Week 9: Lecture B

Networking 101

Thursday, October 24, 2024

Announcements

- **Project 3: WebSec** released
  - **Deadline:** Thursday, November 7th by 11:59PM

Project 3: Web Security

Deadline: Thursday, November 7 by 11:59PM.

Before you start, review the course syllabus for the Lateness, Collaboration, and Ethical Use policies.

You may optionally work alone, or in teams of **at most two** and submit **one project per team**. If you have difficulties forming a team, post on **Piazza's Search for Teammates** forum. Note that the final exam will cover project material, so you and your partner should collaborate on each part.

The code and other answers your group submits must be entirely your own work, and you are bound by the University's Student Code. You may consult with other students about the conceptualization of the project and the meaning of the questions, but you may not look at any part of someone else's solution or collaborate with anyone outside your group. You may consult published references, provided that you appropriately cite them (e.g., in your code comments). **Don't risk your grade and degree by cheating!**

Complete your work in the **CS 4440 VM**—we will use this same environment for grading. You may not use any **external dependencies**. Use only default Python 3 libraries and/or modules we provide you.

Project 3 progress

Working on Part 1 — 0%

Working on Part 2 — 0%

Working on Part 3 — 0%

None of the above — 0%

Announcements

- **Project 2** grades are now available on **Canvas**

- **Statistics:**
  - Average score: **91.64%**

- **Fantastic job!**

Announcements

- **Project 2** grades are now available on **Canvas**
- Think we made an error? Request a regrade!
  - Valid regrade requests:
    - You have verified your solution is correct (i.e., we made an error in grading)

Project 2 Regrade Requests (see **Piazza** pinned link):
Submit by **11:59 PM** on **Monday 10/28** via **Google Form**

Announcements

Announcements

utahsec

See Discord for meeting info!

utahsec.cs.utah.edu

Questions?

Last time on CS 4440…

Isolation-based Web Security
HTTPS, SSL, and TLS

Client-side web security should uphold…

- **Confidentiality**
  - ???
- **Integrity**
  - ???
- **Privacy**
  - ???

Client-side web security should uphold…

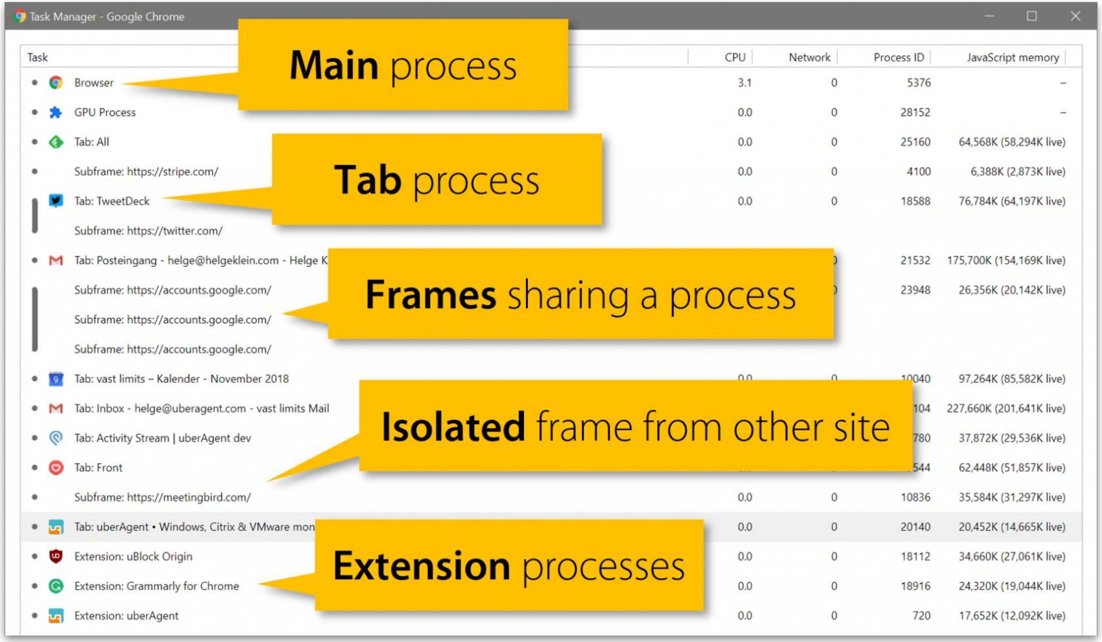
- **Confidentiality**
  - My sensitive information stays private
- **Integrity**
  - My computer and data aren’t tampered
- **Privacy**
  - My online activities are known only to me

Client-side Web Defenses

- **Multi-process Browsing**
  - **???**

Client-side Web Defenses

- **Multi-process Browsing**
  - Each tab, plugin, etc. gets its own unique process
  - Leverage power of MMU to enforce process isolation
  - Compromised process can't read/write memory from other page processes

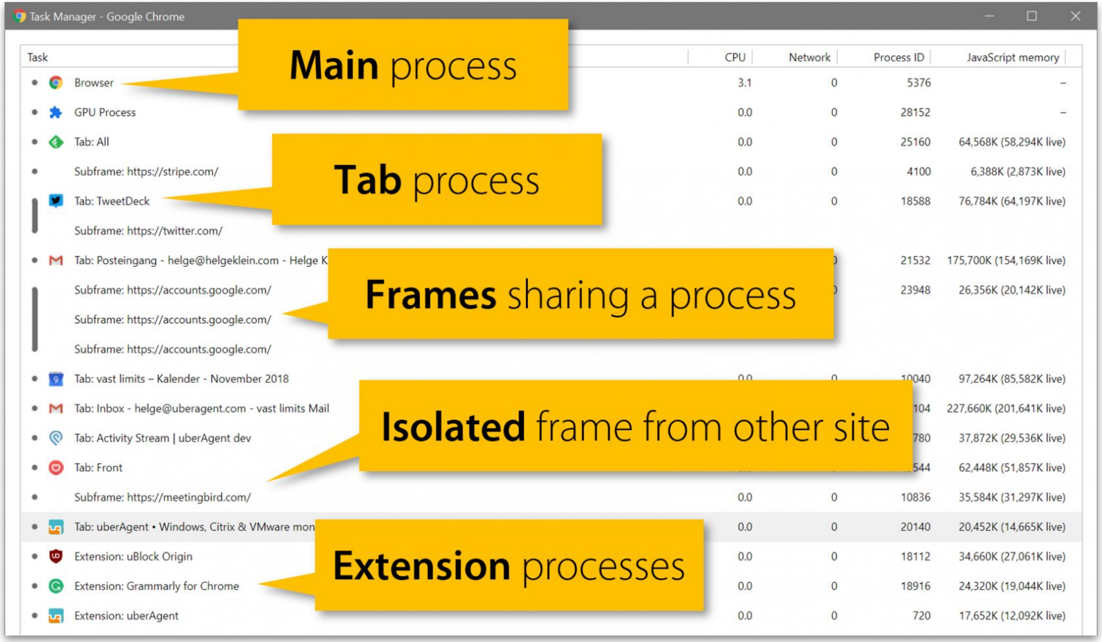


- **Caveat:**
  - ???

Client-side Web Defenses

- **Multi-process Browsing**
  - Each tab, plugin, etc. gets its own unique process
  - Leverage power of MMU to enforce process isolation
  - Compromised process can't read/write memory from other page processes

- **Caveat:**
  - More tabs, more plugins, etc. creates **more overhead**

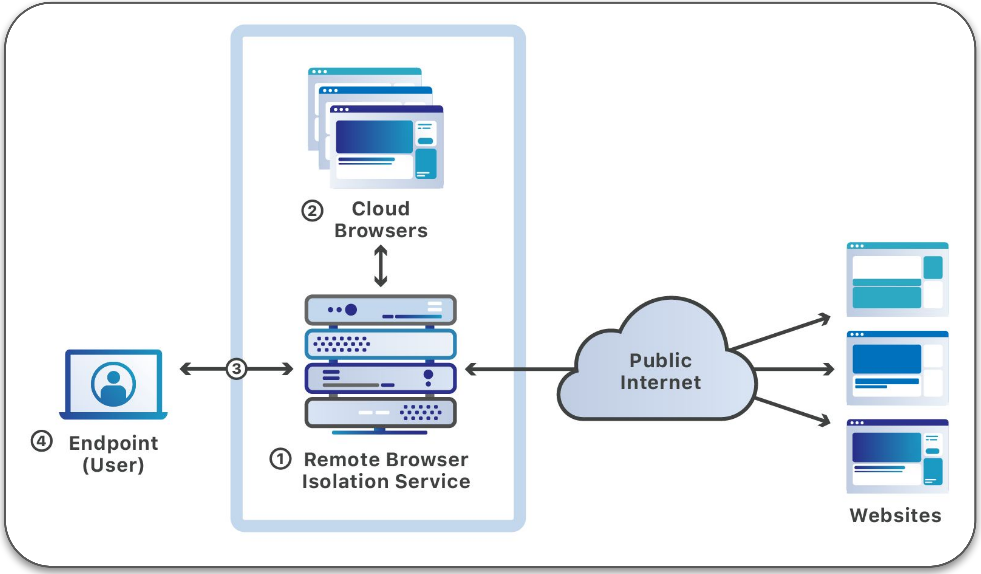


Client-side Web Defenses

- **Remote Pixel Streaming**
  - ???

Client-side Web Defenses

- **Remote Pixel Streaming**
  - Browser lives in the cloud, not the client's system
  - Rendering done in cloud, not on client's system
  - Client only gets "streamed" version of rendered pages
  - Thwarts client-side attacks
- **Caveat:**
  - ???



Client-side Web Defenses

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  - Browser lives in the cloud, not the client's system
  - Rendering done in cloud, not on client's system
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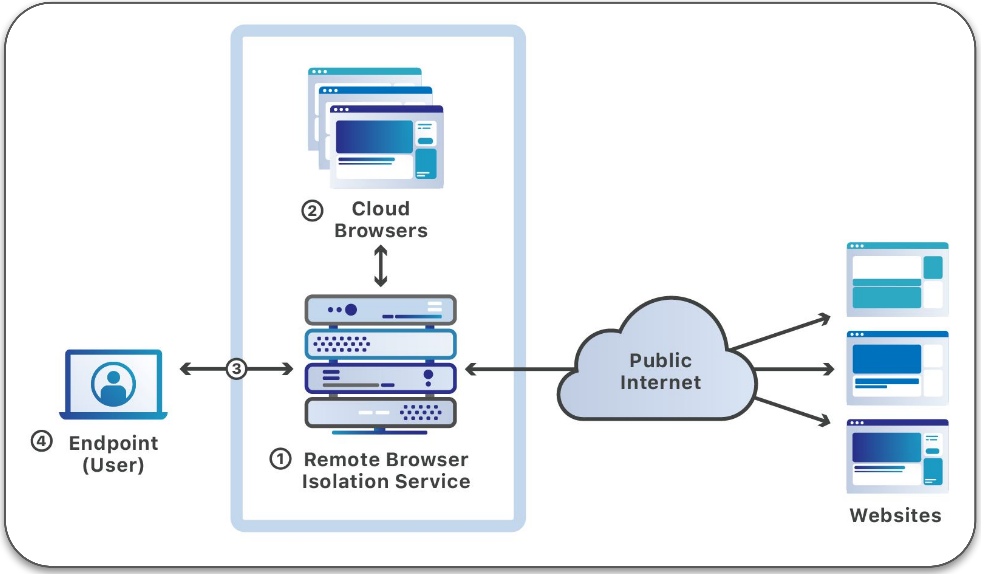
- **Caveat:**
  - Consumes lots of **bandwith**
  - **Bulkier** browsing experience



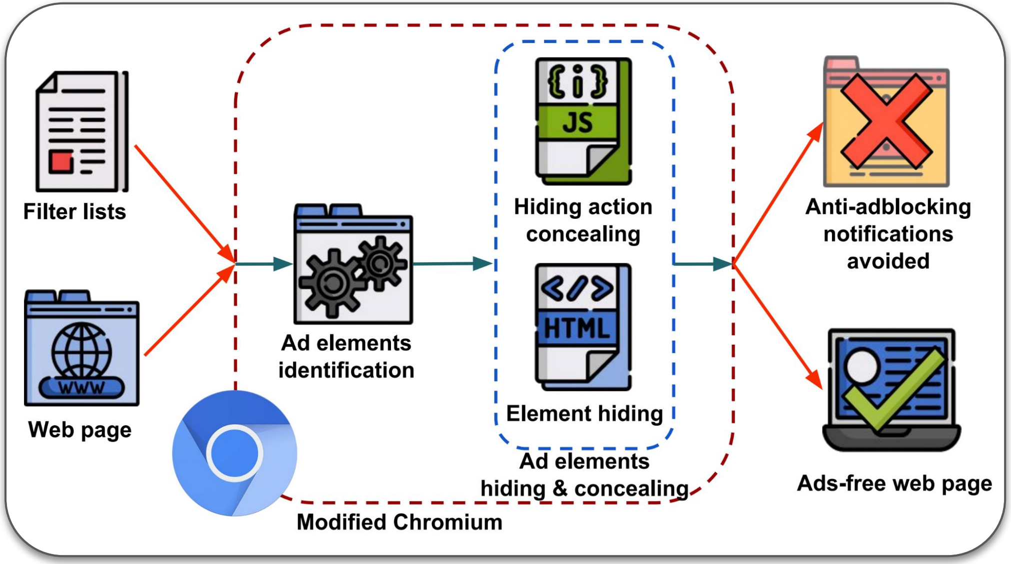
Client-side Web Defenses

- **DOM Tree Mirroring**
  - ???

Client-side Web Defenses

- **DOM Tree Mirroring**
  - Filters-out DOM elements deemed to be unsafe
  - User only gets “safe” DOM
  - List of undesired elements is defined ahead of time

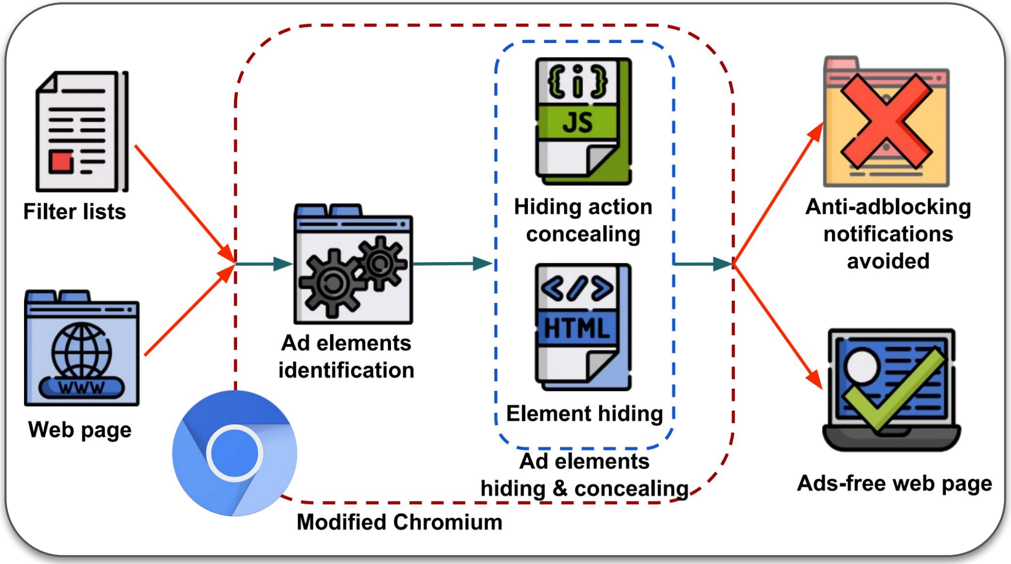
- **Caveat:**
  - ???



Client-side Web Defenses

- **DOM Tree Mirroring**
  - Filters-out DOM elements deemed to be unsafe
  - User only gets "safe" DOM
  - List of undesired elements is defined ahead of time

- **Caveat:**
  - Need to **constantly update** list of unsafe elements
  - Must **retrofit** browsers



Client-side Web Defenses

- **Tagged JS Sandboxing**
  - **???**

Client-side Web Defenses

- **Tagged JS Sandboxing**
  - Follow Same Origin Policy
  - Block JavaScript access based on site’s origin
  - Scripts from same origin can read/write/interact with others from origin
  - Scripts from different origin denied access

- **Caveat:**
  - ???

Client-side Web Defenses

- **Tagged JS Sandboxing**
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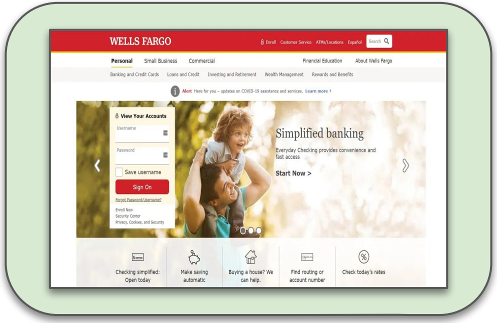

- **Caveat:**
  - Doesn't stop **XSS attacks**

The Same-origin Policy

- Restricts access to content from the same **origin** (**protocol** + **host**)

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- Try the following, comparing to `http://cs4440.eng.utah.edu/project1`

Candidate Request	SOP Result	Explanation
`https://cs4440.eng.utah.edu/project3`		
`http://cs4440.eng.utah.edu/project3/sqlinject0`		
`ftp://cs4440.eng.utah.edu`		
`http://www.cs4440.eng.utah.edu`		
`https://eng.utah.edu/`		

The Same-origin Policy

- Restricts access to content from the same **origin** (**protocol** + **host**)
- Try the following, comparing to `http://cs4440.eng.utah.edu/project1`

Candidate Request	SOP Result	Explanation
`https://cs4440.eng.utah.edu/project3`	**FAIL**	Different protocol (https)
`http://cs4440.eng.utah.edu/project3/sqlinject0`	**PASS**	Same protocol and host
`ftp://cs4440.eng.utah.edu`	**FAIL**	Different protocol (ftp)
`http://www.cs4440.eng.utah.edu`	**FAIL**	Different host (www)
`https://eng.utah.edu/`	**FAIL**	Different protocol and host

Secure web communication should uphold…

- **Integrity**
  - ???
- **Confidentiality**
  - ???
- **Authenticity**
  - ???

Secure web communication should uphold…

- **Integrity**
  - Messages I send should not be tampered
- **Confidentiality**
  - Messages private to only involved parties
- **Authenticity**
  - I should know exactly who I'm talking to

The TLS Handshake

Client Hello: Here's Ciphers I support, and a random

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Client Hello: Here's Ciphers I support, and a random

Server Hello: Chosen Cipher

Certificate: Here is my Certificate with my PubKey

Here's your random back encrypted with my PrivKey

Key Exchange: Our SymKey encrypted with your PubKey

The TLS Handshake

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Switch to a Symmetric Cipher

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Higher-level TLS Handshake

Client says: "Howdy! Here is what cipher suites I support."
"Here is a **random** number for you to encrypt."

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Client says: "Howdy! Here is what cipher suites I support."
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Server says: "Howdy! Let's go with *this* specific cipher."
"Here is my **signed certificate** containing my **public key**."
"Here is your **random** encrypted with my **private key**."

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Client verifies Server's authenticity from its **certificate**; and by decrypting the **Server-encrypted random** via Server's **public key** and checking it to the original.

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Client says: "Great! You are who you say you are. Here's our **symmetric key**."

Higher-level TLS Handshake

Client says: "Howdy! Here is what cipher suites I support."
"Here is a random number for you to encrypt."

Server says: "Ho…
"He… …lic key."
"He… key."

We **do not** expect you to memorize the hairy details about **SSL/TLS**!

Client verifies Server's authenticity from its certificate, and by decrypting the Server-encrypted random via Server's public key and checking it to the original.

Client says: "Great! You are who you say you are. Here's our symmetric key."

Why does the server send back the client's random nonce encrypted?

If client can decrypt with their own private key, the server is verified!

0%

If client can decrypt with server's private key, the server is verified!

0%

If client can decrypt with server's public key, the server is verified!

0%

None of the above

0%

Our HTTPS Ecosystem

- **Certificate: ???**

Our HTTPS Ecosystem

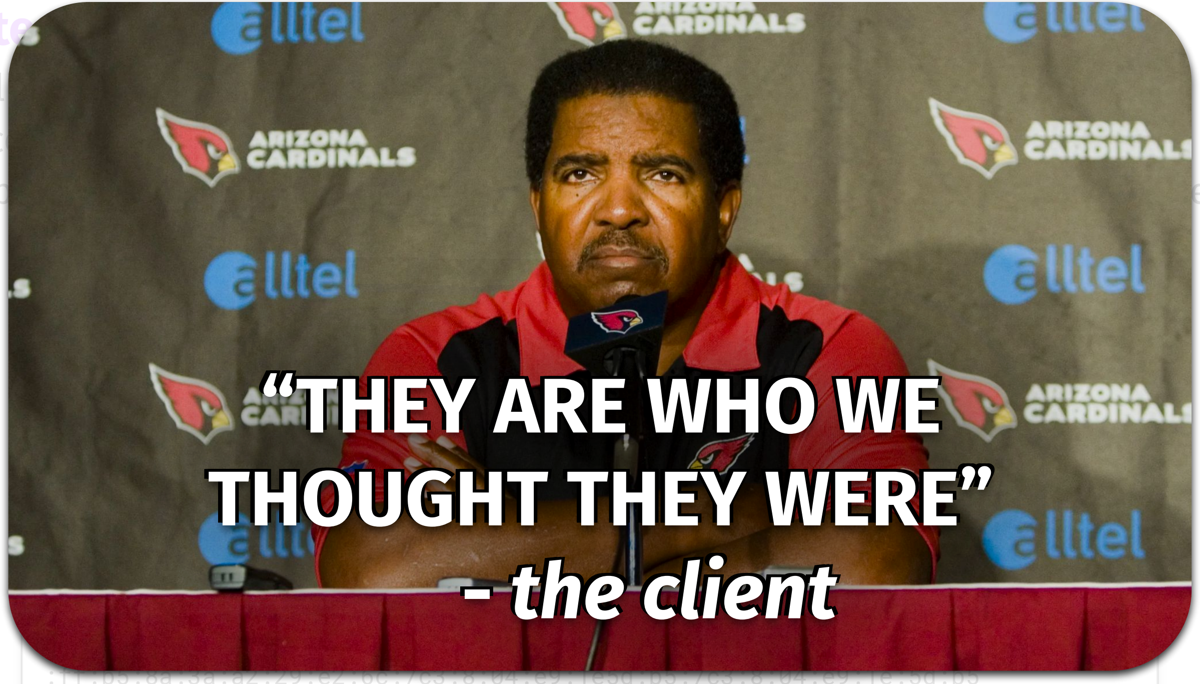
- **Certificate:** the verifiable "proof" of the server's **authenticity**
  - The client (i.e., you) wants to know it is talking to **who it believes it is**
  - Also contains the server's public key, issuer information, expiration, etc.
  - Your browser does **lots of checks** to ensure it's dealing with a valid certificate!

```
Subject:     C=US/O=Google Inc/CN=www.google.com
Issuer: C=US/O=Google Inc/CN=Google Internet Authority
Serial Number: 01:b1:04:17:be:22:48:b4:8e:1e:8b:a0:73:c9:ac:83
Expiration Period: Jul 12 2010 - Jul 19 2012
Public Key Algorithm: rsaEncryption
Public Key: 43:1d:53:2e:09:ef:dc:50:54:0a:fb:9a:f0:fa:14:58:ad:a0:81:b0:3d
7c:be:b1:82:19:b9:7c3:8:04:e9:1e5d:b5:80:af:d4:a0:81:b0:b0:68:5b:a4:a4
:ff:b5:8a:3a:a2:29:e2:6c:7c3:8:04:e9:1e5d:b5:7c3:8:04:e9:39:23:46
```

```
Signature Algorithm:  sha1WithRSAEncryption
```

```
Signature: 39:10:83:2e:09:ef:ac:50:04:0a:fb:9a:f0:fa:14:58:ad:a0:81:b0:3d
7c:be:b1:82:19:b9:7c3:8:04:e9:1e5d:b5:80:af:d4:a0:81:b0:b0:68:5b:a4:a4
:ff:b5:8a:3a:a2:29:e2:6c:7c3:8:04:e9:1e5d:b5:7c3:8:04:e9:1e:5d:b5
```

Our HTTPS Ecosystem



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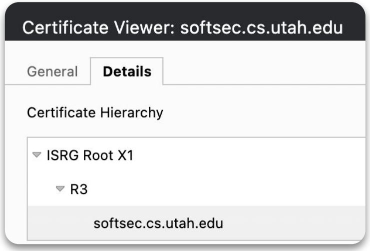
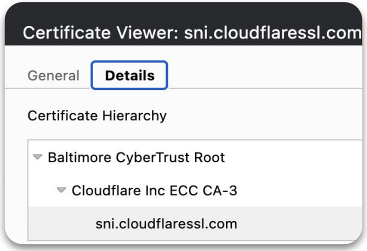
- **Certificate Authority: ???**

Our HTTPS Ecosystem

- **Certificate Authority:** the trusted entity that **vouches for** certificate
  - Acts as a notary for server's certificate





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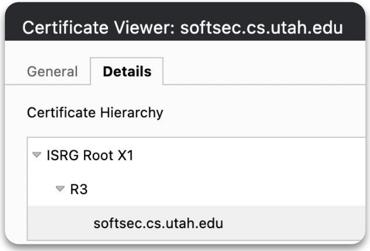
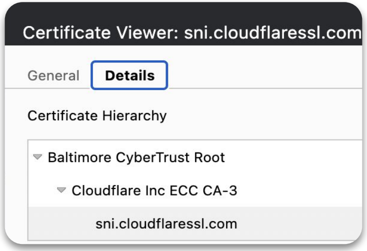
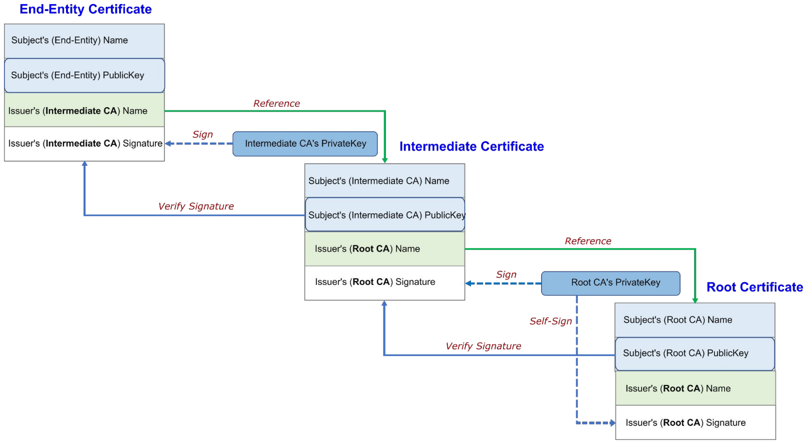
- Certificates are chained together

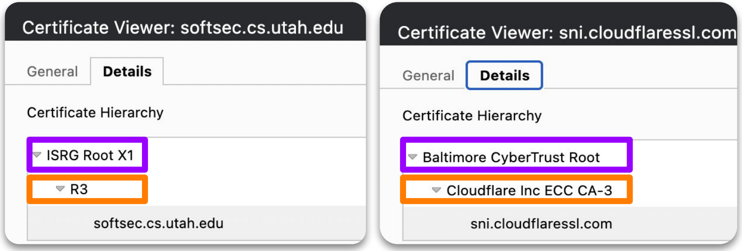


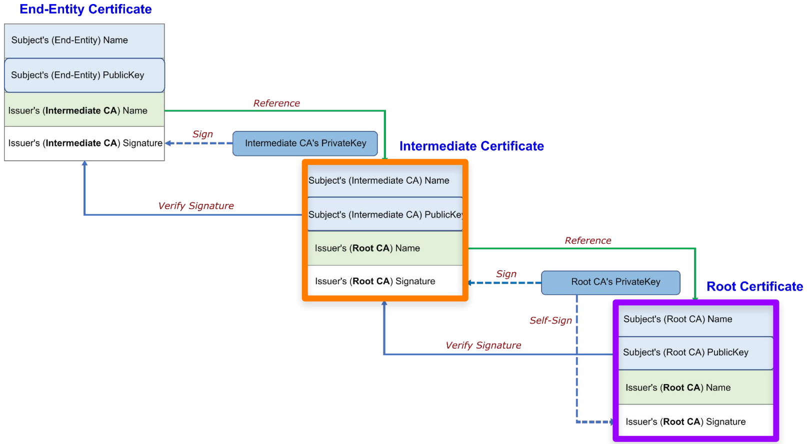




Our HTTPS Ecosystem

- **Certificate Authority:** the trusted entity that **vouches for** certificate
  - Acts as a notary for server's certificate
- Certificates are chained together
  - Links are **intermediate certificates**
  - Ultimately begins in a **root certificate**
    - Your browser "walks" chain to locate certificate that it trusts
  - Anyone can sign a certificate…
    - But if not chained to a **root** certificate, it is **not valid!**





Our HTTPS Ecosystem

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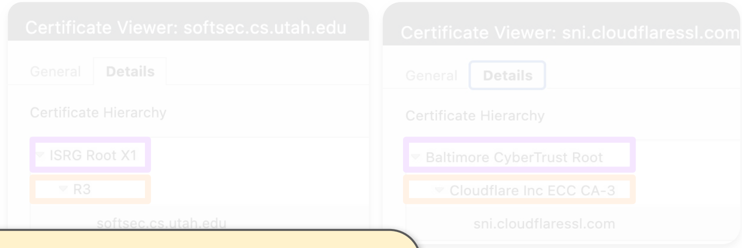
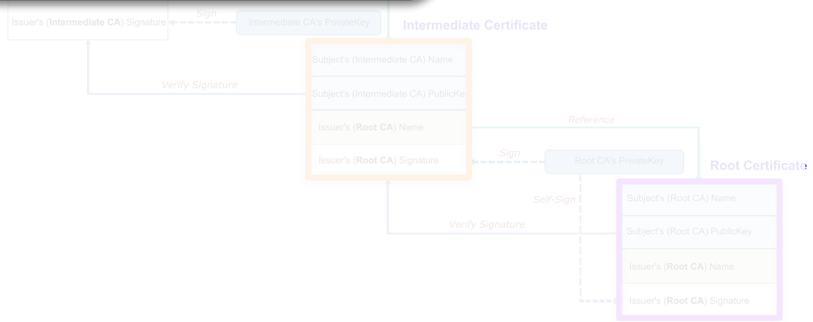


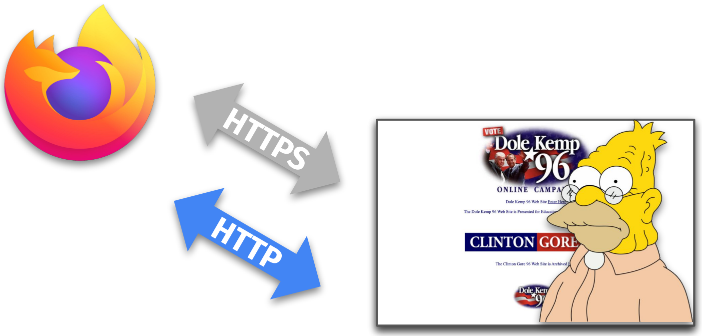
Is HTTPS completely bullet-proof?



Attacking HTTPS: via HTTP

- Browsers permitted HTTP **downgrading**
  - Negotiated during connection establishment
  - Allowed interoperability with legacy sites

- **Attack potential: ???**



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- **Attack potential:** intercept & force **HTTP**
  - Attacker intercepts & **reads client requests**
  - Steal **passwords** of yours on that site


```
POST /login HTTP/1.1
Host: example.com
Content-Type:
application/x-www-form-urlencoded
username=victim&password=h4ck3d
```

Attacking HTTPS: via HTTP

- Browsers permitted HTTP **downgrading**
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- **Attack potential:** intercept & force **HTTP**
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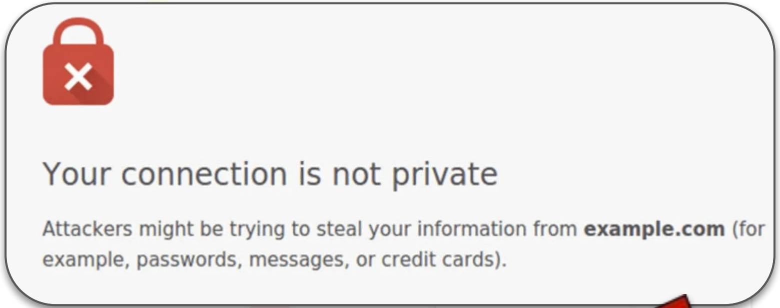
- Nowadays **thwarted via browsers**
  - User would need to add an exception
  - Possible through social engineering?



Modern web browsers **block HTTP** by default

Attacking HTTPS: via HTTP

- Attacking **mixed-content** sites
  - HTTPS page loads some content via HTTP
  - E.g., images, media, JavaScript

- **Risks: ???**

Attacking HTTPS: via HTTP

- Attacking **mixed-content** sites
  - HTTPS page loads some content via HTTP
  - E.g., images, media, JavaScript
- **Risks: loaded** content unencrypted
  - It can be **intercepted and tampered**
  - Attacker may attempt sending scripts
- **Does Same-origin Policy save us?**

Will SOP prevent HTTP scripts execution on HTTPS pages?

Yes! Different origin, so all scripts will be blocked.

0%

No! Same domain, so all scripts will be accepted.

0%

None of the above

0%

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- **Risks:** **loaded** content unencrypted
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- **Does Same-origin Policy save us?**
  - HTTP-transmitted script is **prevented** from accessing the HTTPS page's DOM…
  - But **DOM-*agnostic* scripts** **not blocked**
    - E.g., malicious event handlers!


```
window.onload = function()
{
    alert("PWNED SOP!");
}
```

Attacking HTTPS: via HTTP

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  - HTTPS page loads some content via HTTP
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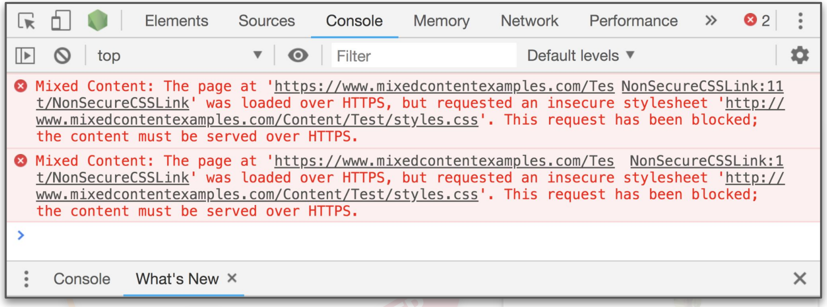
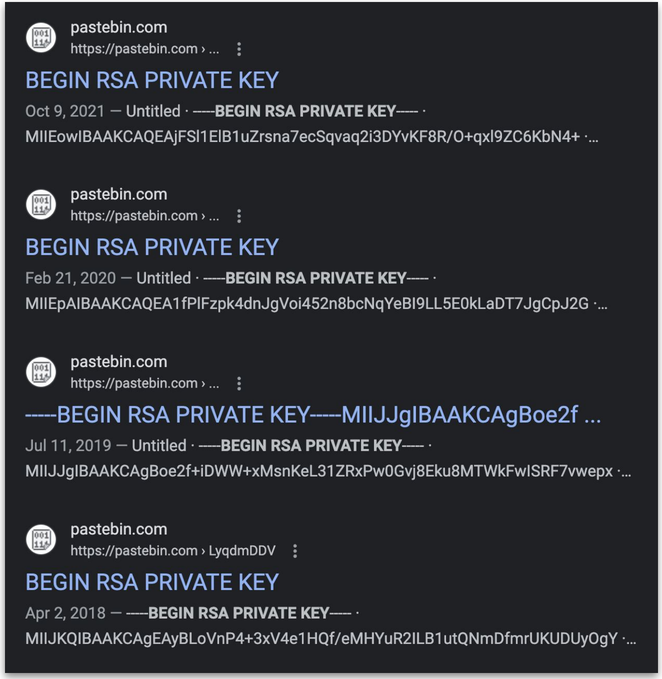


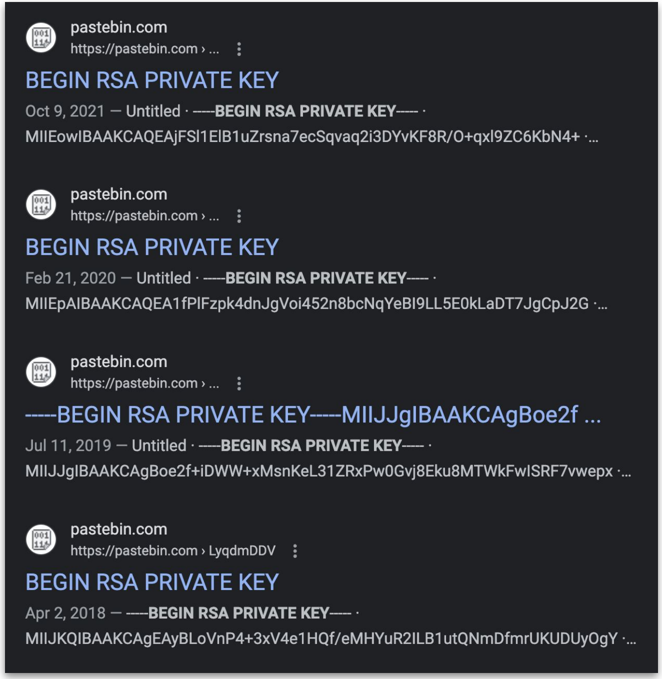
Modern web browsers **block mixed content**

Attacking HTTPS: via Key Theft



Attacking HTTPS: via Key Theft

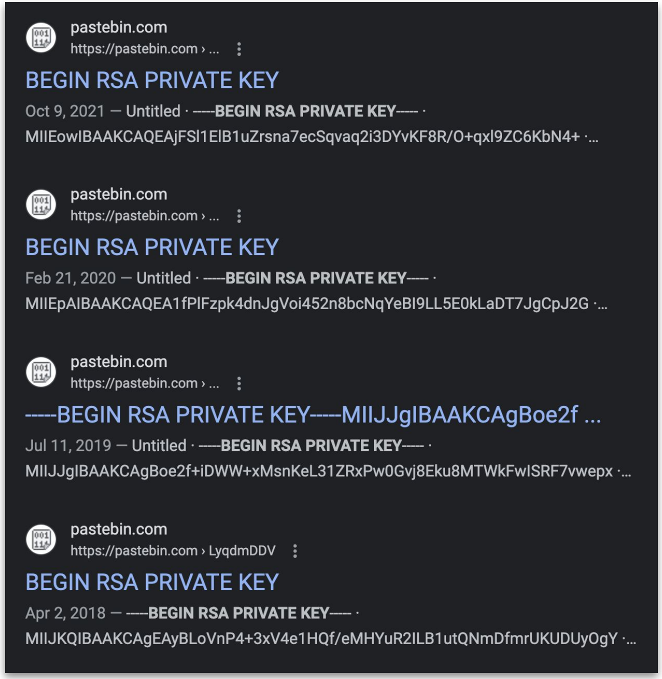
- **What can happen if...**
  - Only **server's** private key stolen:
    - ???
  - Only **client's** private key stolen:
    - ???
  - Both **private** keys are stolen:
    - ???



Attacking HTTPS: via Key Theft

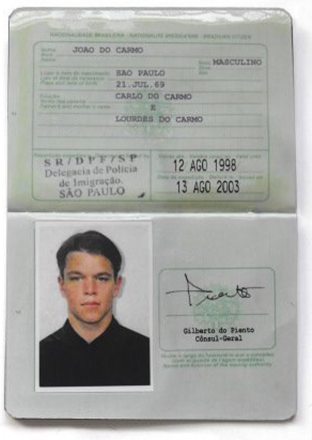
- **What can happen if...**
  - Only **server's** private key stolen:
    - Fake comms **to the client**!
  - Only **client's** private key stolen:
    - Fake comms **to the server**!
  - Both **private** keys are stolen:
    - Full **man-in-the-middle**!

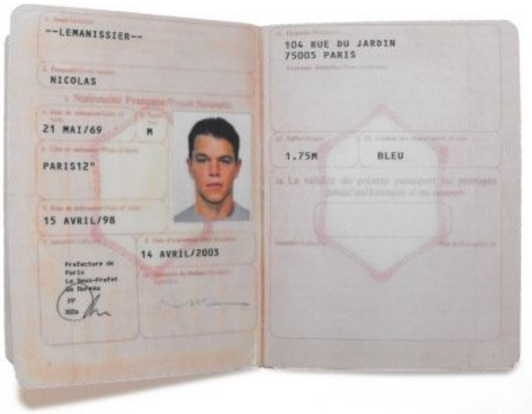
- Don't leave your private keys lying around on public web!

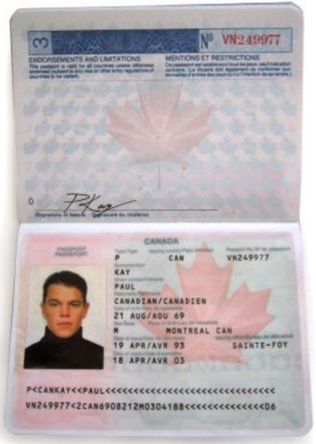


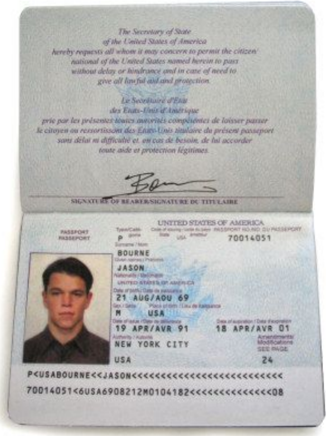
Other ways to attack HTTPS?

- **Certificate Authorities** are what the security of HTTPS depends on
  - If an attacker manages to **breach a CA**, they can sign **any certificate they want**









Other ways to attack HTTPS?

- **Certificate Authorities** are what the security of HTTPS depends on
  - If an attacker manages to **breach a CA**, they can sign **any certificate they want**

Result: attacker can **impersonate** websites that you use—your browser will **accept their certs** as legitimate!

Attacking HTTPS: via Breached CAs

- **Real-world example: DigiNotar**
  - DigiNotar ***was*** a Dutch Certificate Authority
  - On June 10, 2011, `*.google.com` cert was issued to an attacker and subsequently used to perform **man-in-the-middle attacks** in Iran
  - Nobody noticed until someone found the cert in the wild… and posted it to pastebin

DigiNotar
Internet Trust Services

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- DigiNotar later admitted that **dozens of fraudulent certificates** were created
  - Google, Microsoft, Apple and Mozilla all **revoked** the **root** Diginotar certificate
  - Dutch Government took over Diginotar
  - Diginotar went bankrupt and died

DigiNotar
Internet Trust Services

Google Security Blog

The latest news and insights from Google on security and safety on the Internet

An update on attempted man-in-the-middle attacks

August 29, 2011

Posted by Heather Adkins, Information Security Manager

Today we received reports of attempted SSL man-in-the-middle (MITM) attacks against Google users, whereby someone tried to get between them and encrypted Google services. The people affected were primarily located in Iran. The attacker used a fraudulent SSL certificate issued by DigiNotar, a root certificate authority that should not issue certificates for Google (and has since revoked it).

Google Chrome users were protected from this attack because Chrome was able to detect the fraudulent certificate.

Attacking HTTPS: via Breached CAs

The Google webmail of as many as 300,000 Iranians may have been intercepted using fraudulently issued security certificates made after a hack against Dutch certificate authority outfit DigiNotar, according to the preliminary findings of an official report into the megahack.

Between 10 July and 20 July hackers used compromised access to DigiNotar's systems to issue rogue 531 SSL certificate for Google and other domains, including Skype, Mozilla add-ons, Microsoft update and others. DigiNotar only began revoking rogue certificates on 19 July and waited more than a month after this to go public. The fake *.google.com certificate – which was valid for code-signing – wasn't revoked until 29 July.

- Dutch Government took over Diginotar
- Diginotar went bankrupt and died

The latest news and insights from Google on security and safety on the Internet

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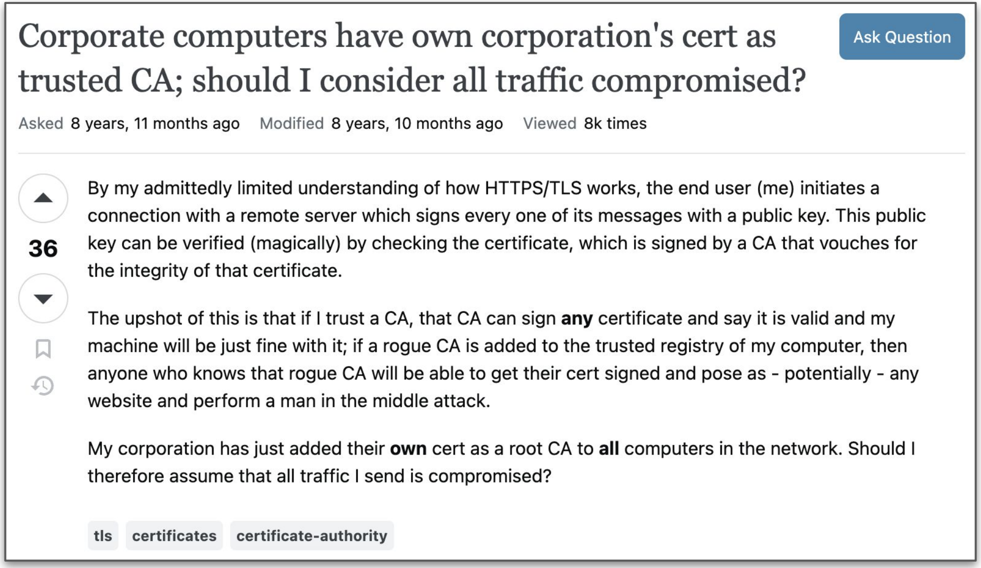
Attacking HTTPS: Employer Eavesdropping

- Can your employer-issued laptop **subvert HTTPS**?

Attacking HTTPS: Employer Eavesdropping

- Can your employer-issued laptop **subvert HTTPS**?
  - No... they're just installing **their own custom root certs**!
  - They own the root certificate = **they own the trust chain**



Corporate computers have own corporation's cert as trusted CA; should I consider all traffic compromised?

Ask Question

Asked 8 years, 11 months ago Modified 8 years, 10 months ago Viewed 8k times

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By my admittedly limited understanding of how HTTPS/TLS works, the end user (me) initiates a connection with a remote server which signs every one of its messages with a public key. This public key can be verified (magically) by checking the certificate, which is signed by a CA that vouches for the integrity of that certificate.

The upshot of this is that if I trust a CA, that CA can sign **any** certificate and say it is valid and my machine will be just fine with it; if a rogue CA is added to the trusted registry of my computer, then anyone who knows that rogue CA will be able to get their cert signed and pose as - potentially - any website and perform a man in the middle attack.

My corporation has just added their **own** cert as a root CA to **all** computers in the network. Should I therefore assume that all traffic I send is compromised?

tls certificates certificate-authority

Questions?

This time on CS 4440…

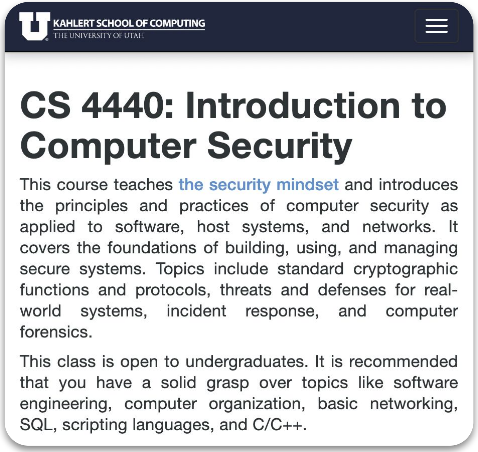
Introduction to Networking
The Physical, Link, Network,
Transport, and Application Layers

What is the Internet?

- **What is it?**

What is the Internet?

- **What is it?**
  - How you trash-talk players in COD game lobbies
  - How Wall Street trades shares faster than you
  - How the CS 4440 website is distributed to you



What *really* is the Internet?

- **Connections**
  - HTTP, HTTPS, FTP, VOIP
- **The Web**
  - Content viewed in a web browser
- How **many** internets?
  - U.S.A. vs. China
  - TOR vs. non-TOR
- What **separates** them?

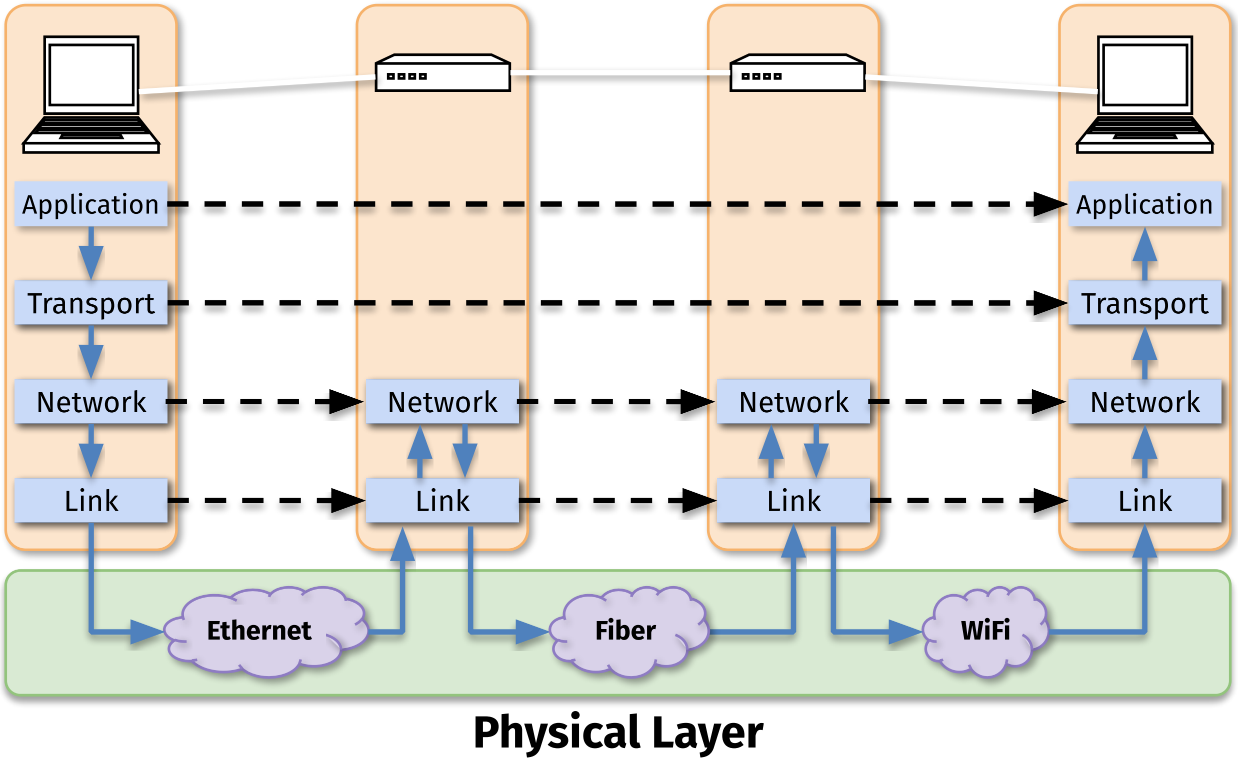
Analogy: Air Travel

- Each **layer** implements a service

Departure Airport	Destination Airport
Ticket (**purchase**)	Ticket (**complain**)
Baggage (**check**)	Baggage (**claim**)
Gate (**load**)	Gate (**unload**)
Runway (**takeoff**)	Runway (**land**)

Routing (**flying**)

The 5-layer Internet



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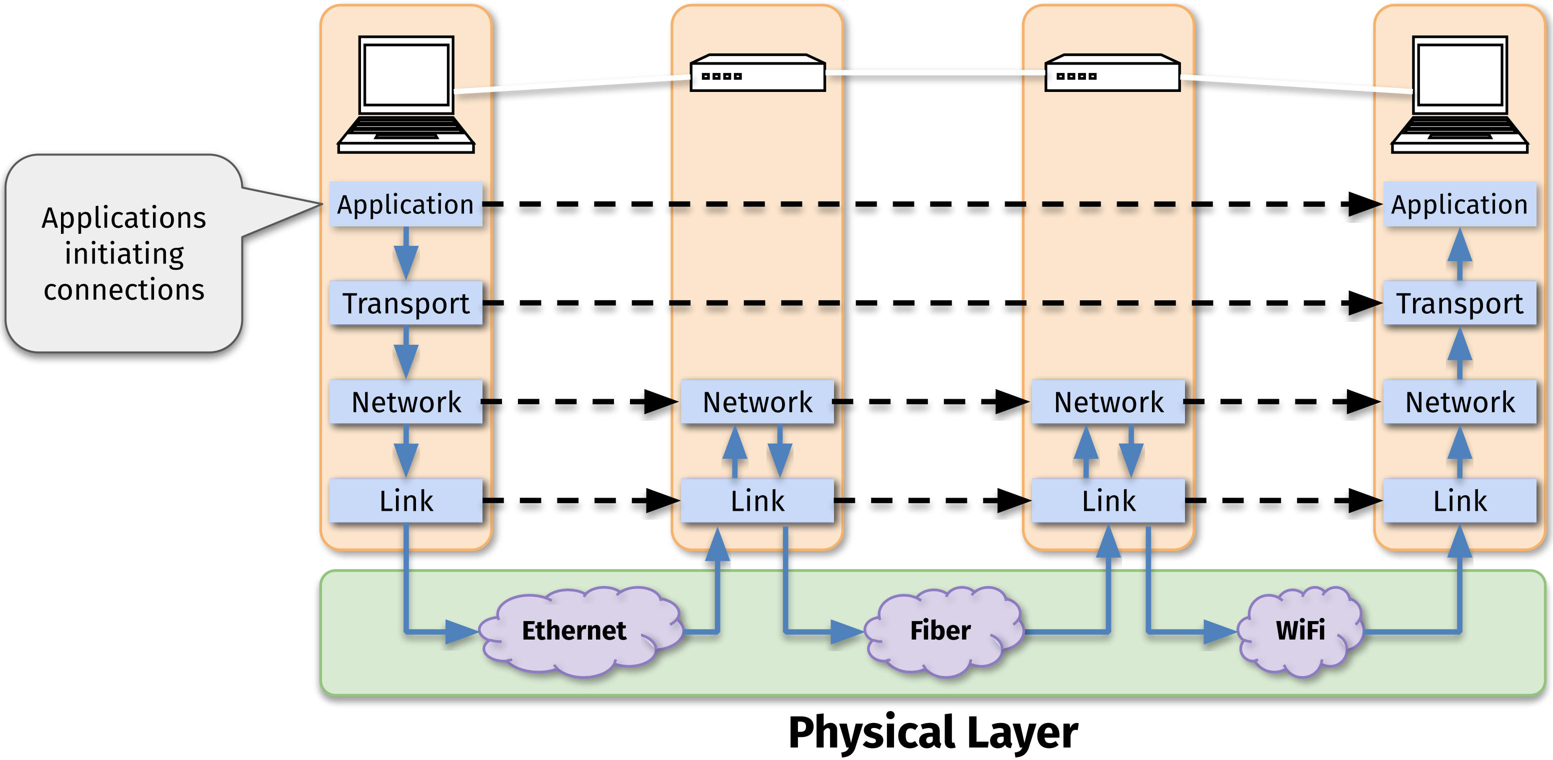

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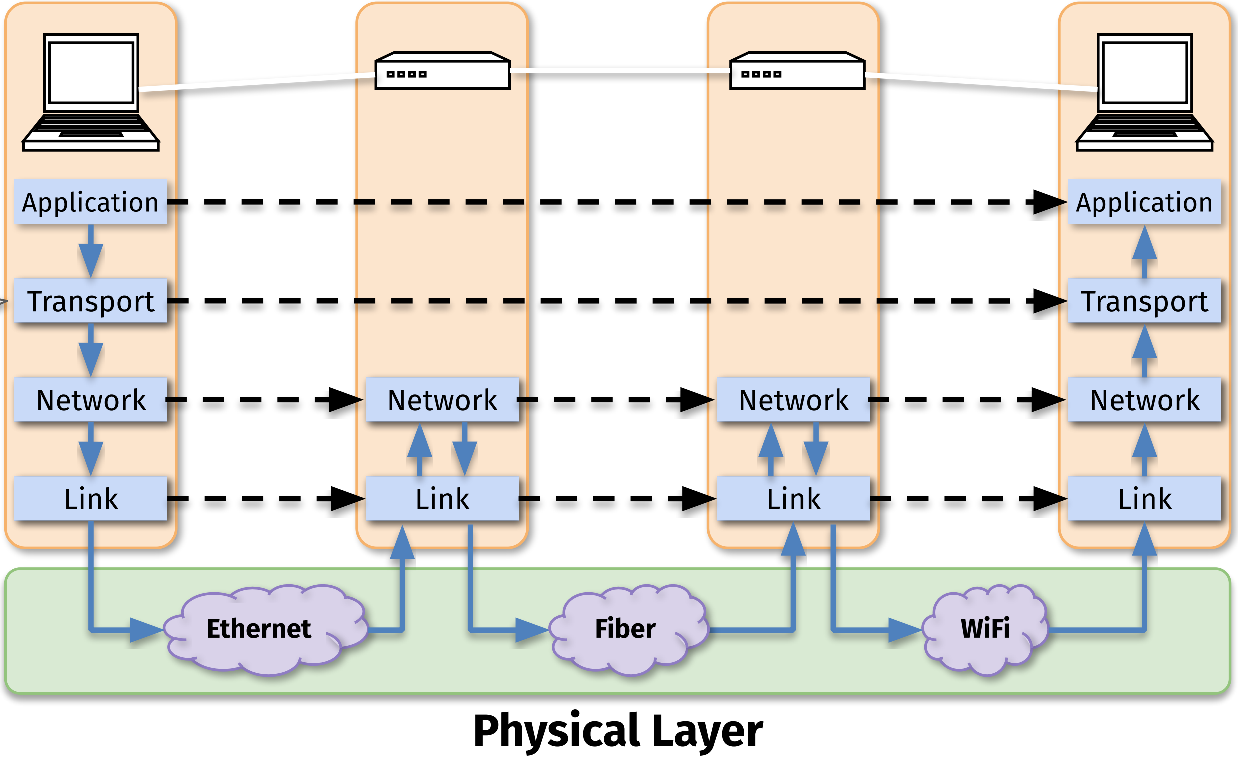
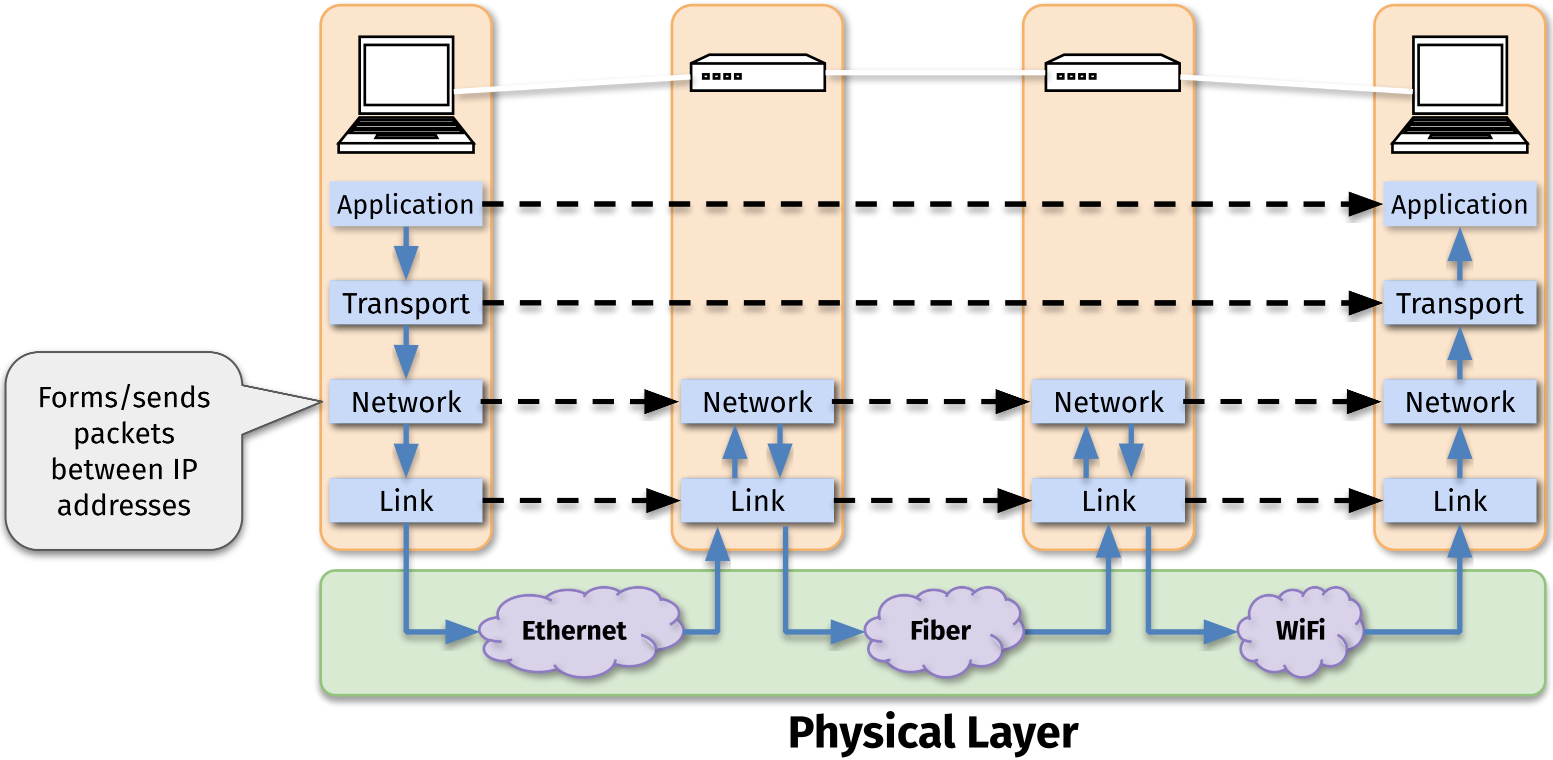


Establishes connections

The 5-layer Internet



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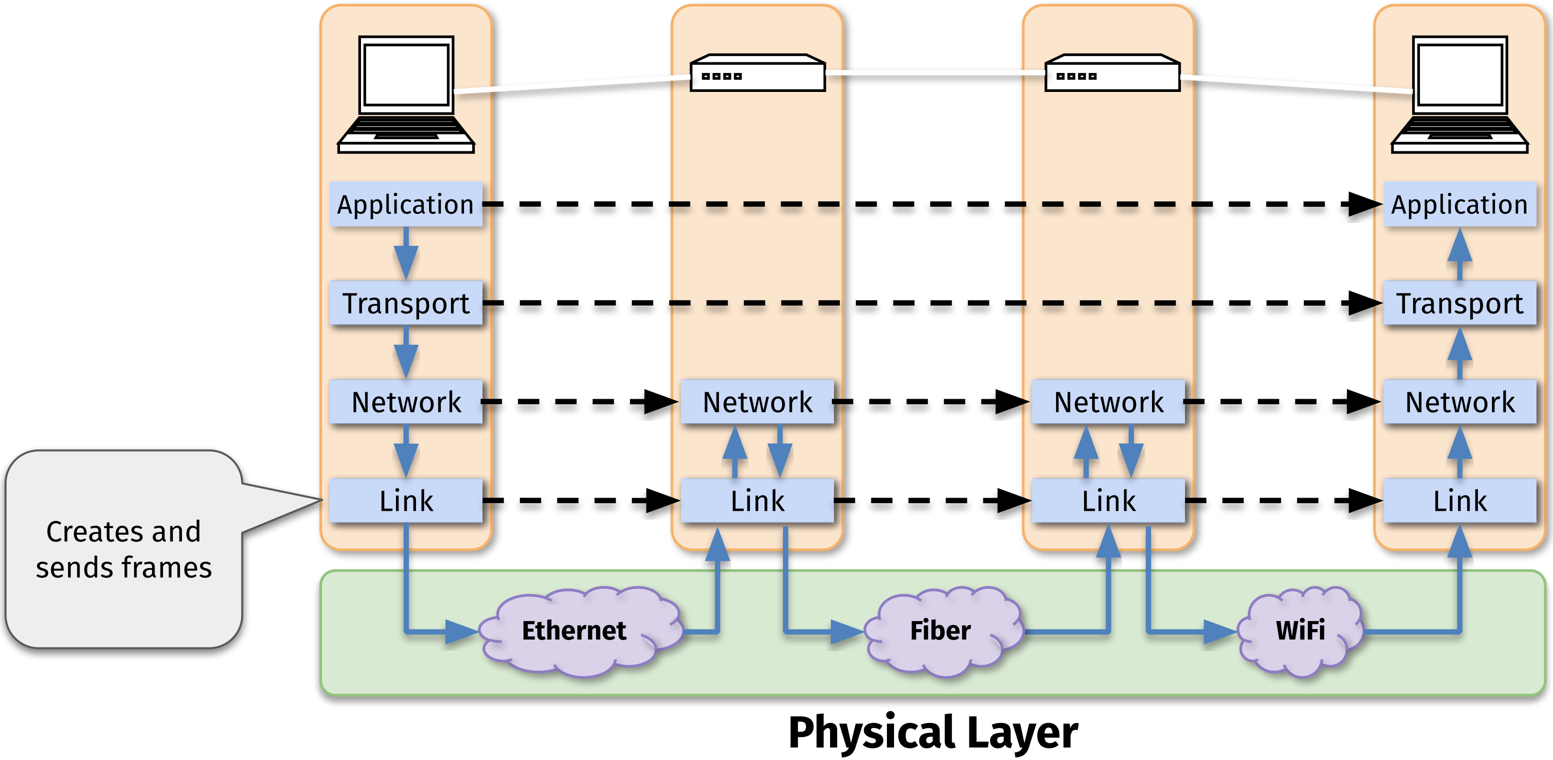

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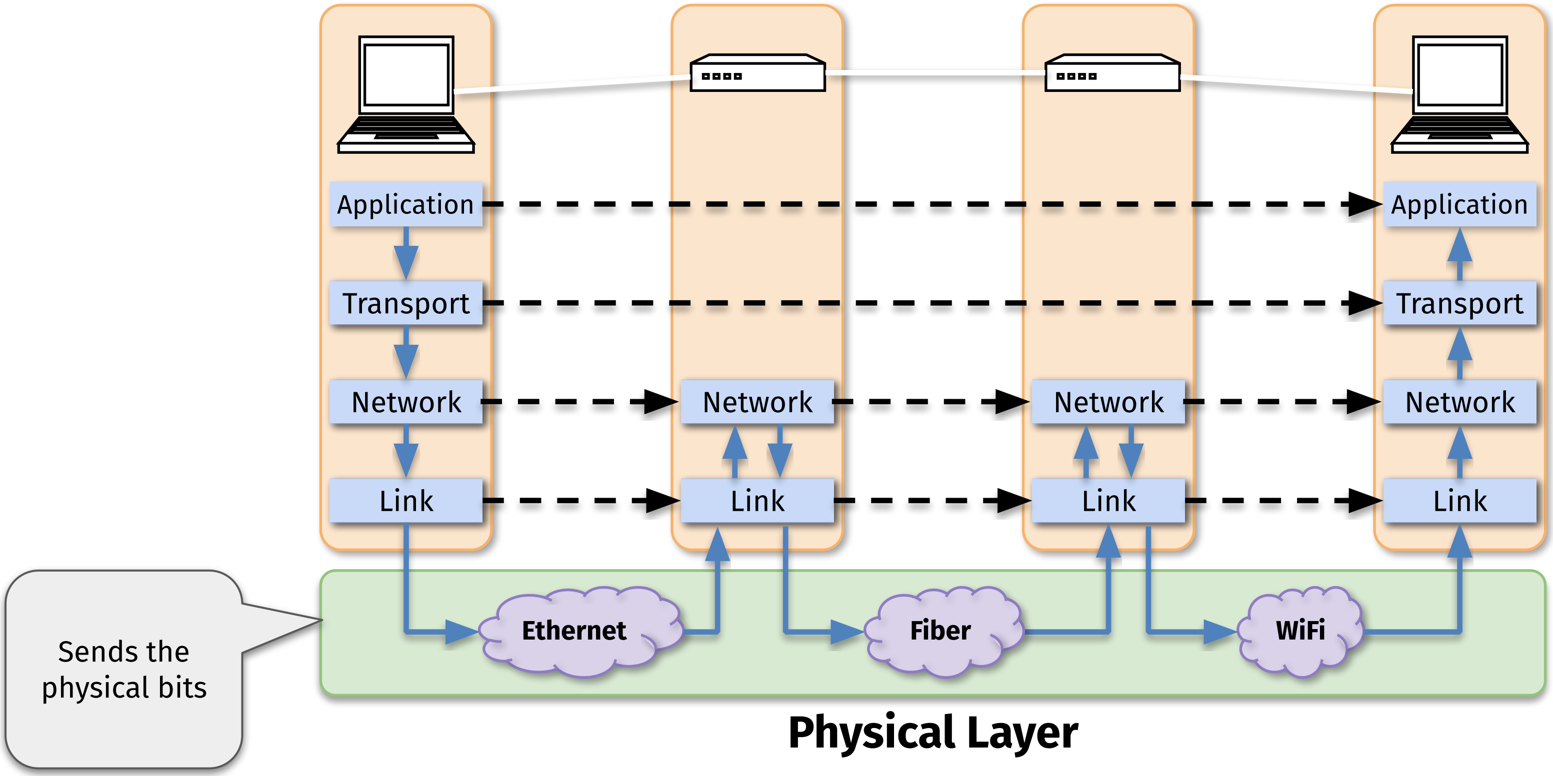

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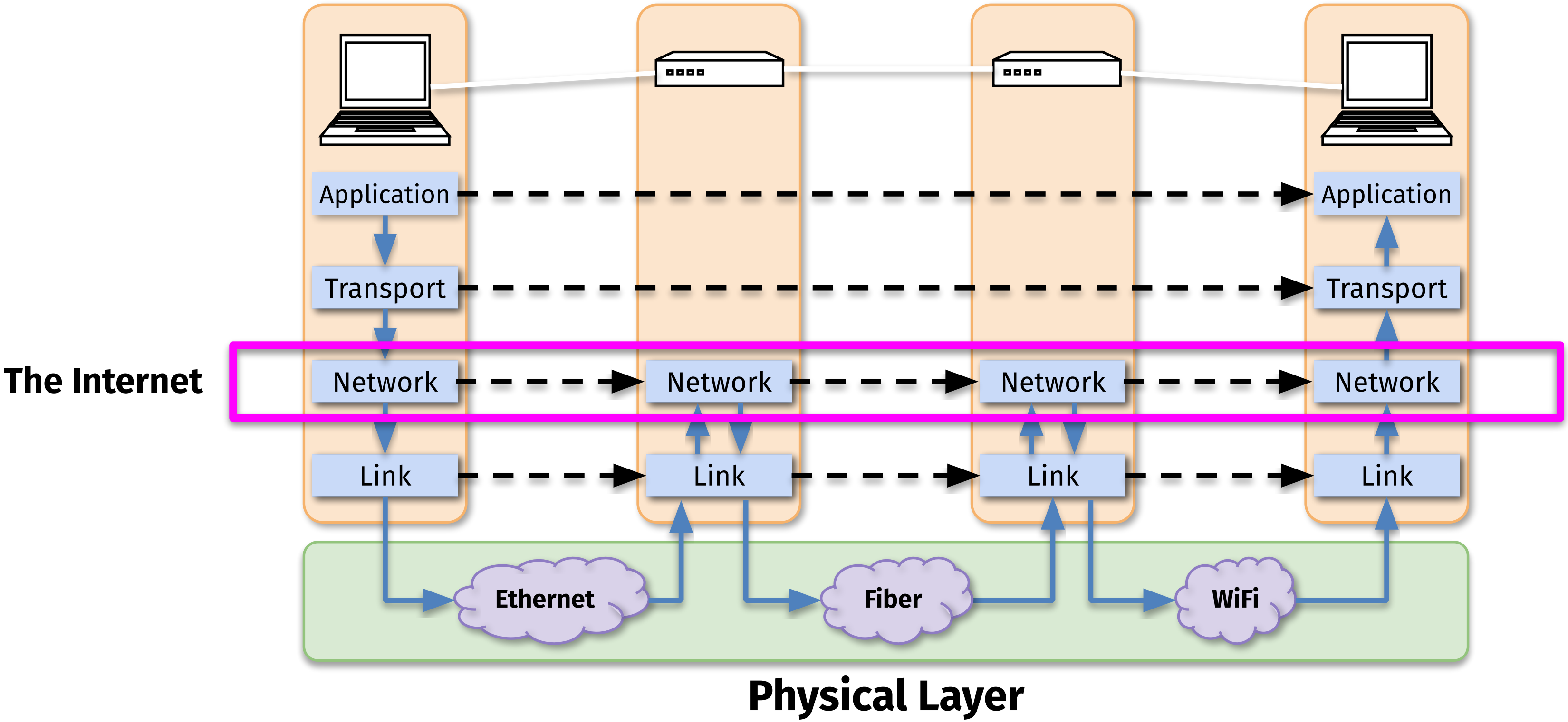
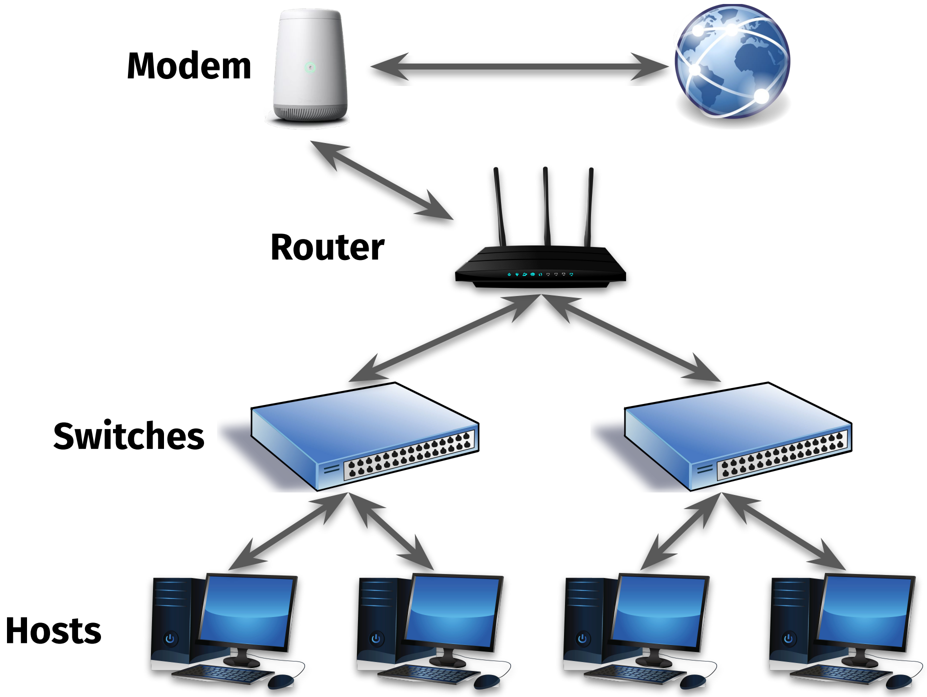


Networking Devices

- **Network layer:**
  - **Router**
    - Connects different networks
- **Data Link layer:**
  - **Switch**
    - Connects multiple devices on the same network
  - **Modem**
    - Aka modulator/demodulator
    - Interface between 0/1 bits and cable/telephone wire



Internet Packet Encapsulation

- How packets are generated and sent

Application Message	**App Layer**

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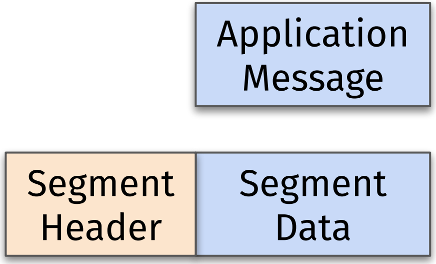

App Layer

Transport Layer

Internet Packet Encapsulation

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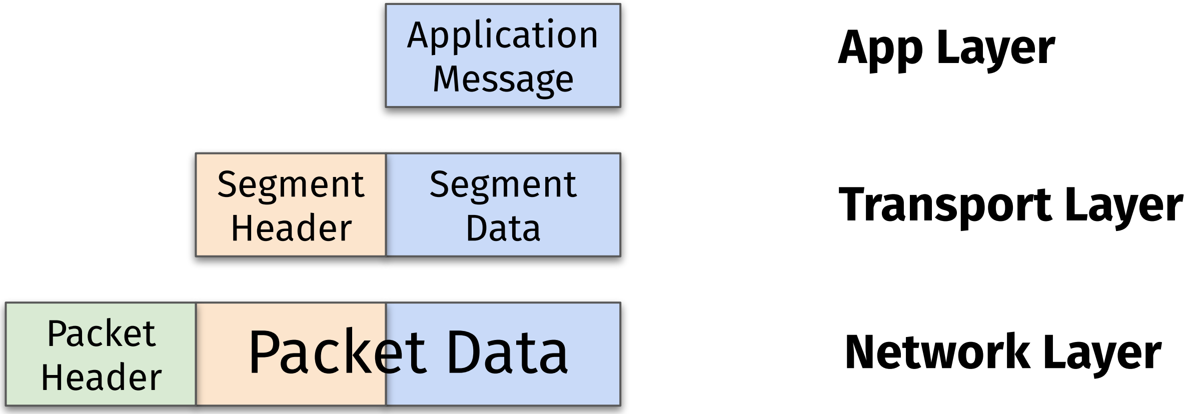

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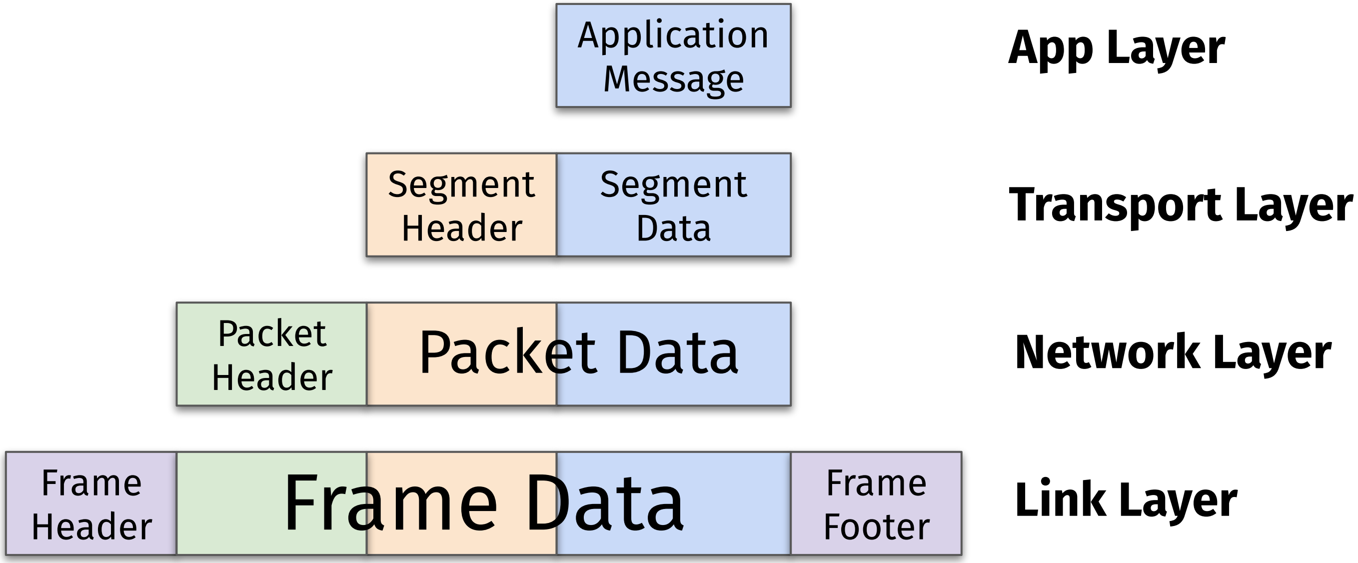

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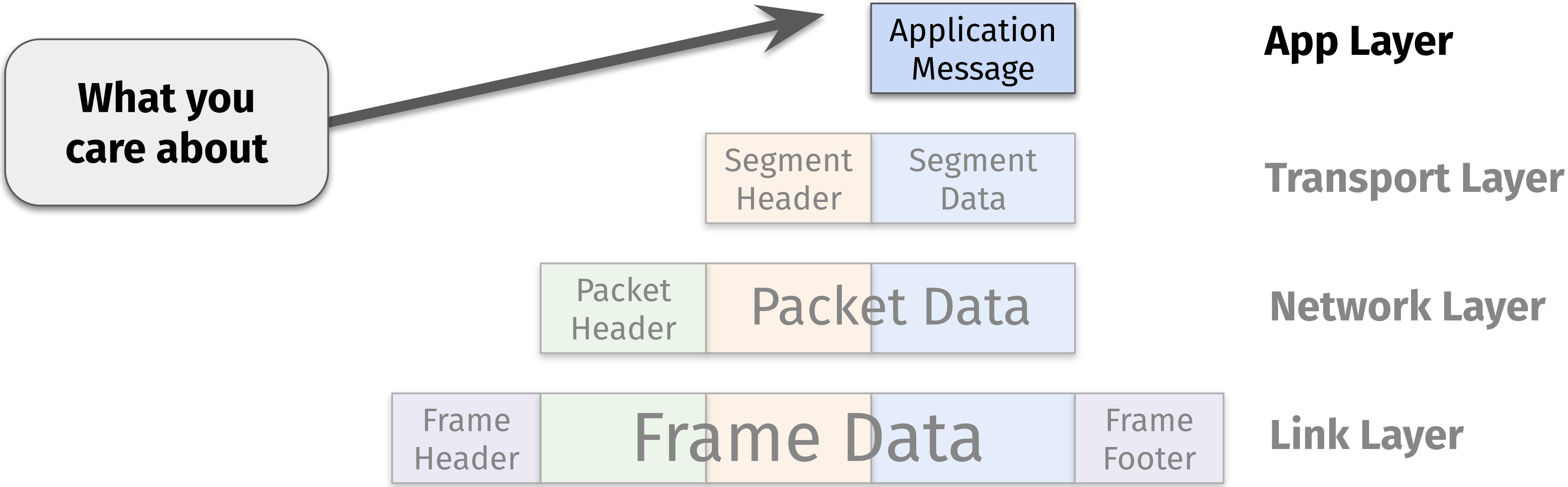

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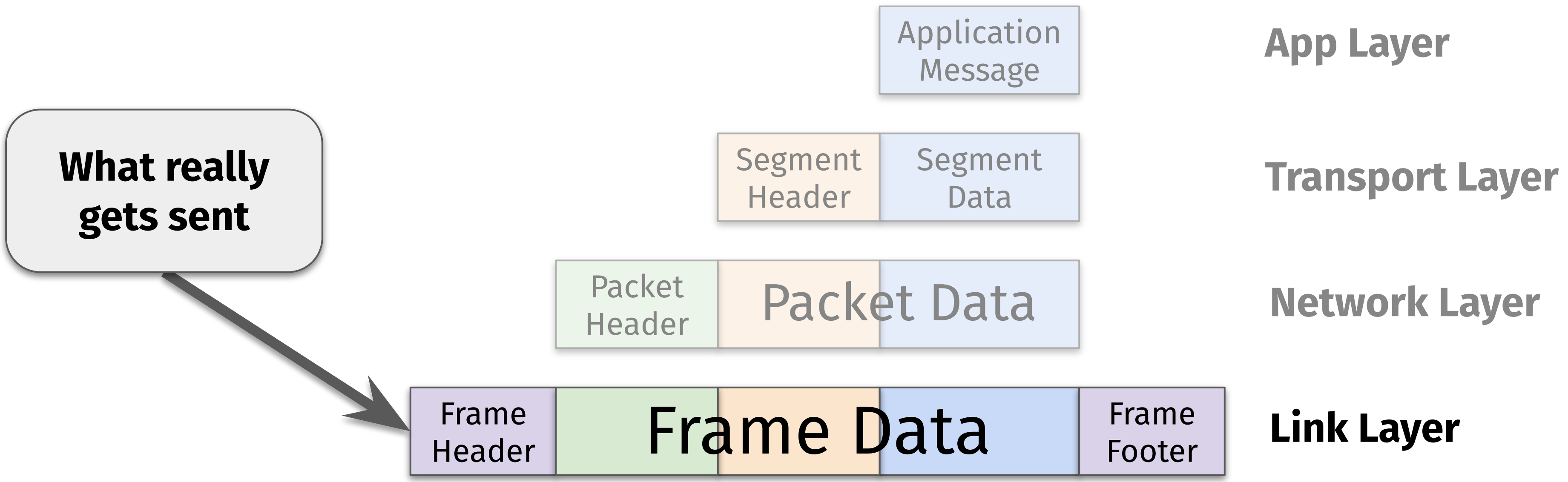

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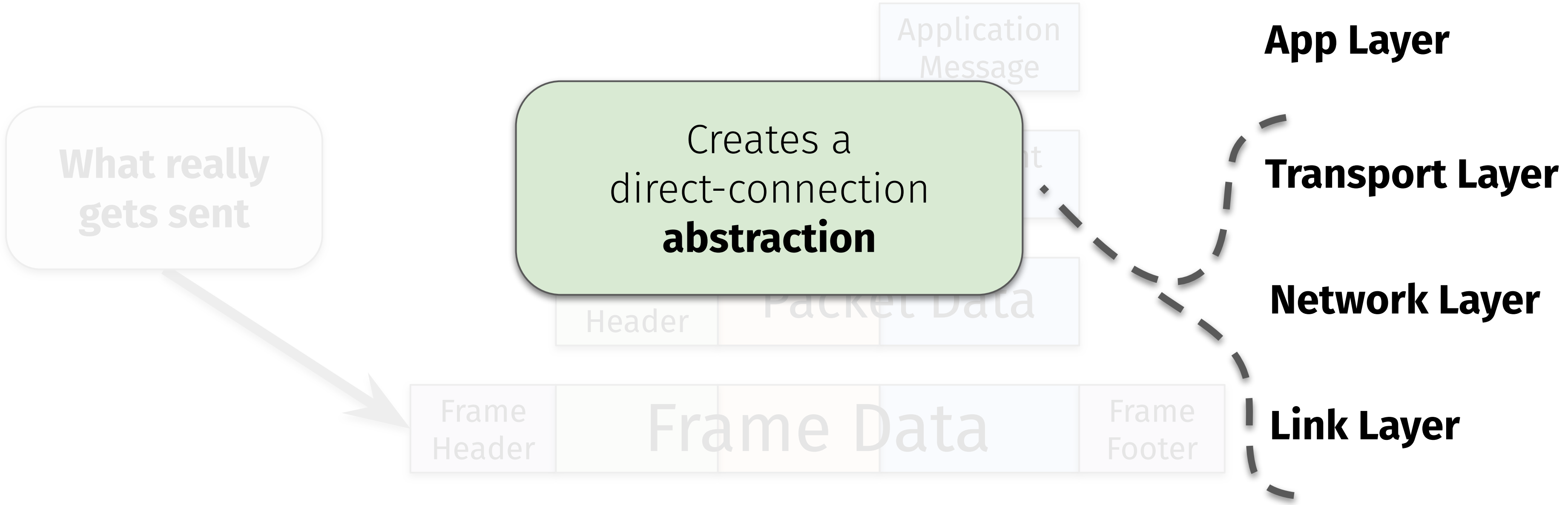
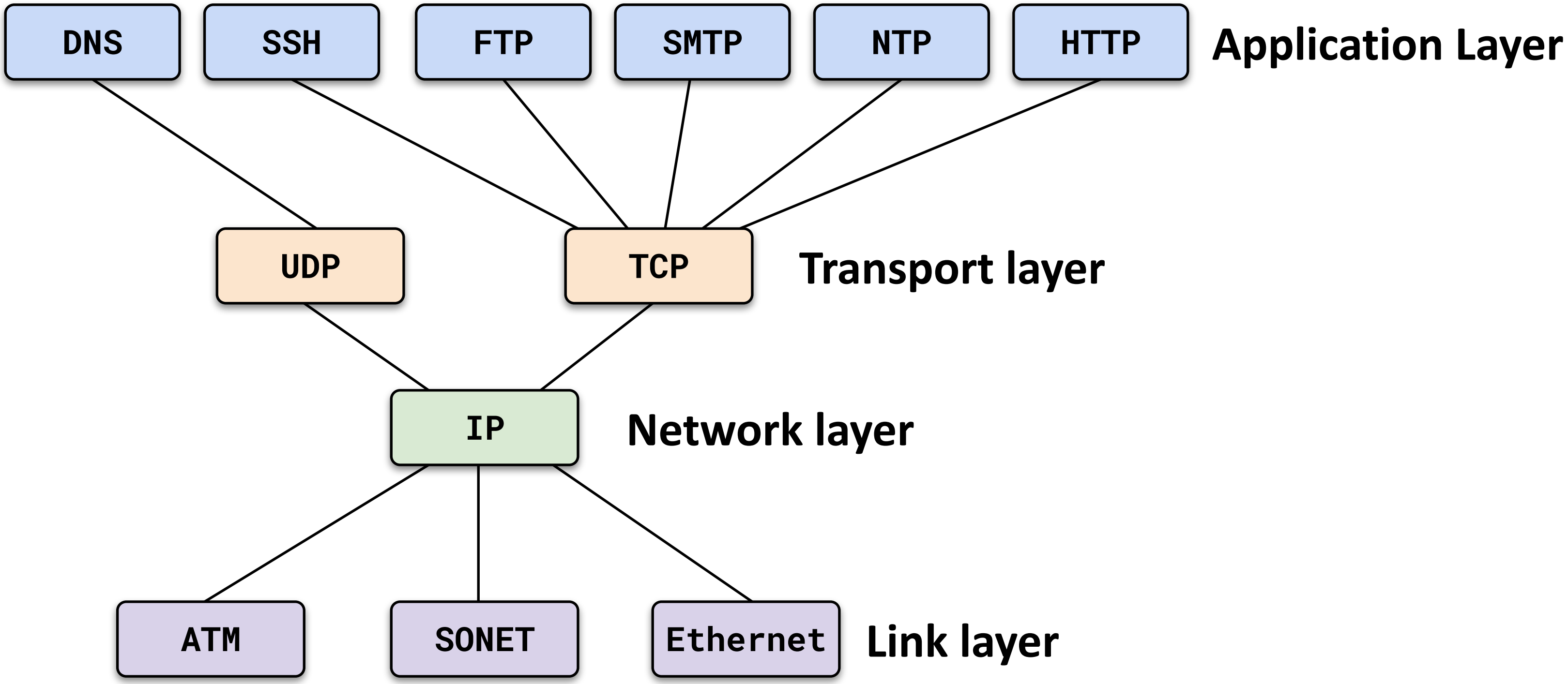


Layering of Protocols



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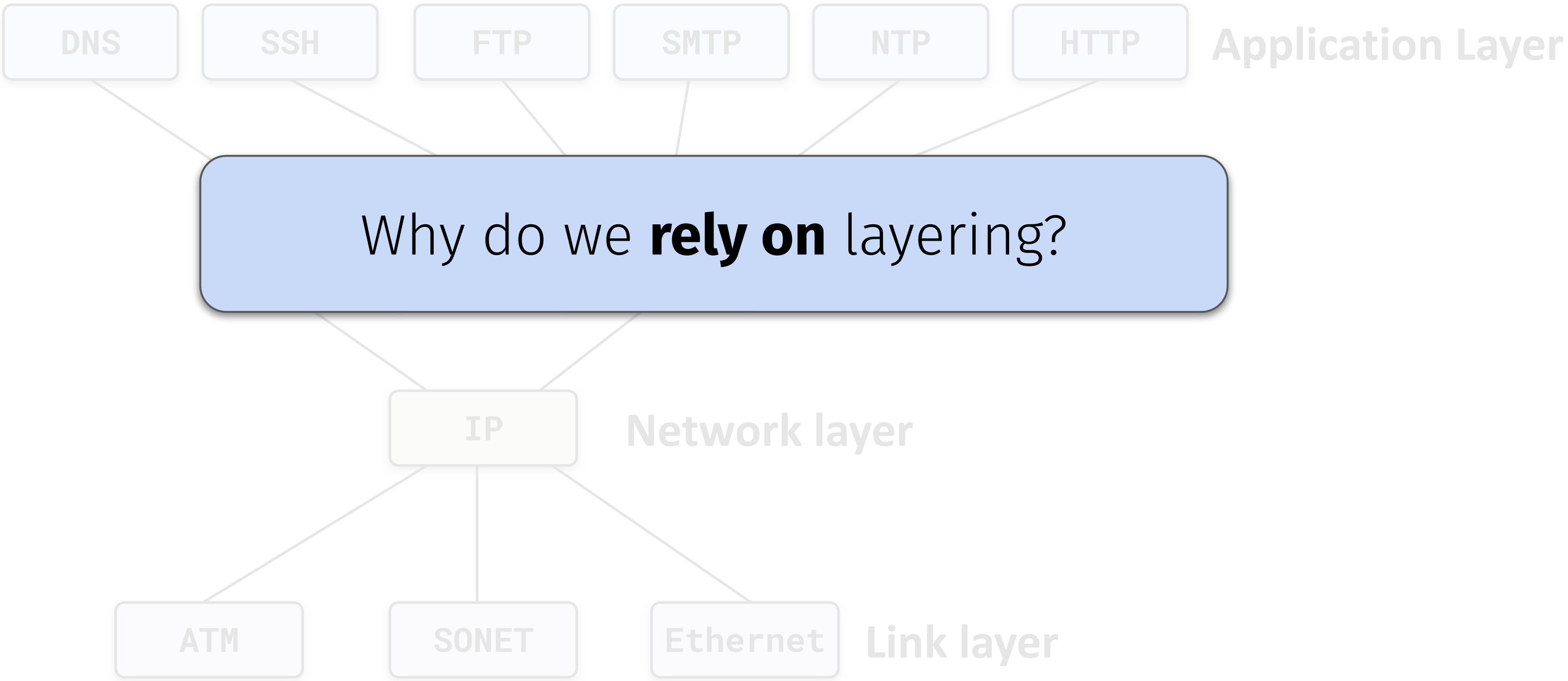
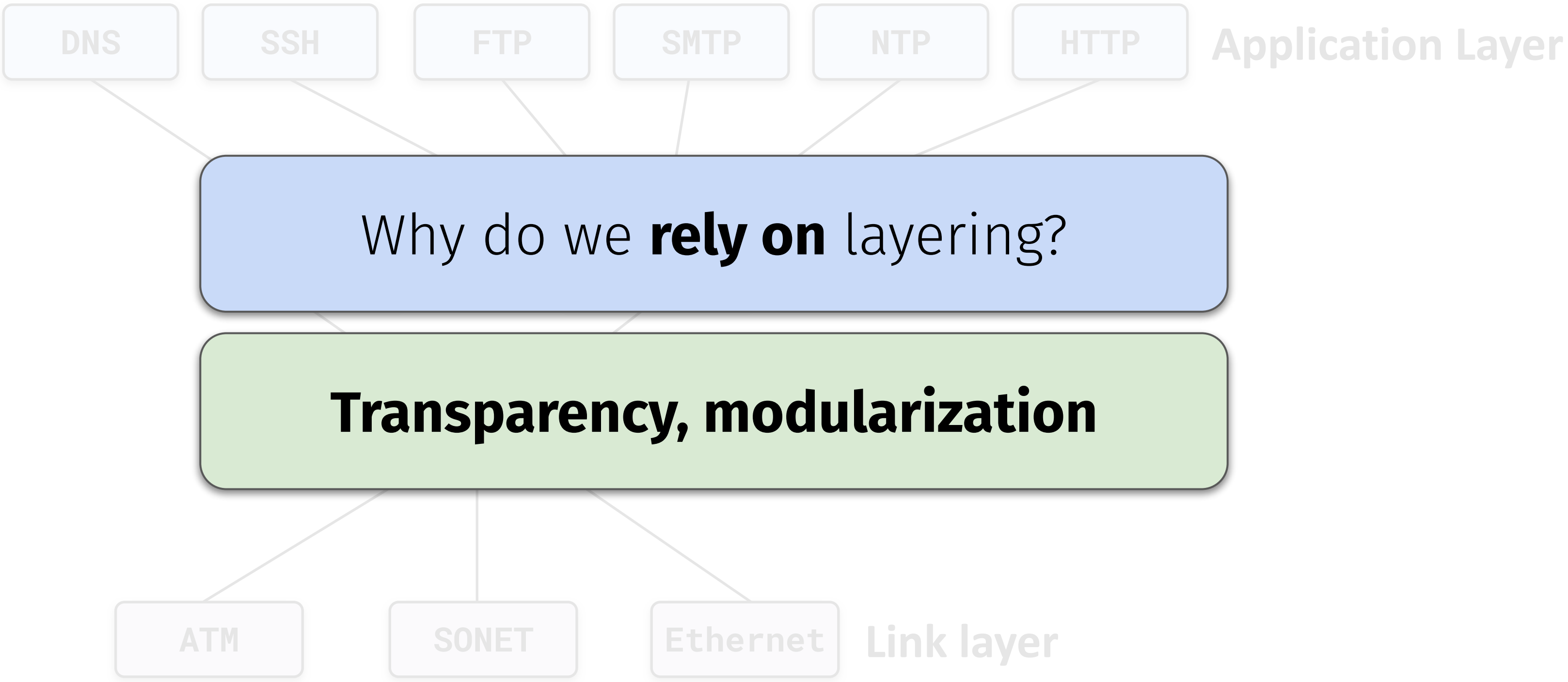


Why do we **rely on** layering?

Layering of Protocols

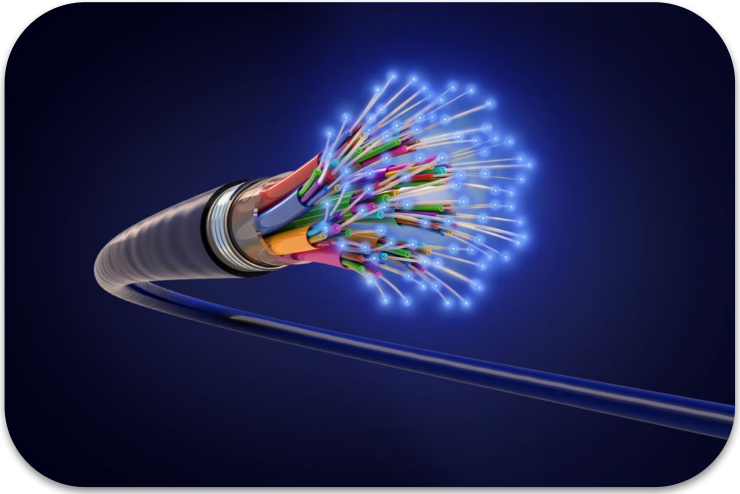


Questions?

The Physical Layer

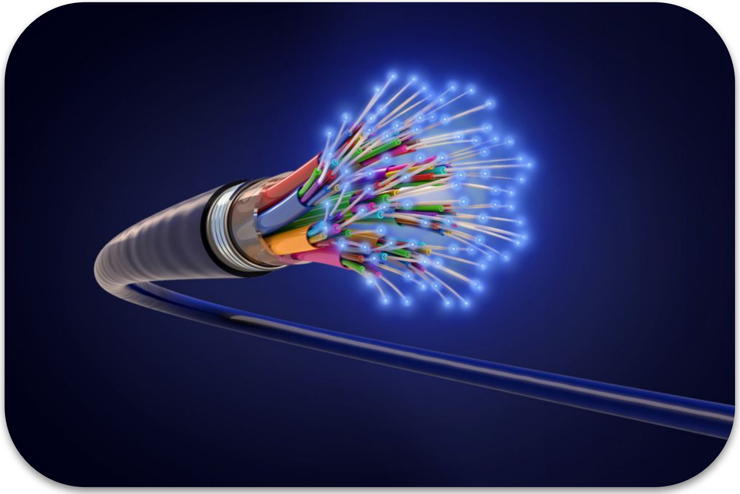
Layer 5: The Physical Layer

- **Last layer** in the 5-layer network model
  - The physical means of sending/receiving data
- **Examples** of physical layers?
  - **???**



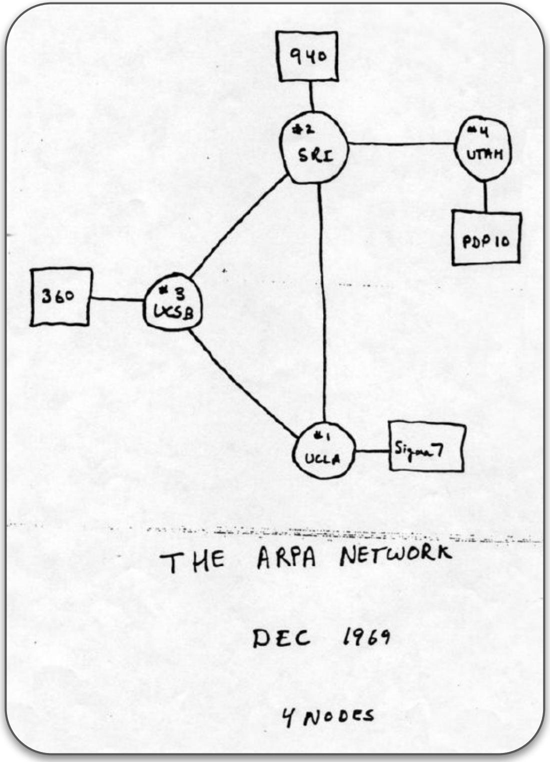
Layer 5: The Physical Layer

- **Last layer** in the 5-layer network model
  - The physical means of sending/receiving data
- **Examples** of physical layers?
  - Radio waves
  - Telephone lines
  - Fiber optic cables
  - Undersea submarine cables



Evolution of the Physical Layer

- **ARPANET:** precursor to today's Internet
  - University of Utah was one of its four nodes!
- Each member **physically linked** by cables



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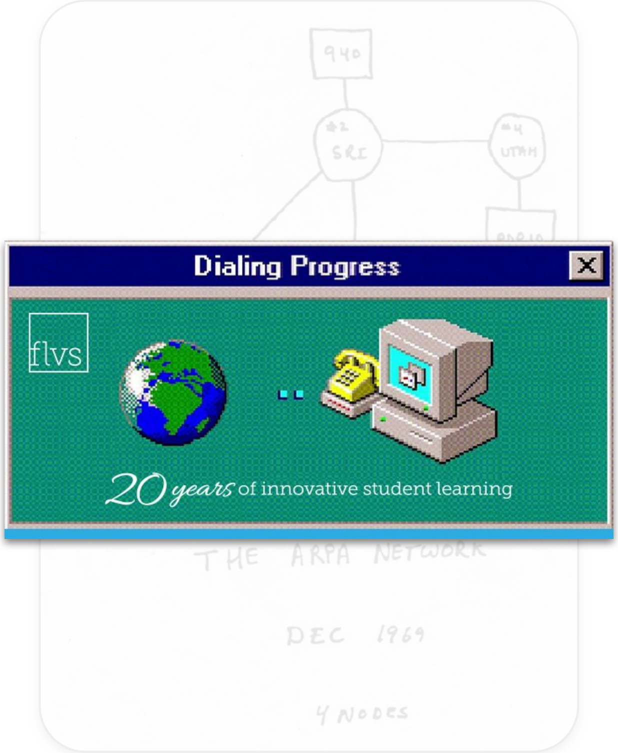

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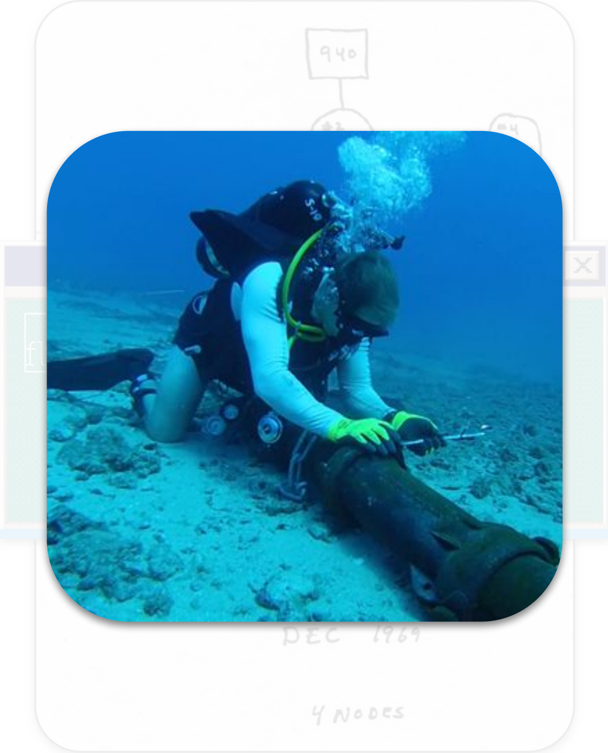
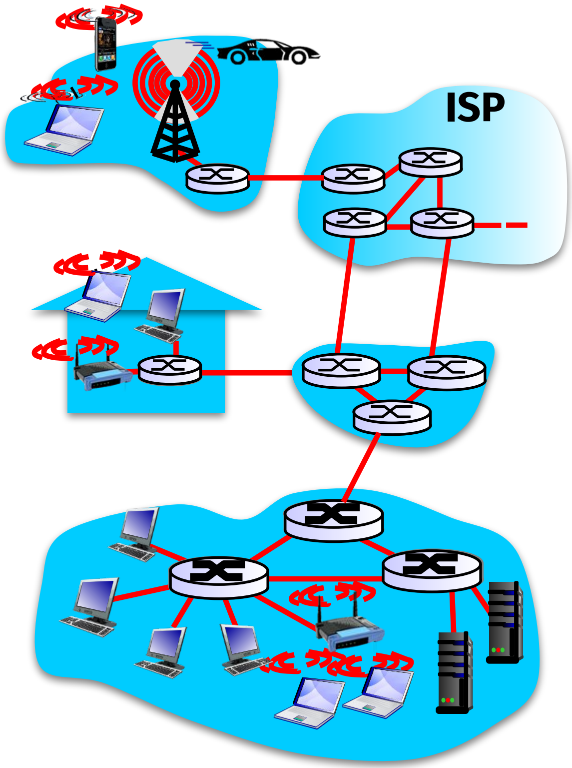
- Today: continents linked via **undersea cables**



The Link Layer

Layer 4: Link / Data-Link

- Hosts and switches: **nodes**
  - **Switches** interface with **hosts**
- Channels connecting adjacent nodes along a path: **links**
  - Wired links
  - Wireless links
  - LANs
- Layer-2 packet: **frame**
  - Encapsulates datagram of the previous three TCP/IP layers



MAC Addresses

- Most network interfaces come with a predefined **MAC address**
  - 48-bit number usually represented in hex
  - E.g., `00-1A-92-D4-BF-86`

- The First three octets of any MAC address are IEEE-assigned Organizationally Unique Identifiers
  - Cisco: `00-1A-A1`
  - D-Link: `00-1B-11`
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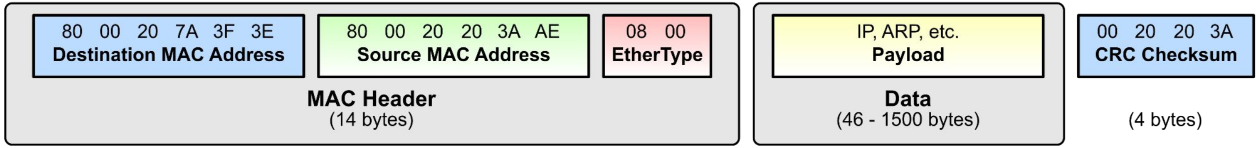
- MACs **can be reconfigured** by network interface driver software
  - This makes MAC address filtering insecure—**they can easily be spoofed**!

Ethernet

- The “dominant” wired LAN technology:
  - First widely used LAN technology
  - Simpler, cheaper than token LANs and ATM
  - Kept up with speed race: 10 Mbps – 100 Gbps

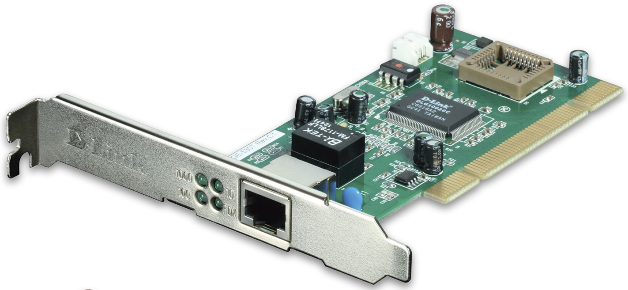
- **Ethernet Frame**
  - How the data is packaged up, sent/received
  - Destination and source MACs, payload, and checksum



Ethernet Type II Frame
(64 to 1518 bytes)

Where is the link layer implemented?

- **In each and every host!**
  - "Adaptor" (aka network interface card)
    - Ethernet card
    - 802.11 card
    - Ethernet chipset
- Implements **link** and **physical** layer
  - Attaches into host's system buses
  - Combination of hardware and firmware



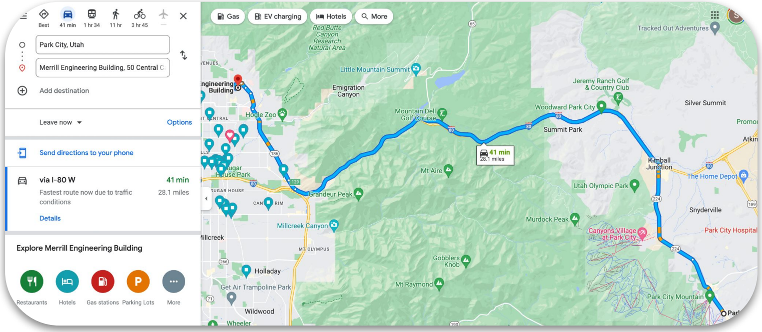
The Network Layer

Layer 3: Network

- Deliver **segment** from sending to receiving hosts
  - **Sender** encapsulates segments into IP datagrams
  - **Receiver** delivers segments to transport layer
  - Delivery based on logical addressing (i.e., IP addresses)
- Network layer protocols in every host, router
  - Router checks headers of IP datagrams passing through

Network Layer Functions

- **Routing:** determine **route taken** by packets from source to dest
  - Works based on IP addresses
  - Ideally aims to find **shortest path** for the packet to its destination



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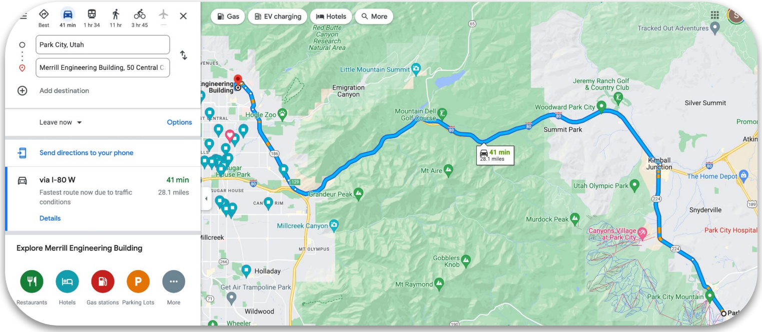

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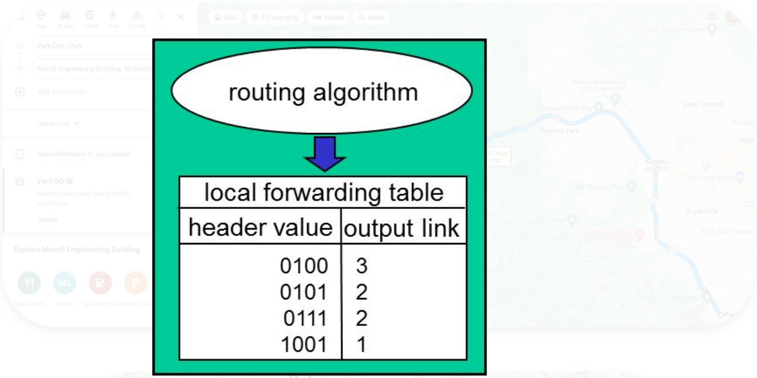
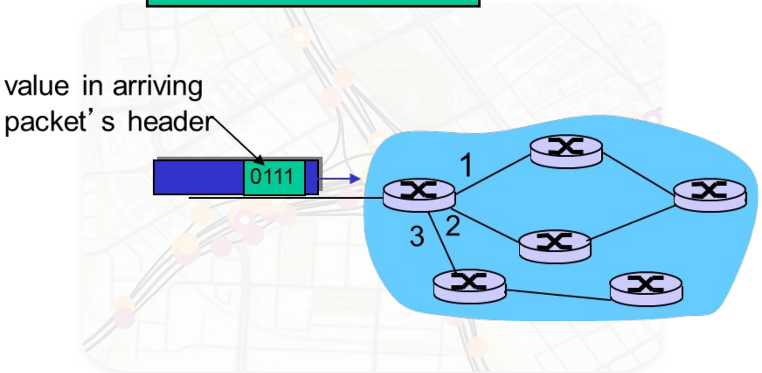




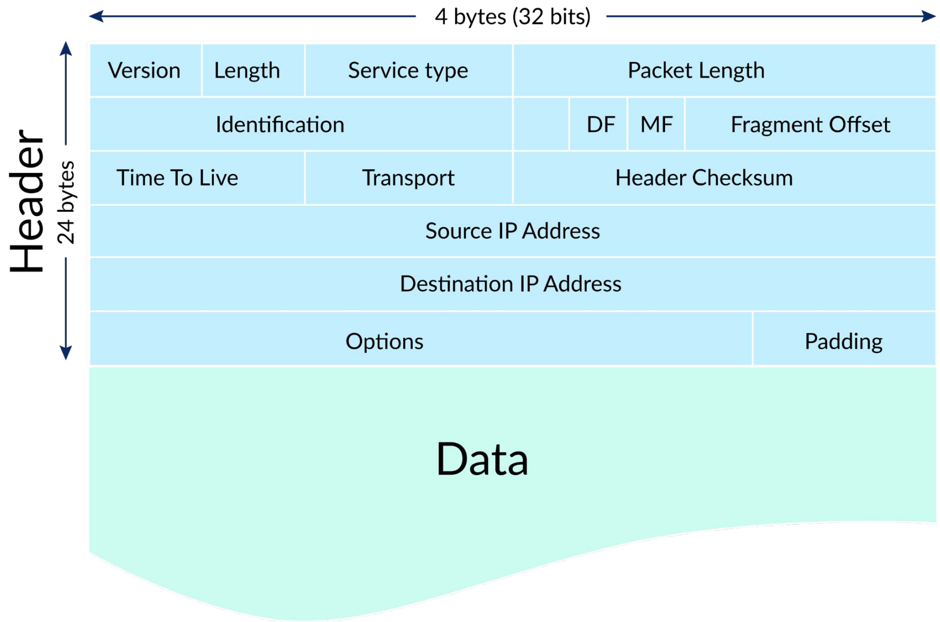
Internet Protocol

- **IP addresses:** routes datagrams in Internet
  - **IPv4:** 32 bit address
  - **IPv6:** 128 bit address

- Two parts: network and host
  - **Network:** used to route packets (ZIP code)
  - **Host:** identifies an individual host (house number)
  - Split between network/host based on address class
  - Usually in dotted decimal notation: 141.211.144.212
    - Each number represents 8 bits: 0–255

IP Packets

- **Header:**
  - Source IP address
  - Destination IP address
  - Lots of other information
    - Version, length, checksum
    - Selected transport protocol
- **Data:**
  - The message!
    - E.g., string of letters
    - E.g., web page characters



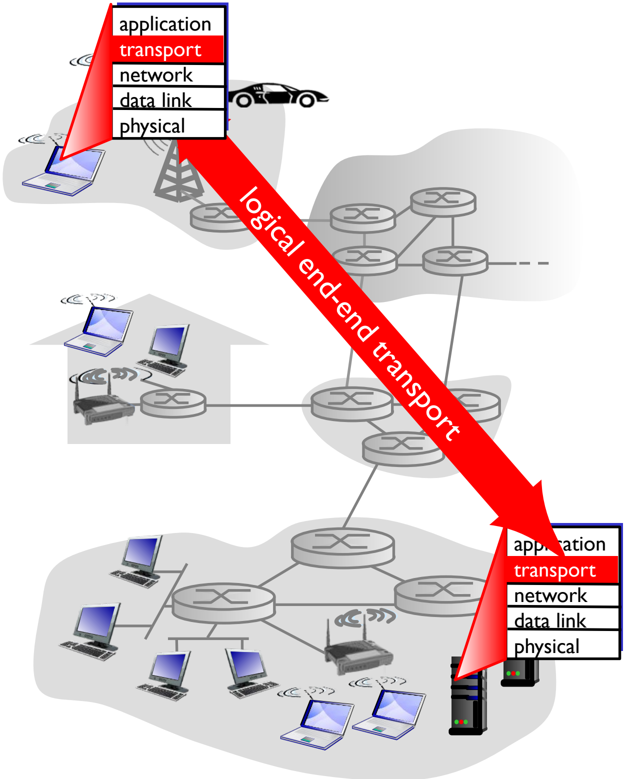
The Transport Layer

Layer 2: Transport

- Provides **logical communication** between application processes running on **different hosts**

- Transport protocols in end systems
  - **Send side:** breaks app messages into segments, passes to network layer
  - **Receive side:** reassembles segments into messages, passes to app layer

- Nowadays, **multiple** transport protocols available
  - Internet: TCP and UDP



Transport Services

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Dependable but **costly**

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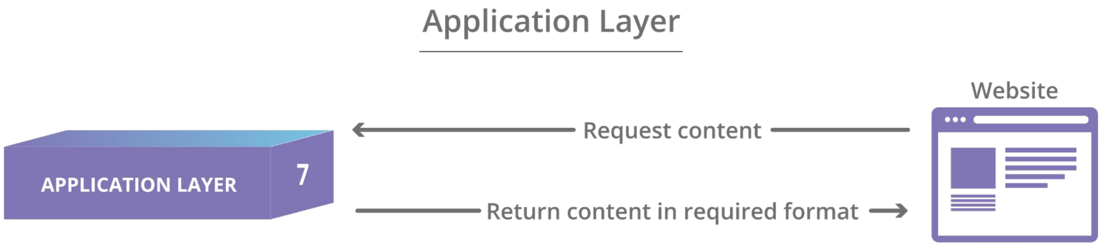
Speedy but **unreliable**

The Application Layer

Layer 1: Application

- Defines the following:
  - **Types** of messages exchanged
    - E.g., requests, responses
  - Message syntax:
    - Message **fields**, how they are delineated
  - Message semantics:
    - The **meaning** of information in each field
  - Rules for **when/how** processes **send/respond** to messages



Example: HTTP Requests

Carriage return character

Line-feed character

Request line
(E.g., GET, POST, HEAD commands)

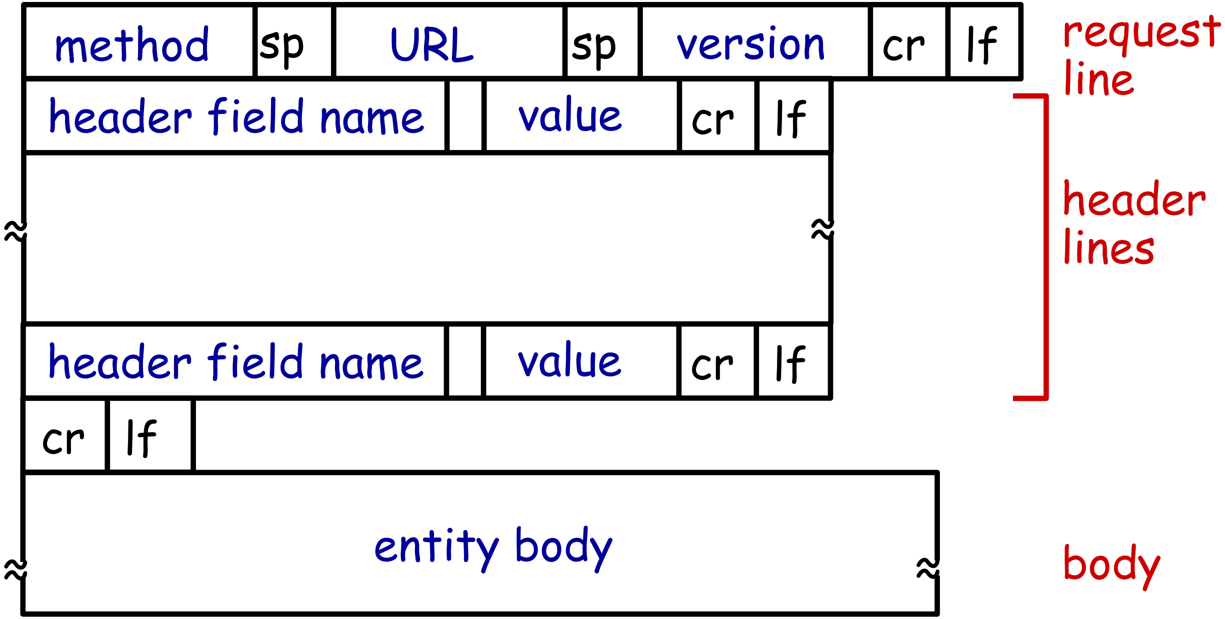
Header lines

Carriage return, line feed at start of line indicates end of header lines

```
GET /index.html HTTP/1.1\r\n
Host: www.cs.utah.edu\r\n
User-Agent: Firefox/3.6.10\r\n
Accept: text/html,application/xhtml+xml\r\n
Accept-Language: en-us,en;q=0.5\r\n
Accept-Encoding: gzip,deflate\r\n
Accept-Charset: ISO-8859-1,utf-8;q=0.7\r\n
Keep-Alive: 115\r\n
Connection: keep-alive\r\n
\r\n
```

Example: HTTP Requests

- What actually gets transmitted:



Protocols Galore

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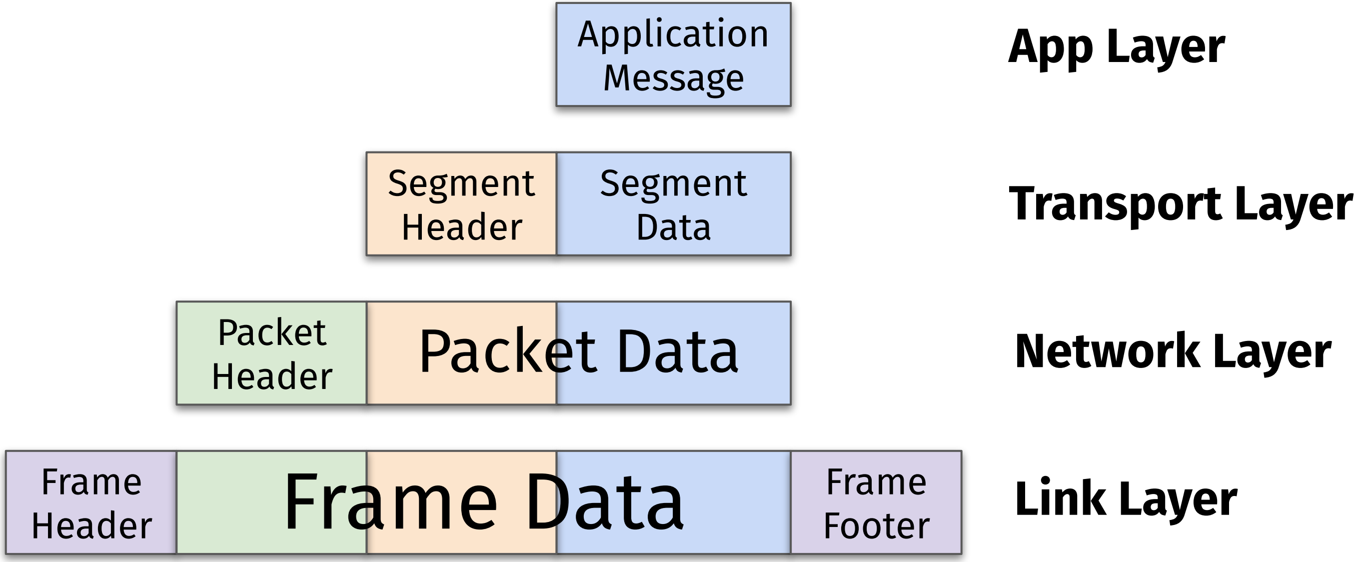
- **Closed-source** proprietary protocols:
  - Examples: Skype, Zoom
  - **Makes security vetting really difficult!**

Food for Thought

- Are any of the five network layers susceptible to **attacks**? If so, **which ones**?



Next time on CS 4440...

Application-layer Network Attacks