# Introduction to Computer Networks

Application Layer Overview

Computer Science & Engineering
UNIVERSITY of WASHINGTON

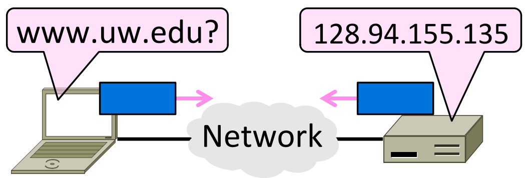
# Where we are in the Course

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

| |
|---|
| Application |
| Transport |
| Network |
| Link |
| Physical |

# Topic

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

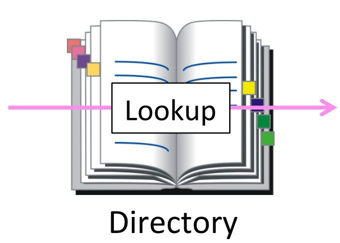





# Names and Addresses

- <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 address
- <u>Resolution</u> (or lookup) is mapping a name to an address

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




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 …

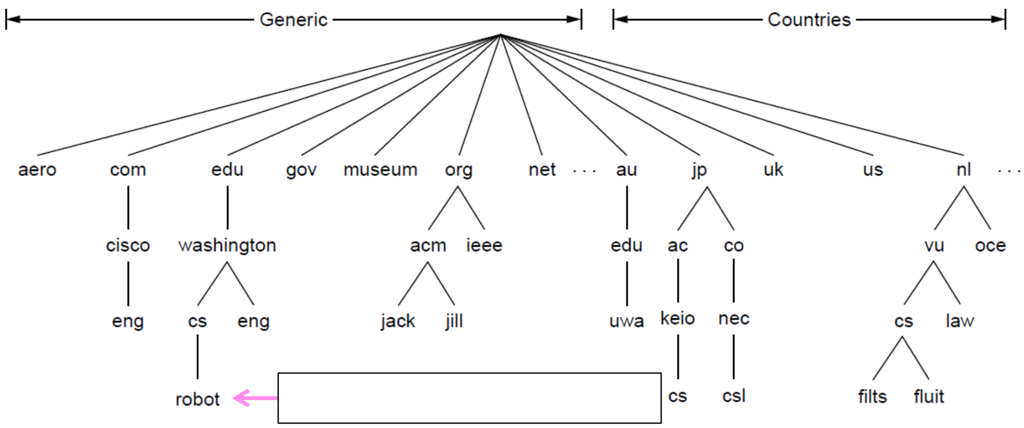


# DNS

- 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)



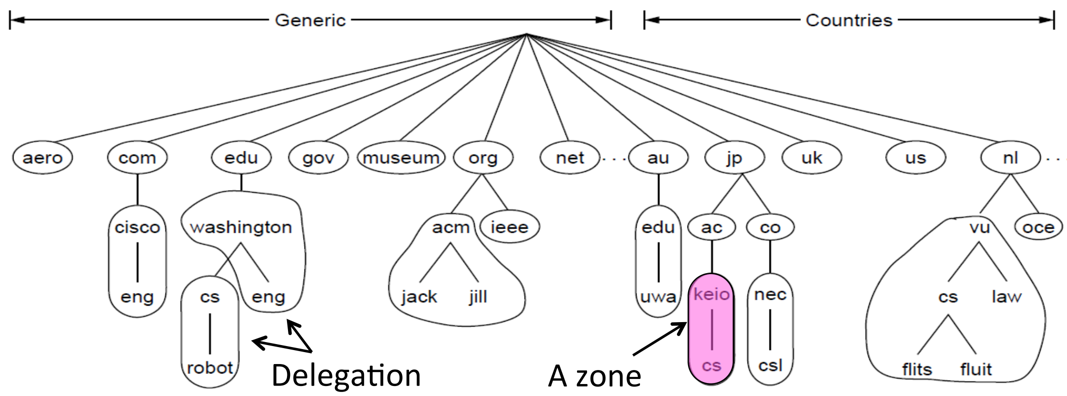



# TLDs (Top-Level Domains)

- 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

- A zone is a contiguous portion of the namespace






# 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

# 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 |

CSE 461 University of Washington 22

# 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 | ← Name server |
| star | 86400 | IN | A | 130.37.56.205 | |
| zephyr | 86400 | IN | A | 130.37.20.10 | |
| top | 86400 | IN | A | 130.37.20.11 | ← IP addresses of computers |
| 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 | ← Mail gateways |
| little-sister | | IN | A | 130.37.62.23 | |
| laserjet | | IN | A | 192.31.231.216 | |

CSE 461 University of Washington 23

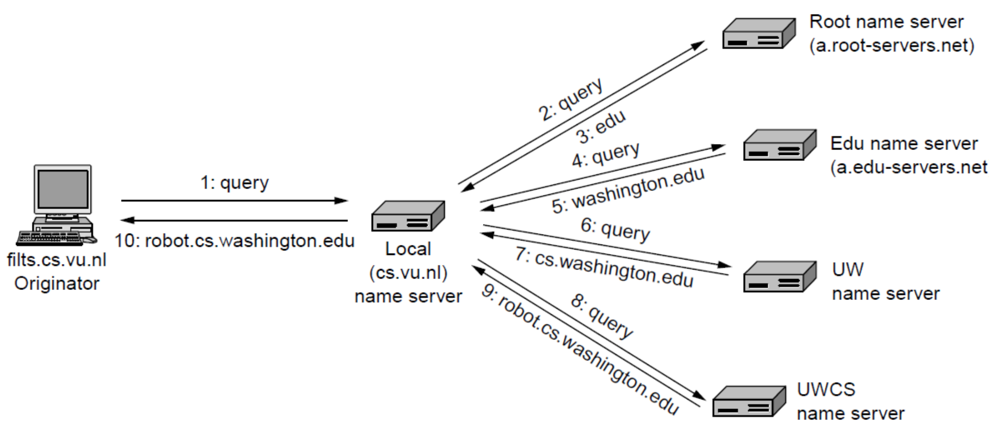
# DNS Resolution

- 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

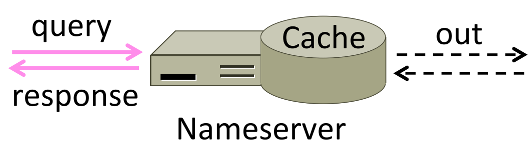


# Iterative vs. Recursive Queries (2)

- 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

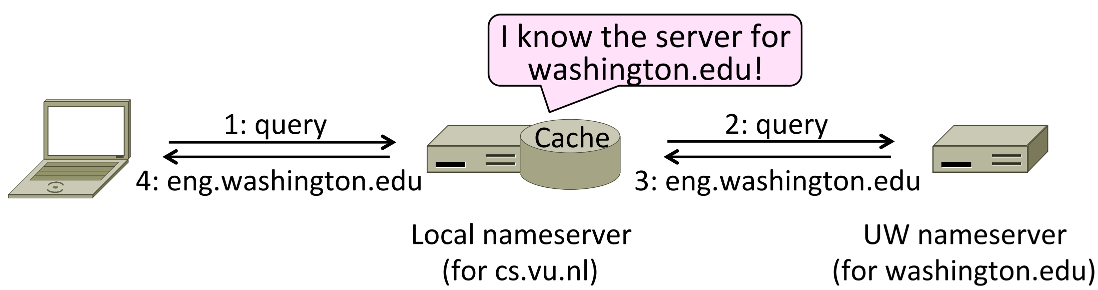
- Resolution latency should be low
  - Adds delay to web browsing
- Cache query/responses to answer future queries immediately
  - Including partial (iterative) answers
  - Responses carry a TTL for caching






# Caching (2)

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



# Local Nameservers

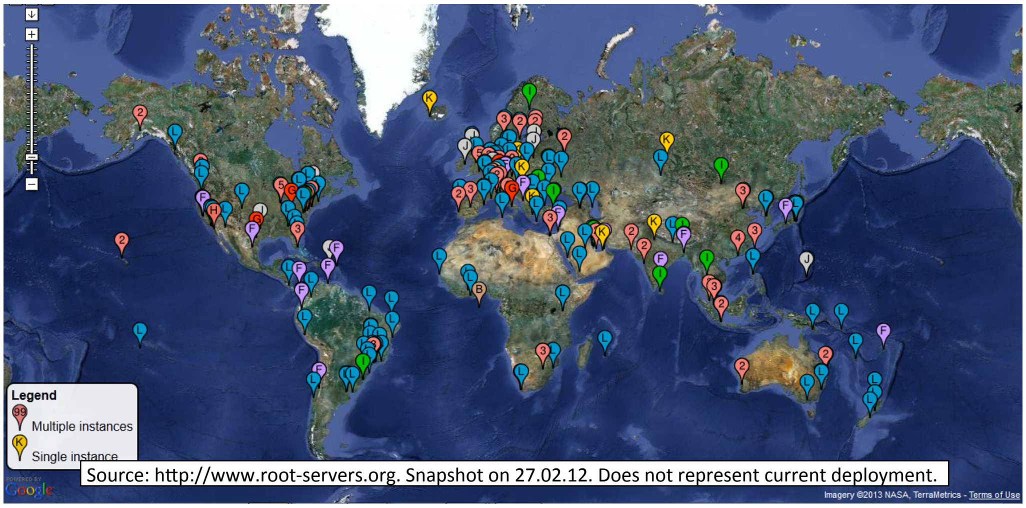
- Local nameservers typically run by IT (enterprise, ISP)
  - But may be your host or AP
  - Or alternatives e.g., Google public DNS
- Clients need to be able to contact their local nameservers
  - Typically configured via DHCP



# 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 IP anycast (Multiple locations advertise same IP! Routes take client to the closest one. See §5.x.x)
  - Servers are IPv4 and IPv6 reachable

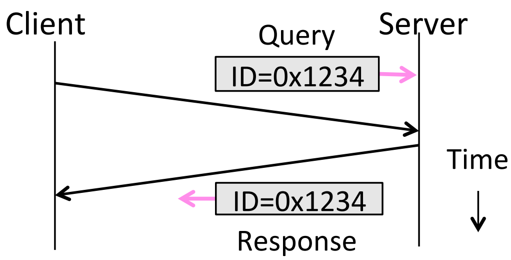
# Root Server Deployment





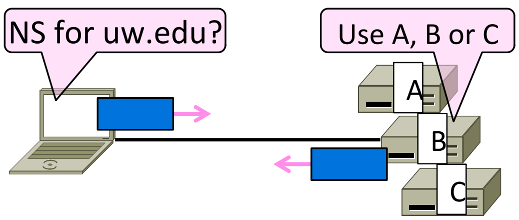

# DNS Protocol

- 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)

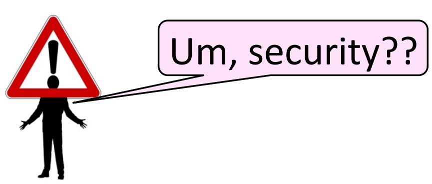
- Service reliability via replicas
  - Run multiple nameservers for domain
  - Return the list; clients use one answer
  - Helps distribute load too






# 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



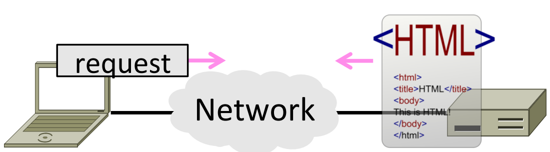
# Introduction to Computer Networks

HTTP, the HyperText Transfer Protocol (§7.3.1-7.3.4)

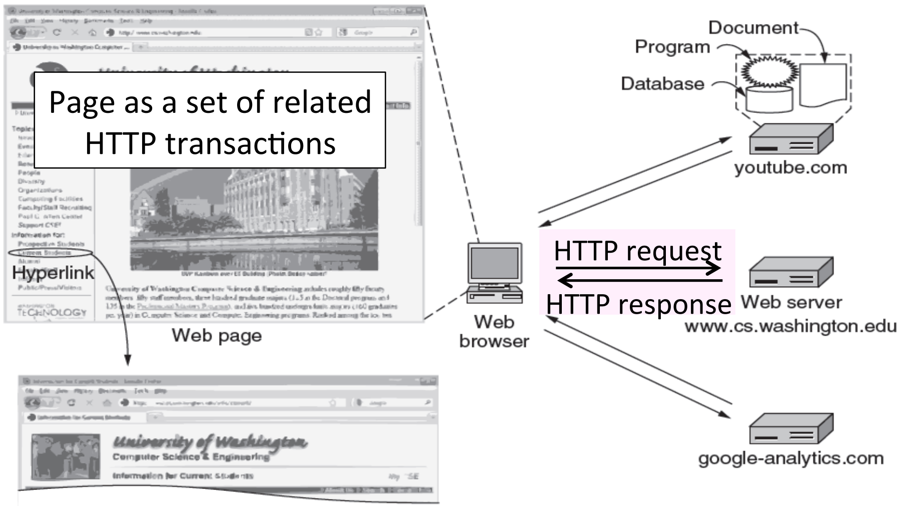
Computer Science & Engineering
UNIVERSITY of WASHINGTON

## Topic

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



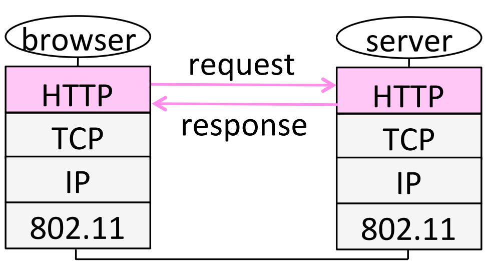
# Web Context




CSE 461 University of Washington 41

# Web Protocol Context

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




CSE 461 University of Washington 43

# Fetching a Web page with HTTP

- Start with the page URL:

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

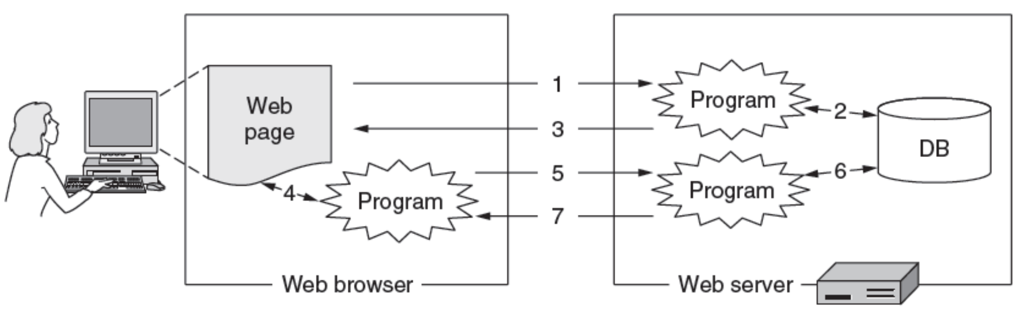
  Protocol — Server — Page on server

- 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 other Web resources / render
  - Clean up any idle TCP connections



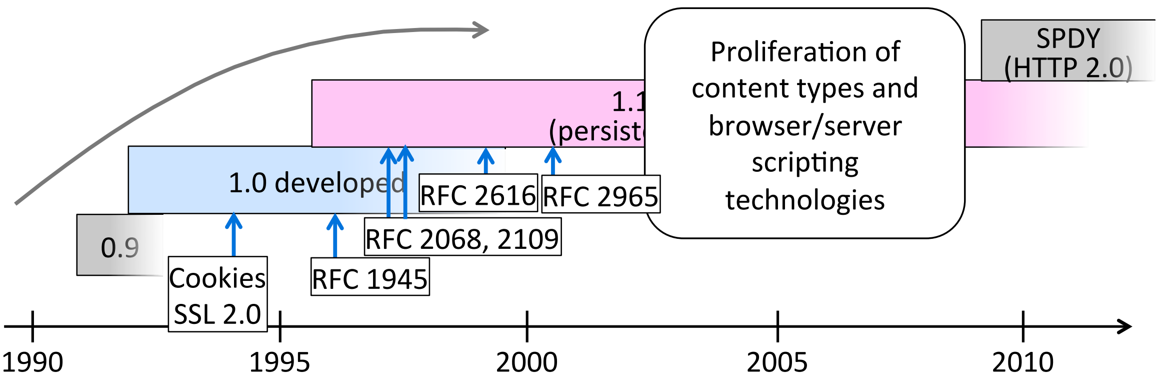
# Static vs Dynamic Web pages

- 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

| 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



# 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

# HTTP Protocol (4)

- Many header fields specify capabilities and content
  - E.g., Content-Type: text/html, Cookie: lect=8-4-http

| Function | Example Headers |
|---|---|
| Browser capabilities (client → server) | User-Agent, Accept, Accept-Charset, Accept-Encoding, Accept-Language |
| Caching related (mixed directions) | If-Modified-Since, If-None-Match, Date, Last-Modified, Expires, Cache-Control, ETag |
| Browser context (client → server) | Cookie, Referer, Authorization, Host |
| Content delivery (server → client) | Content-Encoding, Content-Length, Content-Type, Content-Language, Content-Range, Set-Cookie |



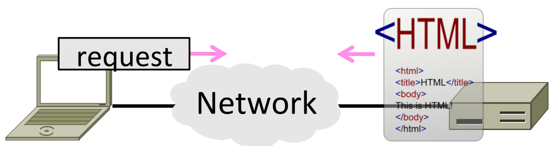
# Introduction to Computer Networks

HTTP Performance and Caching (§7.3.4, §7.5.2)

Computer Science & Engineering
UNIVERSITY of WASHINGTON

# Topic

- Performance of HTTP
  - Parallel and persistent connections
  - Caching for content reuse



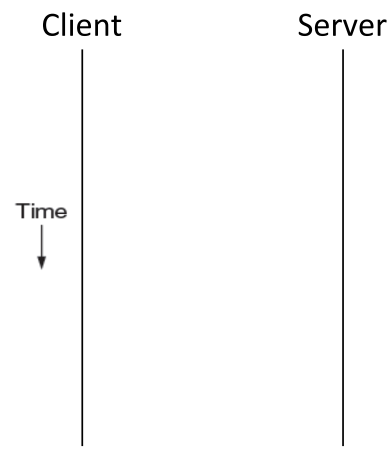



# PLT (Page Load Time)

- 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

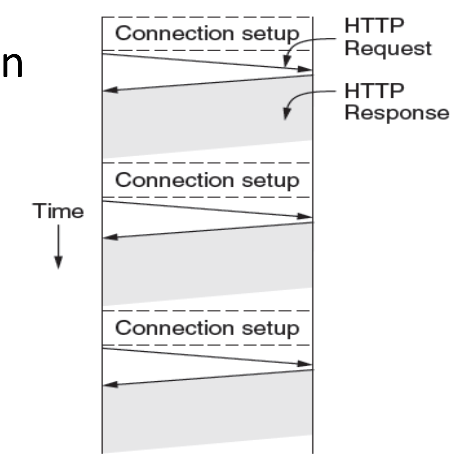
- HTTP/1.0 uses one TCP connection to fetch one web resource
  – Made HTTP very easy to build
  – But gave fairly poor PLT …





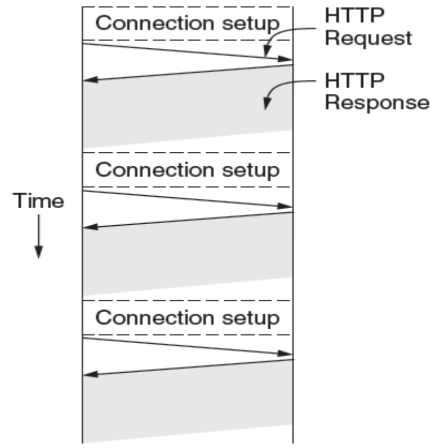

# Early Performance (2)

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



# 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
3. Change HTTP to avoid repeated transfers of the same content
   - Caching, and proxies
4. Relocate content to reduce RTT
   - CDNs [later]

(Items 2–3: This time; Item 4: Later)

# Parallel Connections

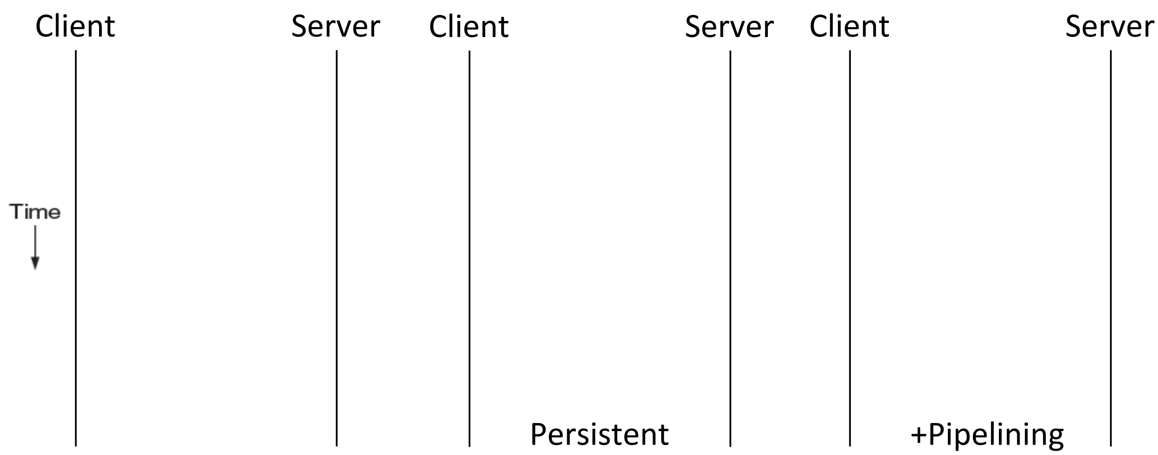
- One simple way to reduce PLT
  - Browser runs multiple (8, say) HTTP instances in parallel
  - Server is unchanged; already handled concurrent requests for many clients
- How does this help?
  - Single HTTP wasn't using network much …
  - So parallel connections aren't slowed much
  - Pulls in completion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



# Persistent Connections

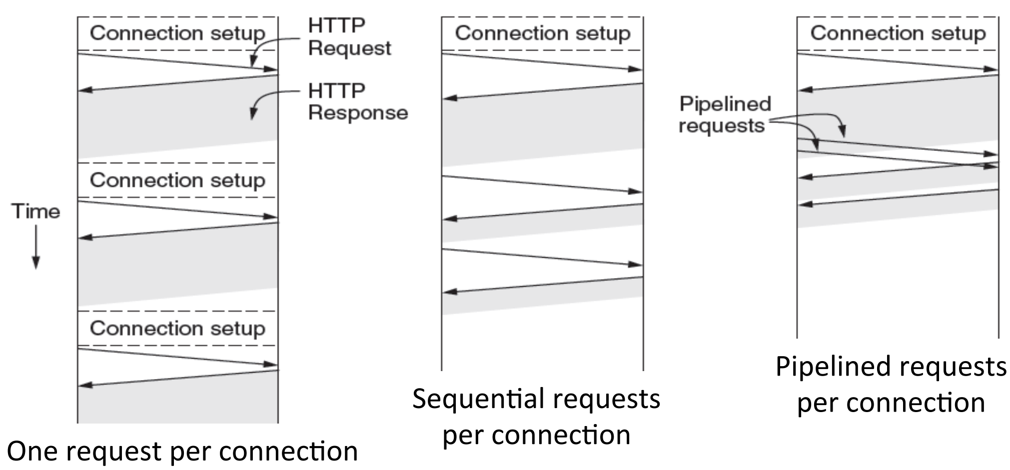
- Parallel connections compete with each other for network resources
  - 1 parallel client ≈ 8 sequential clients?
  - Exacerbates network bursts, and loss
- Persistent connection alternative
  - Make 1 TCP connection to 1 server
  - Use it for multiple HTTP requests

# Persistent Connections (2)






# Persistent Connections (3)



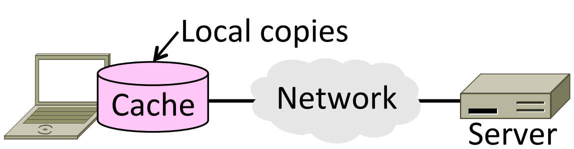
# Persistent Connections (4)

- 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?)



# Web Caching

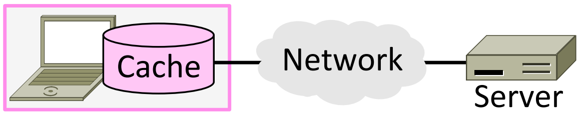
- Users often revisit web pages
  - Big win from reusing local copy!
  - This is caching




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

# Web Caching (2)

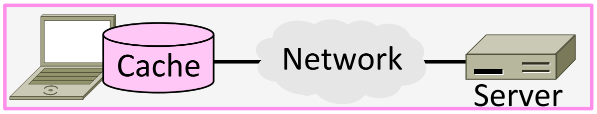
- Locally determine copy is still valid
  - Based on expiry information such as "Expires" header from server
  - Or use a heuristic to guess (cacheable, freshly valid, not modified recently)
  - Content is then available right away





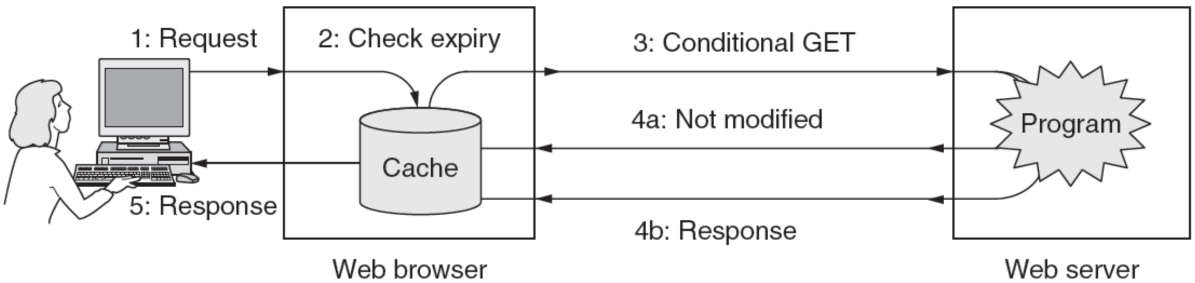

# Web Caching (3)

- Revalidate copy with 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:



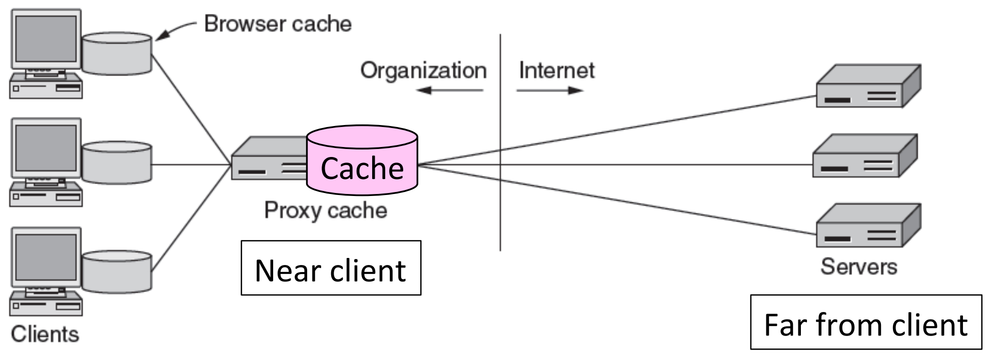



# Web Proxies

- 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 a larger, shared cache
  - Benefits limited by secure and dynamic content, as well as "long tail"

# Web Proxies (2)

- Clients contact proxy; proxy contacts server






# Introduction to Computer Networks

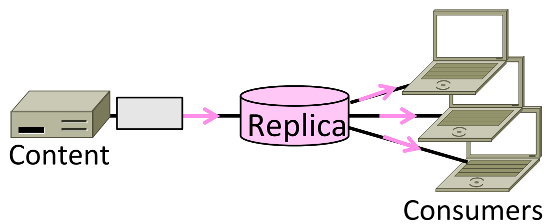
CDNs (Content Delivery Networks) (§7.5.3)

Computer Science & Engineering

UNIVERSITY *of* WASHINGTON

# Topic

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



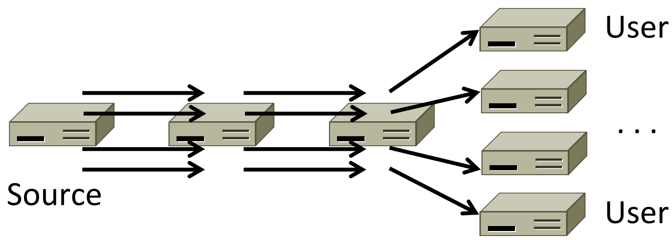



# Context

- 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

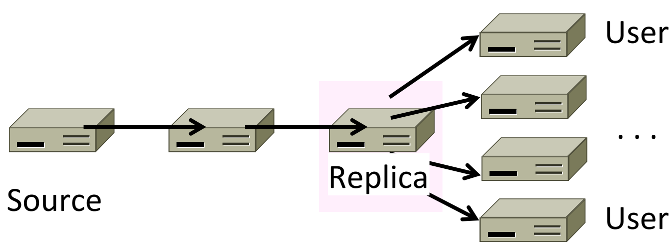
- Sending content from the source to 4 users takes 4 x 3 = 12 "network hops" in the example





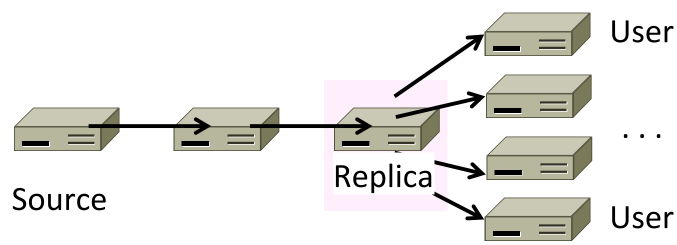

# After CDNs

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



# After CDNs (2)

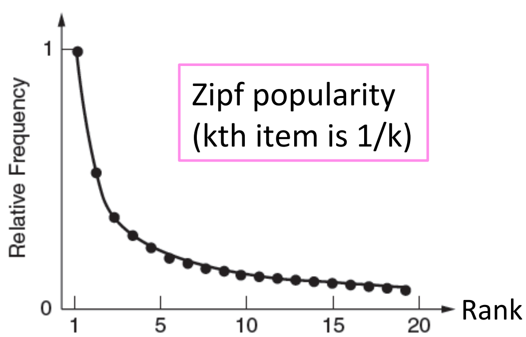
- Benefits assuming popular content:
  - Reduces server, network load
  - Improves user experience (PLT)






# Popularity of Content

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




George Zipf (1902-1950)

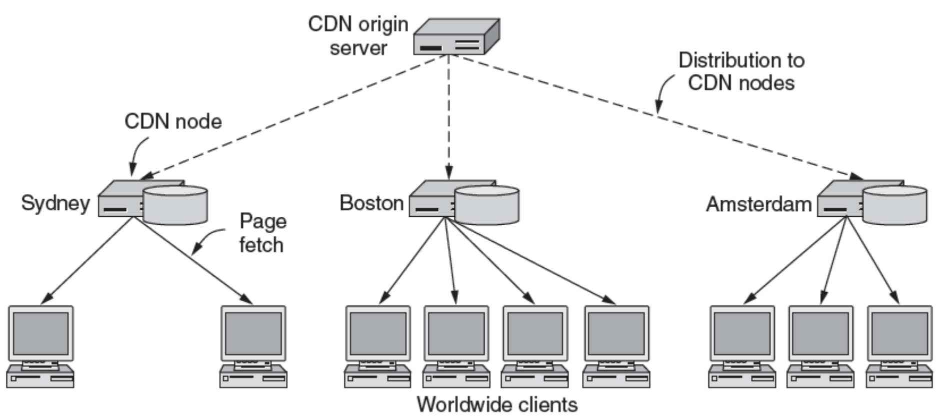
Source: Wikipedia

# 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

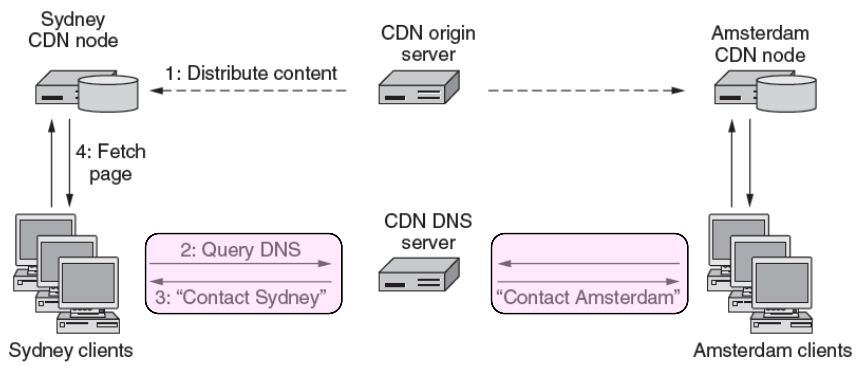


# Content Delivery Network



# Content Delivery Network (2)

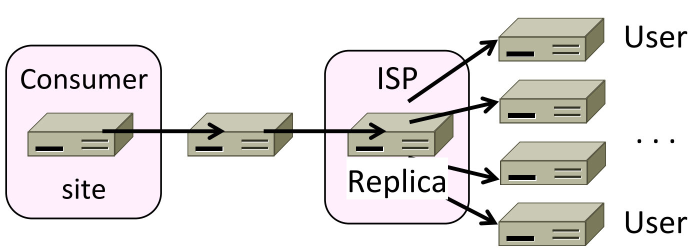
- DNS resolution of site gives different answers to clients
  - Tell each client the site is the nearest replica (map client IP)






# Business Model

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



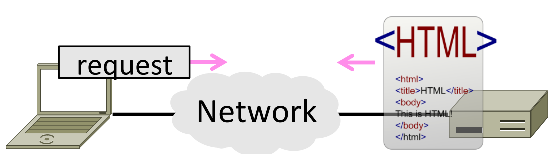
# Introduction to Computer Networks

The Future of HTTP

Computer Science & Engineering
UNIVERSITY *of* WASHINGTON

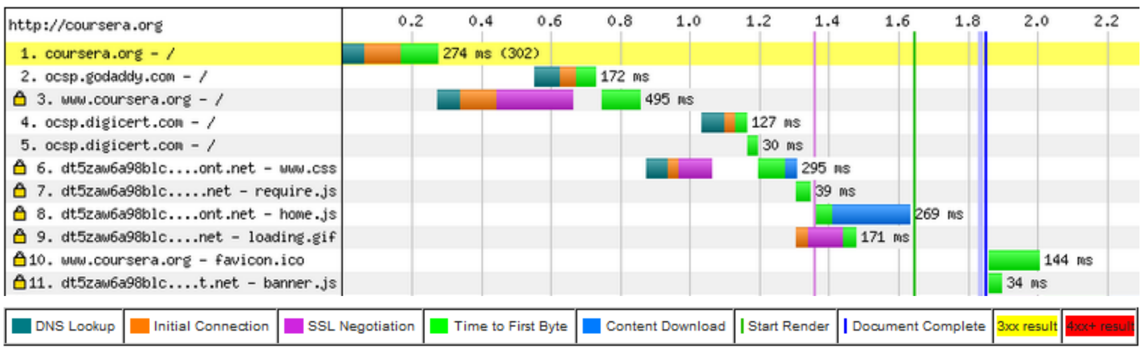
# Topic

- The Future of HTTP
  - How will we make the web faster?
  - A brief look at some approaches



# Modern Web Pages

- Waterfall diagram shows progression of page load




**webpagetest** tool for http://coursera.org (Firefox, 5/1 Mbps, from VA, 3/1/13)



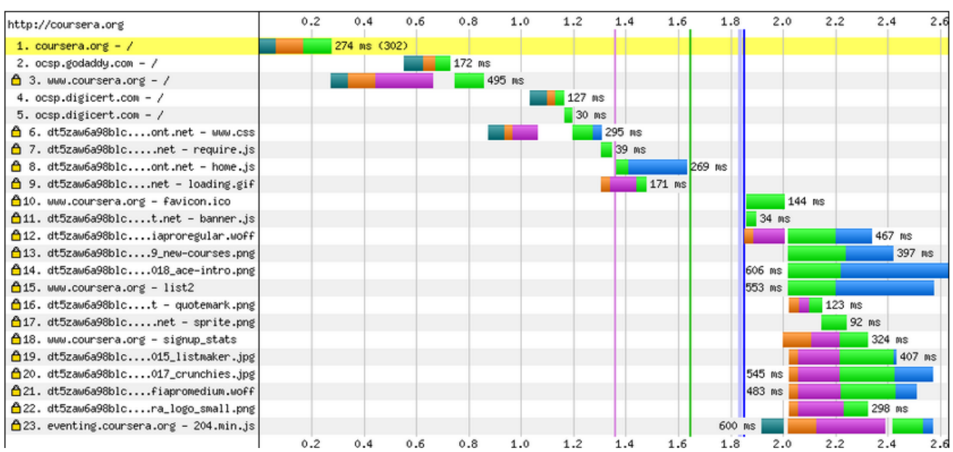
# Modern Web Pages (2)

Yikes!

-23 requests

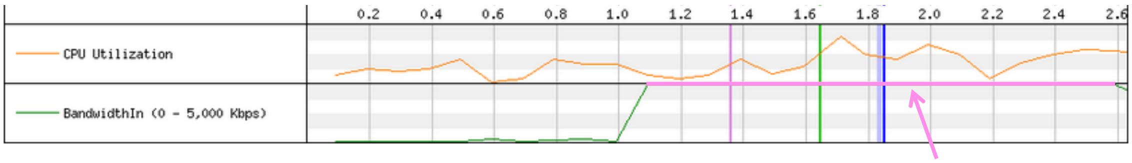
-1 Mb data

-2.6 secs




**webpagetest** tool for http://coursera.org (Firefox, 5/1 Mbps, from VA, 3/1/13)

# Modern Web Pages (3)




Yay! (Network used well)

- Waterfall and PLT depends on many factors
  - Very different for different browsers
  - Very different for repeat page views
  - Depends on local computation as well as network



# Recent work to reduce PLT

Pages grow ever more complex!
- Larger, more dynamic, and secure
- How will we reduce PLT?

1. Better use of the network
   - HTTP/2 effort based on SPDY
2. Better content structures
   - mod_pagespeed server extension

# SPDY ("speedy")

- A set of HTTP improvements
  - Multiplexed (parallel) HTTP requests on one TCP connection
  - Client priorities for parallel requests
  - Compressed HTTP headers
  - Server push of resources
- Now being tested and improved
  - Default in Chrome, Firefox
  - Basis for an HTTP/2 effort



# mod_pagespeed

- Observation:
  - The way pages are written affects how quickly they load
  - Many books on best practices for page authors and developers
- Key idea:
  - Have server re-write (compile) pages to help them load quickly!
  - mod_pagespeed is an example

# mod_pagespeed (2)

- Apache server extension
  - Software installed with web server
  - Rewrites pages “on the fly” with rules based on best practices
- Example rewrite rules:
  - Minify Javascript
  - Flatten multi-level CSS files
  - Resize images for client
  - And much more (100s of specific rules)