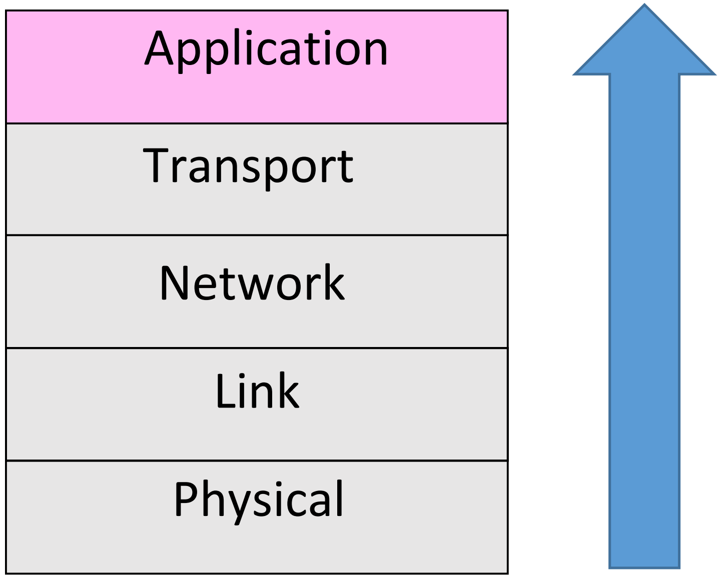
Applications!

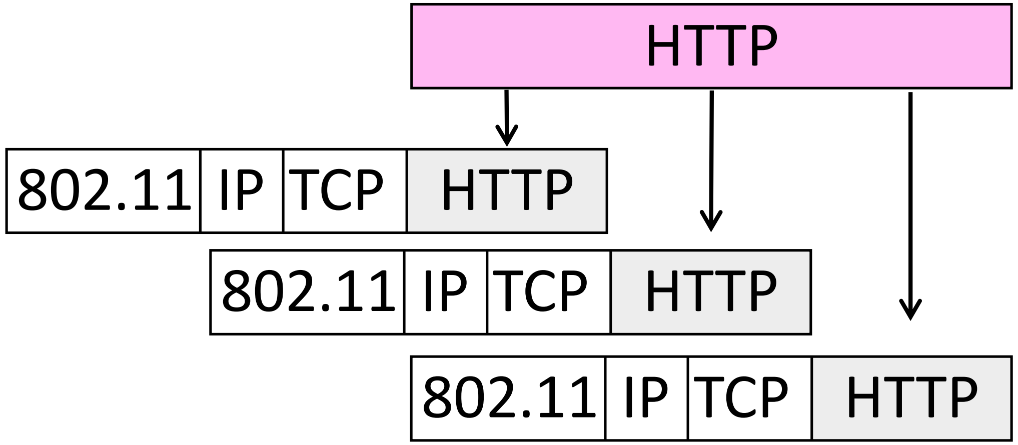
Where we are in the Course

- Application layer protocols are often part of “app”
  - But don’t need a GUI, e.g., DNS



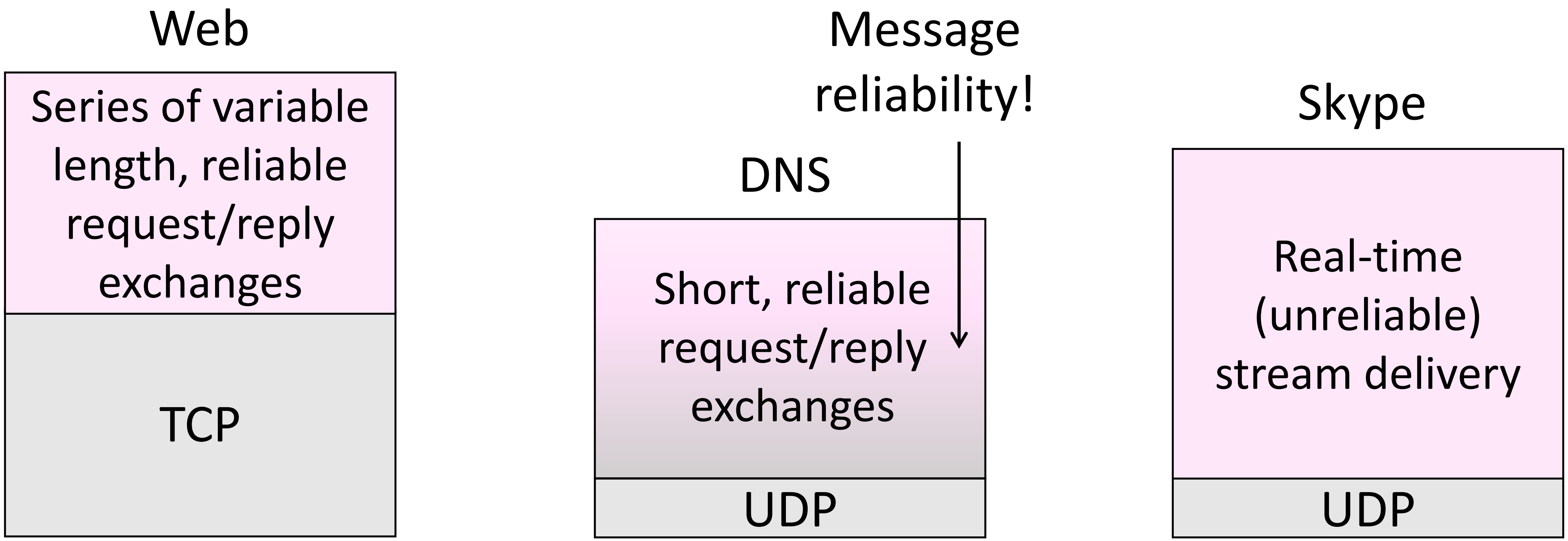
Recall

- Application layer messages are often split over multiple packets
  - Or may be aggregated in a packet …



Application Communication Needs

- Vary widely; must build on Transport services



OSI Session/Presentation Layers

- Remember this? Two relevant concepts …

Considered part of the application, not strictly layered! (layers 6 and 5)

7	Application	– Provides functions needed by users
6	Presentation	– Converts different representations
5	Session	– Manages task dialogs
4	Transport	– Provides end-to-end delivery
3	Network	– Sends packets over multiple links
2	Data link	– Sends frames of information
1	Physical	– Sends bits as signals

Session Concept

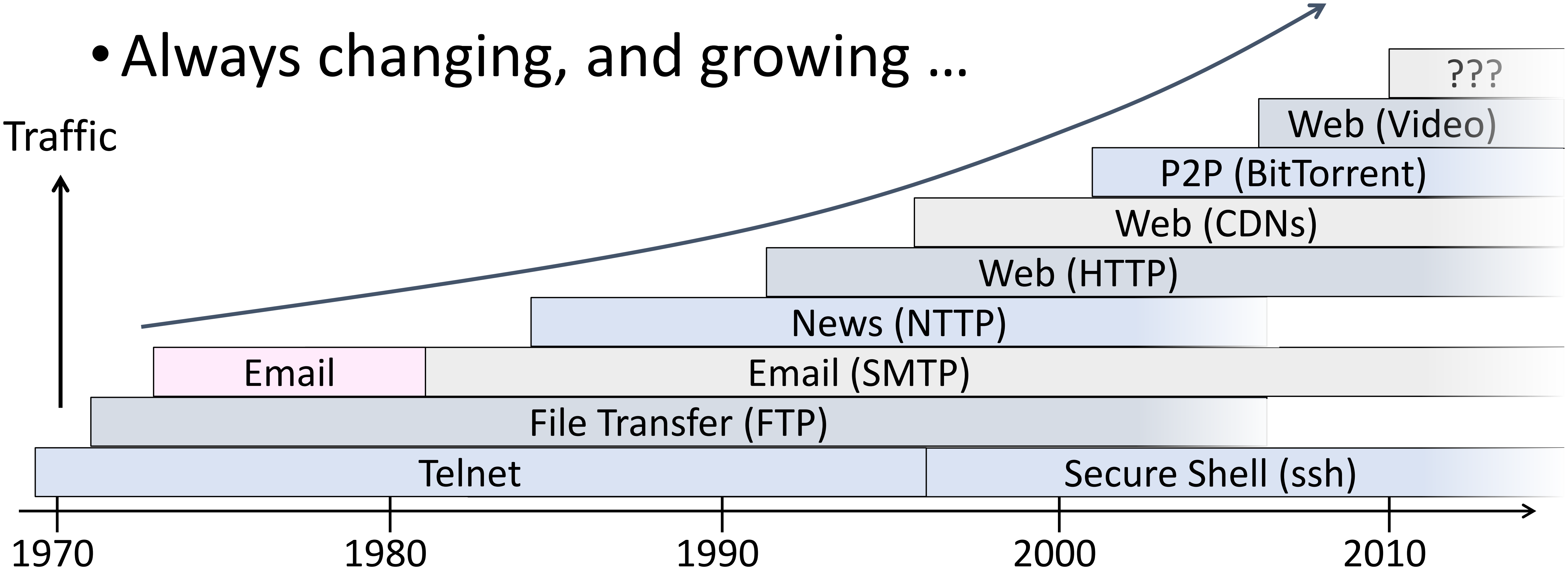
- A session is a series of related network interactions in support of an application task
  - Often informal, not explicit
- Examples:
  - Web page fetches multiple resources
  - Skype call involves audio, video, chat

Presentation Concept

- Apps need to identify the type of content, and encode it for transfer
  - These are Presentation functions
- Examples:
  - Media (MIME) types, e.g., image/jpeg, identify content type
  - Transfer encodings, e.g., gzip, identify the encoding of content
  - Application headers are often simple and readable versus packed for efficiency

Evolution of Internet Applications

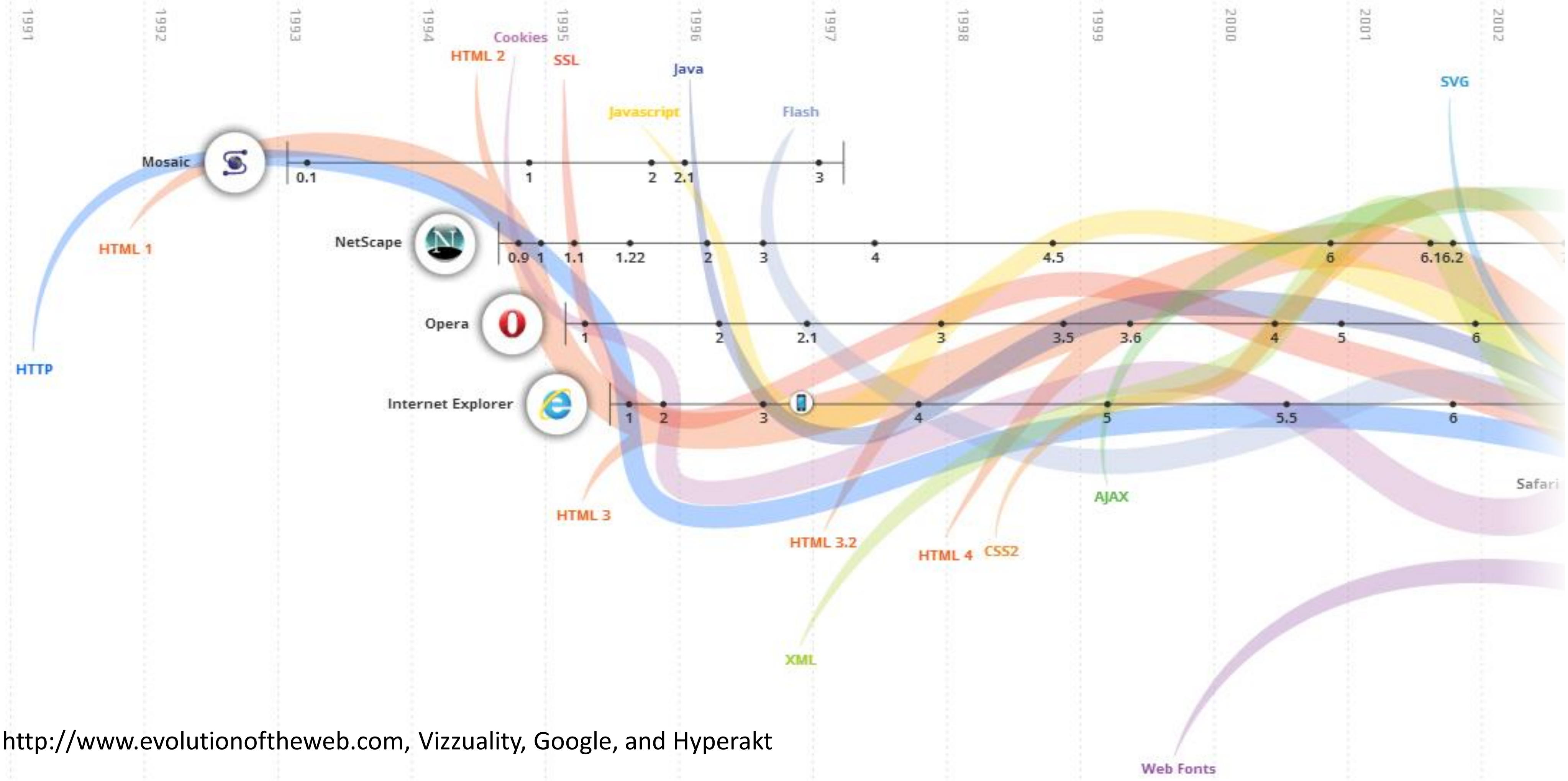
- Always changing, and growing …



Evolution of Internet Applications (2)

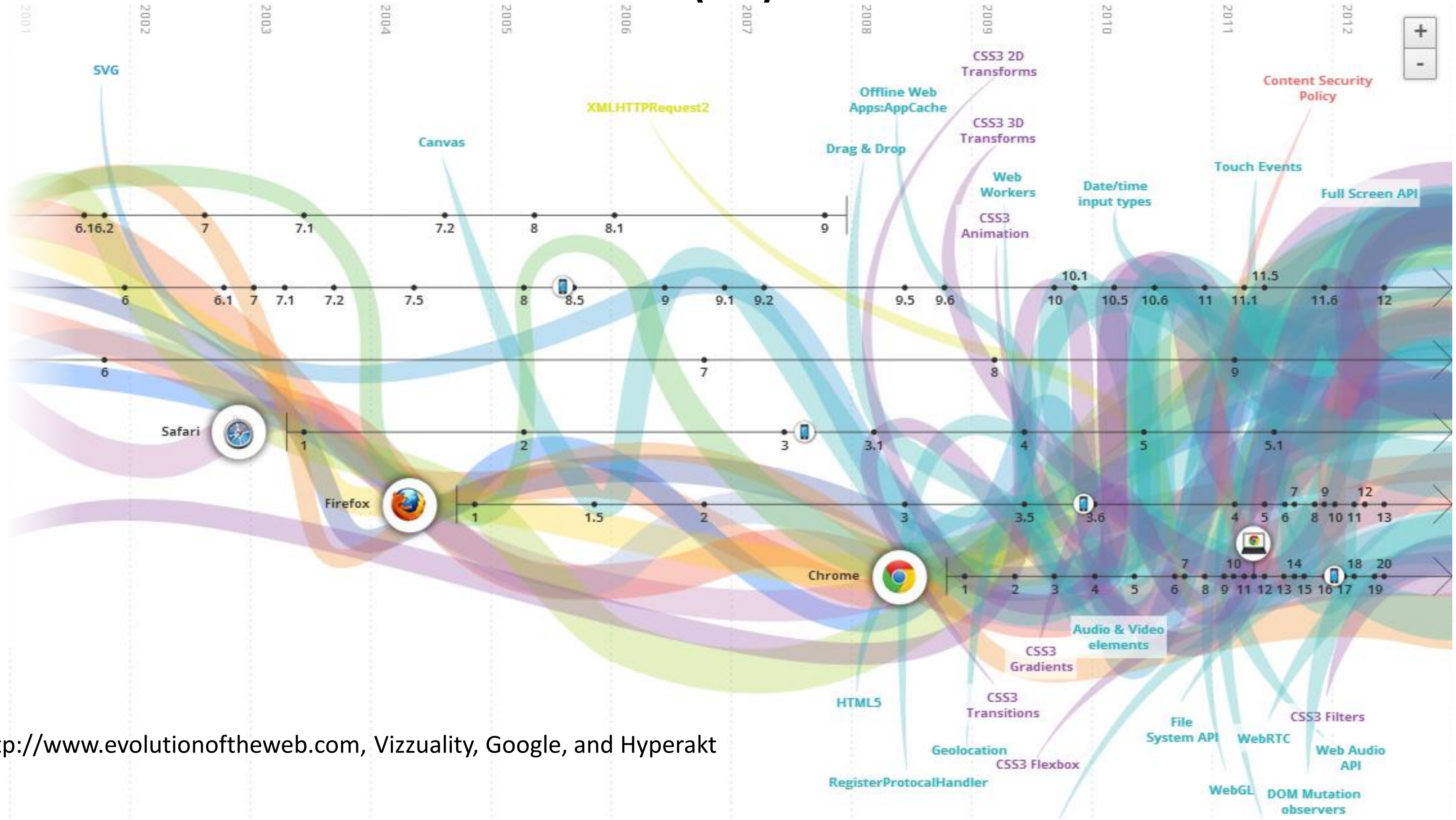
- For a peek at the state of the Internet:
  - Akamai's State of the Internet Report (quarterly)
  - Cisco's Visual Networking Index
  - Mary Meeker's Internet Report
- Robust Internet growth, esp. video, wireless, mobile, cat
  - Most (70%) traffic is video (expected 80% in 2019)
  - Mobile traffic overtakes desktop (2016)
  - 15% of traffic is cats (2013)
  - Growing attack traffic from China, also U.S. and Russia

Evolution of the Web



Source: http://www.evolutionoftheweb.com, Vizzuality, Google, and Hyperakt

Evolution of the Web (2)

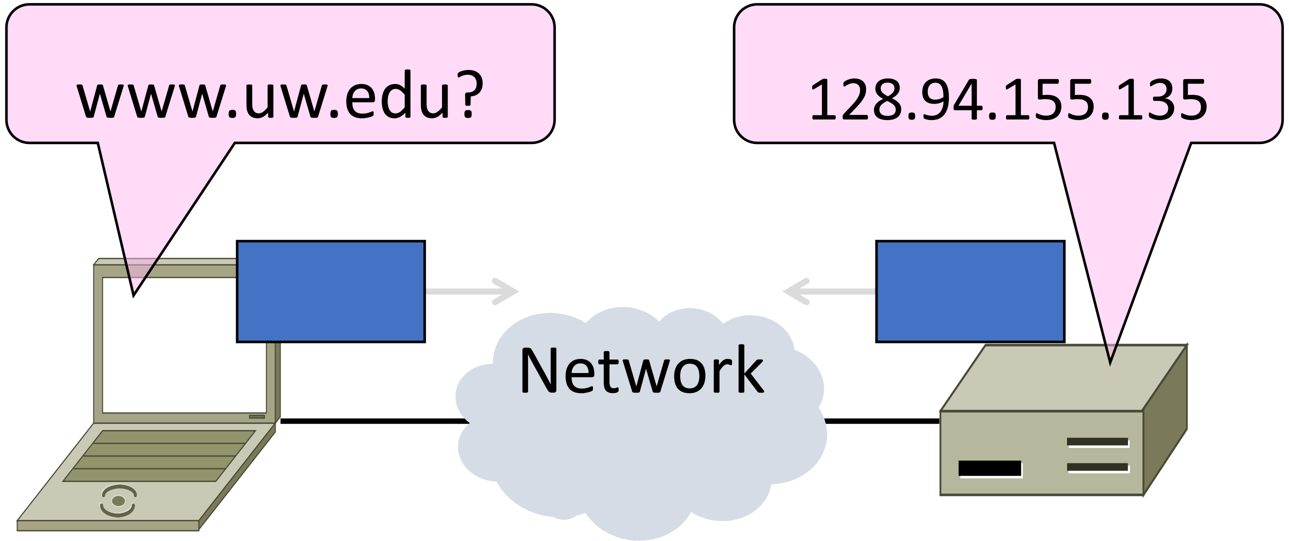


Source: http://www.evolutionoftheweb.com, Vizzuality, Google, and Hyperakt

Domain Name System

DNS

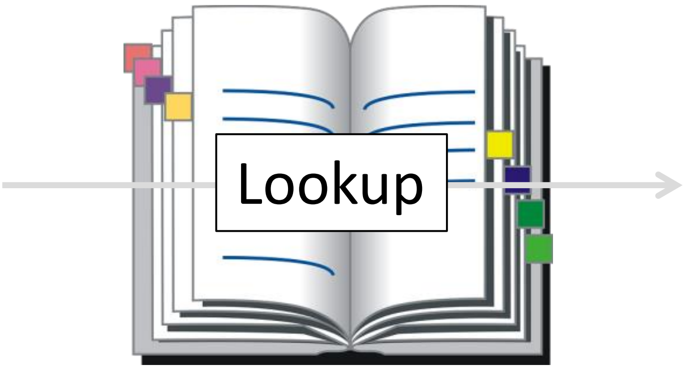
- Human-readable host names, and more



Names and Addresses

- <u>Names</u> are higher-level identifiers for resources
- <u>Addresses</u> are lower-level locators for resources
  - Multiple levels, e.g. full name → email → IP address → Ethernet addr
- <u>Resolution</u> (or lookup) is mapping a name to an address

Name, e.g.
"Andy Tanenbaum,"
or "flits.cs.vu.nl"



Directory

Address, e.g.
"Vrijie Universiteit, Amsterdam"
or IPv4 "130.30.27.38"

Before the DNS – HOSTS.TXT

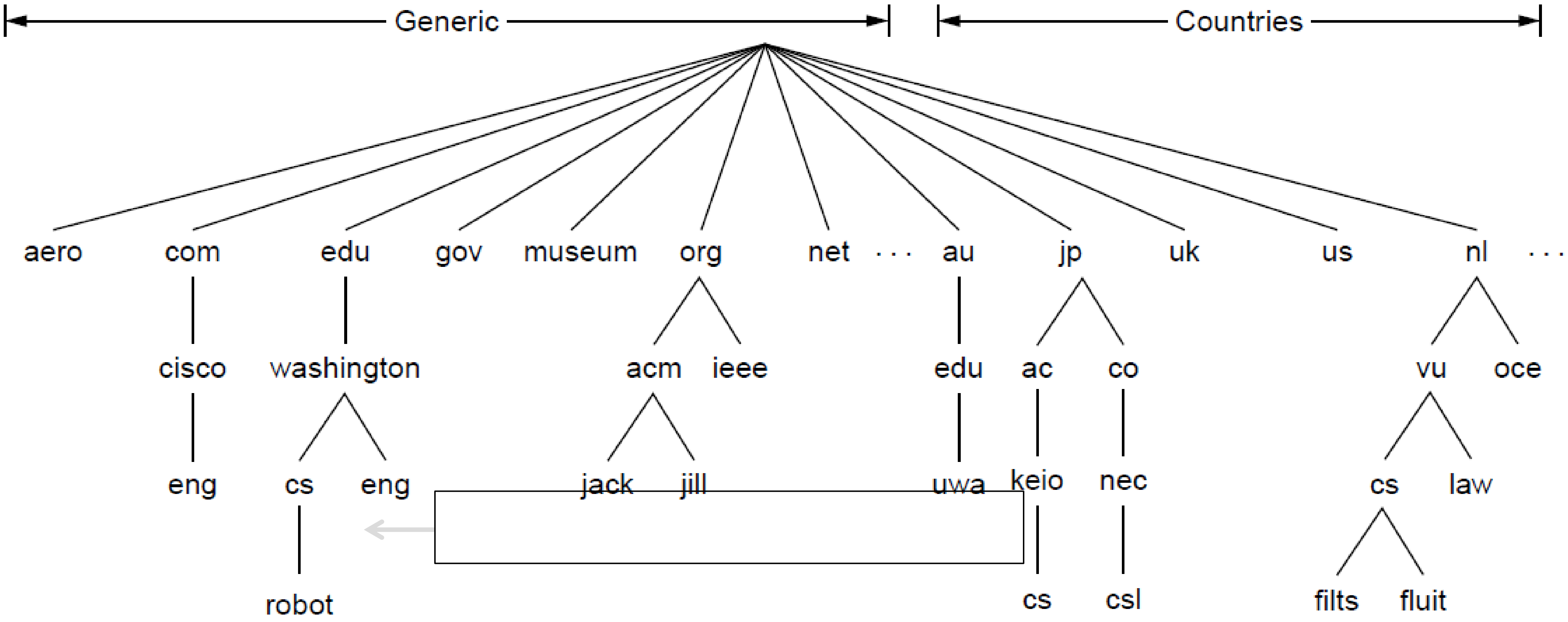
- Directory was a file HOSTS.TXT regularly retrieved for all hosts from a central machine at the NIC (Network Information Center)
- Names were initially flat, became hierarchical (e.g., lcs.mit.edu) ~85
- Not manageable or efficient as the ARPANET grew …

DNS

- A naming service to map between host names and their IP addresses (and more)
  - www.uwa.edu.au → 130.95.128.140
- Goals:
  - Easy to manage (esp. with multiple parties)
  - Efficient (good performance, few resources)
- Approach:
  - Distributed directory based on a hierarchical namespace
  - Automated protocol to tie pieces together

DNS Namespace

- Hierarchical, starting from "." (dot, typically omitted)

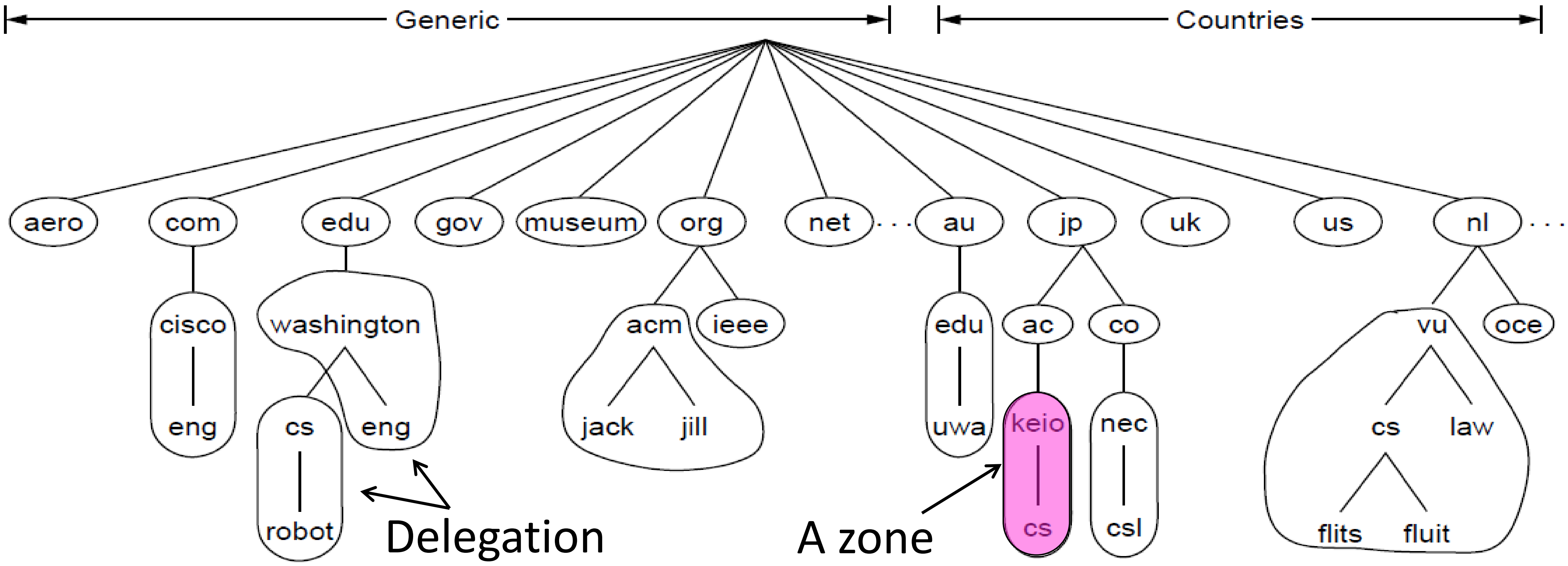


TLDs (Top-Level Domains)

- Run by ICANN (Internet Corp. for Assigned Names and Numbers)
  - Starting in '98; naming is financial, political, and international ☺
- 700+ generic TLDs
  - Initially .com, .edu , .gov., .mil, .org, .net
  - Unrestricted (.com) vs Restricted (.edu)
  - Added regions (.asia, .kiwi), Brands (.apple), Sponsored (.aero) in 2012
- ~250 country code TLDs
  - Two letters, e.g., ".au", plus international characters since 2010
  - Widely commercialized, e.g., .tv (Tuvalu)
  - Many domain hacks, e.g., instagr.am (Armenia), kurti.sh (St. Helena)

DNS Zones

- A <u>zone</u> is a contiguous portion of the namespace



DNS Zones (2)

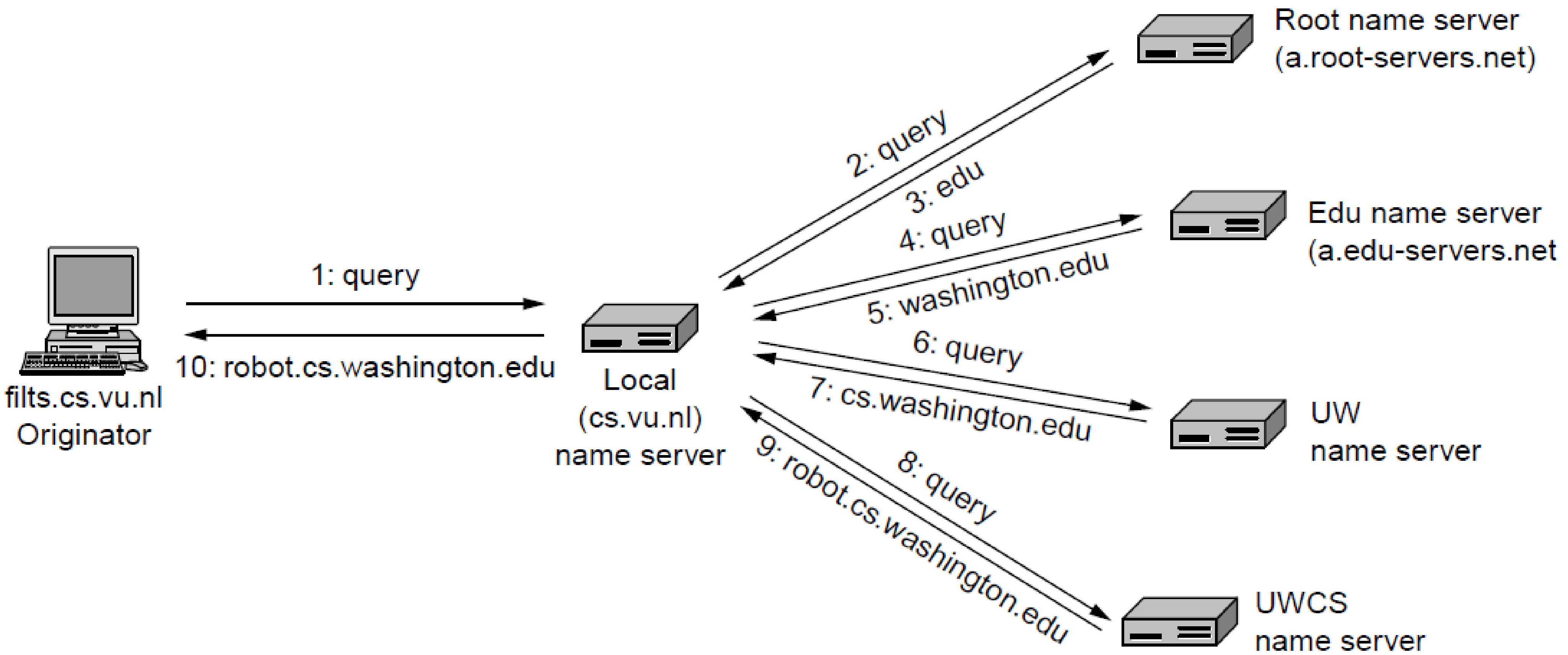
- Zones are the basis for distribution
  - EDU Registrar administers .edu
  - UW administers washington.edu
  - CSE administers cs.washington.edu
- Each zone has a nameserver to contact for information about it
  - Zone must include contacts for delegations, e.g., .edu knows nameserver for washington.edu

DNS Resolution

- DNS protocol lets a host resolve any host name (domain) to IP address
- If unknown, can start with the root nameserver and work down zones
- Let’s see an example first …

DNS Resolution (2)

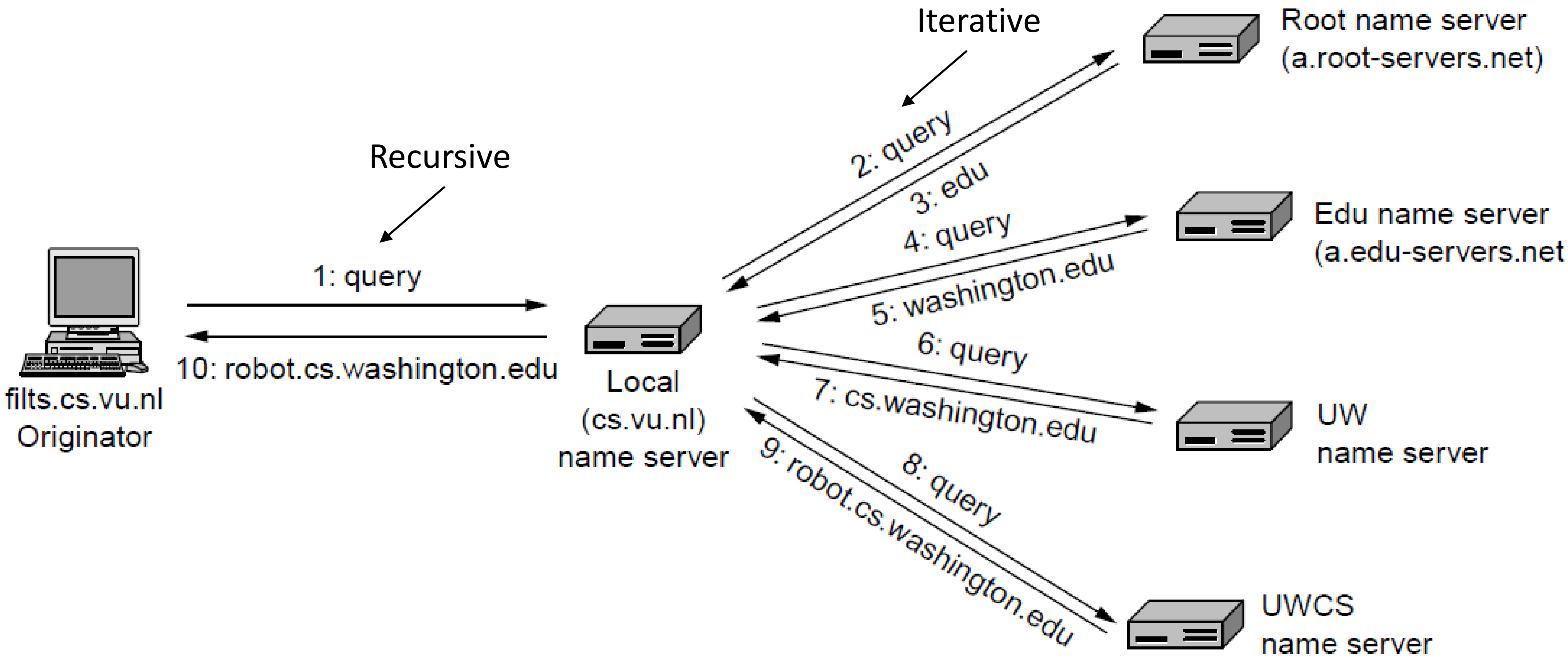
- flits.cs.vu.nl resolves robot.cs.washington.edu



Iterative vs. Recursive Queries

- Recursive query
  - Nameserver resolves and returns final answer
  - E.g., flits → local nameserver
- Iterative (Authoritative) query
  - Nameserver returns answer or who to contact for answer
  - E.g., local nameserver → all others

Iterative vs. Recursive Queries (2)



Iterative vs. Recursive Queries (3)

- Recursive query
  - Lets server offload client burden (simple resolver) for manageability
  - Lets server cache results for a pool of clients
- Iterative query
  - Lets server "file and forget"
  - Easy to build high load servers

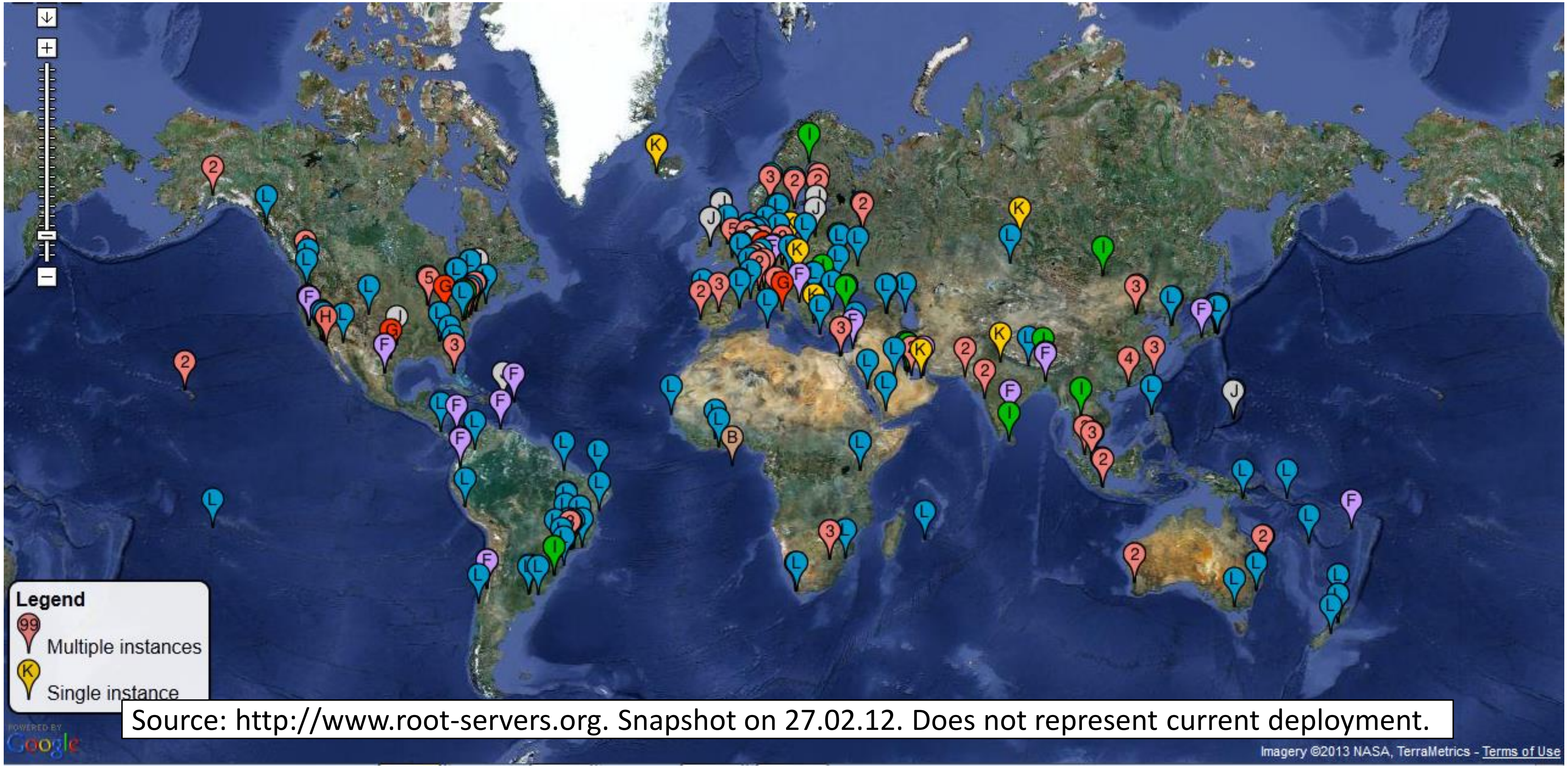
Local Nameservers

- Local nameservers often run by IT (enterprise, ISP)
  - But may be your host or AP
  - Or alternatives e.g., Google public DNS (8.8.8.8) Cloudflare’s public DNS (1.1.1.1)
- Clients need to be able to contact local nameservers
  - Typically configured via DHCP

Root Nameservers

- Root (dot) is served by 13 server names
  - a.root-servers.net to m.root-servers.net
  - All nameservers need root IP addresses
  - Handled via configuration file (named.ca)
- There are >250 distributed server instances
  - Highly reachable, reliable service
  - Most servers are reached by IP anycast (Multiple locations advertise same IP! Routes take client to the closest one.)
  - Servers are IPv4 and IPv6 reachable

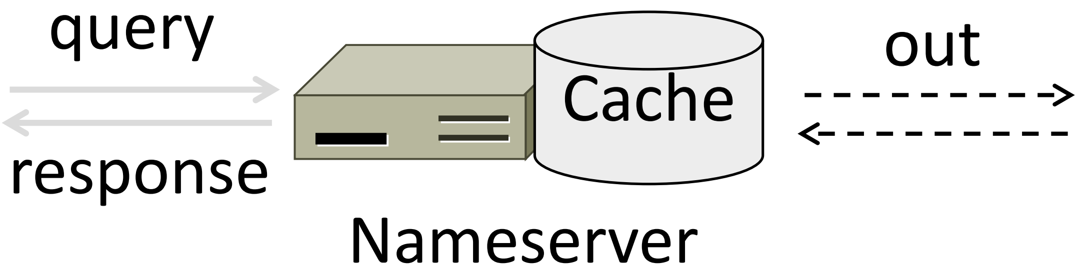
Root Server Deployment



Source: http://www.root-servers.org. Snapshot on 27.02.12. Does not represent current deployment.

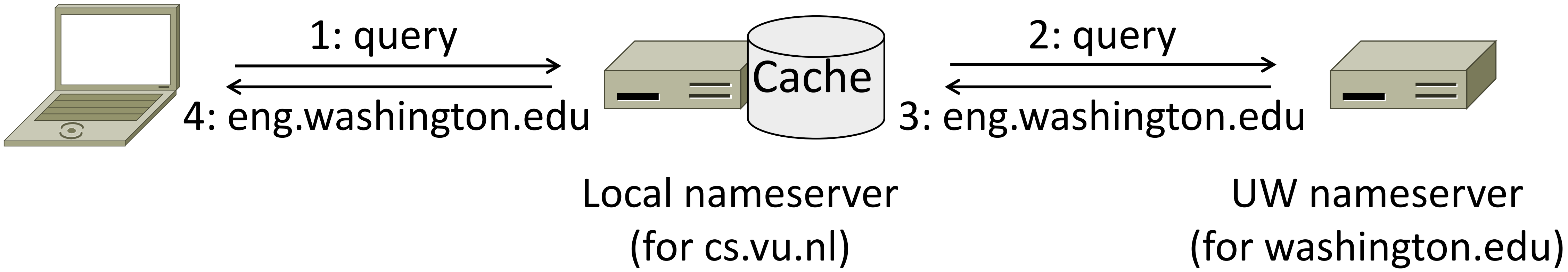
Caching

- Resolution latency needs to be low
- URLs don't have much churn
- Cache query/responses to answer future queries immediately
  - Including partial (iterative) answers
  - Responses carry a TTL for caching



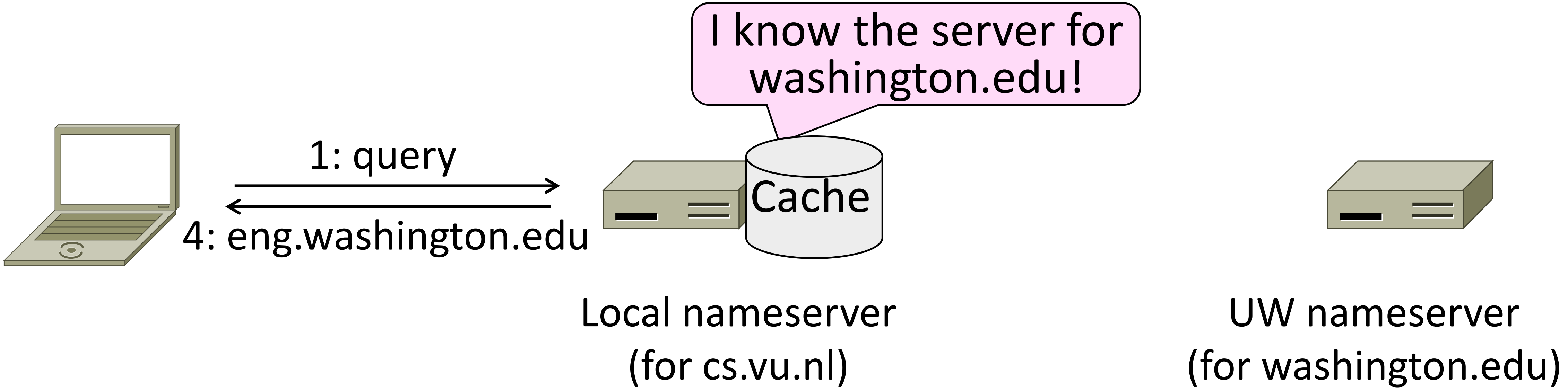
Caching (2)

- flits.cs.vu.nl looks up and stores eng.washington.edu



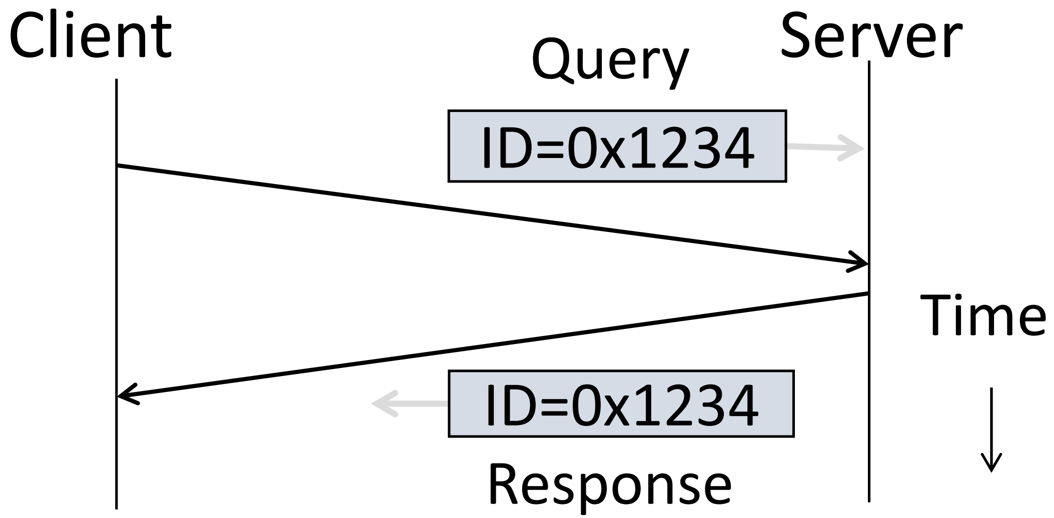
Caching (3)

- flits.cs.vu.nl now directly resolves eng.washington.edu



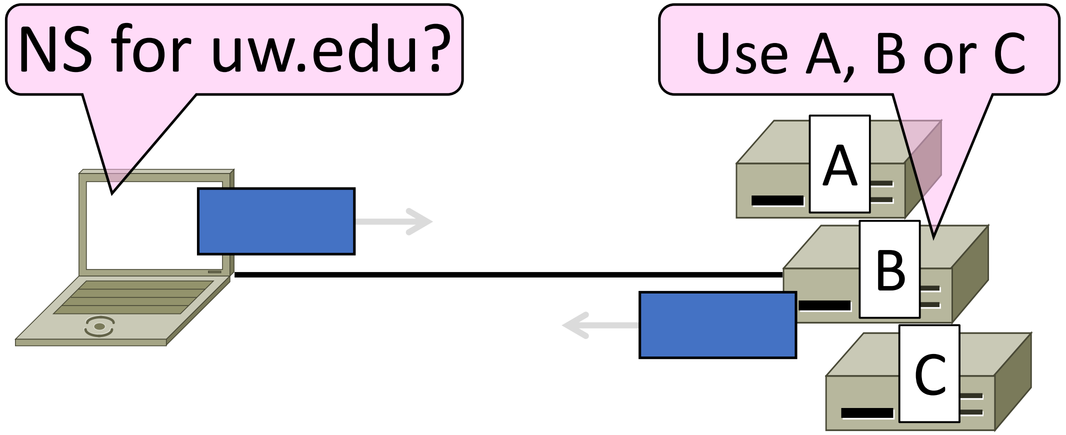
DNS Protocol

- Query and response messages
  - Built on UDP messages, port 53
  - ARQ for reliability; server is stateless!
  - Messages linked by a 16-bit ID field



DNS Protocol (2)

- Service reliability via replicas
  - Run multiple nameservers for domain
  - Return the list; clients use one answer
  - Helps distribute load too



DNS Resource Records

- A zone is comprised of DNS resource records that give information for its domain names

Type	Meaning
SOA	Start of authority, has key zone parameters
A	IPv4 address of a host
AAAA (“quad A”)	IPv6 address of a host
CNAME	Canonical name for an alias
MX	Mail exchanger for the domain
NS	Nameserver of domain or delegated subdomain

DNS Resource Records (2)

```
; Authoritative data for cs.vu.nl
cs.vu.nl.       86400   IN   SOA     star boss (9527,7200,7200,241920,86400)
cs.vu.nl.       86400   IN   MX      1 zephyr
cs.vu.nl.       86400   IN   MX      2 top
cs.vu.nl.       86400   IN   NS      star

star            86400   IN   A       130.37.56.205
zephyr          86400   IN   A       130.37.20.10
top             86400   IN   A       130.37.20.11
www             86400   IN   CNAME   star.cs.vu.nl
ftp             86400   IN   CNAME   zephyr.cs.vu.nl

flits           86400   IN   A       130.37.16.112
flits           86400   IN   A       192.31.231.165
flits           86400   IN   MX      1 flits
flits           86400   IN   MX      2 zephyr
flits           86400   IN   MX      3 top

rowboat                 IN   A       130.37.56.201
                        IN   MX      1 rowboat
                        IN   MX      2 zephyr

little-sister           IN   A       130.37.62.23

laserjet                IN   A       192.31.231.216
```

← Start of Authority (SOA record)

← Name server (NS record)

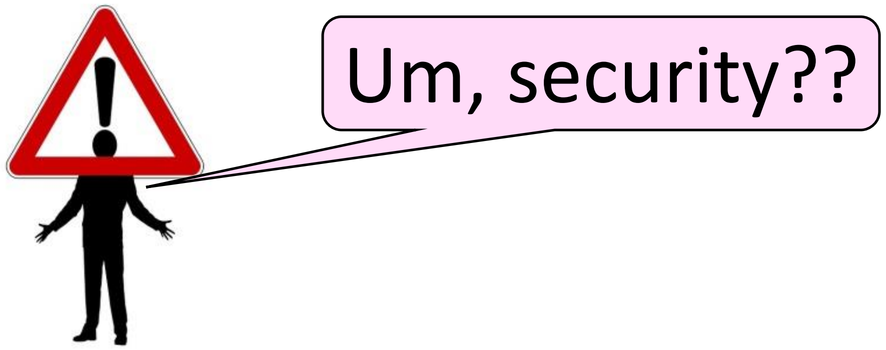
← IP addresses of computers (A records)

← Mail gateways (MX records)

DIG DEMO

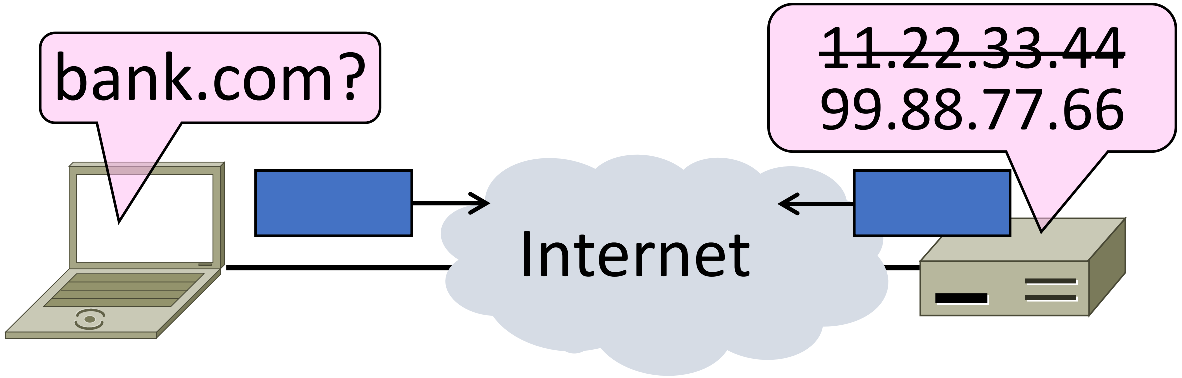
DNS Security

- Security is a major issue
  - Compromise redirects to wrong site!
  - Not part of initial protocols ..
- DNSSEC (DNS Security Extensions)
  - Mostly deployed



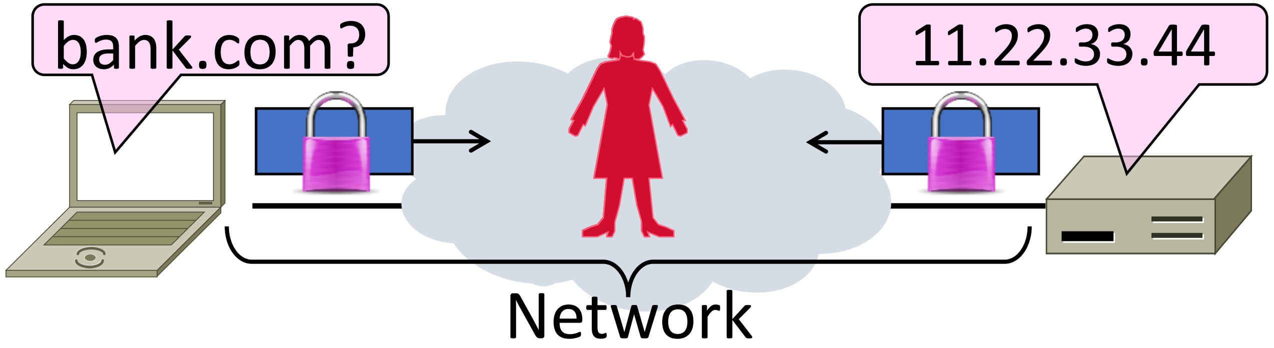
Goal and Threat Model

- Naming is a crucial Internet service
  - Binds host name to IP address
  - Wrong binding can be disastrous…



Goal and Threat Model (2)

- Goal is to secure the DNS so that the returned binding is correct
  - Integrity/authenticity vs confidentiality
- Attacker can tamper with messages on the network



DNS Spoofing

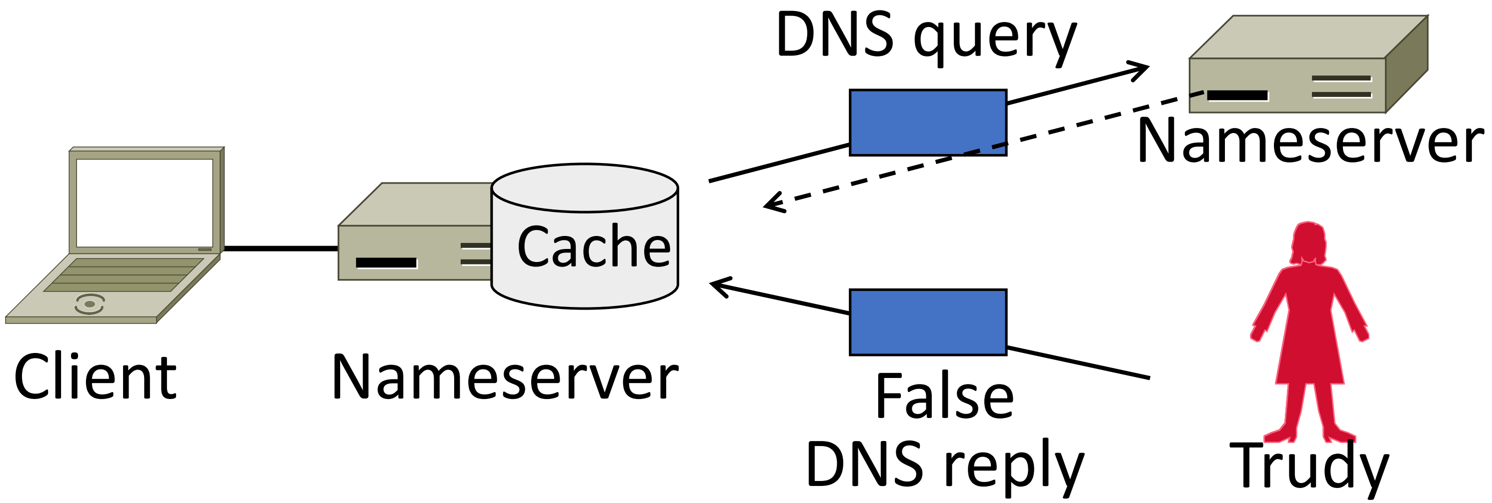
- Hang on – how can attacker corrupt the DNS?

DNS Spoofing

- Hang on – how can attacker corrupt the DNS?
- Can trick nameserver into caching the wrong binding
  - By using the DNS protocol itself
  - This is called DNS spoofing

DNS Spoofing (2)

- To spoof, Trudy returns a fake DNS response that appears to be true
  - Fake response contains bad binding



DNS Spoofing (3)

- Lots of questions!
  1. How does Trudy know when the DNS query is sent and what it is for?
  2. How can Trudy supply a fake DNS reply that appears to be real?
  3. What happens when the real DNS reply shows up?
- There are solutions to each issue …

DNS Spoofing (4)

1. How does Trudy know when the query is sent and what it is for?

DNS Spoofing (5)

1. How does Trudy know when the query is sent and what it is for?

- Trudy can make the query herself!
  - Nameserver works for many clients
  - Trudy is just another client

DNS Spoofing (6)

2. How can Trudy supply a fake DNS reply that appears to be real?

DNS Spoofing (7)

2. How can Trudy supply a fake DNS reply that appears to be real?

- A bit more difficult. DNS checks:
  - Reply is from authoritative nameserver (e.g., .com)
  - Reply ID that matches the request
  - Reply is for outstanding query
- (Nothing about content though …)

DNS Spoofing (8)

2. How can Trudy supply a fake DNS reply that appears to be real?

- Example Technique:
  1. Put IP of authoritative nameserver as the source IP ID is 16 bits (64K)
  2. Send reply right after query
  3. Send many guesses! (Or if a counter, sample to predict.)
- Good chance of succeeding!

DNS Spoofing (8)

3. What happens when real DNS reply shows up?

DNS Spoofing (9)

3. What happens when real DNS reply shows up?

- Likely not be a problem
  - There is no outstanding query after fake reply is accepted
  - So real reply will be discarded

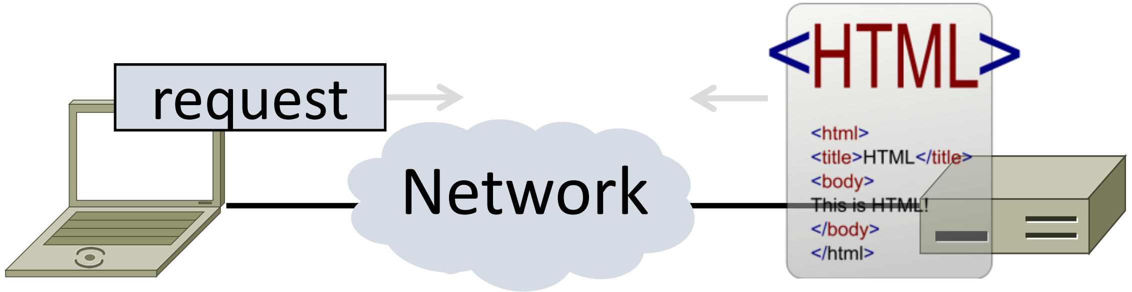
DNSSEC (DNS Security Extensions)

- Extends DNS with new record types
  - RRSIG for digital signatures of records
  - DNSKEY for public keys for validation
  - DS for public keys for delegation
  - First version in ‘97, revised by ’05
- Deployment requires software upgrade at both client and server
  - Root servers upgraded in 2010
  - Followed by uptick in deployment

HTTP

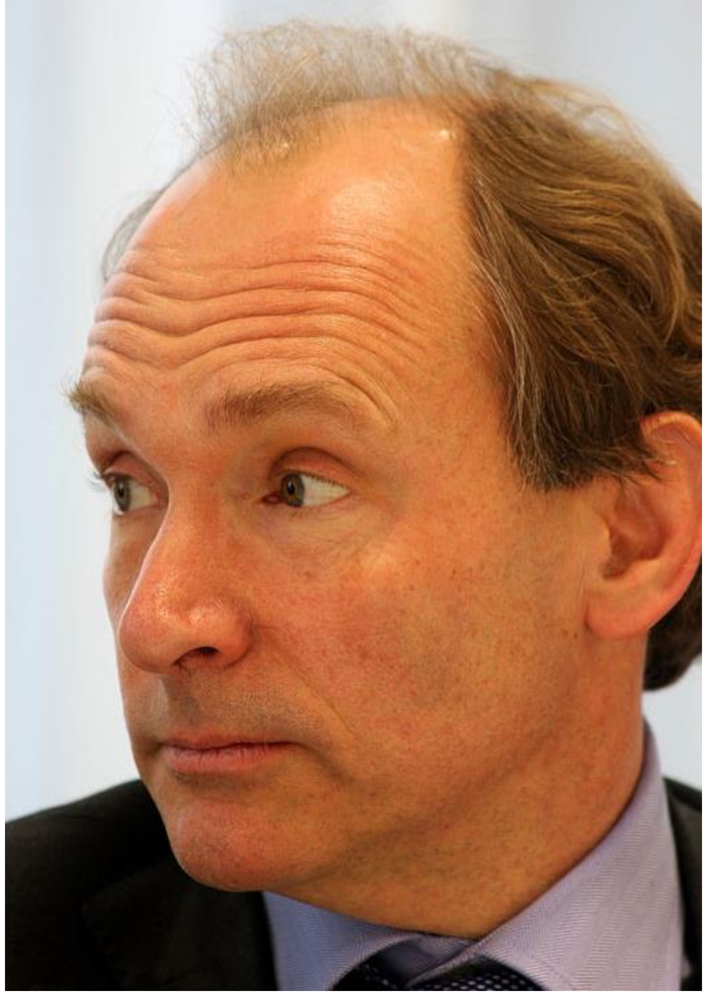
HTTP, (HyperText Transfer Protocol)

- Basis for fetching Web pages



Sir Tim Berners-Lee (1955–)

- Inventor of the Web
  - Dominant Internet app since mid 90s
  - He now directs the W3C
- Developed Web at CERN in ‘89
  - Browser, server and first HTTP
  - Popularized via Mosaic (‘93), Netscape
  - First WWW conference in ’94 …



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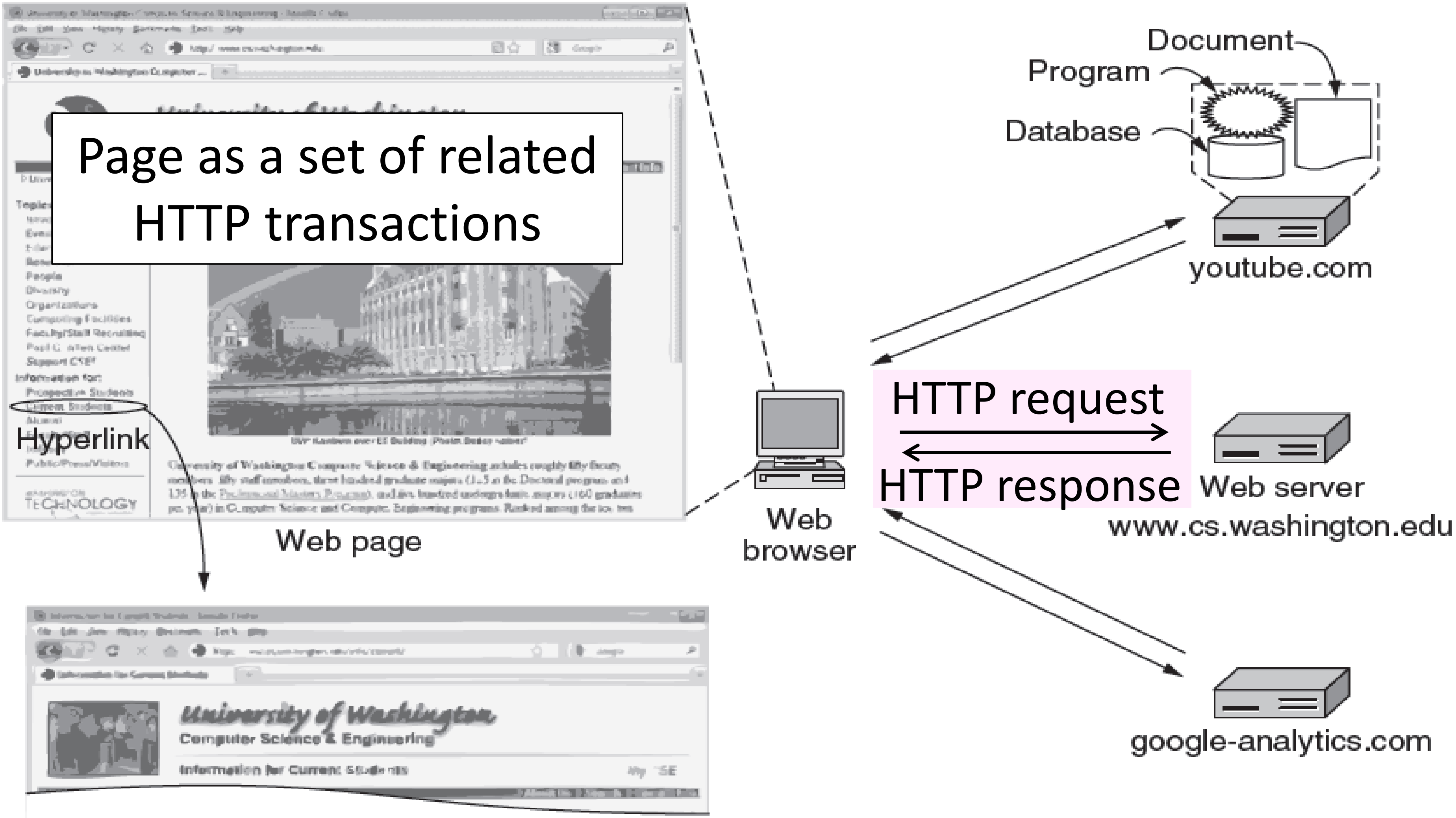
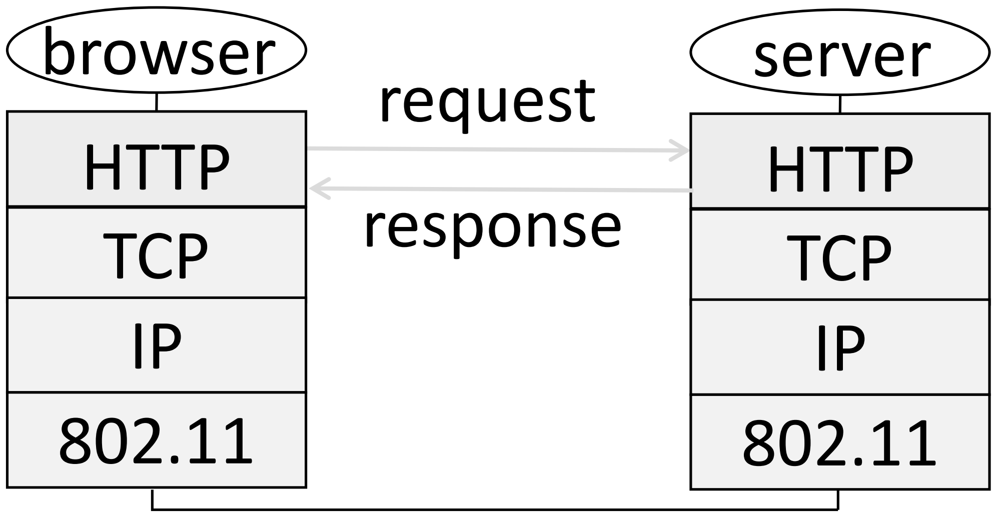
Web Context



Page as a set of related HTTP transactions
Hyperlink
Web page
Web browser
HTTP request
HTTP response
Document
Program
Database
youtube.com
Web server
www.cs.washington.edu
google-analytics.com

Web Protocol Context

- HTTP is a request/response protocol for fetching Web resources
  - Runs on TCP, typically port 80
  - Part of browser/server app



Fetching a Web page with HTTP

- Start with the page URL (Uniform Resource Locator):

  http://en.wikipedia.org/wiki/Vegemite

  Protocol Server Page on server

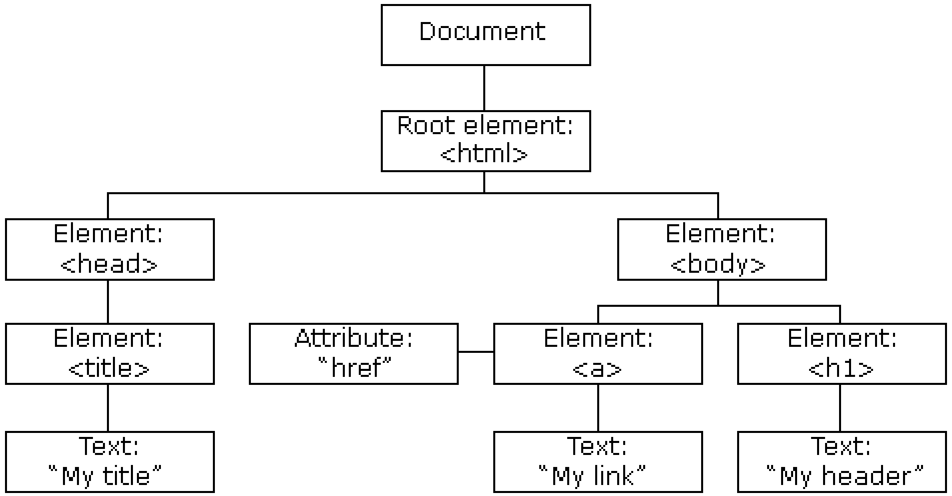
- Steps:
  - Resolve the server to IP address (DNS)
  - Set up TCP connection to the server
  - Send HTTP request for the page
  - (Await HTTP response for the page)
  - Execute/fetch embedded resources/render
  - Clean up any idle TCP connections

HTML

- Hypertext Markup Language (HTML)
  - Uses Extensible Markup Language (XML) to build a markup language for web content
  - Key innovation was the “hyperlink”, an HTML element linking to other HTML elements using URLs
  - Also includes Cascading Style Sheets (CSS) for maintaining look-and-feel across a domain
  - Specific standards have been the subject of many “browser wars”

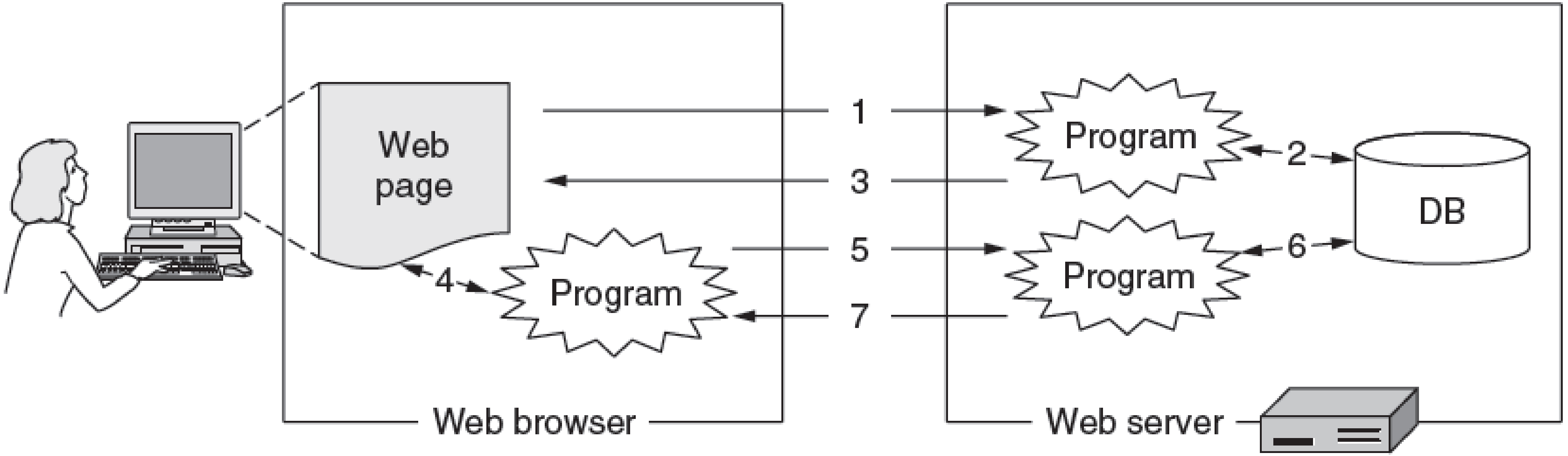
DOM (Document Object Model)

- Base primitive for web browsers interacting with HTML
- Use HTML (XML) to create a tree of elements
- Javascript code is embedded in the page and modifies the DOM based on:
  - User actions
  - Asynchronous Javascript
  - Other server-side actions



Static vs Dynamic Web pages

- Static is just static files, e.g., image
- Dynamic has ongoing computation of some kind
    - Javascript on client, PHP on server, or both



HTTP Protocol

- Originally a simple protocol, with many options added over time
  - Text-based commands, headers
- Try it yourself:
  - As a “browser” fetching a URL
  - Run “telnet en.wikipedia.org 80”
  - Type “GET /wiki/Vegemite HTTP/1.0” to server followed by a blank line
  - Server will return HTTP response with the page contents (or other info)

HTTP Protocol (2)

- Commands used in the request

Method	Description
GET	Read a Web page
HEAD	Read a Web page's header
POST	Append to a Web page
PUT	Store a Web page
DELETE	Remove the Web page
TRACE	Echo the incoming request
CONNECT	Connect through a proxy
OPTIONS	Query options for a page

Fetch page → GET

Upload data → POST

Basically defunct → PUT, DELETE

HTTP Protocol (3)

- Codes returned with the response

Code	Meaning	Examples
1xx	Information	100 = server agrees to handle client's request
2xx	Success	200 = request succeeded; 204 = no content present
3xx	Redirection	301 = page moved; 304 = cached page still valid
4xx	Client error	403 = forbidden page; 404 = page not found
5xx	Server error	500 = internal server error; 503 = try again later

Yes! → (2xx)

Representational State Transfer (REST)

- Using HTTP for general network services
- An ideal for design of HTTP-based APIs
  - Called RESTful APIs
- 5 Core Tenants:
  - Stateless (no state on server)
  - Cachable (individual urls can be cached)
  - Layered (no visibility under REST hood)

Representational State Transfer (REST)

- RESTful Interfaces use HTTP to provide a variety of other media (e.g., JSON)
  - For example, GET will always be *safe* and change nothing

HTTP methods

Uniform Resource Locator (URL)	GET	PUT	POST	DELETE
Collection, such as http://api.example.com/resources/	**List** the URIs and perhaps other details of the collection's members.	**Replace** the entire collection with another collection.	**Create** a new entry in the collection. The new entry's URI is assigned automatically and is usually returned by the operation.[17]	**Delete** the entire collection.
Element, such as http://api.example.com/resources/item17	**Retrieve** a representation of the addressed member of the collection, expressed in an appropriate Internet media type.	**Replace** the addressed member of the collection, or if it does not exist, **create** it.	Not generally used. Treat the addressed member as a collection in its own right and **create** a new entry within it.[17]	**Delete** the addressed member of the collection.

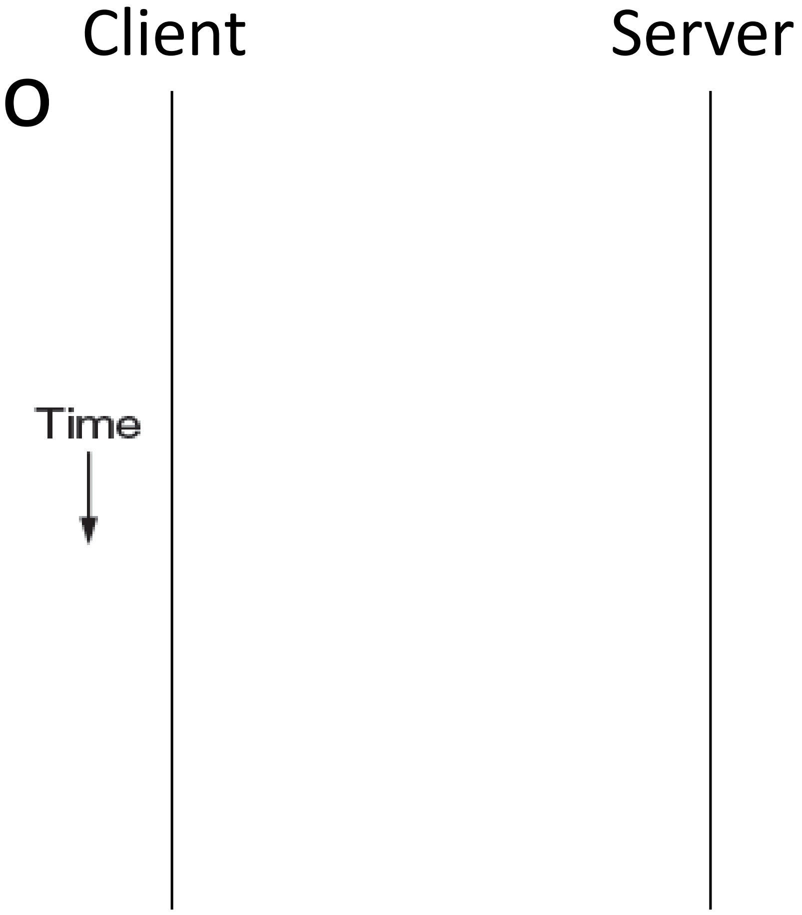
Performance

PLT (Page Load Time)

- PLT was the key measure of web performance
  - From click until user sees page
  - Small increases in PLT decrease sales
- PLT depends on many factors
  - Structure of page/content
  - HTTP (and TCP!) protocol
  - Network RTT and bandwidth

Early Performance

- HTTP/1.0 uses one TCP connection to fetch one web resource
  - Made HTTP very easy to build
  - But gave fairly poor PLT …



Early Performance (2)

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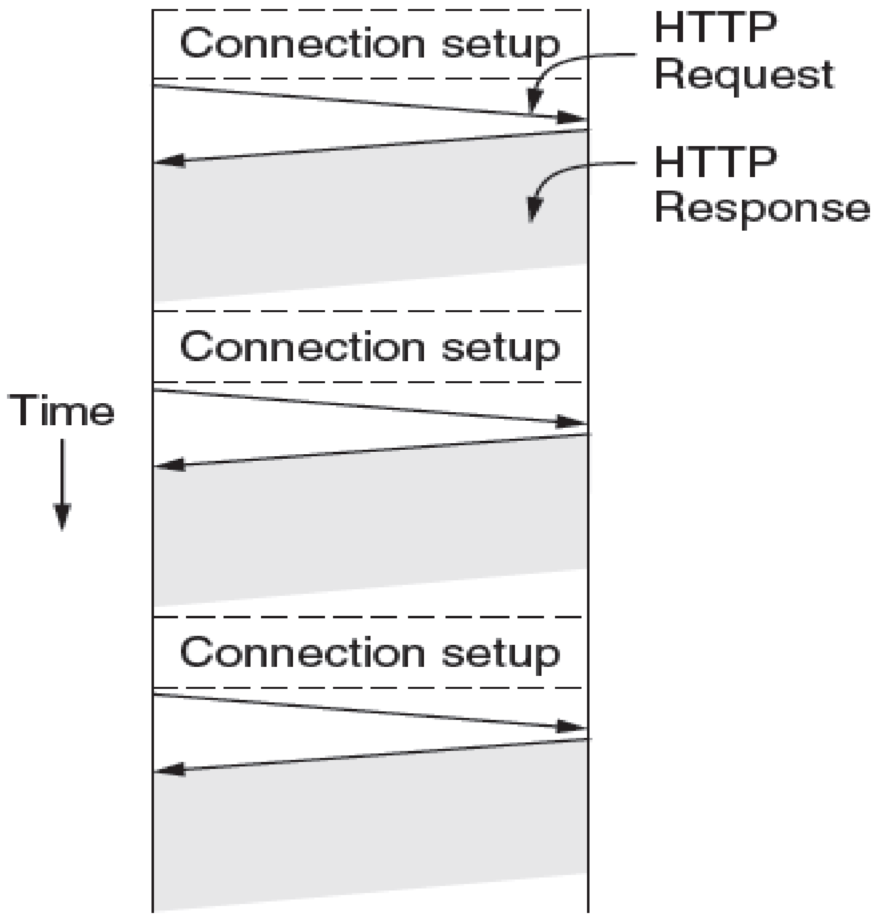
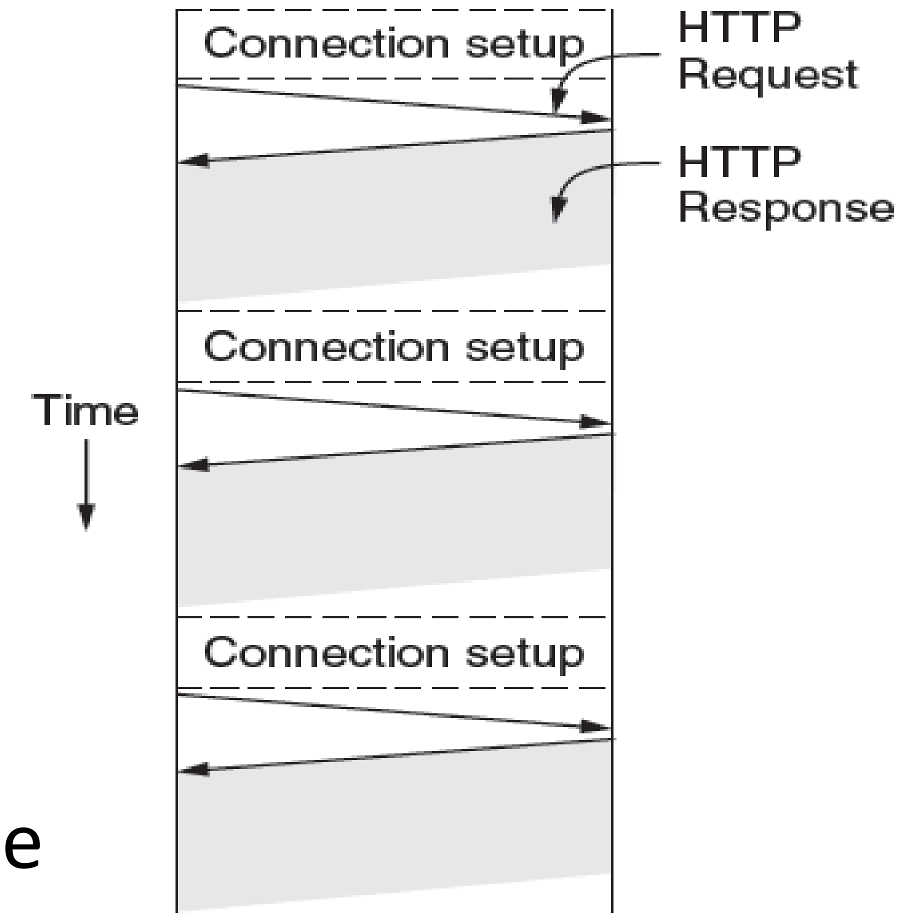


Early Performance (3)

- Many reasons why PLT is larger than necessary
  - Sequential request/responses, even when to different servers
  - Multiple TCP connection setups to the same server
  - Multiple TCP slow-start phases
- Network is not used effectively
  - Worse with many small resources / page



Ways to Decrease PLT

1. Reduce content size for transfer
   - Smaller images, gzip
2. Change HTTP to make better use of bandwidth
3. Change HTTP to avoid repeat sending of same content
   - Caching, and proxies
4. Move content closer to client
   - CDNs [later]

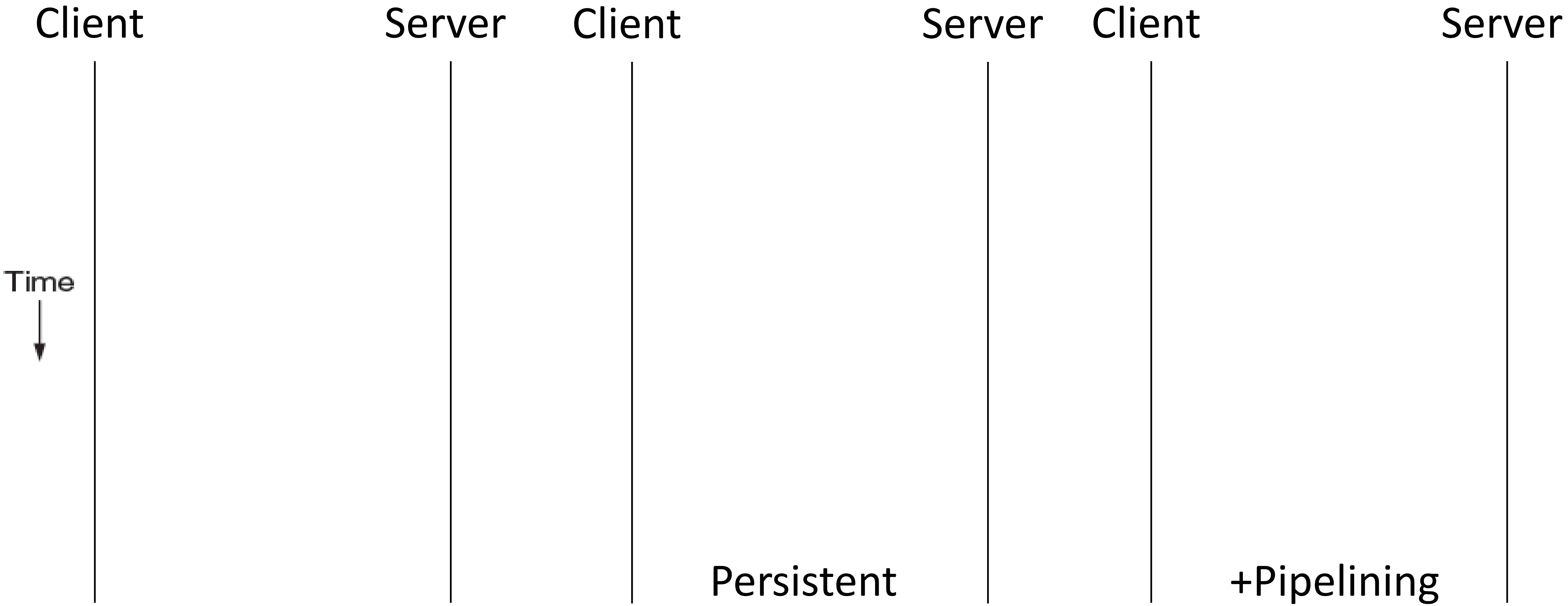
Parallel Connections

- One simple way to reduce PLT
  - Browser runs multiple (8, say) HTTP instances in parallel
  - Server is unchanged; already handled concurrent requests for many clients
- How does this help?
  - Single HTTP wasn't using network much …
  - So parallel connections aren't slowed much
  - Pulls in completion time of last fetch

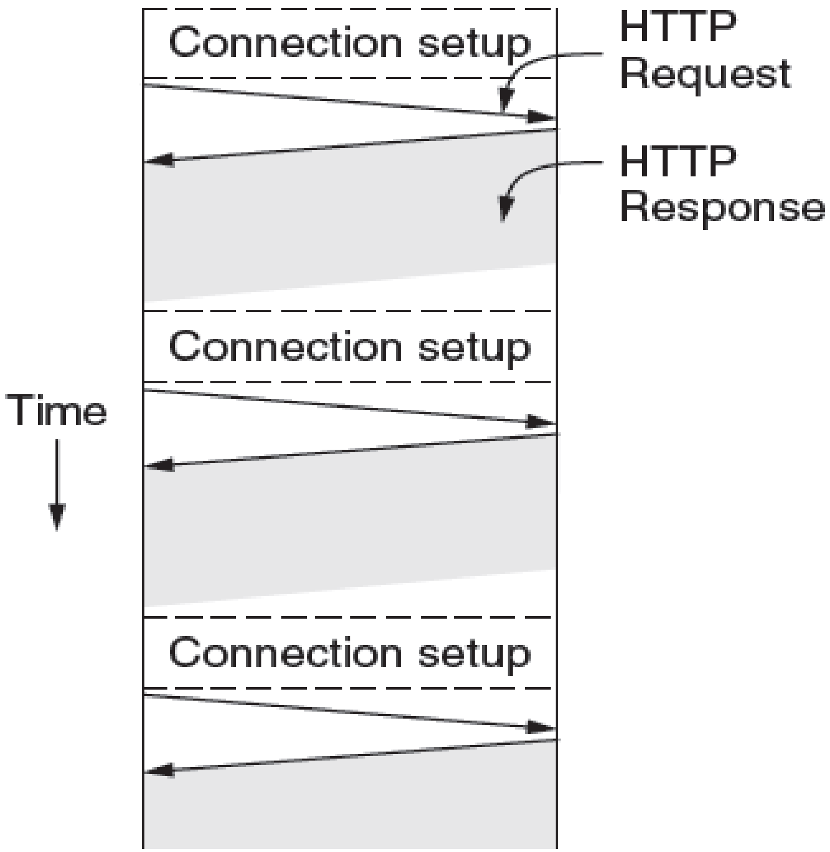
Persistent Connections

- Parallel connections compete with each other for network resources
  - 1 parallel client ≈ 8 sequential clients?
  - Exacerbates network bursts, and loss
- Persistent connection alternative
  - Make 1 TCP connection to 1 server
  - Use it for multiple HTTP requests

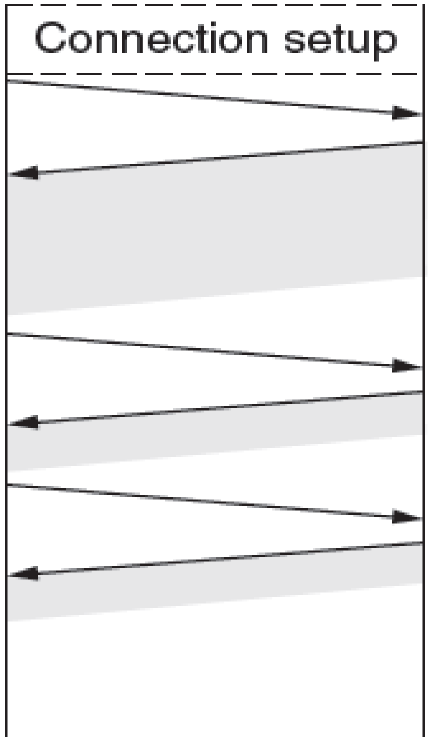
Persistent Connections (2)



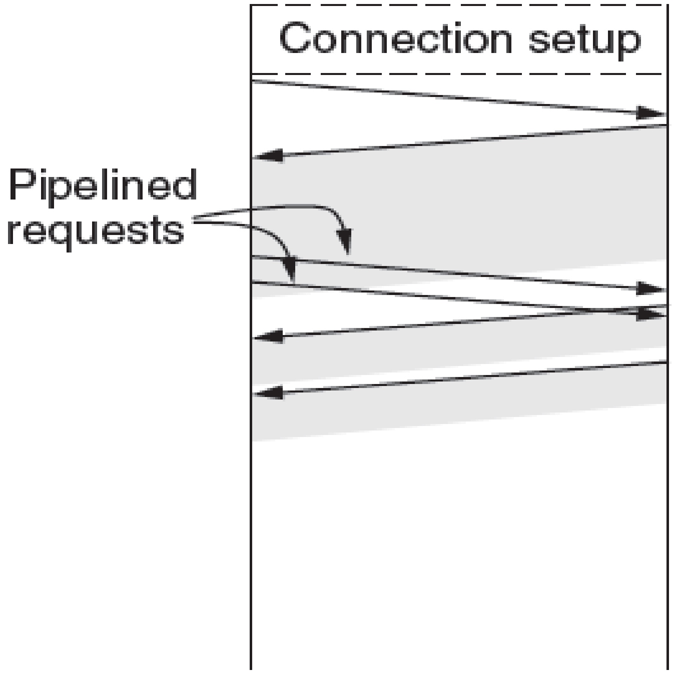
Persistent Connections (3)



One request per connection



Sequential requests per connection



Pipelined requests per connection

Persistent Connections (4)

- Widely used as part of HTTP/1.1
  - Supports optional pipelining
  - PLT benefits depending on page structure, but easy on network

HTTP Futures

HTTP 1.1

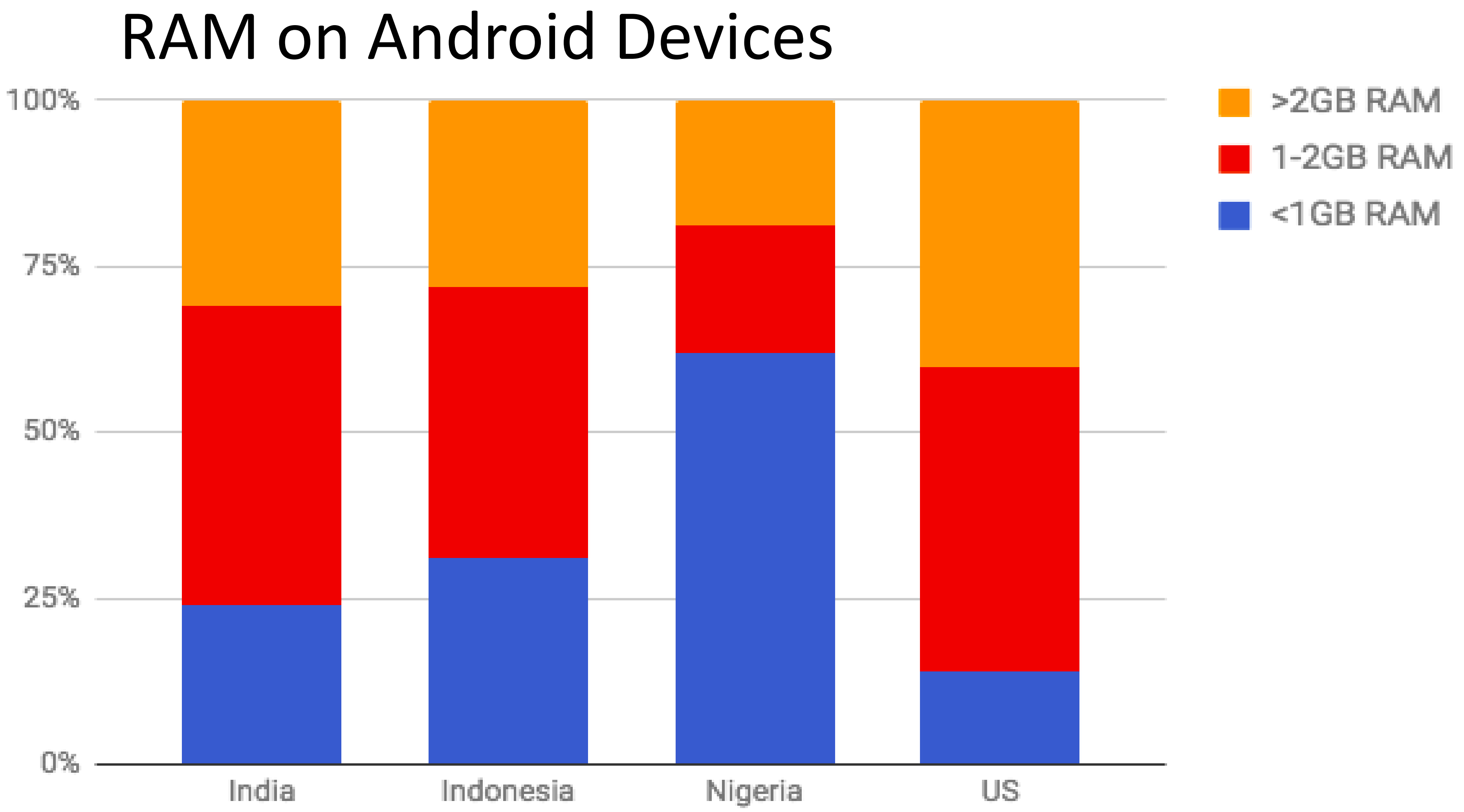
- This was it! Standard protocol until circa 2015.
- HTTP 1.1 everywhere for all web access
- Until our favorite massive web company started noticing some trends….

Continued Growth

Country	Mobile-Only Internet Users
Egypt	70%
India	59%
South Africa	57%
Indonesia	44%
United States	25%

Thanks to Ben Greenstein @ google for slides

Continued Growth (2)



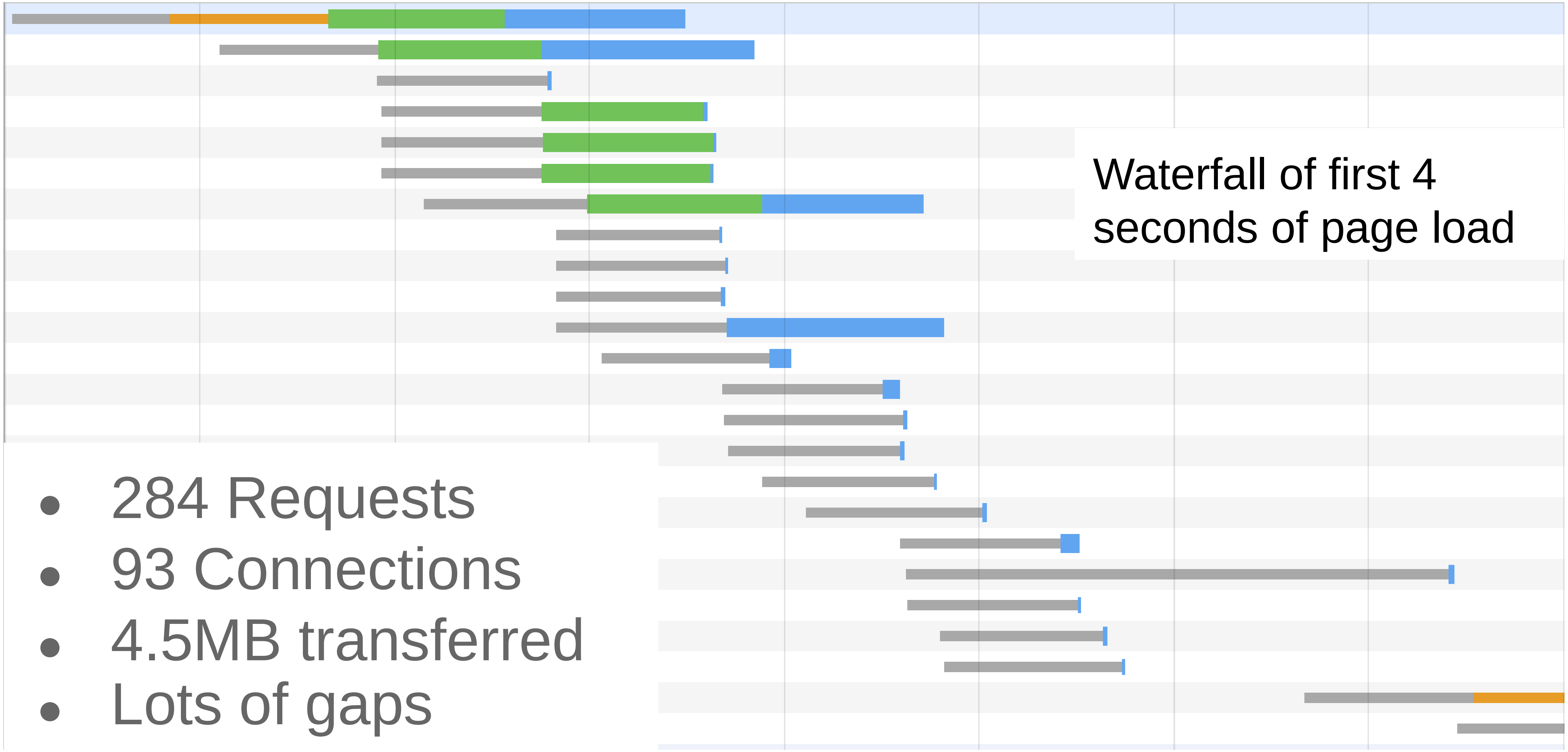
Continued Growth (3)

Tecno Y2
512MB RAM, 8GB ROM
1.3GHz dual-core Cortex-A7
2G & 3G only
4” (480x800)

Tecno W3
1GB RAM, 8GB ROM
1.3GHz dual-core Cortex-A7
2G & 3G only
5” (480x854)

Infinix Hot 4 Lite
1GB RAM, 16GB ROM
1.3GHz quad-core Cortex-A7
2G & 3G only
5.5” (720x1280)

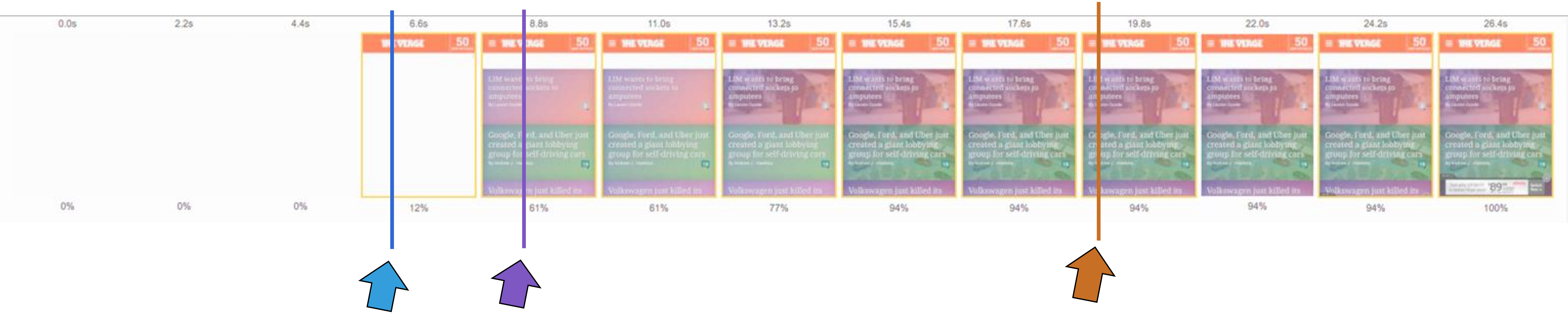
Source: Chrome logs



Waterfall of first 4 seconds of page load

- 284 Requests
- 93 Connections
- 4.5MB transferred
- Lots of gaps

Key user moments (PLT is Dumb)



- First Contentful Paint (FCP) **"is it happening?"**
- First Meaningful Paint (FMP) **"is it useful?"**
- Time to Interactive (TTI) **"is it usable?"**

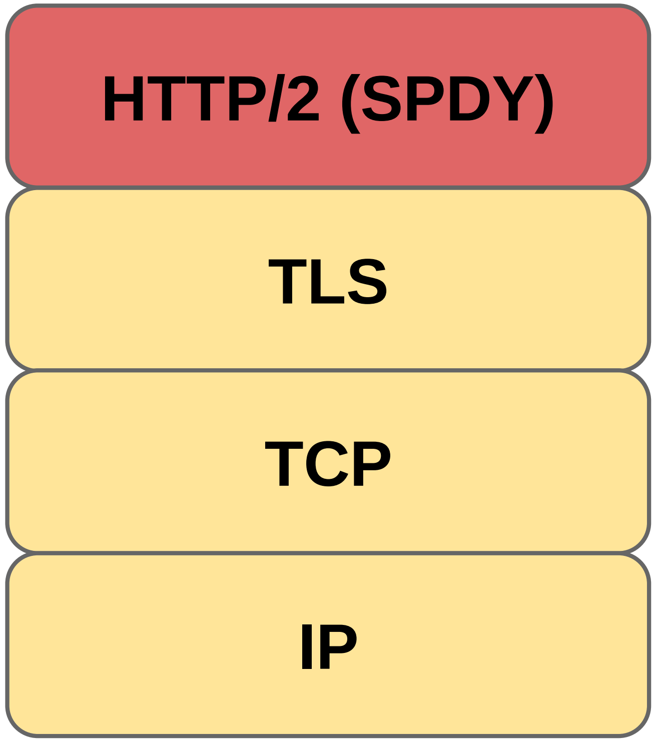
HTTP Changes

HTTP/1.0: TCP connection per request

HTTP/1.1: Persistence and pipelining

HTTP2/SPDY: Targeted performance specifically

- All happens below HTTP layer
- Prioritized stream multiplexing
- Header compression
- Server push
- Started as SPDY, standardized as HTTP/2 in 2015 after ~~every possible bikeshed~~ deep discussion



HTTP 2 Optimizations

Prioritized Stream Multiplexing

- HTTP 1.0: Each HTTP connection has own TCP
- HTTP 1.1: Share one TCP connection to save setup
- HTTP 2.0: Allow multiple *concurrent* HTTP connections in a single TCP flow to avoid head-of-line blocking

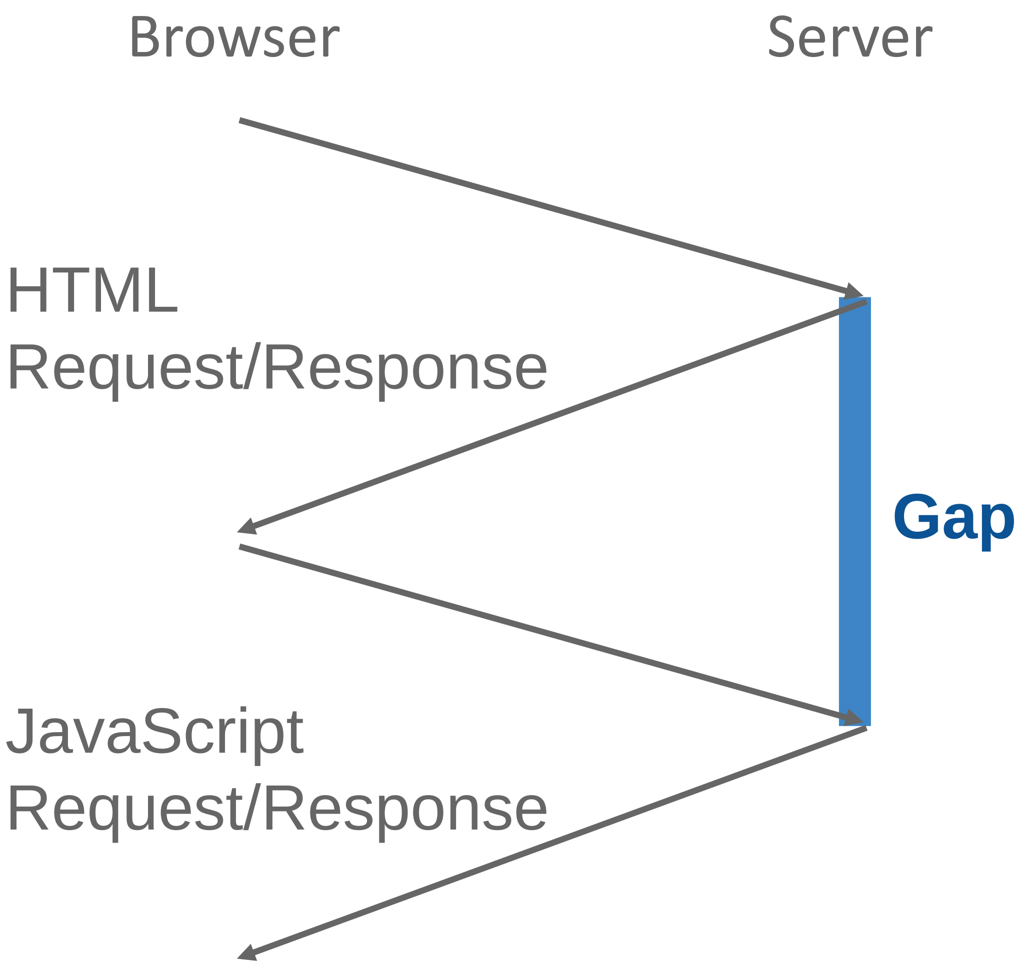
Header Compression

- HTTP Headers very wordy; Designed to be human readable
- This was dumb. Lets compress them (usually gzip).

Server Push: example resource loading gap

- Browser requests and receives HTML, encounters `<script src=”...”>`

- Similarly, JavaScript might src a dependent JavaScript file

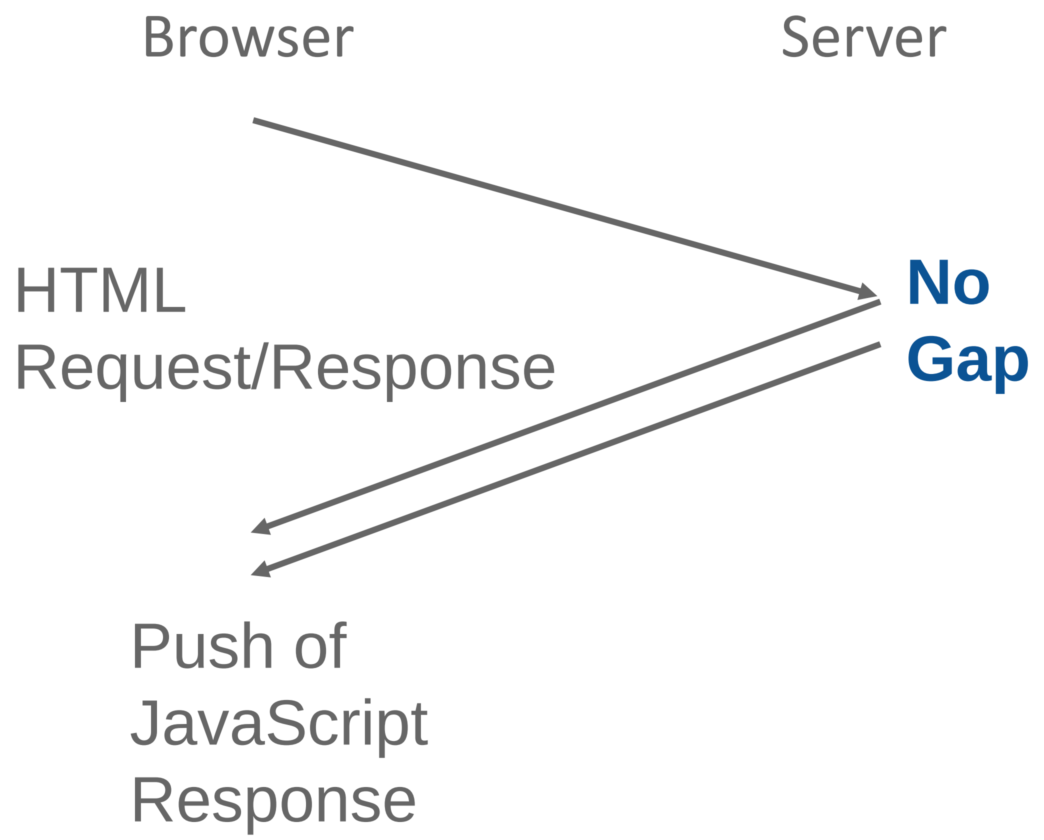


Server Push: example resource loading gap

Use **HTTP/2 server push** to close gaps

Or use **Link: rel=preload**

- Particularly useful for **hidden render blocking resources (HRBRs)**

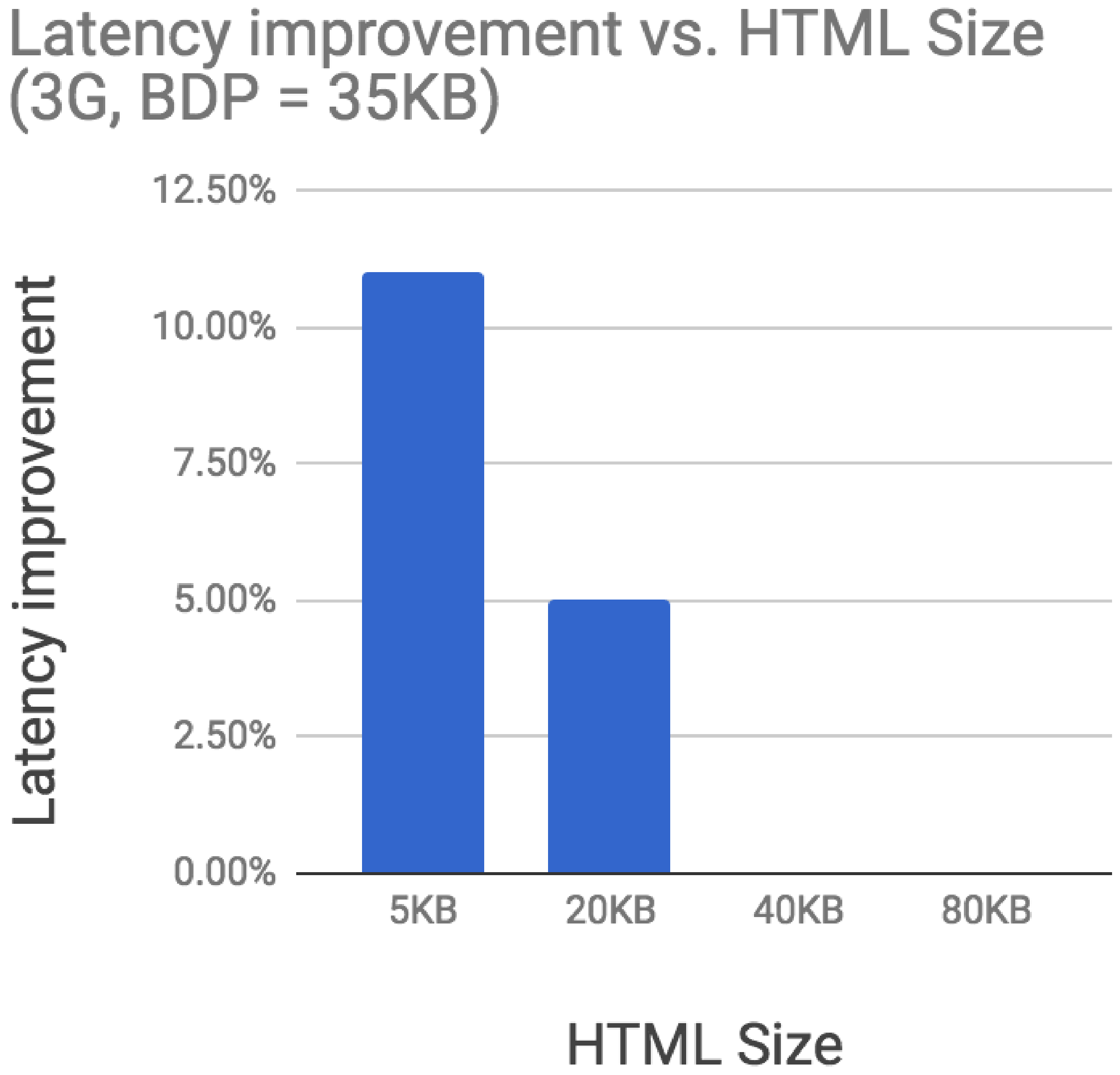


Simple server push lab experiment

Result: No benefit when HTML size > BD Product

Why? No gap even without push.

Opportunity only on high BDP networks, e.g., LTE and Cable



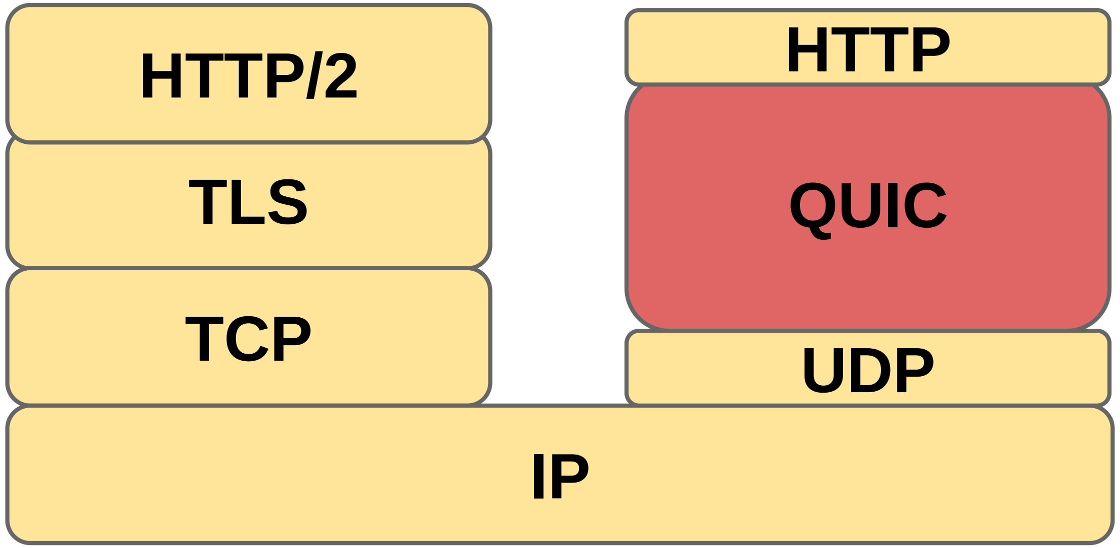
QUIC/HTTP 3.0

Goal: make HTTPS transport **even faster!**

Deployed at Google starting **2014**

IETF working group formed in 2016

Standardized as HTTP 3.0 in October 2018



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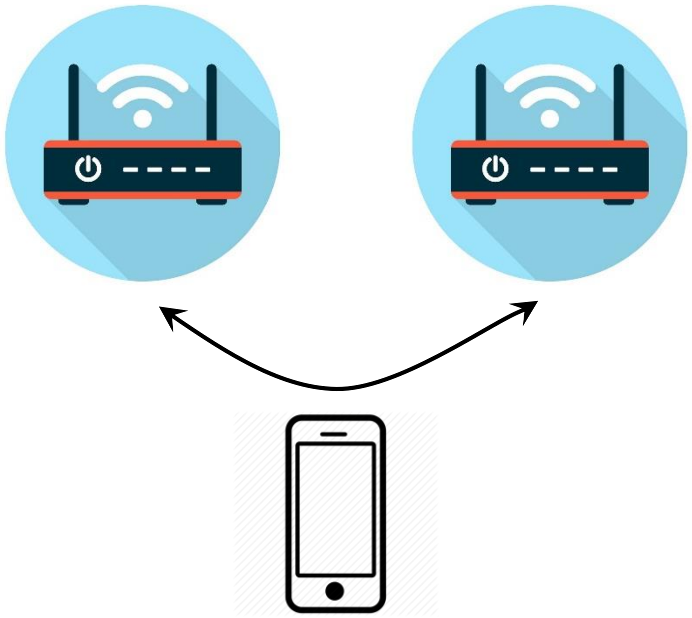
QUIC/HTTP 3.0: Problem of Mobility

- What happens to IP addresses and HTTP sessions when a user moves between wifi APs?



QUIC/HTTP 3.0: Problem of Mobility

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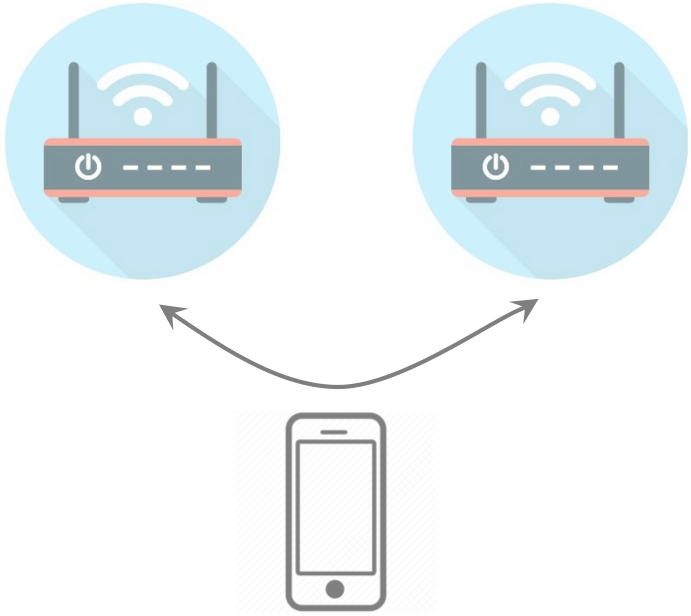
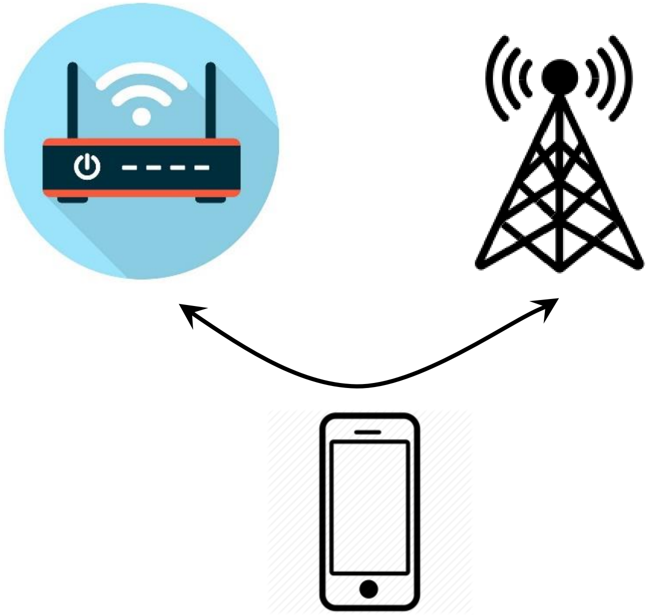


- What happens to IP addresses and HTTP sessions when a user moves between cellular and wifi?



IP Mobility

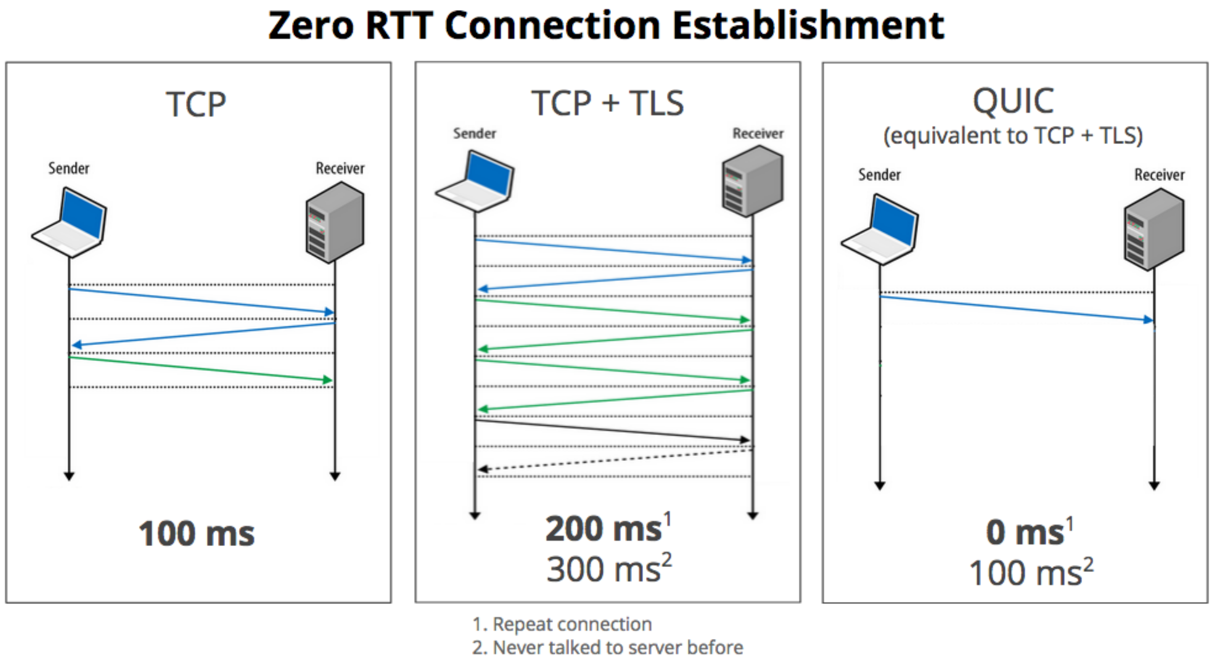
- Hard problem: IP addresses are supposed to identify nodes in the network but change as nodes move around.
- Proposed solutions:
  - IP Anchor: Place a server at an IP and tunnel traffic to user.
  - DNS Anchor: Have DNS server which rapidly updates as user moves between IP addresses
  - All try to keep some global state constant: IP or DNS Name

QUIC/HTTP 3.0 Innovations (1)

- Remove TCP/Switch to UDP
  - Error correction: Groups of packets contain a FEC packet which can be used to recreate a lost packet.
  - Congestion control: all packets carry new sequence numbers, allows for precise roundtrip-time calculation.
  - Reduces setup time and helps with mobility
- Include TLS/Encryption in the connection establishment
  - All traffic encrypted (mostly)

QUIC/HTTP 3.0 Innovations (2)

- Support mobility through 64-bit stream IDs
  - This means you can change IP address or ports but still keep your connection alive

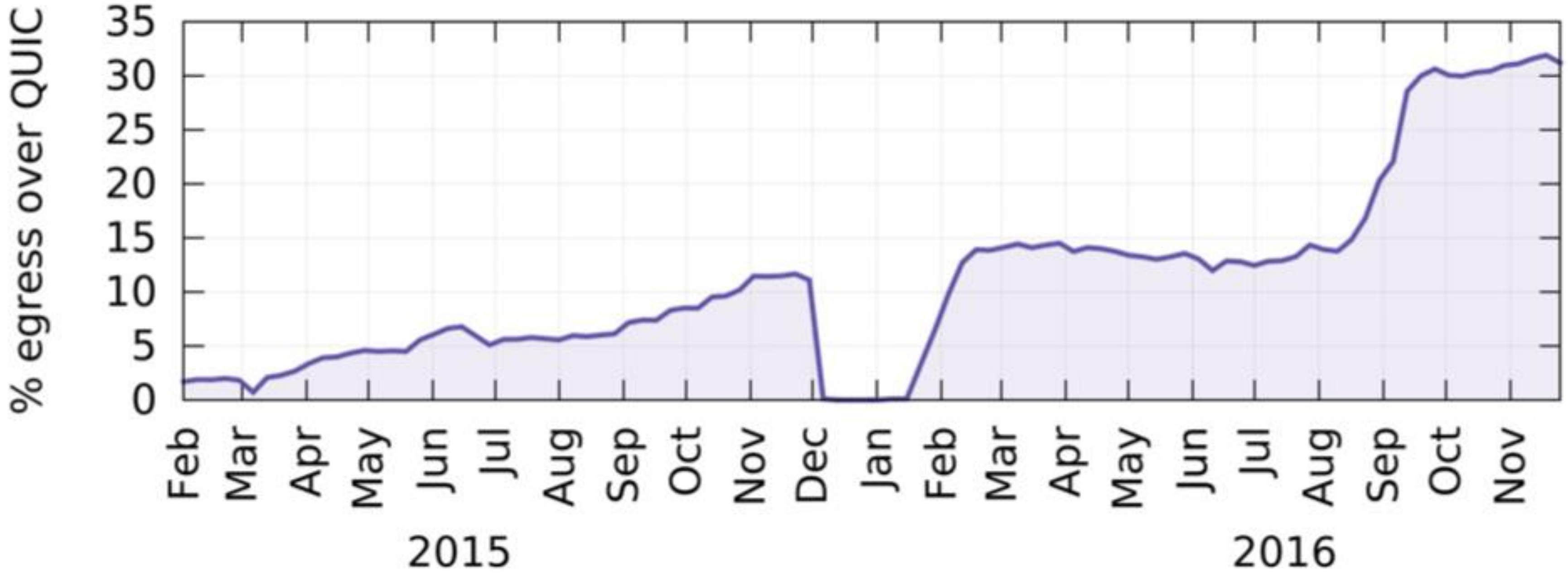


QUIC summary

Makes HTTPS faster, particularly in the tail

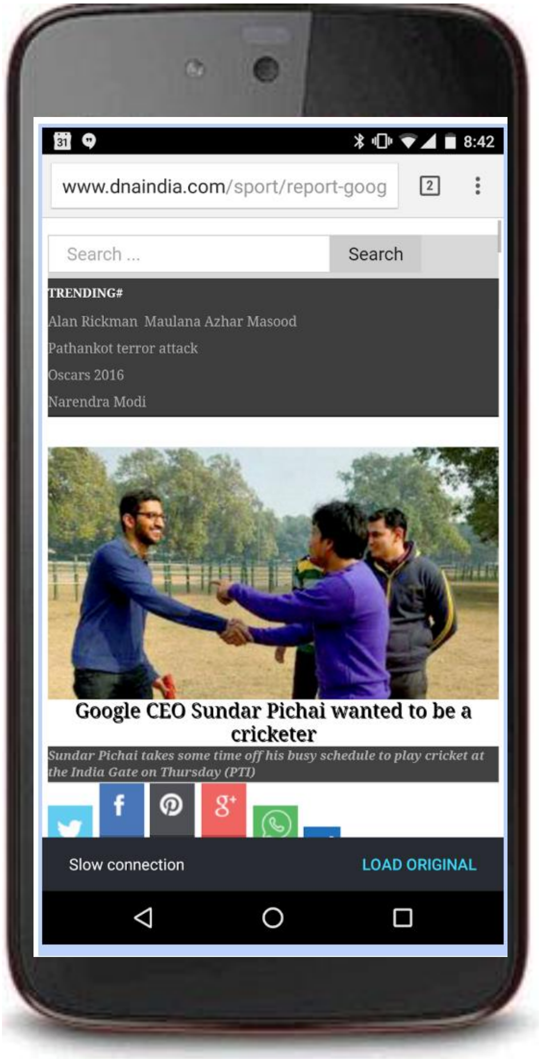
35% of Google's egress traffic (7% of the Internet)

Deploying at Google was 3+ years of hard work



Going Farther

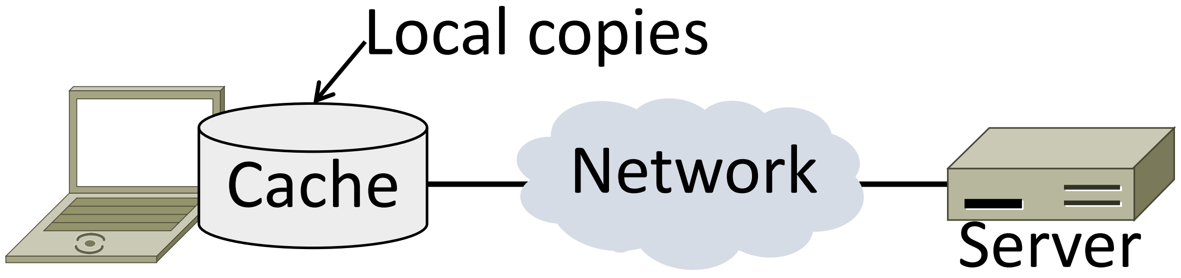
- Flywheel **proxy** service
  - **Compresses HTTP pages** by 60%.
  - **Transcodes** to **WebP**, **WebM**, **Brotli**
    Uses **HTTP/2** and **QUIC**
- Render the page on the server
  - 50% speedup, >90% compression
  - Trades **fidelity loss** for **speed**, so we do this only on **very slow networks**



Web Caching/CDNs

Web Caching

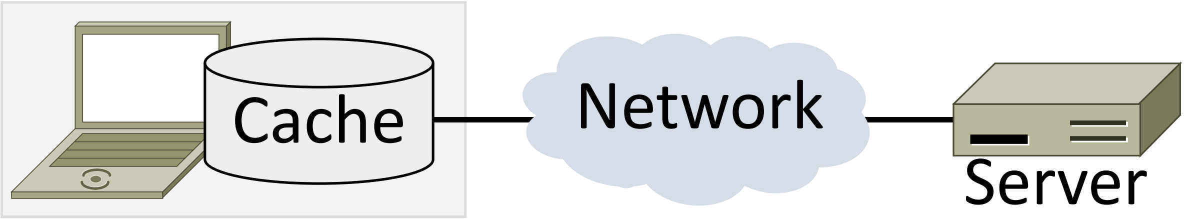
- Users often revisit web pages
  - Big win from reusing local copy!
  - This is caching



- Key question:
  - When is it OK to reuse local copy?

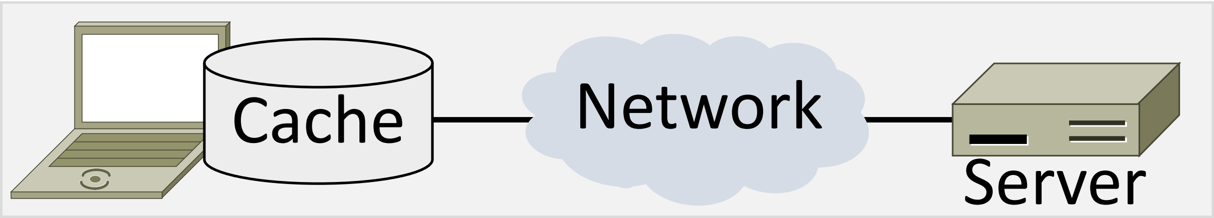
Web Caching (2)

- Locally determine copy is still valid
  - Based on expiry information such as “Expires” header from server
  - Or use a heuristic to guess (cacheable, freshly valid, not modified recently)
  - Content is then available right away



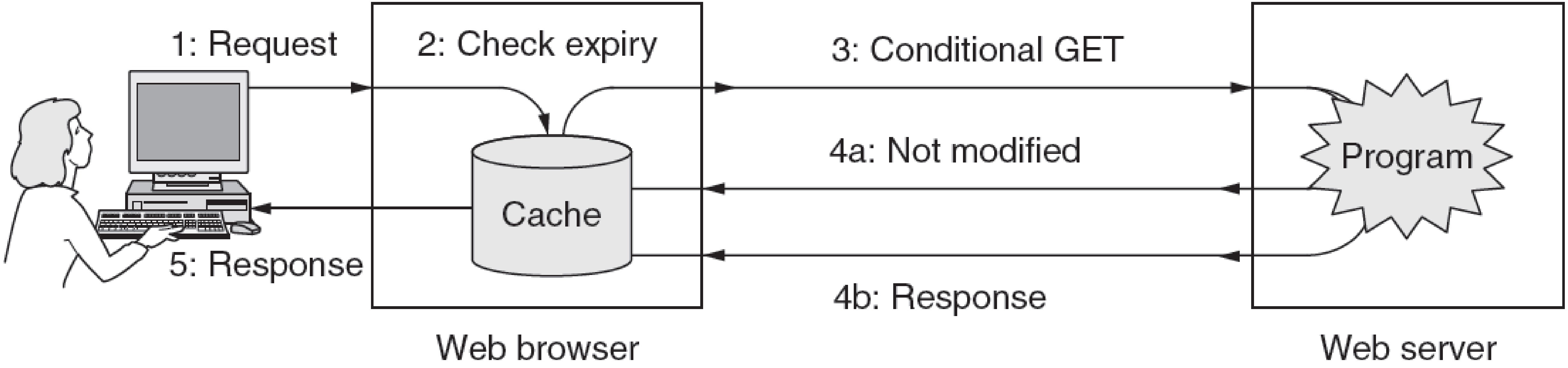
Web Caching (3)

- Revalidate copy with remote server
  - Based on timestamp of copy such as “Last-Modified” header from server
  - Or based on content of copy such as “Etag” server header
  - Content is available after 1 RTT



Web Caching (4)

- Putting the pieces together:

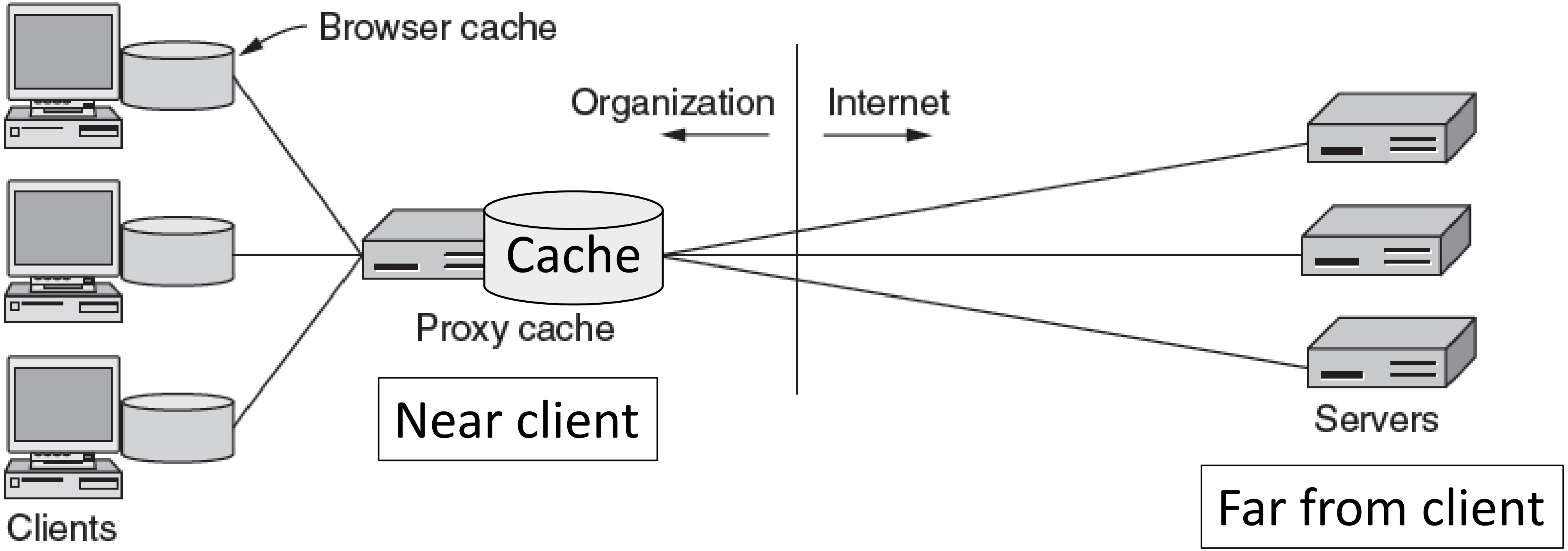


Web Proxies

- Place intermediary between pool of clients and external web servers
  - Benefits for clients include caching and security checking
  - Organizational access policies too!
- Proxy caching
  - Clients benefit from larger, shared cache
  - Benefits limited by secure / dynamic content, as well as "long tail"

Web Proxies (2)

- Clients contact proxy; proxy contacts server

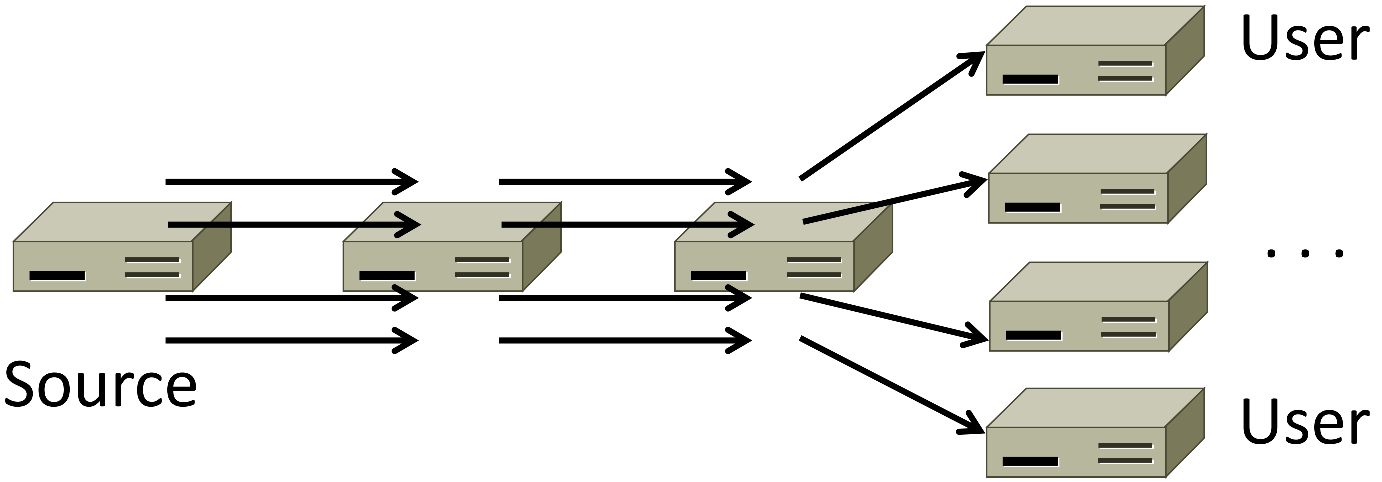


Content Delivery Networks

- As the web took off in the 90s, traffic volumes grew and grew. This:
  1. Concentrated load on popular servers
  2. Led to congested networks and need to provision more bandwidth
  3. Gave a poor user experience
- Idea:
  - Place popular content near clients
  - Helps with all three issues above

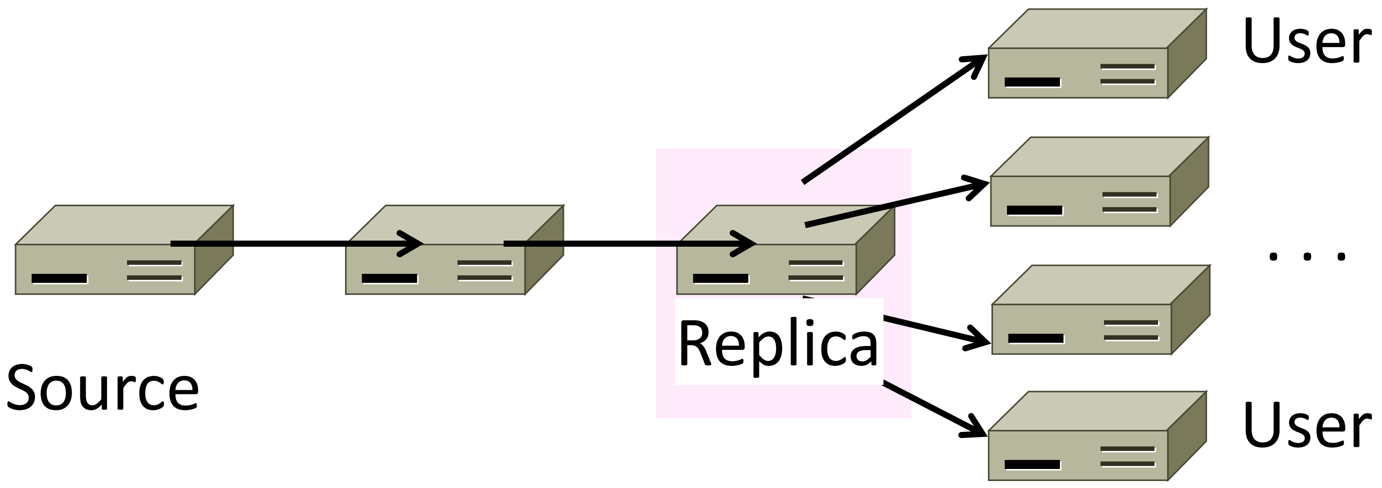
Before CDNs

- Sending content from the source to 4 users takes 4 x 3 = 12 “network hops” in the example



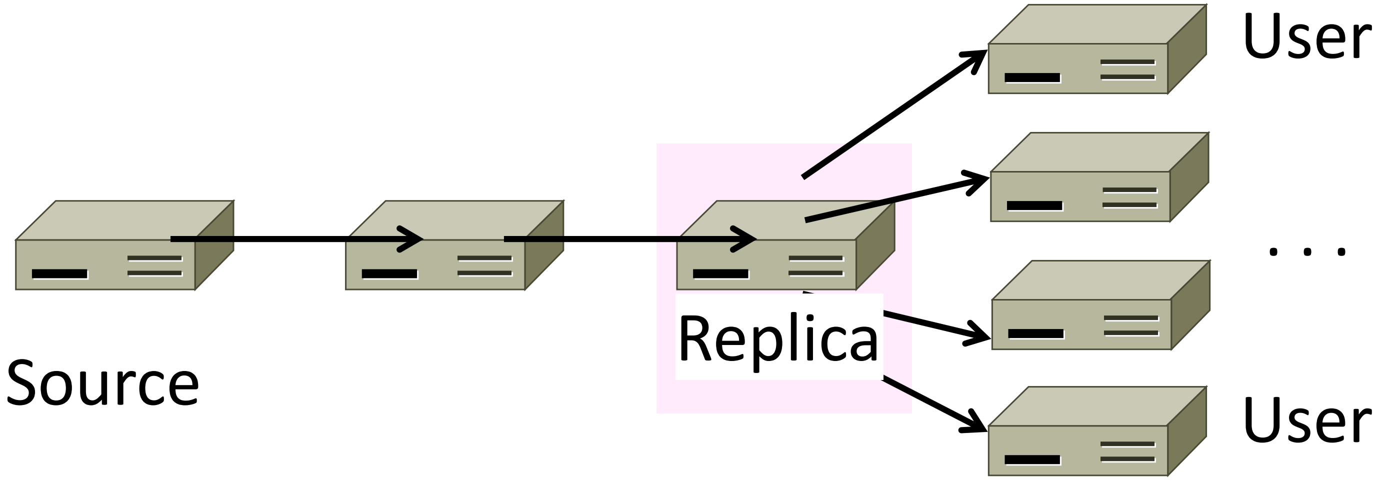
After CDNs

- Sending content via replicas takes only 4 + 2 = 6 "network hops"



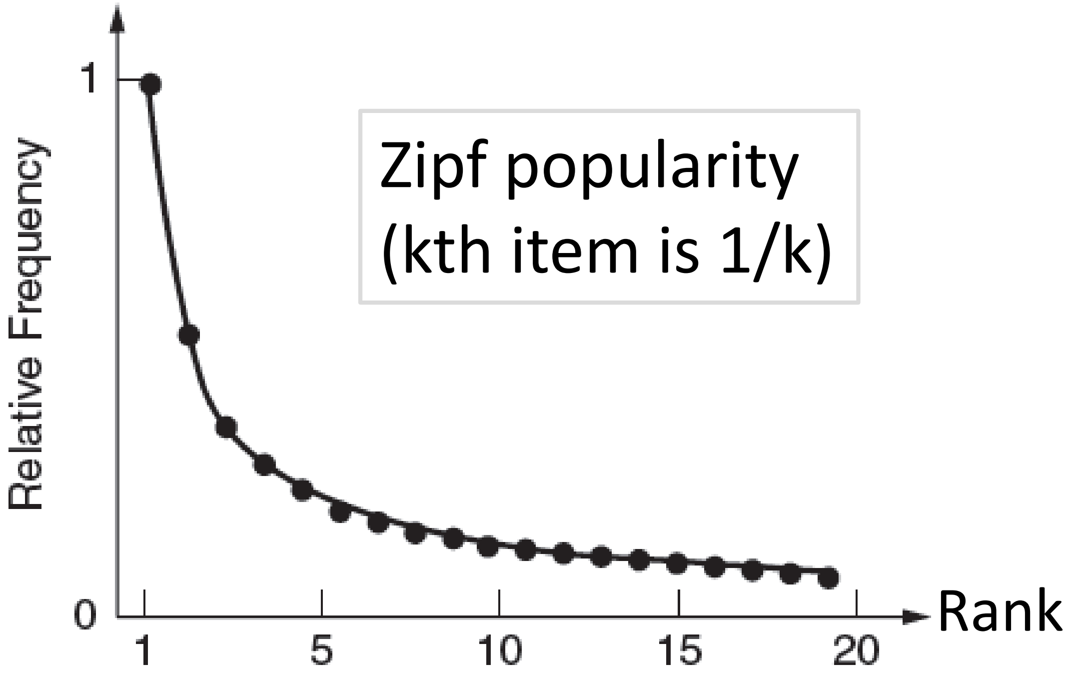
After CDNs (2)

- Benefits assuming popular content:
  - Reduces server, network load
  - Improves user experience



Popularity of Content

- Zipf's Law: few popular items, many unpopular ones; both matter



George Zipf (1902-1950)

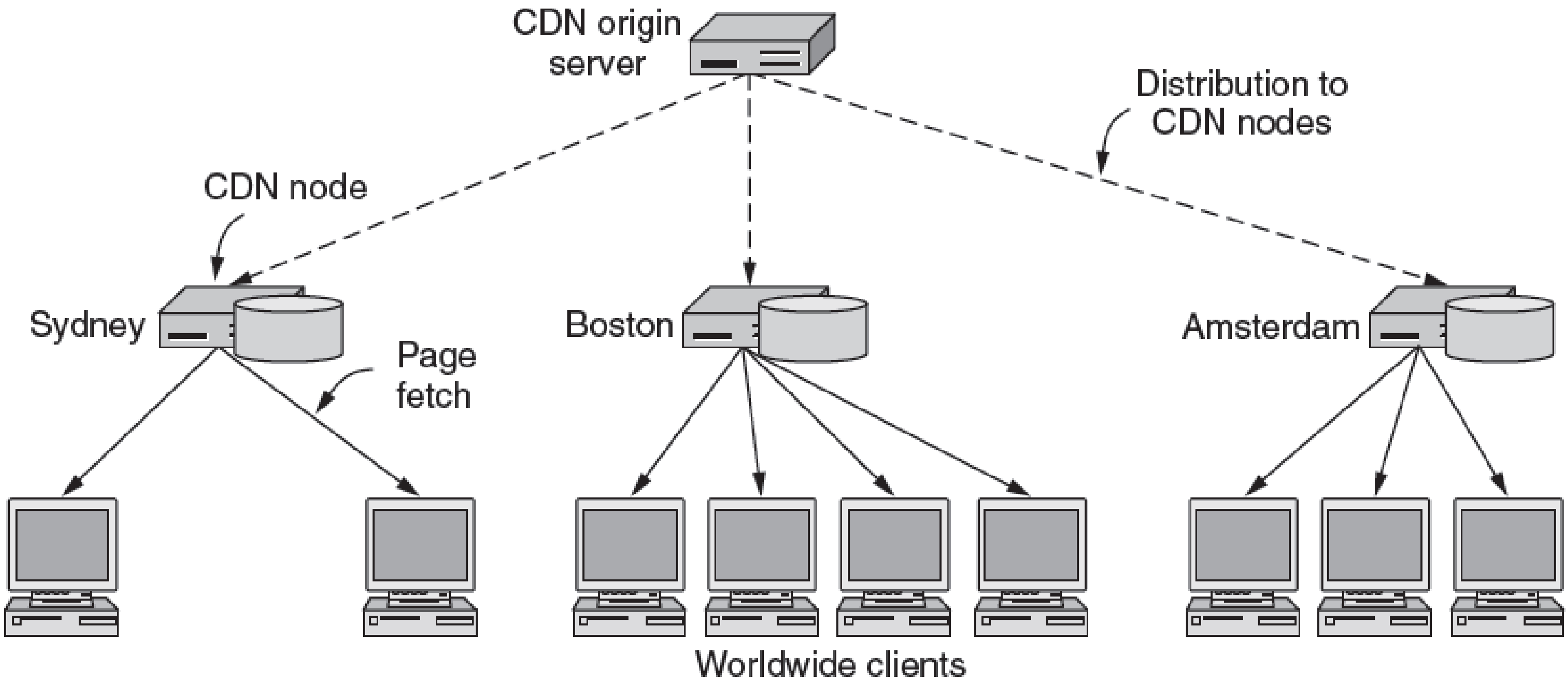
Source: Wikipedia

How to place content near clients?

How to place content near clients?

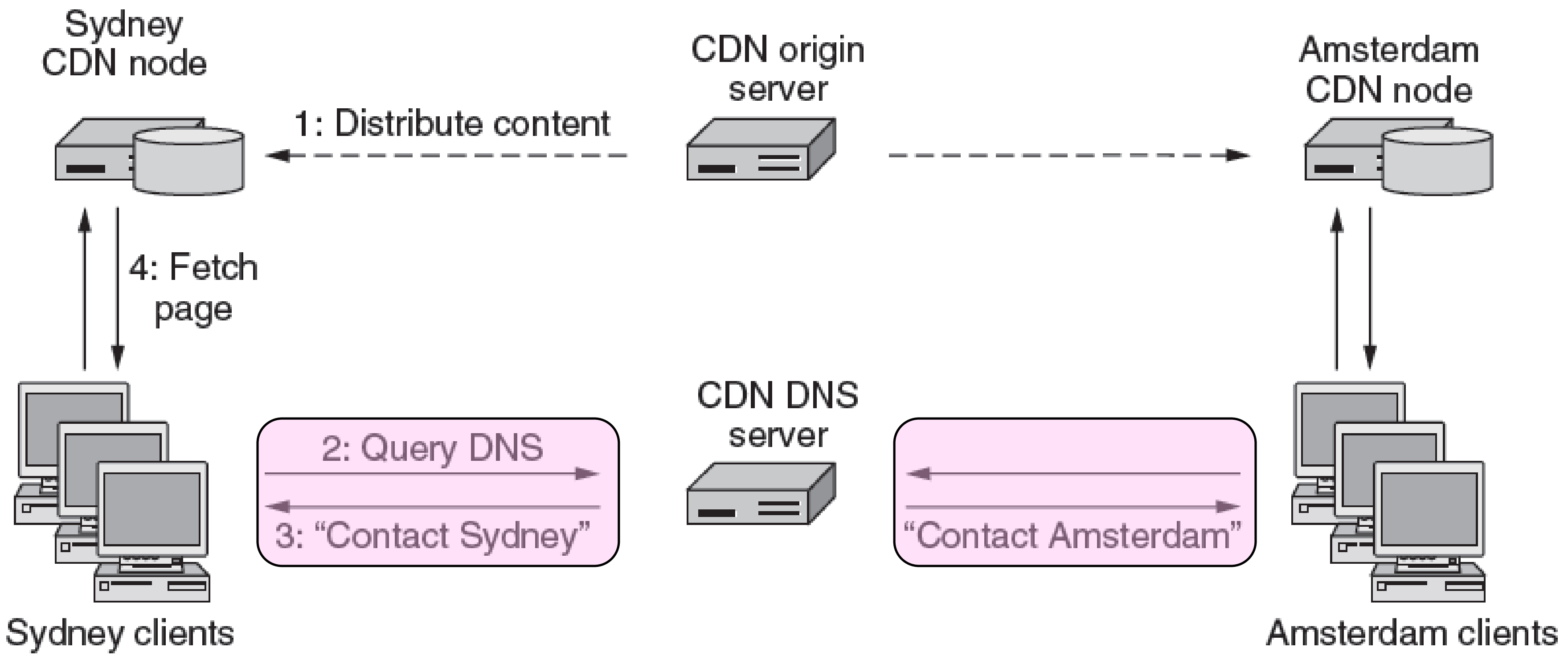
- Use browser and proxy caches
  - Helps, but limited to one client or clients in one organization
- Want to place replicas across the Internet for use by all nearby clients
  - Done by clever use of DNS

Content Delivery Network



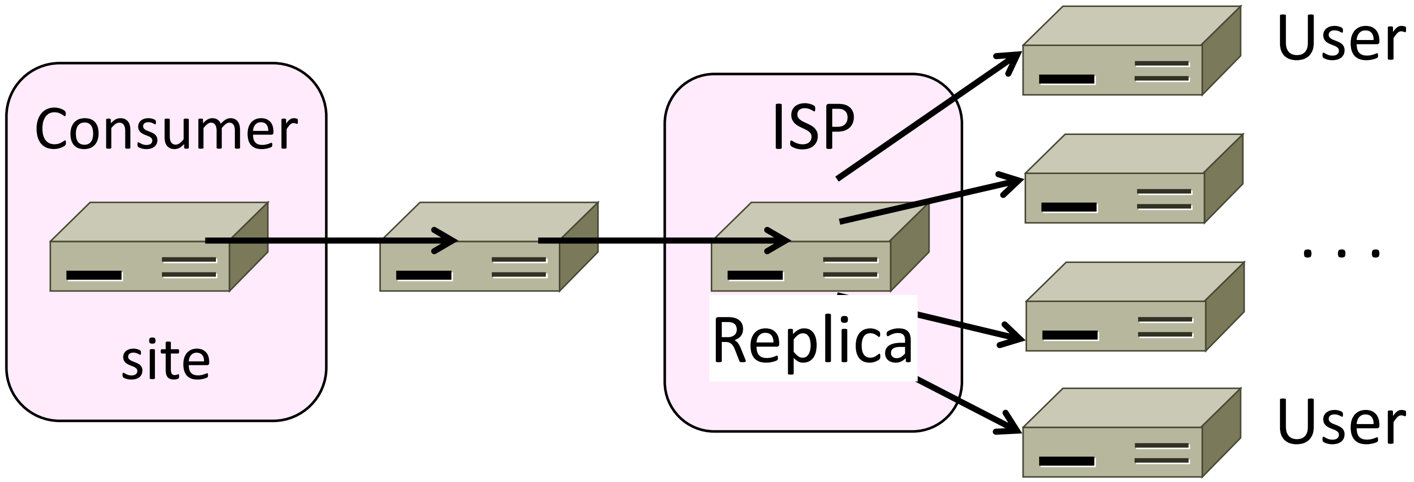
Content Delivery Network (2)

- DNS gives different answers to clients
  - Tell each client the nearest replica (map client IP)



Business Model

- Clever model pioneered by Akamai
  - Placing site replica at an ISP is win-win
  - Improves site experience and reduces ISP bandwidth usage



CDNs - Issues

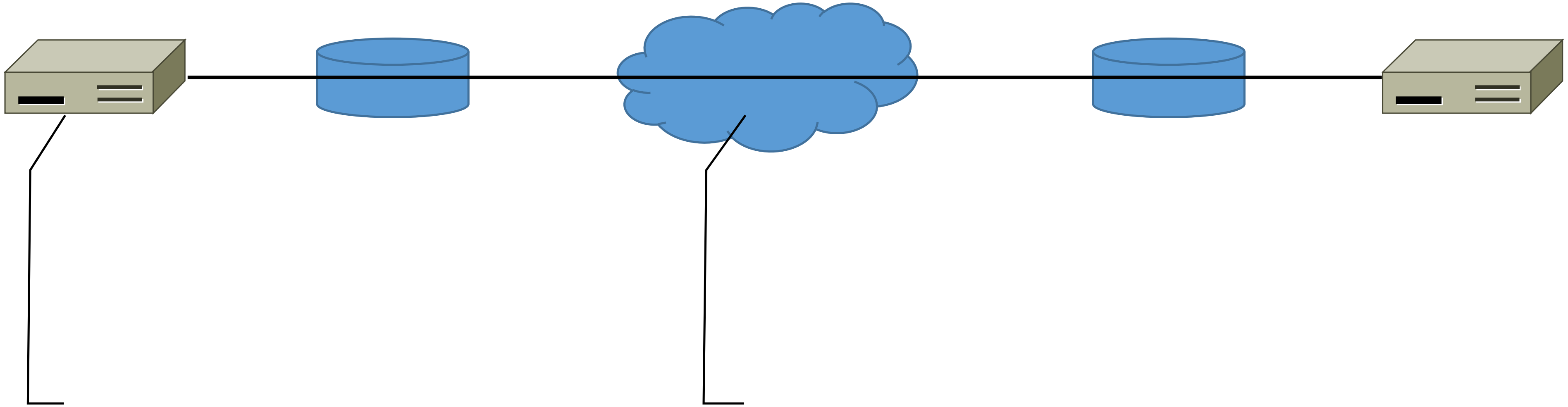
- Security
  - What about private information?
  - How to cache/forward encrypted content?
    - Basically can’t! Big players just share keys.
- Net neutrality
  - I.org, FreeBasics -> Basically CDNs
    - But for reasons of price, not efficiency
  - Who decides who gets to place CDNs?

End-to-End principle

End-to-end Principle

- Broad networking principle
  - French CYCLADES network (after ARPA) first to implement
- Idea: The network cannot be trusted. Do it yourself.
  - “Reliability and raw error rates are secondary. The network must be built with the expectation of heavy damage anyway. Powerful error removal methods exist.”

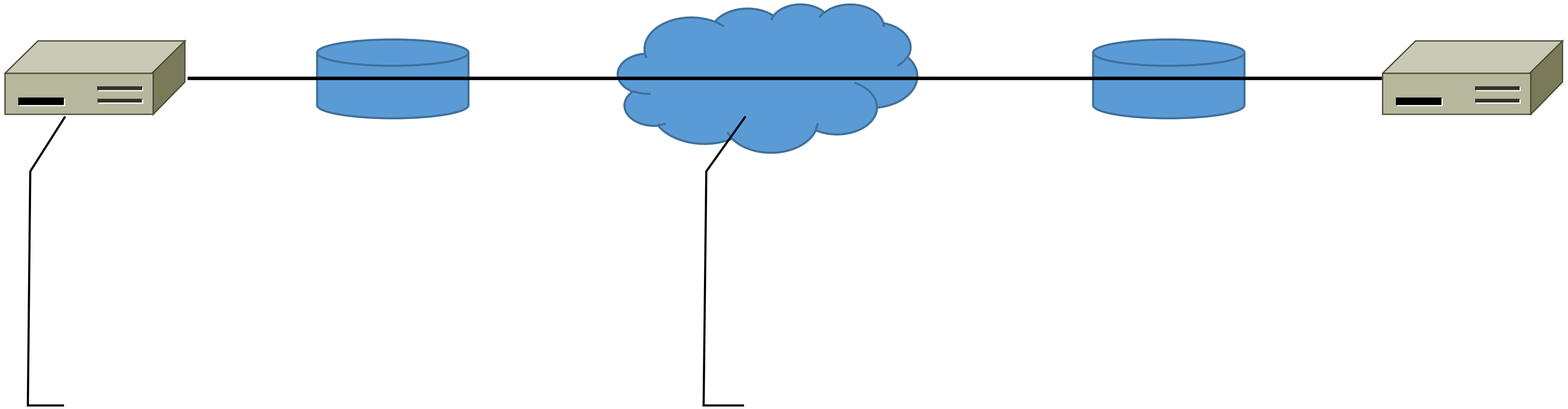
E2E Example: Error-correcting codes



IP:
Host detects errors

802.11:
Link detects errors

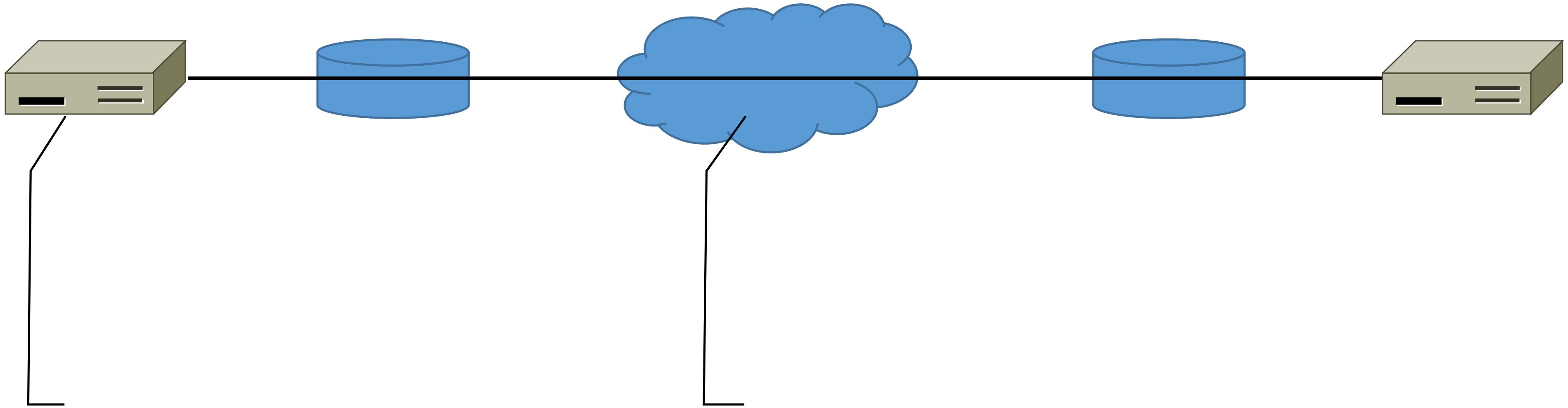
E2E Example: ARQ



TCP:
Host retransmits
on failure

802.11:
Link detects drops
and retransmits

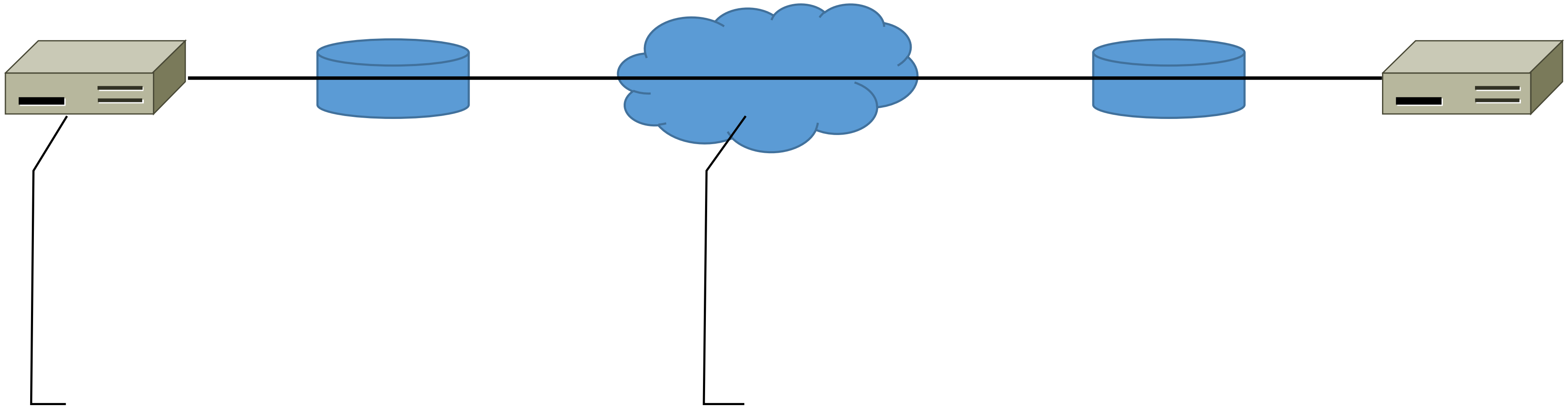
E2E Example: In-order delivery



TCP:
Host enforces in-order delivery

SS5:
Network enforces in-order delivery

E2E Example: Security



SSL:
Host encrypts content

GSM:
Network encrypts content

End-to-End

- What are the limitations of the End-to-End principle?