

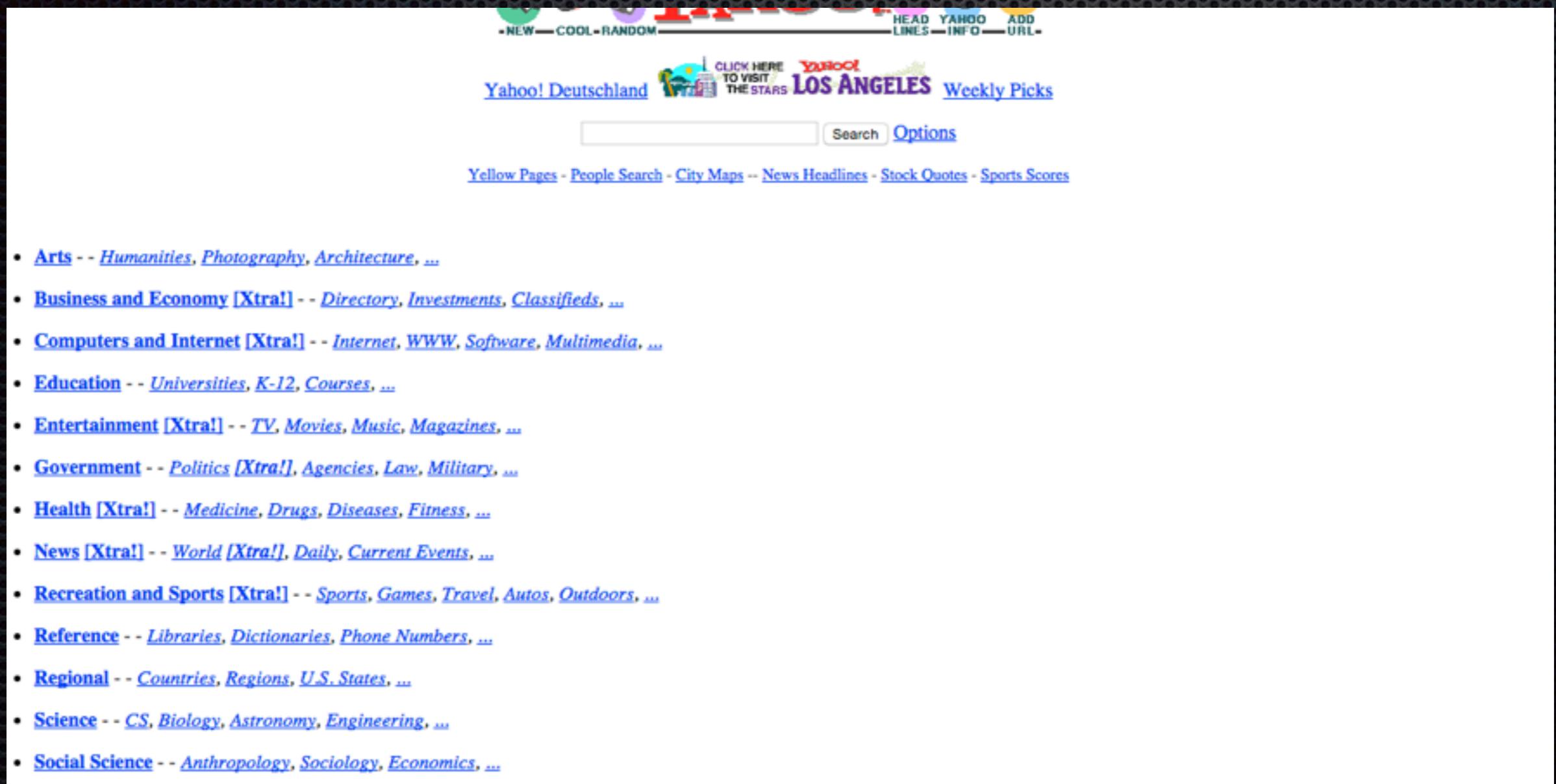
Http/2

Hadi Hariri



What is this?

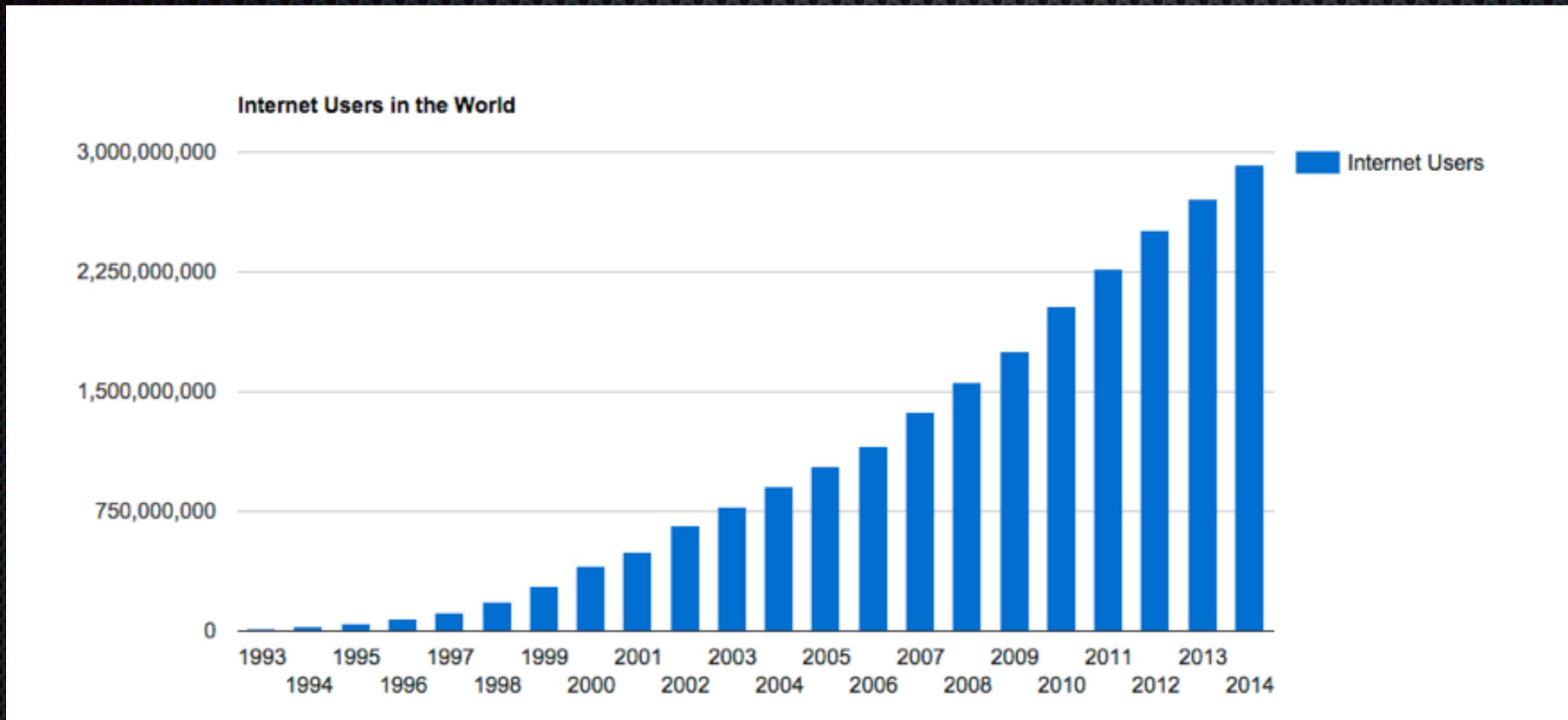
The World Wide Web in 1996



A screenshot of the Yahoo! homepage from 1996. The page features a dark background with a grid pattern. At the top, there's a decorative banner with various icons. Below the banner, the word "YAHOO!" is written in large, colorful letters. To the left of "YAHOO!" are links for "NEW", "COOL", and "RANDOM". To the right are links for "HEAD LINES", "YAHOO INFO", and "ADD URL". Below the main title, there's a section for "Yahoo! Deutschland" with a "CLICK HERE TO VISIT THE STARS" link and an image of the Eiffel Tower. To the right of this is a "YAHOO LOS ANGELES" section with "Weekly Picks". There's also a search bar and an "Options" link. At the bottom of the page, there are links for "Yellow Pages", "People Search", "City Maps", "News Headlines", "Stock Quotes", and "Sports Scores". A large list of categories follows:

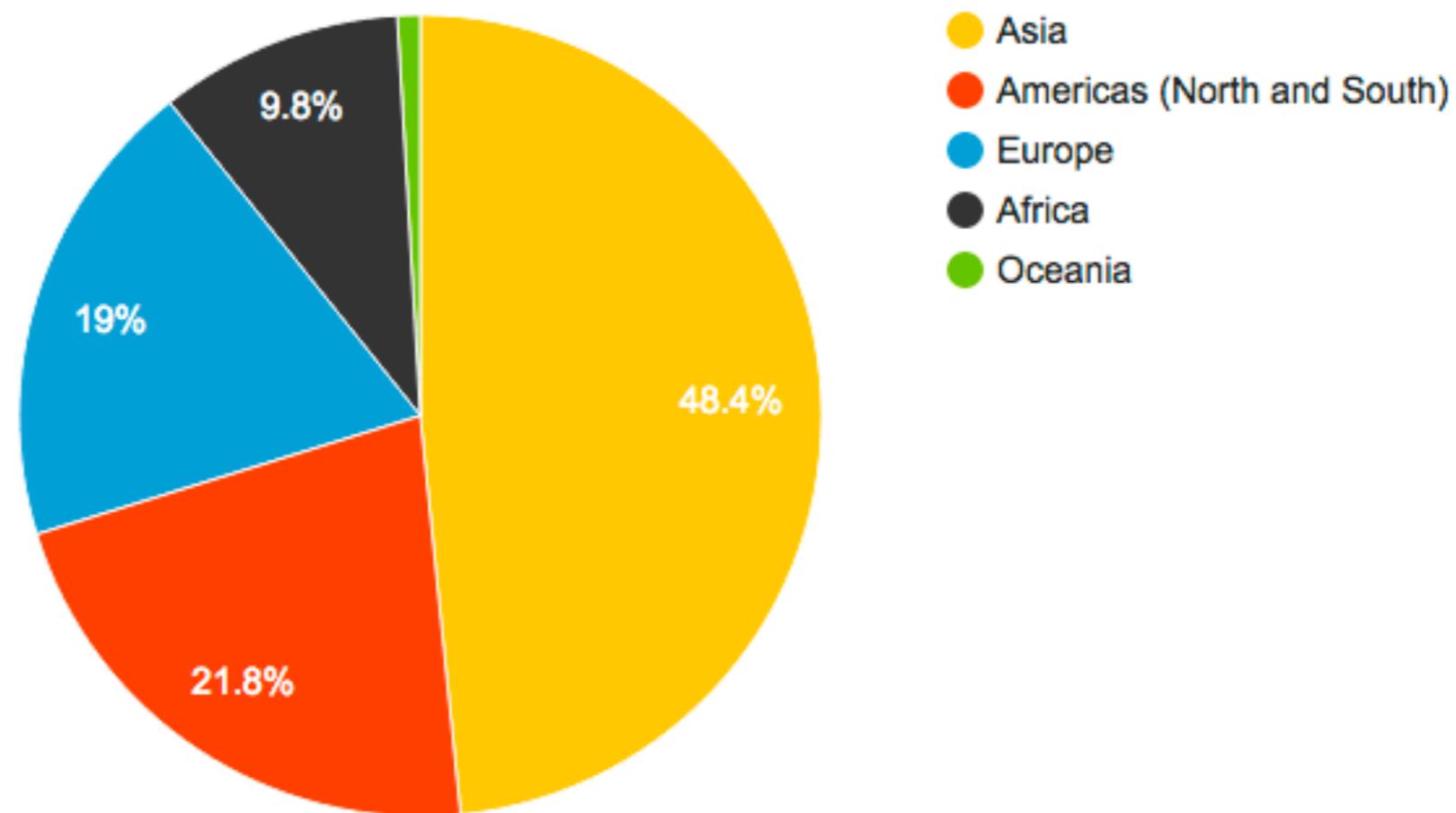
- [Arts](#) - - [Humanities](#), [Photography](#), [Architecture](#), ...
- [Business and Economy \[Xtra!\]](#) - - [Directory](#), [Investments](#), [Classifieds](#), ...
- [Computers and Internet \[Xtra!\]](#) - - [Internet](#), [WWW](#), [Software](#), [Multimedia](#), ...
- [Education](#) - - [Universities](#), [K-12](#), [Courses](#), ...
- [Entertainment \[Xtra!\]](#) - - [TV](#), [Movies](#), [Music](#), [Magazines](#), ...
- [Government](#) - - [Politics \[Xtra!\]](#), [Agencies](#), [Law](#), [Military](#), ...
- [Health \[Xtra!\]](#) - - [Medicine](#), [Drugs](#), [Diseases](#), [Fitness](#), ...
- [News \[Xtra!\]](#) - - [World \[Xtra!\]](#), [Daily](#), [Current Events](#), ...
- [Recreation and Sports \[Xtra!\]](#) - - [Sports](#), [Games](#), [Travel](#), [Autos](#), [Outdoors](#), ...
- [Reference](#) - - [Libraries](#), [Dictionaries](#), [Phone Numbers](#), ...
- [Regional](#) - - [Countries](#), [Regions](#), [U.S. States](#), ...
- [Science](#) - - [CS](#), [Biology](#), [Astronomy](#), [Engineering](#), ...
- [Social Science](#) - - [Anthropology](#), [Sociology](#), [Economics](#), ...

Internet Users



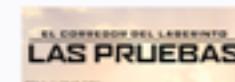
1993 - 14M

Users by Country



Better User Experiences and Visuals

- [Correo](#)
- [Noticias](#)
- [Deportes](#)
- [Finanzas](#)
- [Celebrity](#)
- [Vida y Estilo](#)
- [Cine](#)
- [Horóscopo](#)
- [Videos](#)

[Más >](#)[eBay](#)[Amazon](#)[Meetic](#)[Publicidad](#)

El corredor del
Laberinto:
Las pruebas
En cines 18/09/2015

Establecer
YAHOO! como
página de inicio

Al utilizar Yahoo, aceptas que nosotros y nuestros **socios** podamos definir **cookies** para distintos fines, tales como personalizar el contenido y la publicidad.



10 trucos para acelerar tu metabolismo

No tienes que pasarte el día en el gimnasio, basta con entrenamientos en intervalos de alta intensidad para quemar calorías, y sin dieta. [Maneras rápidas de perder peso »](#)

1-5 de 45

[Titulares](#) [Noticias](#) [Deportes](#) [Finanzas](#) [Celebrity](#)

Liga - De Gea-United 2019: Algunas sorprendentes preguntas sin respuesta

El portero David de Gea ha renovado su contrato con el Manchester United y pone punto y final a uno de los grandes culebrones de los últimos tiempos.
Eurosport

Los 10 lugares donde mejor se come de España

Desde Sevilla a San Sebastián haciendo parada en Cáceres, Madrid o Segovia, nos vamos a comer el paella, bocado a bocado

Skyscanner Patrocinado



Lo más buscado

- | | |
|-----------------------------------|-------------------------------------|
| 1 Liga BBVA | 6 Oferta hoteles |
| 2 US Open | 7 Lionel Messi |
| 3 Casas rurales | 8 Vestidos mujer |
| 4 Eurobasket 2015 | 9 Floyd Mayweather |
| 5 Horóscopo | 10 Previsión tiempo |

NUEVO FORD ECOSPORT 
» Apertura Sin Llave
Desde 12.990€

[Descúbrelo](#)

29660, Marbella (Ubicación actual)

27 °F | °C
Buen tiempo

Hoy



29° 19°

Lu.



29° 19°

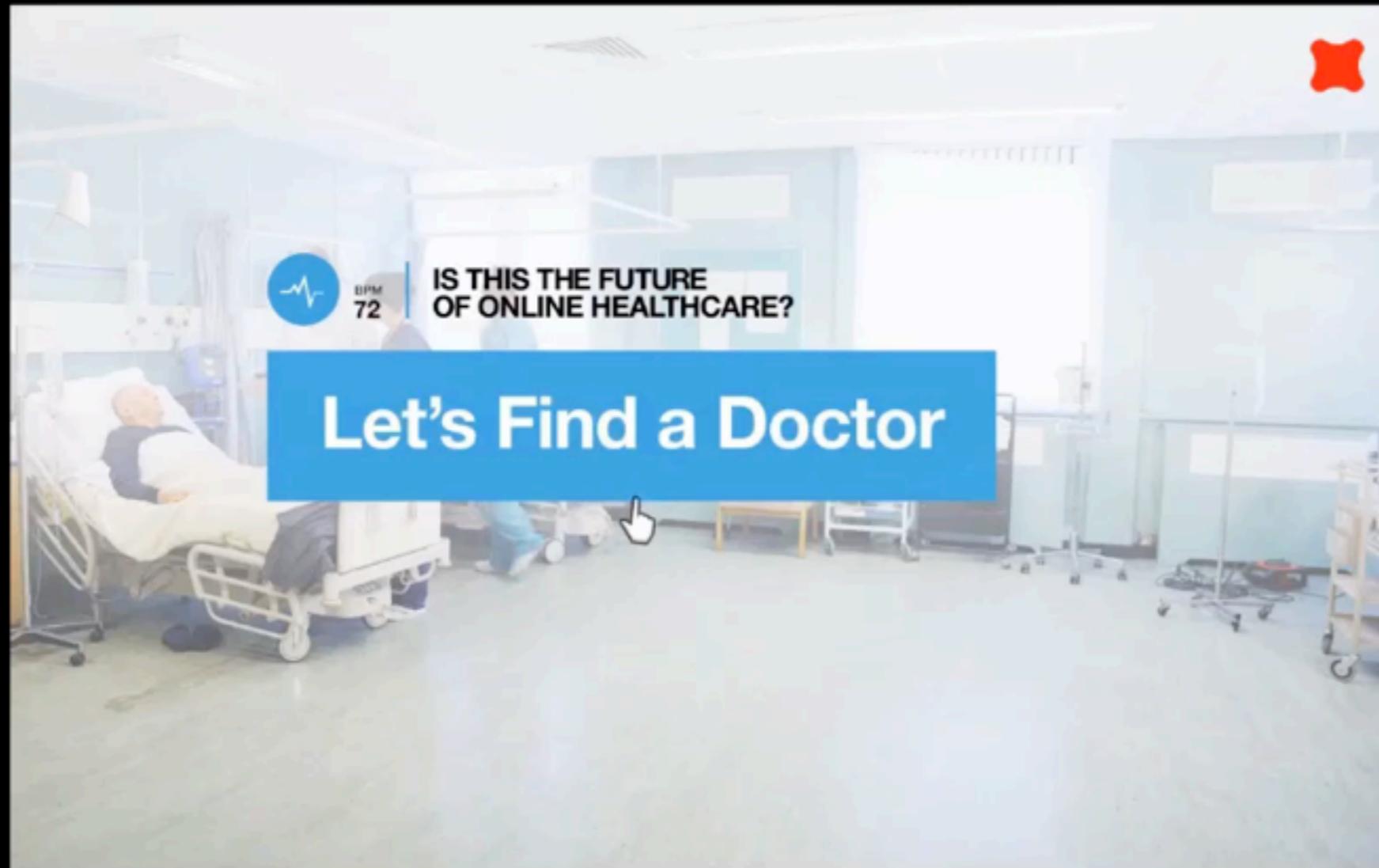


Ma.



28° 18°

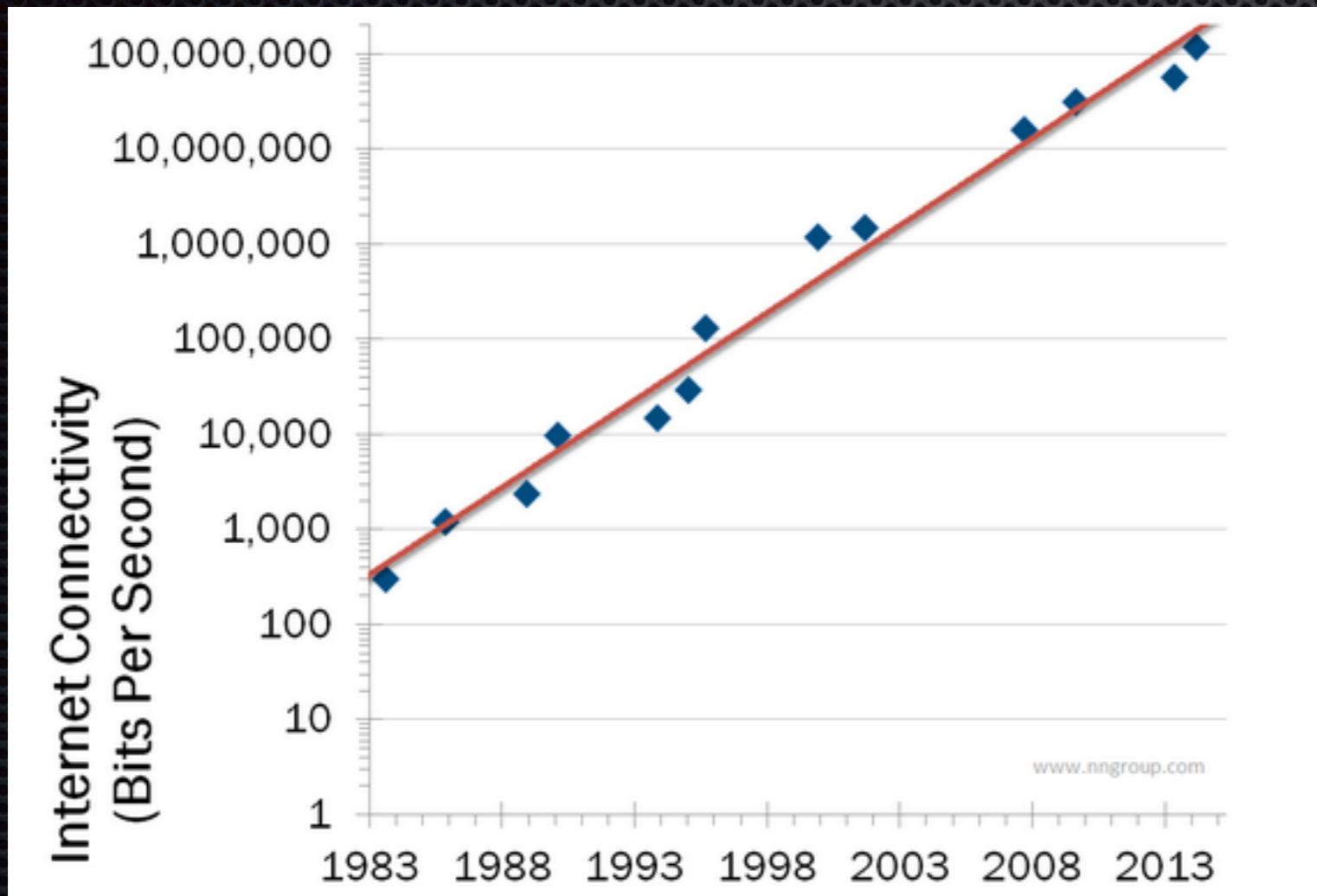
[Ver más »](#)



It's all good. Everything runs smooth

Everyone has more bandwidth

Nielsen's Law of Bandwidth



1984 - 300 bps
50% Growth per Year

Bandwidth by Country

Position	Country	Speed (Mbps)
1	South Korea	25.3
2	Hong Kong	16.3
3	Japan	15
4	Switzerland	14.5
...
12	United States	11.5
13	Belgium	11.4
...
24	Germany	8.7
...
28	Spain	7.8
...
30	Australia	6.9
31	France	6.9
...
55	Bolivia	1.1

Mobile Networks

Region	Average Speed (Mbps)
Europe	20.4
North America	9.6
Asia Pacific	8.8
South America	7.0
Africa	4.8

So why are we dumping HTTP 1.1?

The problem is no longer bandwidth

It's the Latency, Stupid

- **Bandwidth**

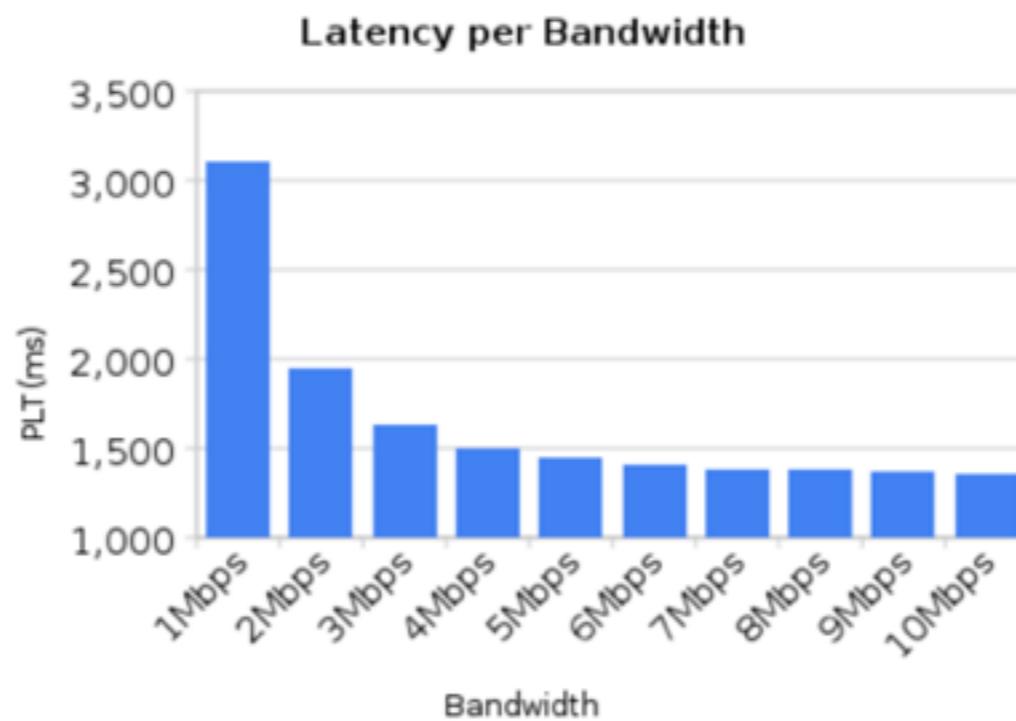
In computing, bandwidth is the bit-rate of available or consumed information capacity expressed typically in metric multiples of bits per second. Variously, bandwidth may be characterized as network bandwidth, data bandwidth, or digital bandwidth.

- **Latency**

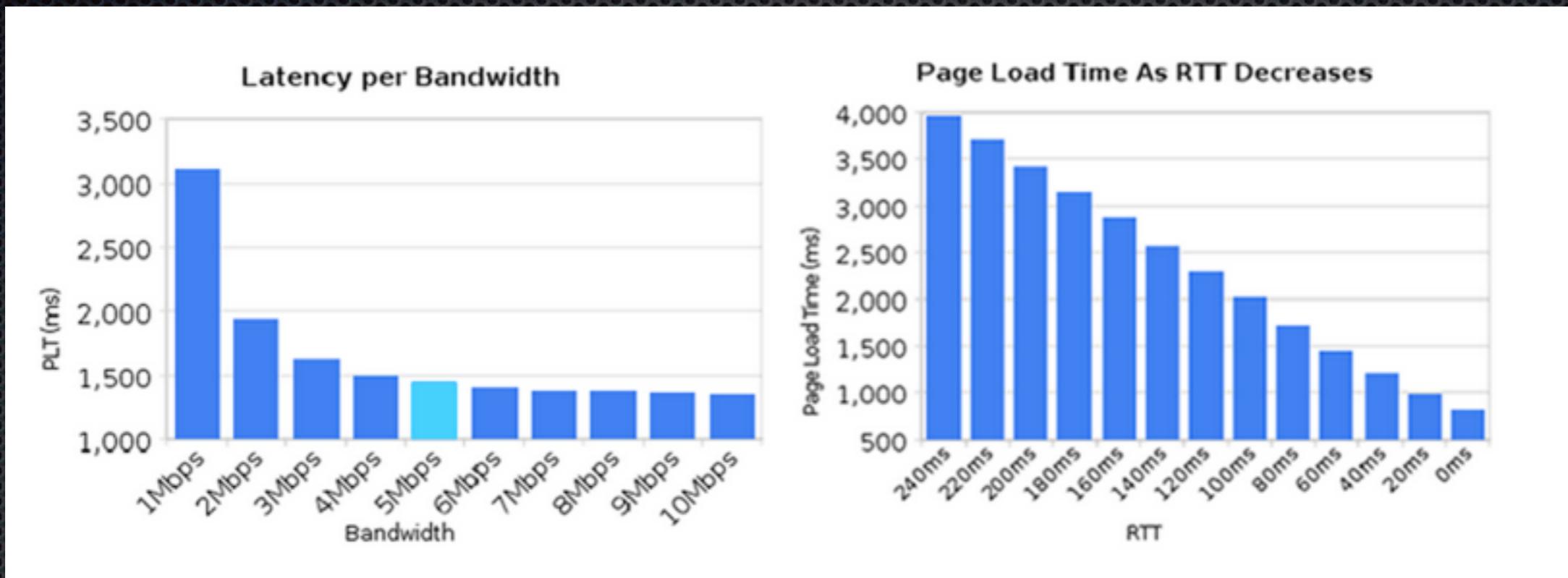
Latency is a time interval between the stimulation and response, or, from a more general point of view, as a time delay between the cause and the effect of some physical change in the system being observed.

Latency

Bandwidth	Page Load Time via HTTP
1Mbps	3106
2Mbps	1950
3Mbps	1632
4Mbps	1496
5Mbps	1443
6Mbps	1406
7Mbps	1388
8Mbps	1379
9Mbps	1368
10Mbps	1360

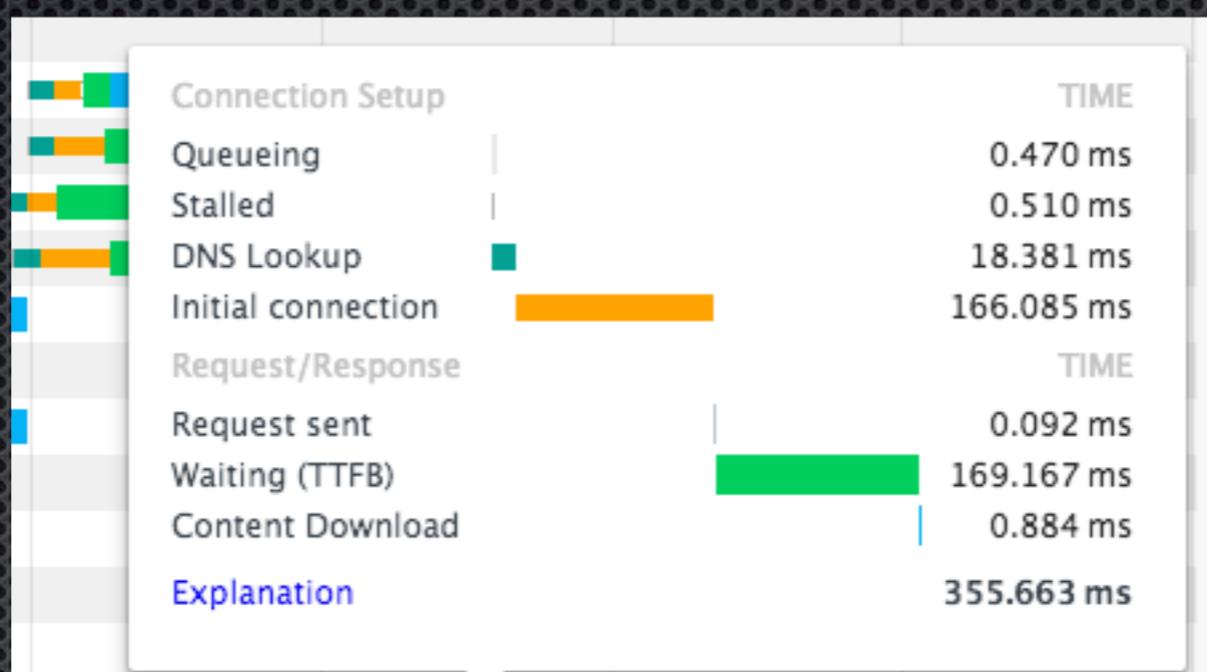


Latency



And latency is per connection

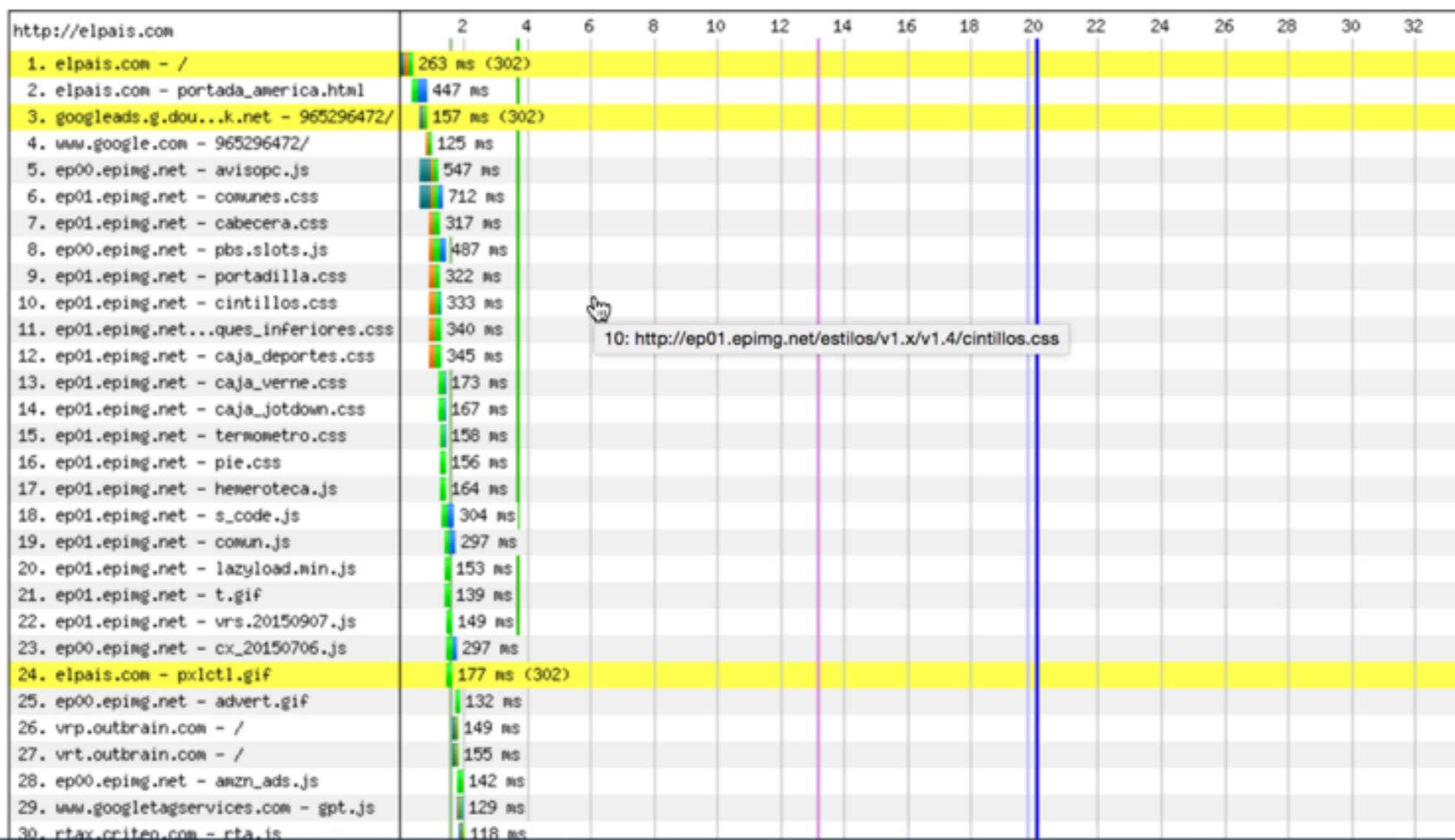
Name	Method	Status	Type	Initiator	Size	Time	▲
comunes.css	GET	200	stylesheet	(index):37	(from cache)	42 ms	
pxlctl2.gif?r=2&m=1&s=25c10673e...	GET	302	gif	http://pxlctl.elpais.com/pxlc...	508 B	58 ms	
advert.gif?648618153	GET	200	gif	(index):164	392 B	59 ms	
caja_tlife.css	GET	200	stylesheet	(index):1619	793 B	70 ms	
pxlctl2.gif?m=1&r=2&w=2123515	GET	302	gif	http://elpais.com/pxlctl.gif?...	347 B	80 ms	
?script=0&random=4019638651&ip...	GET	200	gif	http://www.google.com/ads...	343 B	94 ms	
gpt.js	GET	304	script	pbs.slots.js:1	363 B	95 ms	
rta.js?netId=4045&cookieName=crt...	GET	200	script	pbs.slots.js:1	457 B	118 ms	
pxlctl.gif?m=1&r=2&w=2123515	GET	302	text/html	(index):164	241 B	121 ms	
elpais.com	GET	200	document	http://www.elpais.es/	61.9 KB	123 ms	
?script=0&random=4019638651	GET	302	text/html	http://googleads.g.doublecli...	380 B	138 ms	
rep.gif?ver=1&typ=pgv&rnd=iemvn...	GET	200	gif	(index):165	404 B 380B	147 ms	
bid?src=3226&u=http%3A%2F%2Felp...	GET	200	script	amzn_ads.js:1	217 B	191 ms	
s64909375414717?AQB=1&pccr=tr...	GET	302	text/plain	http://prisacom.112.2o7.net...	811 B	213 ms	
?value=0&guid=ON&script=0	GET	302	gif	(index):164	651 B	226 ms	
?idsite=255&url=http%3A%2F%2Felp...	GET	200	xhr	vrs.20150907.js:6	337 B	355 ms	
?transport=jsonp&idsite=255&url=h...	GET	200	xhr	vrs.20150907.js:6	1.1 KB	369 ms	
s64909375414717?AQB=1&ndh=1&...	GET	302	text/plain	(index):165	1.8 KB	432 ms	
ads?gdfp_req=1&correlator=231131...	GET	200	script	pubads_impl_72.js:189	29.4 KB	528 ms	



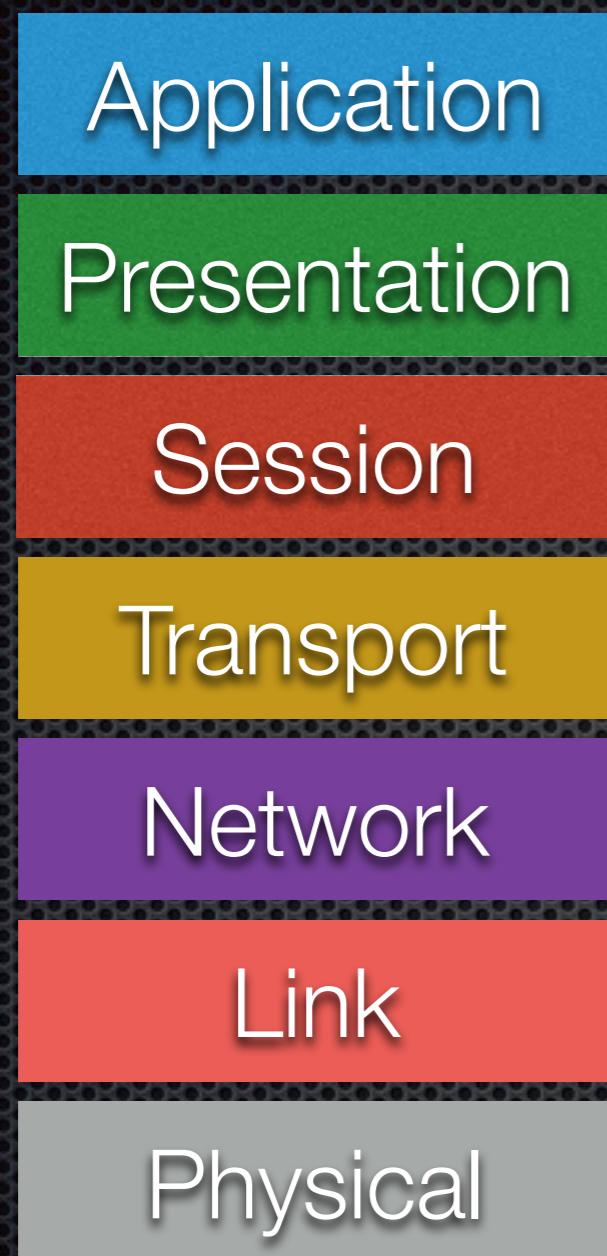
Load Time	First Byte	Start Render	Visually Complete	Speed Index	DOM Elements	Result (error code)	Document Complete			Fully Loaded		
							Time	Requests	Bytes In	Time	Requests	Bytes In
20.077s	0.498s	3.669s	16.500s	11235	3578	99999	20.077s	267	2,605 KB	33.400s	339	2,920 KB

RUM First Paint	domContentLoaded	loadEvent
1.568s	13.154s - 13.176s (0.022s)	19.735s - 19.744s (0.009s)

Waterfall View

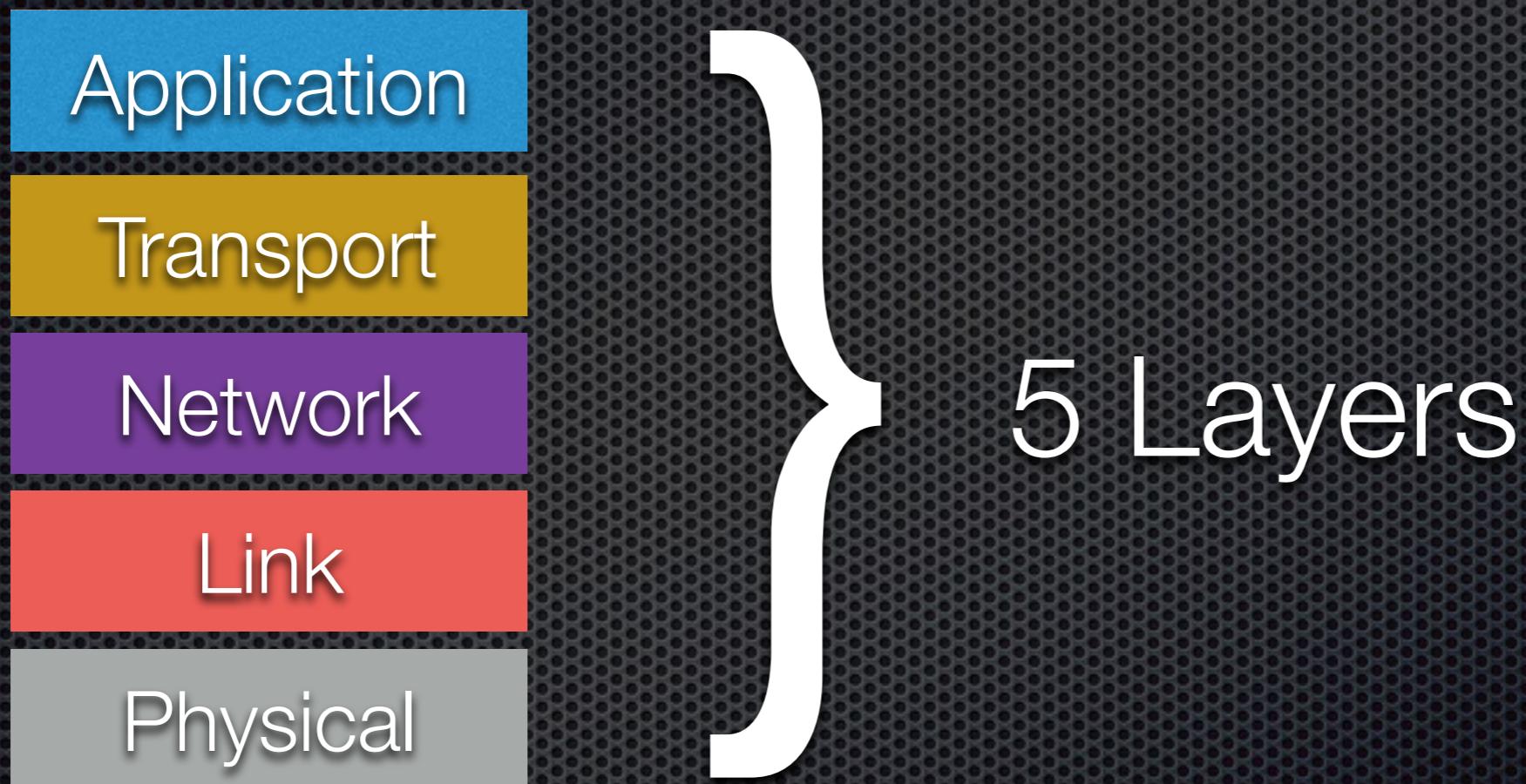


The Network



ISO OSI Layers

The Internet



Everything is on TCP

Transport

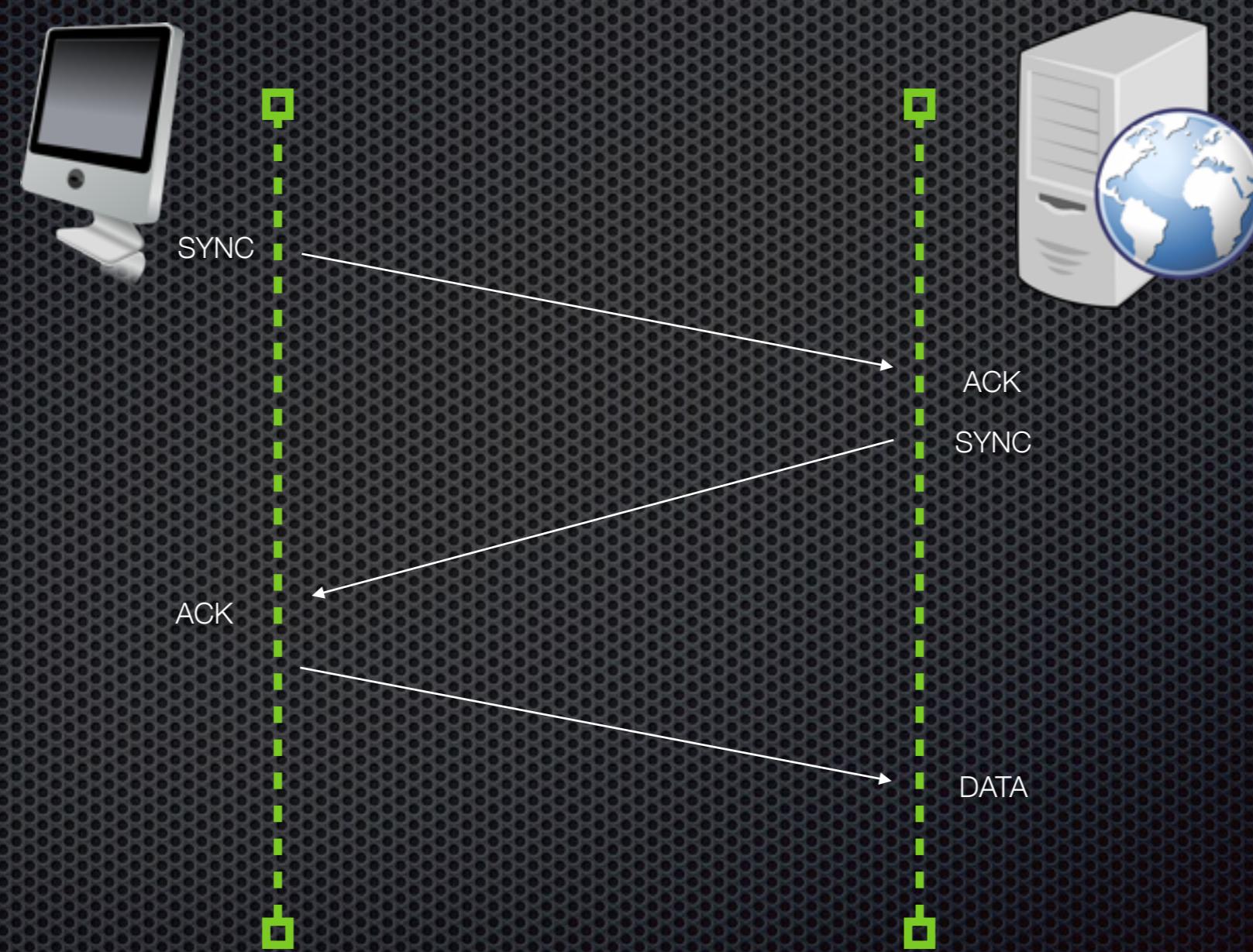
TCP

TCP has “issues”

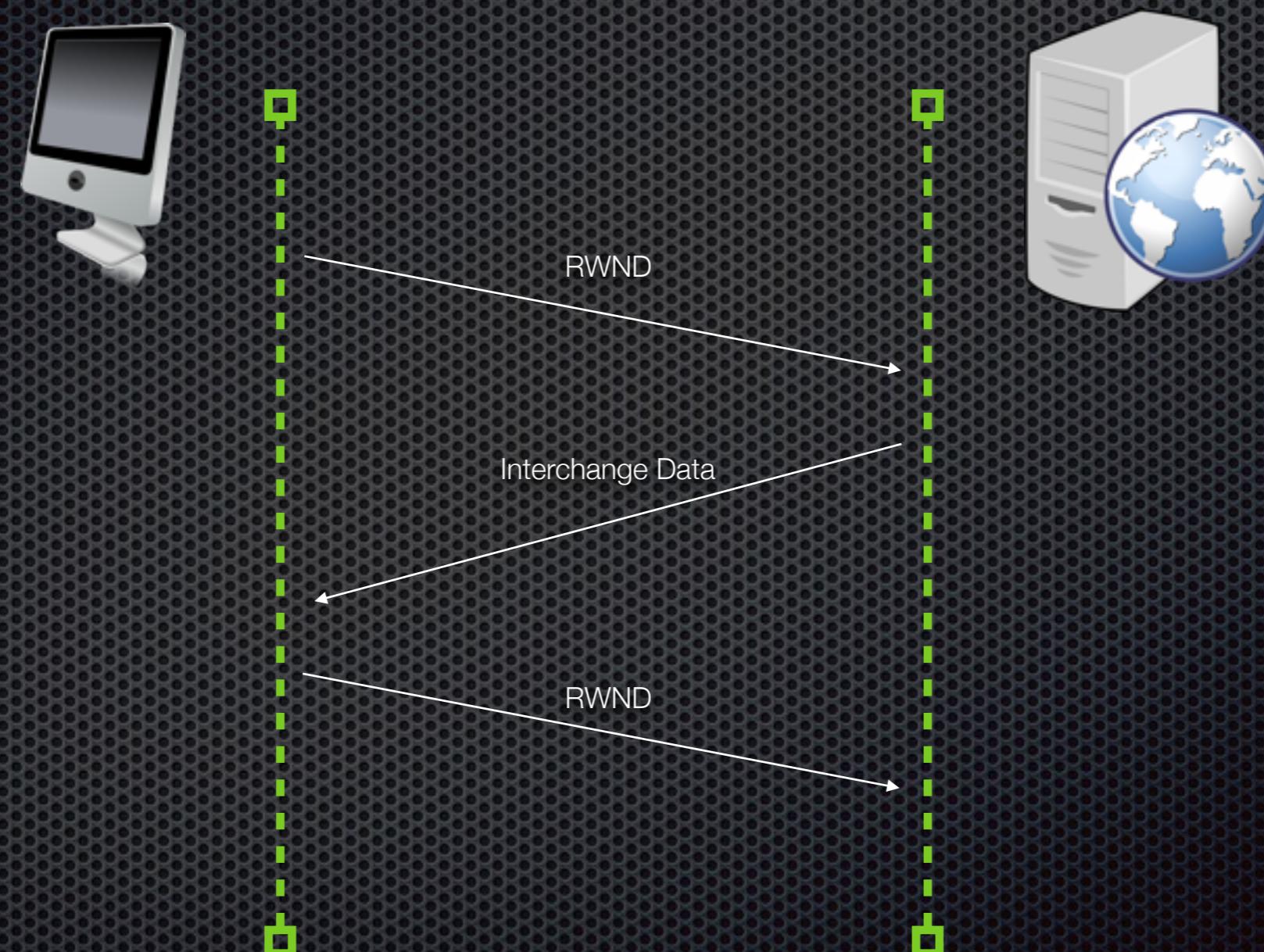
A Simple Hello Echo Server

No.	Protocol	Time	Source	Destination	Info	Length	CumBytes
158	TCP	5.006783	127.0.0.1	127.0.0...	49852→9000 [SYN] Seq=0 Win=65535 Len=0 MSS=1634...	68	68
159	TCP	5.006881	127.0.0.1	127.0.0...	9000→49852 [SYN, ACK] Seq=0 Ack=1 Win=65535 Len...	68	136
160	TCP	5.006892	127.0.0.1	127.0.0...	49852→9000 [ACK] Seq=1 Ack=1 Win=408288 Len=0 T...	56	192
161	TCP	5.006902	127.0.0.1	127.0.0...	[TCP Window Update] 9000→49852 [ACK] Seq=1 Ack=...	56	248
300	TCP	12.470111	127.0.0.1	127.0.0...	49852→9000 [PSH, ACK] Seq=1 Ack=1 Win=408288 Le...	63	311
301	TCP	12.470142	127.0.0.1	127.0.0...	9000→49852 [ACK] Seq=1 Ack=8 Win=408288 Len=0 T...	56	367
302	TCP	12.471421	127.0.0.1	127.0.0...	9000→49852 [PSH, ACK] Seq=1 Ack=8 Win=408288 Le...	57	424
303	TCP	12.471446	127.0.0.1	127.0.0...	49852→9000 [ACK] Seq=8 Ack=2 Win=408288 Len=0 T...	56	480
304	TCP	12.471458	127.0.0.1	127.0.0...	9000→49852 [PSH, ACK] Seq=2 Ack=8 Win=408288 Le...	58	538
305	TCP	12.471466	127.0.0.1	127.0.0...	49852→9000 [ACK] Seq=8 Ack=4 Win=408288 Len=0 T...	56	594
306	TCP	12.471473	127.0.0.1	127.0.0...	9000→49852 [PSH, ACK] Seq=4 Ack=8 Win=408288 Le...	59	653
307	TCP	12.471480	127.0.0.1	127.0.0...	49852→9000 [ACK] Seq=8 Ack=7 Win=408288 Len=0 T...	56	709

The Handshake



Flow Control and Congestion



Affected by Slow Start

HTTP 0.9 - 1991

GET /index.htm

<HTML>

<HEAD>

...

</HEAD>

<BODY>

...

</BODY>

</HTML>

HTTP 1.0 - 1996

GET /index.htm HTTP/1.0

User-Agent: Netscape

Accept: text/html

HTTP/1.0 200 OK

Content-Type: text/html

<HTML>

<HEAD>

...

</HEAD>

<BODY>

...

HTTP 1.1 - 1999

GET /index.htm HTTP/1.0

User-Agent: Netscape

Accept: text/html

Connection: close*

HTTP/1.0 200 OK

Content-Type: text/html

<HTML>

<HEAD>

...

</HEAD>

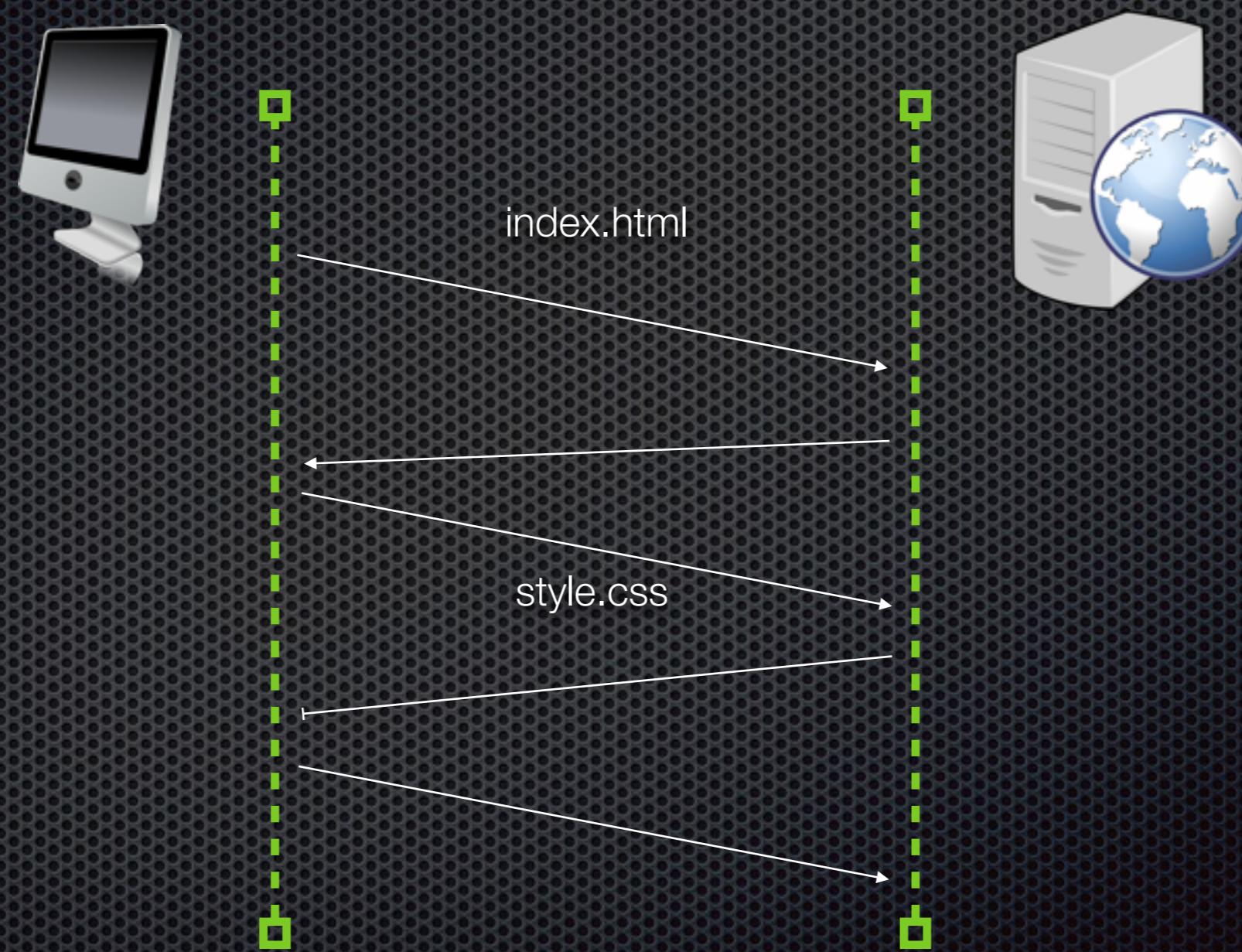
<BODY>

...

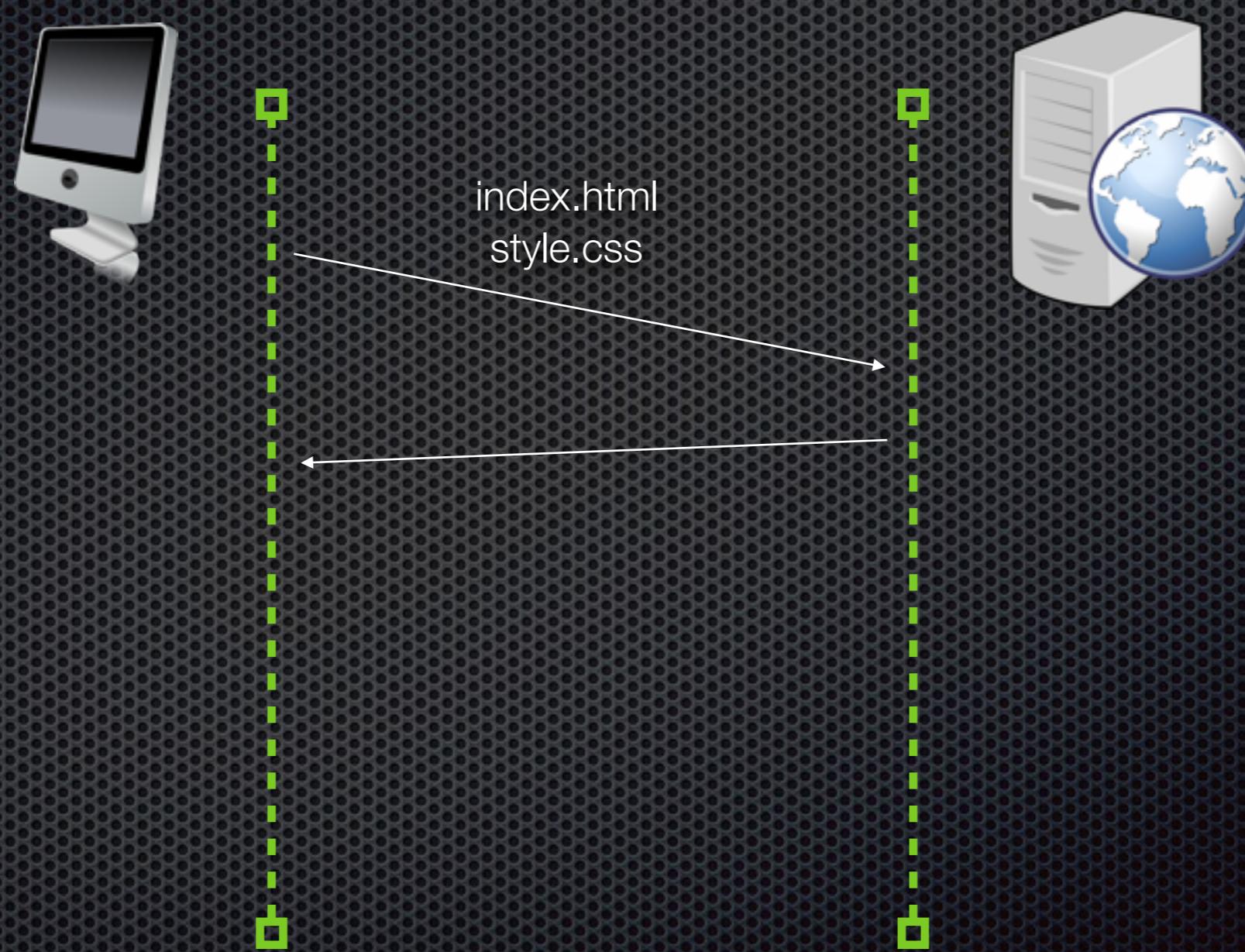
**Connection default: keep-alive*

New Optimization Possibilities

Single Connection



Pipelining



Head-of-line Blocking



Multiple Connections

- Use multiple TCP Connections to perform parallel requests
- Limited to 6 connections
 - Domain Sharding
 - More DNS lookups
- Still creates overhead on client/server with many open connections

Other techniques

- Inlining resources
 - No Cache usage
 - Encoding overhead
- Concatenating and Spriting resources
 - Cache Issues
 - Delay in processing

The culprit is HTTP on TCP

- Http 1.1 chatty
- TCP is not made for chatty protocols
- TCP has slow start and head of line blocking

Http/2

It's about performance!

In a few words

- Binary Communication
- Compression and optimization techniques
- No change in HTTP semantics
- Not compatible with HTTP 1.x but can be used on top of it

Is it SPDY?

Http/2

```
GET /index.htm HTTP/1.0  
User-Agent: Netscape  
Accept: text/html  
  
<html>...</html>
```

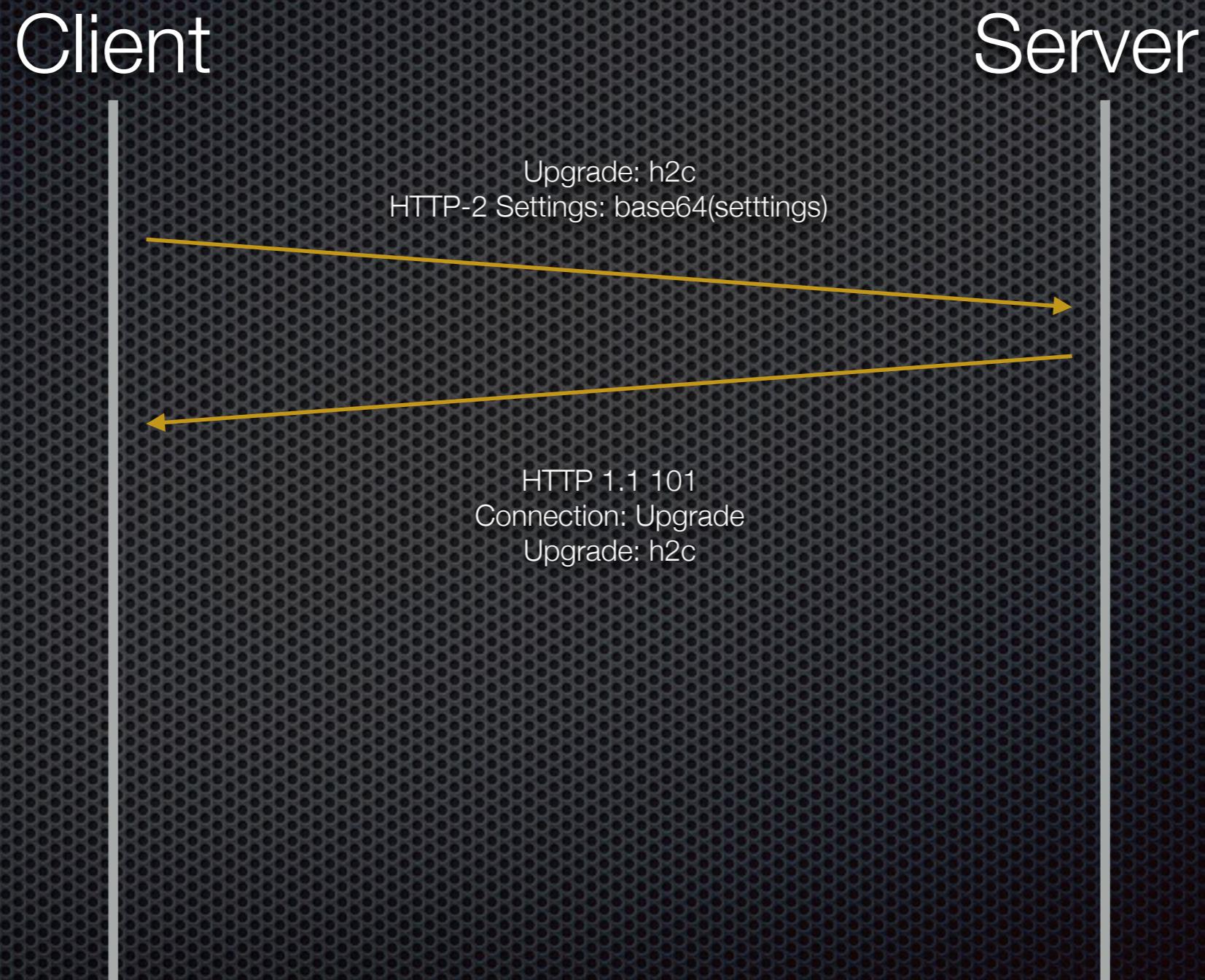


Binary Framing

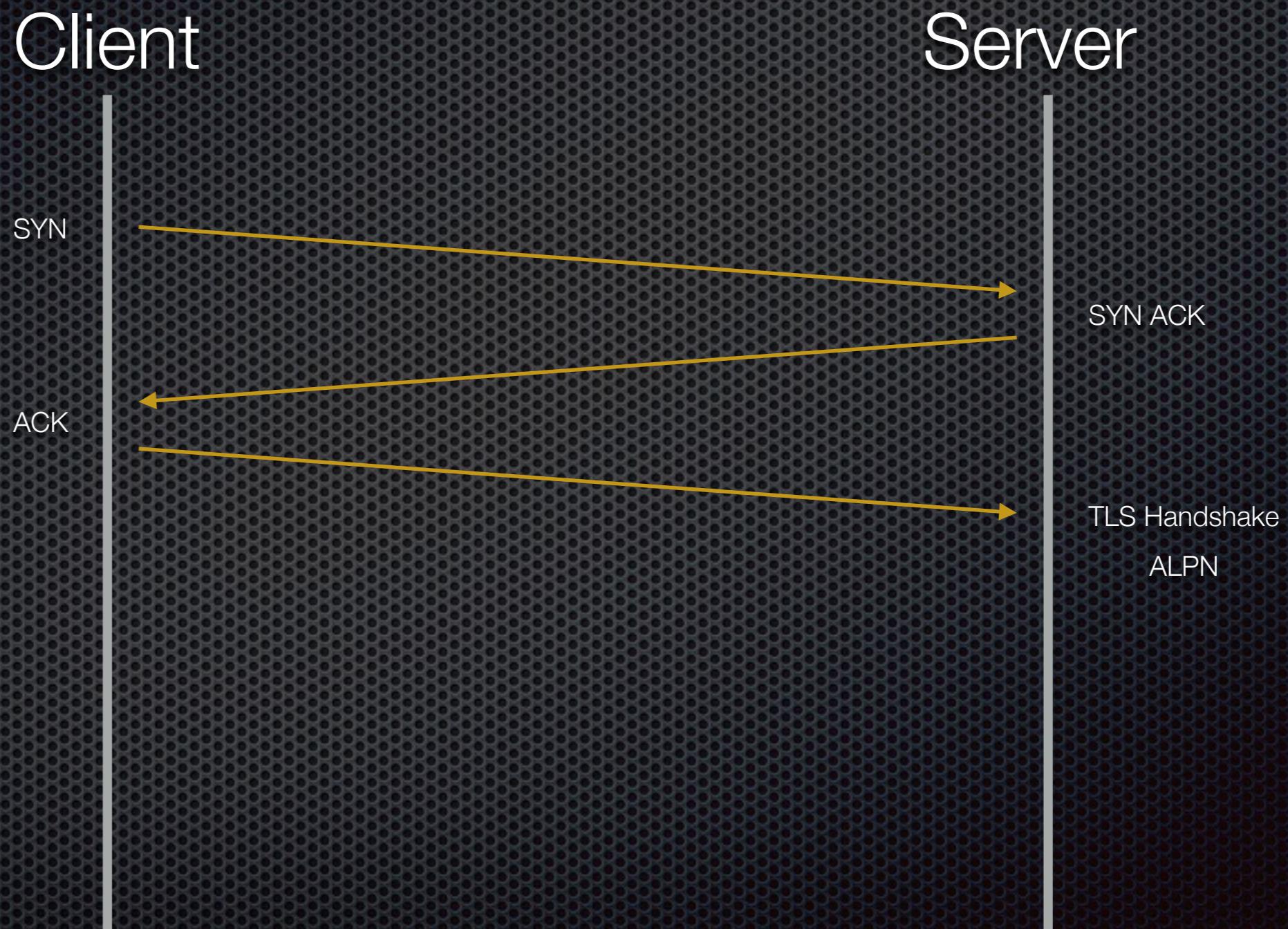
HEADER
FRAME

DATA
FRAME

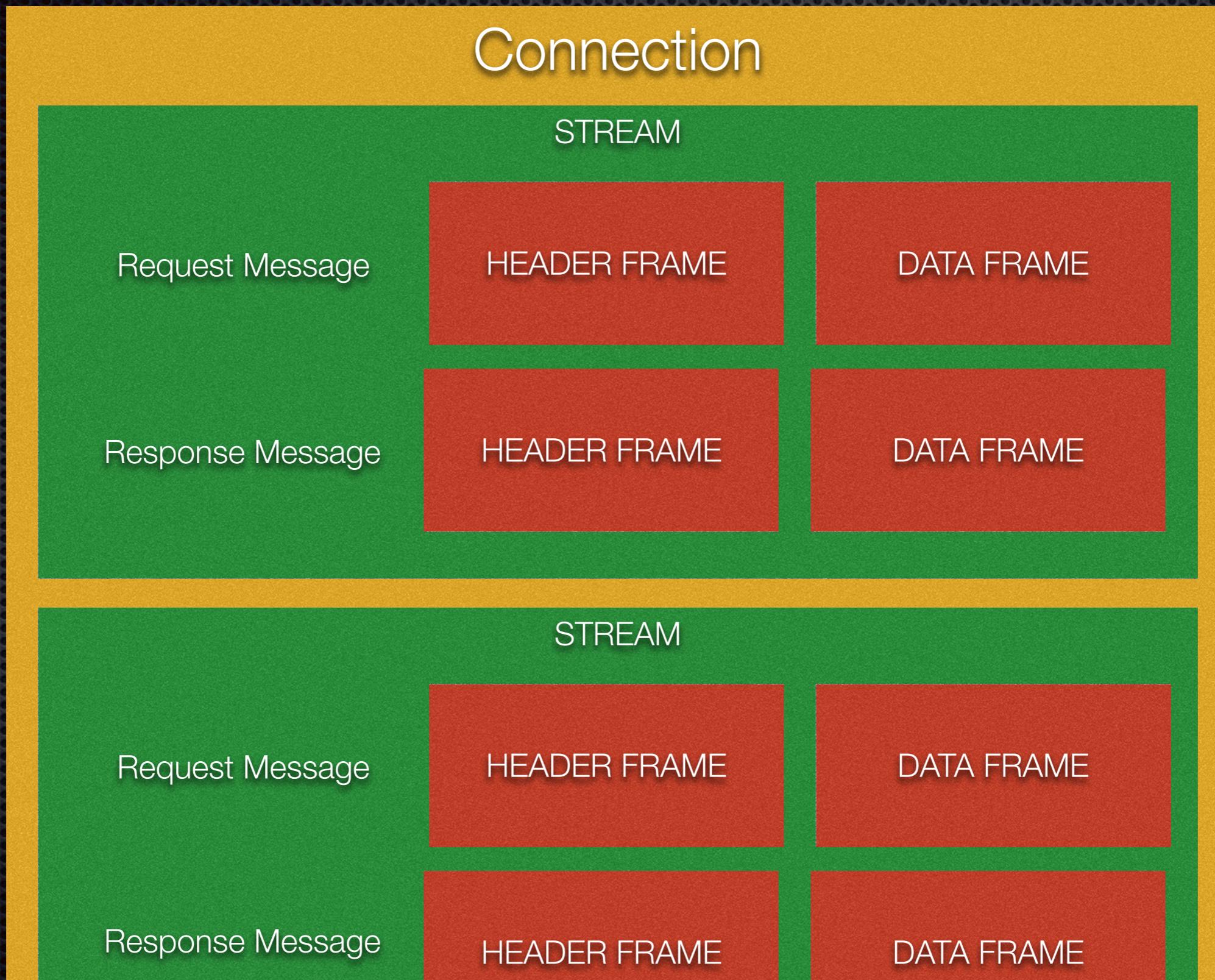
Http/2 Upgrade (h2c)



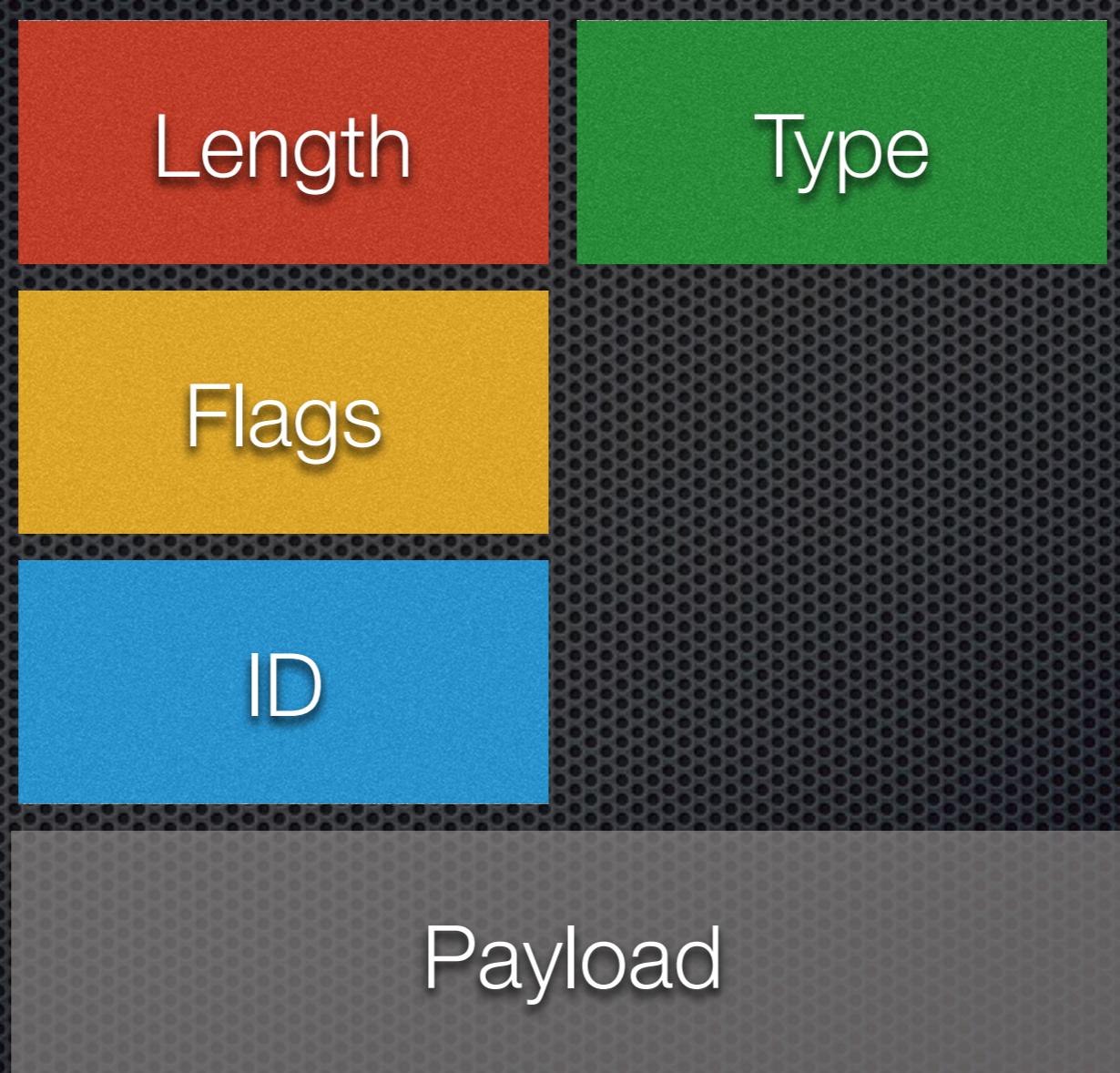
Http/2 TLS + ALPN (h2)



Single Connection



A Frame



Frame Types

- DATA
- HEADER
- WINDOW_UPDATE
- SETTINGS
- PRIORITY
- RST_STREAM
- PUSH_PROMISE
- PING
- GOAWAY
- CONTINUATION

Header Frame

Frame 210: 730 bytes on wire (5840 bits), 730 bytes captured (5840 bits) on interface 0
Ethernet II, Src: Mitrasta_66:d9:58 (b0:46:fc:66:d9:58), Dst: Apple_8b:a0:c3 (20:c9:d0:8b:a0:c3)
Internet Protocol Version 4, Src: 185.59.220.53 (185.59.220.53), Dst: 192.168.1.38 (192.168.1.38)
Transmission Control Protocol, Src Port: 80 (80), Dst Port: 62803 (62803), Seq: 1, Ack: 324, Len: 664
Hypertext Transfer Protocol
HyperText Transfer Protocol 2 (draft-13)
Stream: HEADERS, Stream ID: 16781328, Length 0
..00 0000 0000 0000 = Length: 0
00.. = Reserved: 0
Type: HEADERS (1)
Flags: 0x00
0.... = Reserved: 0x00000000
.000 0001 0000 0000 0001 0000 0001 0000 = Stream Identifier: 16781328
[Pad Length: 0]
Header Block Fragment: <MISSING>
Padding: <MISSING>
Stream: HEADERS, Stream ID: 536897540, Length 0

0000	20 c9 d0 8b a0 c3 b0 46	fc 66 d9 58 08 00 45 00F .f.X..E.
0010	02 cc fb 34 40 00 31 06	f4 b7 b9 3b dc 35 c0 a8	...4@.1.;.5..
0020	01 26 00 50 f5 53 0a 19	cb 21 4d 2b 67 48 80 18	.&.P.S.. .!M+gH..
0030	00 eb 66 99 00 00 01 01	08 0a 04 6a 30 12 4b 11	..f..... ...j0.K.
0040	a0 82 48 54 54 50 2f 31	2e 31 20 32 30 30 20 4f	..HTTP/1 .1 200 0
0050	4b 0d 0a 44 61 74 65 3a	20 54 68 75 2c 20 31 37	K..Date: Thu, 17
0060	20 53 65 70 20 32 30 31	35 20 30 33 3a 32 36 3a	Sep 201 5 03:26:
0070	33 33 20 47 4d 54 0d 0a	43 6f 6e 74 65 6e 74 2d	33 GMT.. Content-
0080	54 79 70 65 3a 20 69 6d	61 67 65 2f 78 2d 69 63	Type: im age/x-ic
0090	6f 6e 0d 0a 54 72 61 6e	73 66 65 72 2d 45 6e 63	on..Transf-Enc
00a0	6f 64 69 6e 67 3a 20 63	68 75 6e 6b 65 64 0d 0a	oding: chunked..
00b0	43 6f 6e 6e 65 63 74 69	6f 6e 3a 20 6b 65 65 70	Connecti on: keep
00c0	2d 61 6c 69 76 65 0d 0a	43 61 63 68 65 2d 43 6f	-alive.. Cache-Co
00d0	6e 74 72 6f 6c 3a 20 6e	6f 2d 63 61 63 68 65 0d	ntrol: no-cache..
00e0	0a 41 63 63 65 73 73 2d	43 6f 6e 74 72 6f 6c 2d	.Access- Control-
00f0	41 6c 6c 6f 77 2d 4f 72	69 67 69 6e 3a 20 2a 0d	Allow-Or igin: *.
0100	0a 53 65 72 76 65 72 3a	20 43 44 4e 37 37 2d 54	.Server: CDN77-T
0110	75 72 62 6f 0d 0a 58 2d	43 61 63 68 65 3a 20 48	urbo..X- Cache: H
0120	49 54 0d 0a 58 2d 41 67	65 3a 20 31 36 39 39 37	IT..X-Ag e: 16997
0130	37 34 0d 0a 43 6f 6e 74	65 6e 74 2d 45 6e 63 6f	74..Cont ent-Enc

Frame (730 bytes) De-chunked entity body (384 bytes) Uncompressed entity body (1150 bytes)

Data Frame

210	10.511556000	185.59.220.53	192.168.1.38	HTTP2	HEADERS, HEADERS
2251	16.817271000	192.168.1.38	185.59.220.53	HTTP2	Magic, Unknown type
2294	17.300852000	192.168.1.38	185.59.220.53	HTTP2	DATA
2378	17.420429000	185.59.220.53	192.168.1.38	SSL	[SSL segment of file]

0000	b0	46	fc	66	d9	58	20	c9	d0	8b	a0	c3	08	00	45	00	.F.f.XE.
0010	00	8c	2c	dc	40	00	40	06	b6	50	c0	a8	01	26	b9	3b	...,.@.@.	.P....&..;
0020	dc	35	f5	5c	01	bb	71	b6	2b	40	db	20	82	00	80	18	.5.\..q.	+@.
0030	10	00	e2	4f	00	00	01	01	08	0a	4b	11	ba	a2	04	6a	...0....	..K....j
0040	36	59	17	03	03	00	53	00	00	00	00	00	00	00	13	bf	6Y....S.
0050	68	ea	aa	1f	41	8b	63	84	2f	d0	dd	98	56	5b	55	22	h...A.c.	/...V[U"
0060	b0	44	db	a0	d5	12	53	5a	a4	7b	c1	ff	73	09	c3	d2	.D....SZ	{.s...
0070	73	b6	35	92	ad	0a	1b	03	21	71	4a	f7	50	79	5b	1b	s.5.....	!qJ.Py[.
0080	1d	6d	fb	50	50	06	59	ce	4b	aa	67	fd	b6	d5	ec	ee	.m.PP.Y.	K.g.....
0090	61	29	f7	c0	75	31	97	a4	ae	a6							a)...u1...	..

Proper Multiplexing



- Allows interleaving of different requests and responses
- Bidirectional
- Each frame has a unique identifier
- Eliminates head-of-line blocking
- Single connection for parallel processing

Headers

▼ General

Remote Address: 23.235.43.133:443
Request URL: <https://assets-cdn.github.com/images/spinners/octocat-spinner-32.gif>
Request Method: GET
Status Code: 304 Not Modified

▼ Response Headers [view source](#)

Age: 18081317
Cache-Control: max-age=31536000, public
Connection: keep-alive
Date: Fri, 23 Oct 2015 19:41:06 GMT
ETag: "520df3f4-906"
Expires: Sun, 27 Mar 2016 13:05:48 GMT
timing-allow-origin: https://github.com
Vary: Accept-Encoding
Via: 1.1 varnish
X-Cache: HIT
X-Cache-Hits: 58603
X-Served-By: cache-fra1228-FRA
X-Timer: S1445629266.428735,VS0,VE0

▼ Request Headers [view source](#)

Accept: image/webp,image/*,*/*;q=0.8
Accept-Encoding: gzip, deflate, sdch
Accept-Language: en-US,en;q=0.8,es;q=0.6
Cache-Control: max-age=0
Connection: keep-alive

▼ General

Remote Address: 23.235.43.133:443
Request URL: <https://assets-cdn.github.com/images/spinners/octocat-spinner-128.gif>
Request Method: GET
Status Code: 304 Not Modified

▼ Response Headers [view source](#)

Age: 12769322
Cache-Control: max-age=31536000, public
Connection: keep-alive
Date: Fri, 23 Oct 2015 19:41:06 GMT
ETag: "5238dfe2-2dc9"
Expires: Sat, 28 May 2016 00:39:03 GMT
timing-allow-origin: https://github.com
Vary: Accept-Encoding
Via: 1.1 varnish
X-Cache: HIT
X-Cache-Hits: 80109
X-Served-By: cache-fra1247-FRA
X-Timer: S1445629266.394153,VS0,VE0

▼ Request Headers [view source](#)

Accept: image/webp,image/*,*/*;q=0.8
Accept-Encoding: gzip, deflate, sdch
Accept-Language: en-US,en;q=0.8,es;q=0.6
Cache-Control: max-age=0
Connection: keep-alive

Header Compression

- Uses HPACK
- Huffman code for encoding headers
- An index table is maintained between client and server
- CRIME prevented use of zlib

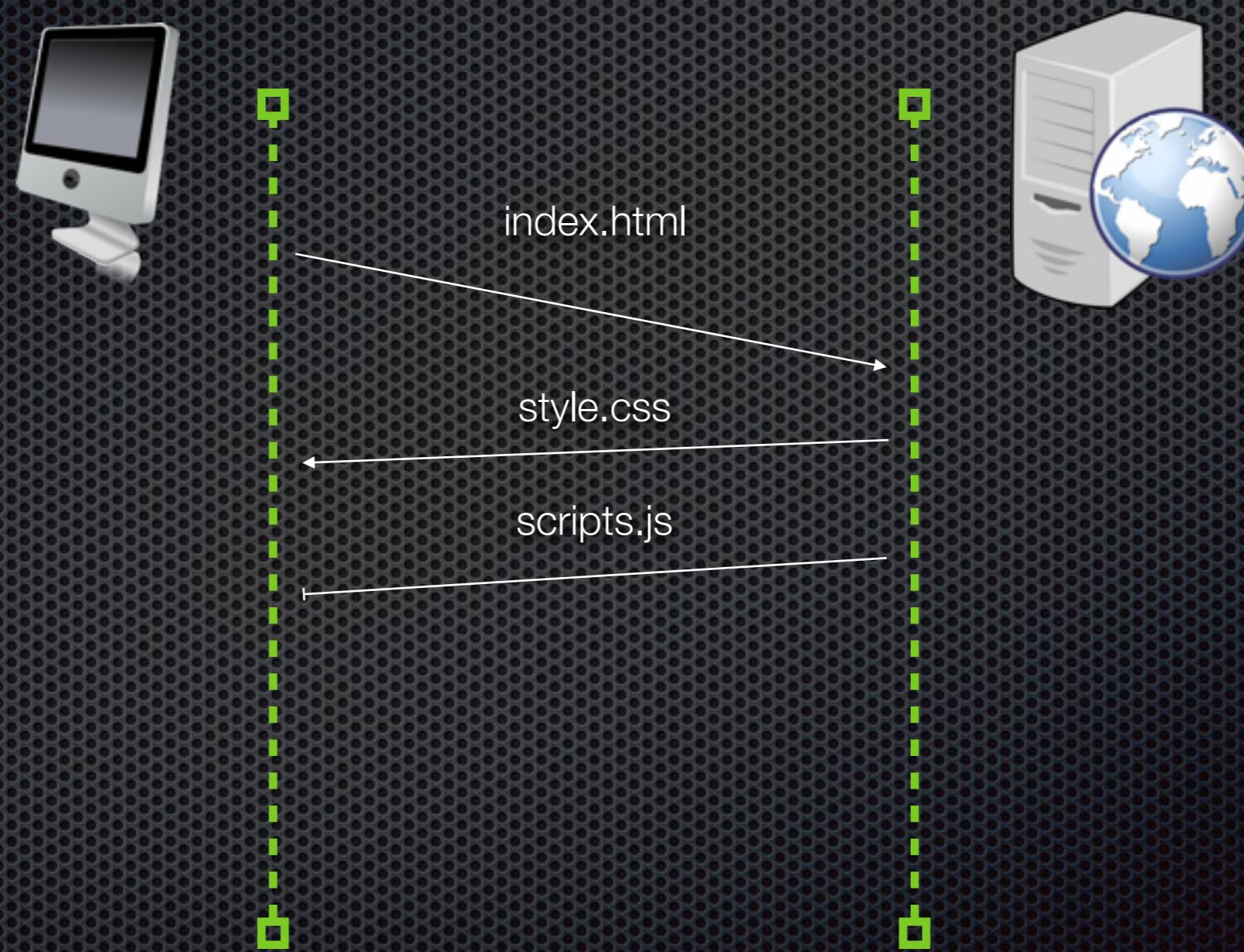
Streams need Priorities

- Define priorities of different streams
- Each stream has a weight and dependencies

Flow Control

- Multiplexing requires ability of flow control
- WINDOW_UPDATE

Server Push



Server Push

- Replaces inlining of resources
- PUSH_PROMISE from server (even numbered streams)
- Allows for caching
- Allows for cancellation by client

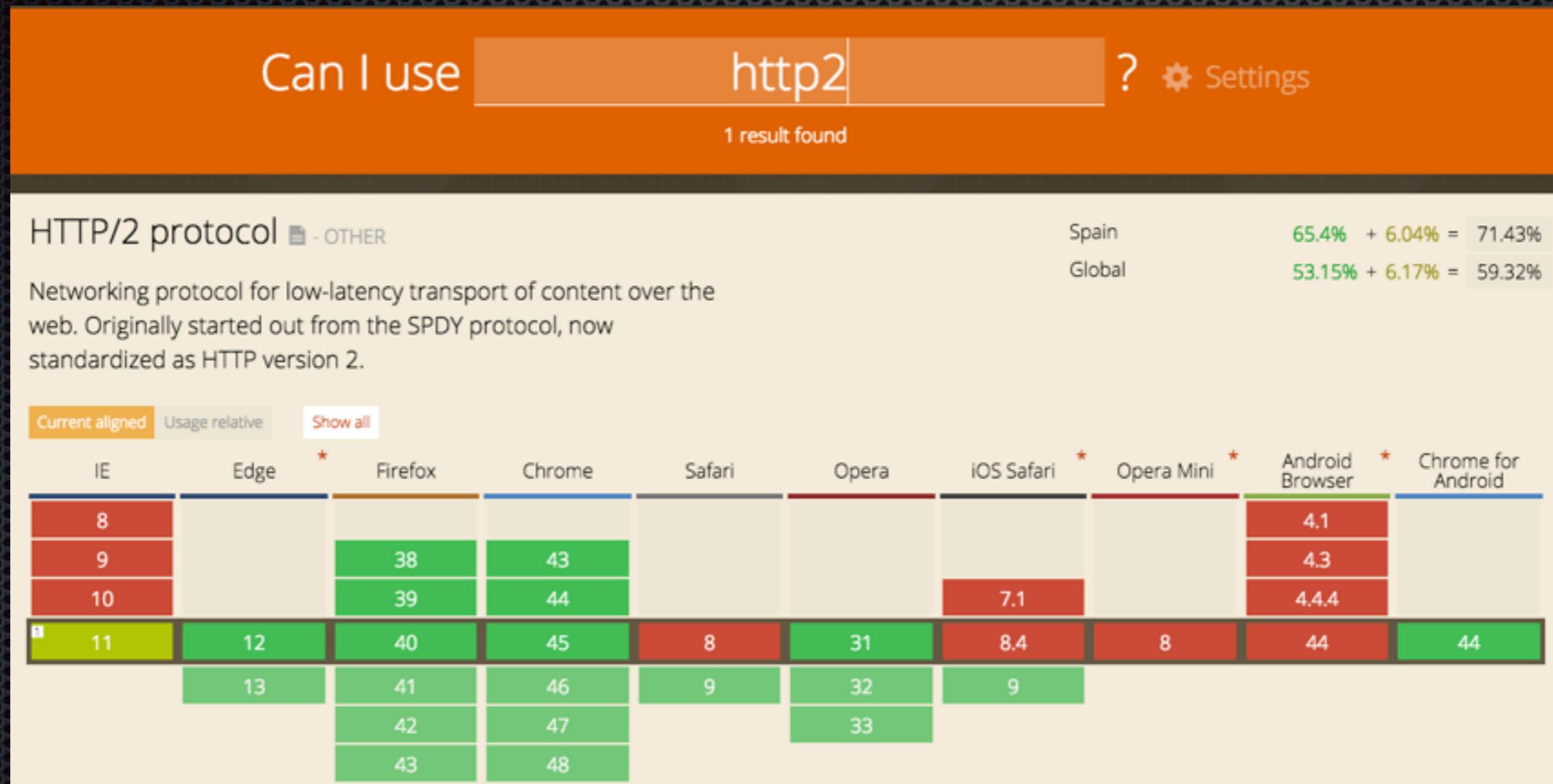
Security

- Not forced
- TLS implemented by all supported browsers

Current Status

- May 2015 RFC 7540
- May 2015 RFC 7541 (HPACK)

Browser Support



Server Support

- H2O
- Akamai Edge
- Apache 2.4.12
- Jetty 9.3
- Wildly 9
- Ngnix 1.9.5
- IIS in Windows 10 and Server 2016

*Java 7, 8 require ALPN Extensions

Client and Library Support

- Jetty
- Netty
- Curl,
- OkHttp

Tooling

- Curl
- Chrome Tools
- Wireshark
- WebPageTest

Demos

- <https://http2.akamai.com/>
- <http://www.http2demo.io/>

How does it affect our applications?

Mostly transparent

Web Apps

“De-optimize”

- Multiple TCP Connections
- Domain Sharding
- Concatenation and Spriting
- Inlining

API's

API's

- HTTP as a Protocol
 - No more concerns about chatty API's
- Library API's
 - Low Level or simple HTTP Semantics?

Demos

- OkHttp
- Netty

Not all roses...

- Adding transport level complexity to application level
 - Priorities
 - Flow Control
- How will Push really work?

More information

- Starting point: <https://github.com/http2>
- High Performance Browser Networking by Ilya Grigorik
- My course on Pluralsight (HTTP/2 Fundamentals)

Thank you

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