EECS 489
Computer Networks

Winter 2023

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Material with thanks to Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.

Agenda

- HTTP and the Web
- Improving HTTP Performance

The Web: Precursor

- 1945, Vannevar Bush, Memex
  - Concept of the web based on microfilms
- 1967, Ted Nelson, Project Xanadu
  - A world-wide publishing network to store information as connected literature
  - Coined the term “Hypertext”
- 1968, Douglas Engelbart, NLS (oN-Line System)
  - The mother of all demos

The Web: History

- World Wide Web (WWW): a distributed database of "pages" linked through Hypertext Transfer Protocol (HTTP)
  - First HTTP implementation – 1990
    - Tim Berners-Lee at CERN
  - HTTP/0.9 – 1991
    - Simple GET command for the Web
  - HTTP/1.0 – 1992
    - Client/server information, simple caching

AWARD WINNER

Sir Tim Berners-Lee

ACM A. M. Turing Award (2016)

ACM Software System Award (1995)

2016 ACM A.M. Turing Award

The Web: History (cont’d)

- World Wide Web (WWW): a distributed database of “pages” linked through Hypertext Transfer Protocol (HTTP)
  - HTTP/1.1 – 1996
    - Performance and security optimizations
  - HTTP/2 – 2015
    - Latency optimizations via request multiplexing over a single TCP connection
    - Binary protocol instead of text
    - Server push

The Web: History (cont'd)

- World Wide Web (WWW): a distributed database of "pages" linked through Hypertext Transport Protocol (HTTP)
  - HTTP/3 – June 2022 (RFC9114)
    - »Built on top of QUIC, which is a user-space congestion control protocol on UDP
    - »Solves head-of-line (HOL) blocking problem in multiplexing over single TCP connection

What does it consist of?

- Who uses it?
- Who provides the content?
- How do they communicate?

- How do we find the content?
- How is the content organized?
- How is it displayed?

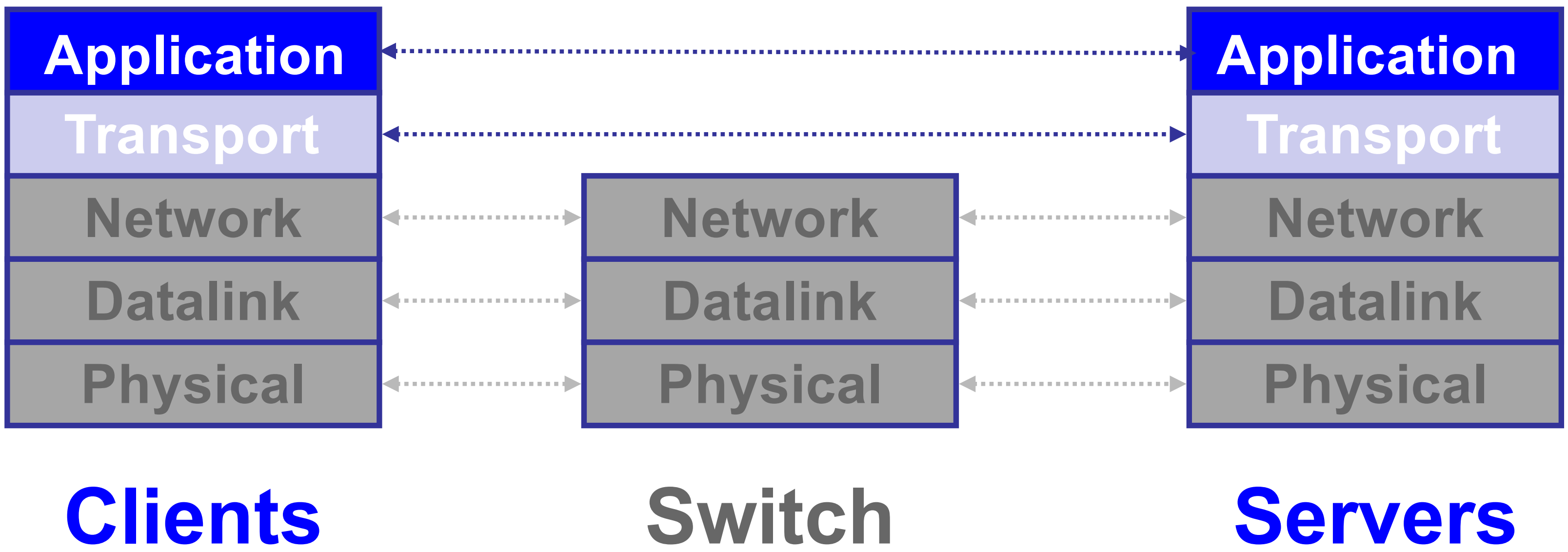
Web components

- Infrastructure:
  - Clients
  - Servers (DNS, CDN, Datacenters)

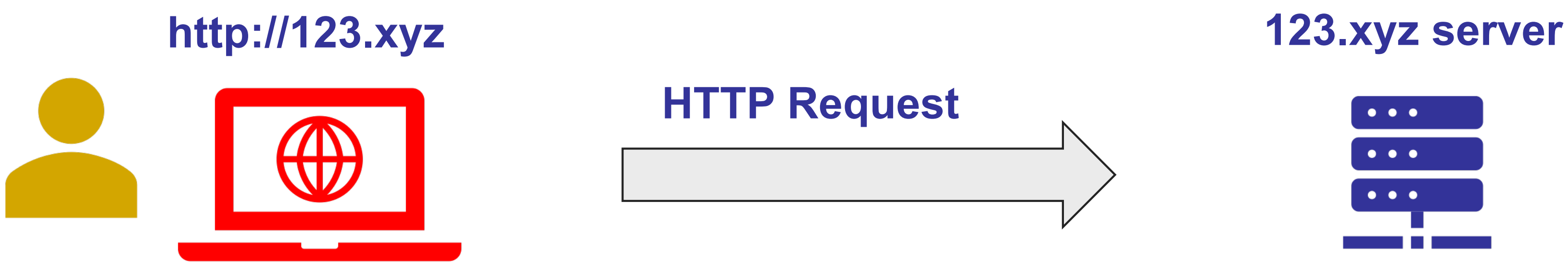
- Content:
  - URL: naming content
  - HTML: formatting content

- Protocol for exchanging information: HTTP

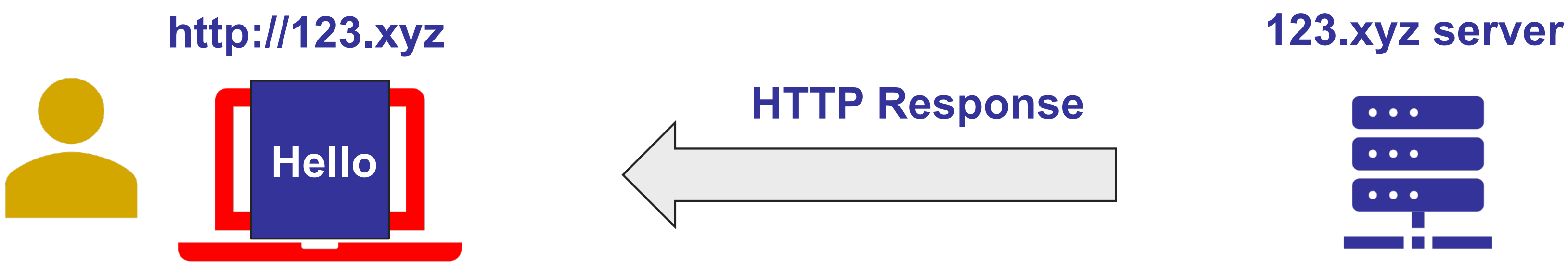
Why is there nothing about the network?



What we want



What we get



URL: Uniform Record Locator

- `protocol://host-name[:port]/directory-path/resource`

- Extend the idea of hierarchical hostnames to include anything in a file system
  - https://github.com/morleydragon/eecs489/blob/main/slides/PDF/010923.pdf
- Extend to program executions as well…
  - `https://www.google.com/search?q=eecs489`
  - Server-side processing can be included in the name

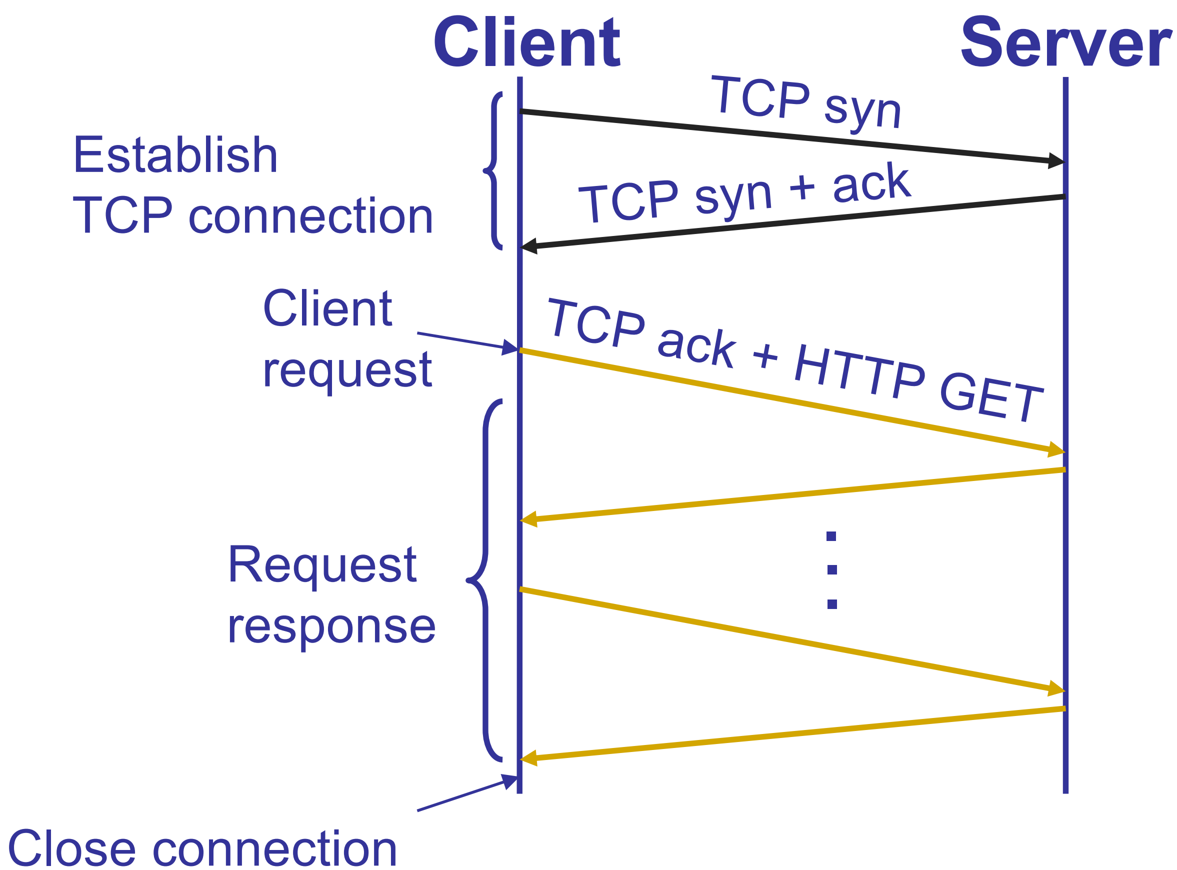
URL: Uniform Record Locator

- `protocol://host-name[:port]/directory-path/resource`
  - `protocol`: http, ftp, https, smtp, rtsp, *etc*.
  - `host-name`: DNS name, IP address
  - `port`*:* defaults to protocol's standard port
    - *E.g.,* http: 80, https: 443
  - `directory path`: hierarchical, reflecting file system
  - `resource`: Identifies the desired resource

Hyper Text Transfer Protocol (HTTP)

- Client-server architecture
  - Server is “always on” and “well known”
  - Clients initiate contact to server
- Synchronous request/reply protocol
  - Runs over TCP, Port 80
- Stateless
- ASCII format
  - Before HTTP/2

Steps in HTTP request/response



Method types (HTTP 1.1)

- GET, HEAD
- POST
  - Send information (e.g., web forms)
- PUT
  - Uploads file in entity body to path specified in URL field
- DELETE
  - Deletes file specified in the URL field

Client-to-server communication

- HTTP Request Message
  - Request line: method, resource, and protocol version

request line

header lines

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language: fr
(blank line)
```

carriage return line feed indicates end of message

Client-to-server communication

- HTTP Request Message
  - Request line: method, resource, and protocol version
  - Request headers: provide info or modify request
  - Body: optional data (e.g., to “POST” data to server)

request line

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language: fr
(blank line)
```

header lines

carriage return line feed indicates end of message

Server-to-client communication

- HTTP Response Message
  - Status line: protocol version, status code, status phrase
  - Response headers: provide information
  - Body: optional data

status line
(protocol, status code, status phrase)

header lines

data
e.g., requested HTML file

```
HTTP/1.1 200 OK
Connection close
Date: Thu, 06 Jan 2017 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 2006 ...
Content-Length: 6821
Content-Type: text/html
(blank line)
data data data data data ...
```

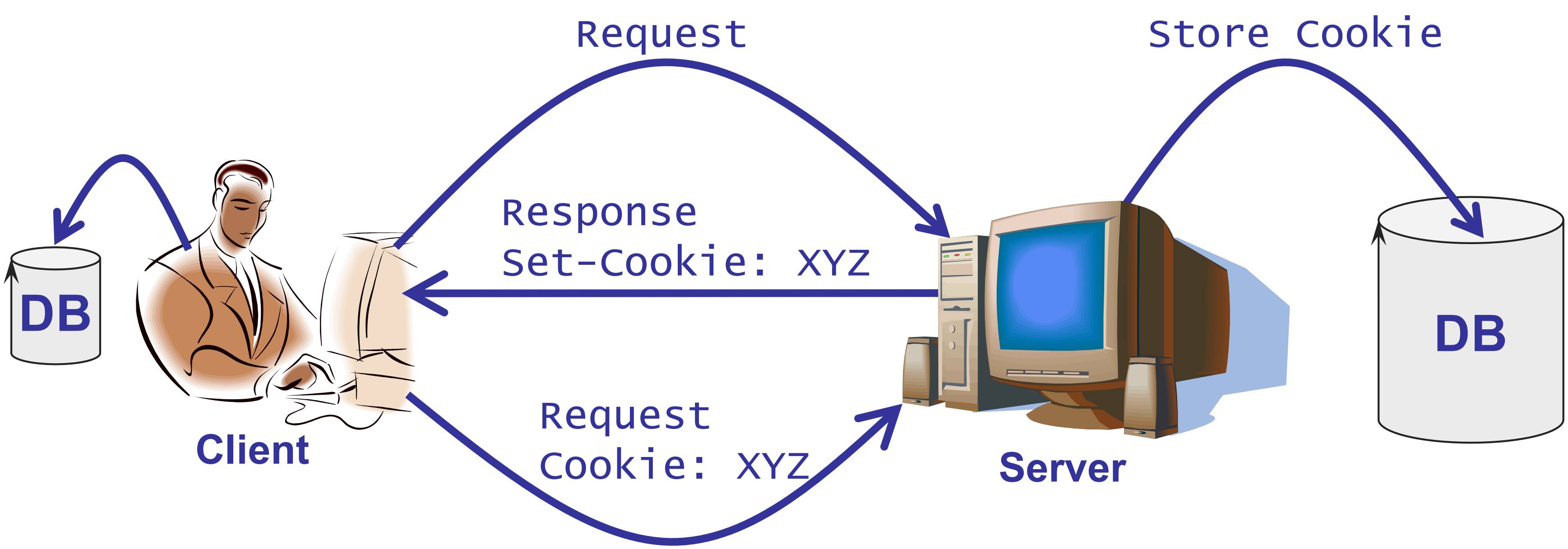
HTTP is stateless

- Each request-response treated independently
  - Servers not required to retain state
- Good: Improves scalability on the server-side
  - Failure handling is easier
  - Can handle higher rate of requests
  - Order of requests doesn't matter
- Bad: Some applications need persistent state
  - Need to uniquely identify user or store temporary info
  - e.g., Shopping cart, user profiles, usage tracking, …

How does a stateless protocol keep state?

State in a stateless protocol: Cookies

- Client-side state maintenance
  - Client stores small state on behalf of server
  - Client sends state in future requests to the server
- Can provide authentication



Beyond cookies

- Cookies provide excellent marketing opportunities and create concerns for privacy
  - Advertising companies tracks your preferences and viewing history across sites
- Many are trying to replace personalized cookies with group-based identifiers
  - Example: FLoC in Google Chrome that uses federated learning
    The FLoC or Federated Learning of Cohorts clusters individuals with similar browsing patterns into large groups or cohorts and assigns unique cohort IDs.

5-MINUTE BREAK!

Announcements

- Assignment 1 is due on Jan 27, 2023
  - Quite a few of you haven't yet created Github repo!
  - Start ASAP!!!

- Group formation for A2-A4 by Jan 22
  - https://forms.gle/3UF5WuW4zaW3m2yXA

Performance goals

- User
  - Fast downloads (not identical to low-latency communication!)
  - High availability
- Content provider
  - Happy users (hence, above)
  - Cost-effective infrastructure
- Network (secondary)
  - Avoid overload

Solutions?

Improve networking protocols including HTTP, TCP, etc.

- User
  - Fast downloads (not identical to low-latency communication!)
  - High availability
- Content provider
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Solutions?

Improve networking protocols including HTTP, TCP, etc.

- User
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Caching and replication

Solutions?

Improve networking protocols including HTTP, TCP, etc.

- User
  - Fast downloads (not identical to low-latency communication!)
  - High availability
- Content provider
  - Happy users (hence, above)
  - Cost-effective infrastructure
- Network (secondary)
  - Avoid overload

Caching and replication

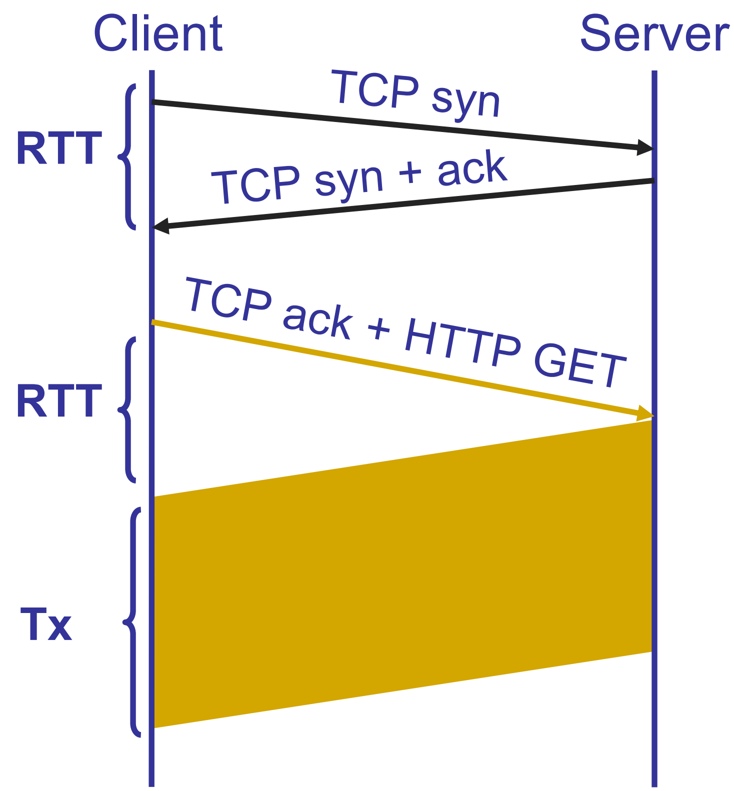
Exploit economies of scale; e.g., webhosting, CDNs, datacenters

HTTP performance

- Most Web pages have multiple objects
  - e.g., HTML file and a bunch of embedded images
- How do you retrieve those objects (naively)?
  - One item at a time
- New TCP connection per (small) object!

Object request response time

- RTT (round-trip time)
  - Time for a small packet to travel from client to server and back
- Response time
  - 1 RTT for TCP setup
  - 1 RTT for HTTP request and first few bytes
  - Transmission time
  - Total = 2RTT + Transmission Time

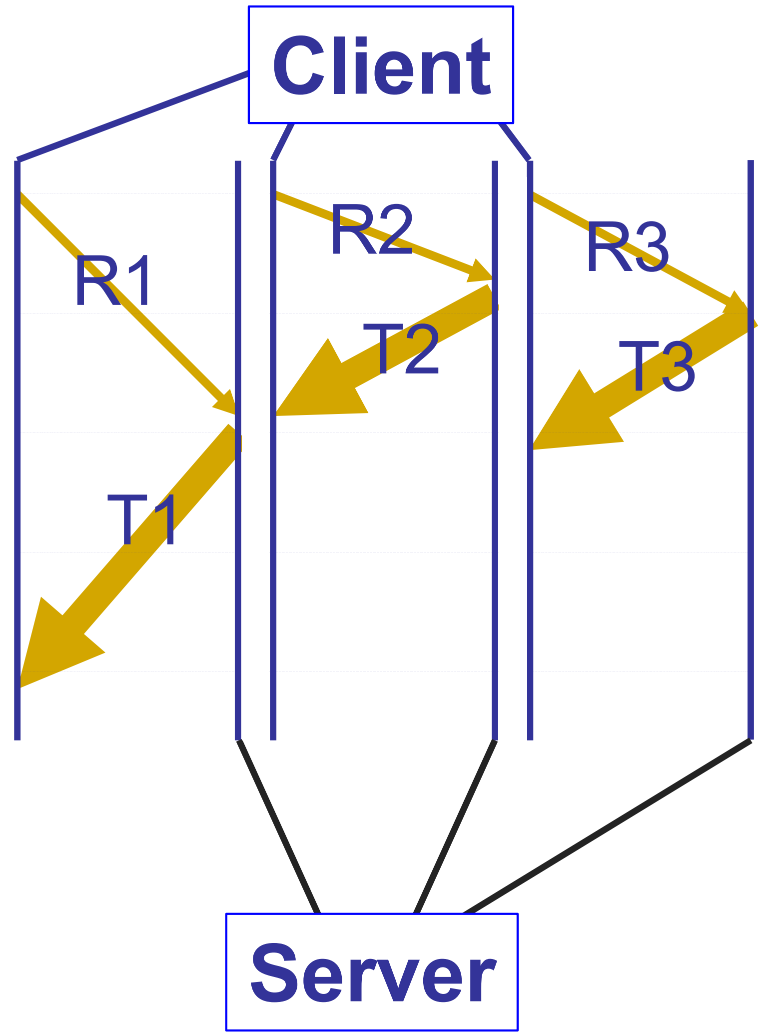


Non-persistent connections

- Default in HTTP/1.0
- 2RTT+△ for each object in the HTML file!
  - One more 2RTT+△ for the HTML file itself
- Doing the same thing over and over again
  - Inefficient

Concurrent requests and responses

- Use multiple connections in parallel
- Does not necessarily maintain order of responses



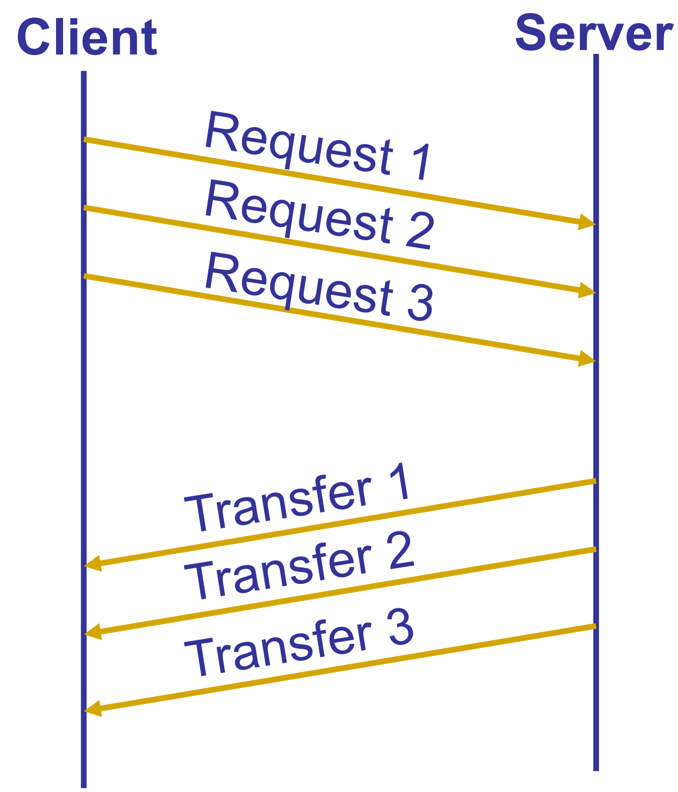
- Client = ☺
- Content provider = ☺
- Network = ☹ Why?

Persistent connections

- Maintain TCP connection across multiple requests
  - Including transfers subsequent to current page
  - Client or server can tear down connection
- Advantages
  - Avoid overhead of connection set-up and tear-down
  - Allow underlying layers (e.g., TCP) to learn about RTT and bandwidth characteristics
- Default in HTTP/1.1

Pipelined requests & responses

- Batch requests and responses to reduce the number of packets
  - Multiple requests can be contained in one TCP segment
- Data are sent in a FIFO manner
  - Can lead to head-of-line (HOL) blocking if many small responses follow a large one
  - Not supported by default by major browsers circa 2015
- Solution
  - Priority and preemption



Scorecard: Getting n small objects

- Time dominated by latency

- One-at-a-time: ~2n RTT
- m concurrent: ~2[n/m] RTT
- Persistent: ~ (n+1) RTT
- Pipelined: ~2 RTT
- Pipelined and Persistent: ~2 RTT first time; RTT later for another n from the same site

Scorecard: Getting n large objects each of size F

- Time dominated by TCP throughput B_C ($<= B_L$), where link bandwidth is referred by B_L

- One-at-a-time: ~ nF/B_C
- m concurrent: ~ $nF/(mB_C)$
  - Assuming each TCP connection gets the same throughput and $mB_C <= B_L$
- Pipelined and/or persistent: ~ nF/B_C
  - The only thing that helps is higher throughput

Caching

- Why does caching work?
  - Exploits locality of reference
- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests
    - A universal story!
    - Effectiveness of caching grows logarithmically with size

Caching: How

- Modifier to GET requests:
  - `If-modified-since` – returns "not modified" if resource not modified since specified time

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
If-modified-since: Wed, 18 Jan 2017 10:25:50 GMT
(blank line)
```

Caching: How

- Modifier to GET requests:
  - `If-modified-since` – returns "not modified" if resource not modified since specified time
- Client specifies "`if-modified-since`" time in request
- Server compares this against "last modified" time of resource
- Server returns "Not Modified" if resource has not changed
- …. or a "OK" with the latest version otherwise

Caching: How

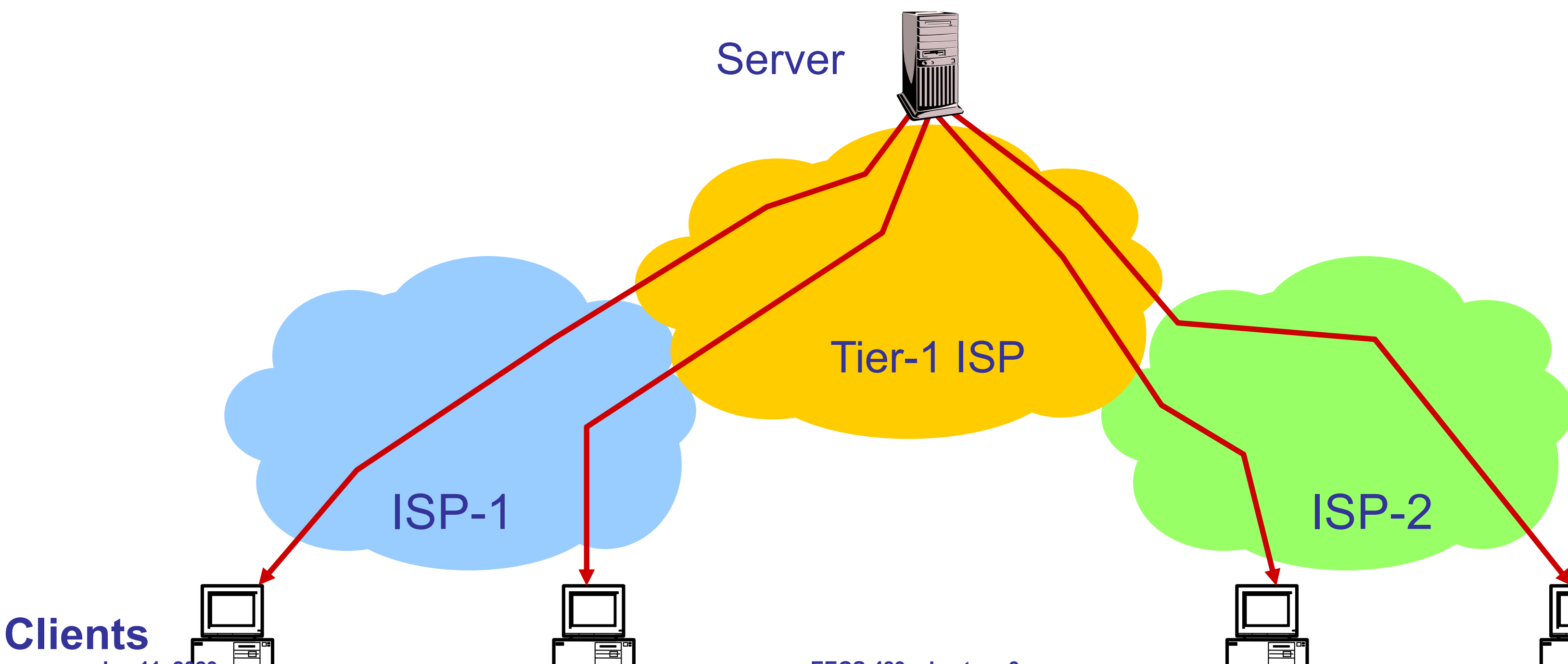
- Modifier to GET requests:
  - `If-modified-since` – returns "not modified" if resource not modified since specified time
- Response header:
  - `Expires` – how long it's safe to cache the resource
  - `No-cache` – ignore all caches; always get resource directly from server

Caching: Where?

- Options
  - Client (browser)
  - Forward proxies
  - Reverse proxies
  - Content Distribution Network

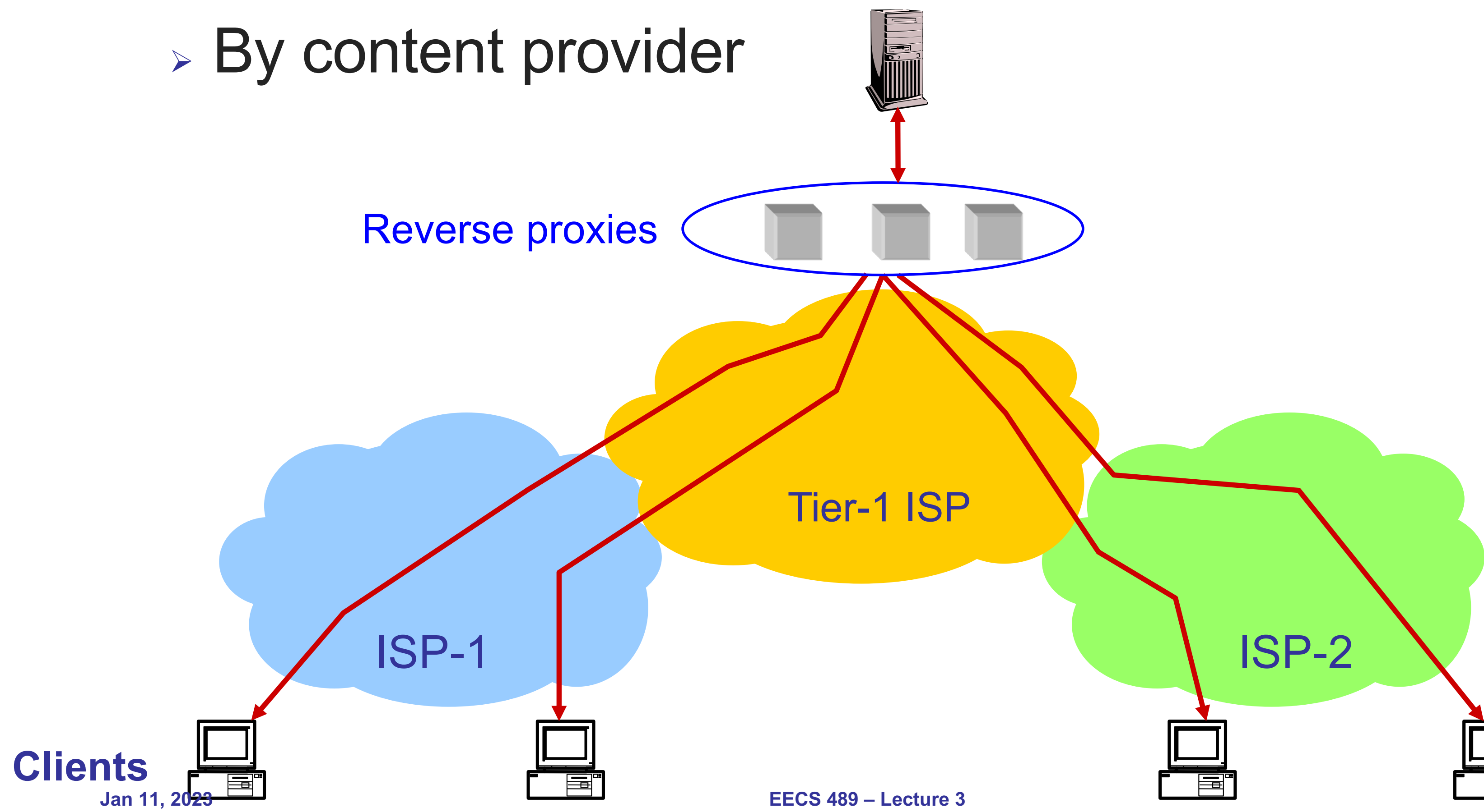
Caching: Where?

- Many clients transfer same information
  - Generate unnecessary server and network load
  - Clients experience unnecessary latency



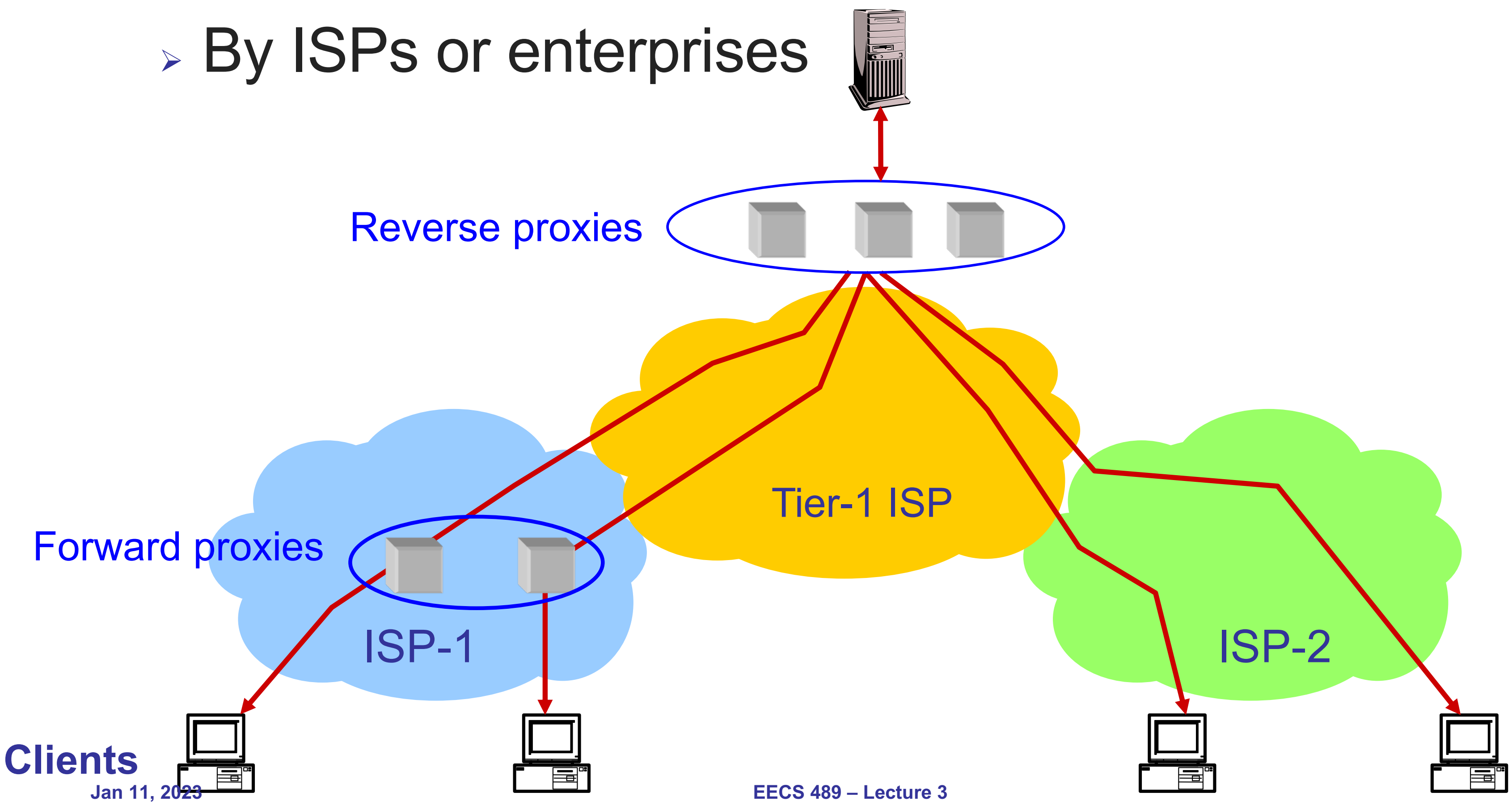
Caching with Reverse Proxies

- Cache documents close to server
  - Decrease server load
  - By content provider



Caching with Forward Proxies

- Cache documents close to clients
  - Reduce network traffic and decrease latency
  - By ISPs or enterprises



Summary

- HTTP/1.1
  - Text-based protocol
  - Replaced by binary HTTP/2 protocol, which being replaced by HTTP/3
- Many ways to improve performance
  - Pipelining and batching
  - Caching in proxies and CDNs
  - Datacenters