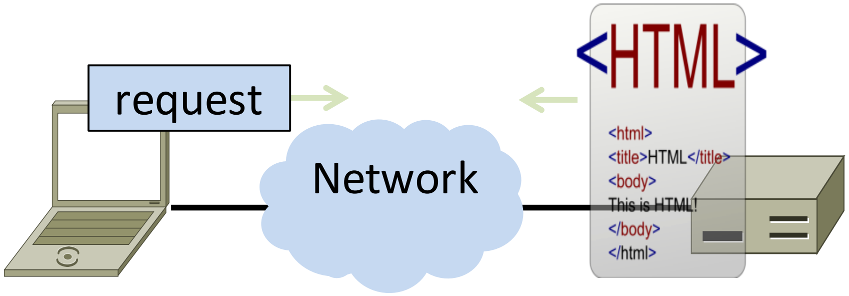
2- Application Level Protocols HTTP 1.0/1.1/2

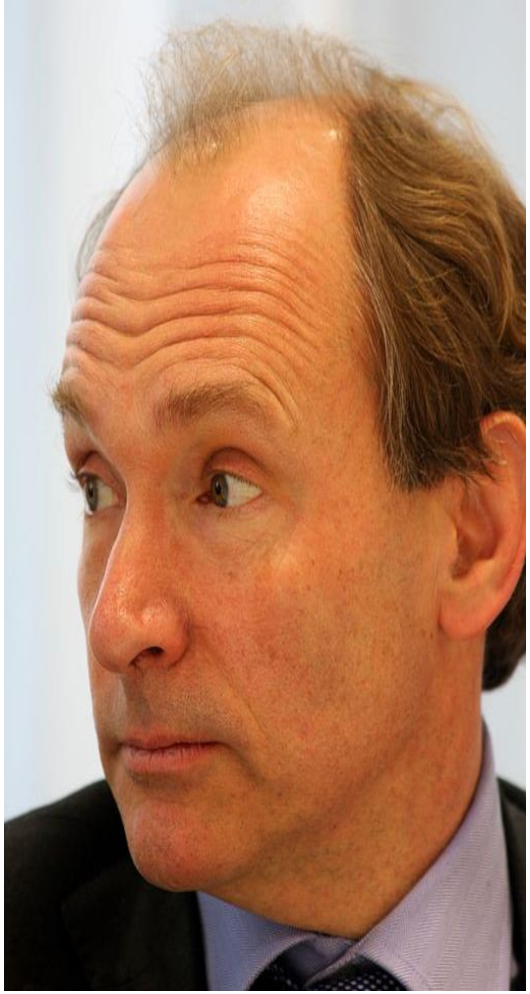
HTTP, (HyperText Transfer Protocol)

- Basis for fetching Web pages



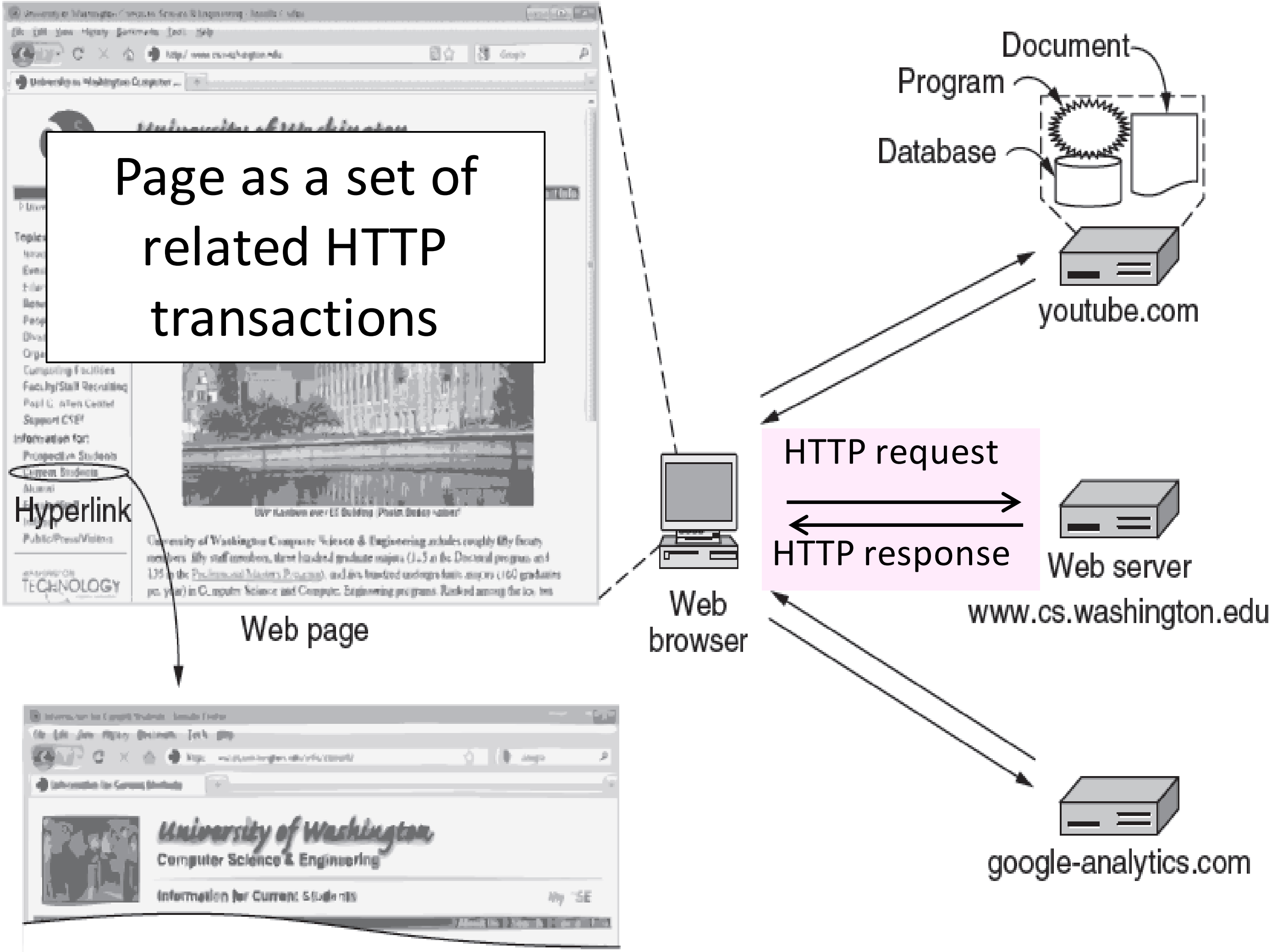
Sir Tim Berners-Lee (1955–)

- 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

Web Context



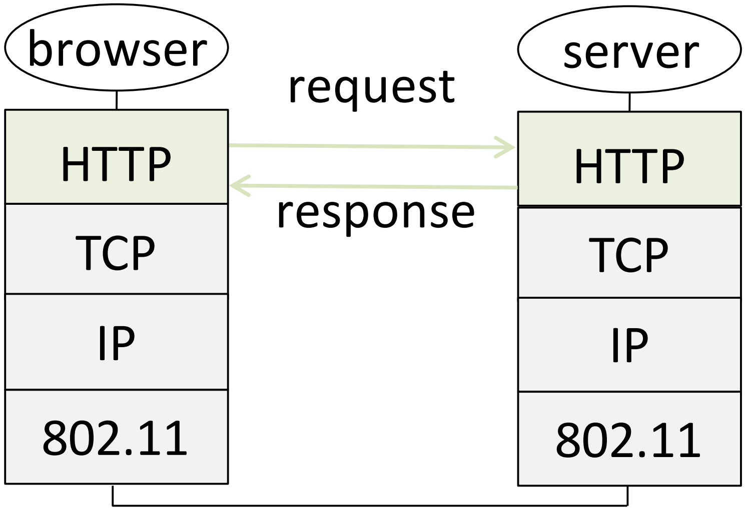
Page as a set of related HTTP transactions

HTTP request

HTTP response

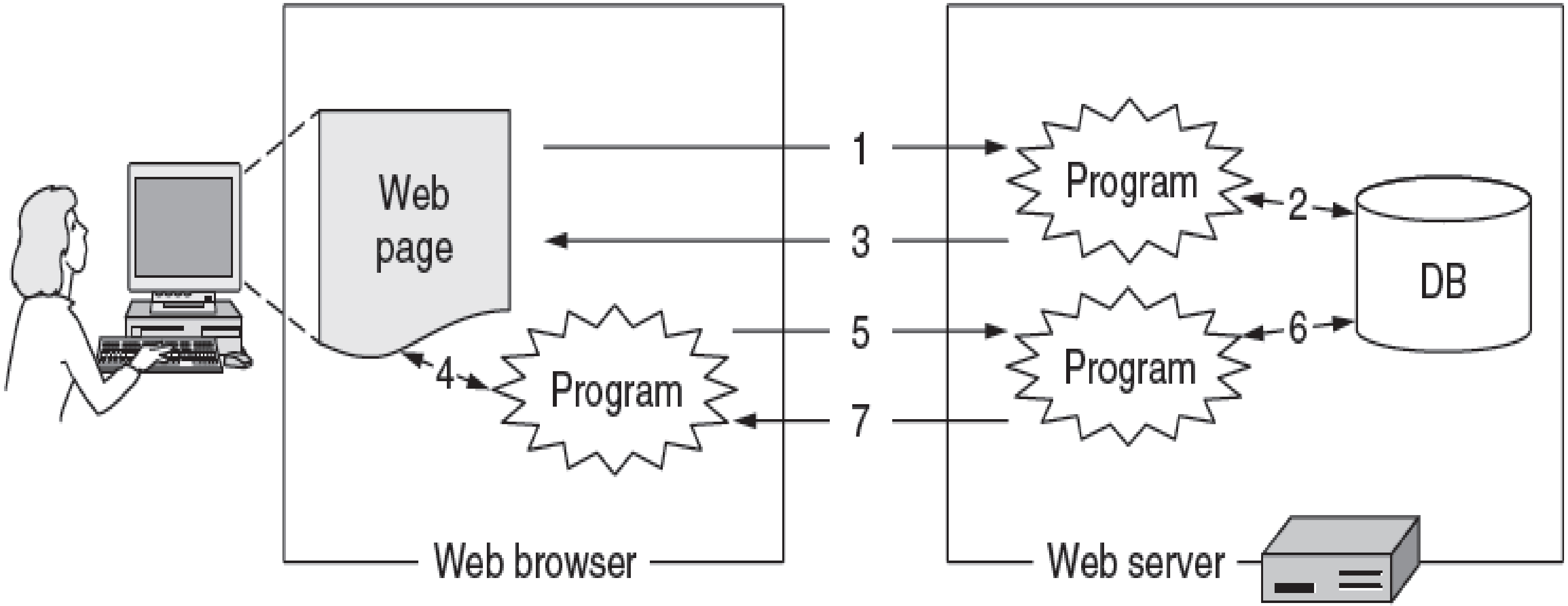
Web Protocol Context

- HTTP is a request/response protocol for fetching Web resources
  - Runs on TCP, typically port 80
    - HTTPS typically on port 443
  - Part of browser/server app



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



HTTP Protocol

- Originally a simple protocol, with many options added over time
- HTTP transports typed data
  - TCP transports bytes
- HTTP is a request-response protocol
  - Client sends request message, server sends response message
- HTTP messages have a header and a payload section
- Header is encoded as text
- HTTP is carried over a TCP

Fetching a Web Page From a Browser

- Browser starts with the page URL:

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

- Browser steps:
  - Resolve the server name to an IP address (DNS)
  - Set up a TCP connection to the server
  - Send HTTP request for the page
  - Wait for and then read HTTP response
  - (Assuming no errors) Process response data and render page
  - Clean up any idle TCP connections

HTTP Message Format

Special command line\r\n

Tag: *value*\r\n

Tag: *value*\r\n

…

Tag: *value\r\n*

\r\n

<payload>

- Header is encoded as text
- Header is a sequence of lines
- Each line ends with \r\n
- Header ends with \r\n\r\n

- Payload length is given by either:
  - Content-length tag in header
  - Payload is encoded in a format that uses a sentinel (special value that marks the end)

Try It Yourself: View HTTP Request

- *$ nc –l 8080*
  Opens a TCP socket on port 8080 and waits for an incoming connection

- Point a browser running on the same machine to
  http://localhost:8080/first/second/third.html

- The output of the nc window is the HTTP request sent by the browser

Example HTTP Request

```
$ nc -l 8080
GET /first/second/third.html HTTP/1.1
Host: localhost:8080
Connection: keep-alive
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/61.0.3163.100 Safari/537.36
Upgrade-Insecure-Requests: 1
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,image/apng,*/*;q=0.8
DNT: 1
Accept-Encoding: gzip, deflate, br
Accept-Language: en-US,en;q=0.8
```

What the browser sent

Try It Yourself: HTTP Response

```
$ nc www.washington.edu 80
```

request

```
GET / HTTP/1.0
Host: www.washington.edu

```

response

```
HTTP/1.1 200 OK
Date: Tue, 10 Oct 2017 15:58:14 GMT
Server: Apache/2.2.24 (Unix) mod_ssl/2.2.24 OpenSSL/1.0.1e-fips PHP/5.6.26
mod_pubcookie/3.3.4a mod_uwa/3.2.1
Last-Modified: Mon, 09 Oct 2017 21:45:12 GMT
ETag: "180cd3-c459-55b241ae94a00"
Accept-Ranges: bytes
Content-Length: 50265
Vary: Accept-Encoding,User-Agent
Connection: close
Content-Type: text/html

<!DOCTYPE html><html class="no-js"><head><meta content="IE=edge" http-equiv="X-UA-
Compatible"/><title> UW Homepage </title><meta charset="utf-8"/><meta
content="University of Washington" name="d.... <50265 bytes of data in all>
```

Try It Yourself: HTTP Response 2

```
$ nc uw.edu 80
GET / HTTP/1.0
Host: uw.edu

HTTP/1.1 301 Moved Permanently
Date: Tue, 10 Oct 2017 16:04:20 GMT
Server: Apache/2.2.24 (Unix) mod_ssl/2.2.24 OpenSSL/1.0.1e-fips PHP/5.6.26 mod_pubcookie/3.3.4a mod_uwa/3.2.1
Location: http://www.washington.edu/
Vary: Accept-Encoding
Content-Length: 385
Connection: close
Content-Type: text/html; charset=iso-8859-1

<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML 2.0//EN">
<html><head>
<title>301 Moved Permanently</title>
</head><body>
<h1>Moved Permanently</h1>
<p>The document has moved <a href="http://www.washington.edu/">here</a>.</p>
<hr>
<address>Apache/2.2.24 (Unix) mod_ssl/2.2.24 OpenSSL/1.0.1e-fips PHP/5.6.26 mod_pubcookie/3.3.4a mod_uwa/3.2.1 Server at uw.edu
Port 80</address>
</body></html>
```

HTTP Protocol

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

PUT, DELETE ← Basically defunct

HTTP Protocol

Result 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! →

PERFORMANCE

Performance Measure: PLT (Page Load Time)

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

NEUROSCIENCE

You Now Have a Shorter Attention Span Than a Goldfish

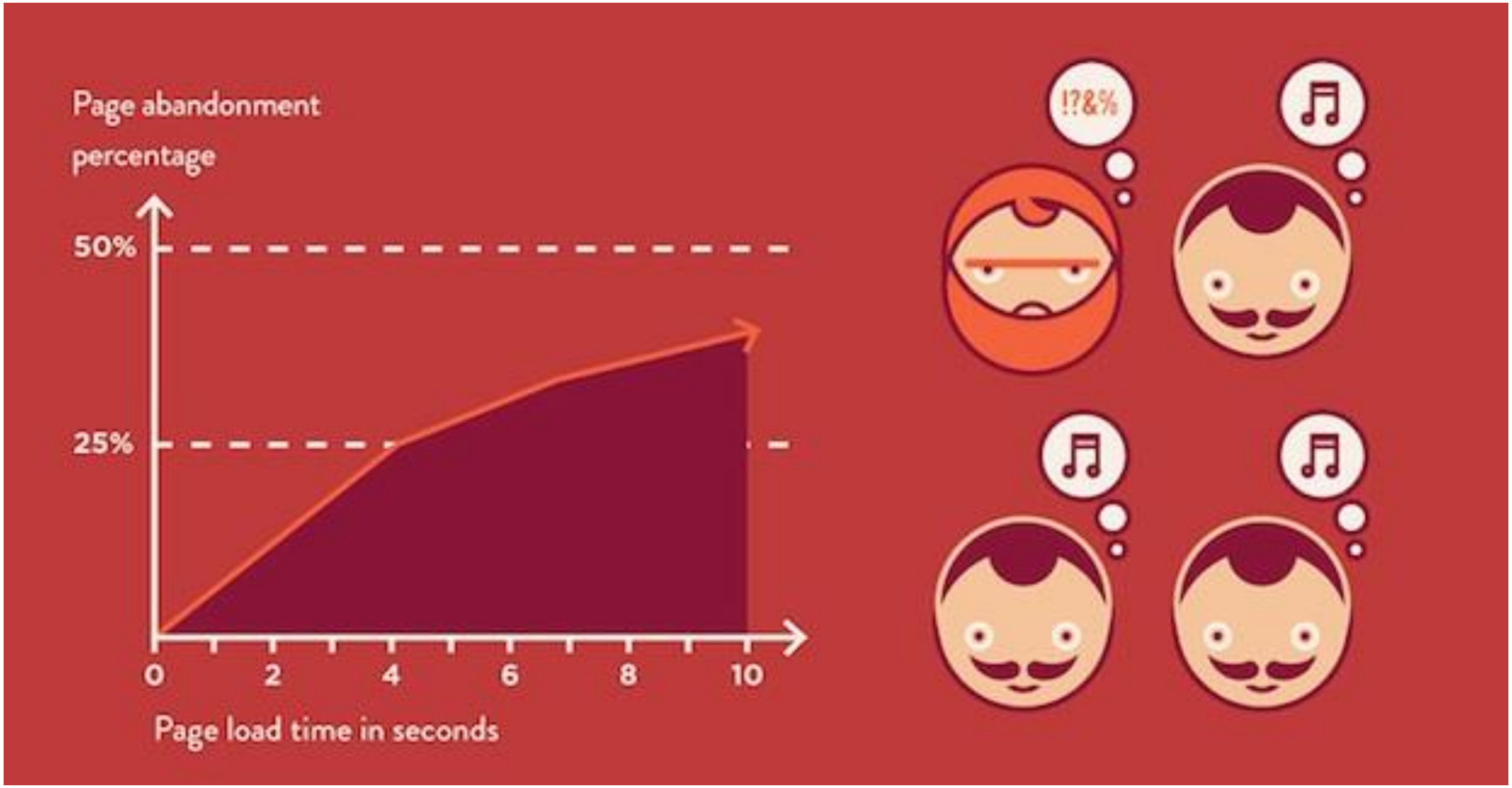
Kevin McSpadden
May 13, 2015

TIME Health

For more, visit TIME Health.

The average attention span for the notoriously ill-focused goldfish is nine seconds, but according to a new study from Microsoft Corp., people now generally lose concentration after eight seconds, highlighting the affects of an increasingly digitalized lifestyle on the brain.

Page Load Time Impact

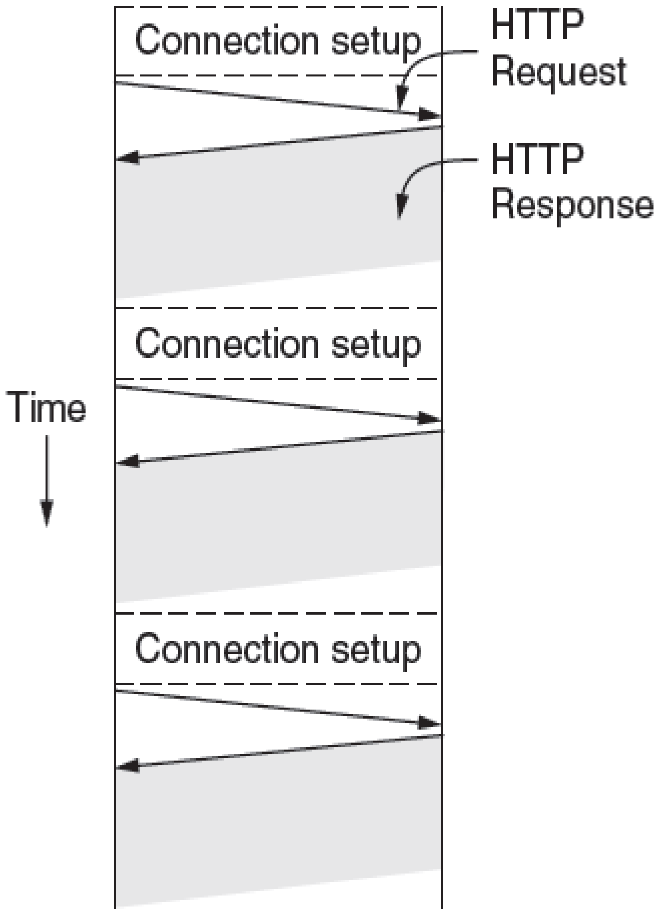


From *How One Second Could Cost Amazon $1.6 Billion In Sales,* March 15, 2012
`https://www.fastcompanycom/1825005/how-one-second-could-cost-amazon-16-billion-sales`

HTTP 1.0 (1996)

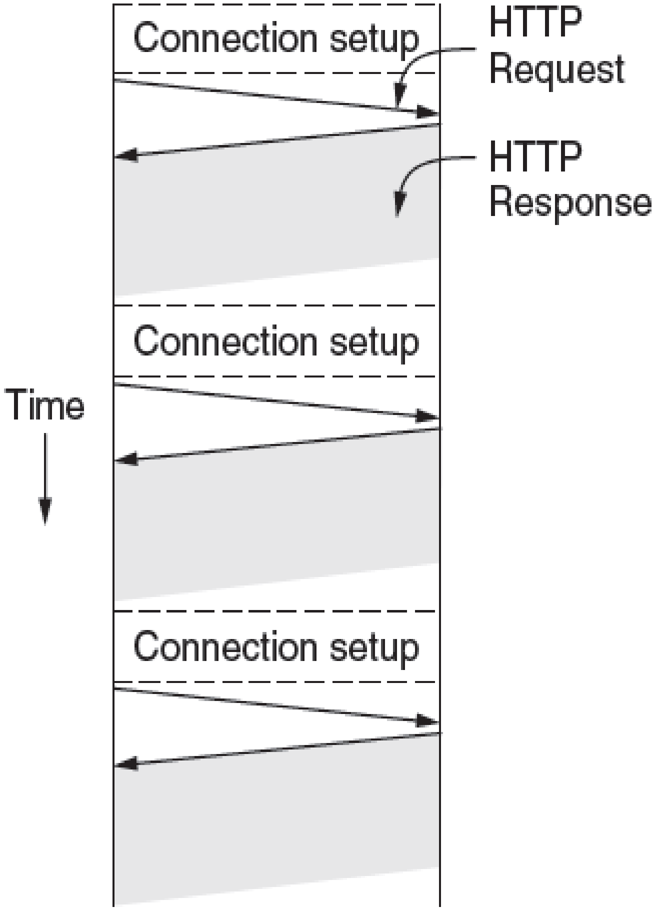
- HTTP/1.0 uses one TCP connection to fetch one web resource
  - Made HTTP very easy to build
  - But gave fairly poor PLT …

- Framing?
  - Length?
  - Sentinel?



HTTP 1.0

- Many reasons why PLT is larger than necessary
  - Sequential request/responses, even when to different servers
  - Multiple TCP connection setups to the same server



Parallel Connections

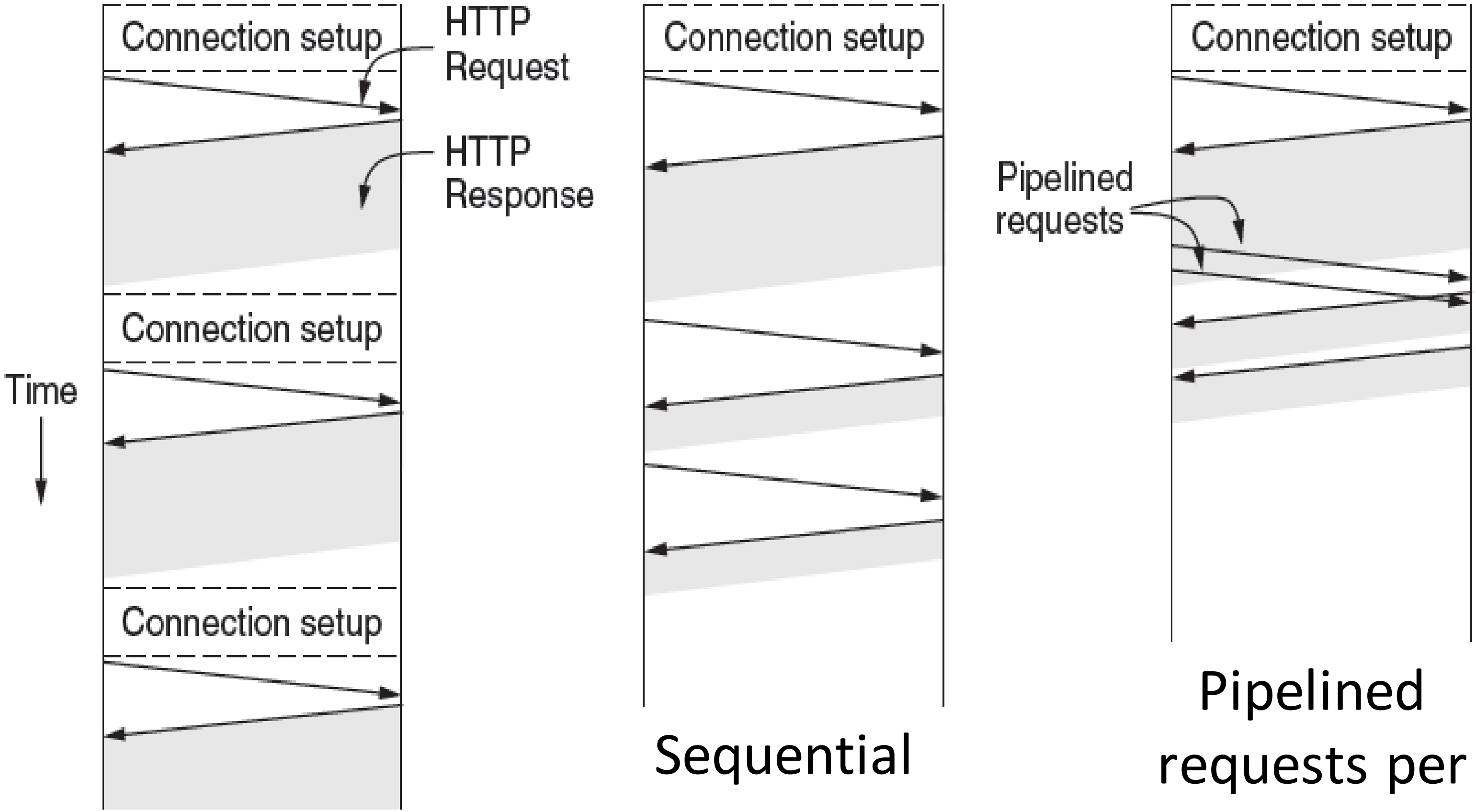
- One simple way to reduce PLT
  - Browser runs multiple (8, say) HTTP instances in parallel
  - Server is unchanged; already handled concurrent requests for many clients
- How does this help?
  - Single HTTP wasn't using network much …
  - So parallel connections aren't slowed much
  - Pulls in completion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

HTTP 1.1 (1997)
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



One request per connection

Sequential requests per connection

Pipelined requests per connection

Persistent Connections: Framing

- How are requests and responses framed?
  - Enforce use of content-length header field?
    - What if content is dynamically generated?

  - If not that, then what?

Persistent Connections

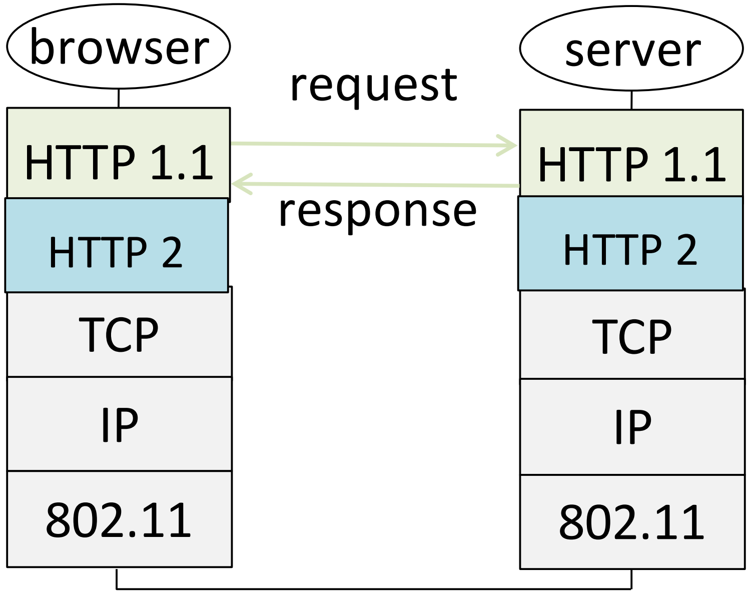
- Widely used as part of HTTP/1.1
  - Supports optional pipelining (?)
  - PLT benefits depending on page structure, but easy on network
- How can we reduce PLT even more?

HTTP 2 (2015)

- HTTP 2 preserves the semantics of HTTP 1.0 / 1.1
  - Client still says GET and server still responds OK
- However, the requests are
  - encoded differently (compressed)
  - transferred differently (streams and frames)

- IETF RFC 7540, May 2015
  - Successor to Google's SPDY protocol

HTTP 2



This is the idea of how HTTP 2 fits in. A particular implementation might well combine HTTP 1.1 and HTTP 2

HTTP 2 – Main Features

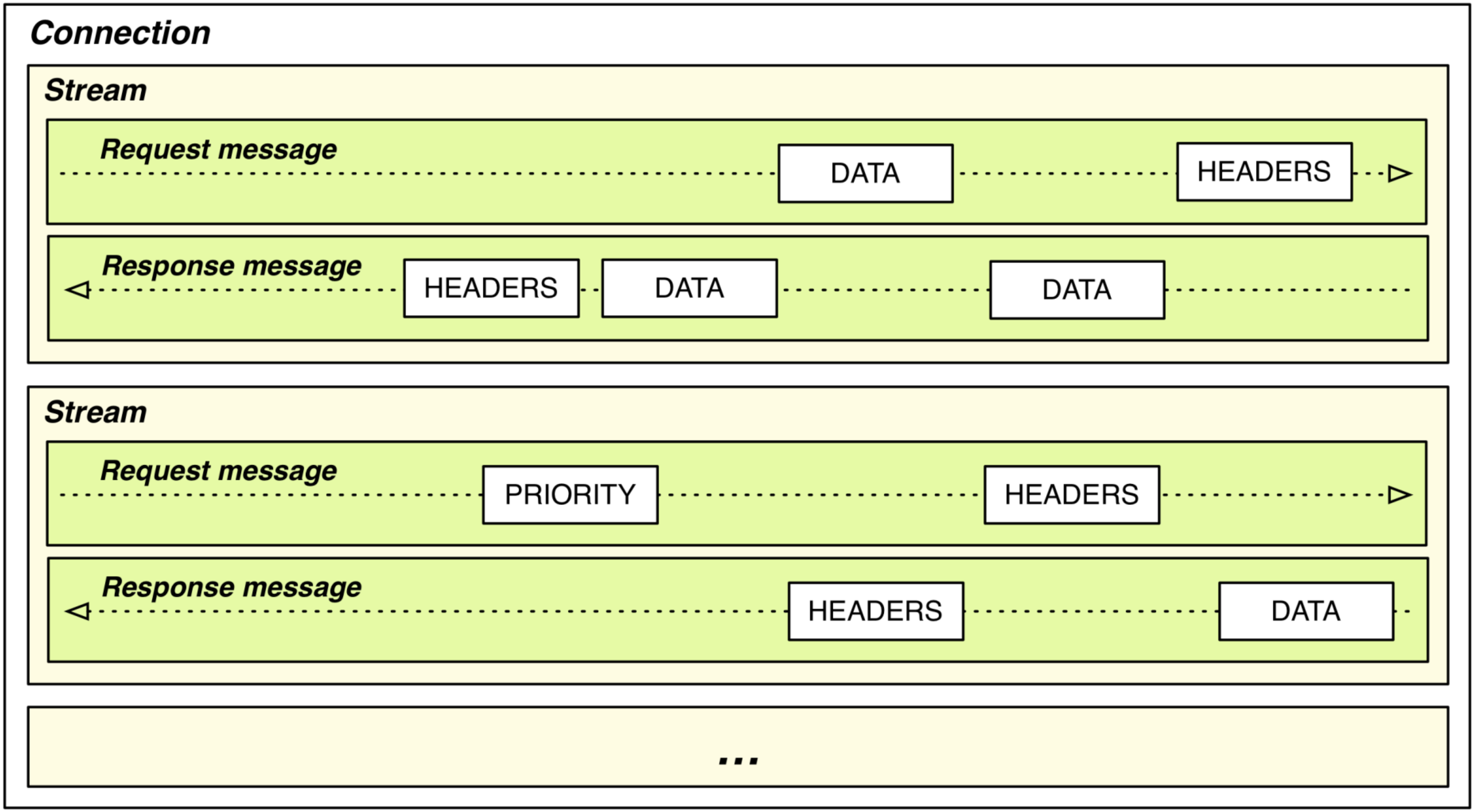
- Allows “real pipelining” of requests on persistent connections
  - We have to “name” each request explicitly so that we can match responses to requests
    - Why can’t we use ordering?
- Headers have gotten big
  - compress headers
- Servers can supply data that wasn’t requested
  - “server push”
- Clients can advertise priorities among their requests

Note: “real pipelining” allows the server to apply its own idea of priority, since it doesn’t have to reply in order

HTTP 2 – Streams and Frames

- A *connection* is a TCP connection between client and server
    - long lived, just like HTTP 1.1
- A *stream* is an ordered, bidirectional flow of information between client and server
- There is one connection between a client and server
- There is (roughly) one stream per HTTP request

HTTP 2 – Streams & Frames



Streams

- Each stream has a unique ID
  - Successive stream IDs must be increasing
  - When run out of stream IDs, have to create a new connection
- Race condition if both ends try to create stream IDs
  - Solution: “client” uses odd numbers, server uses evens
- A stream is created by sending a frame with a new stream ID

Frame Types

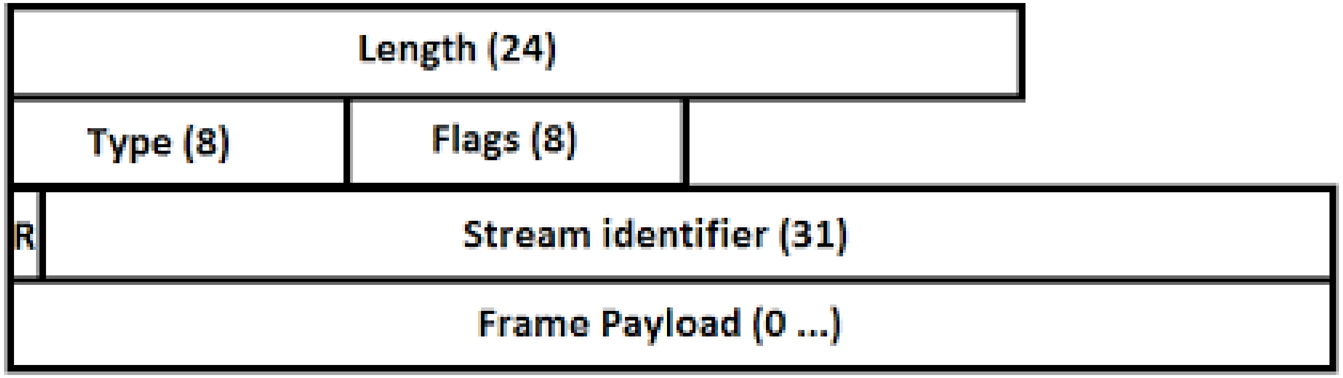
Frame type	Description
DATA	HTTP body
HEADERS	Header fields
PRIORITY	Sender-advised priority of stream
RST_STREAM	Signal termination of stream
SETTINGS	Configuration parameters for the connection
PUSH_PROMISE	Signal a promise (push) of referenced sources
PING	Measure roundtrip time and "liveness"
GOAWAY	Inform peer to stop creating streams for current connection
WINDOW_UPDATE	Connection flow control
CONTINUATION	Continue a segment of header block fragments

Simples encoding of an HTTP request

- Send a HEADER frame followed by zero or more CONTINUATION frames
  - Set END_HEADERS flag on last one
- Send DATA frames for request data, if needed
  - Set END_STREAM flag on last

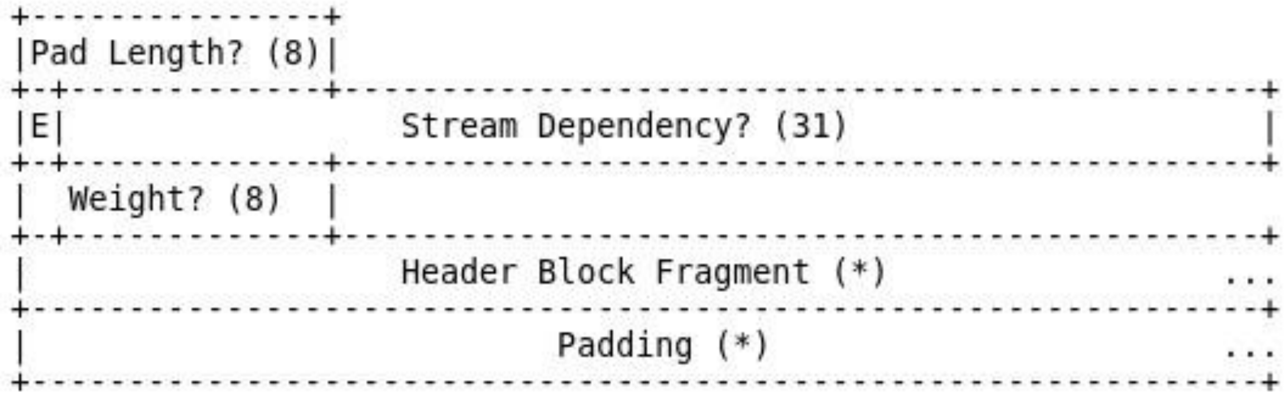
- Response is the same, in reverse

Frame Header



- Length: length of payload
  - header is always 9 bytes
- Type: frame type
- Flags: depends on type
- R: reserved; *“must be unset when sending and ignored when receiving”*
- Stream ID: 0x0 is reserved for frames associated with the connection (not an individual stream)

HEADER frame

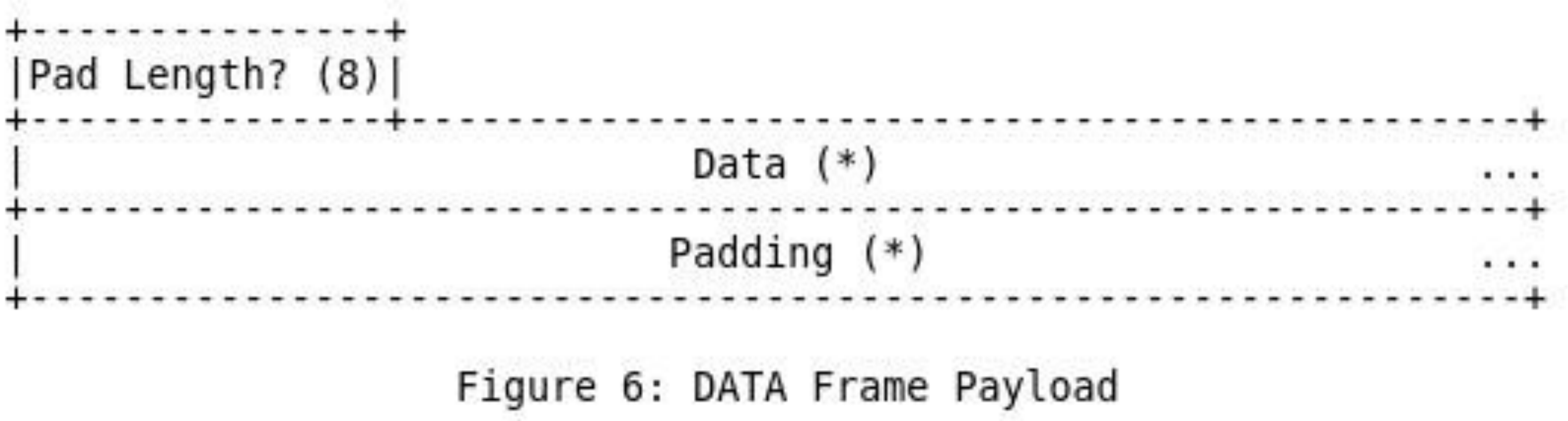


```
+---------------+
|Pad Length? (8)|
+-+-------------+-----------------------------------------------+
|E|                 Stream Dependency? (31)                     |
+-+-------------+-----------------------------------------------+
|  Weight? (8)  |
+-+-------------+-----------------------------------------------+
|                   Header Block Fragment (*)                 ...
+---------------------------------------------------------------+
|                           Padding (*)                       ...
+---------------------------------------------------------------+
```

Figure 7: HEADERS Frame Payload

- Padding is for security – obfuscate lengths
- Stream dependency – make this stream a child of named stream
  - If server can’t make progress on parent, assign resources proportional to weights to children
- Header block fragment – take the HTTP 1.1 header and compress it, then send it in chunks (if necessary)
- Frame header flags: END_HEADERS and END_STREAM

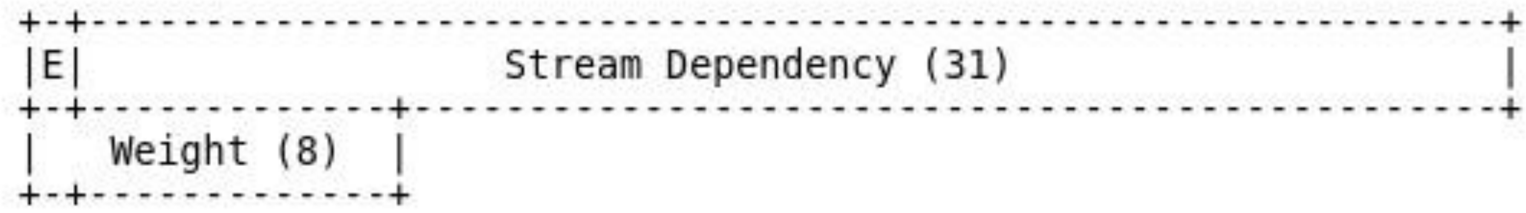
DATA Frame



```
+---------------+
|Pad Length? (8)|
+---------------+-----------------------------------------------+
|                            Data (*)                         ...
+---------------------------------------------------------------+
|                           Padding (*)                       ...
+---------------------------------------------------------------+
```

Figure 6: DATA Frame Payload

PRIORITY Frame

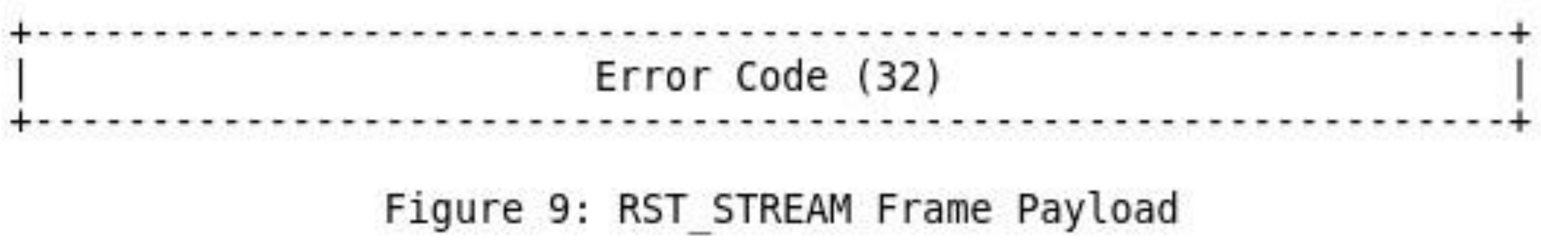


```
+-+-------------------------------------------------------------+
|E|                  Stream Dependency (31)                     |
+-+-------------+-----------------------------------------------+
|   Weight (8)  |
+-+-------------+
```

Figure 8: PRIORITY Frame Payload

- E: exclusive bit – inserts this stream as only child of parent stream, moving existing children to be children of this stream

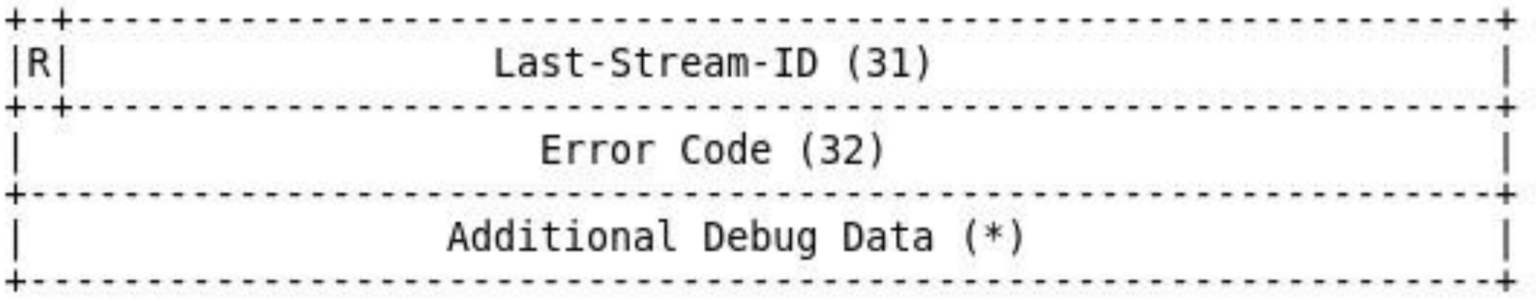
RST_STREAM Frame



```
+---------------------------------------------------------------+
|                        Error Code (32)                        |
+---------------------------------------------------------------+

                 Figure 9: RST_STREAM Frame Payload
```

- Ends a stream
  - Why is this useful?
    - Also have END_STREAM flag bit...

GOAWAY Frame

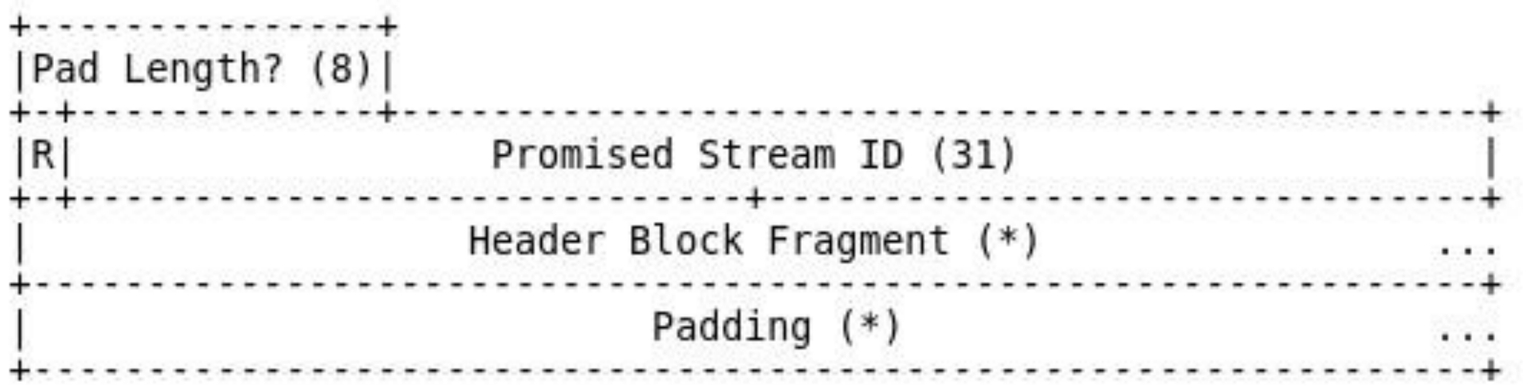


```
+-+-------------------------------------------------------------+
|R|                  Last-Stream-ID (31)                        |
+-+-------------------------------------------------------------+
|                      Error Code (32)                          |
+---------------------------------------------------------------+
|                  Additional Debug Data (*)                    |
+---------------------------------------------------------------+
```

Figure 13: GOAWAY Payload Format

- Closes connection
- Provides largest id of any stream that the server may have acted on
  - Why?

PUSH_PROMISE Frame

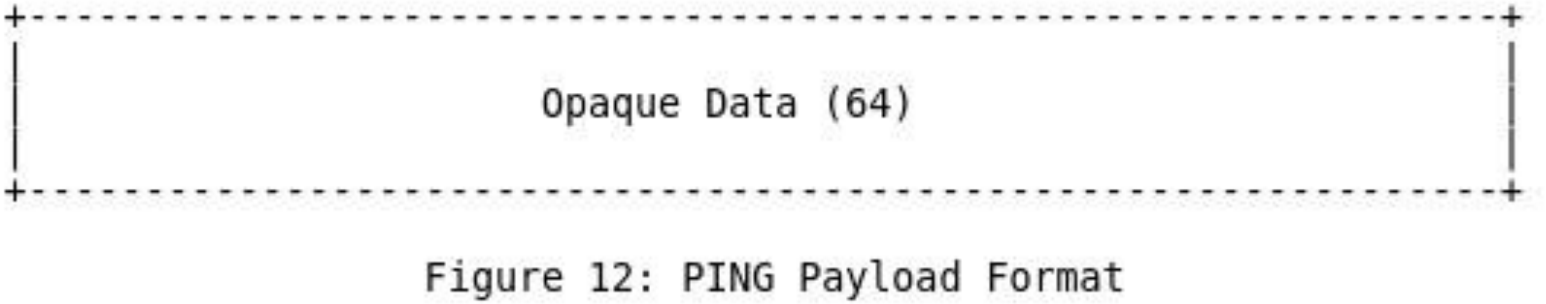


```
+---------------+
|Pad Length? (8)|
+-+-------------+-----------------------------------------------+
|R|                  Promised Stream ID (31)                    |
+-+-----------------------------+-------------------------------+
|                   Header Block Fragment (*)                 ...
+---------------------------------------------------------------+
|                           Padding (*)                       ...
+---------------------------------------------------------------+
```

Figure 11: PUSH_PROMISE Payload Format

- Allows server to send something not yet asked for
  - E.g., a style sheet or a javascript program or an embedded image
- Acts like a HEADERS frame
  - Can have CONTINUATIONs following for more header

PING Frame

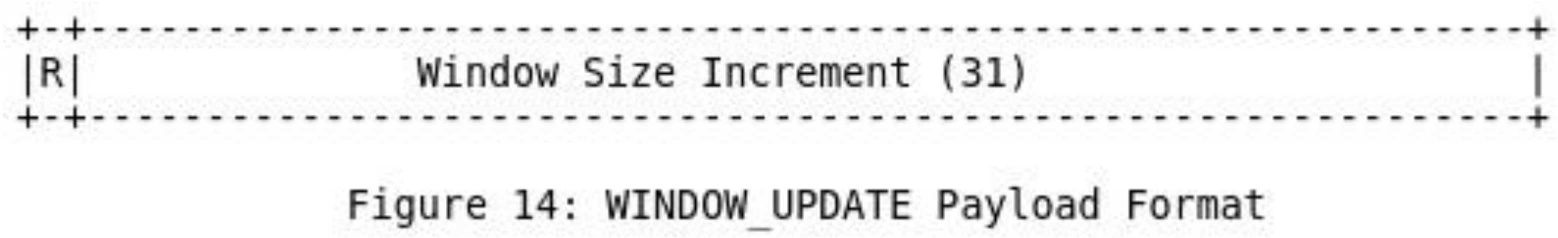


```
+---------------------------------------------------------------+
|                                                               |
|                      Opaque Data (64)                         |
|                                                               |
+---------------------------------------------------------------+
```

Figure 12: PING Payload Format

- Is other end still there?
  - Responds with PING with ACK flag bit set
- Measure latency to other end
  - PING frames have highest priority…

WINDOW_UPDATE Frame



```
+-+-------------------------------------------------------------+
|R|              Window Size Increment (31)                     |
+-+-------------------------------------------------------------+
```

Figure 14: WINDOW_UPDATE Payload Format

- TCP does flow control on entire connection
  - but need flow control on a per stream basis as well

Getting There From Here

- HTTP 2 is supposed to be an optimized transport of HTTP requests
  - Needs to be backward compatible with HTTP 1/1.1

- Main problem:
  - How to tell if client and server can both speak HTTP 2?
    - Client could try HTTP 2 and then revert to 1.1
    - Client could start with HTTP 1.1 then upgrade to 2

Dynamically Upgrading to HTTP 2

- Client:

```
GET / HTTP/1.1
Host: server.example.com
Connection: Upgrade, HTTP2-Settings
Upgrade: h2c
HTTP2-Settings: <base64url encoding of HTTP/2
SETTINGS payload>
```

Server Refuses Upgrade

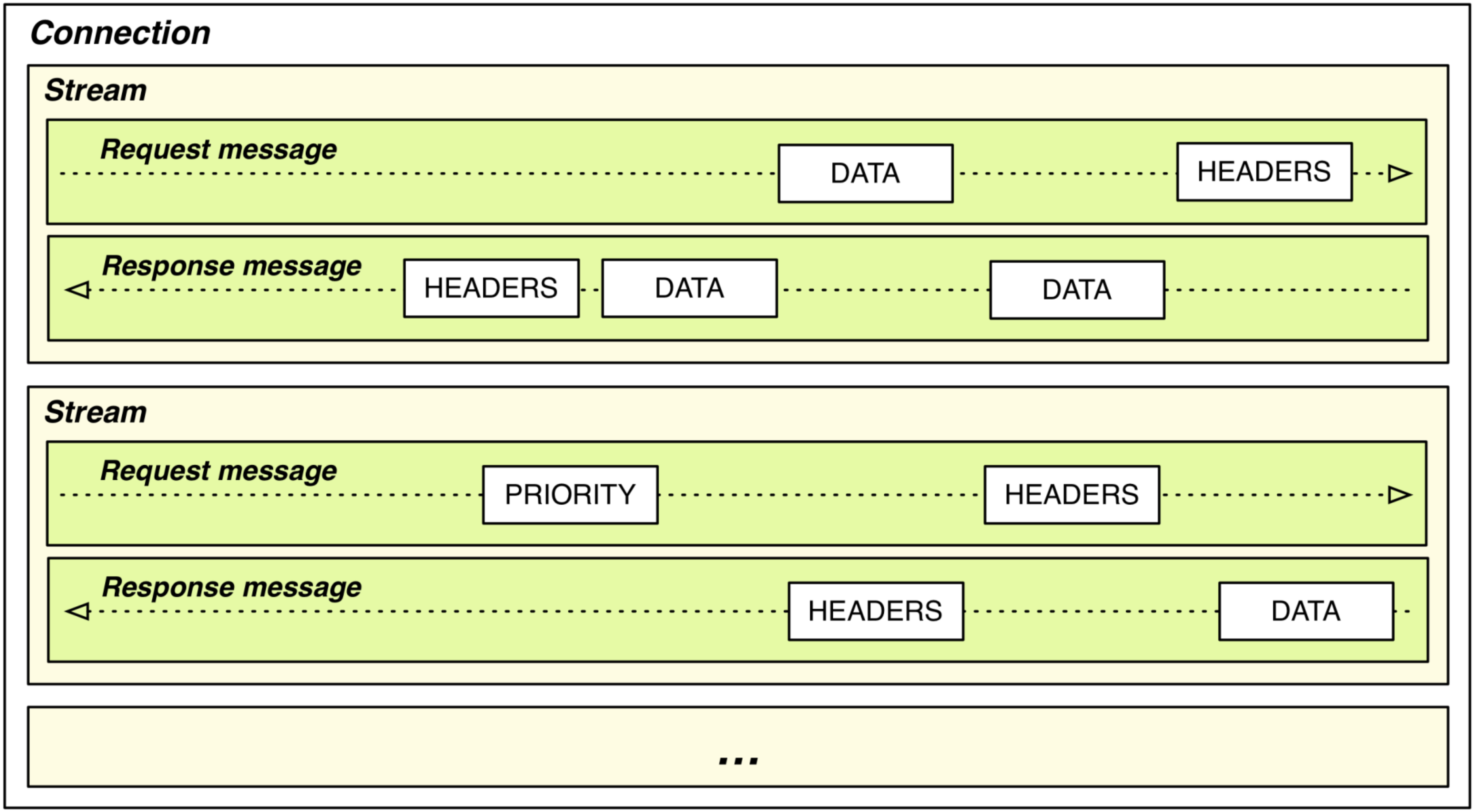
- Server may simply not recognize the upgrade request if it isn't HTTP 2 capable

```
HTTP/1.1 200 OK
Content-Length: 243
Content-Type: text/html
 ...
```

Server Wants to Upgrade

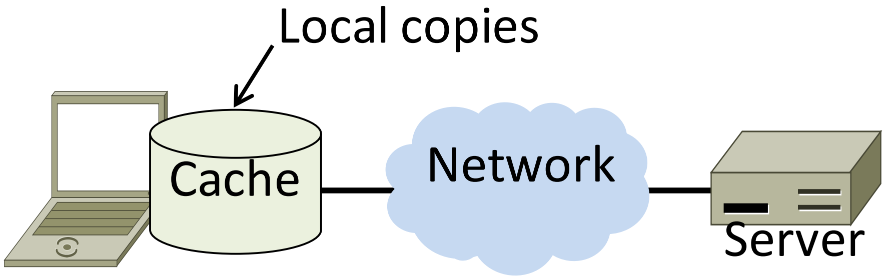
```
HTTP/1.1 101 Switching Protocols
Connection: Upgrade
Upgrade: h2c

[ HTTP/2 connection ...
```

HTTP 2 Wrap-up



Web Caching

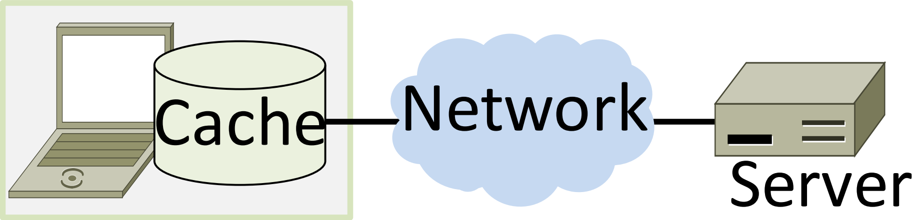
- Users often revisit web pages
  - – Big win from reusing local copy!
  - – This is caching



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

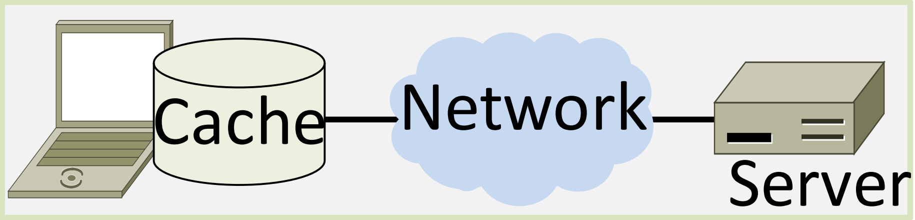
Web Caching (2)

- 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



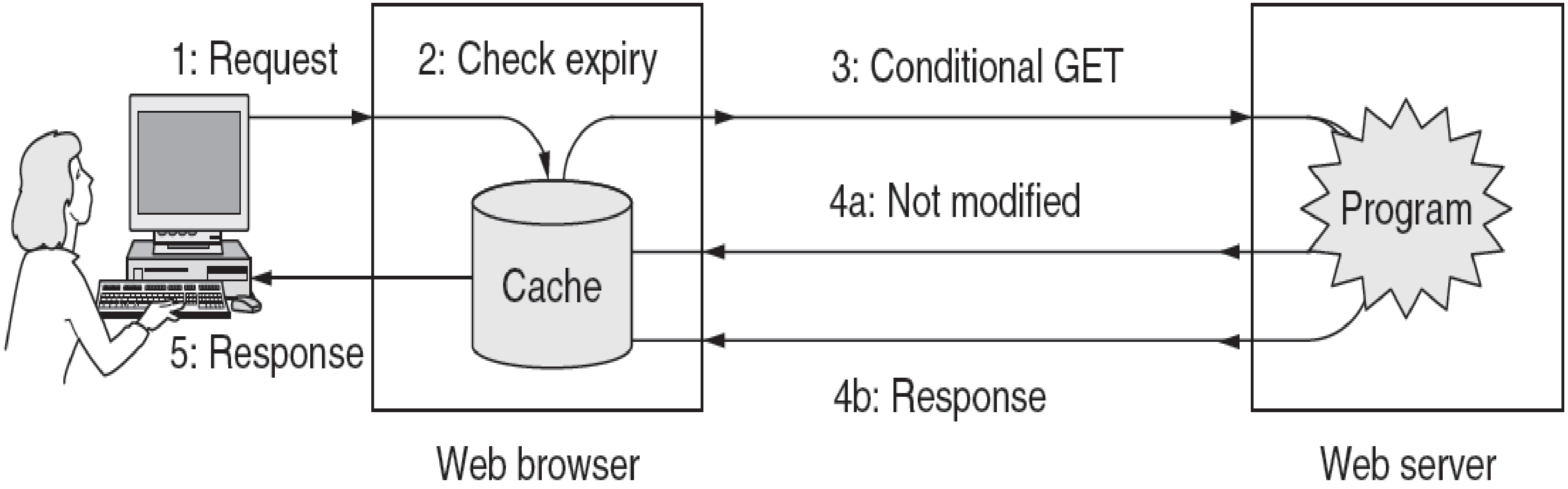
Web Caching (3)

- 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:



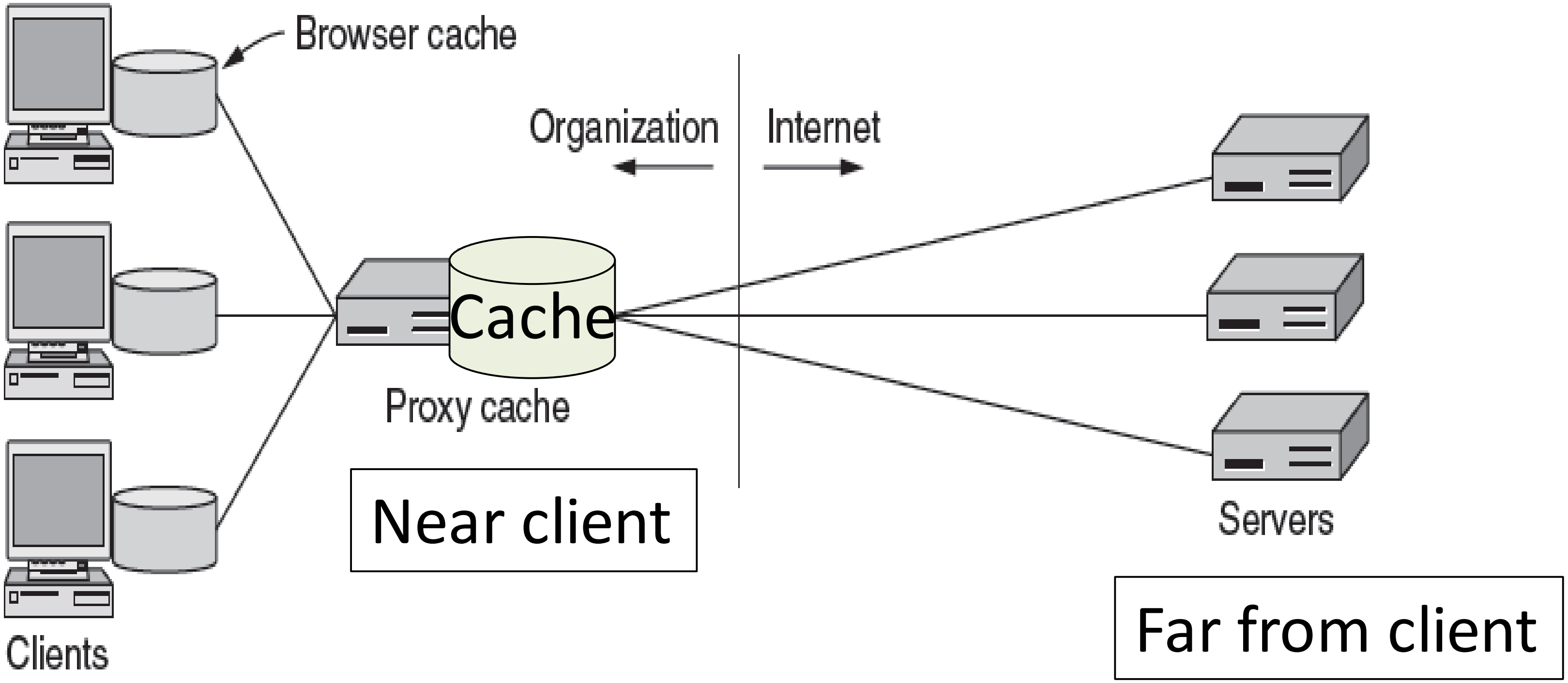
Web Proxies

- 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

- Clients contact proxy; proxy contacts server



Near client

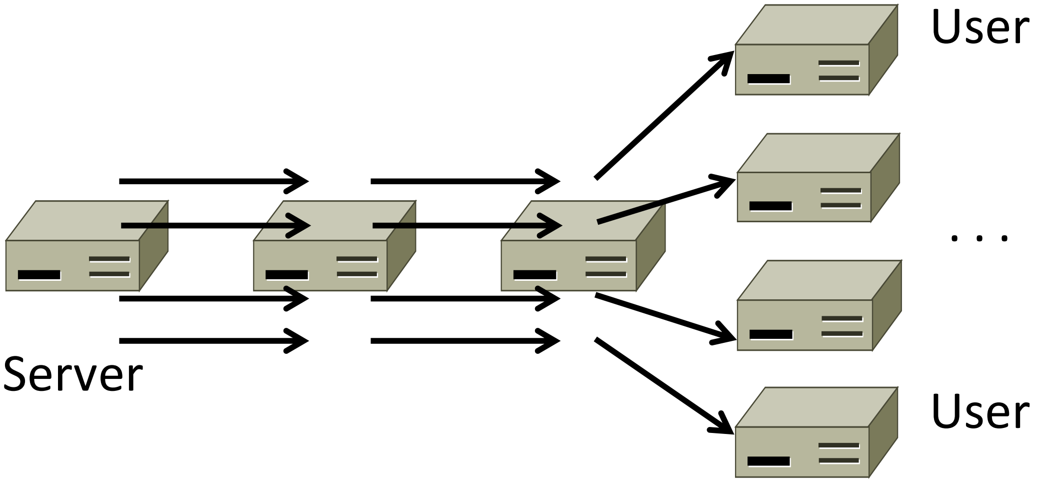
Far from client

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

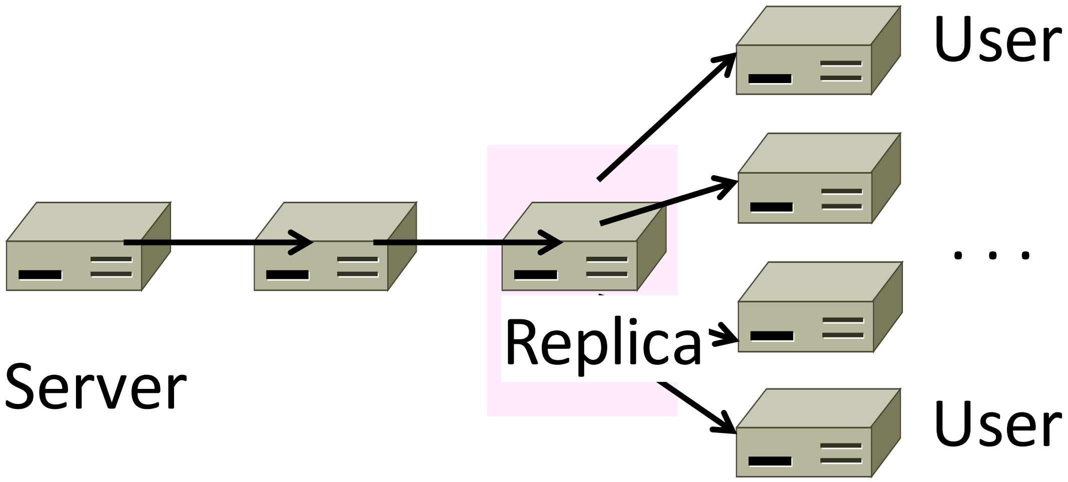
Before CDNs

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



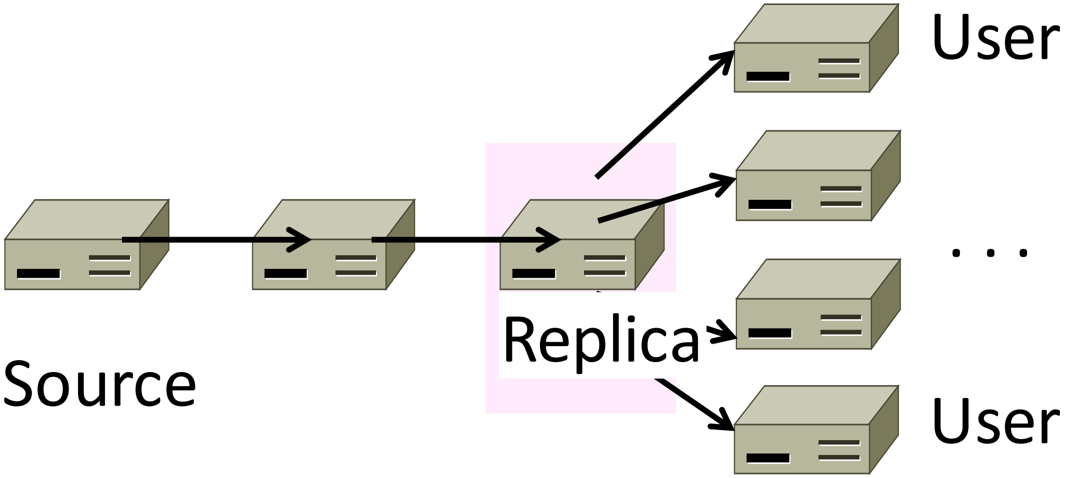
After CDNs

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



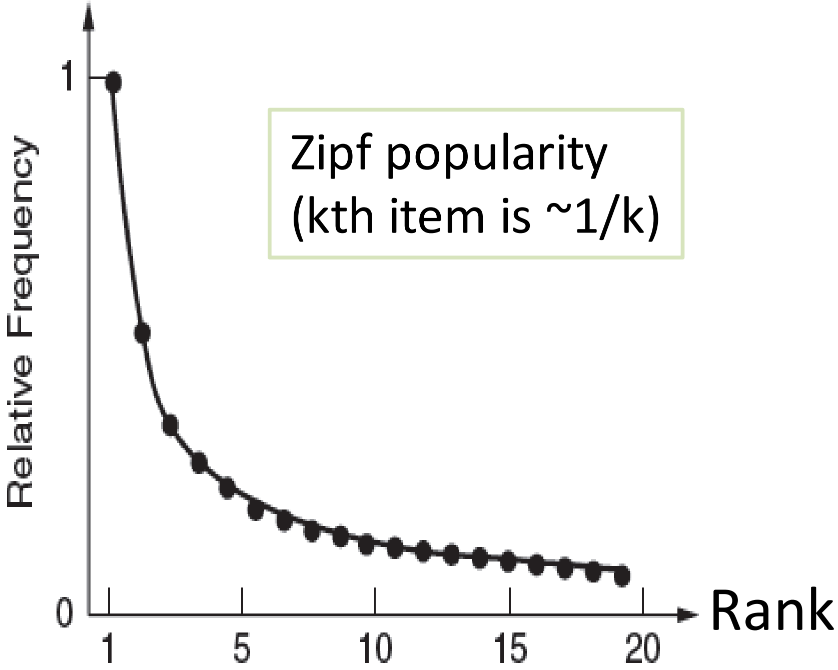
After CDNs

- 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



Zipf popularity (kth item is ~1/k)

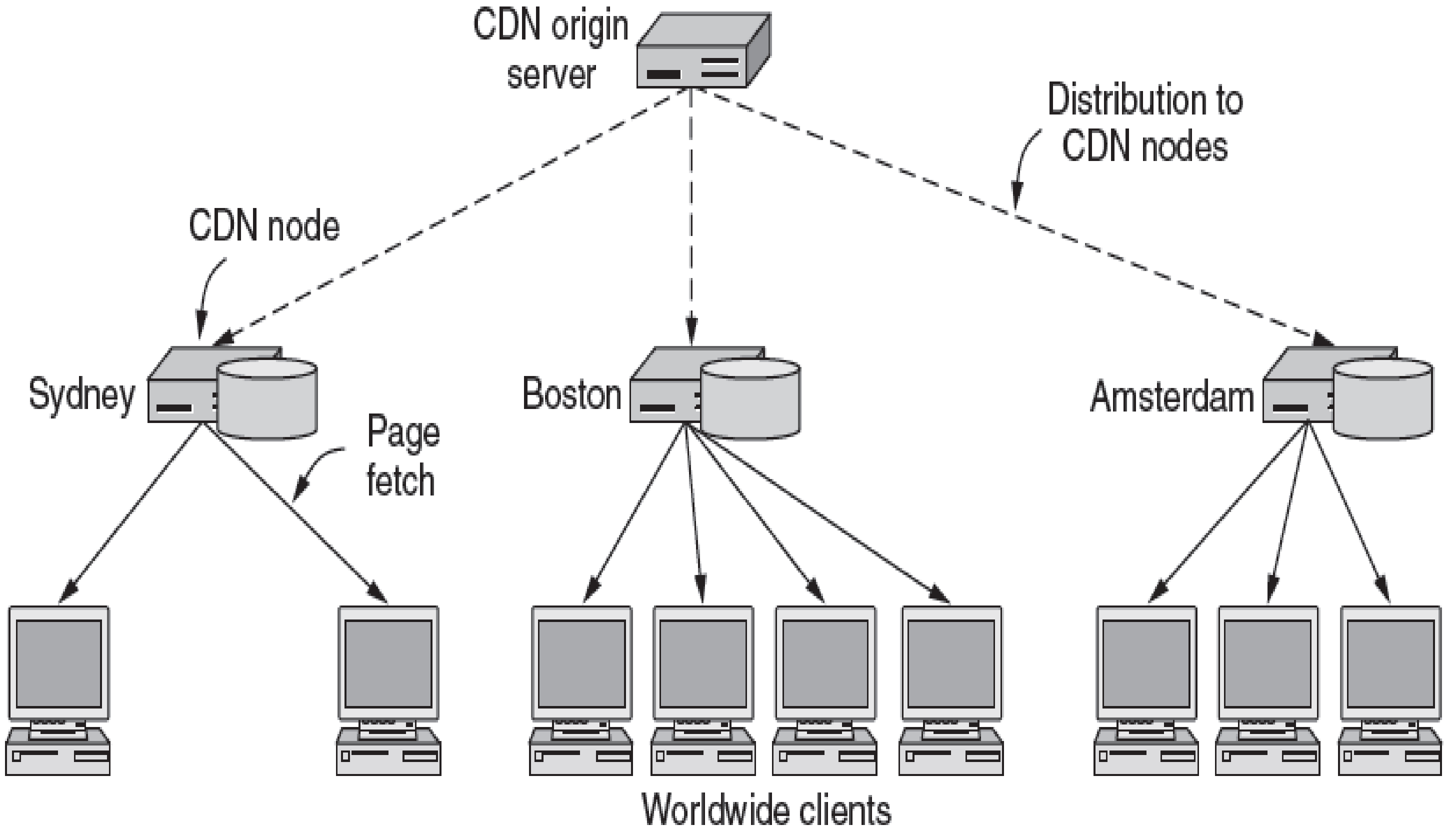
George Zipf (1902-1950)

Source: Wikipedia

How to place content near clients?

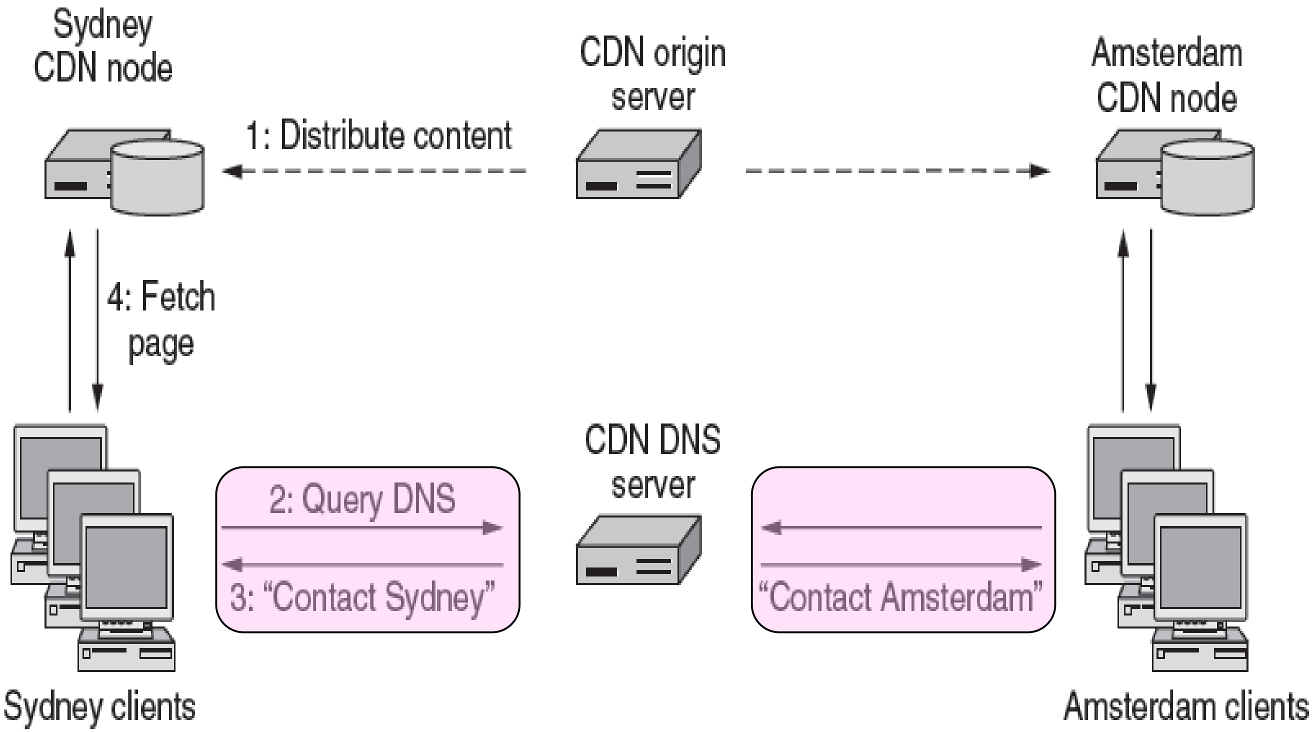
- Use browser and proxy caches
  - Helps, but limited to one client or clients in one organization
- Want to place replicas across the Internet for use by all nearby clients
  - Done by clever use of DNS

Content Delivery Network



Content Delivery Network (2)

- DNS 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