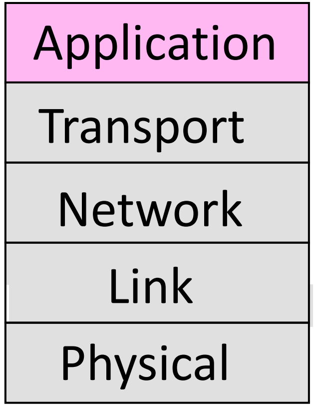
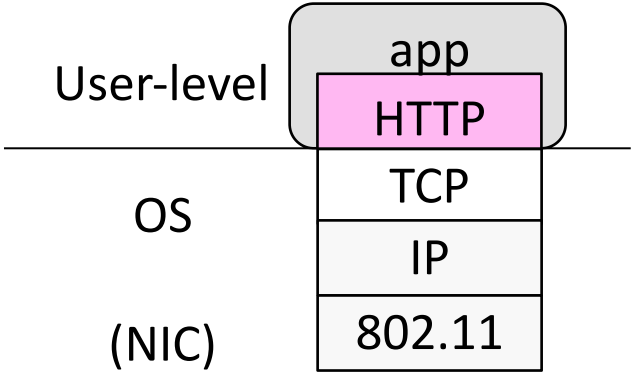
Where we are in the Course

- Starting the Application Layer!
  - Builds distributed “network services” (DNS, Web) on Transport services



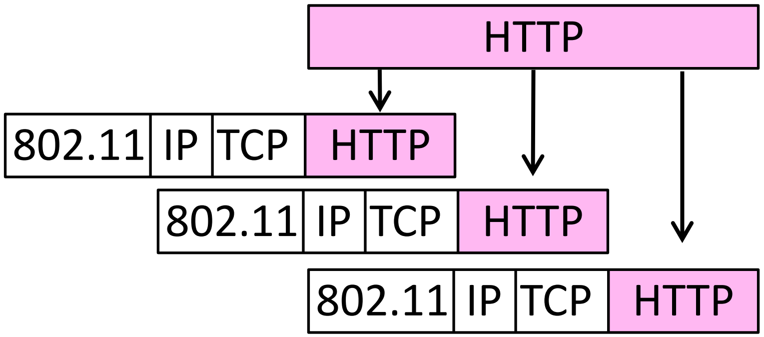
Recall

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



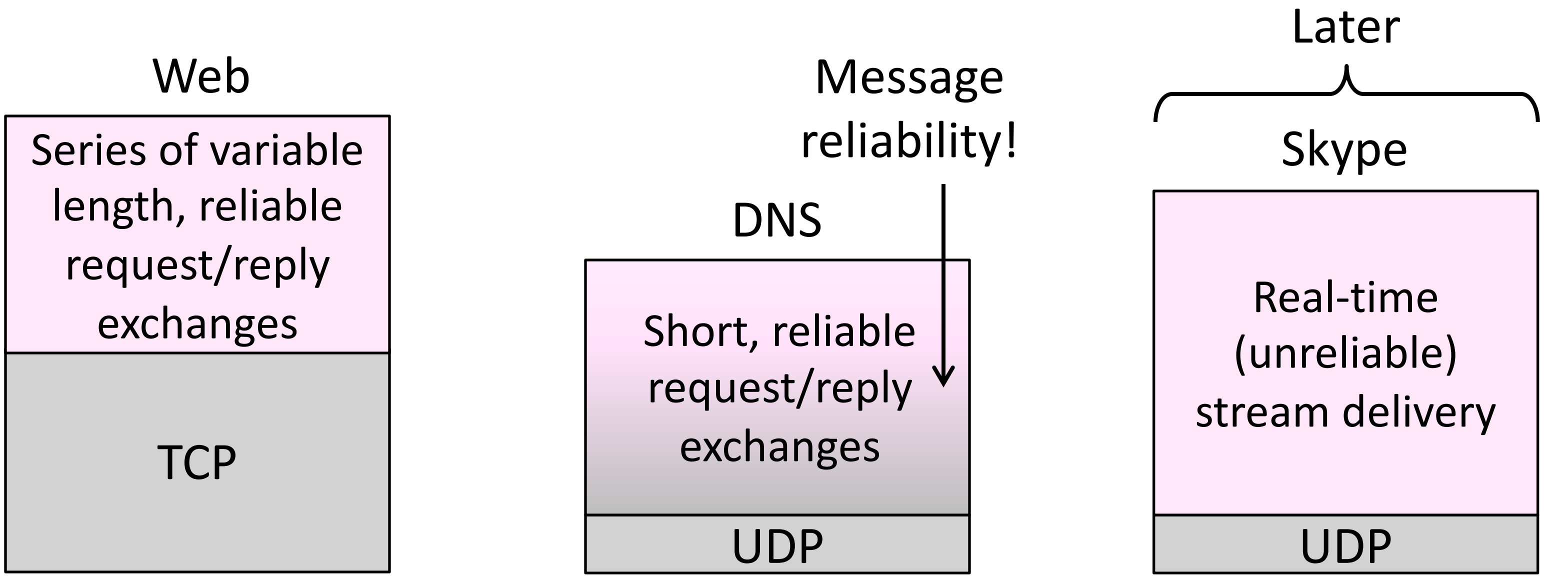
Recall (2)

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



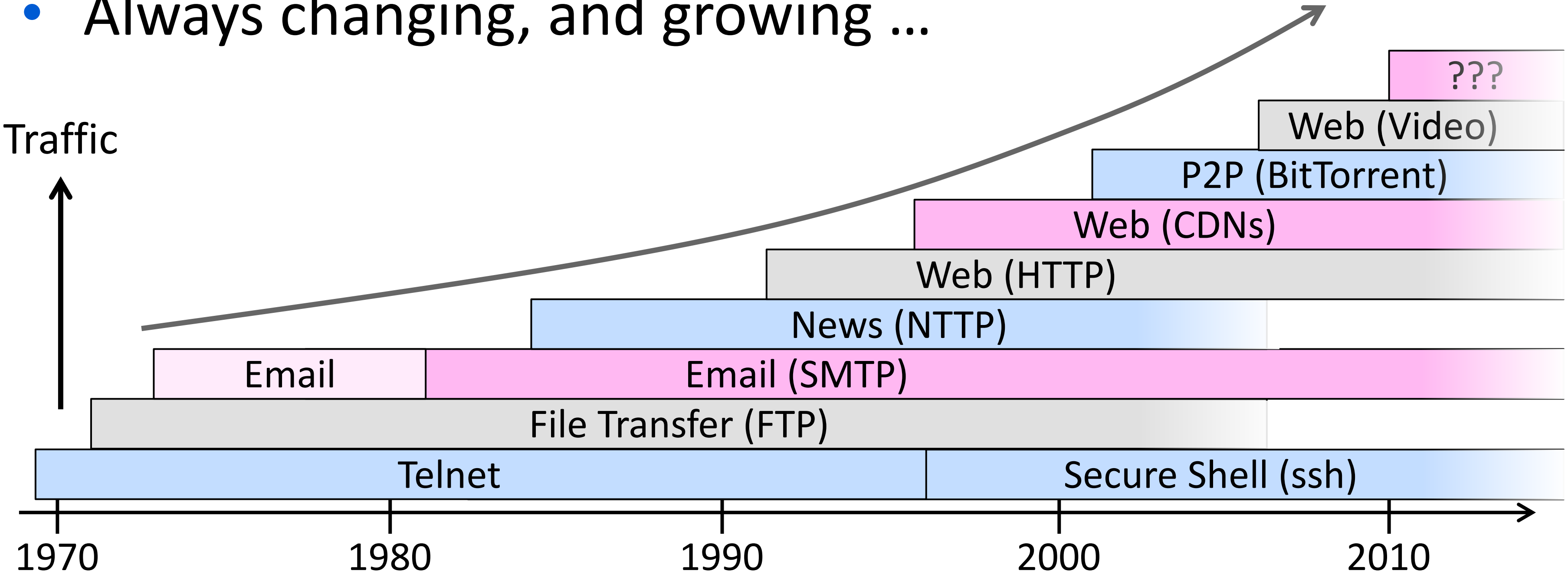
Application Communication Needs

- Vary widely with app; must build on Transport services



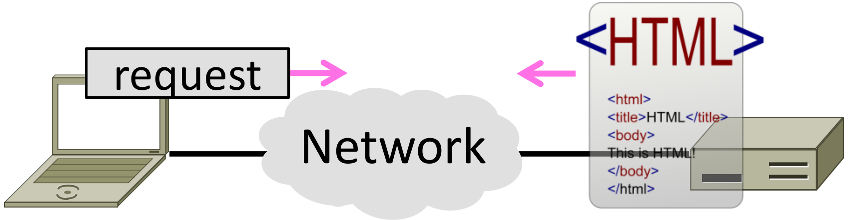
Evolution of Internet Applications

- Always changing, and growing …



Topic

- HTTP, (HyperText Transfer Protocol)
  - Basis for fetching Web pages

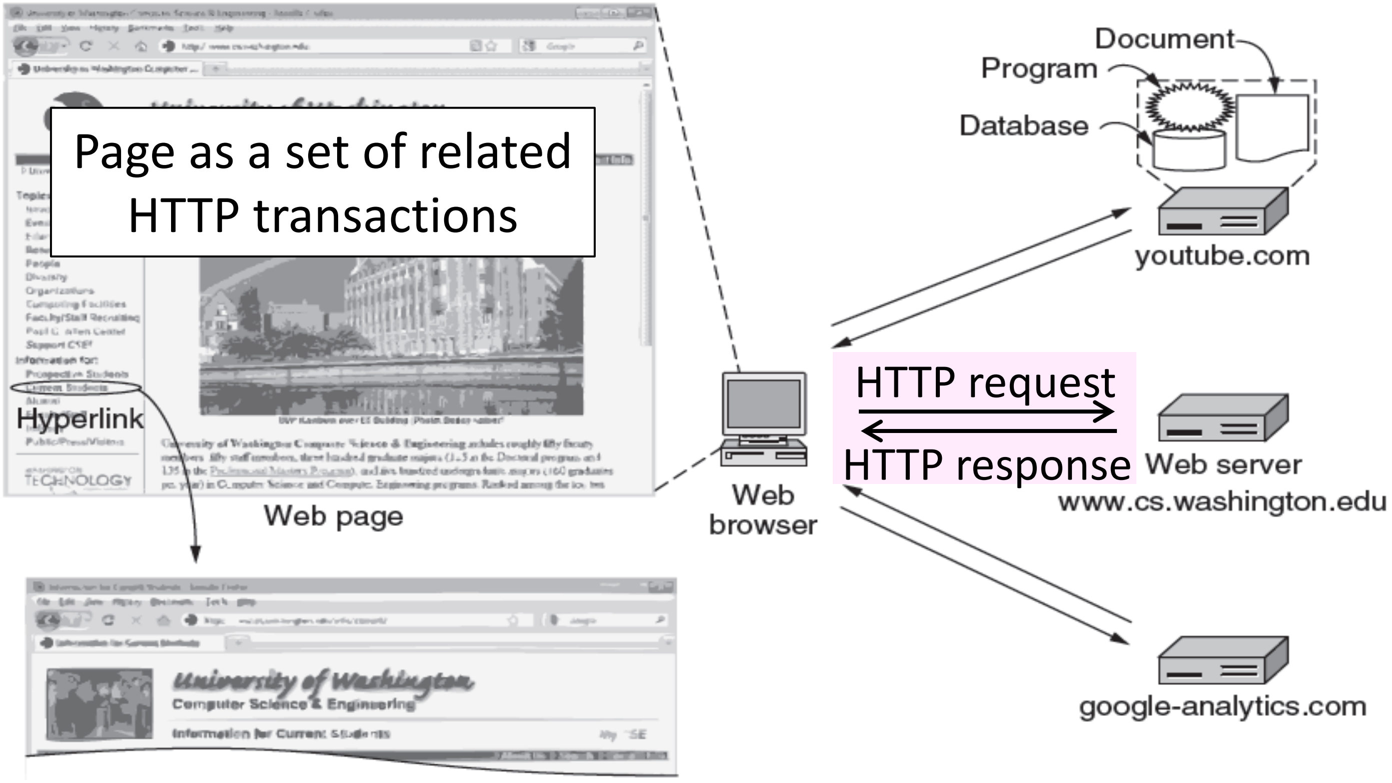


Sir Tim Berners-Lee (1955–)

- 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 …

Source: By Paul Clarke, CC-BY-2.0, via Wikimedia Commons

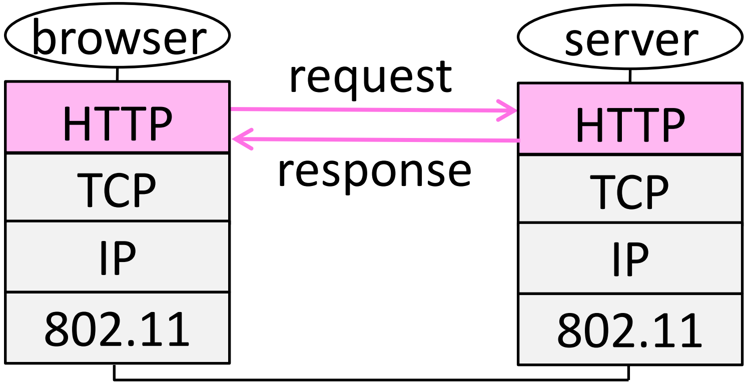
Web Context



Page as a set of related HTTP transactions
Hyperlink
Web page
Document
Program
Database
youtube.com
HTTP request
HTTP response
Web browser
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

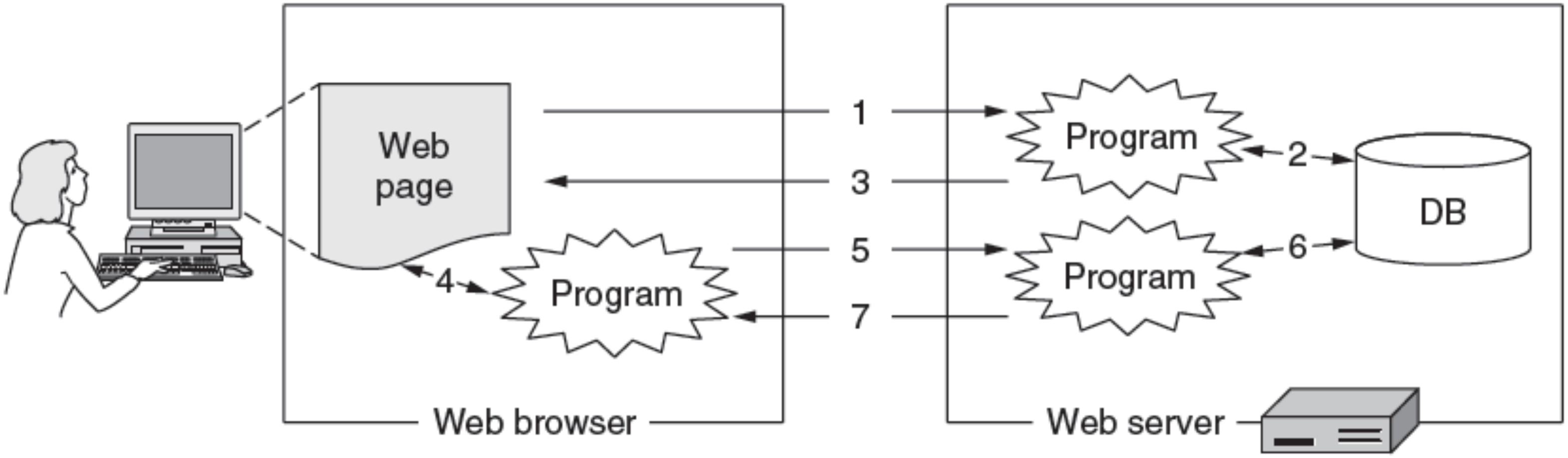
- Start with the page URL:

  $\underbrace{\text{http}}_{\text{Protocol}}\text{://}\underbrace{\text{en.wikipedia.org}}_{\text{Server}}\underbrace{\text{/wiki/Vegemite}}_{\text{Page on server}}$

- 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

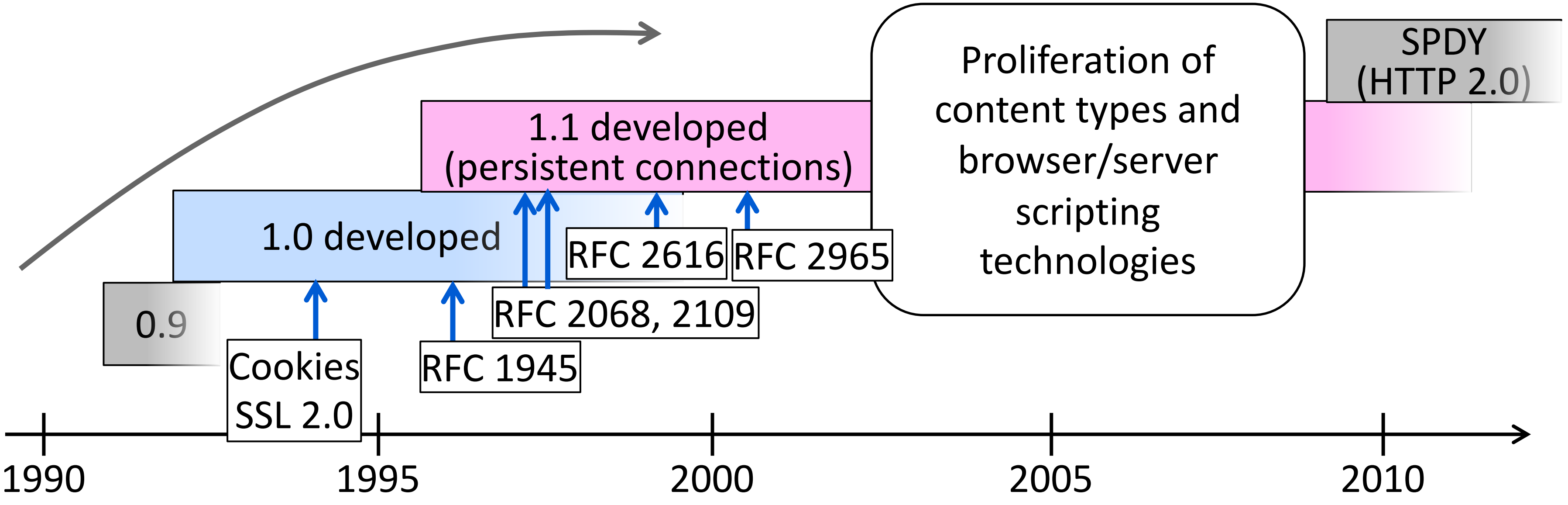
Static vs Dynamic Web pages

- Static web page is a file contents, e.g., image
- Dynamic web page is the result of program execution
  - Javascript on client, PHP on server, or both



Evolution of HTTP

- Consider security (SSL/TLS for HTTPS) later



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

Fetch page

Upload data

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

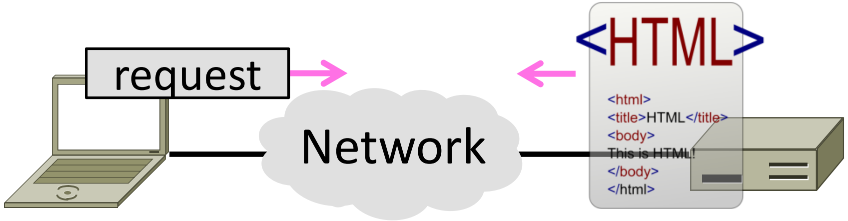
HTTP Protocol (3)

- Codes returned with the response

Code	Meaning	Examples
1xx	Information	100 = server agrees to handle client's request
Yes! → 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

Topic

- Performance of HTTP
  - Parallel and persistent connections

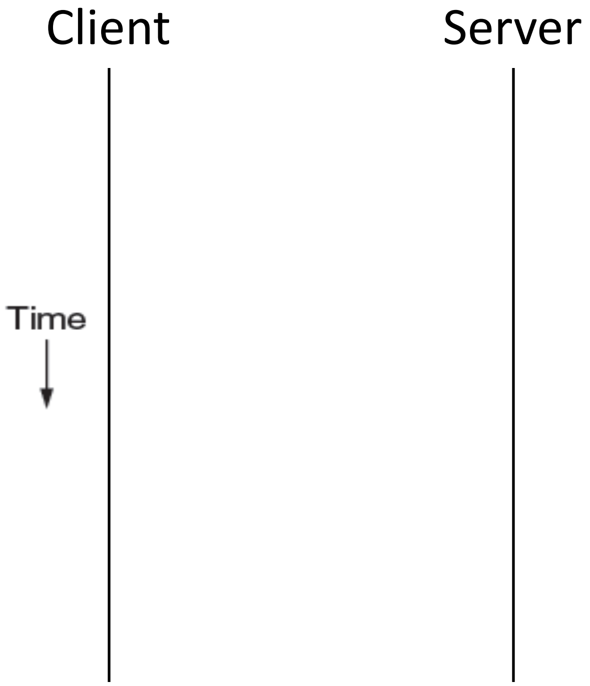


PLT (Page Load Time)

- PLT is 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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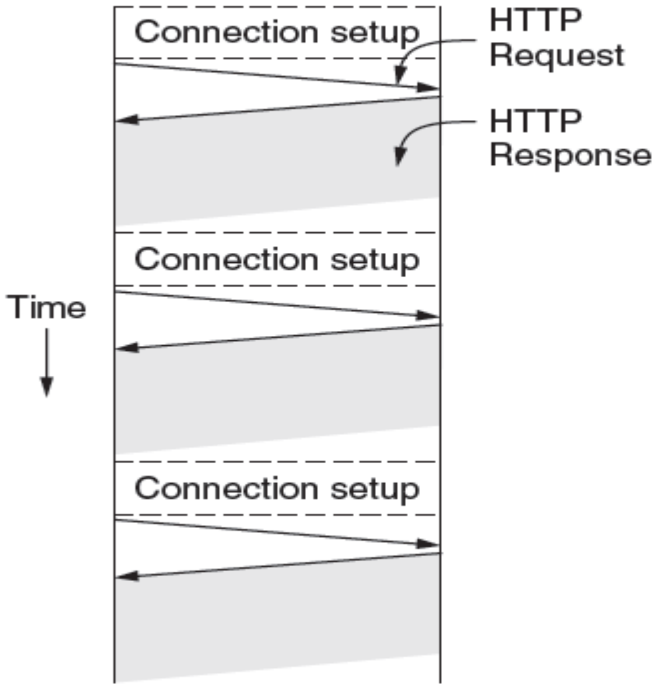
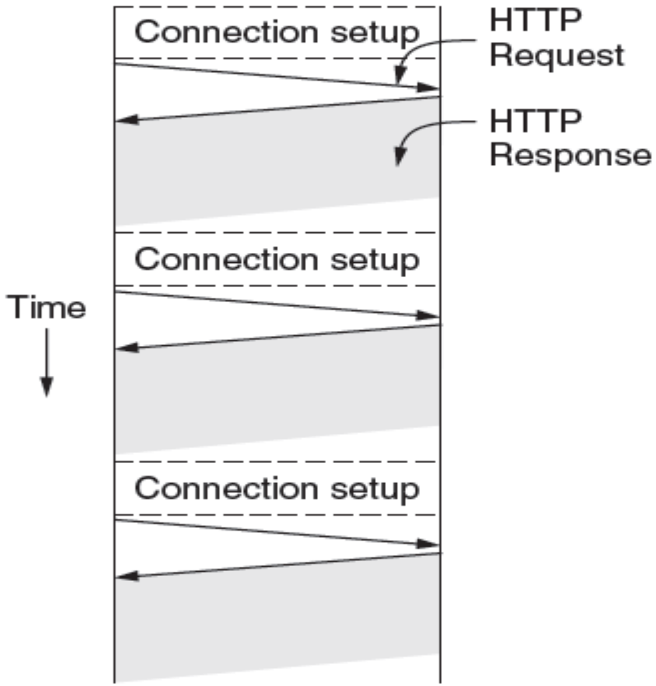


Early Performance (3)

- 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 available bandwidth

   This time

3. Change HTTP to avoid repeated transfers of the same content
   – Caching, and proxies

   Next time

4. Move content closer to client
   – CDNs [later]

   Later

Parallel Connections

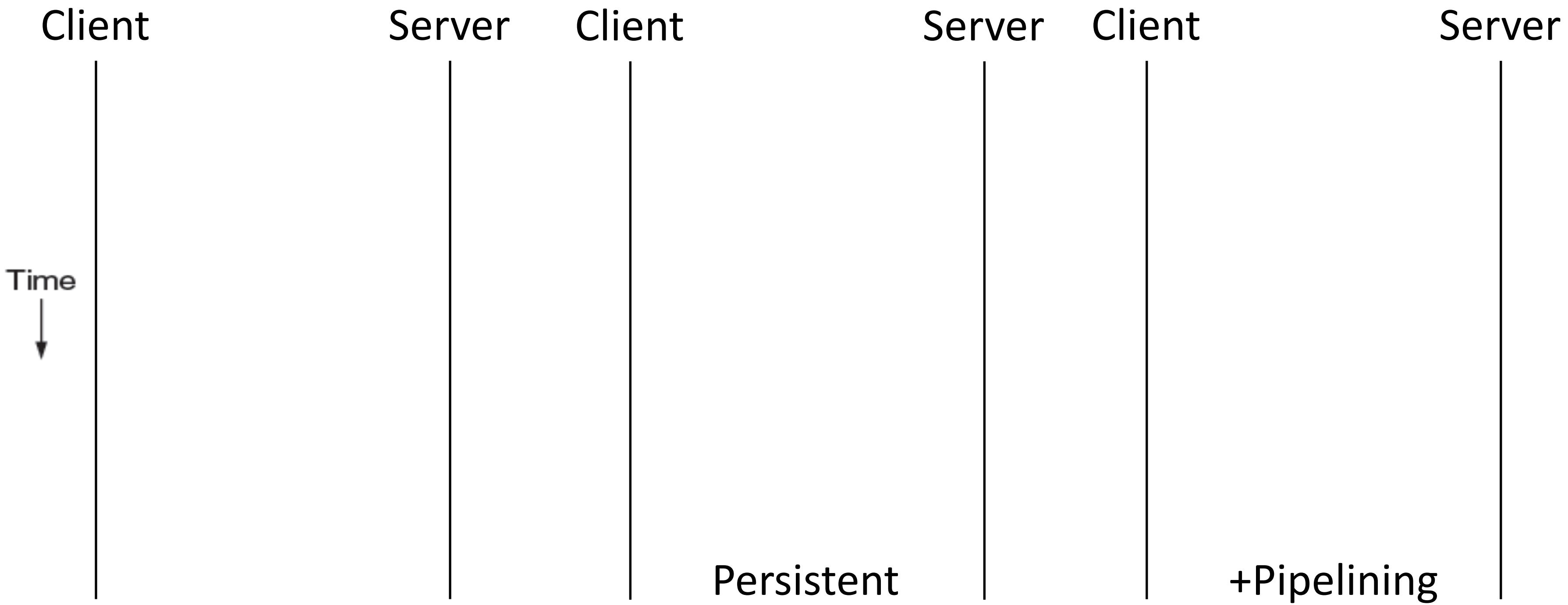
- One simple way to reduce PLT
  - Browser runs multiple (8, say) HTTP instances in parallel
  - Server is unchanged; already handled concurrent requests for many clients
- How does this help?
  - Single HTTP wasn't using network much …
  - So parallel connections aren't slowed much
  - Pulls in completion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

Persistent Connections

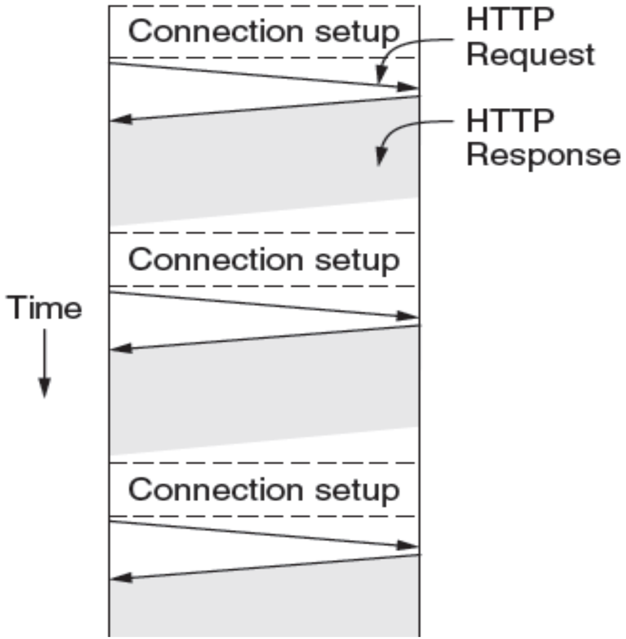
- Parallel connections compete with each other for network resources
  - 1 parallel client ≈ 8 sequential clients?
  - Exacerbates network bursts, and loss

- Persistent connection alternative
  - Make 1 TCP connection to 1 server
  - Use it for multiple HTTP requests

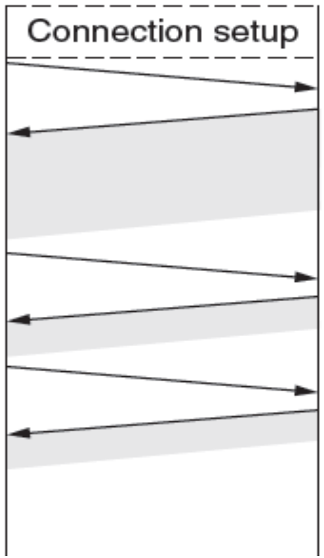
Persistent Connections (2)



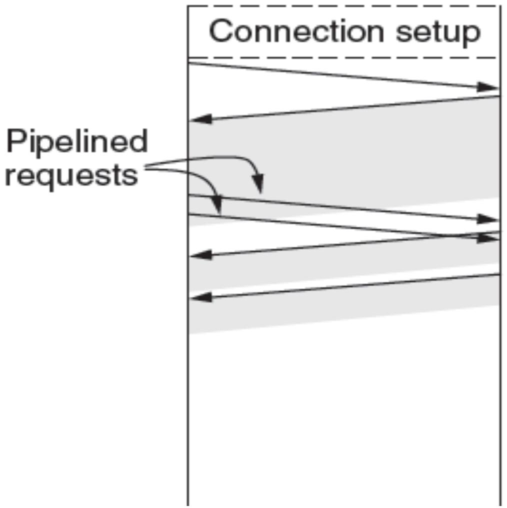
Persistent Connections (3)



One request per connection



Sequential requests per connection



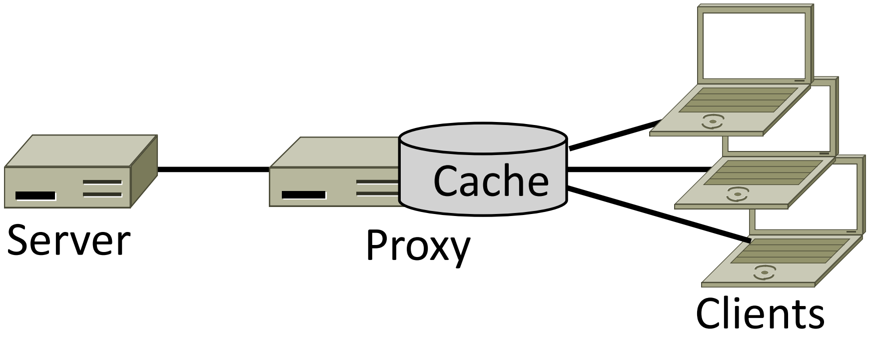
Pipelined requests per connection

Persistent Connections (4)

- Widely used as part of HTTP/1.1
  - Supports optional pipelining
  - PLT benefits depending on page structure, but easy on network
- Issues with persistent connections
  - How long to keep TCP connection?
  - Can it be slower? (Yes. But why?)

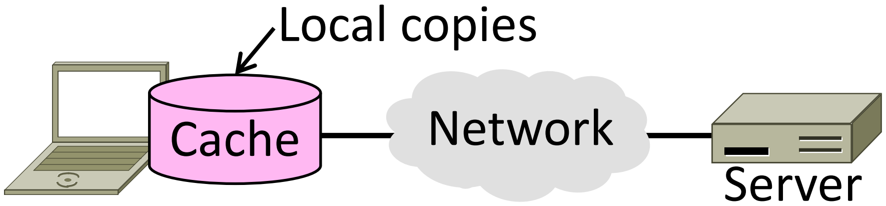
Topic

- HTTP caching and proxies
  - Enabling content reuse



Web Caching

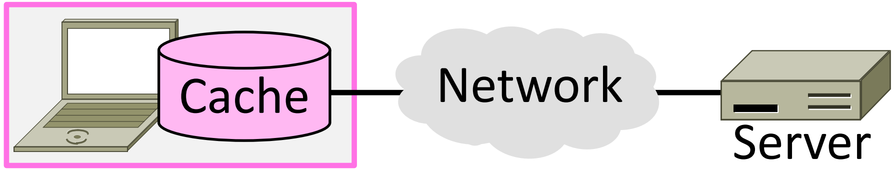
- Users often revisit web pages
  - Big win from reusing local copy!
  - This is caching



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

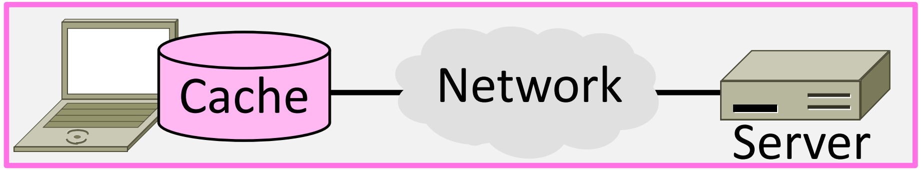
Web Caching (2)

- 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



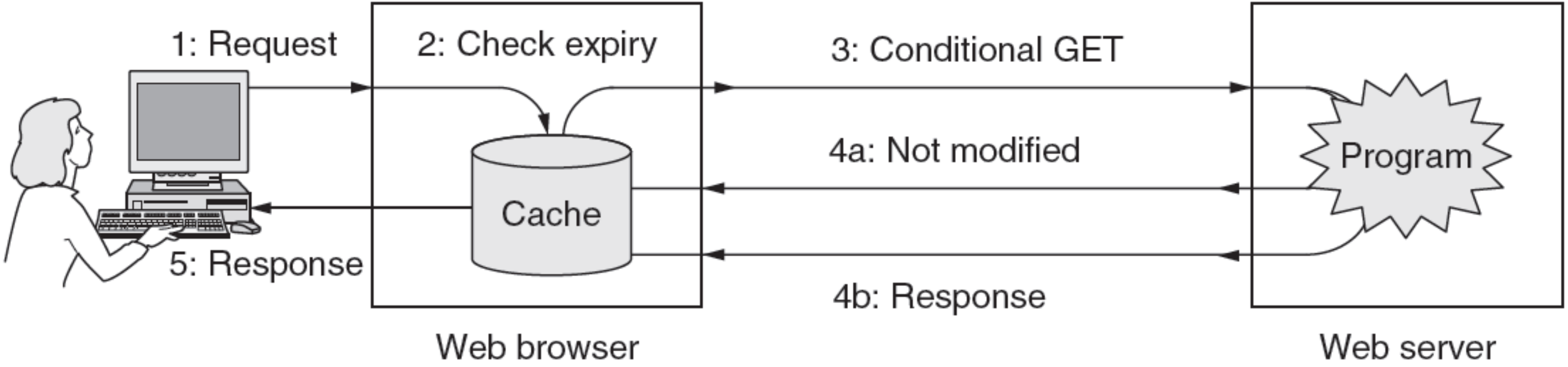
Web Caching (3)

- 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" header from server
  - Content is available after 1 RTT



Web Caching (4)

- Putting the pieces together:



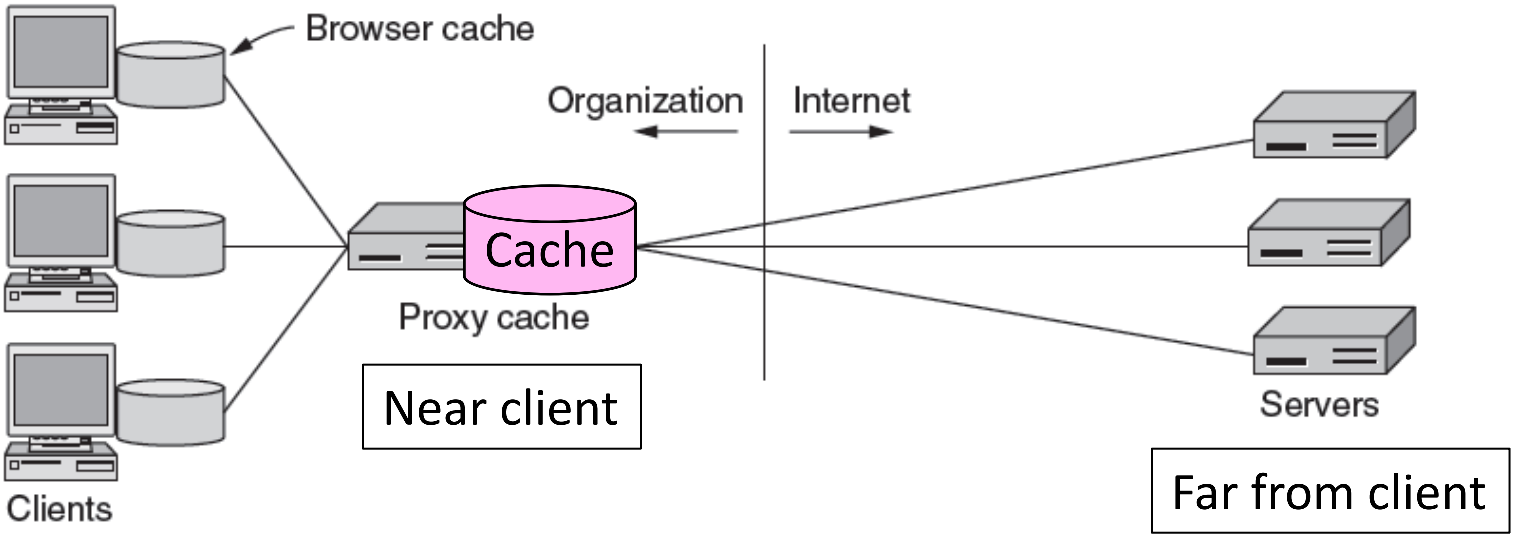
Web Proxies

- Place intermediary between pool of clients and external web servers
  - Benefits for clients include greater 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”

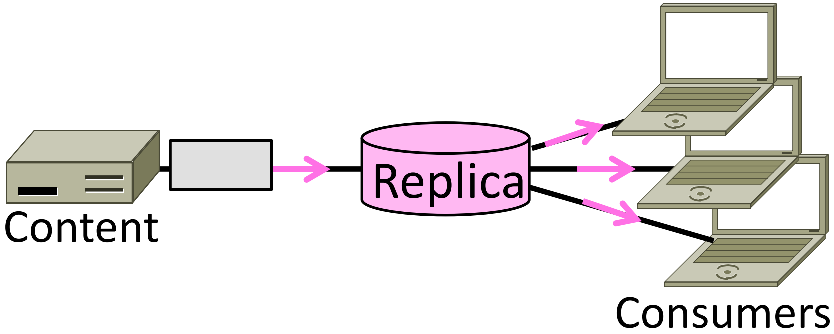
Web Proxies (2)

- Clients contact proxy; proxy contacts server



Topic

- CDNs (Content Delivery Networks)
  - Efficient distribution of popular content; faster delivery for clients

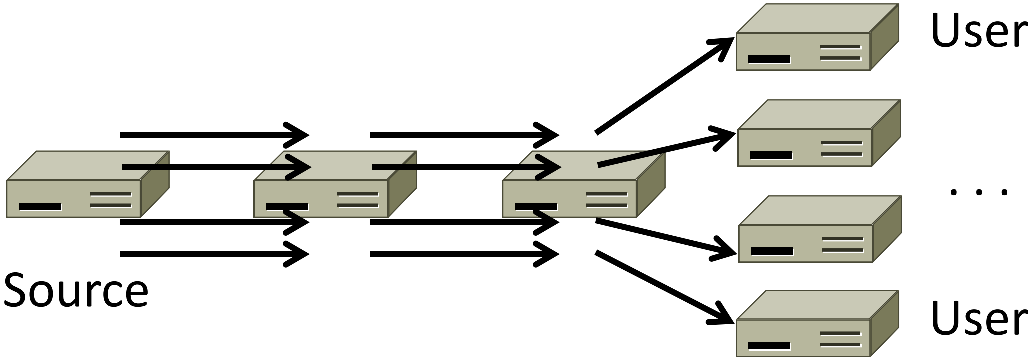


Context

- 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

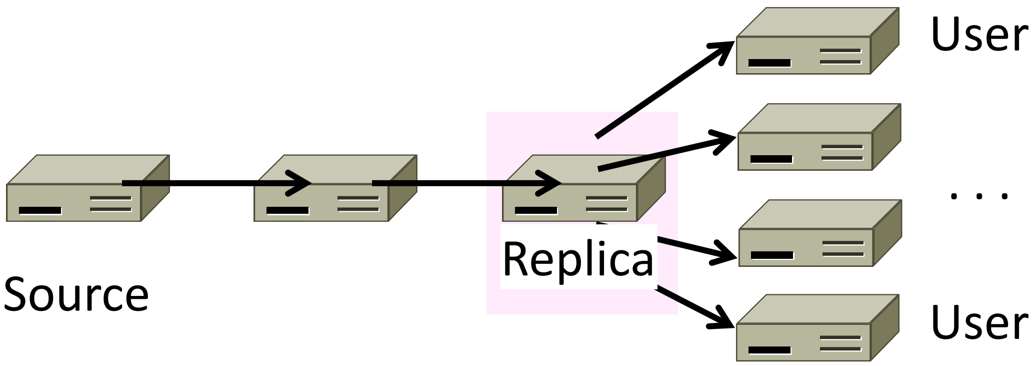
Before CDNs

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



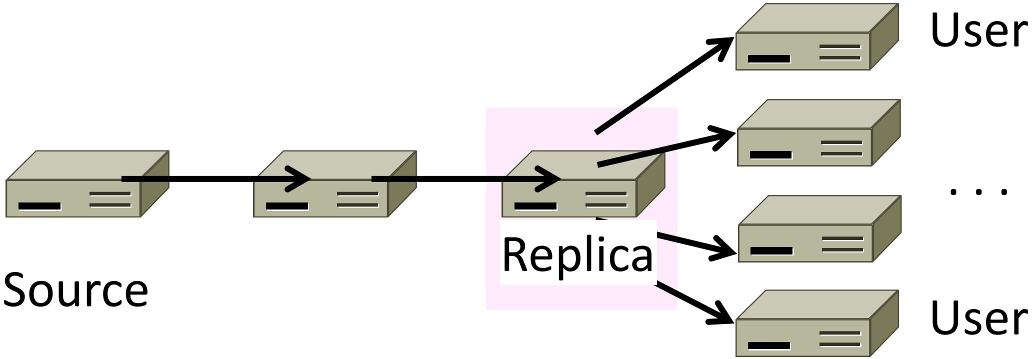
After CDNs

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



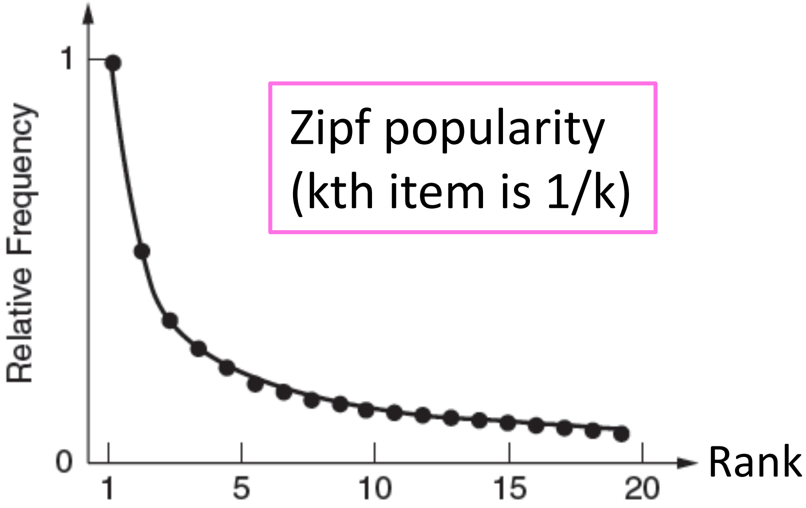
After CDNs (2)

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



Popularity of Content

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



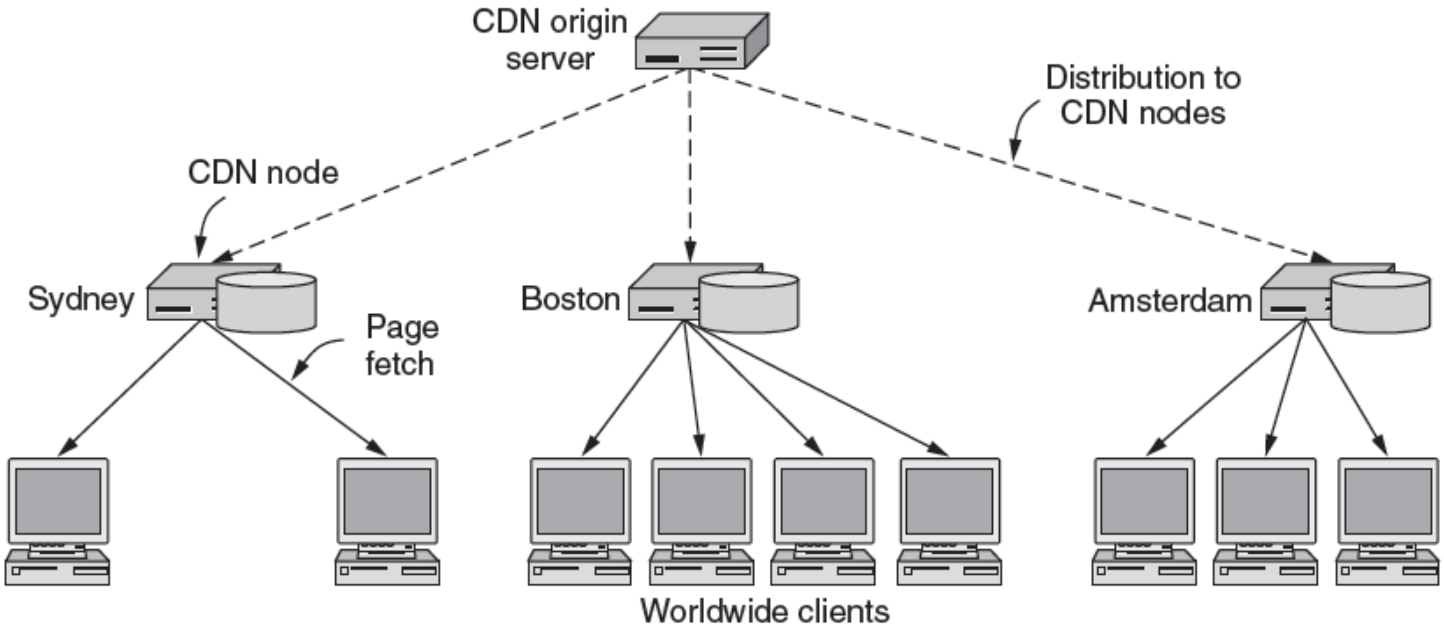
George Zipf (1902-1950)

Source: Wikipedia

How to place content near clients?

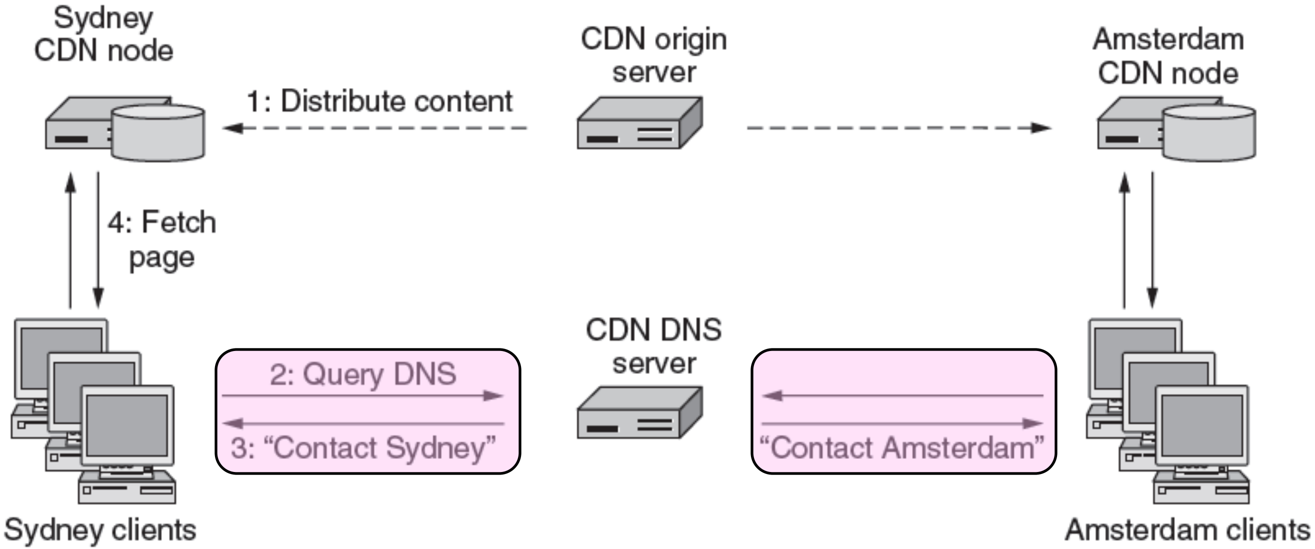
- Use browser and proxy caches
  - Helps, but limited to one client or clients in one organization
- Want to place replicas across the Internet for use by all nearby clients
  - Done by clever use of DNS

Content Delivery Network



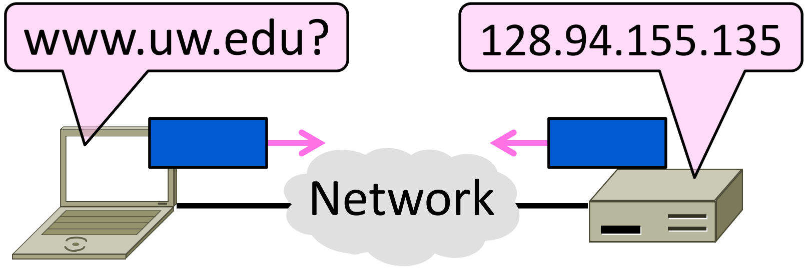
Content Delivery Network (2)

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



Topic

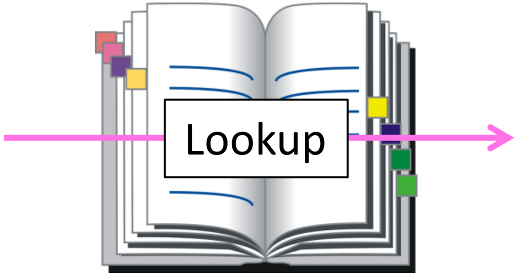
- The DNS (Domain Name System)
  - Human-readable host names, and more
  - Part 1: the distributed namespace



Names and Addresses

- Names are higher-level identifiers for resources
- Addresses are lower-level locators for resources
  - Multiple levels, e.g. full name → email → IP address → Ethernet address
- Resolution (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

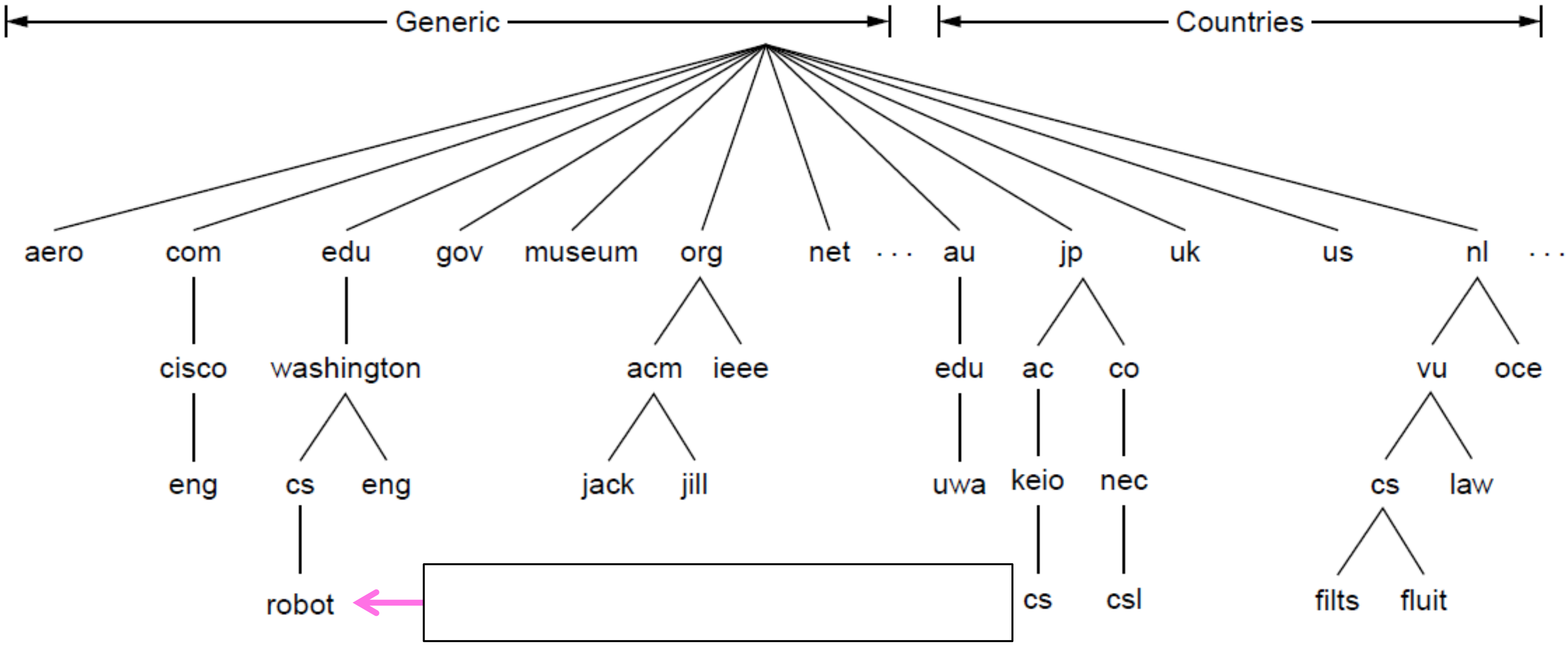
- Directory was a file HOSTS.TXT regularly retrieved for all hosts from a central machine at the NIC (Network Information Center)
- Names were initially flat, became hierarchical (e.g., lcs.mit.edu) ~85
- Neither manageable nor efficient as the ARPANET grew …

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)

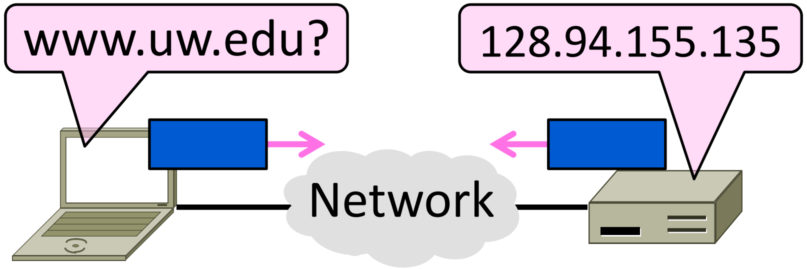
- Run by ICANN (Internet Corp. for Assigned Names and Numbers)
  - Starting in '98; naming is financial, political, and international ☺
- 22+ generic TLDs
  - Initially .com, .edu , .gov., .mil, .org, .net
  - Added .aero, .museum, etc. from '01 through .xxx in '11
  - Different TLDs have different usage policies
- ~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), goo.gl (Greenland)

DNS Zones (2)

- Zones are the basis for distribution
  - EDU Registrar administers .edu
  - UW administers washington.edu
  - CS&E 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

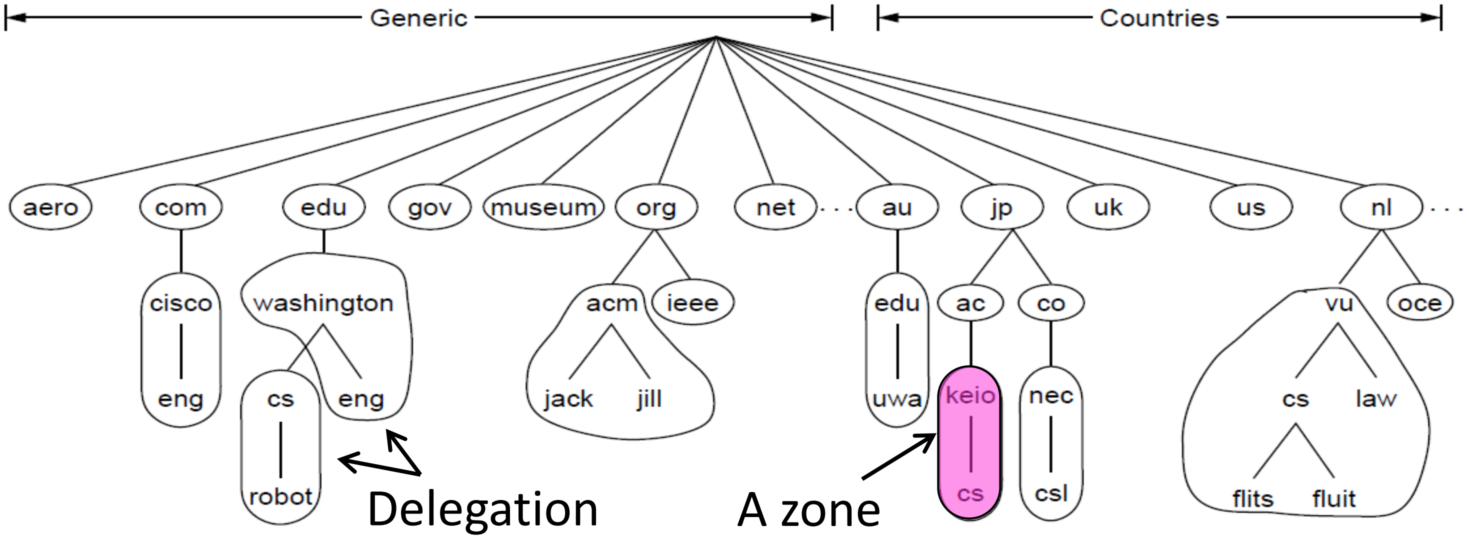
Topic

- The DNS (Domain Name System)
  - Human-readable host names, and more
  - Part 2: Name resolution



Recall

- A <u>zone</u> is a contiguous portion of the namespace
  - Each zone is managed by one or more <u>nameservers</u>

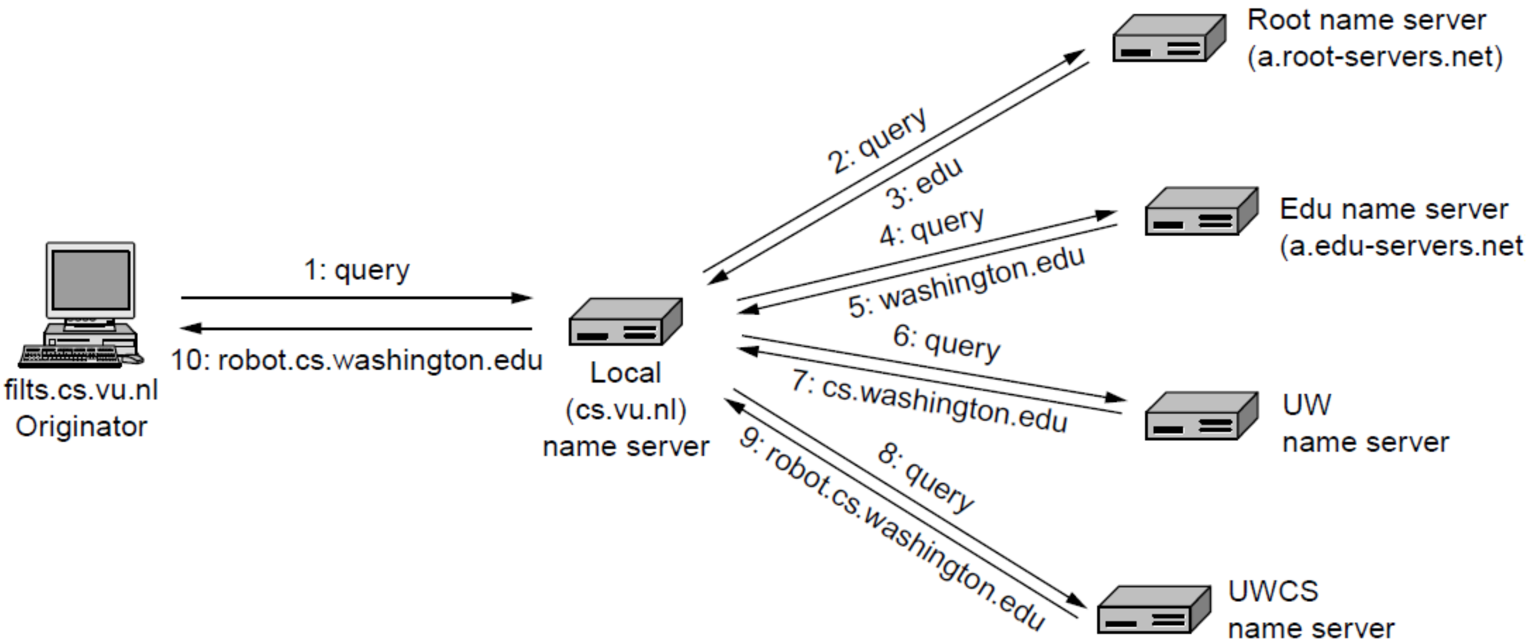


DNS Resolution

- 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

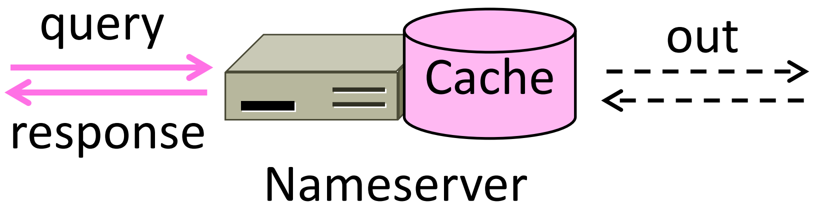
- Recursive query
  - Nameserver completes resolution and returns the final answer
  - E.g., flits → local nameserver
- Iterative query
  - Nameserver returns the answer or who to contact next for the answer
  - E.g., local nameserver → all others

Iterative vs. Recursive Queries (2)

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

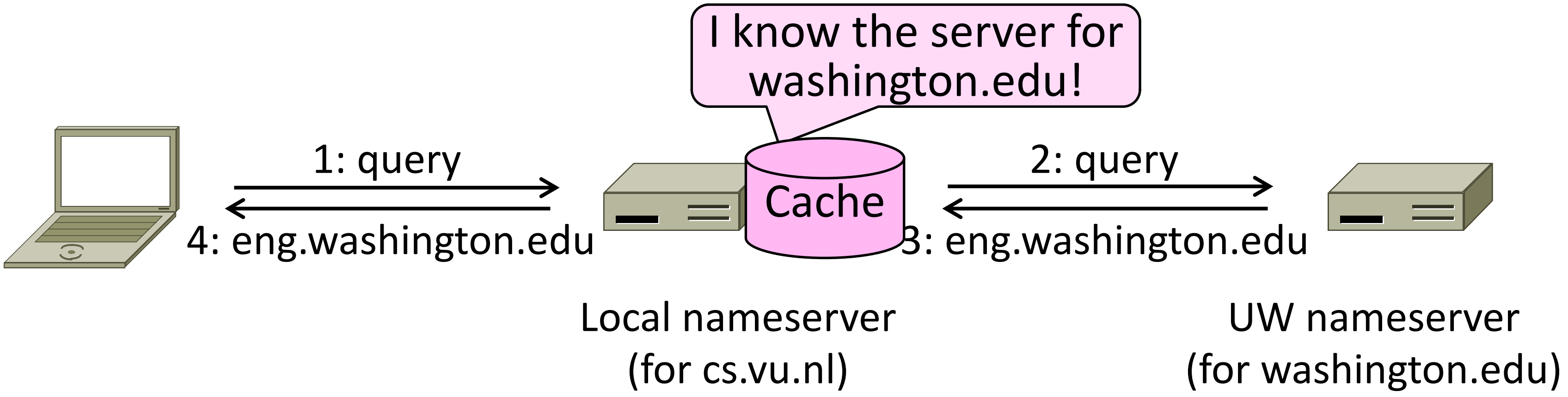
Caching

- Resolution latency should be low
  - Adds delay to web browsing
- Cache query/responses to answer future queries immediately
  - Including partial (iterative) answers
  - Responses carry a TTL for caching



Caching (2)

- flits.cs.vu.nl now resolves eng.washington.edu
  - And previous resolutions cut out most of the process



Local Nameservers

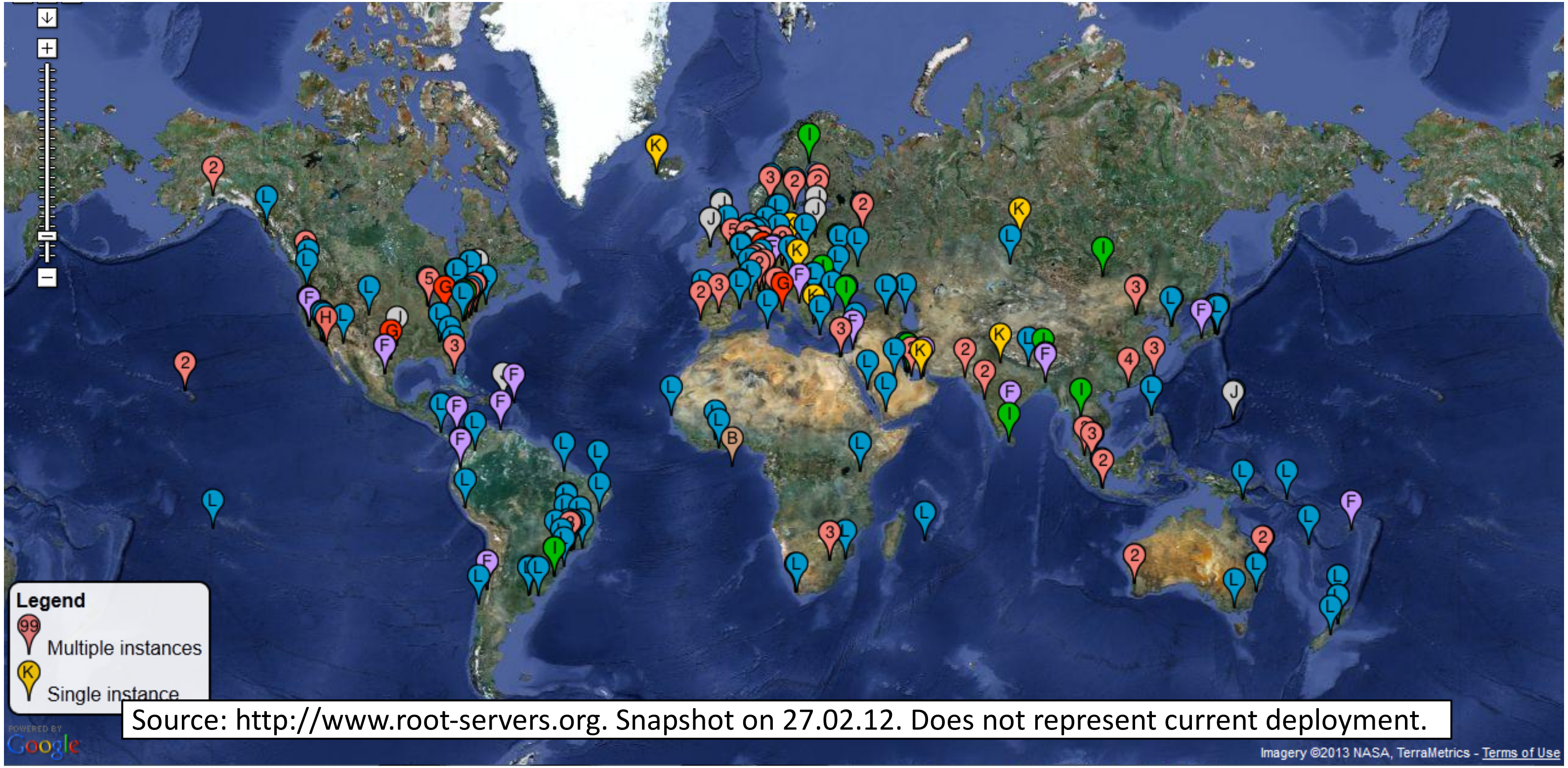
- Local nameservers typically run by IT (enterprise, ISP)
  - But may be your host or AP
  - Or alternatives e.g., Google public DNS
- Clients need to be able to contact their local nameservers
  - Typically configured via DHCP

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 <u>IP anycast</u> (Multiple locations advertise same IP! Routes take client to the closest one. See §5.2.9)
  - Servers are IPv4 and IPv6 reachable

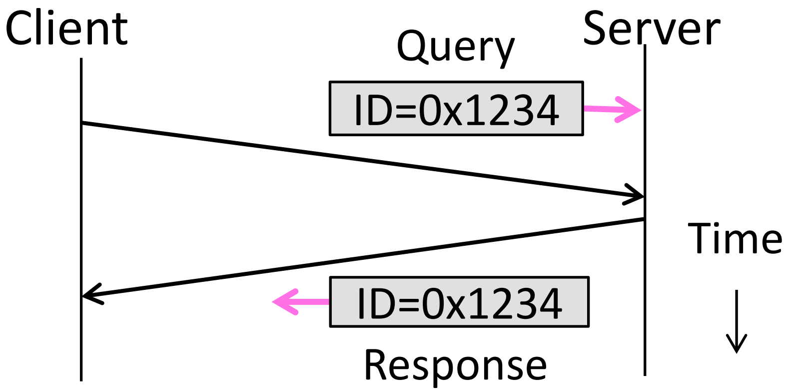
Root Server Deployment



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

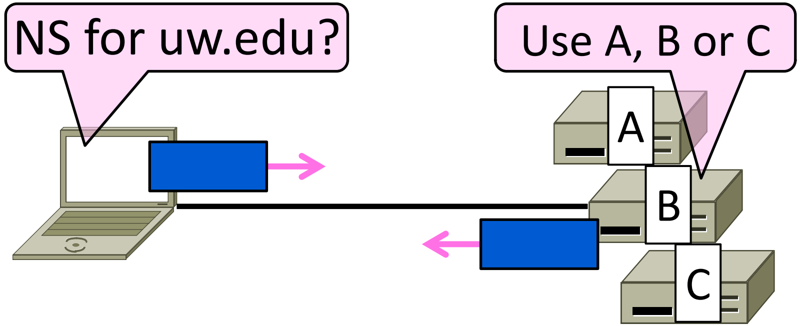
DNS Protocol

- 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 Protocol (3)

- Security is a major issue
  - Compromise redirects to wrong site!
  - Not part of initial protocols ..
- DNSSEC (DNS Security Extensions)
  - Long under development, now partially deployed. We'll look at it later