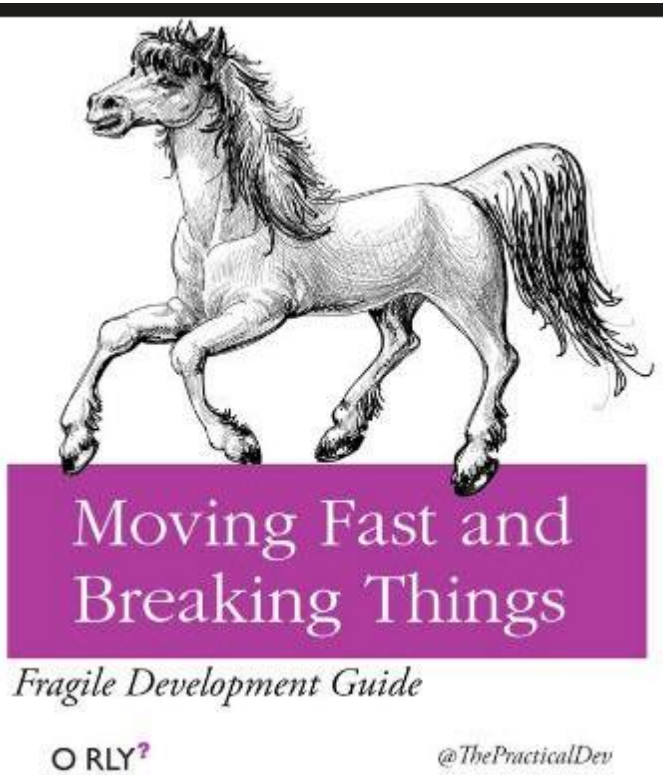

Concatenation, Embedding and Sharding:

Do HTTP/1 Performance Best Practices Make Sense in HTTP/2?

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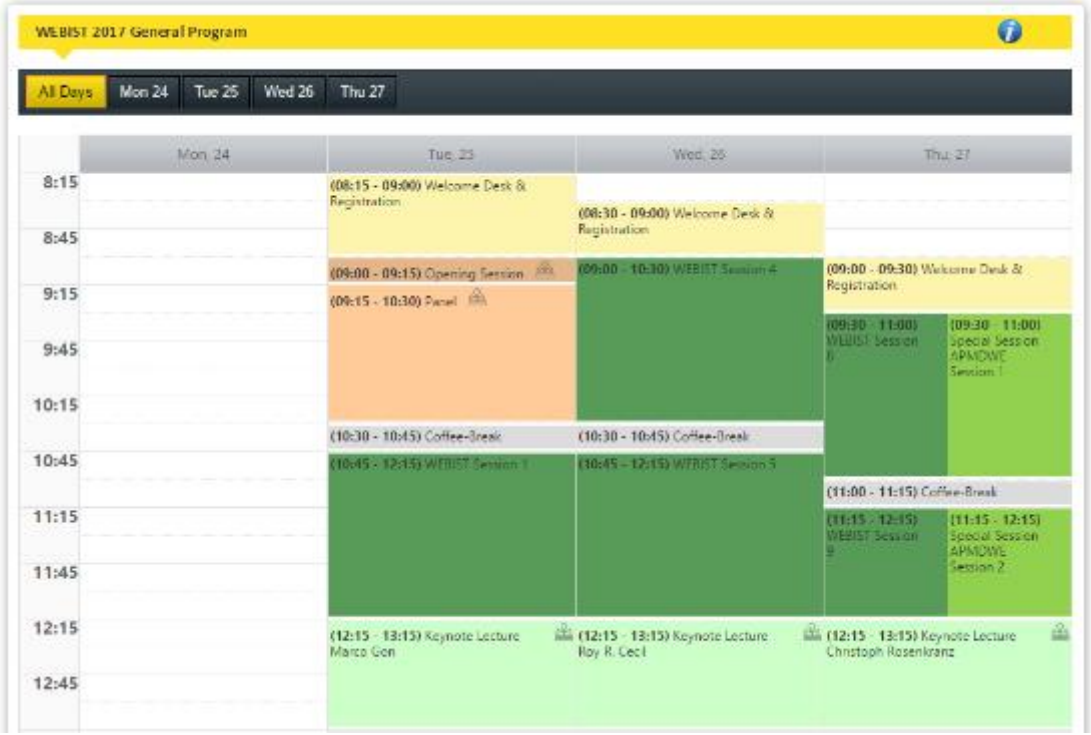
Robin Marx
PhD Researcher
robin.marx@uhasselt.be

PRIMORIS
EVENT MANAGEMENT SYSTEM



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Web Performance

- HTTP/2 is the new kid in town!
- Replaces good old trusted HTTP/1.1
  - Currently 13.3% of sites is on H2*

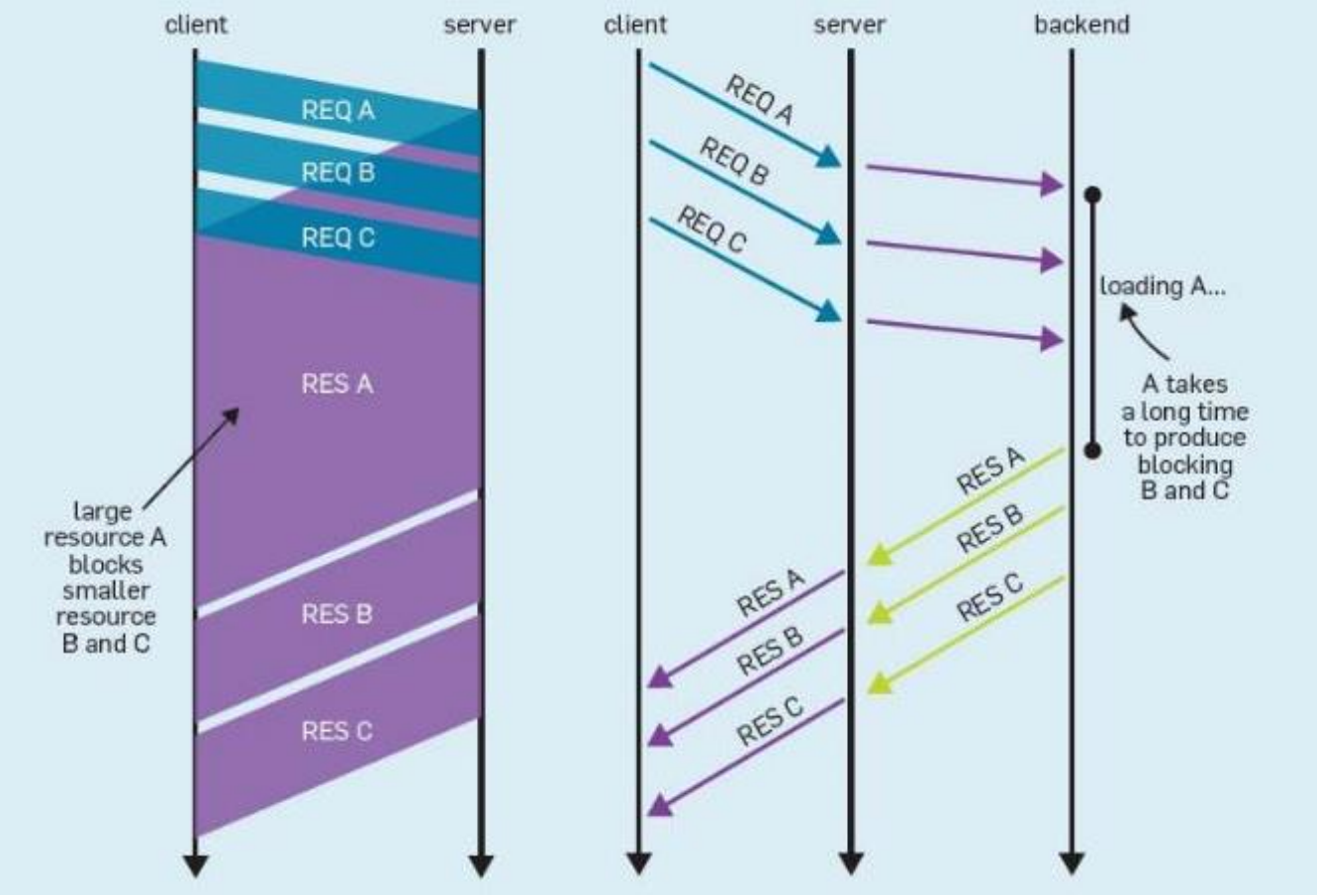
- How is HTTP/2 different from HTTP/1.1?
- Is h2 always faster than h1? And why?

- Do we need to change our sites to get the most out of h2?

*https://w3techs.com/technologies/details/ce-http2/all/all

HTTP/1.1 : the bad and the ugly 1

- Single resource at a time per TCP connection
- "Head of Line" (HOL) blocking



http://deliveryimages.acm.org/10.1145/2390000/2380673/figs/f5.jpg

HTTP/1.1 : The solution!

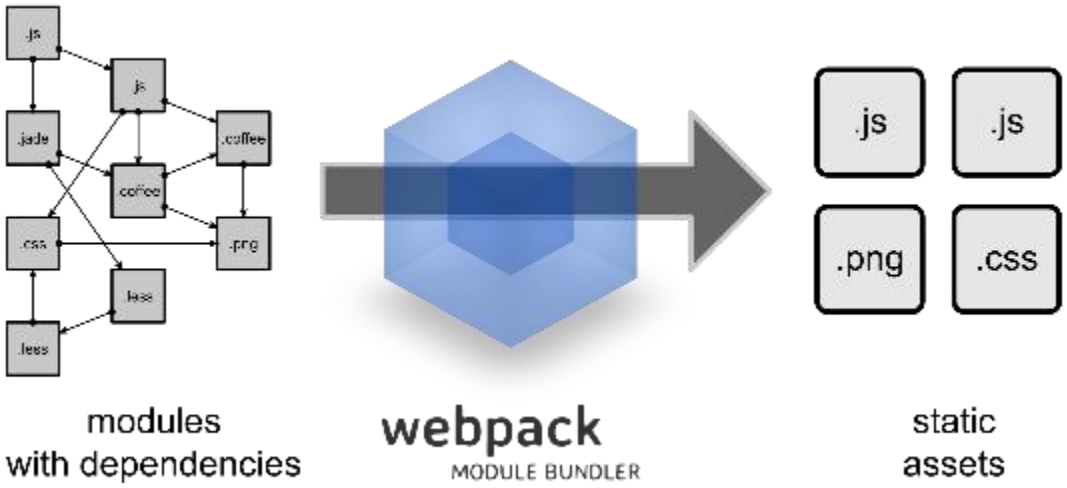
- 6 parallel TCP/HTTP connections per domain

http://www.splicemarketing.co.uk/_blog/Splice_Blog/post/the-arrival-of-http2/

HTTP/1.1 : 6 is not enough!

- Best Practice 1 : Concatenation
- = merge files together to reduce # resources

- 1.js + 2.js + 3.js = scripts.js
- Downside: reduced cacheability

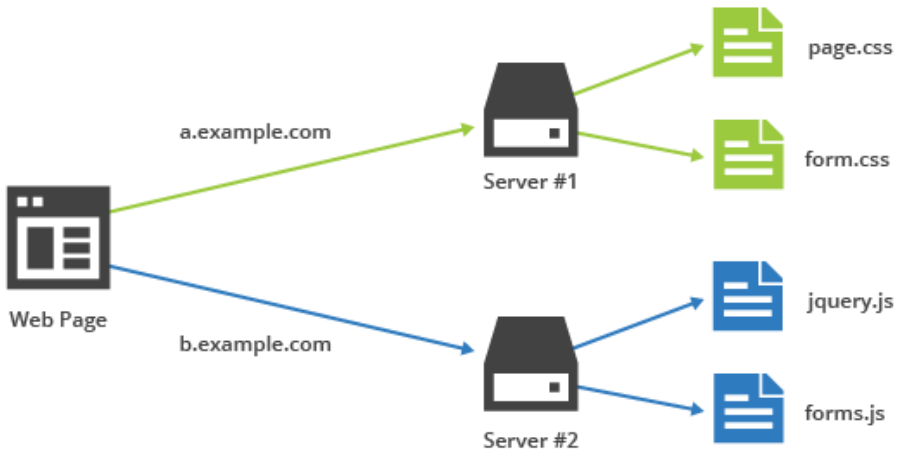


https://www.phase2technology.com/blog/bundle-your-front-end-with-webpack/

HTTP/1.1 : 6 is not enough!

- Best Practice 2 : Domain Sharding
- Content Delivery Networks (CDNs)
- img1.site.com, img2.site.com, static.site.com

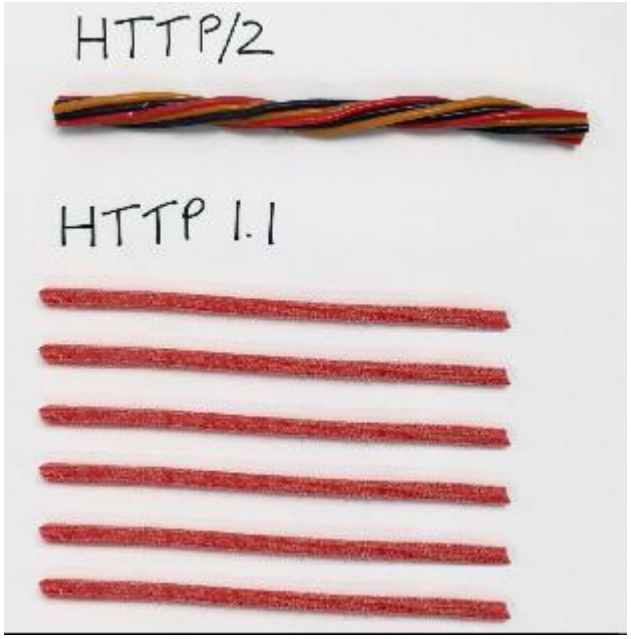
- Downside: serverside overhead

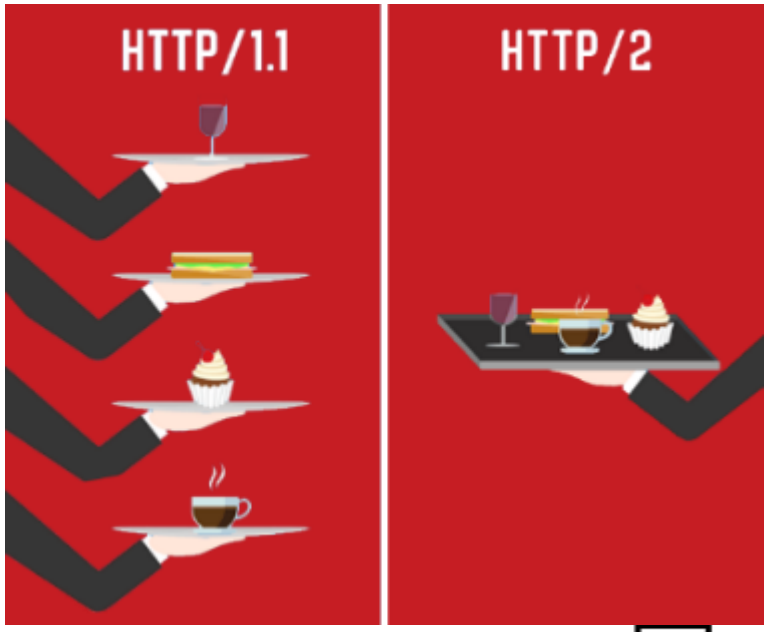


https://blog.cloudflare.com/content/images/2015/12/domain-sharding-1.png

HTTP/2 : The Challenger

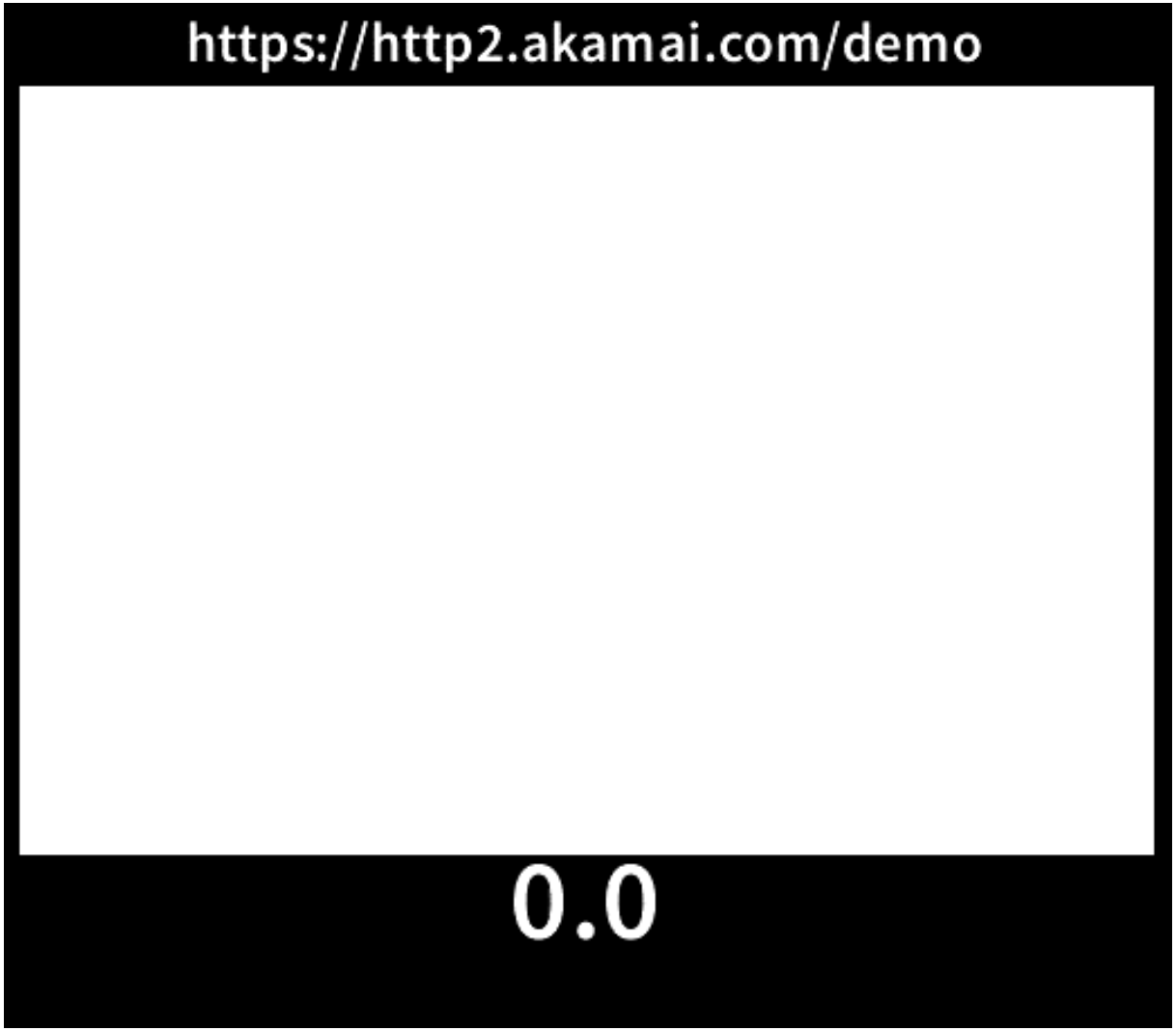
- Started as SPDY, standardized in 2016
- Back to 1 TCP connection
  - Priority-based multiplexing of resource streams





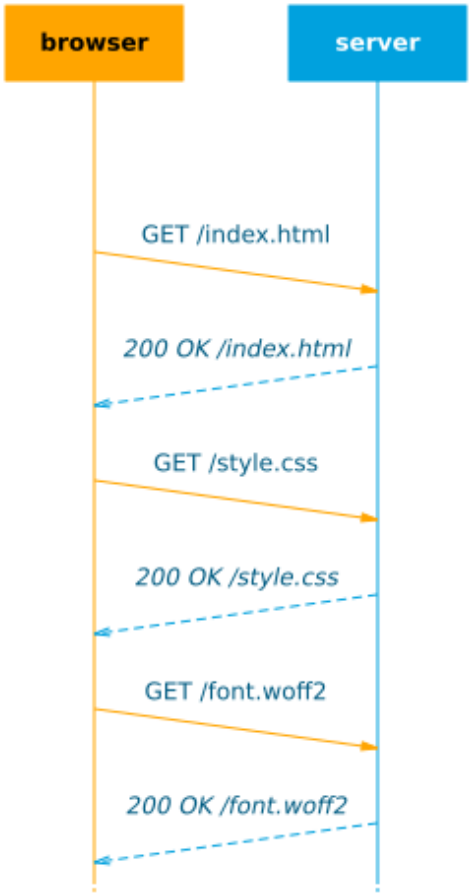
http://www.splicemarketing.co.uk/_blog/Splice_Blog/post/the-arrival-of-http2/

HTTP/2 : Solves HOL blocking!



HTTP/1.1 : the bad and the ugly 2

- Round trip times cause most of the delay
- “dependency graph” / resource discovery



Index.html
references
Style.css
references
Font.woff2

-> min. 3 round-trips needed before rendering can start!

https://calendar.perfplanet.com/2016/http2-push-the-details/

HTTP/1.1 : Round trip times

- Best Practice 3 : Resource embedding
- = Inline resource inside HTML file

- <link rel="stylesheet" href="style.css" />
  VS
- <style> #myDiv{ color: #FFBEEF; } </style>

- Downside: reduced cacheability

HTTP/2 : The Challenger

- Ability to Push resources along

https://calendar.perfplanet.com/2016/http2-push-the-details/

HTTP/2 : The bad and the ugly

- In theory, H1 best practices are now obsolete
  - High-performance browser networking (Grigorik, 2013)
- But: Single TCP connection
  - More sensitive to loss than # parallel connections
- But: TCP in-order guarantee (kernel-level)
  - ~Head-of-line blocking when retransmit
- Problems expected on bad connections
- Difficult to estimate actual impact…

Epic battles in contradictory previous work

Epic battles in contradictory previous work

1. Implementations change
   - SPDY vs H2
   - Server and Browser support
2. Test setups are limited
   - Single browser, server, metric, network, tool, platform, …

? Protocol-inherent or implementation-based ?

The Speeder Framework

TEST ALL THE THINGS!

The Speeder Framework

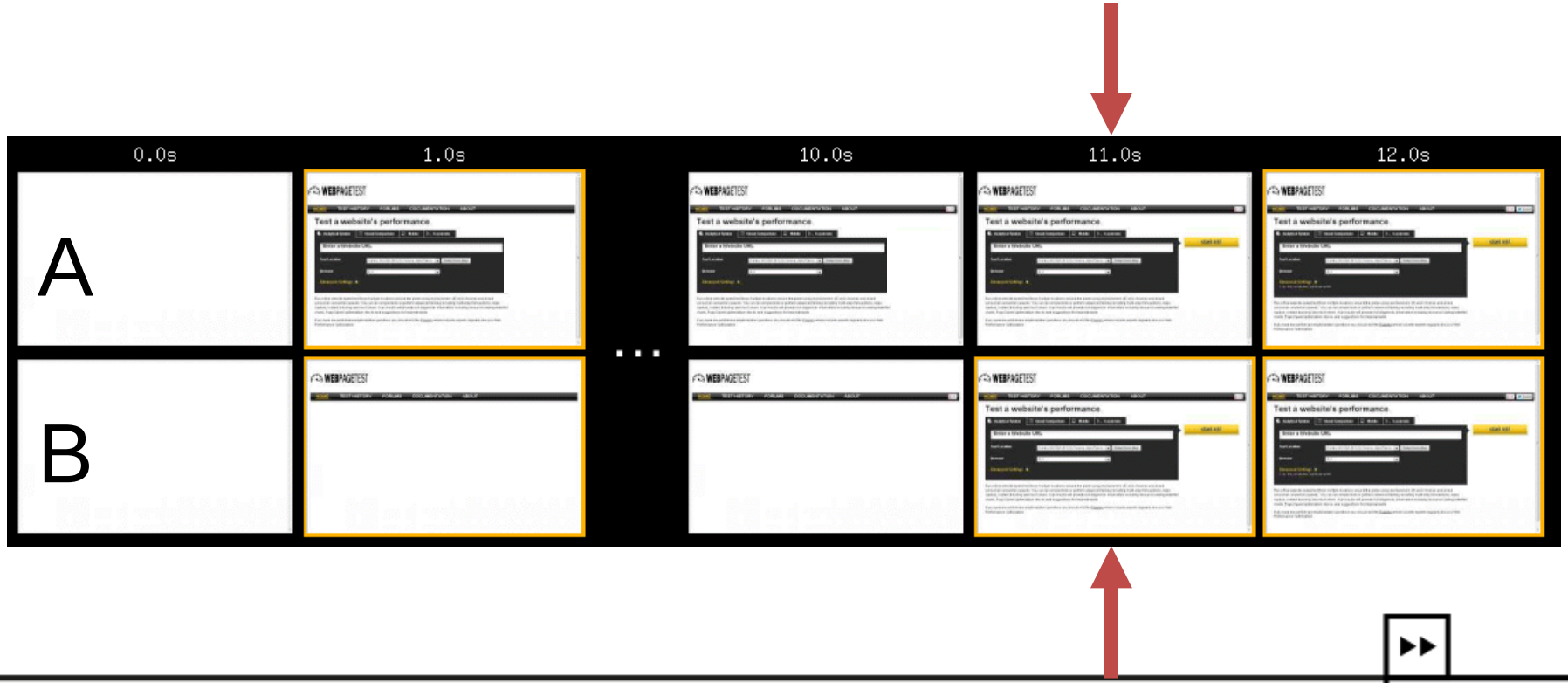
Table 1: Speeder software and metrics.

Protocols	HTTP/1.1 (cleartext), HTTPS/1.1, HTTPS/2
Browsers	Chrome (51 - 54), Firefox (45 - 49)
Test drivers	Sitespeed.io (3), Webpagetest (2.19)
Servers	Apache (2.4.20), NGINX (1.10), NodeJS (6.2.1)
Network	- `DUMMYNET` (cable and cellular) (Webpagetest) - fixed `TC NETEM` (cable and cellular) - dynamic `TC NETEM` (cellular) (Goel et al., 2016)
Metrics	All Navigation Timing values (Wang, 2012), SpeedIndex, firstPaint, visualComplete, other Webpagetest metrics (Meenan, 2016)

TEST MOST OF THE THINGS!

loadEventEnd vs SpeedIndex

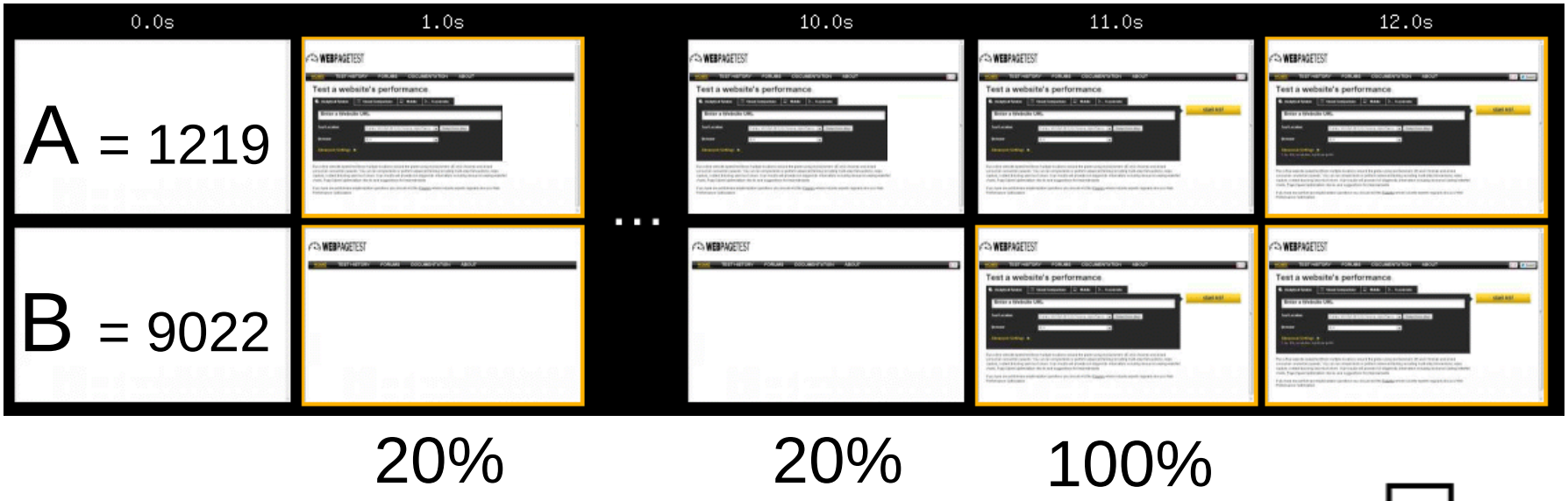
- loadEventEnd
  - document.onload
  - = Everything is downloaded and rendered



https://sites.google.com/a/webpagetest.org/docs/using-webpagetest/metrics/speed-index

loadEventEnd vs SpeedIndex

- SpeedIndex
  - % of visual complete over time (video frames!)
  - Quick to render = better for user experience
  - Measured in milliseconds = LOWER IS BETTER



https://sites.google.com/a/webpagetest.org/docs/using-webpagetest/metrics/speed-index

The Speeder Framework

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Metrics	All Navigation Timing values (Wang, 2012), SpeedIndex, firstPaint, visualComplete, other Webpagetest metrics (Meenan, 2016)

TEST MOST OF THE THINGS!

The Speeder Framework

- Automate this setup using Docker
  - Light-weight stateless VMs based on install scripts
  - Easy to Update!
  - Easy to Share!

- Available on speeder.edm.uhasselt.be
- Go forth and reproduce!

Recap

1. 3 Best Practices to combat H1 downsides
2. HTTP/2 performance is unclear
3. Test many permutations with Speeder

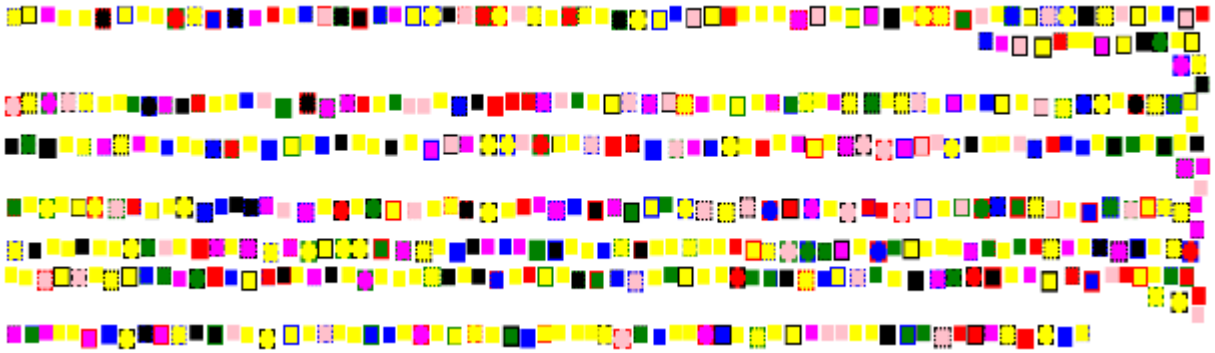
? Impact on developer workflow ?

- Synthetic test cases for best practices
- Realistic test cases

1. Concatenation

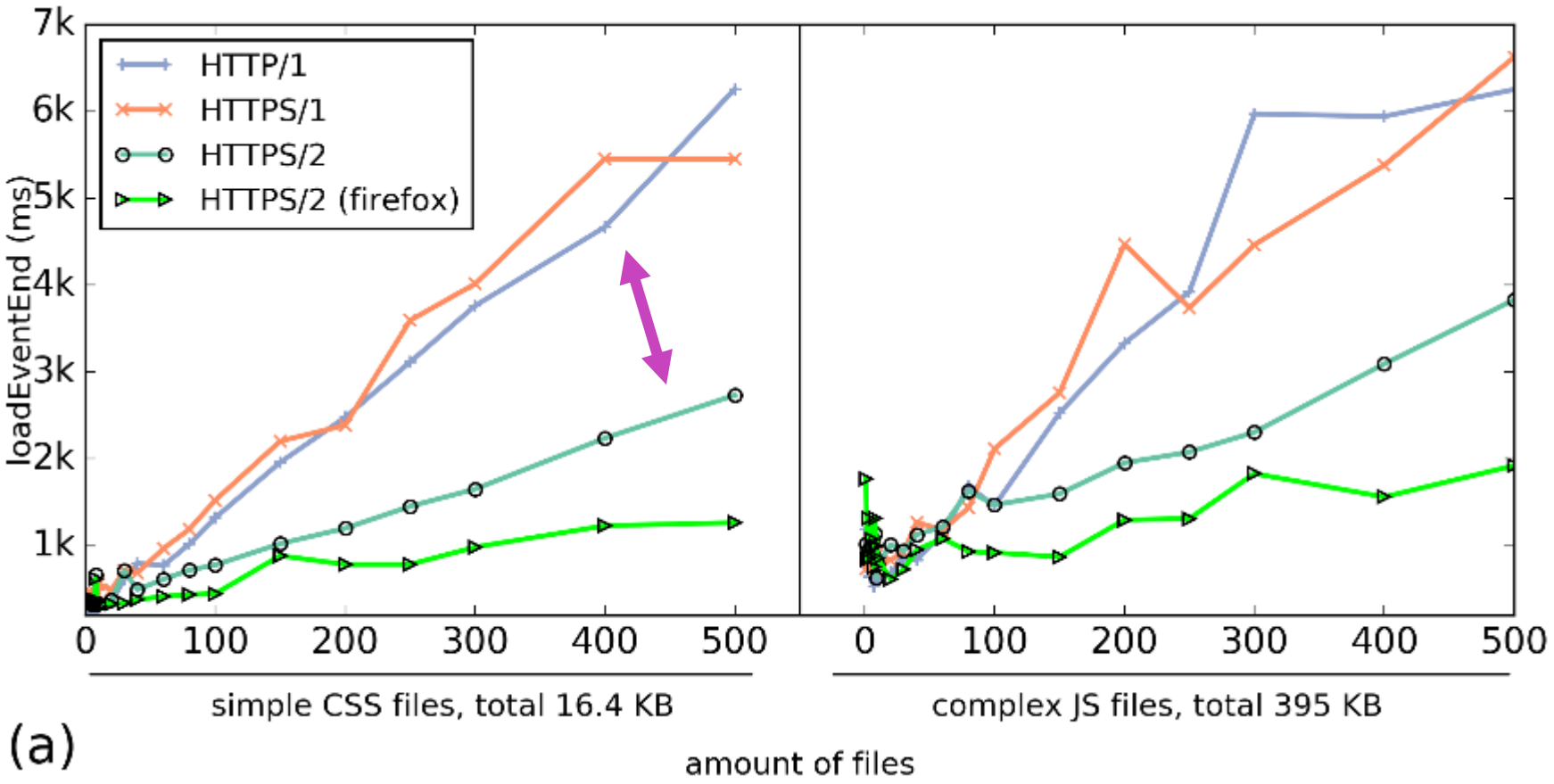
- CSS/JavaScript : 1 – 500 files,
  simple and complex

1 line per



multiple lines
per

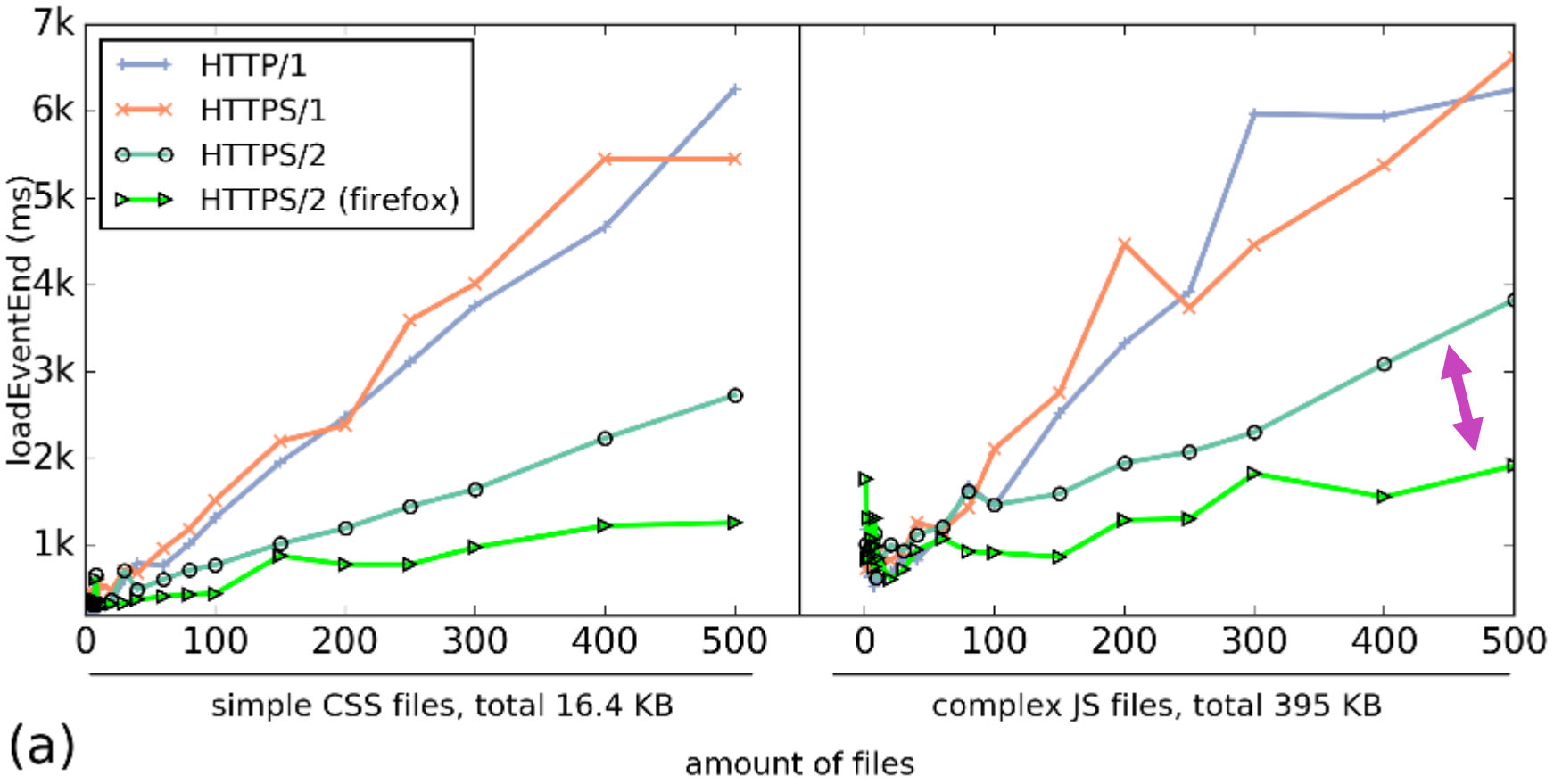
1. Concatenation : 500 CSS/JS



CSS Simple

JS Complex

1. Concatenation : 500 CSS/JS



CSS Simple

JS Complex

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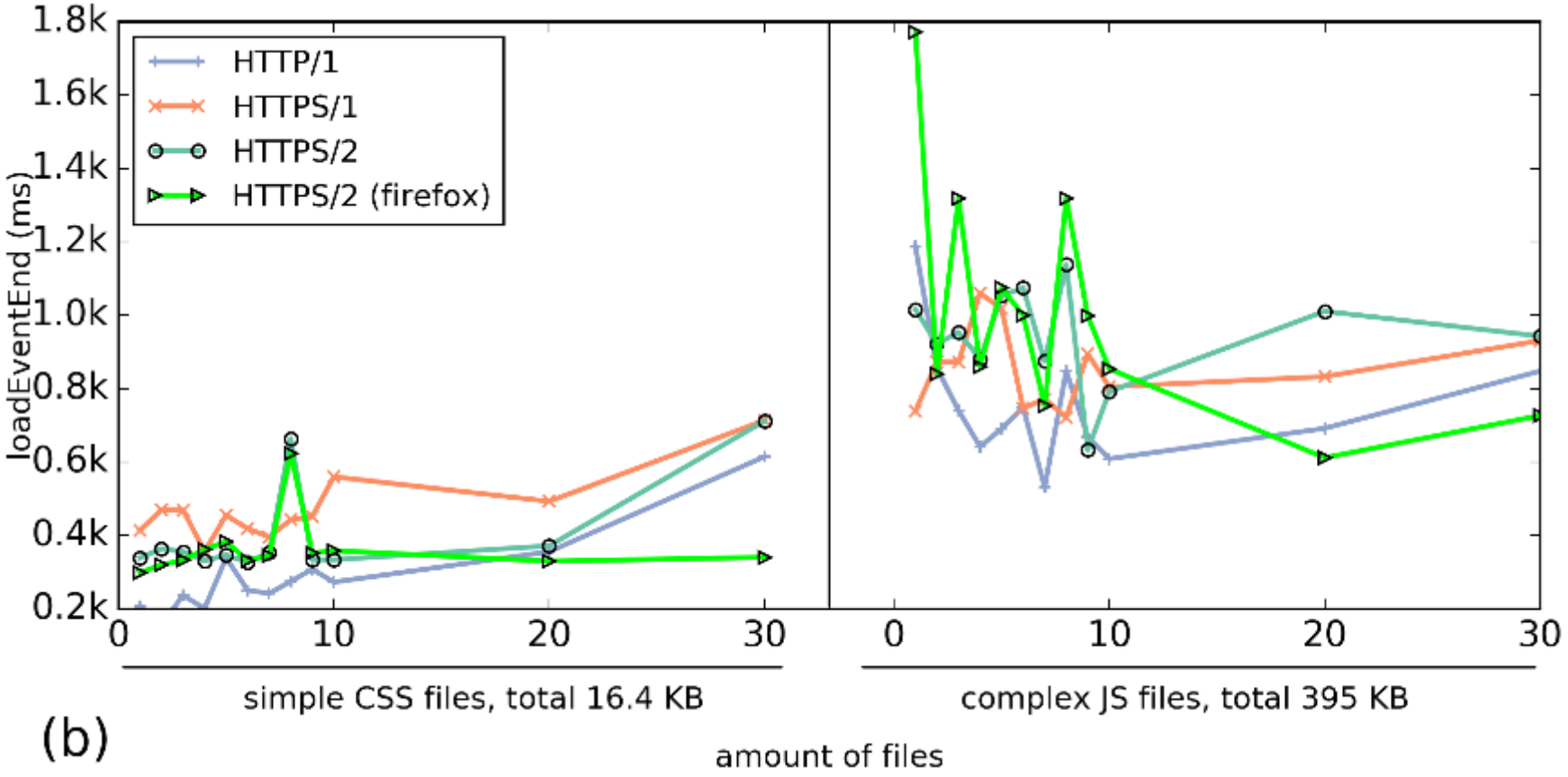
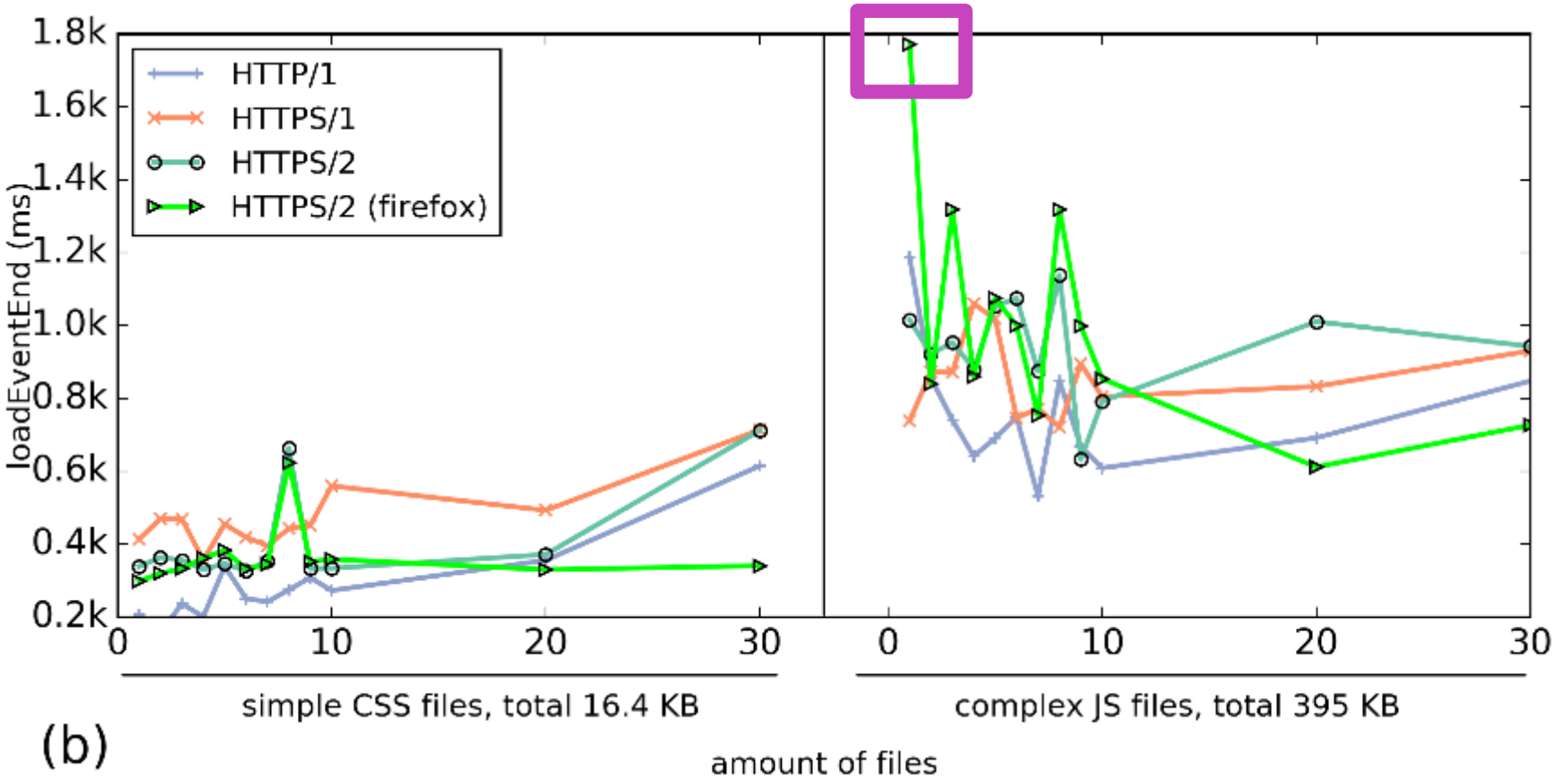
1. Concatenation : 30 CSS/JS



CSS Simple

JS Complex

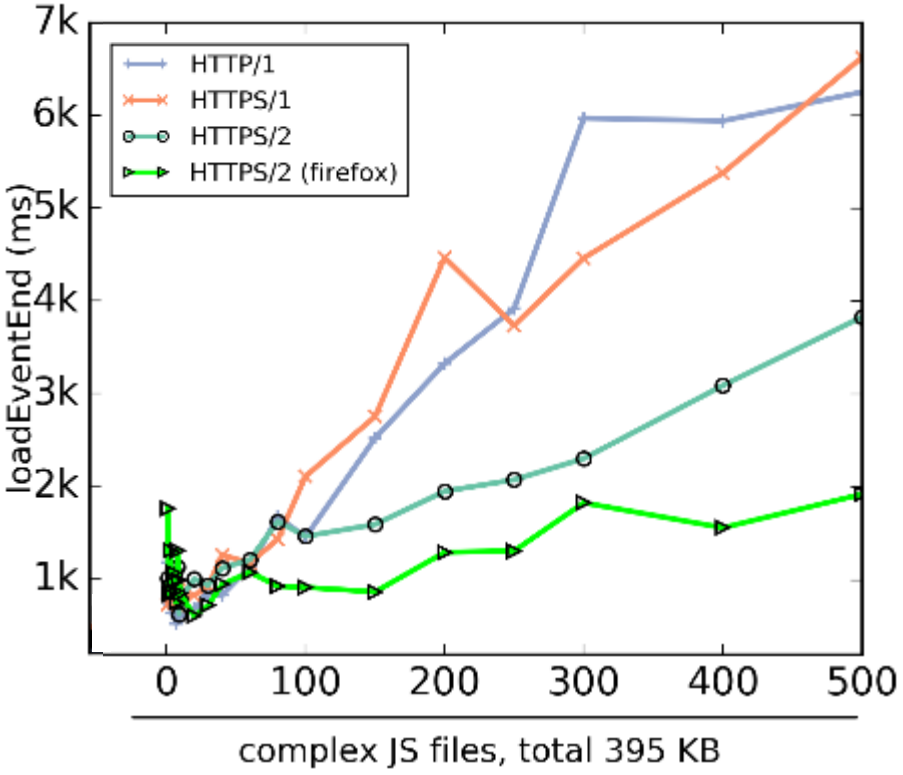
1. Concatenation : 30 CSS/JS

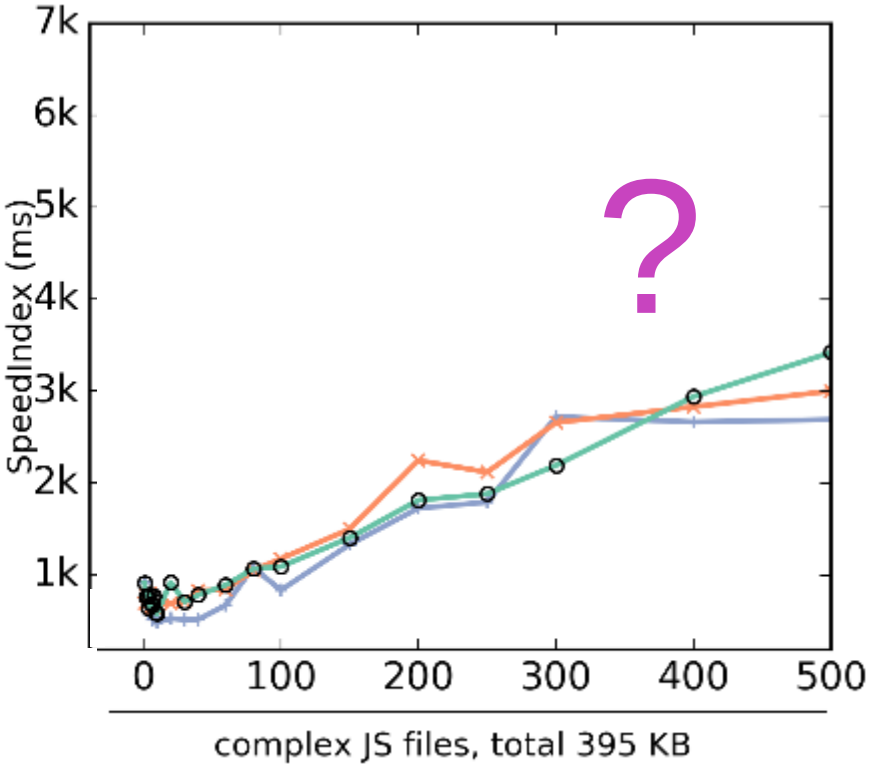


CSS Simple

JS Complex

1. Concatenation : JS SpeedIndex

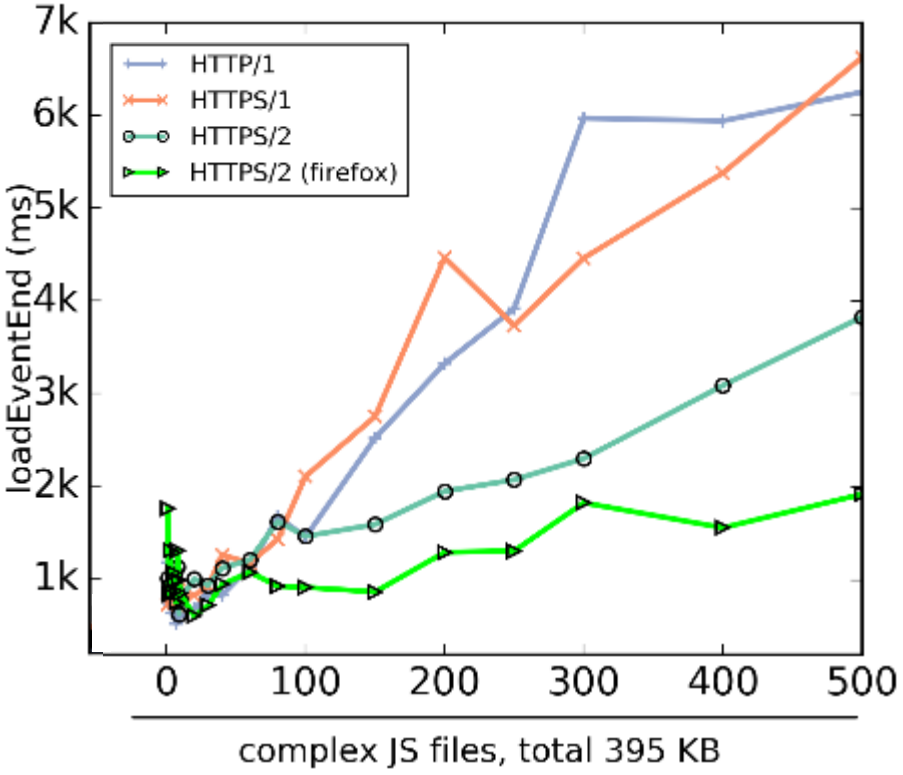


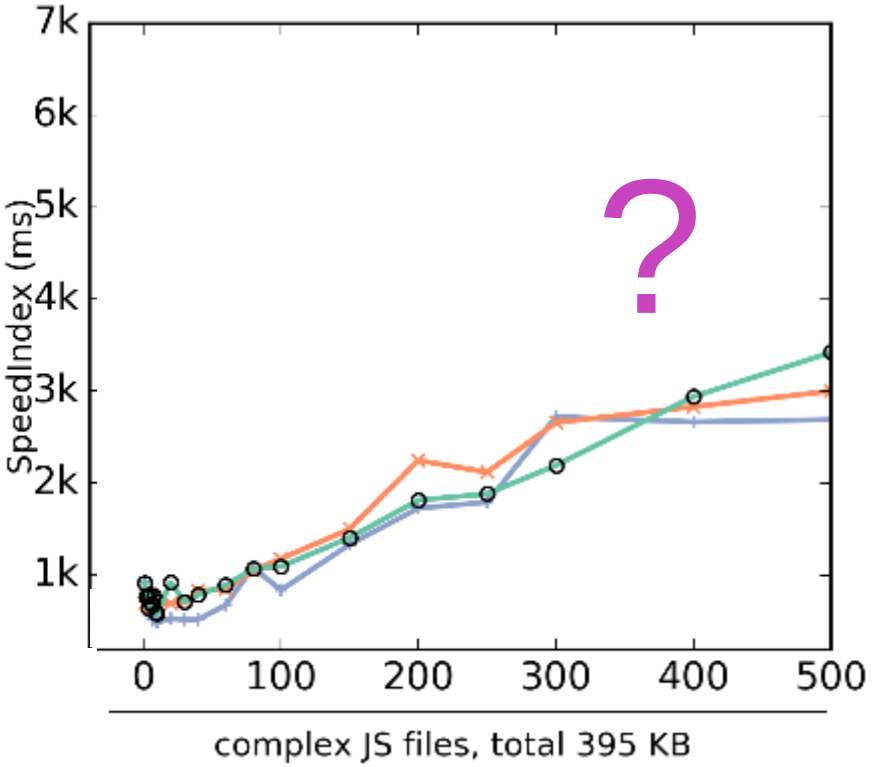


loadEventEnd

SpeedIndex

1. Concatenation : JS SpeedIndex



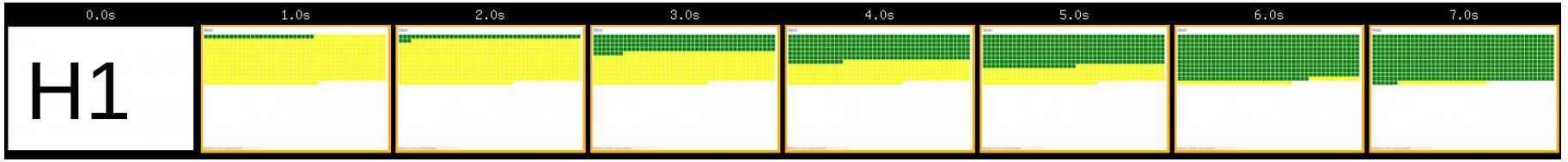


H1 is much lower = rendering starts ASAP

H2 is ~ the same = rendering is delayed

1. Concatenation : JS SpeedIndex

- 500 individual files



SpeedIndex H1 = 2729
SpeedIndex H2 = 3217

2. Sharding

- Images : 380 small, 42 medium, 30 large
- Sharded over 4 hosts (24 H1 conns, 4 H2)

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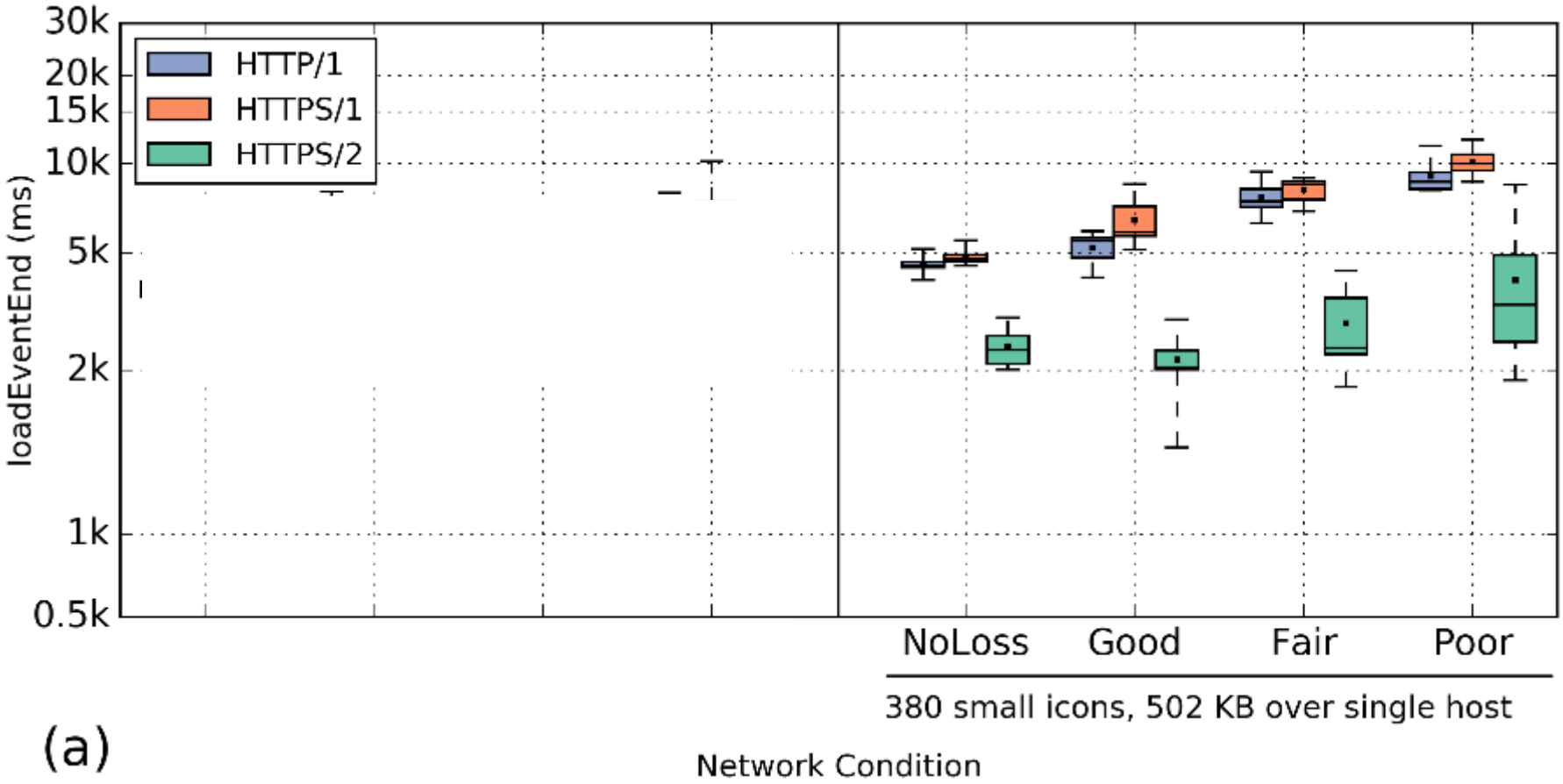
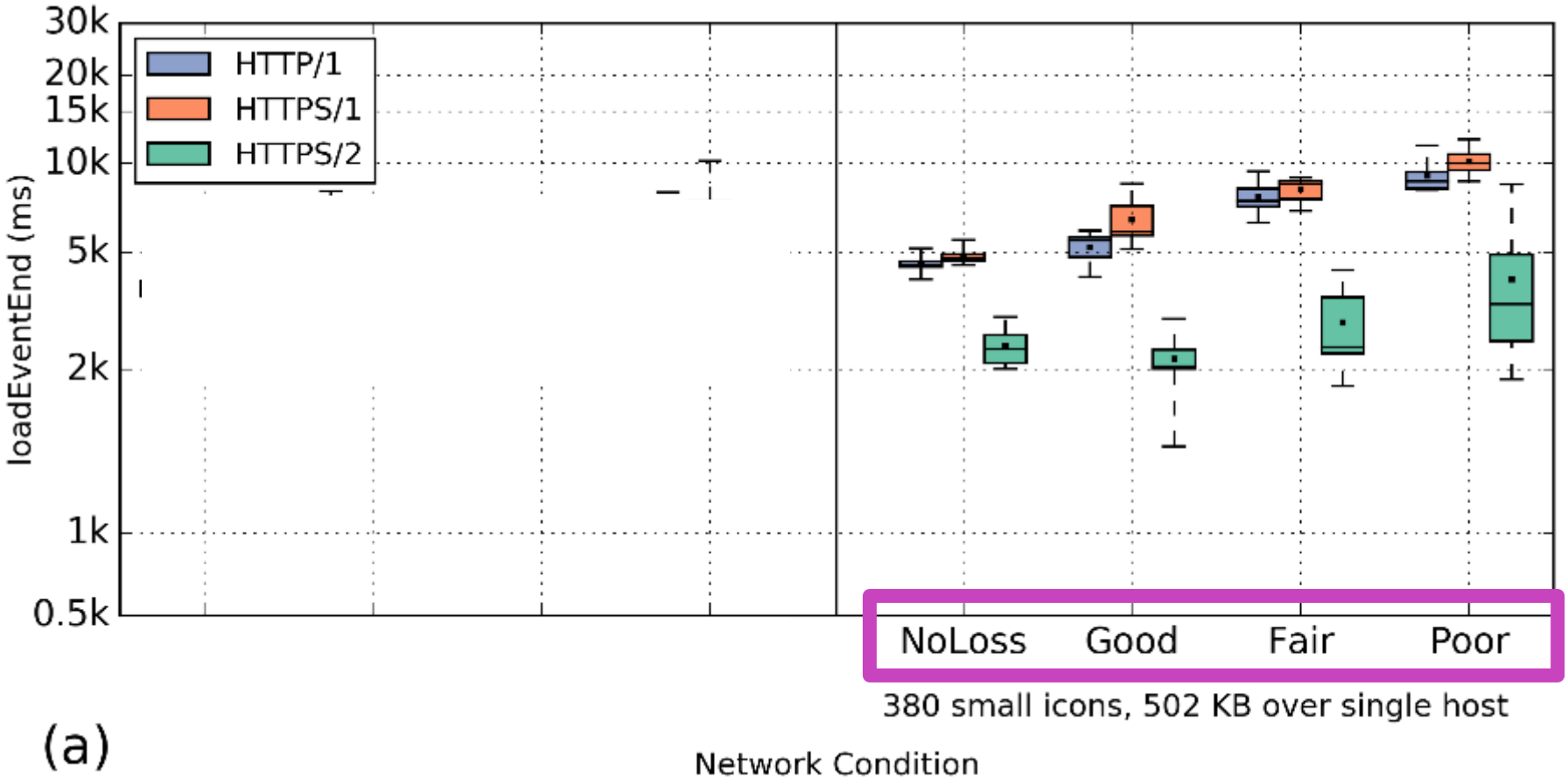
2. Sharding : 380 small images



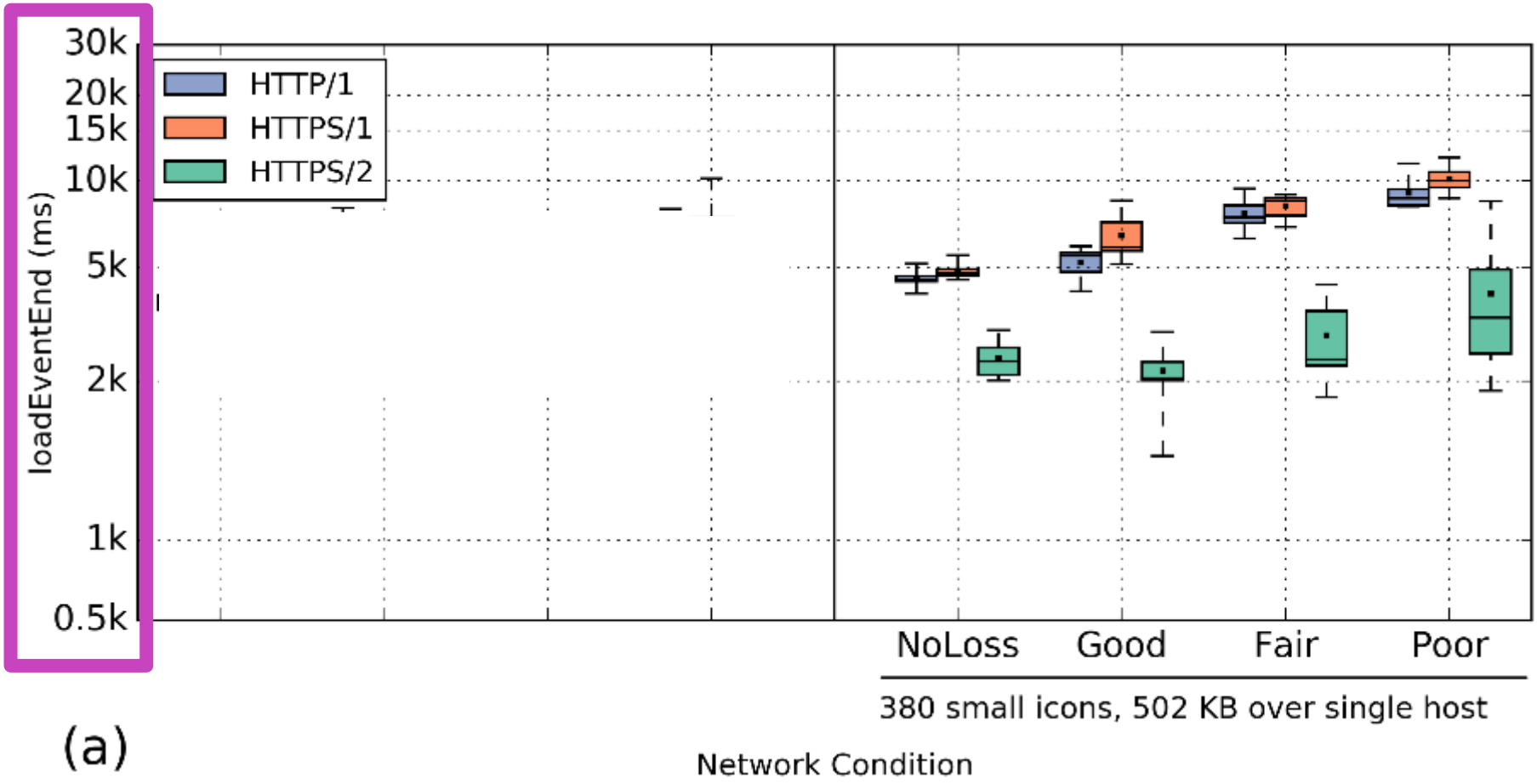
NOT OPTIMIZED

2. Sharding : 380 small images



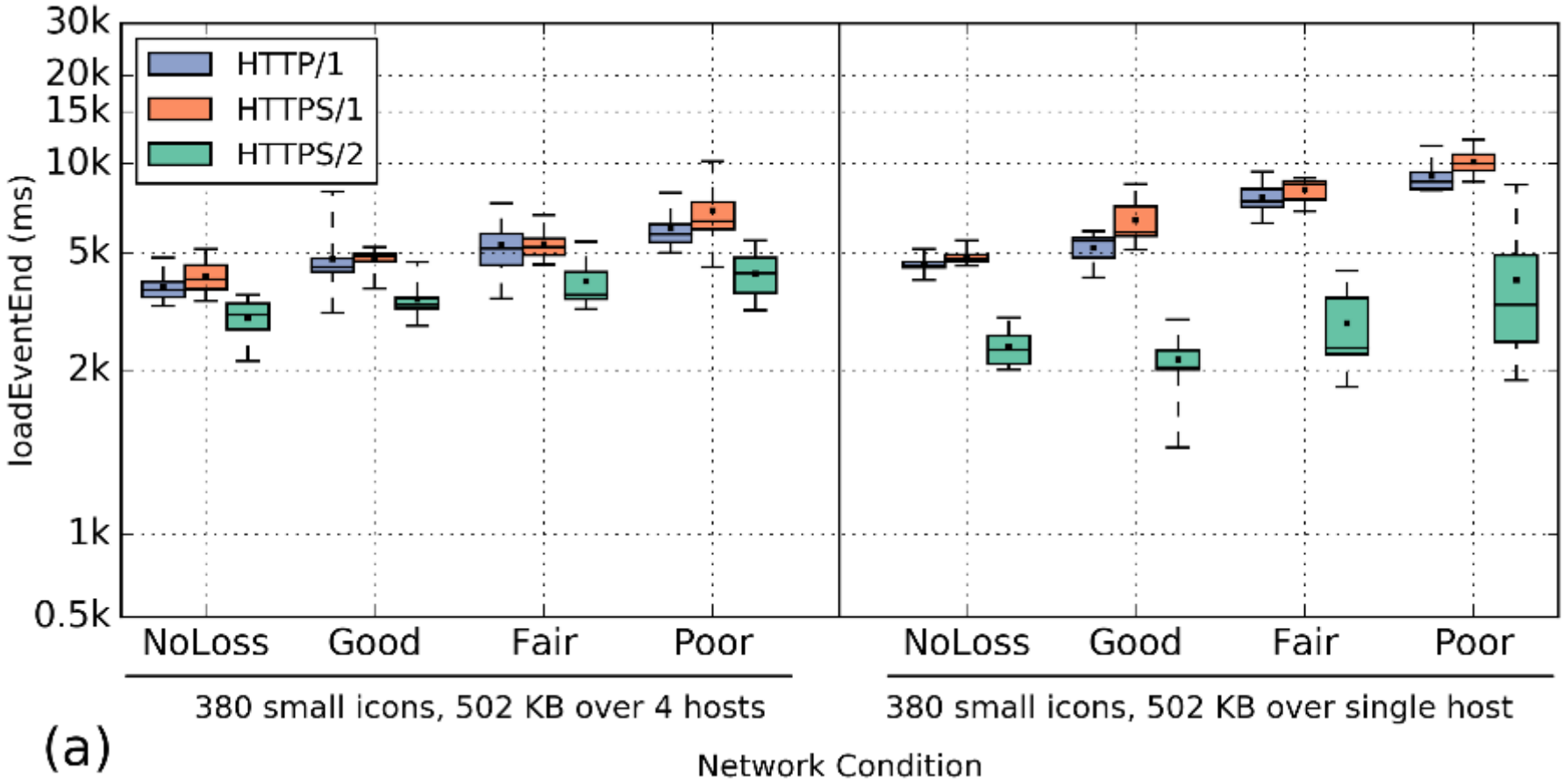
NOT OPTIMIZED

2. Sharding : 380 small images



NOT OPTIMIZED

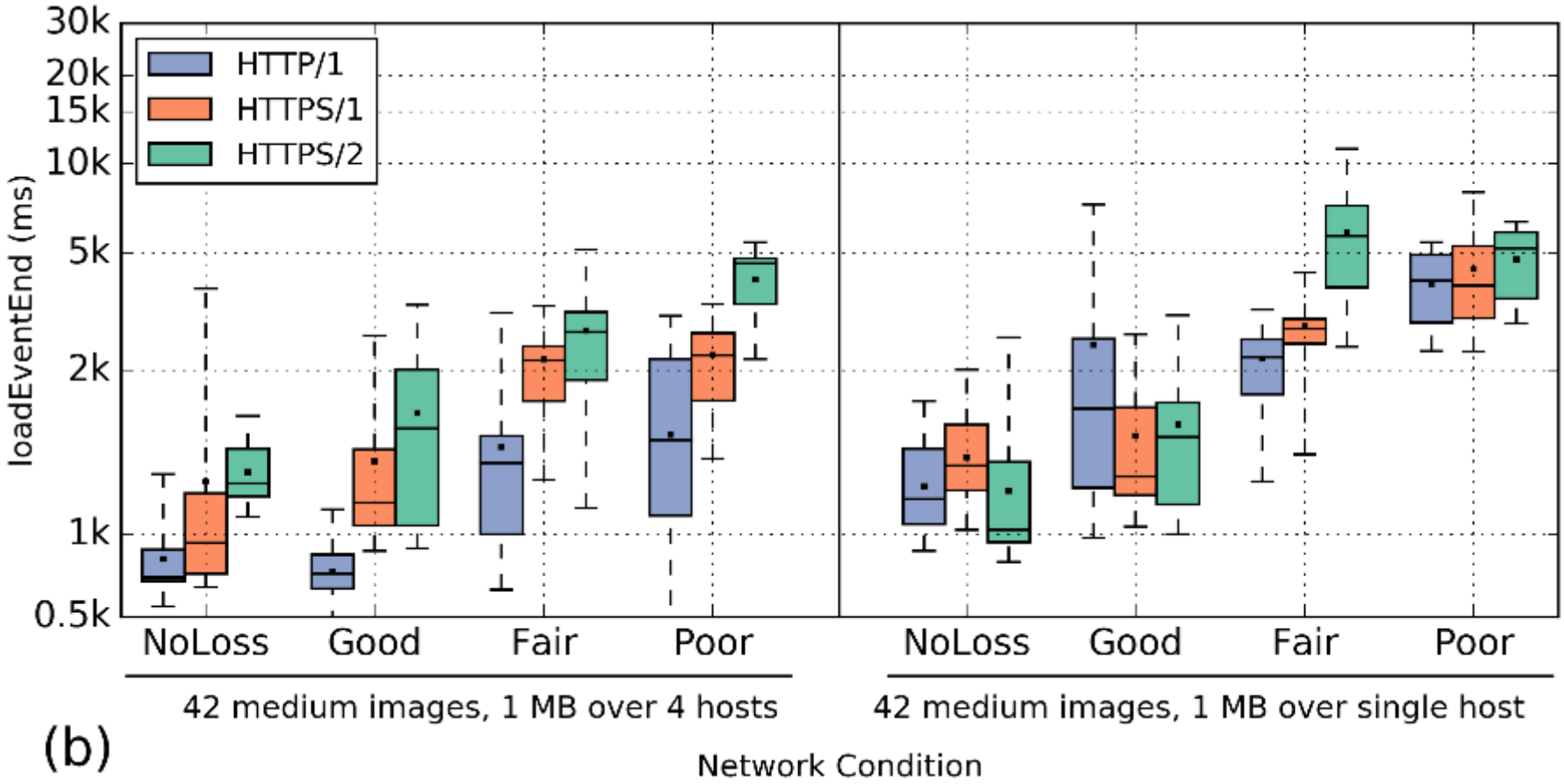
2. Sharding : 380 small images



OPTIMIZED

NOT OPTIMIZED

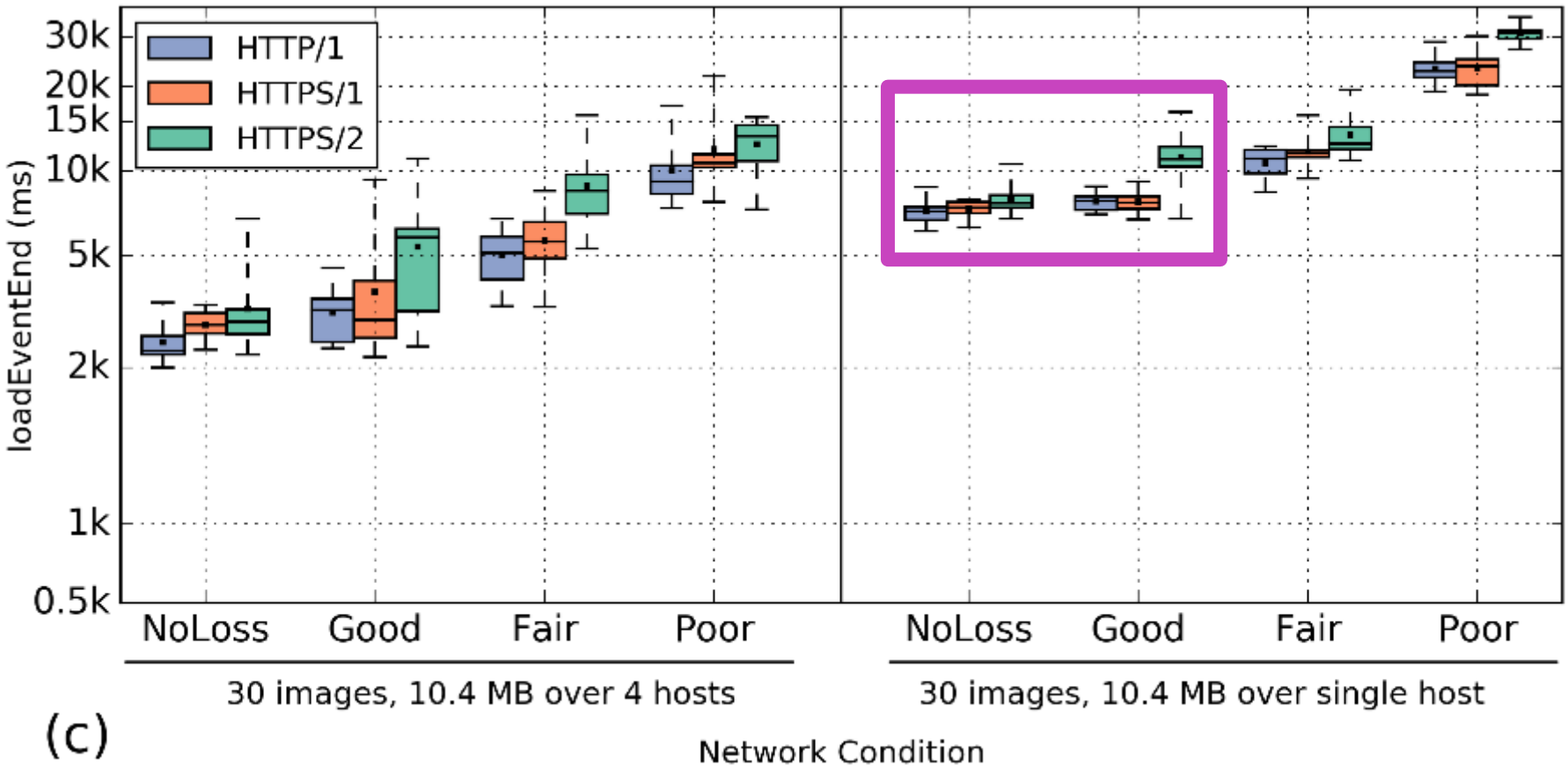
2. Sharding : 42 medium images



OPTIMIZED

NOT OPTIMIZED

2. Sharding : 30 large images



OPTIMIZED

NOT OPTIMIZED

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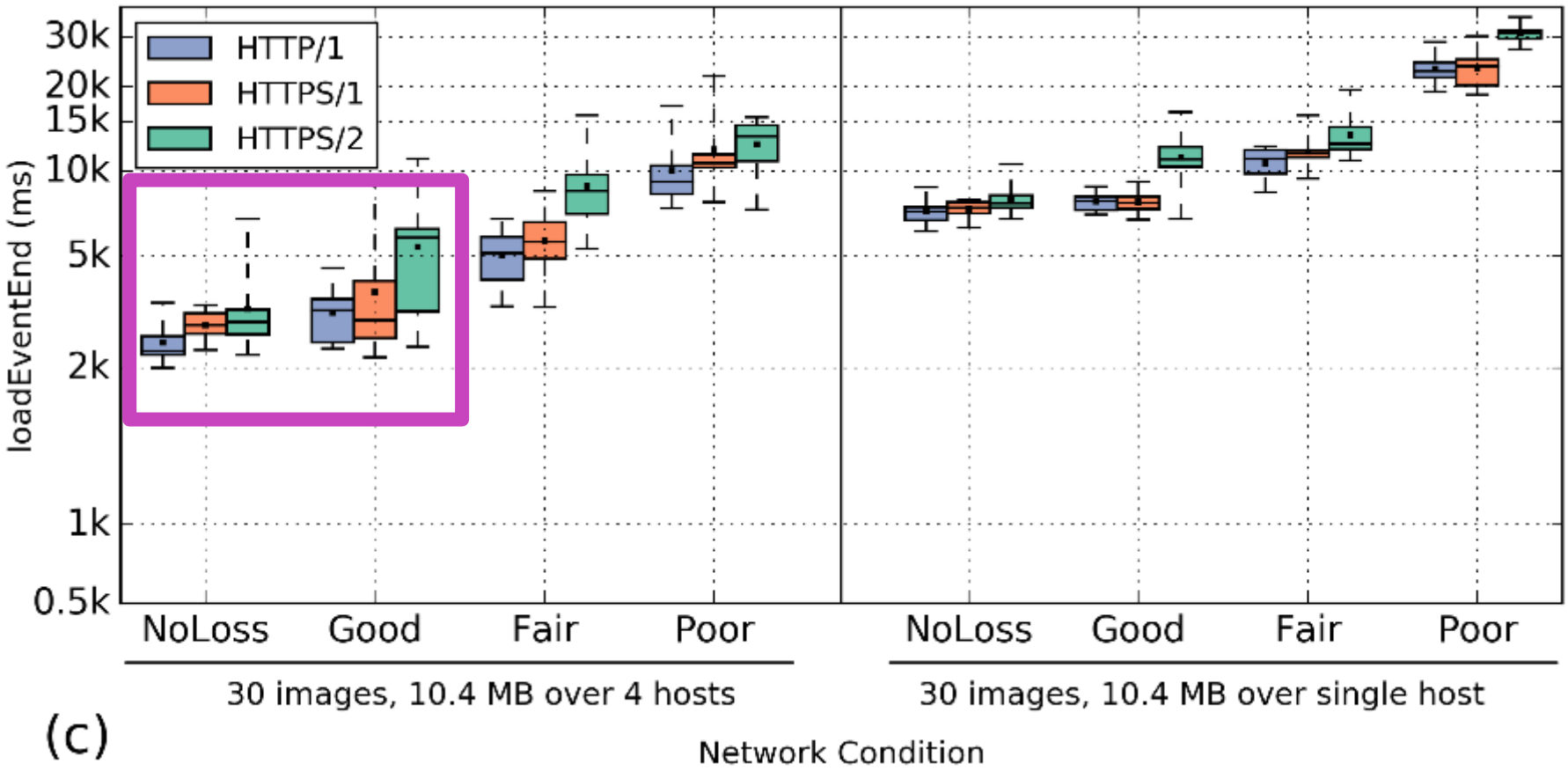
2. Sharding : 30 large images



OPTIMIZED

NOT OPTIMIZED

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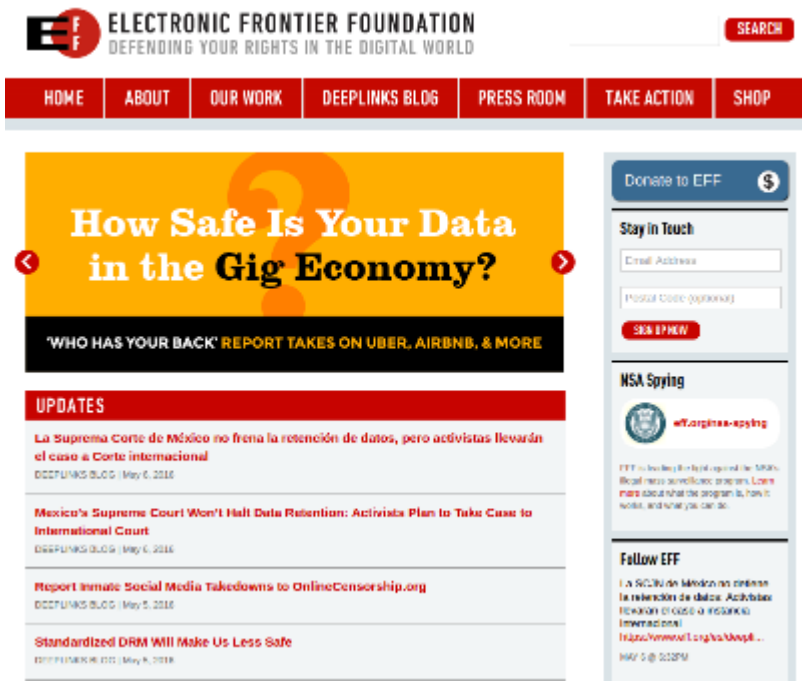
3. Embedding and Push

- Embedding : critical CSS
- Push : various test cases

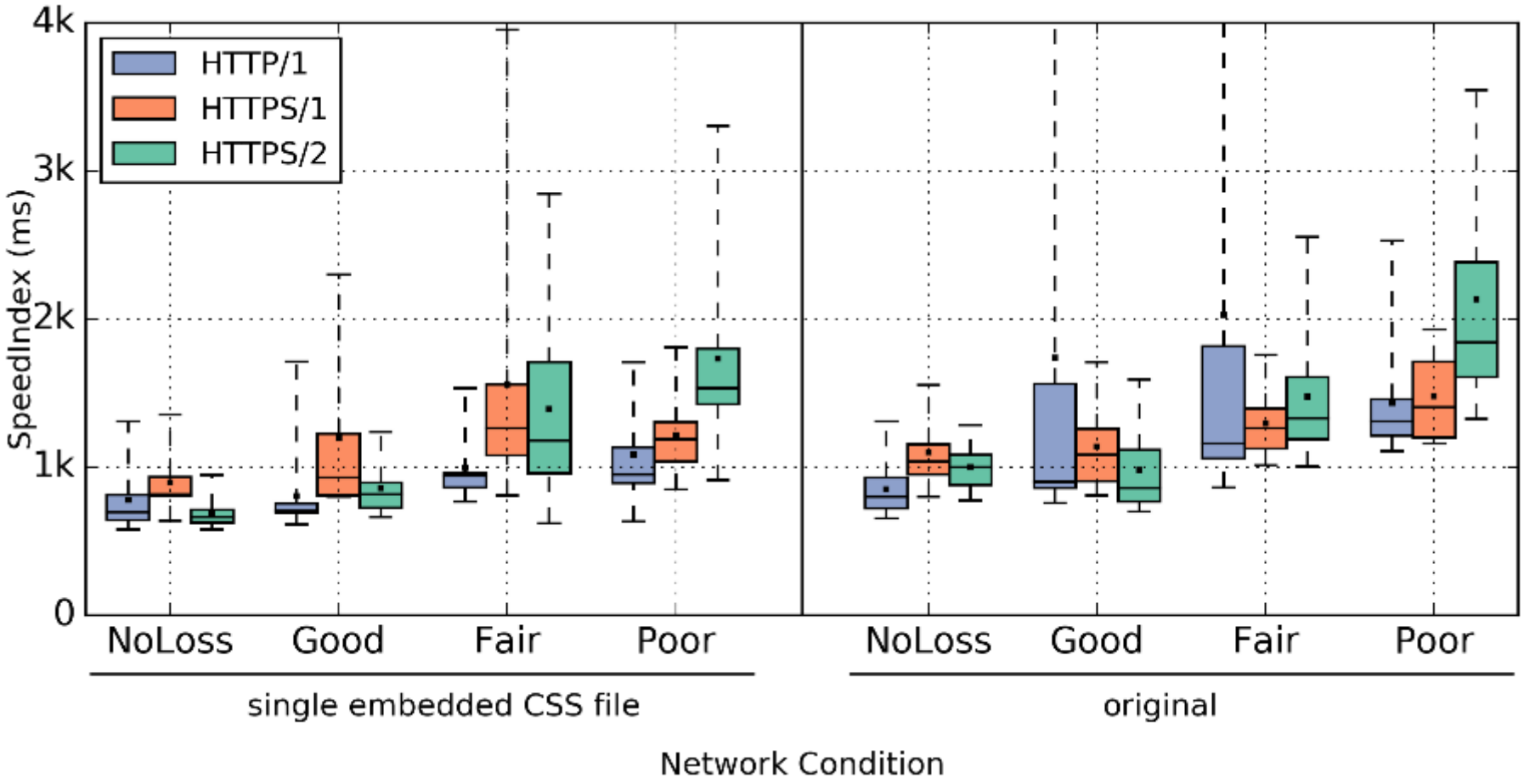


FULL SITE

CRITICAL CSS

https://github.com/bradleyfalzon/h2push-demo

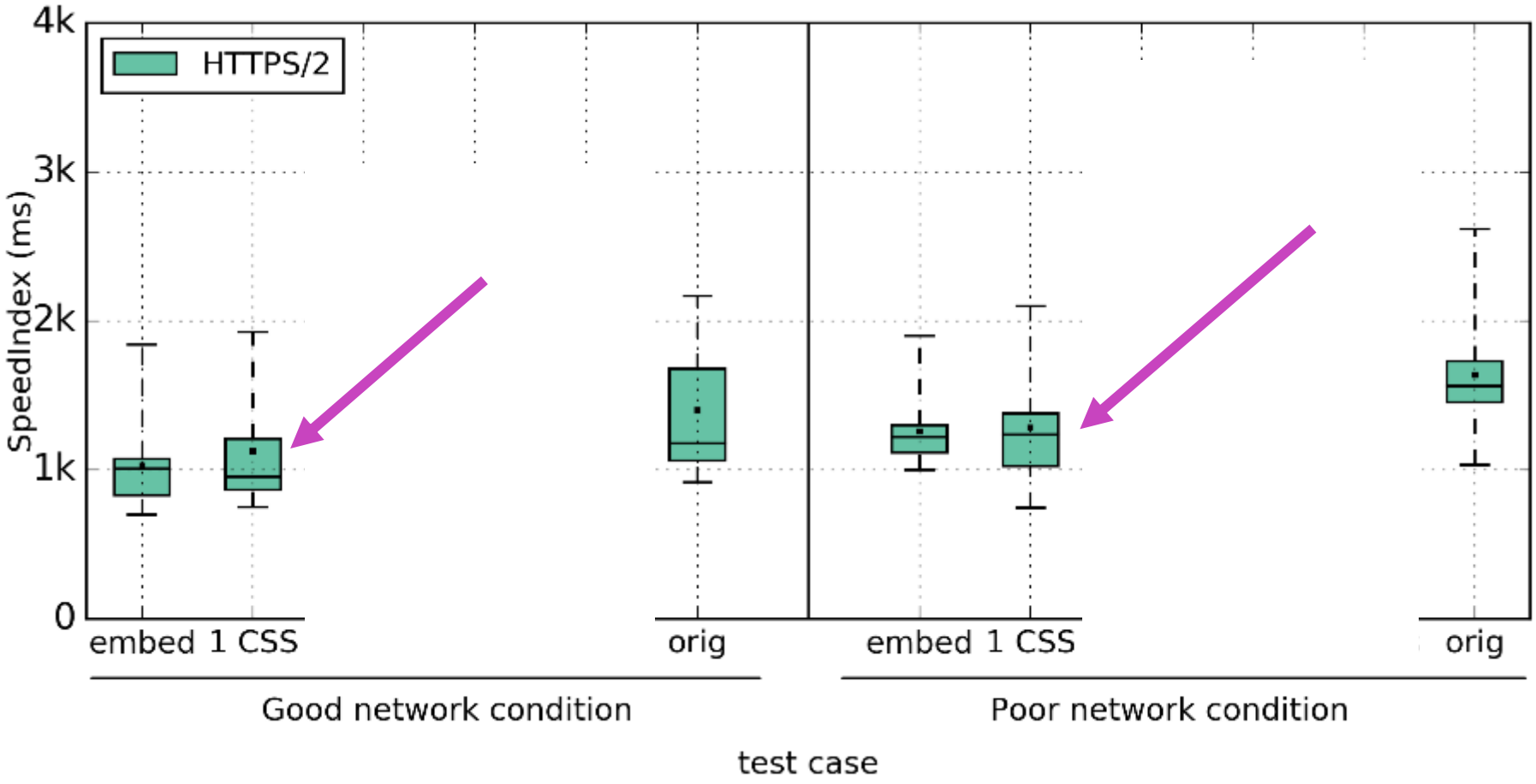
3. Embedding



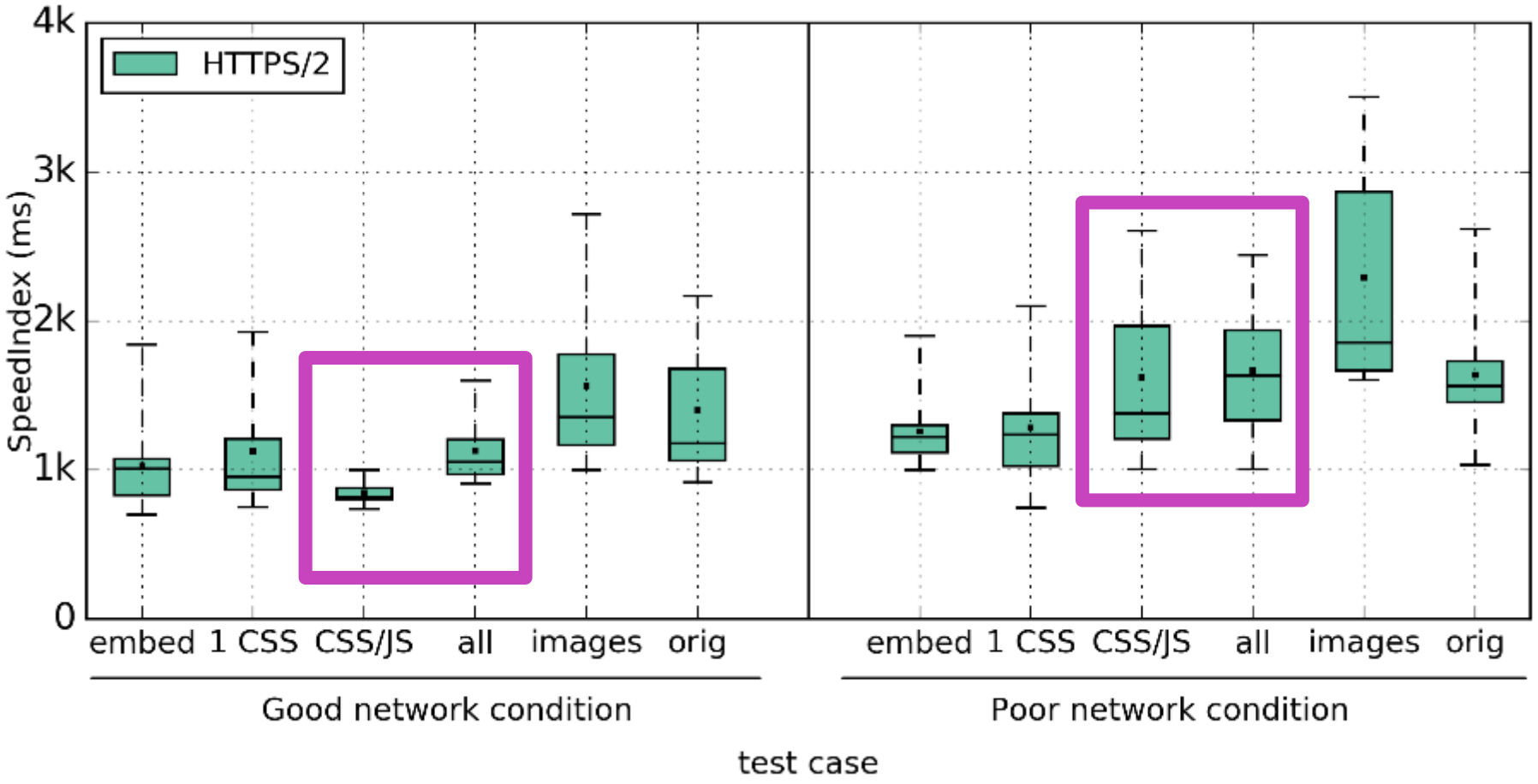
OPTIMIZED

NOT OPTIMIZED

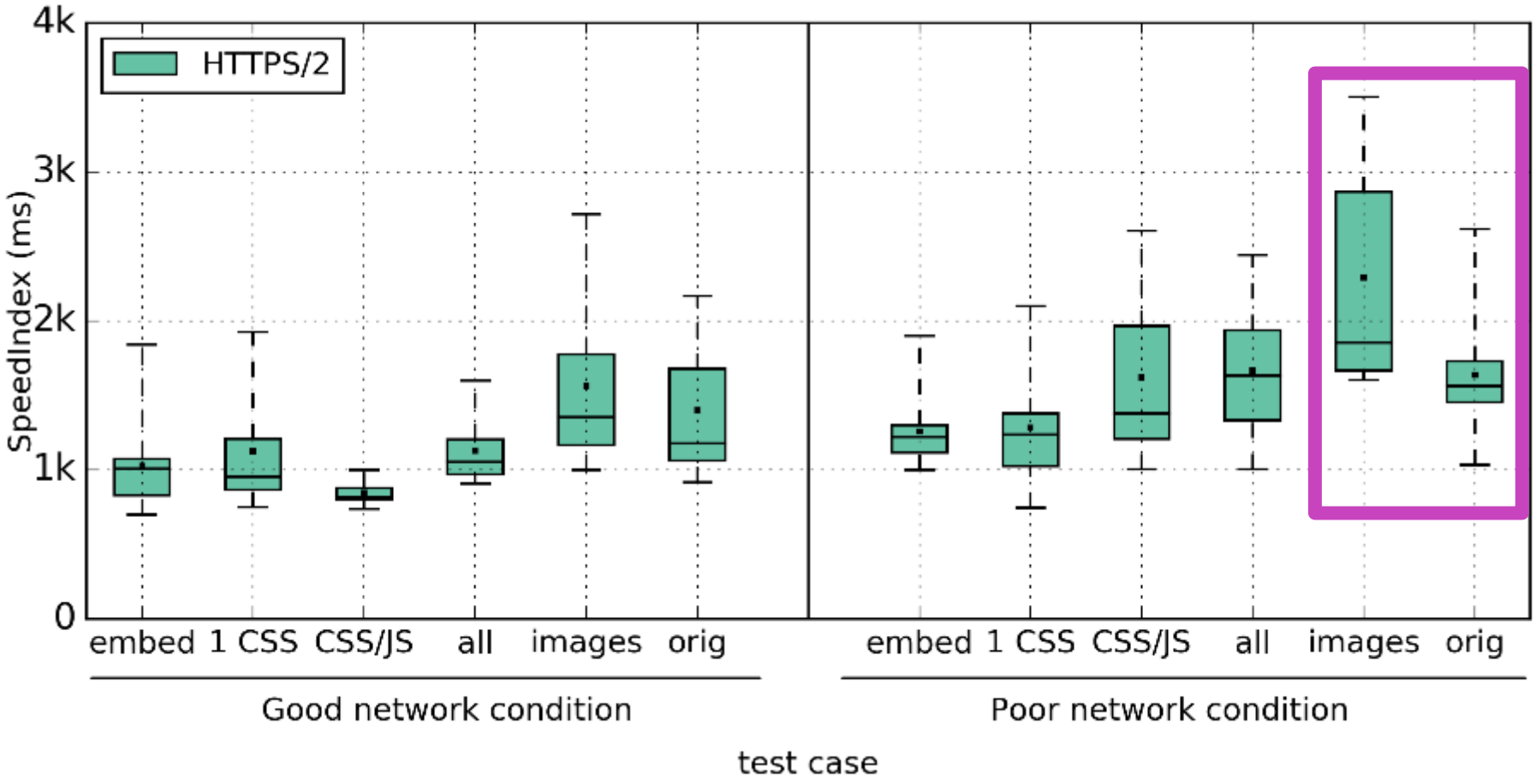
3. Push


HTTPS/2
SpeedIndex (ms)
4k
3k
2k
1k
0
embed 1 CSS
orig
embed 1 CSS
orig
Good network condition
Poor network condition
test case

3. Push

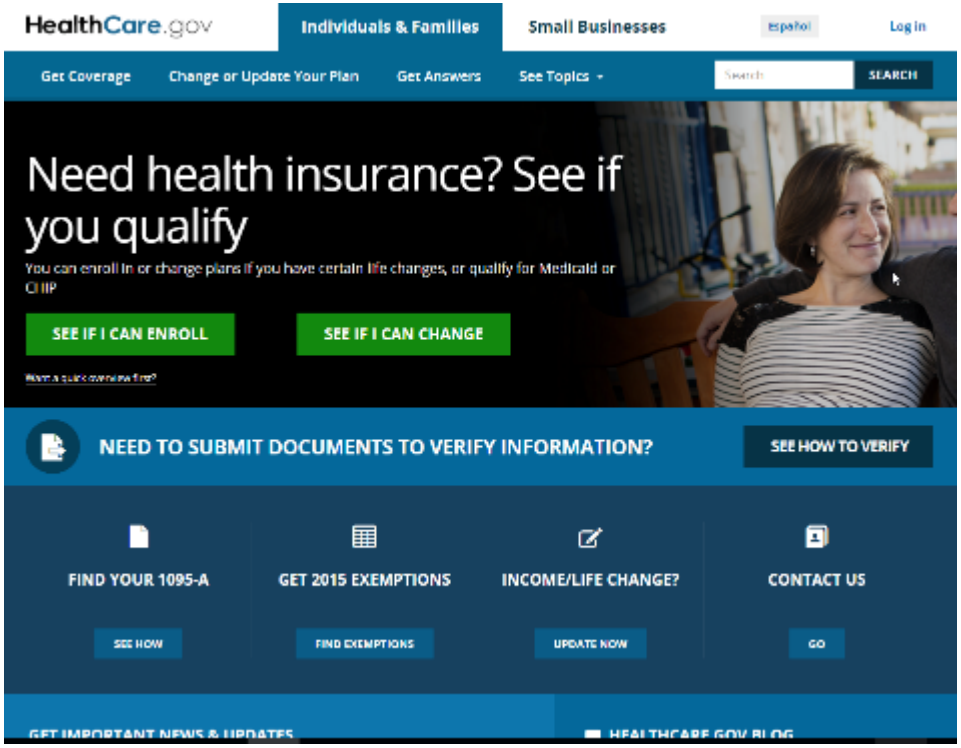

HTTPS/2
SpeedIndex (ms)
4k
3k
2k
1k
0
embed
1 CSS
CSS/JS
all
images
orig
embed
1 CSS
CSS/JS
all
images
orig
Good network condition
Poor network condition
test case

3. Push


HTTPS/2
SpeedIndex (ms)
4k
3k
2k
1k
0
embed
1 CSS
CSS/JS
all
images
orig
embed
1 CSS
CSS/JS
all
images
orig
Good network condition
Poor network condition
test case

4. Realistic websites

- How would a developer test H2 on his site?
- No sharding for main assets (~H2 should win)



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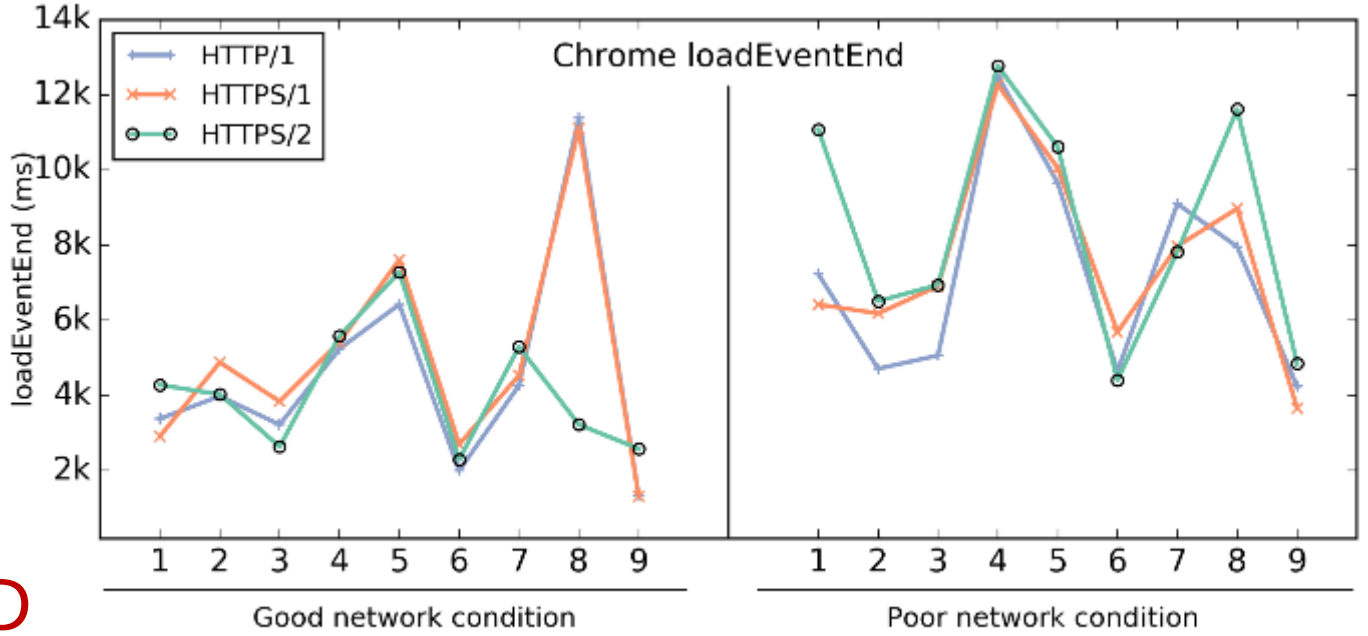
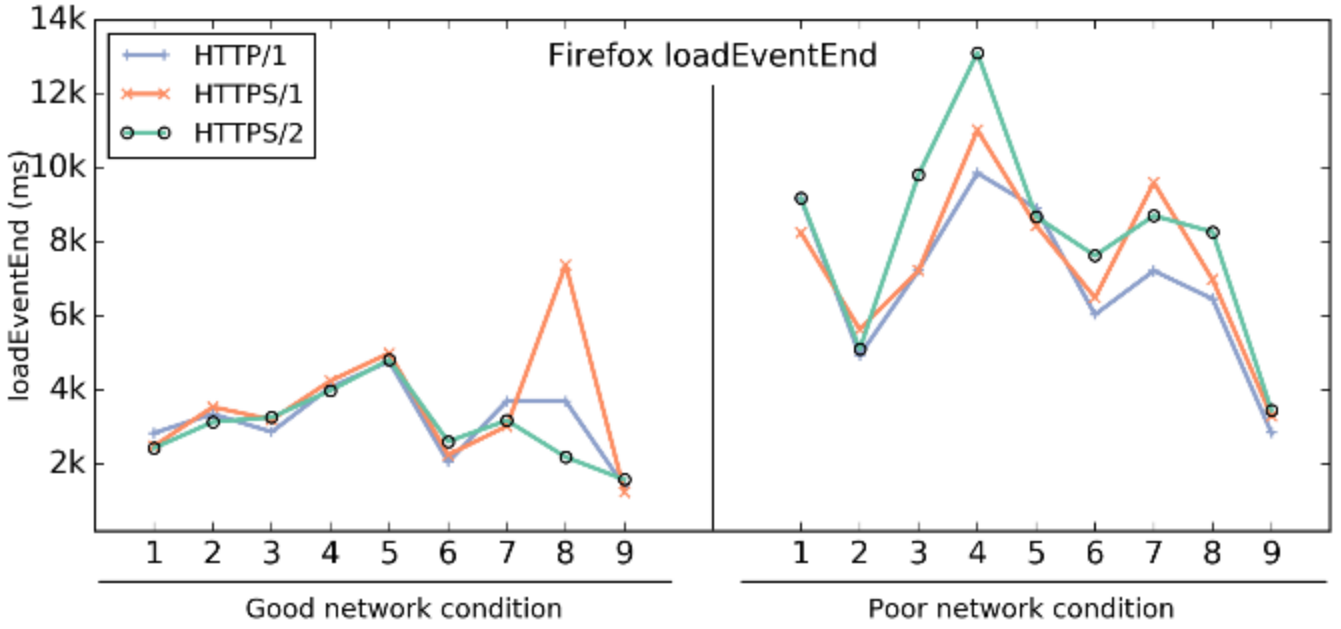
4.



GOOD

POOR



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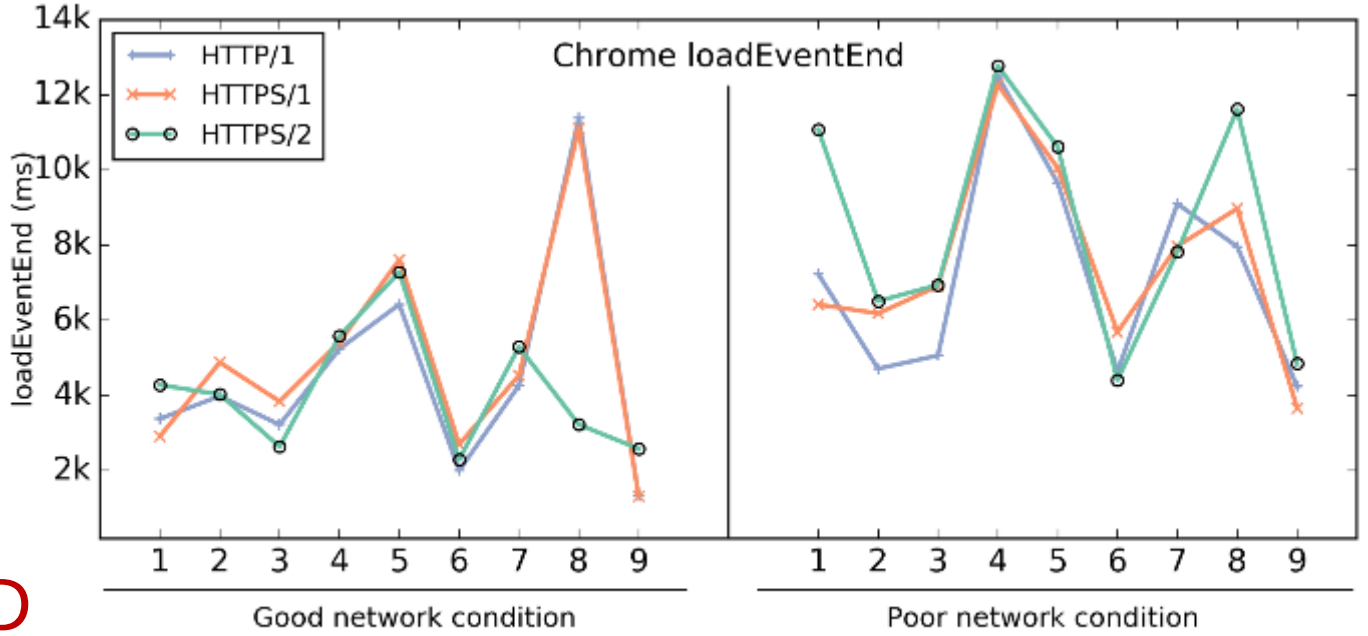
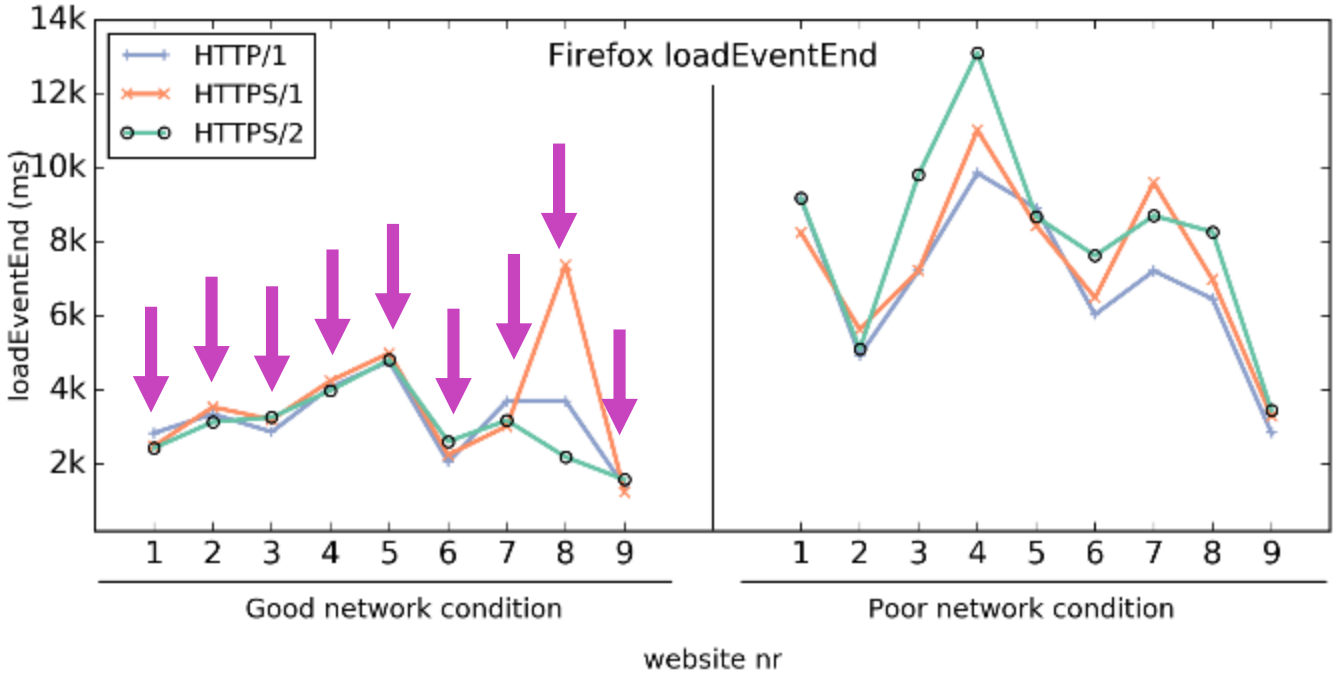
4.



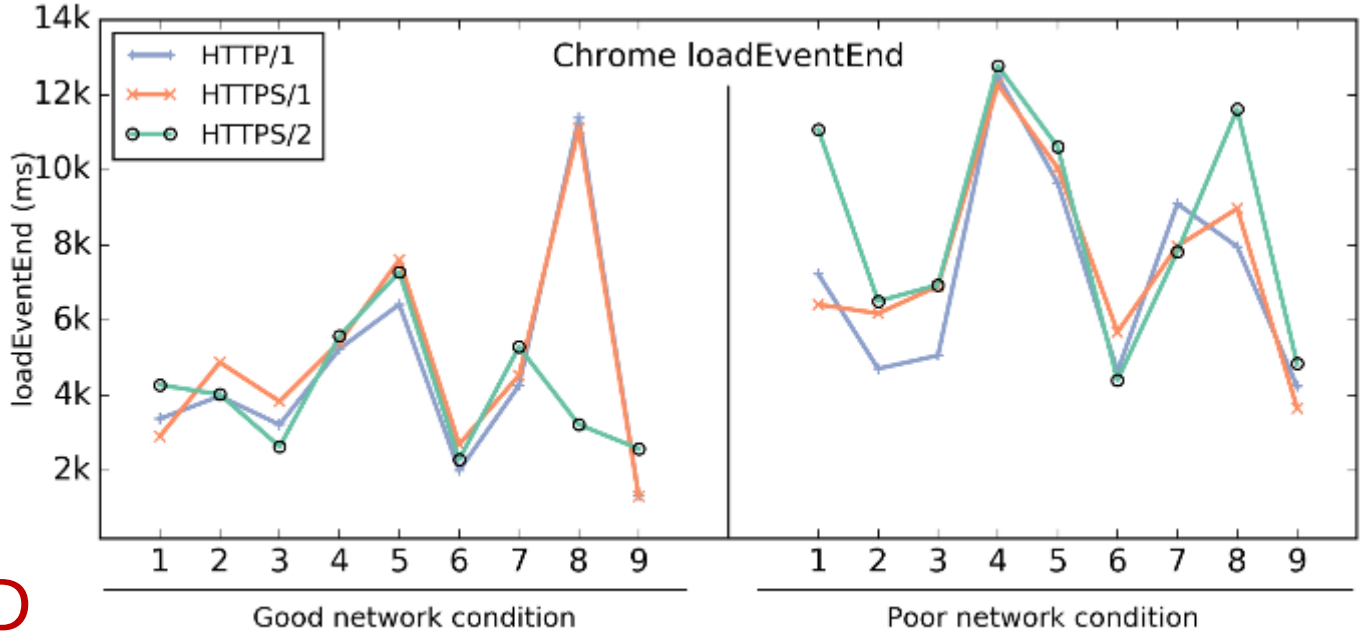
GOOD

POOR



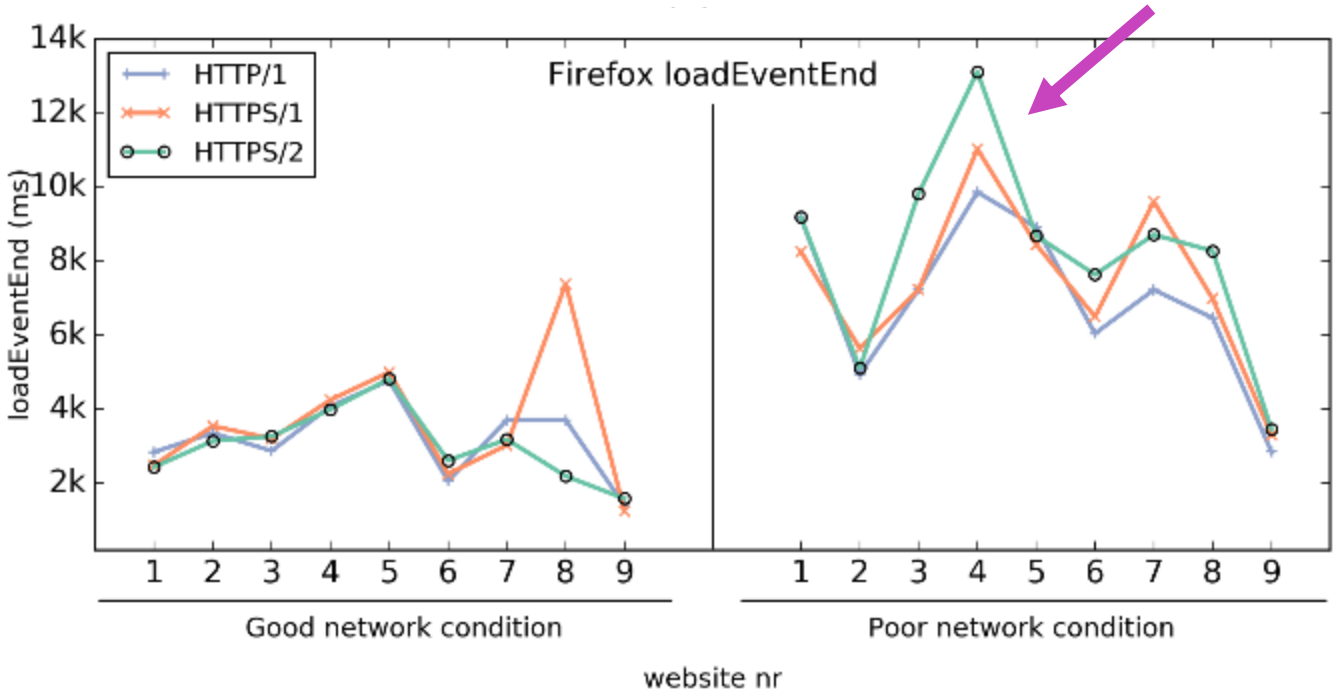
UHASSELT
KNOWLEDGE IN ACTION

4.



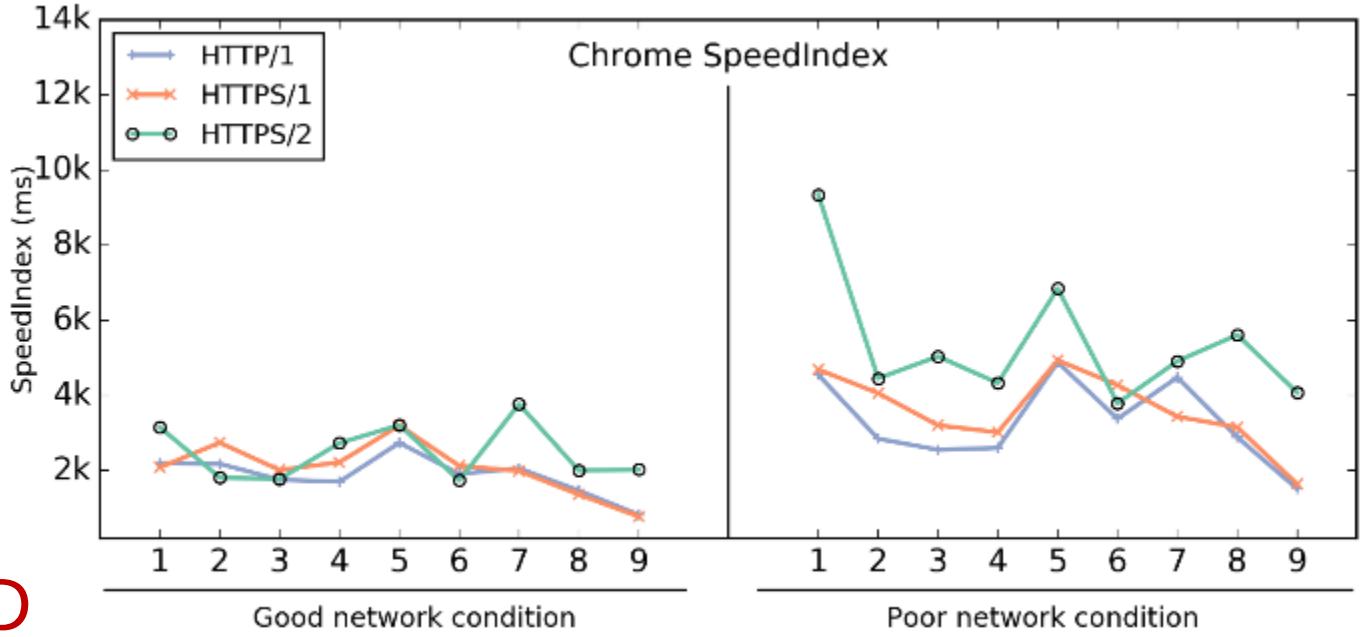
GOOD

POOR



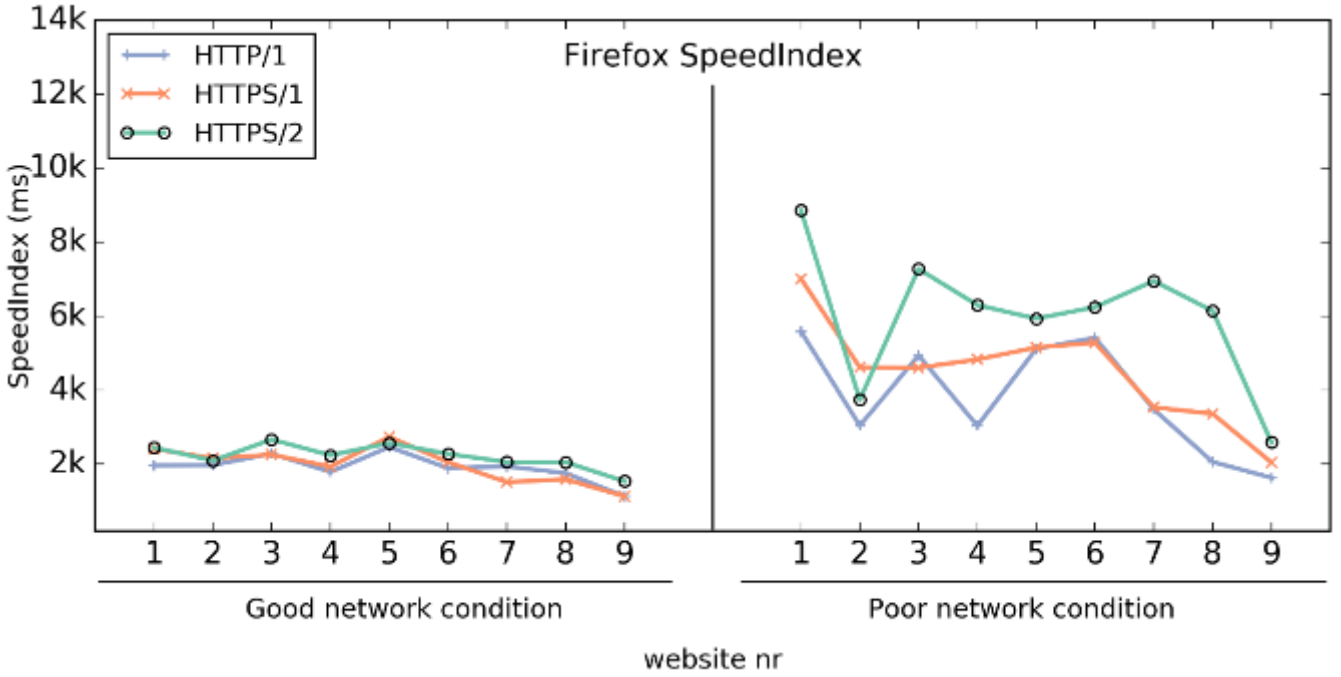
UHASSELT
KNOWLEDGE IN ACTION

4.



GOOD

POOR



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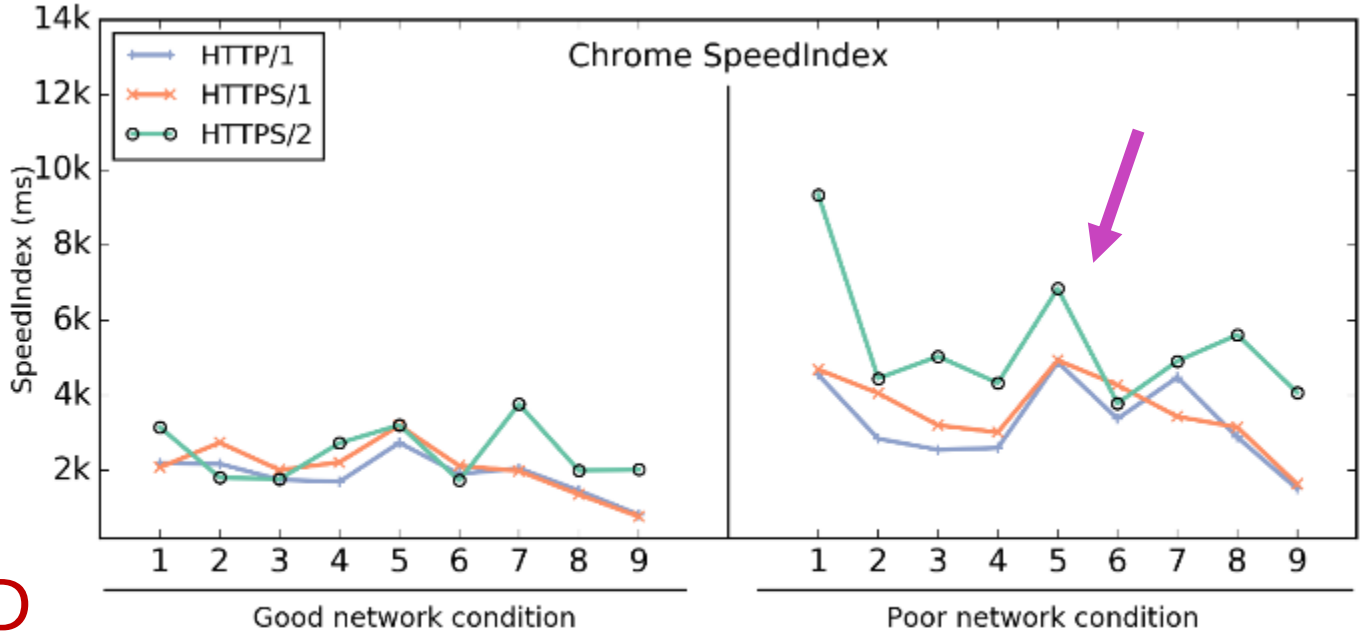
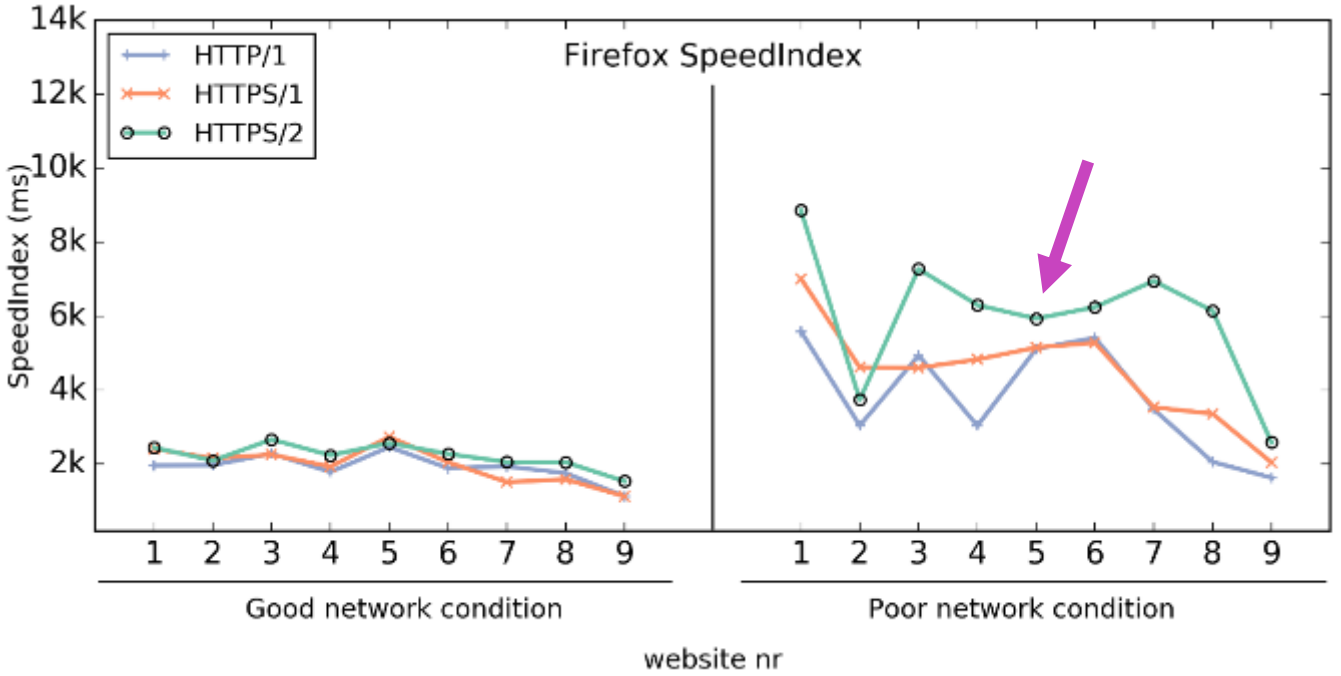
KNOWLEDGE IN ACTION

4.



GOOD

POOR



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Conclusions : HTTP/2

- Better for large amounts of small files
- Worse for larger files

- Suffers from bad networks but so does HTTP/1

- For most "average" testcases, performance is similar between H1 and H2, with (much) less overhead (# connections) from H2

Conclusions : HTTP/1 Best Practices

- Concatenation: implementation-limited
- Sharding: protocol-inherent
- Embedding: can be replaced by Push

- Most "average" H1 websites can be transferred to H2 without much work ☺

Conclusions : Outlook

- More fine-grained caching (web components, Single Page Apps, …)
- Bigger websites remain difficult (4k images, VR/gaming, …)

- QUIC is already being standardized!

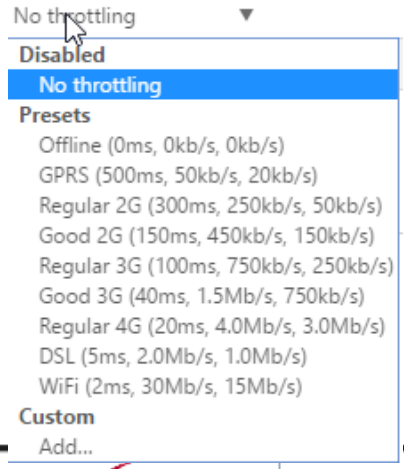
Ask me about:

- Cellular network emulation
- QUIC protocol
- TCP slow start and embedding/push
- HPACK header compression
- Browser rendering behavior
- Website optimization anecdotes
- Docker / The Speeder Framework
- HTTPS vs HTTP cleartext
- Other uses of HTTP/2 Push

Cellular network emulation

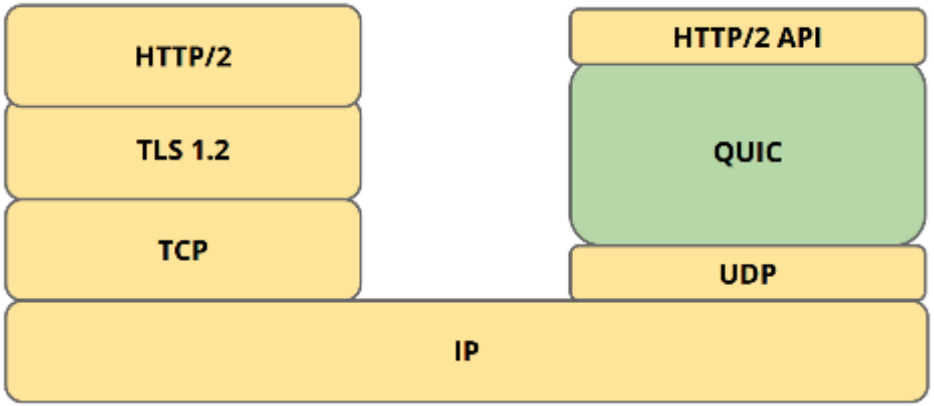
- "Http/2 performance in cellular networks" (Goel et al., 2016) – MobiCOM
- Traces of real networks @ CDN edge
- Modulate `TC NETEM` parameters every 70 ms
- https://github.com/akamai/cell-emulation-util

- Fixed model based on Chrome Devtools
  - Add loss
  - Typically clearer but similar trends



QUIC protocol

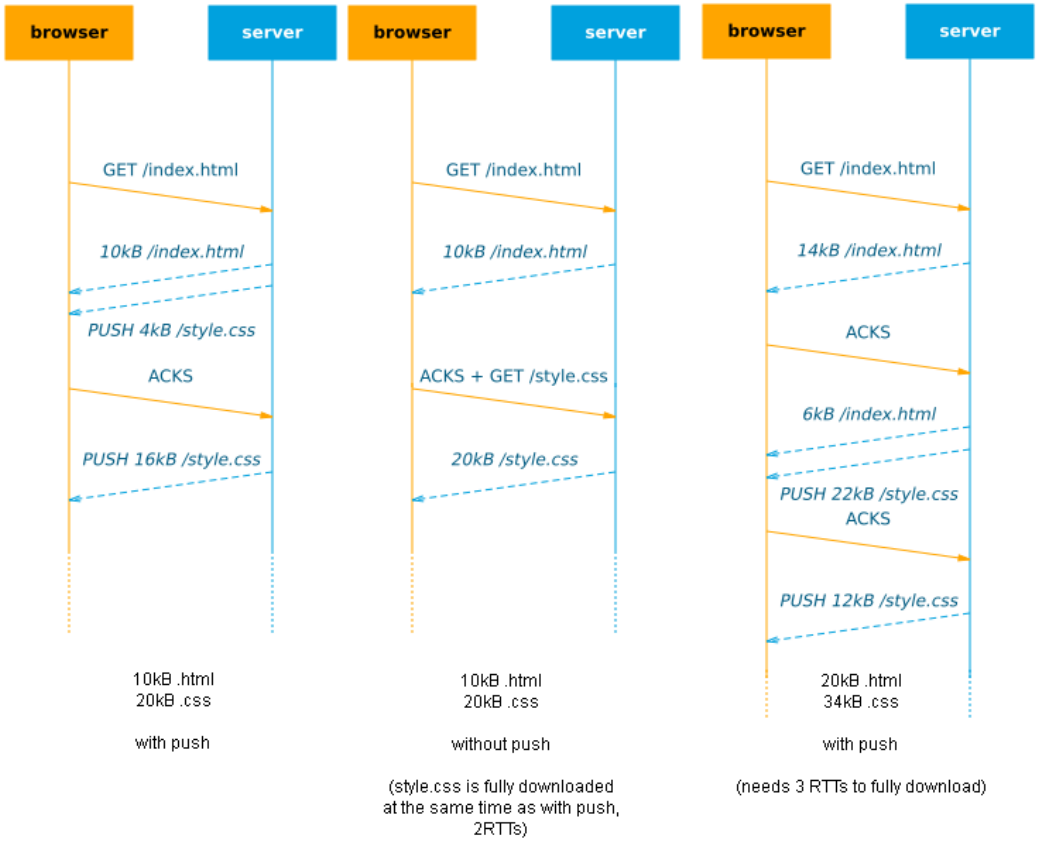
- QUIC = Quick UDP Internet Connections
  - "Re-implement TCP in application layer" ~TCP 2.0
  - Removes TCP HOL-blocking and adds smarter flow-control / less sensitive to loss
  - FEC, Connection UUID/handoffs, multipath, …



- https://ma.ttias.be/googles-quic-protocol-moving-web-tcp-udp/

TCP slow start and embedding/push

- TCP slow start uses congestion window
  - Initial value is ~14KB in modern linux
  - Grows when data is ACK'ed (takes roundtrip)
- If data > 14KB limit, additional RTTs needed!



HPACK header compression

- HTTP headers are often the same
  - Especially important for large cookies
- HPACK uses dynamic dictionary encoding
  - Learns during connection, builds dict at both sides

Table 4: Total bytes sent by Google Chrome (~ HTTP headers) and ratio to total page size. For many small files, the HTTP header overhead is significant.

File count	Protocol	1 host BytesOut	4 hosts BytesOut	Total page size	4 hosts % of total page size
42 files	h2s	649	1362	1075000	0.1%
	h1s	2786	3346	1075000	0.3%
400 files	h2s	29580	38680	610000	6%
	h1s	165300	177600	610000	19%

Browser rendering behavior

- "Render blocking"
  - CSS and sync JS : could change DOM/CSSOM!
- Mitigation: Place on bottom of <body>

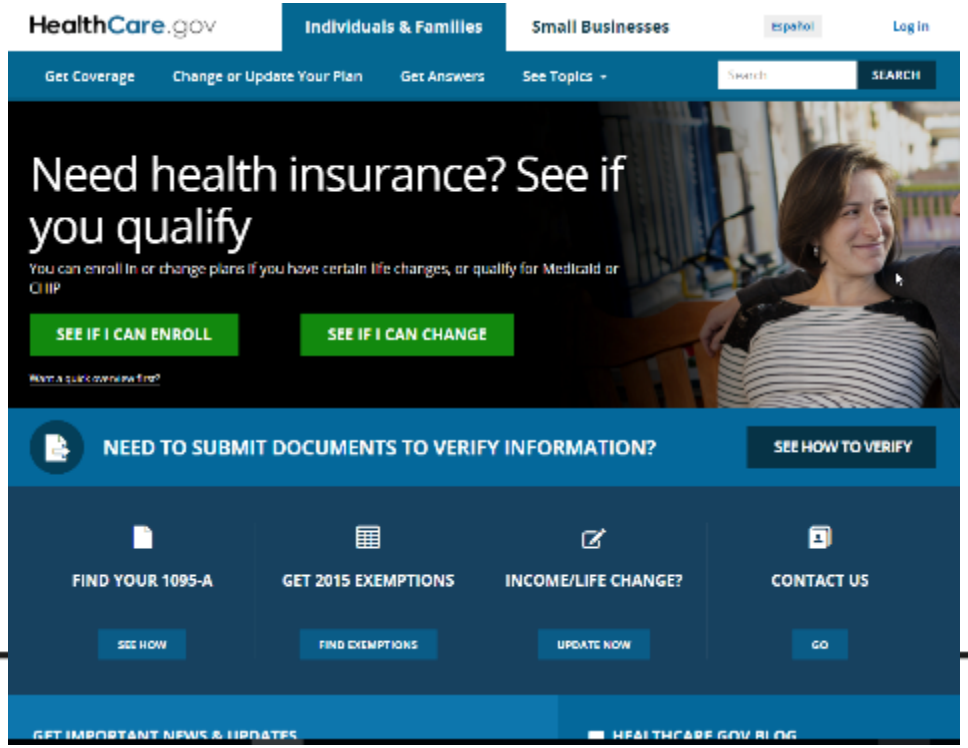
Table 3: Observed browser render-blocking behavior. Chrome blocks on too much, while Firefox doesn't seem to block on anything.

	Expected <head>	**Chrome** <head>	**Firefox** <head>
CSS	blocking	blocking	*progressive*
JavaScript	blocking	*progressive*	*progressive*

	Expected bottom	**Chrome** bottom	**Firefox** bottom
CSS	progressive	*blocking*	progressive
JavaScript	progressive	progressive	progressive

Website Optimization anecdotes

- Hero image halfway on the page
  - 6 HTTP/1 connections had been taken up, HTTP/2 gives all images same priority
  - Concatenation : only benefits HTTP/1
  - Moving image up in HTML : benefits both



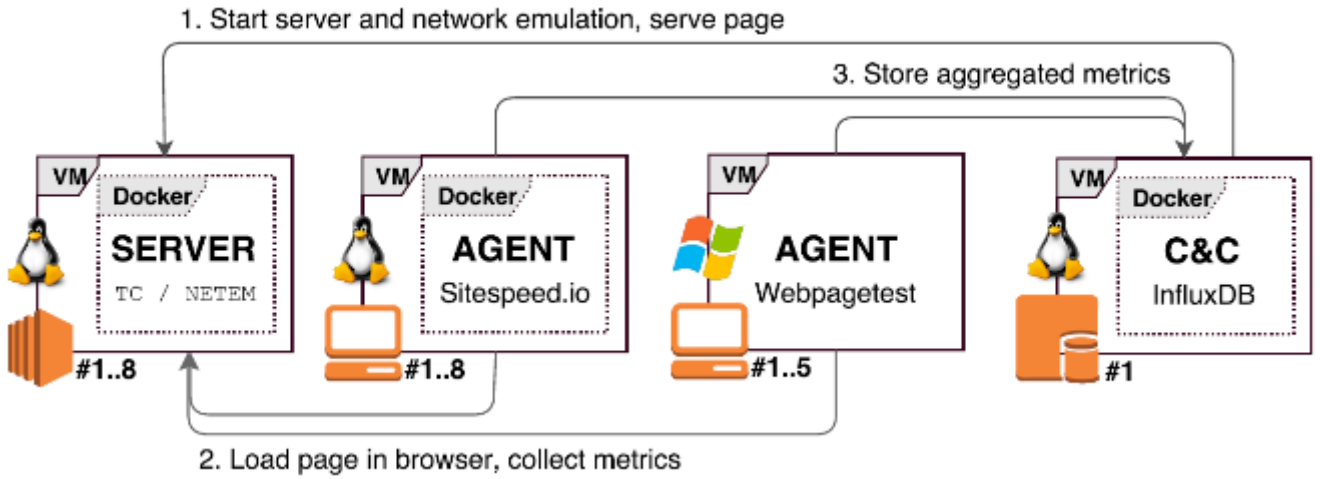
Website Optimization anecdotes

- Embedding is Best Practice!
  - Let's embed our fonts as well! Base64-style!
  - Embeds > 100KB in fonts that are not cached…
  - Every new page load, flash-of-unstyled-content despite embedding

imec UHASSELT KNOWLEDGE IN ACTION

Docker / The Speeder Framework

- 3 Docker containers
  - Base (C&C), Backend and Agents
  - Dockerfile is easy to update, rebuild, deploy
- 5 private WebPageTest instances
- C&C starts instances and restarts all running software before each test
- Spread over 16 Linux VMs and 5 Windows VMs



Docker / The Speeder Framework

- Simple GUI for starting tests

0 tests sheduled

Testrun:
debug_test

Label:

Run count:
2

Option 1 : choose a locally served testcase (use Speeder backend setup)

Testcases: 0 / 286

- 2v1_aggregation 0 / 57
- 2v1_aggregationComplex 0 / 57
- 2v1_aggregationLibrary 0 / 13
- 2v1_domainSharding 0 / 10
- 2v1_gzlib 0 / 16
- 2v1_http2Priority 0 / 4
- 2v1_images 0 / 11
- 2v1_inlining 0 / 33
- 2v1_inliningComplex 0 / 33
- 2v1_loadingJS 0 / 8
- 2v1_redirect 0 / 9
- 2v1_sanitychecks 0 / 1
- 2v1_serverPush 0 / 24
- 2v1_template 0 / 2
- H2priorities_H2oWithVsWithoutHttp2Prios 0 / 1
- H2priorities_test1debug 0 / 1
- VoDLib_NginxVsNode 0 / 4
- drupal_main 0 / 0
- examples_customconfigs 0 / 2

Backends:

- node
- nginx
- apache
- custom

Frontends:

- sitespeed
  - chrome
  - firefox
  - slimer
- browsertime_chrome
- SRUMdriver_chrome
- SRUMextension_chrome
- wpt
  - chrome
  - firefox
  - ie

Protocols:

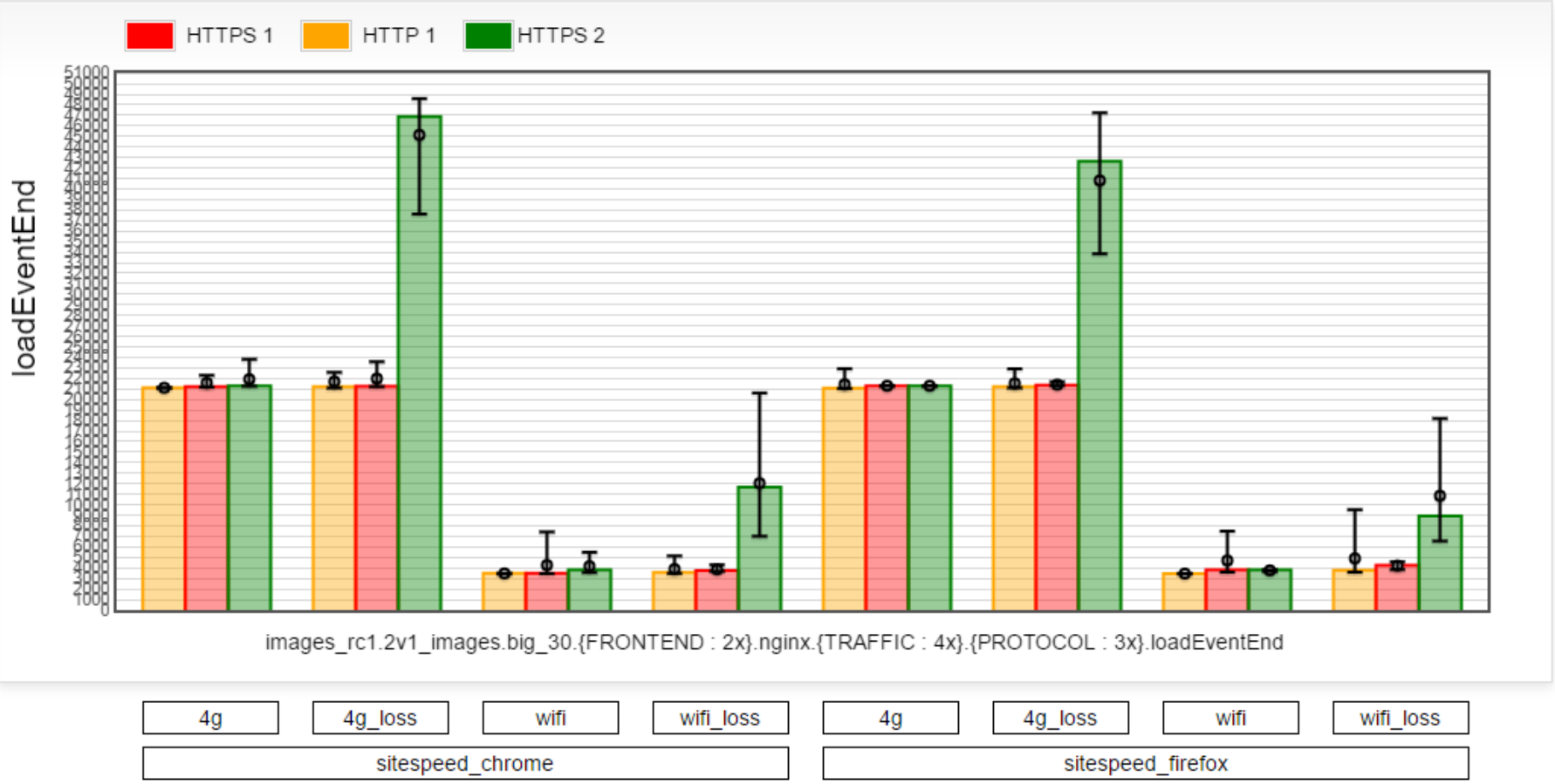
- HTTPS 2
- HTTPS 1.1
- HTTP 1.1

Traffic:

- none
- wifi
- wifi_transatlantic
- wifi_transatlantic_loss
- 4g
- 4g_transatlantic
- 4g_transatlantic_loss
- 3g_loss
- 2g_loss
- cellular_noloss
- cellular_good
- cellular_fair
- cellular_passable
- cellular_poor
- cellular_verypoor

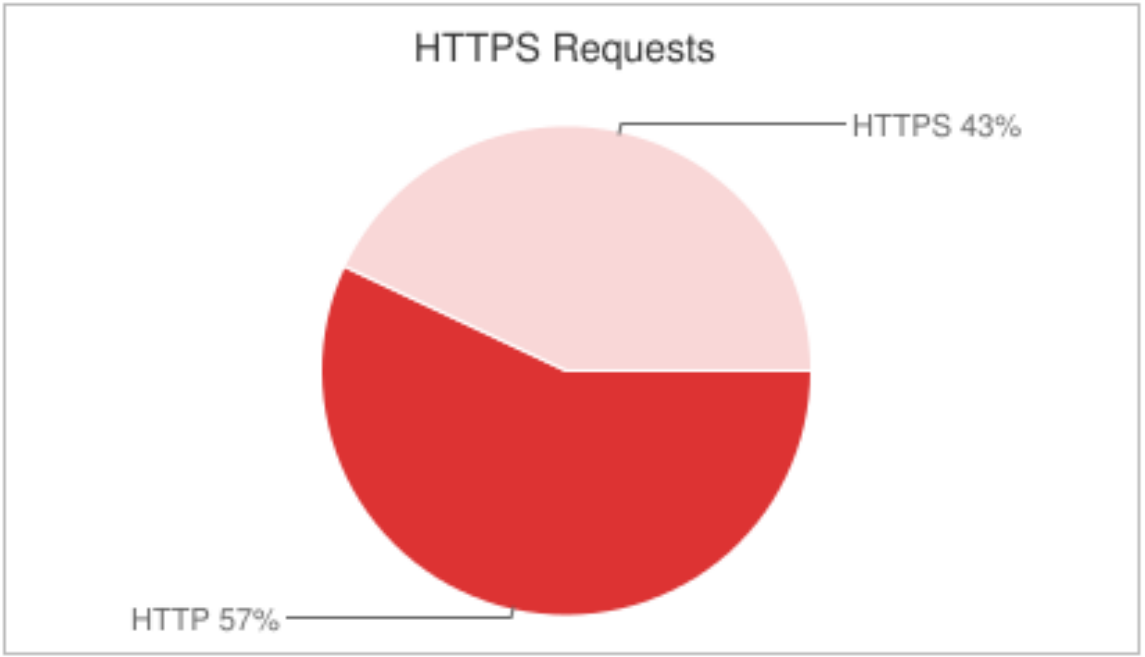
Docker / The Speeder Framework

- Quick graphing of results



HTTPS vs HTTP cleartext

- Push towards a safer web
- H2 cleartext isn’t supported by any browser
- Many of the newer (performance) features only work over HTTPS



httparchive.org

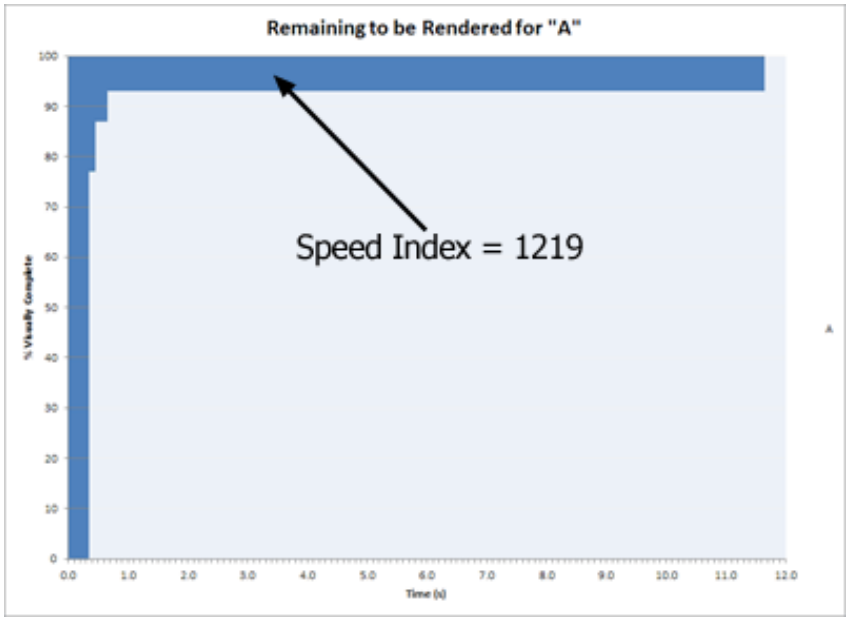
Other uses of HTTP/2 Push

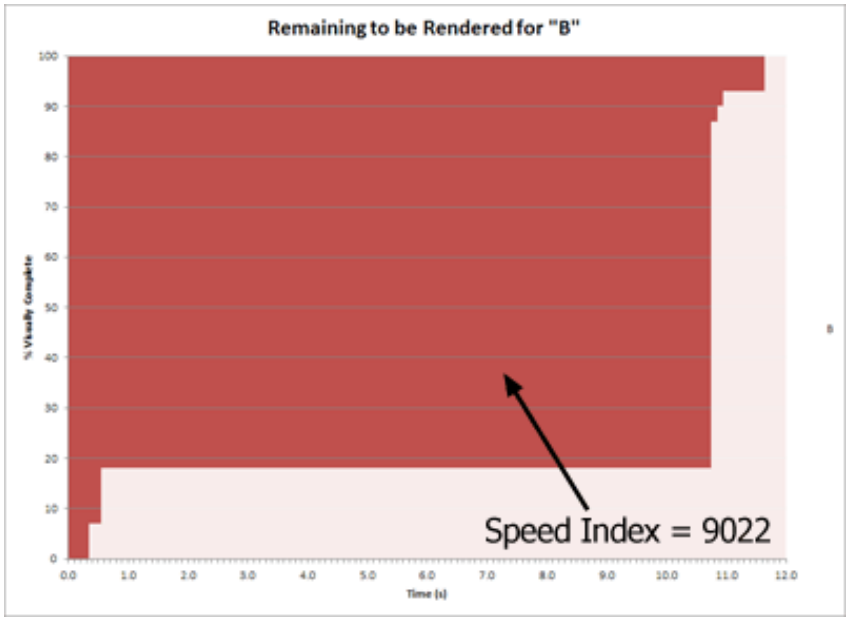
- Warm vs cold connections
- Single Page Apps / REST APIs
- Service Workers
- Video streaming
- CDN-side

- But: Caching problems!
- But: Server support!
- But: Re-prioritization!

loadEventEnd vs SpeedIndex

- SpeedIndex
  - % of visual complete over time (video frames!)
  - Quick to render = better for user experience
  - Measured in milliseconds = LOWER IS BETTER





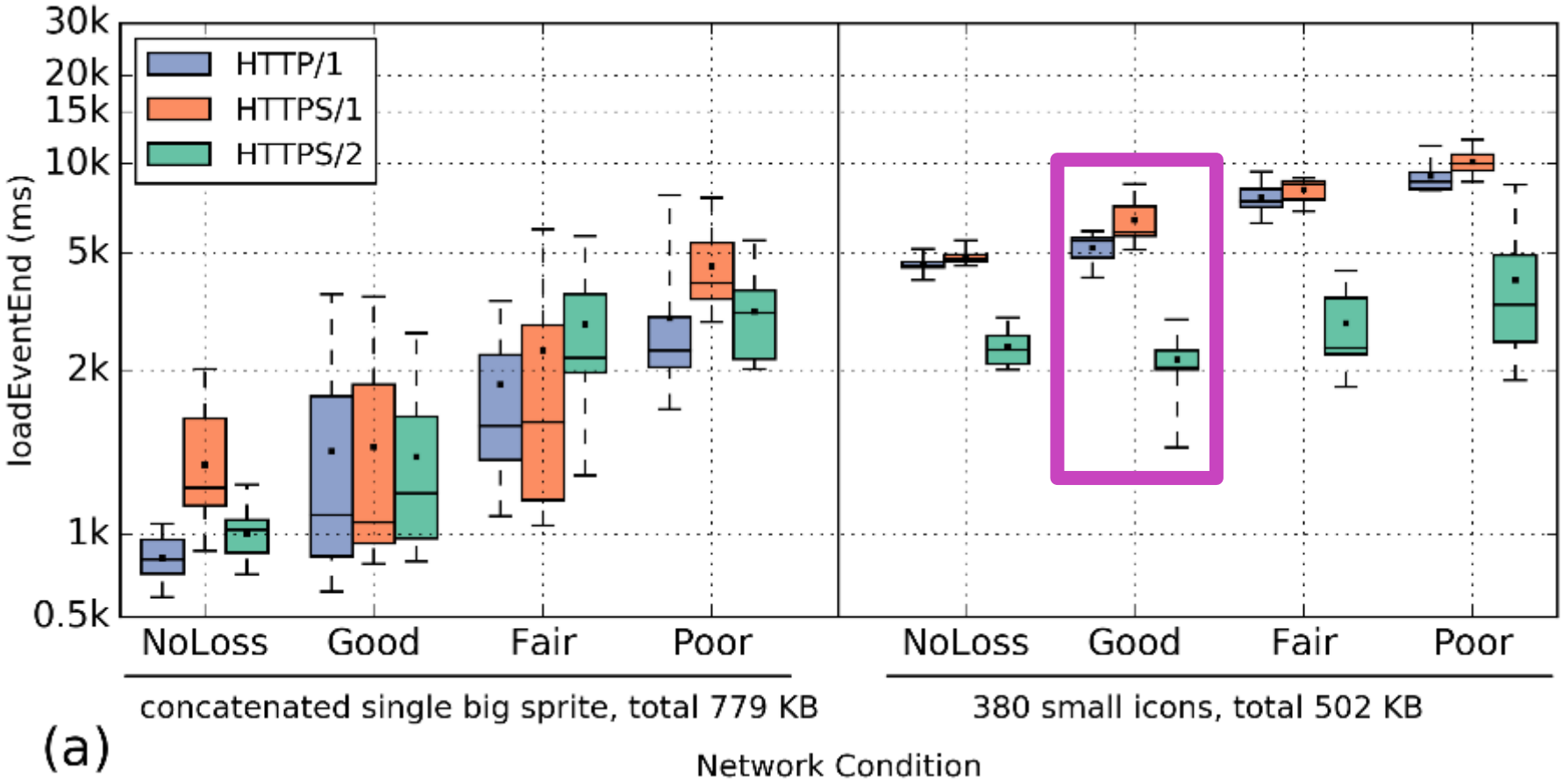
https://sites.google.com/a/webpagetest.org/docs/using-webpagetest/metrics/speed-index

1. Concatenation

- Images : 380 small, 42 medium, 30 large
- CSS/JavaScript : 1 – 500 files, simple and complex

http://www.netflix.com

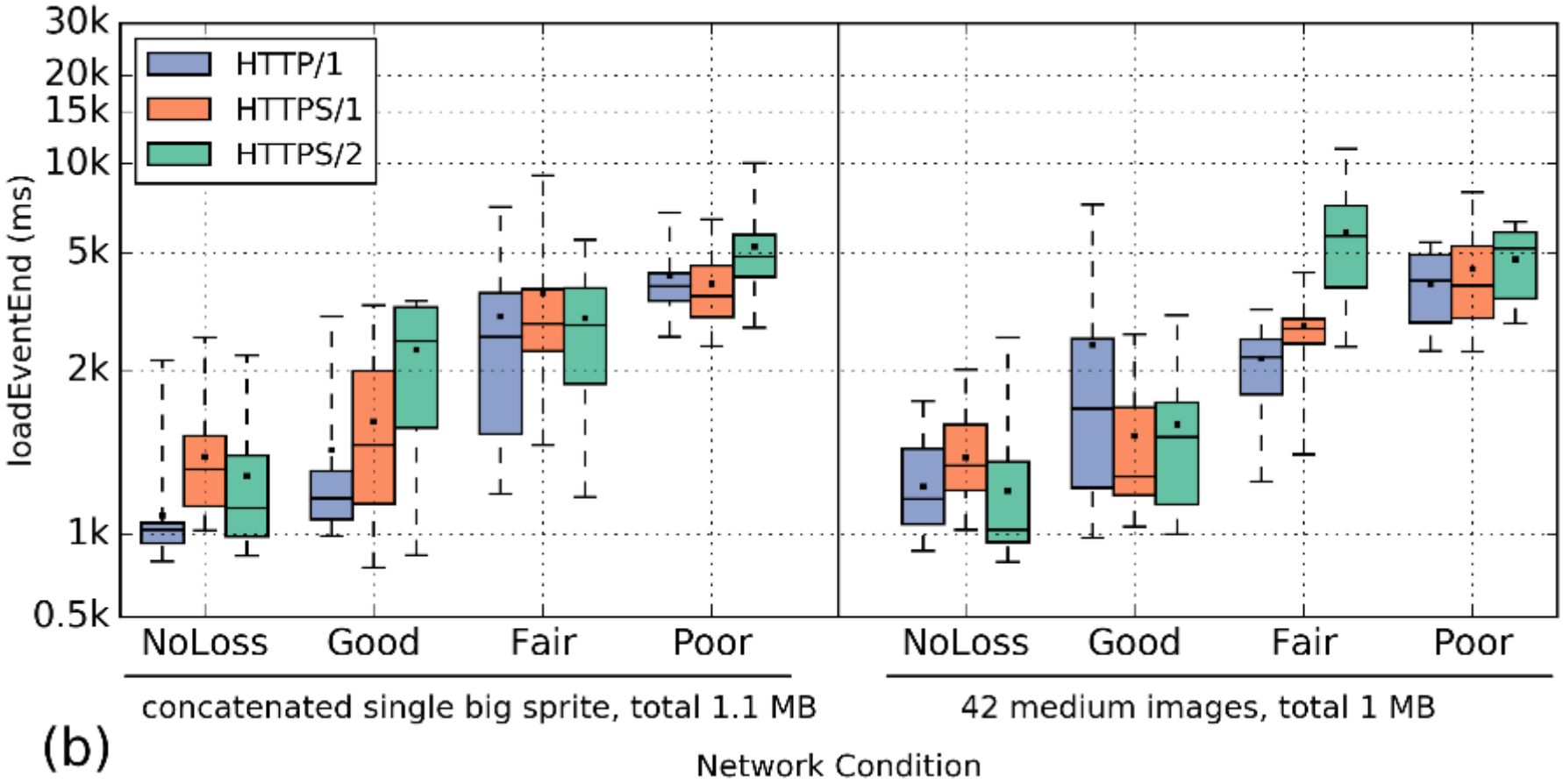
1. Concatenation : 380 small images



OPTIMIZED

NOT OPTIMIZED

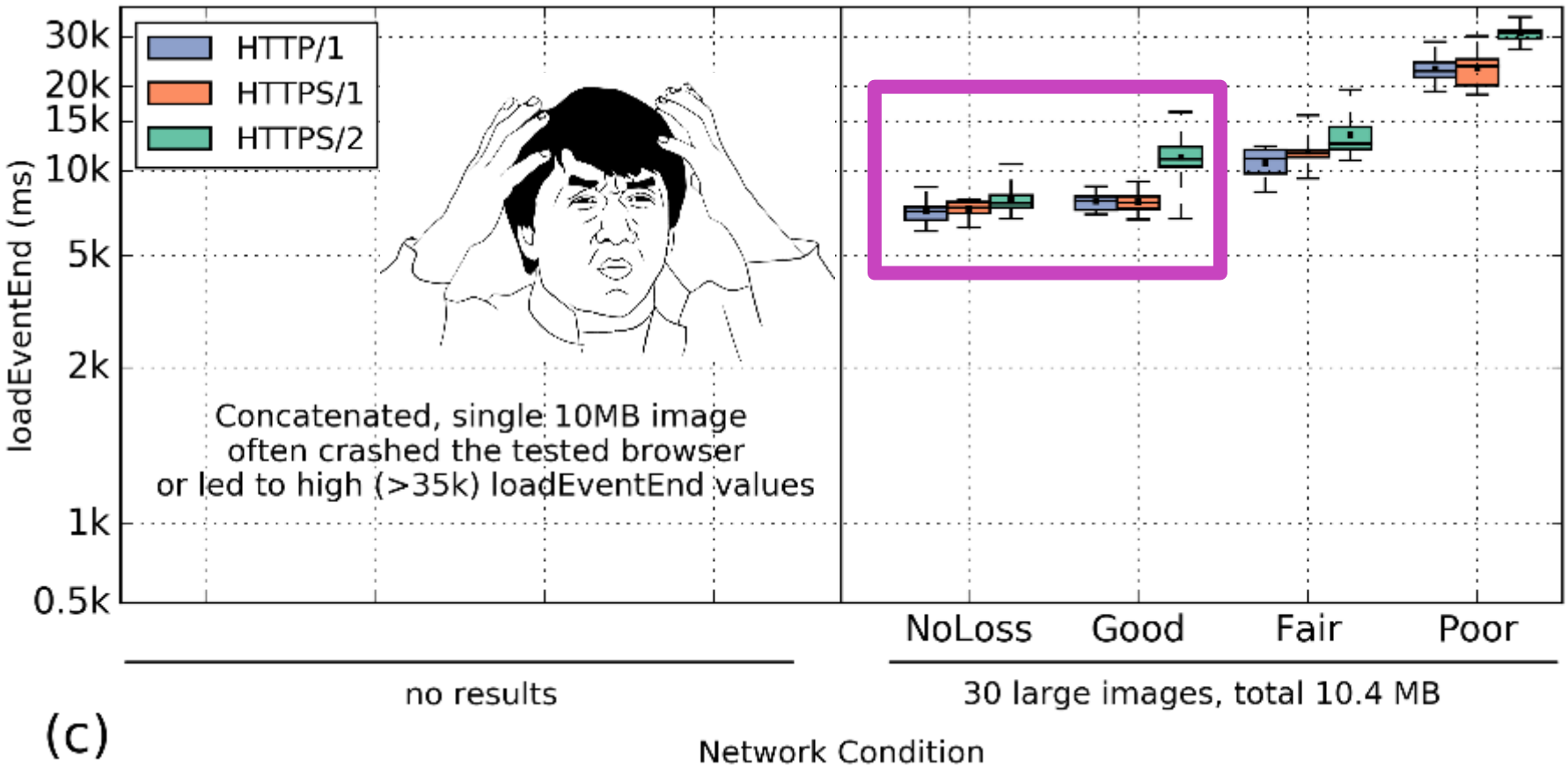
1. Concatenation : 42 medium images



OPTIMIZED

NOT OPTIMIZED

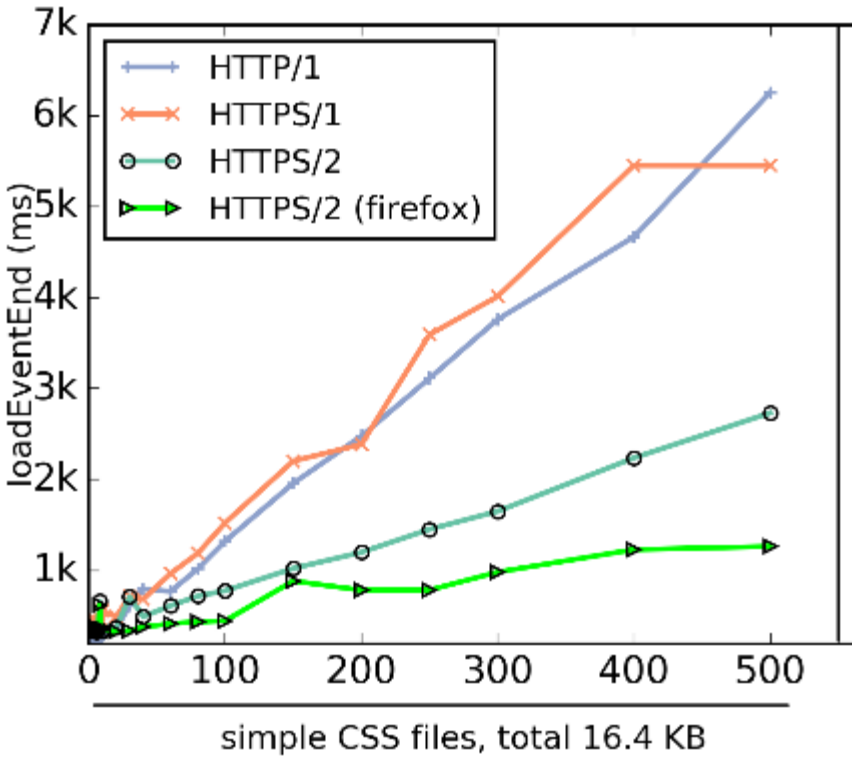
1. Concatenation : 30 large images

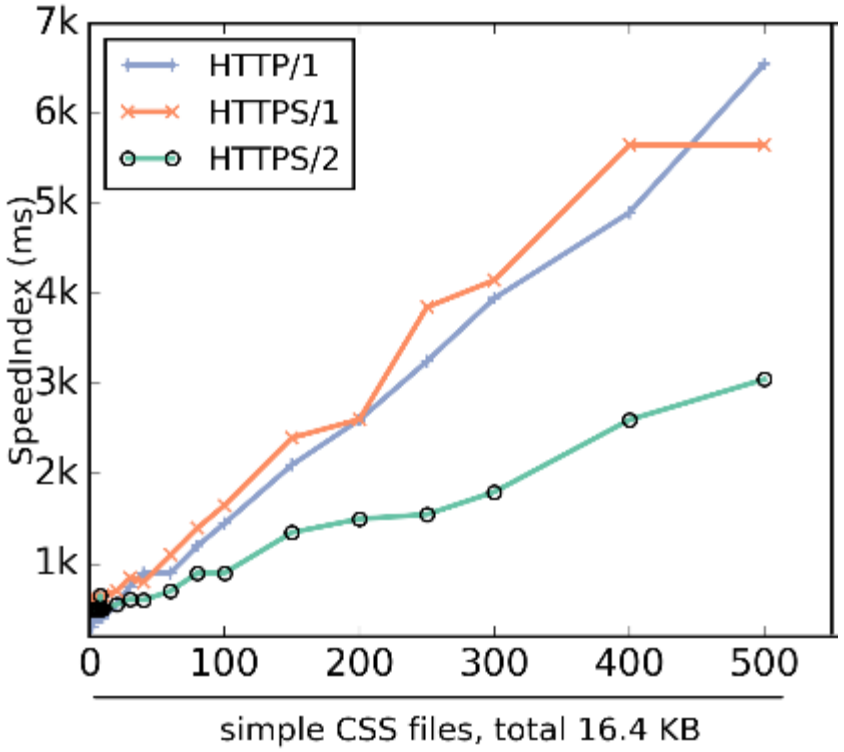


OPTIMIZED

NOT OPTIMIZED

1. Concatenation : CSS SpeedIndex

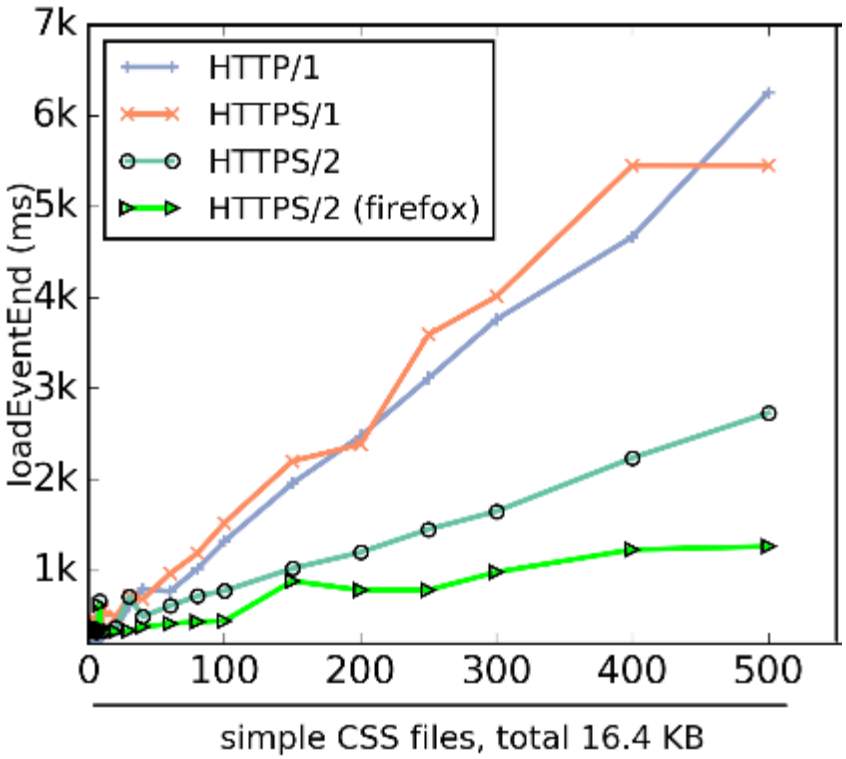


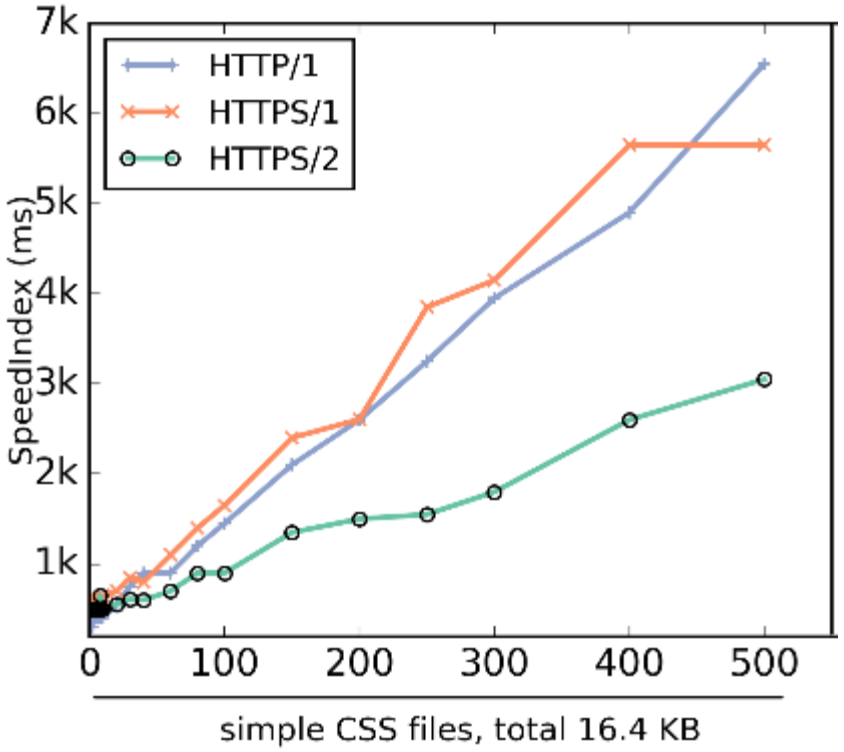


loadEventEnd

SpeedIndex

1. Concatenation : CSS SpeedIndex





Both are the same = rendering started at onLoad
=> Page was white until all CSS was loaded

4. Realistic websites

- Many factors contribute to load times
  - Polaris (Netravali et al.), Shandian (Wang et al.)

- Other related work exists
  - http://isthewebhttp2yet.com (Varvello et al.)

Can we simply transfer HTTP/1 sites to HTTP/2 ?

Image Sources

- http://deliveryimages.acm.org/10.1145/2390000/2380673/figs/f5.jpg
- https://dab1nmslvvntp.cloudfront.net/wp-content/uploads/2017/01/1484692838webpack-dependency-tree.png
- https://blog.cloudflare.com/content/images/2015/12/domain-sharding-1.png
- https://calendar.perfplanet.com/2016/http2-push-the-details/
- http://www.splicemarketing.co.uk/_blog/Splice_Blog/post/the-arrival-of-http2/
- http://s1377.photobucket.com/user/barteks11/media/Marvel%20gifs/h20wkj2-iron-man-vs-captain-america-who-sides-with-who-in-marvel-s-civil-war-jpeg-151871_zpsarkko07f.jpg.html
- https://sites.google.com/a/webpagetest.org/docs/using-webpagetest/metrics/speed-index
- https://twitter.com/officialrtsf
- https://twitter.com/ThePracticalDev
- http://www.netflix.com