupt any TCP connection

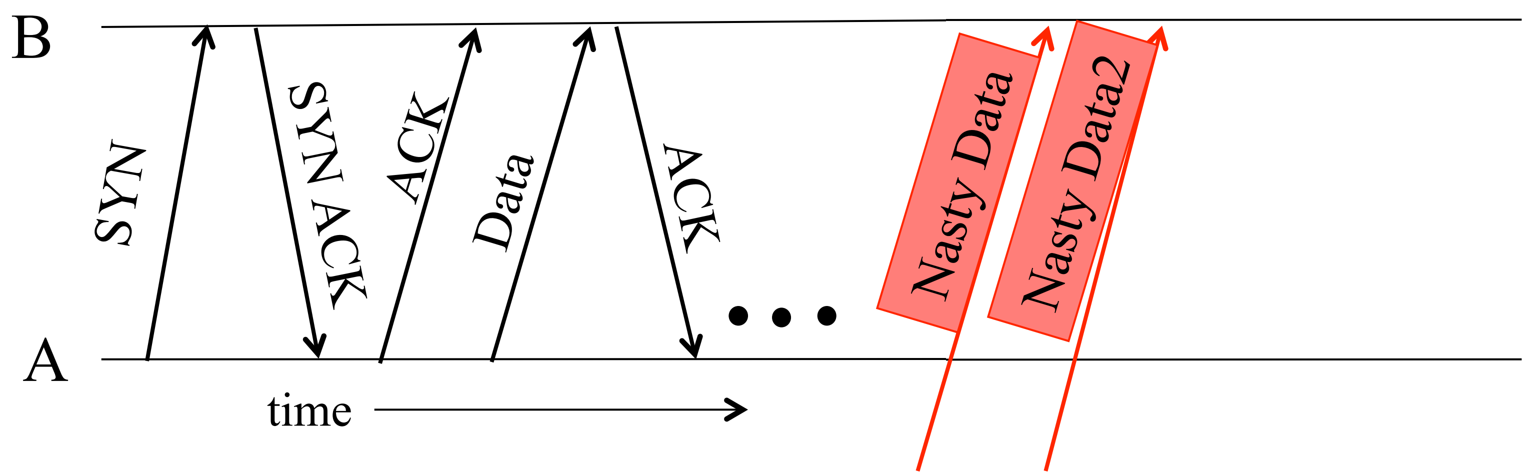
TCP *RST Injection*



TCP *RST Injection*

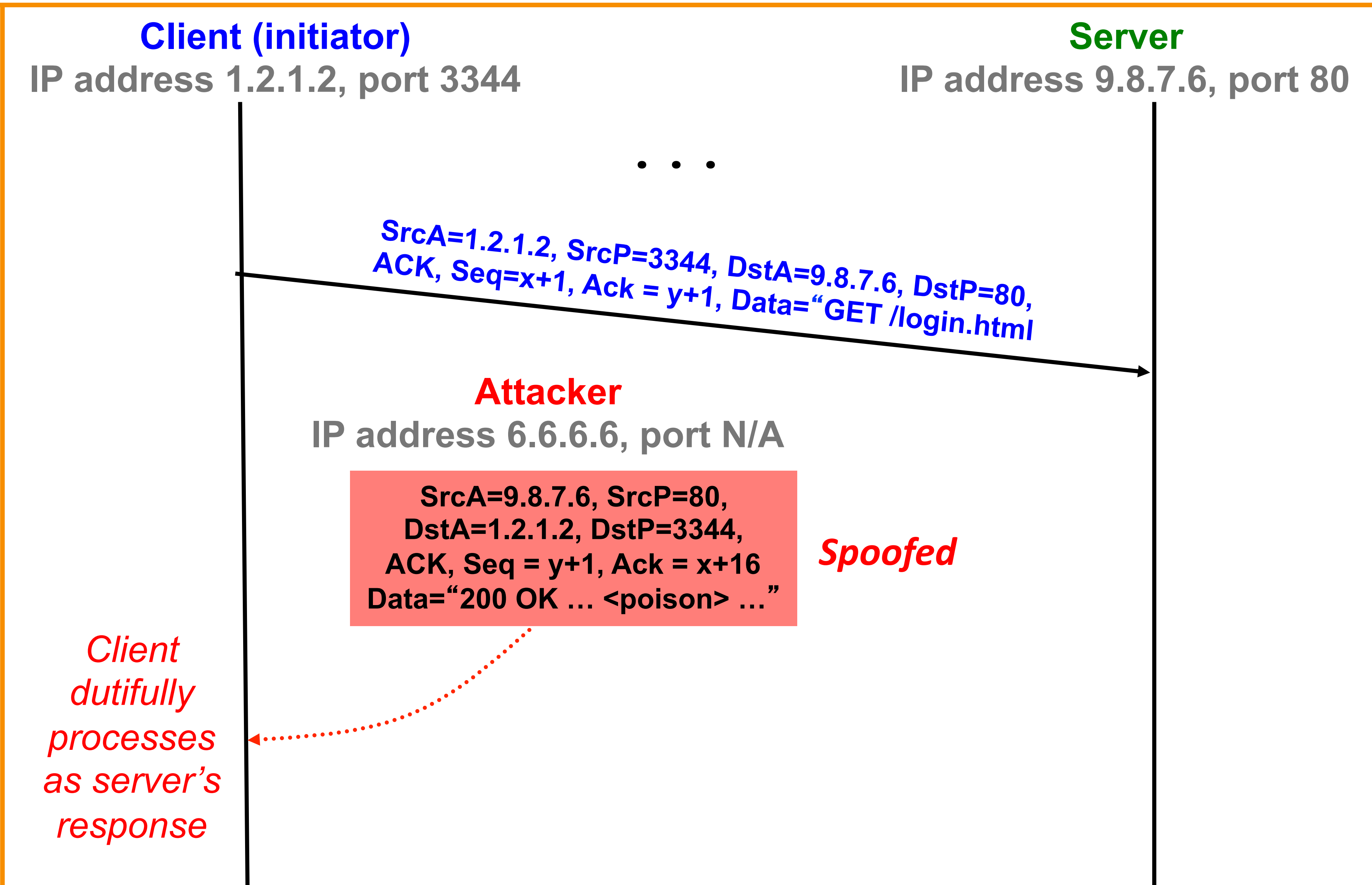


TCP Threat: Data Injection

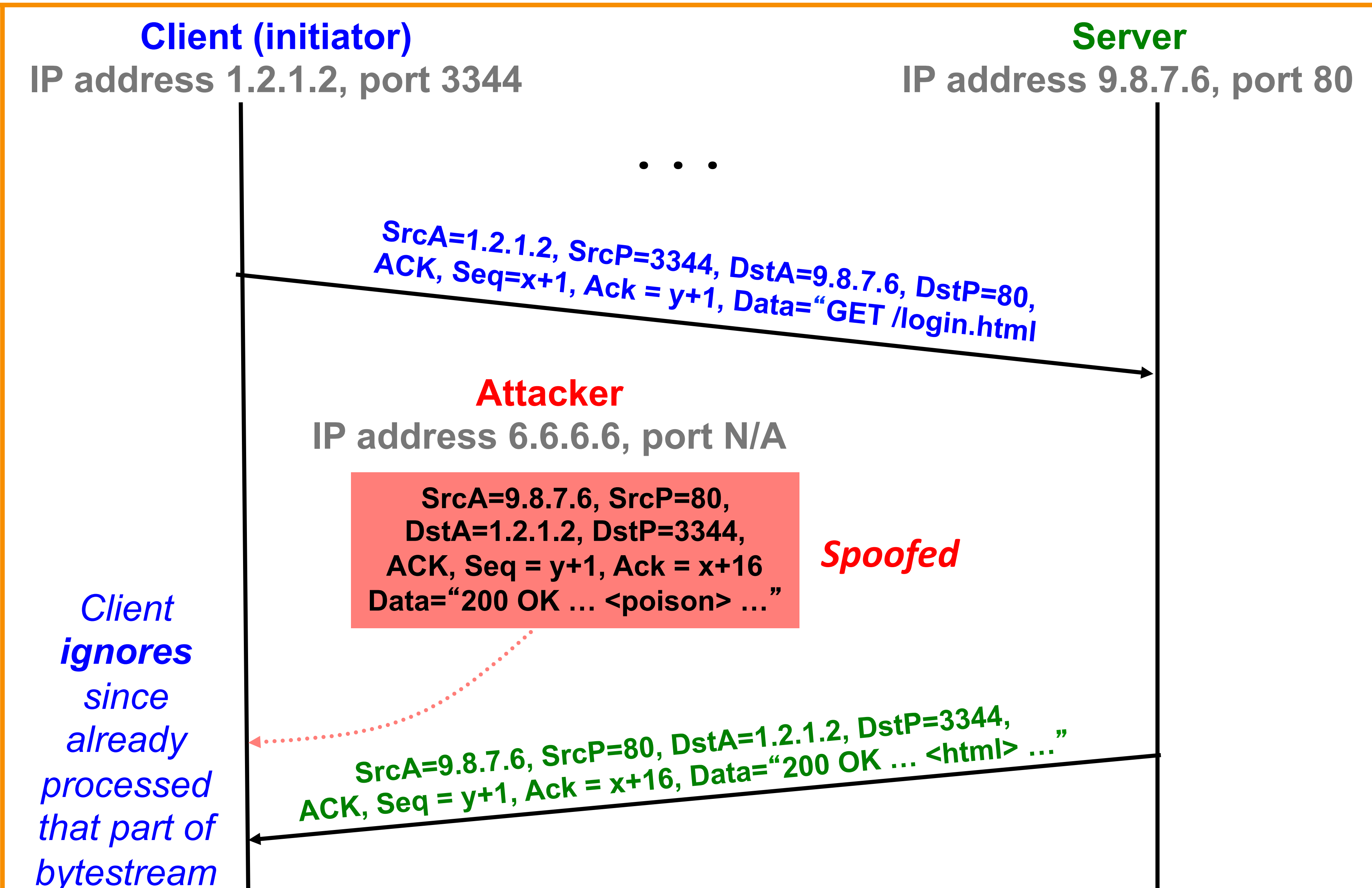


- What about inserting data rather than disrupting a connection?
  - Again, all that's required is attacker knows correct ports, seq. numbers
  - Receiver B is *none the wiser!*
- Termed TCP connection hijacking (or "*session hijacking*")
  - A general means to take over an already-established connection!
- **We are toast if an attacker can see our TCP traffic!**
  - Because then they immediately know the port & sequence numbers

TCP *Data Injection*



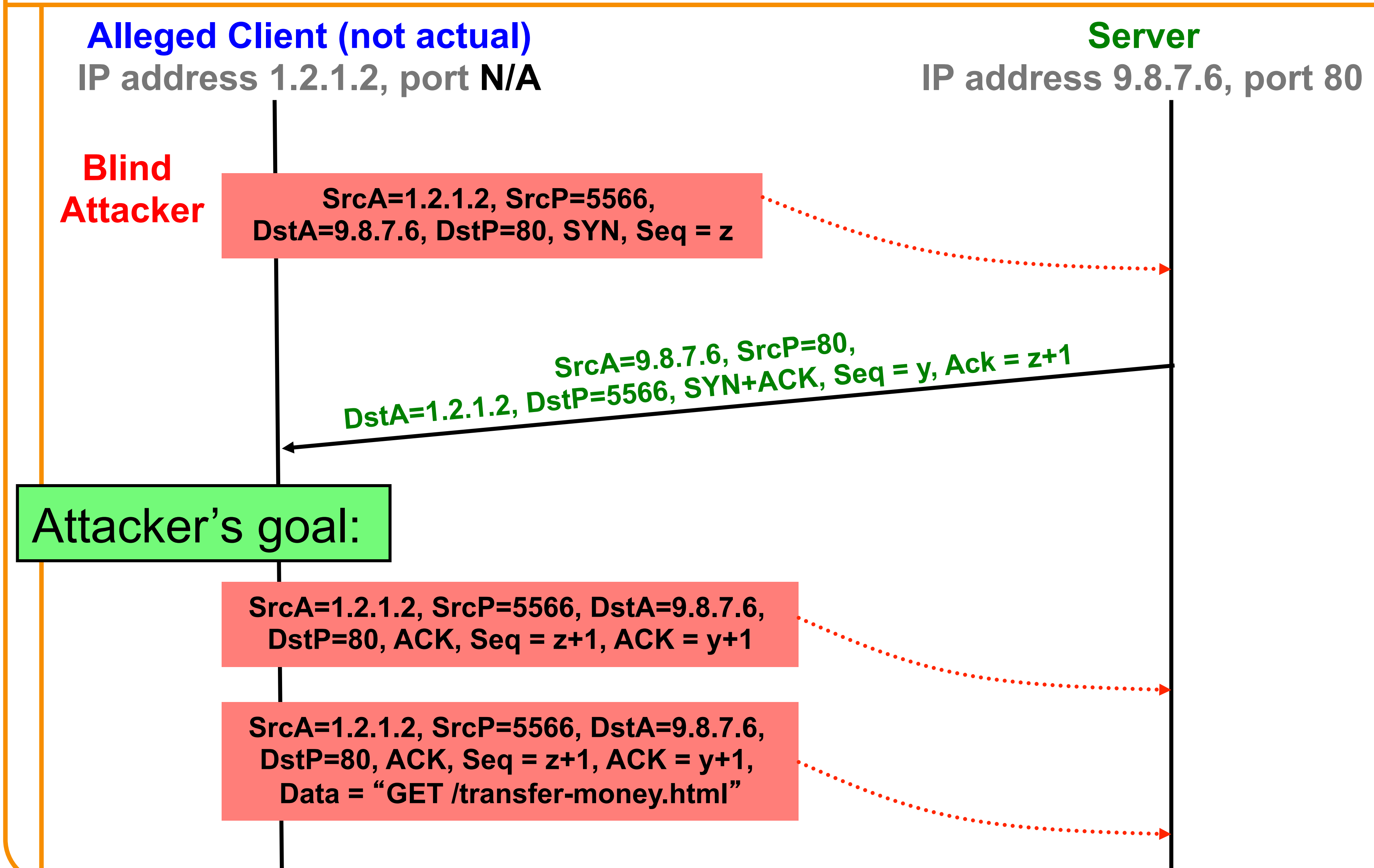
TCP *Data Injection*



TCP Threat: Blind Spoofing

- Is it possible for an attacker to inject into a TCP connection even if they can't see our traffic?
- YES: if somehow they can infer or guess the port and sequence numbers
- Let's look at a simpler related attack where the goal of the attacker is to create a fake connection, rather than inject into a real one
  - Why?
  - Perhaps to leverage a server's trust of a given client as identified by its IP address
  - Perhaps to frame a given client so the attacker's actions during the connections can't be traced back to the attacker

Spoofing an Entire TCP Connection



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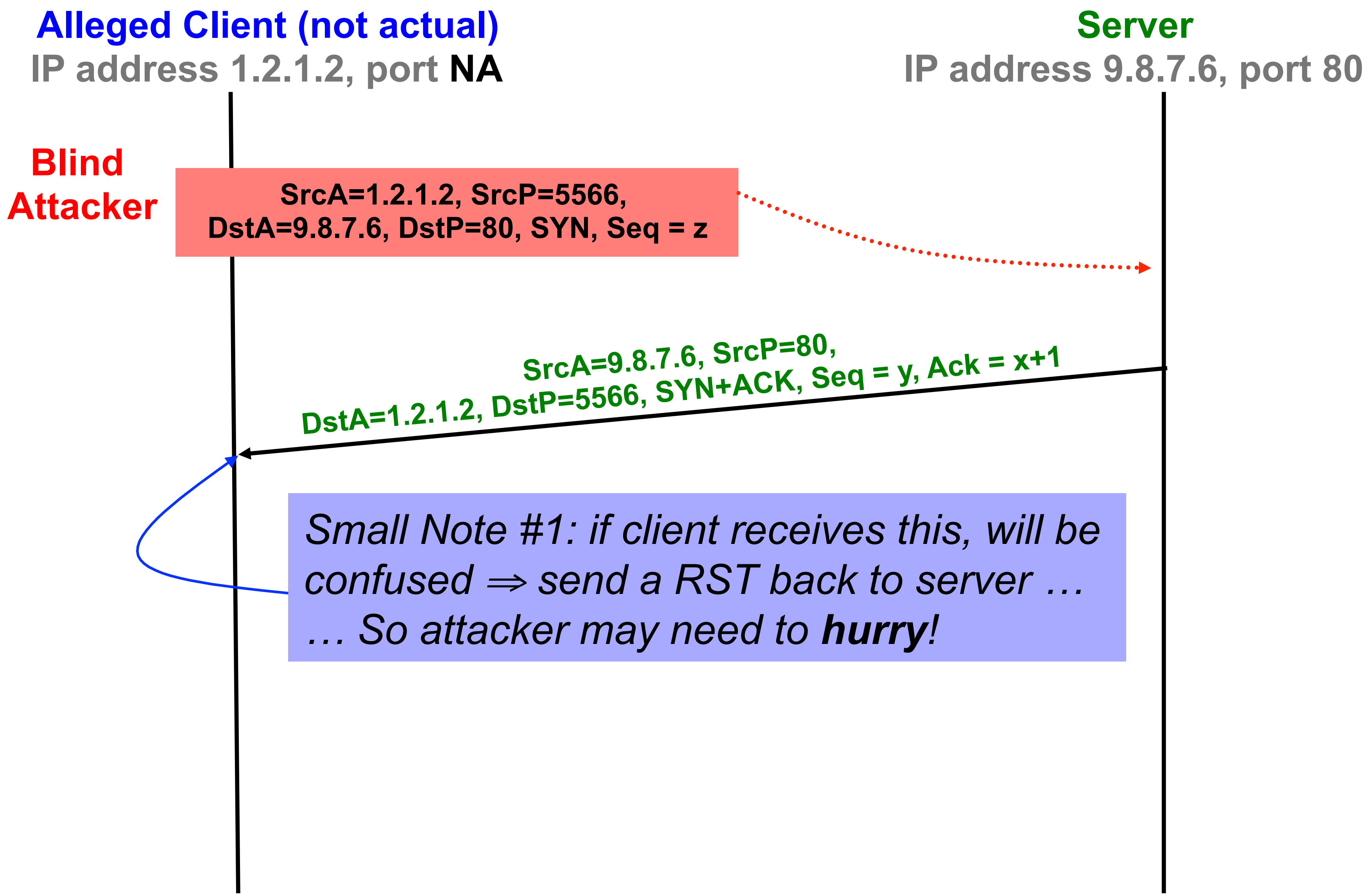

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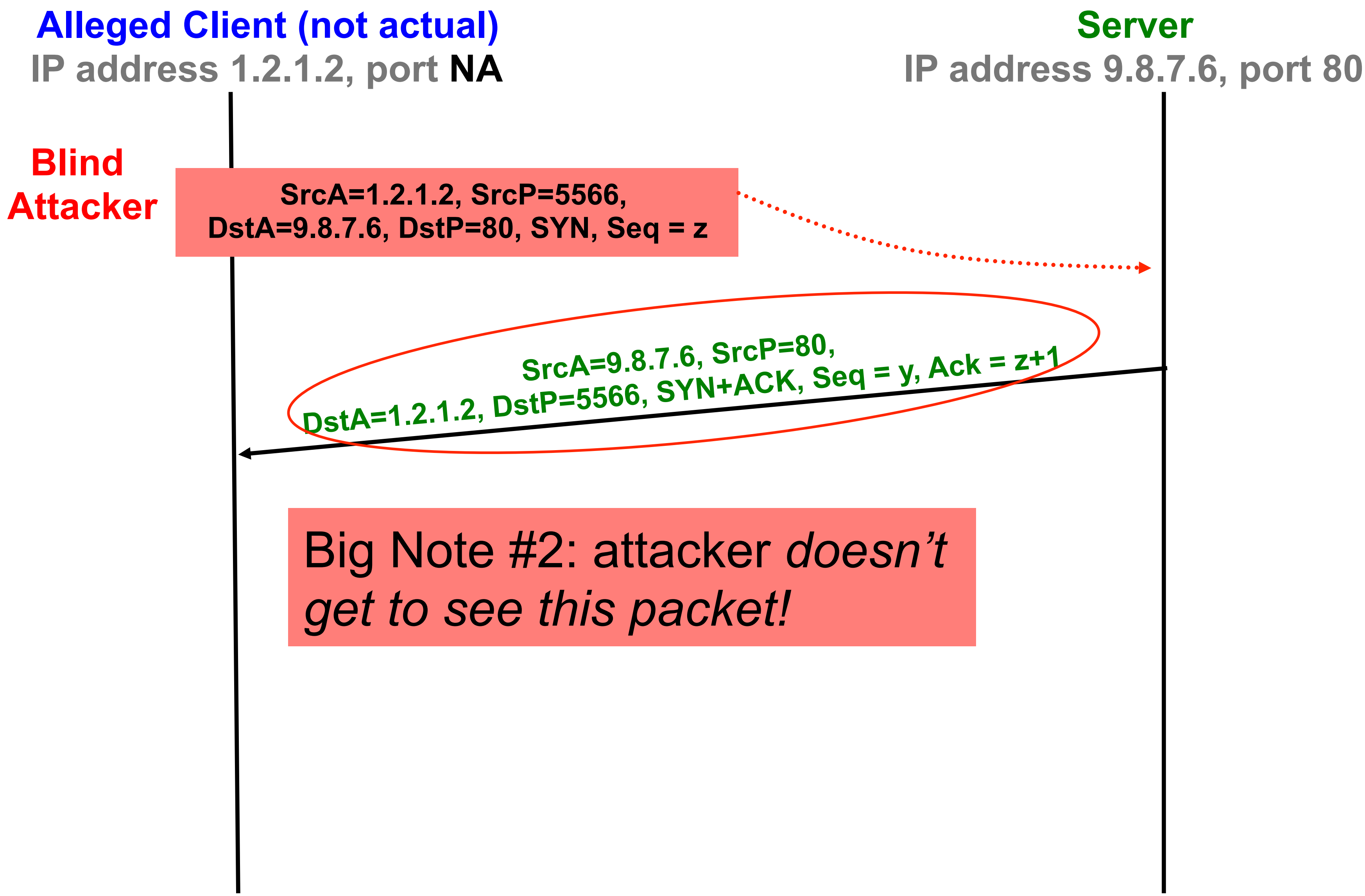
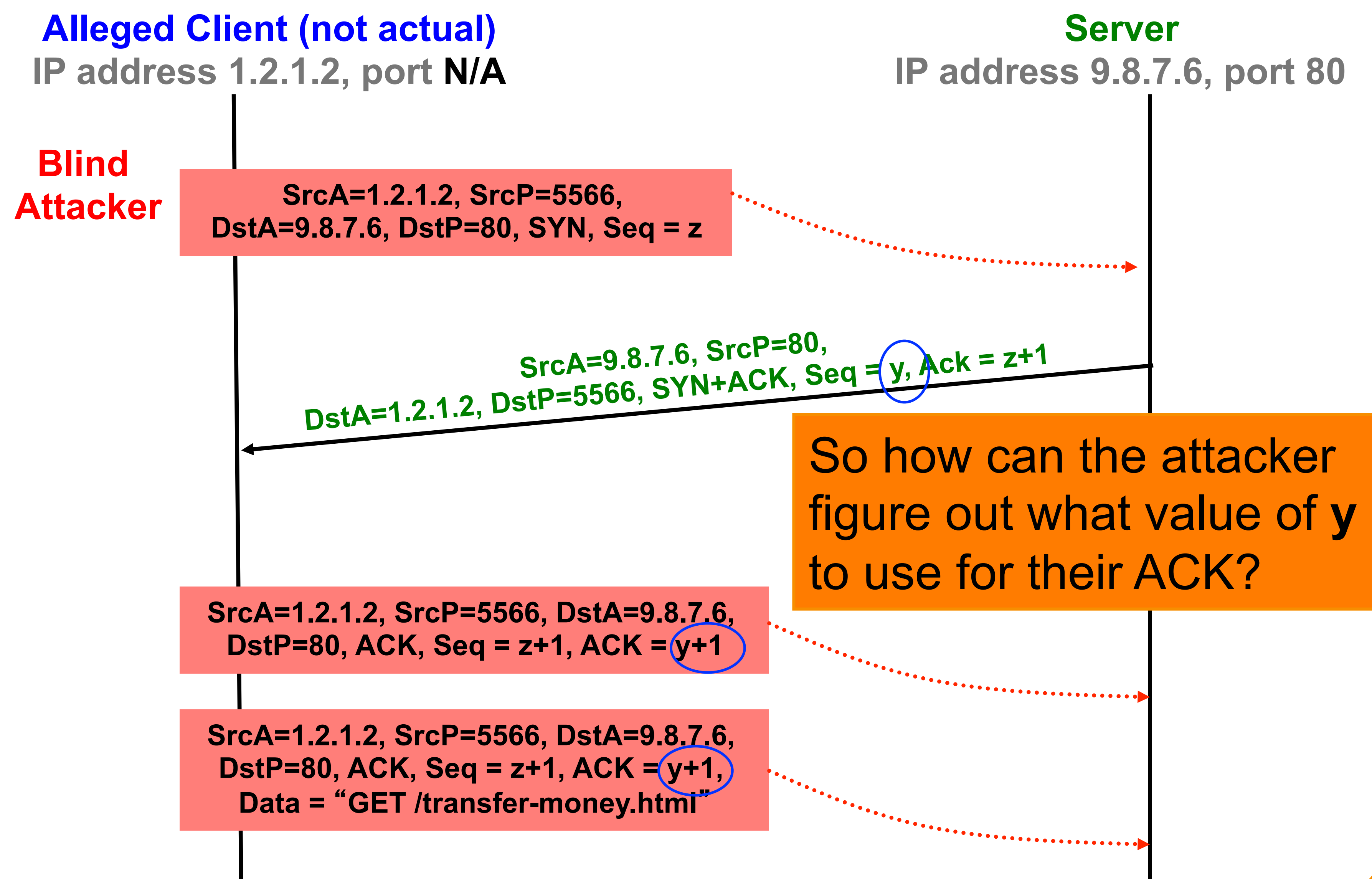
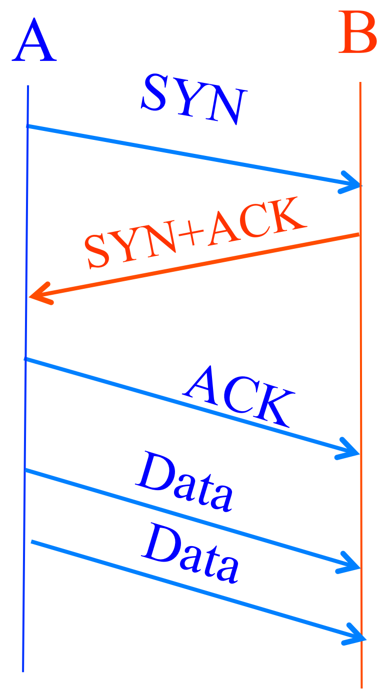


Big Note #2: attacker *doesn't get to see this packet!*

Spoofing an Entire TCP Connection



Reminder: Establishing a TCP Connection



Each host tells its *Initial Sequence Number* (ISN) to the other host.

(Spec says to pick based on a clock)

Hmm, any way for the attacker to know ***this?***

How Do We Fix This?

Use a (Pseudo)-*Random* ISN

Sure - make a non-spoofed connection *first*, and see what server used for ISN y then!

Summary of TCP Security Issues

- An attacker who can observe your TCP connection can manipulate it:
  - Forcefully **terminate** by forging a RST packet
  - **Inject** (*spoof*) data into either direction by forging data packets
  - Works because they can include in their spoofed traffic the correct sequence numbers (both directions) and TCP ports
  - *Remains a major threat today*

Summary of TCP Security Issues

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  - Works because they can include in their spoofed traffic the correct sequence numbers (both directions) and TCP ports
  - *Remains a major threat today*
- An attacker who can predict the ISN chosen by a server can "blind spoof" a connection to the server
  - Makes it appear that host ABC has connected, and has sent data of the attacker's choosing, when in fact it hasn't
  - *Undermines any security based on trusting ABC's IP address*
  - Allows attacker to "frame" ABC or otherwise avoid detection
  - **Fixed** (mostly) today by choosing **random** ISNs

5 Minute Break

Questions Before We Proceed?

DNS: Operation & Threats

Host Names vs. IP addresses

- Host names
  - Examples: `www.cnn.com` and `bbc.co.uk`
  - Mnemonic name appreciated by humans
  - Variable length, full alphabet of characters
  - Provide little (if any) information about location
- IP addresses
  - Examples: `64.236.16.20` and `212.58.224.131`
  - Numerical address appreciated by routers
  - Fixed length, binary number
  - Hierarchical, related to host location

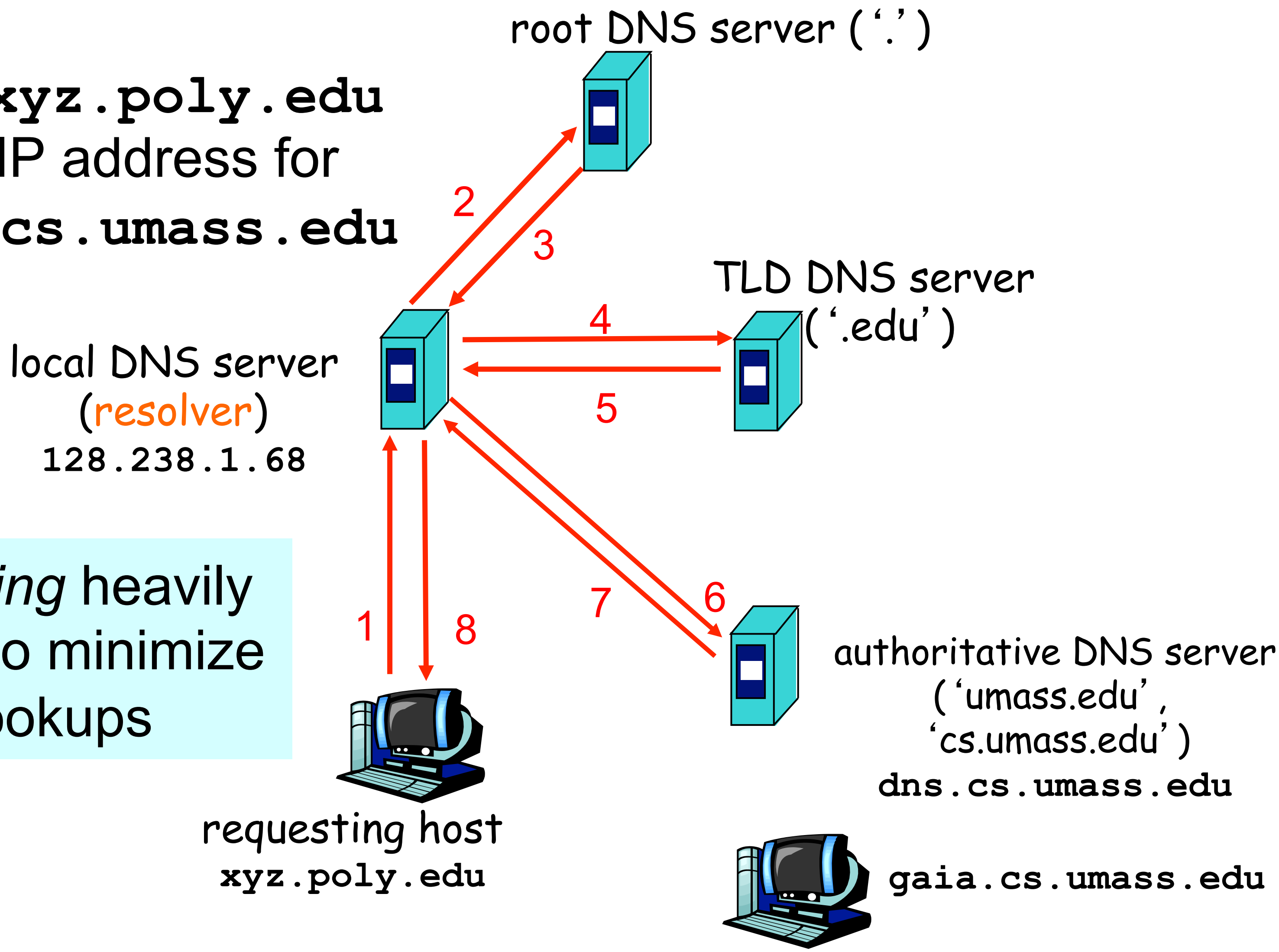
Mapping Names to Addresses

- Domain Name System (DNS)
  - Hierarchical name space divided into sub-trees ("*zones*")
    - *E.g. .edu, .berkeley.edu, .eecs.berkeley.edu*
  - Zones distributed over collection of DNS *name servers*
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
    - E.g. .com, .org, .net, .uk, .biz
  - "Authoritative" DNS servers (e.g. for *facebook.com*)
- End systems configured with IP address of a *resolver* to contact for their lookups

DNS Lookups via a *Resolver*

Host at **`xyz.poly.edu`** wants IP address for **`gaia.cs.umass.edu`**

Caching heavily used to minimize lookups



DNS Threats

- DNS: path-critical for just about everything we do
  - Maps hostnames ⇔ IP addresses
  - Design only **scales** if we can minimize lookup traffic
    - #1 way to do so: caching
    - #2 way to do so: return not only answers to queries, but additional info that will likely be needed shortly
- What if attacker eavesdrops on our DNS queries?
  - Simple to then redirect us w/ **spoofed** misinformation
- Consider attackers who *can't* eavesdrop - but still aim to manipulate us via *how the protocol functions*
- Directly interacting w/ DNS: **`dig`** program on Unix
  - Allows querying of DNS system
  - Dumps each field in DNS responses

dig eecs.mit.edu A

Use Unix "`dig`" utility to look up IP address ("`A`") for hostname `eecs.mit.edu` via DNS

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
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;eecs.mit.edu.                  IN      A

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eecs.mit.edu.           21600   IN      A       18.62.1.6

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mit.edu.                11088
mit.edu.                11088   IN      NS      W20NS.mit.edu.
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```

This is `dig` identifying its version and the query it is attempting to look up

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;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

Status values returned from the remote name server queried by `dig`

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           2160

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

Including a 16-bit **transaction identifier** that enables the DNS client (`dig`, in this case) to match up the reply with its original request

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                                        0NS.mit.edu.
mit.edu.                                        RAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

The name server echoes back the question that it is answering as the first part of its reply

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode
;; flags: qr rd ra; QU                                   IONAL: 3
```

> "**Answer**" tells us the IP address associated with `eecs.mit.edu` is `18.62.1.6` and we can *cache* the result for 21,600 seconds

```
;; QUESTION SECTION:
;eecs.mit.edu.                IN      A

;; ANSWER SECTION:
eecs.mit.edu.         21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.              11088   IN      NS      BITSY.mit.edu.
mit.edu.              11088   IN      NS      W20NS.mit.edu.
mit.edu.              11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.       126738  IN      A       18.71.0.151
BITSY.mit.edu.        166408  IN      A       18.72.0.3
W20NS.mit.edu.        126738  IN      A       18.70.0.160
```