Communication Networks

Spring 2020

Laurent Vanbever

nsg.ee.ethz.ch

ETH Zürich (D-ITET)

May 4 2020

Materials inspired from Scott Shenker, Jennifer Rexford, and Ankit Singla

Last week on

Communication Networks

Congestion Control

DNS

google.ch ⟷ 172.217.16.131

(the beginning)

Congestion Control

DNS

Congestion control aims at solving three problems

#1	bandwidth estimation	How to adjust the bandwidth of a single flow to the bottleneck bandwidth? could be 1 Mbps or 1 Gbps…
#2	bandwidth adaptation	How to adjust the bandwidth of a single flow to variation of the bottleneck bandwidth?
#3	fairness	How to share bandwidth “fairly" among flows, without overloading the network

Congestion control differs from flow control

both are provided by TCP though

Flow control	prevents one fast sender from overloading a slow receiver
Congestion control	prevents a set of senders from overloading the network

The sender adapts its sending rate based on these two windows

Receiving Window RWND	How many bytes can be sent without overflowing the receiver buffer? based on the receiver input
Congestion Window CWND	How many bytes can be sent without overflowing the routers? based on network conditions
Sender Window	minimum(CWND, RWND)

The 2 key mechanisms of Congestion Control

detecting congestion	reacting to congestion

The 2 key mechanisms of Congestion Control

detecting congestion	reacting to congestion

Detecting losses can be done using ACKs or timeouts, the two signal differ in their degree of severity

duplicated ACKs	mild congestion signal packets are still making it
timeout	severe congestion signal multiple consequent losses

The 2 key mechanisms of Congestion Control

detecting
congestion

reacting to
congestion

TCP approach is to gently increase when not congested and to rapidly decrease when congested

question

What increase/decrease function should we use?

it depends on the problem we are solving…

Congestion control aims at solving three problems

#1	bandwidth estimation	How to adjust the bandwidth of a single flow to the bottleneck bandwidth? could be 1 Mbps or 1 Gbps…
#2	bandwidth adaptation	How to adjust the bandwidth of a single flow to variation of the bottleneck bandwidth?
#3	fairness	How to share bandwidth “fairly" among flows, without overloading the network

#1 bandwidth estimation

How to adjust the bandwidth of a single flow to the bottleneck bandwidth?

could be 1 Mbps or 1 Gbps…

Initially, you want to quickly get a first-order estimate of the available bandwidth

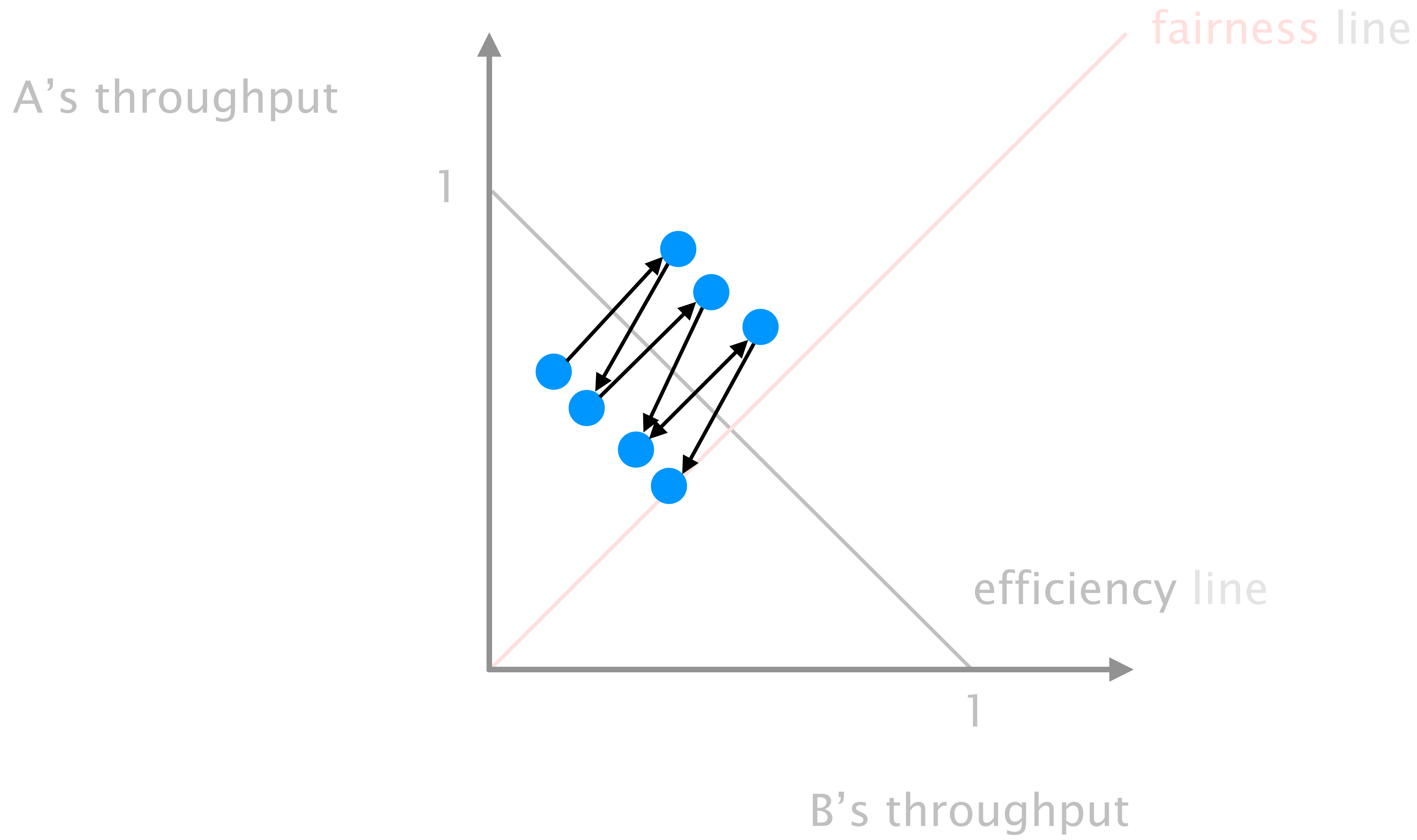
Intuition	Start slow but rapidly increase until a packet drop occurs	
Increase policy	cwnd = 1	initially
	cwnd += 1	upon receipt of an ACK

#2	bandwidth adaptation	How to adjust the bandwidth of a single flow to variation of the bottleneck bandwidth?

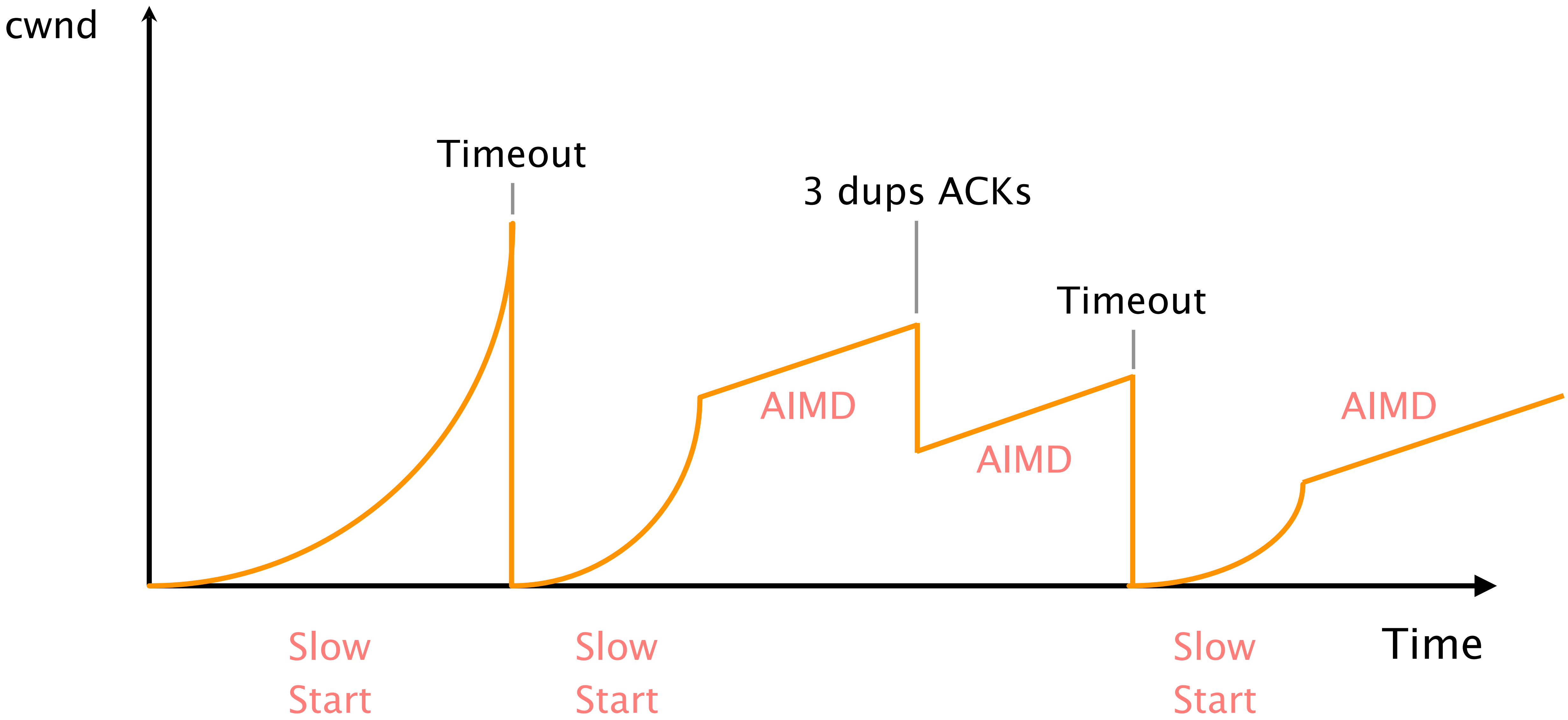
	increase behavior	decrease behavior
AIAD	gentle	gentle
AIMD	gentle	aggressive
MIAD	aggressive	gentle
MIMD	aggressive	aggressive

#3 fairness How to share bandwidth "fairly" among flows, without overloading the network

AIMD converge to fairness and efficiency,
it then fluctuates around the optimum (in a stable way)



Congestion control makes TCP throughput look like a “sawtooth”



Congestion Control

DNS

google.ch ⟷ 172.217.16.131

(the beginning)

The DNS system is a distributed database
which enables to resolve a name into an IP address

DNS

name ⟷ IP address

www.ethz.ch 129.132.19.216

To scale,
DNS adopt three intertwined hierarchies

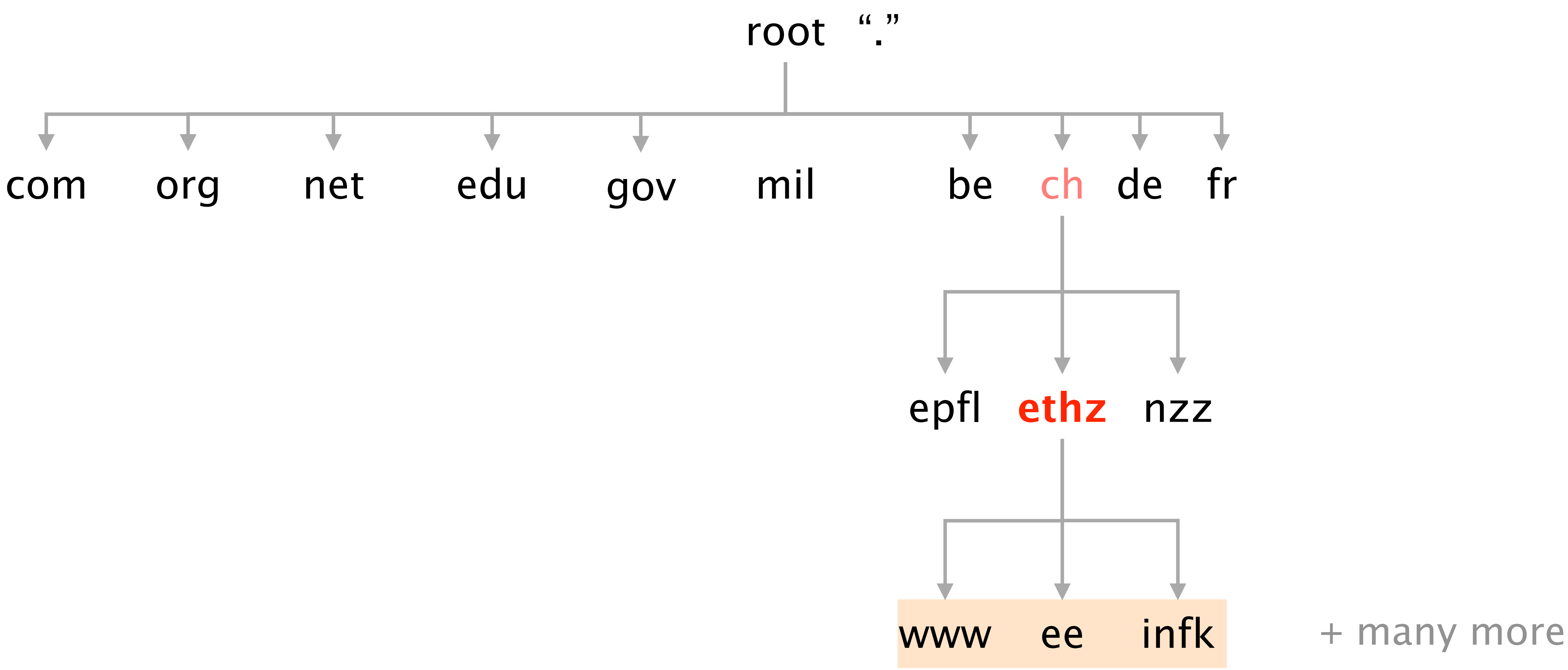
naming structure	addresses are hierarchical www.ee.ethz.ch
management	hierarchy of authority over names
infrastructure	hierarchy of DNS servers

naming structure

addresses are hierarchical

www.ee.ethz.ch

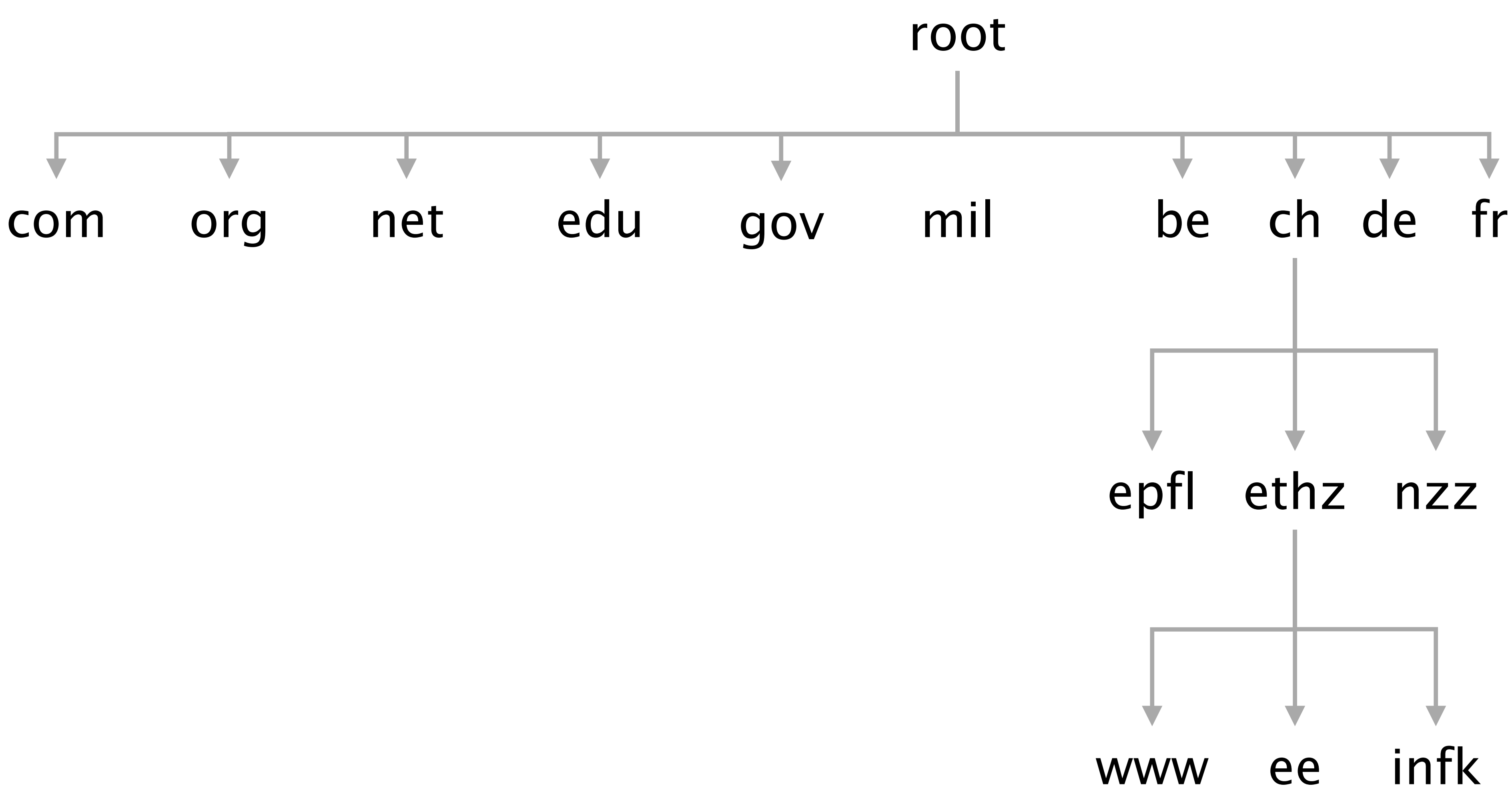
A name, *e.g.* ee.ethz.ch, represents a leaf-to-root path in the hierarchy



management

hierarchy of authority
over names

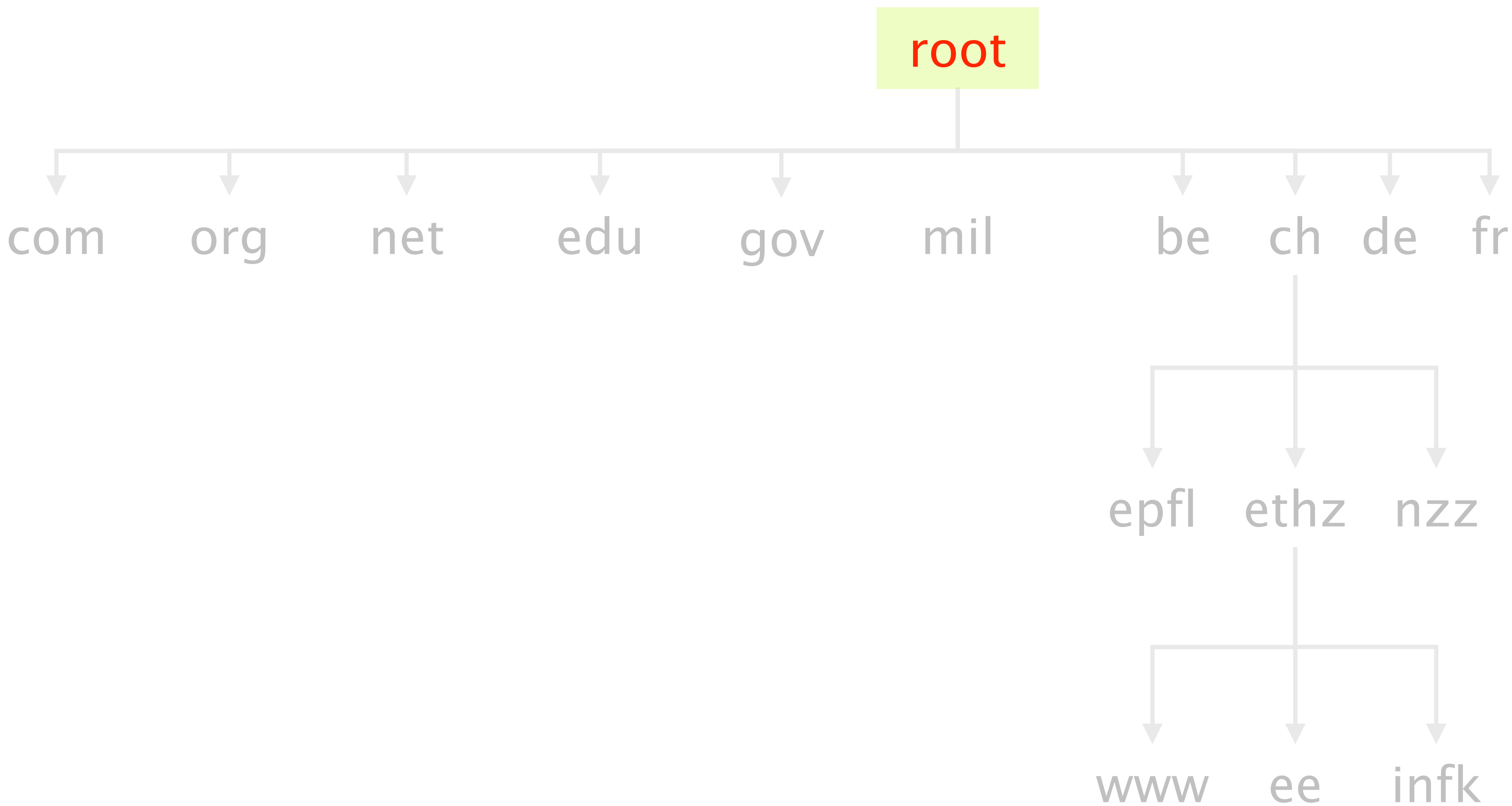
The DNS system is hierarchically administered



infrastructure

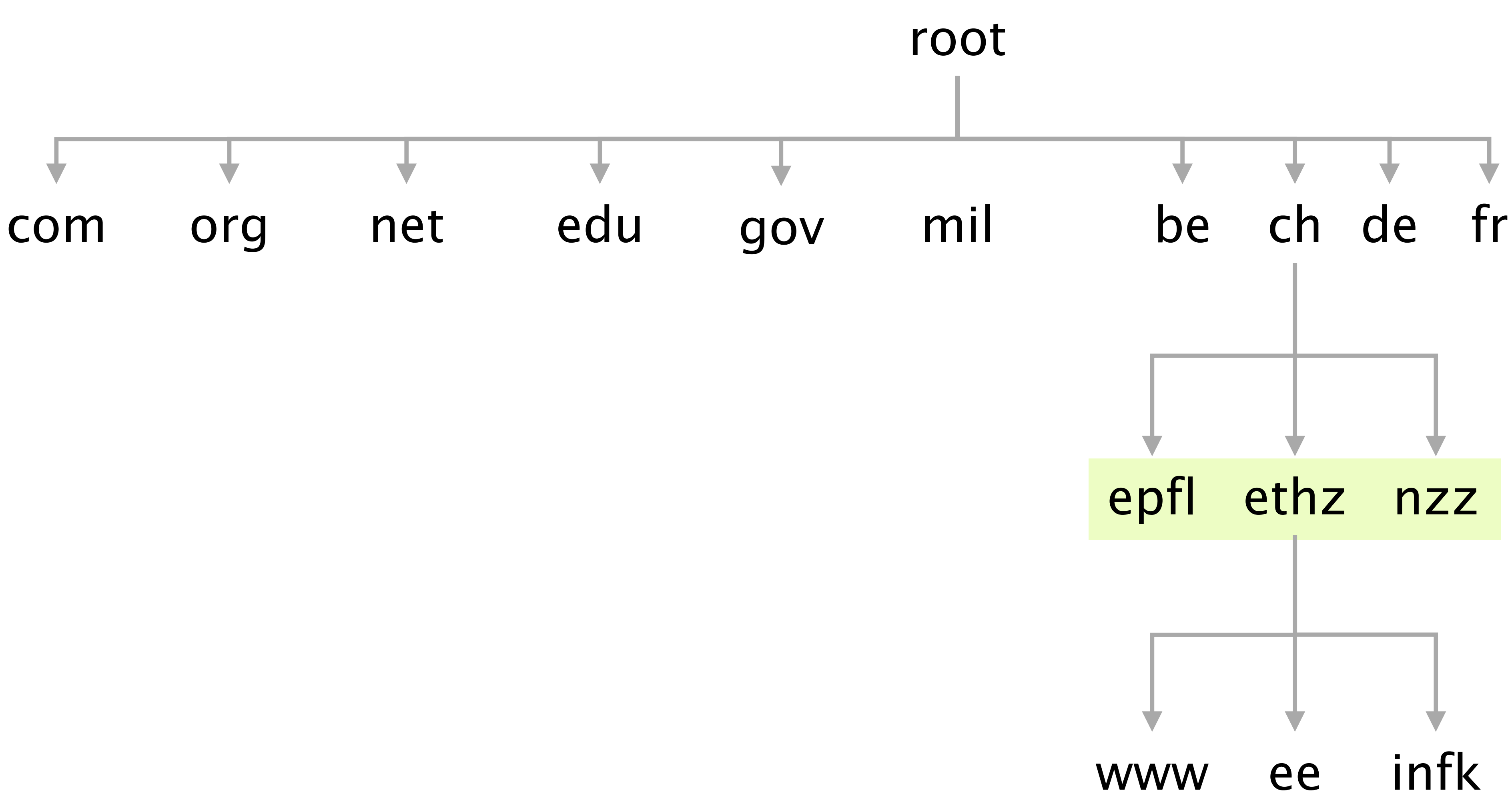
hierarchy of DNS servers

13 root servers (managed professionally) serve as root (*)



(*) see http://www.root-servers.org/

The bottom (and bulk) of the hierarchy is managed by Internet Service Provider or locally



Every server knows the address of the root servers (*)

required for bootstrapping the systems

(*) see https://www.internic.net/domain/named.root

Each server knows the address of all children

This week on

Communication Networks

DNS

Web

google.ch ⟷ 172.217.16.131

(the end)

http://www.google.ch

DNS

Web

google.ch ⟷ 172.217.16.131

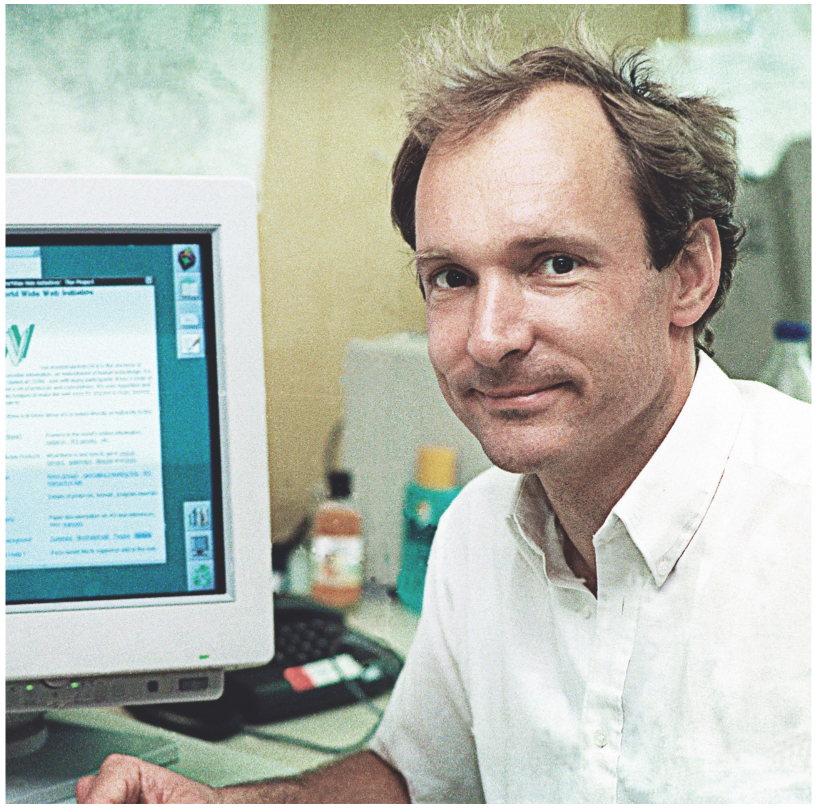
starting from slide 47/90

DNS

Web

http://www.google.ch

The Web as we know it was founded in ~1990, by Tim Berners-Lee, physicist at CERN



Tim Berners–Lee Photo: CERN

His goal:

provide distributed access to data

The World Wide Web (WWW):

a distributed database of “pages” linked together via the Hypertext Transport Protocol (HTTP)

The Web was and still is so successful as it enables everyone to self-publish content

Self-publishing on the Web is easy, independent & free

and accessible, to everyone

People weren't looking for technical perfection

little interest in collaborative or idealistic endeavor

People essentially want to make their mark

and find something neat…

The WWW is made of three key components

Infrastructure	Content	Implementation
Clients/Browser	Objects files, pictures, videos, …	URL: name content
Servers	*organized* in	HTTP: transport content
Proxies	Web sites a collection of objects	

We'll focus on its implementation

Infrastructure	Content	Implementation
Clients/Browser	Objects	URL: name content
	files, pictures, videos, ...	
Servers	*organized* in	HTTP: transport content
Proxies	Web sites	
	a collection of objects	

Infrastructure	Content	Implementation
Clients/Browser	Objects	**URL: name content**
	files, pictures, videos, …	HTTP: transport content
Servers	*organized* in	
Proxies	Web sites	
	a collection of objects	

A Uniform Resource Locator (URL)
refers to an Internet ressource

protocol://hostname[:port]/directory_path/resource

protocol://hostname[:port]/directory_path/resource

HTTP(S)

FTP

SMTP…

protocol://hostname[:port]/directory_path/resource

DNS Name

IP address

default to protocol’s standard

HTTP:80, HTTPs:443

protocol://hostname[:port]/directory_path/resource

protocol://hostname[:port]/directory_path/resource

identify the resource
on the destination

Infrastructure	Content	Implementation
Clients/Browser	Objects	URL: name content
	files, pictures, videos, ...	**HTTP: transport content**
Servers	*organized* in	
Proxies	Web sites	
	a collection of objects	

HTTP is a rather simple synchronous request/reply protocol

HTTP is layered over a bidirectional byte stream

typically TCP, but QUIC is ramping up

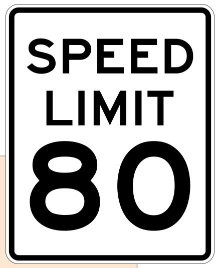
HTTP is text-based (ASCII)

human readable, easy to reason about

HTTP is stateless

it maintains *no info* about past client requests

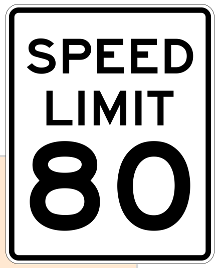
Protocol



Performance

http://

Protocol

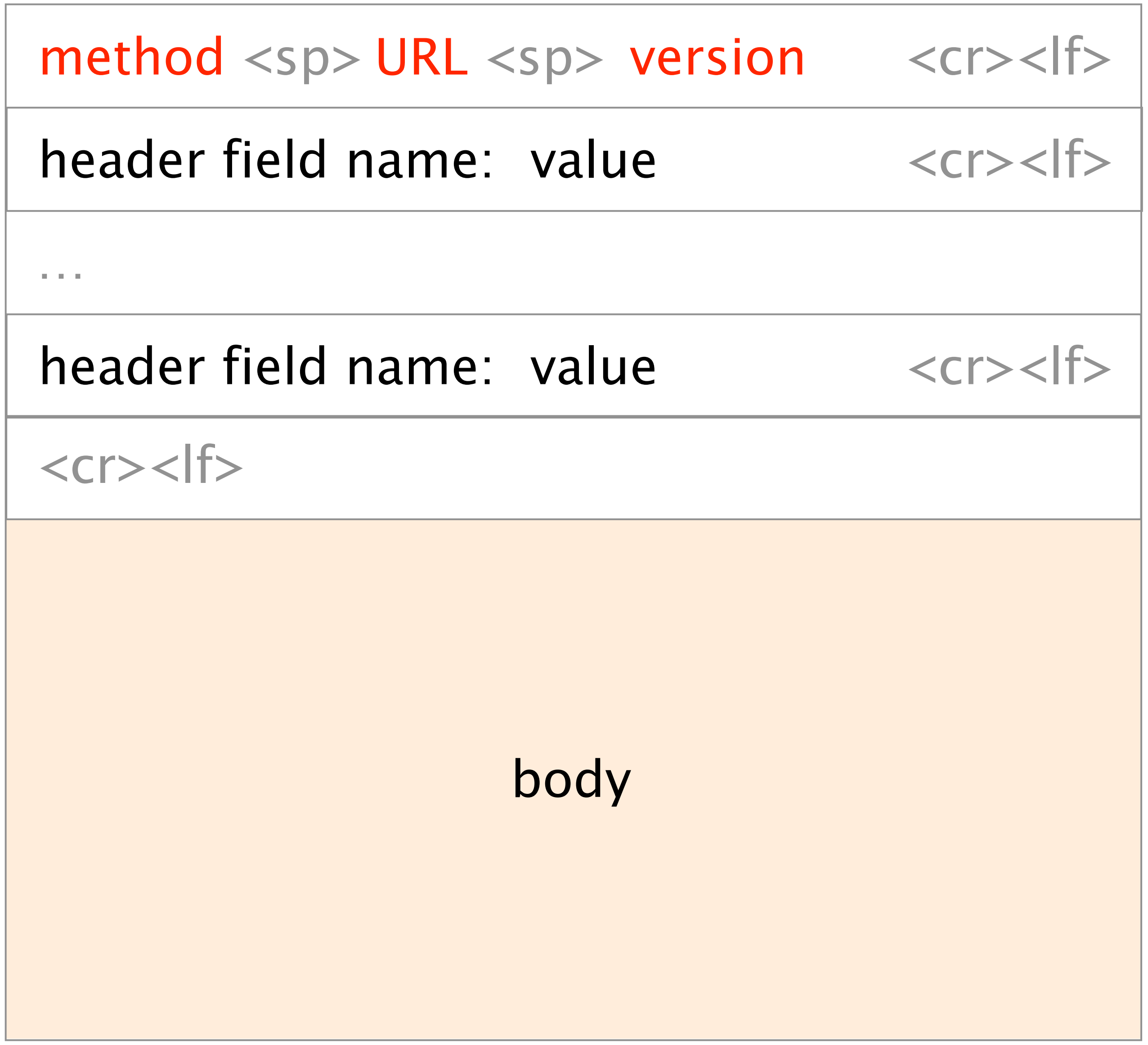


Performance

HTTP clients make request to the server

HTTP
request

method <sp> URL <sp> version <cr><lf>
header field name: value <cr><lf>
…
header field name: value <cr><lf>
<cr><lf>
body


method <sp> URL <sp> version <cr><lf>
header field name: value <cr><lf>
...
header field name: value <cr><lf>
<cr><lf>
body

method	GET	return resource
	HEAD	return headers only
	POST	send data to server (forms)
URL		relative to server (*e.g.*, /index.html)
version		1.0, 1.1, 2.0

HTTP clients make request to the server

HTTP
request

Request headers are of variable lengths, but still, human readable

Uses	Authorization info
	Acceptable document types/encoding
	From (user email)
	Host (identify the server to which the request is sent)
	If-Modified-Since
	Referrer (cause of the request)
	User Agent (client software)

Uses

Authorization info

Acceptable document types/encoding

From (user email)

Host (identify the server to which the request is sent)

If-Modified-Since

Referrer (cause of the request)

User Agent (client software)

Recall that multiple DNS names can map to the same IP address

name ← DNS →	IP address
www.ethz.ch	129.132.19.216
vanbever.eu	82.130.102.71
route-aggregation.net	82.130.102.71
comm-net.ethz.ch	82.130.102.71

The "Host" header indicates the server (82.130.102.71) the desired domain name (this is known as virtual hosting)

name ← DNS →	IP address
www.ethz.ch	129.132.19.216
vanbever.eu	82.130.102.71
route-aggregation.net	82.130.102.71
comm-net.ethz.ch	82.130.102.71

Virtual hosting enables *one* IP address
to host *multiple* websites

82.130.102.71

(resolved through DNS)

connect openssl s_client -crlf -quiet -connect comm-net.ethz.ch:443

request

```
GET / HTTP/1.1
Host: comm-net.ethz.ch
```

answer

```
HTTP/1.1 200 OK
Date: Fri, 01 May 2020 08:36:56 GMT
Server: Apache/2.4.18 (Ubuntu)

<head>
…
    <title>Communication Networks 2020</title>
….
```

82.130.102.71
(resolved through DNS)

connect openssl s_client -crlf -quiet -connect comm-net.ethz.ch:443

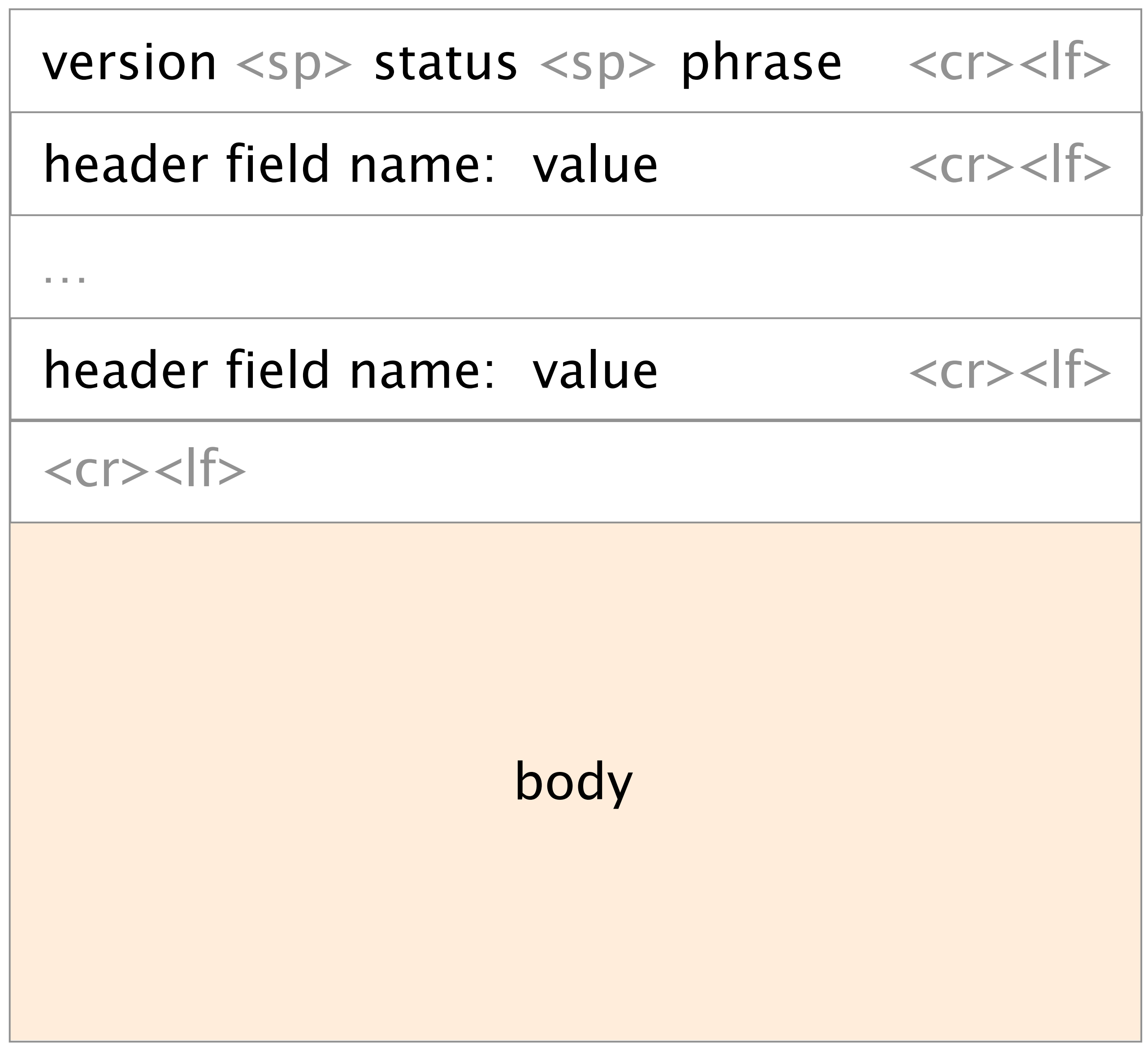
request GET / HTTP/1.1
Host: **vanbever.eu**

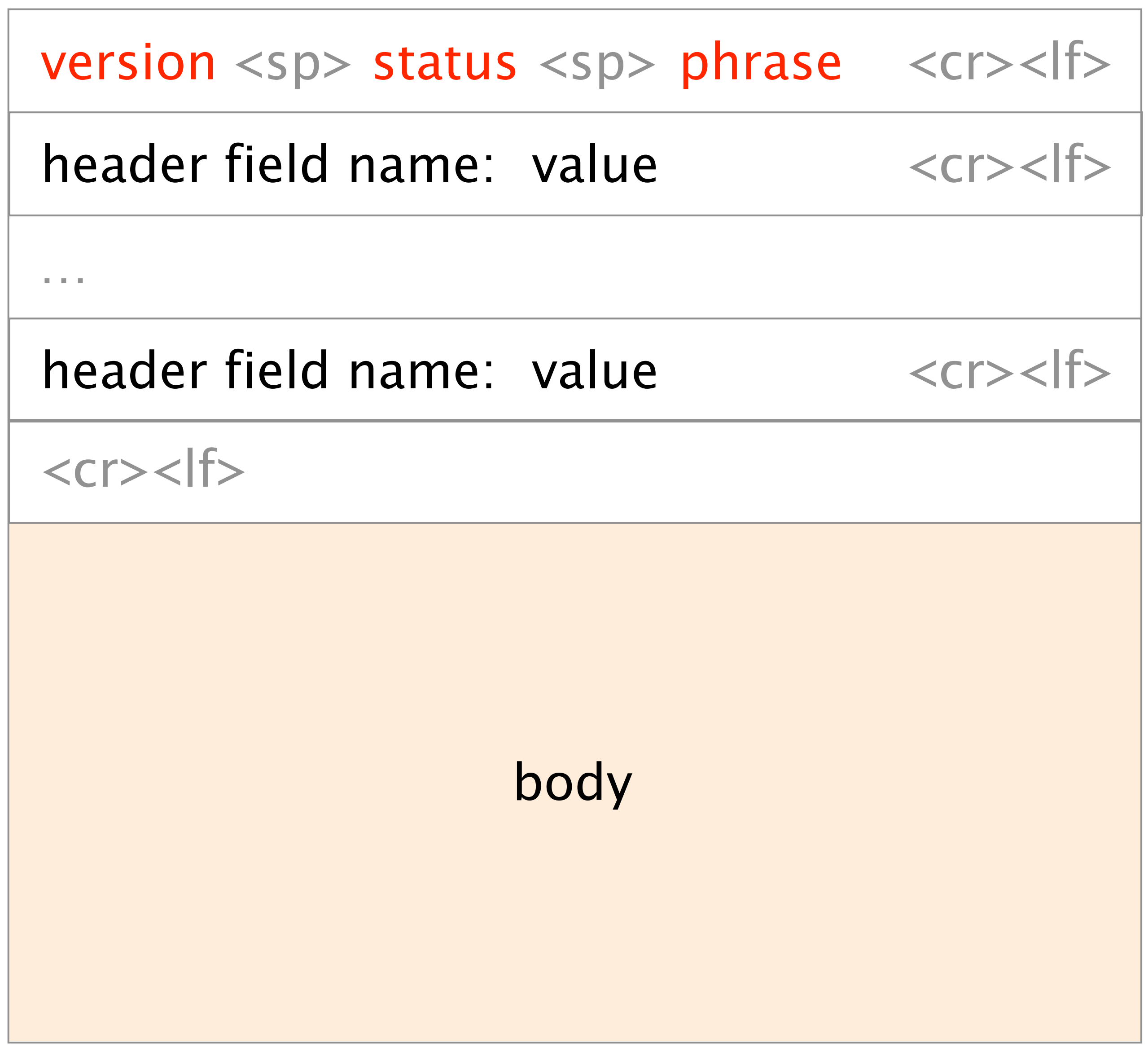
answer HTTP/1.1 200 OK
Date: Fri, 01 May 2020 08:44:26 GMT
Server: Apache/2.4.18 (Ubuntu)

<head>
…
<title>Laurent Vanbever</title>
….

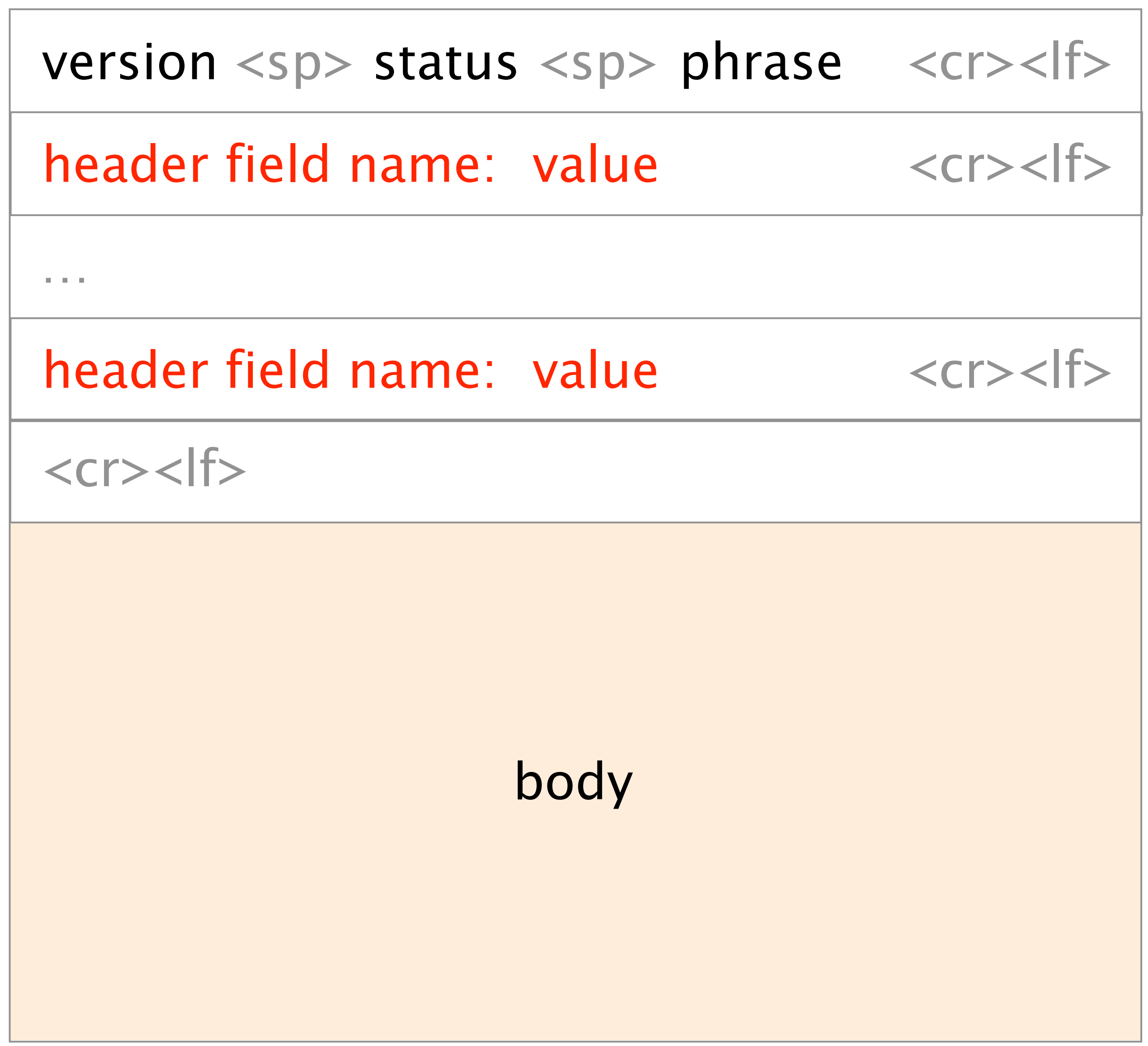
HTTP servers answers to clients’ requests

HTTP response




version <sp> status <sp> phrase <cr><lf>
header field name: value <cr><lf>
...
header field name: value <cr><lf>
<cr><lf>
body

	3 digit response code			reason phrase
Status	1XX	informational		
	2XX	success	200	OK
	3XX	redirection	301	Moved Permanently
			303	Moved Temporarily
			304	Not Modified
	4XX	client error	404	Not Found
	5XX	server error	505	Not Supported


version <sp> status <sp> phrase <cr><lf>
header field name: value <cr><lf>
...
header field name: value <cr><lf>
<cr><lf>
body

Like request headers, response headers are of variable lengths and human-readable

Uses	Location (for redirection)
	Allow (list of methods supported)
	Content encoding (*e.g.*, gzip)
	Content-Length
	Content-Type
	Expires (caching)
	Last-Modified (caching)

HTTP is a stateless protocol,
meaning each request is treated independently

advantages

server-side scalability

failure handling is trivial

disadvantages

some applications need state!

(shopping cart, user profiles, tracking)

How can you maintain state in a stateless protocol?

HTTP makes the client maintain the state.

This is what the so-called cookies are for!

client stores small state

on behalf of the server *X*

client sends state

in all future requests to *X*

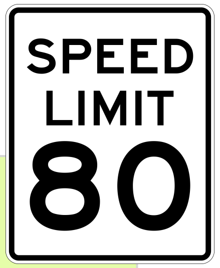
can provide authentication

telnet google.ch 80

request	GET / HTTP/1.1 Host: www.google.ch
answer	HTTP/1.1 200 OK Date: Sun, 01 May 2016 14:10:30 GMT Cache-Control: private, max-age=0 Content-Type: text/html; charset=ISO-8859-1 Server: gws
browser will relay this value in following requests	Set-Cookie: NID=79=g6lgURTq_BG4hSTFhEy1gTVFmSncQVsy TJI260B3xyiXqy2wxD2YeHq1bBlwFyLoJhSc7jmcA 6TlFIBY7- dW5lhjiRiQmY1JxT8hGCOtnLjfCL0mYcBBkpk8X4 NwAO28; expires=Mon, 31-Oct-2016 14:10:30 GMT; path=/; domain=.google.ch; HttpOnly

http://

Protocol



Performance

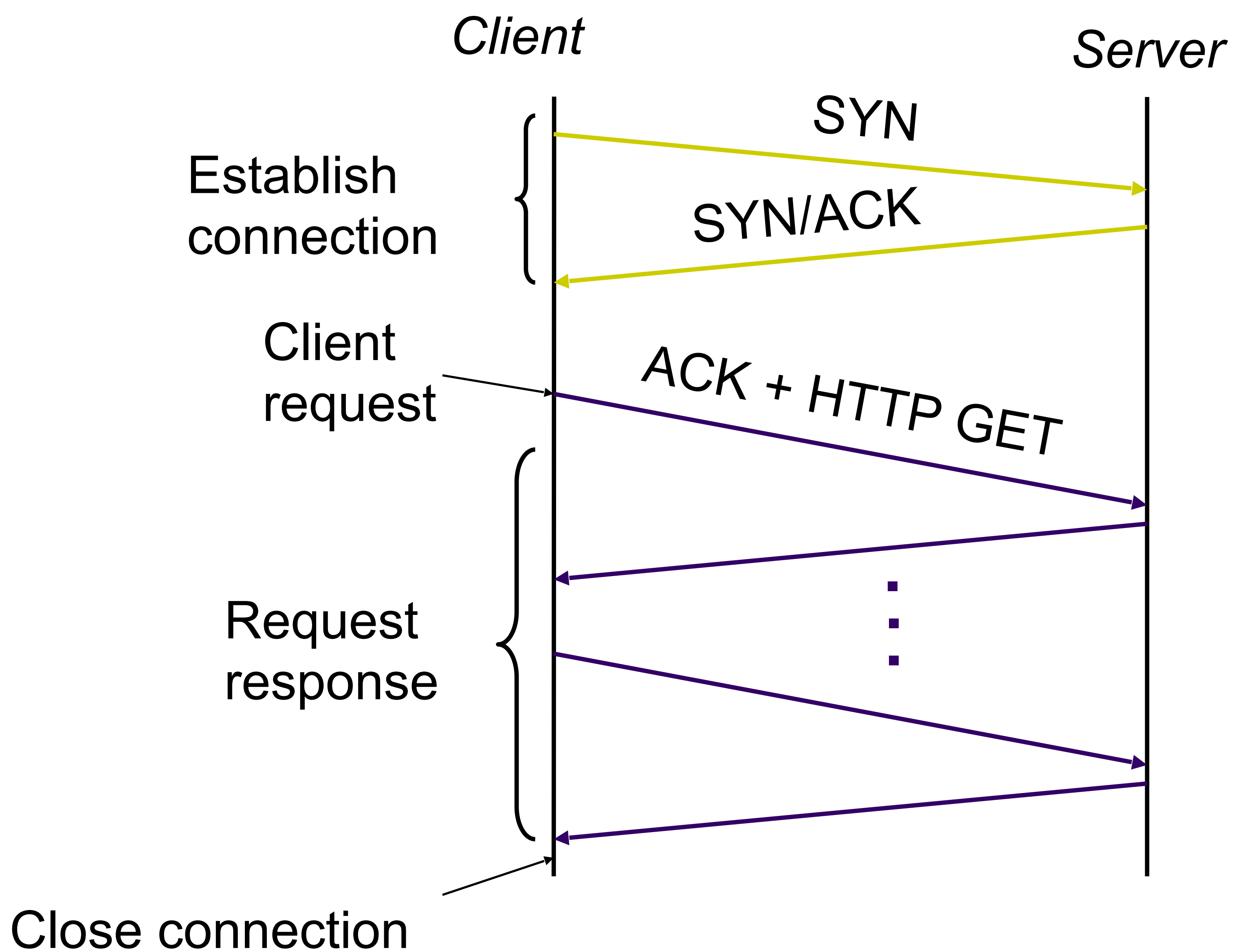
Performance goals vary depending on who you ask

	User	Network operators	Content provider
			NETFLIX
wish	fast downloads high availability	no overload	happy users cost-effective infrastructure
solution	Improve HTTP to compensate for TCP weakspots	Caching and Replication	

User

wish	fast downloads
	high availability
solution	Improve HTTP to compensate for TCP weakspots

Relying on TCP forces a HTTP client to open a connection before exchanging anything



Most Web pages have multiple objects,
naive HTTP opens one TCP connection for each…

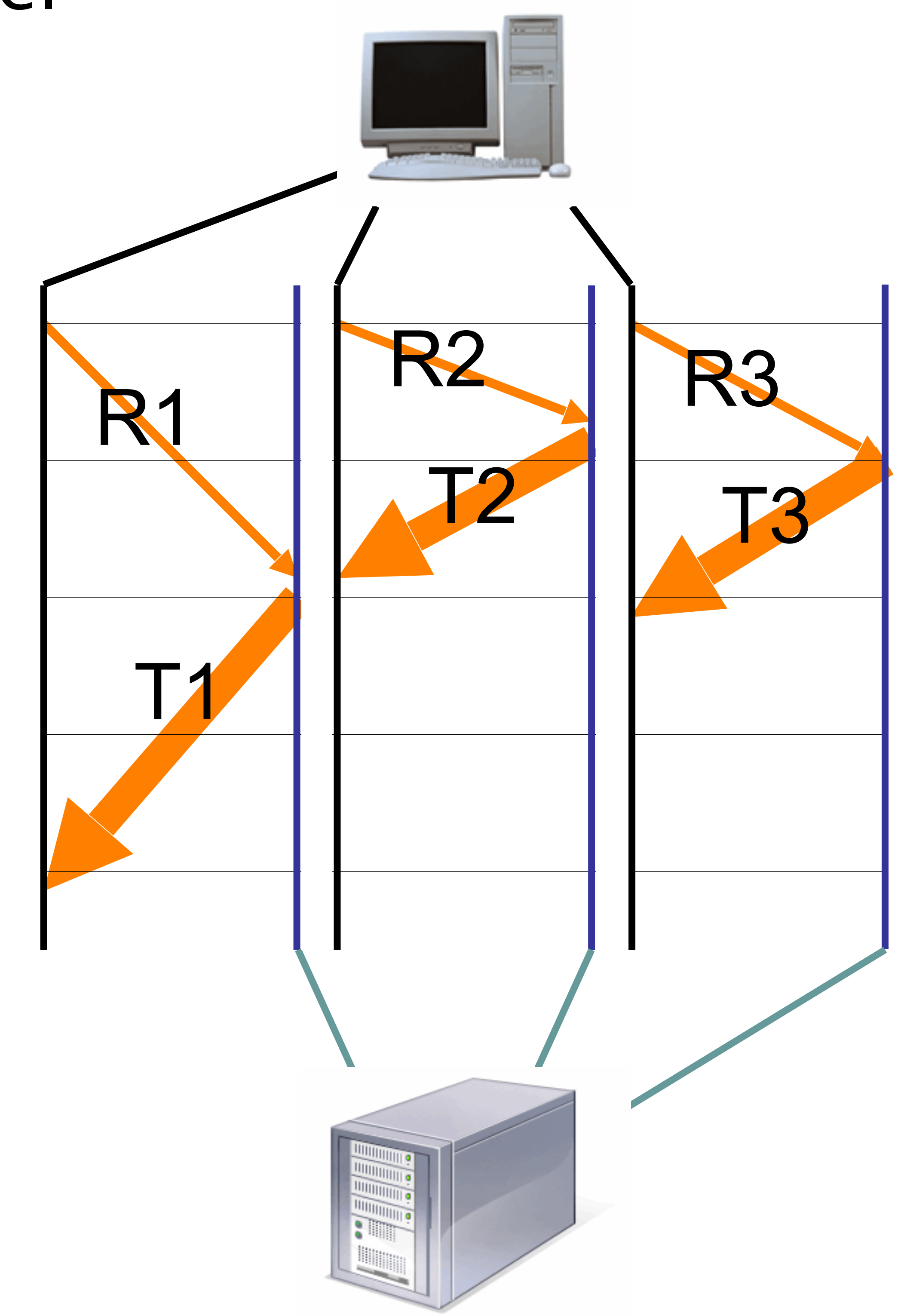
Fetching *n* objects requires ~2*n* RTTs

TCP establishment

HTTP request/response

One solution to that problem is to use multiple TCP connections in parallel

User	Happy!
Content provider	Happy!
Network operator	Not Happy!
	Why?



Another solution is to use persistent connections across multiple requests (the default in HTTP/1.1)

Avoid overhead of connection set-up and teardown

clients or servers can tear down the connection

Allow TCP to learn more accurate RTT estimate

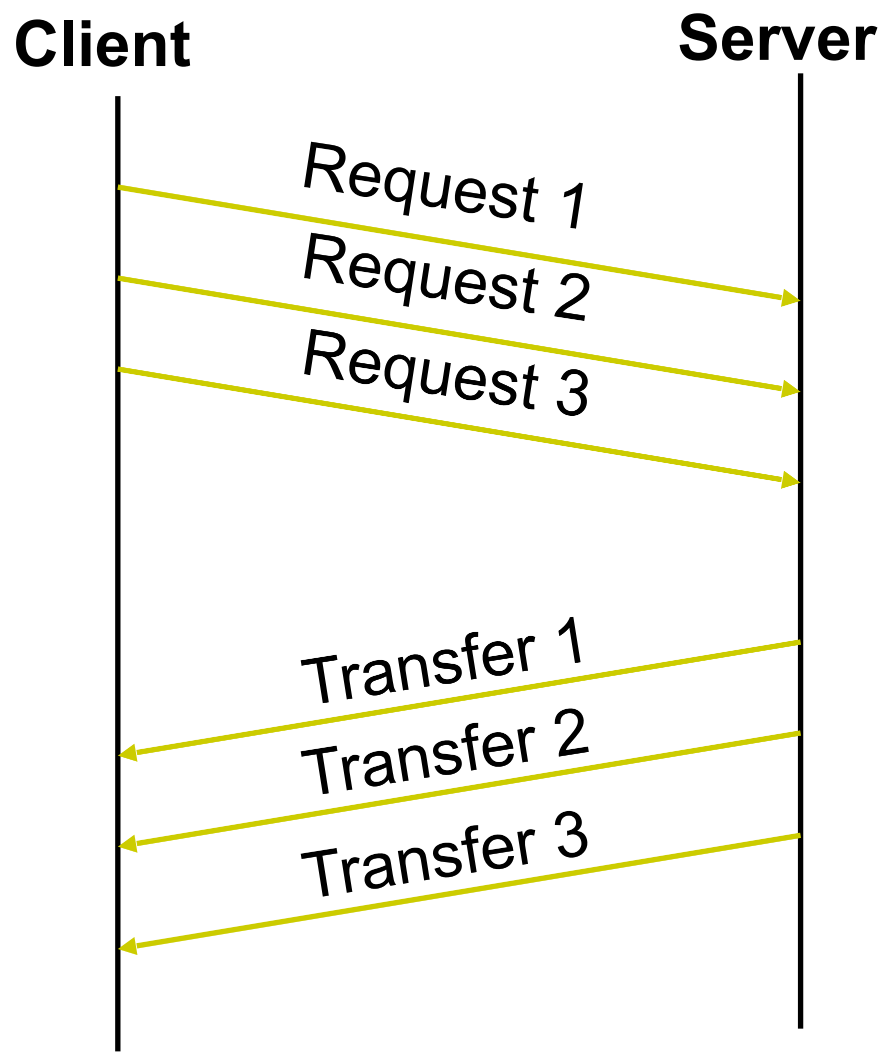
and with it, more precise timeout value

Allow TCP congestion window to increase

and therefore to leverage higher bandwidth

Yet another solution is to pipeline requests & replies asynchronously, on one connection

- batch requests and responses to reduce the number of packets
- multiple requests can be packed into one TCP segment



Considering the time to retrieve *n* small objects, pipelining wins

	# RTTS
one-at-a-time	$\sim 2n$
M concurrent	$\sim 2n/M$
persistent	$\sim n+1$
pipelined	2

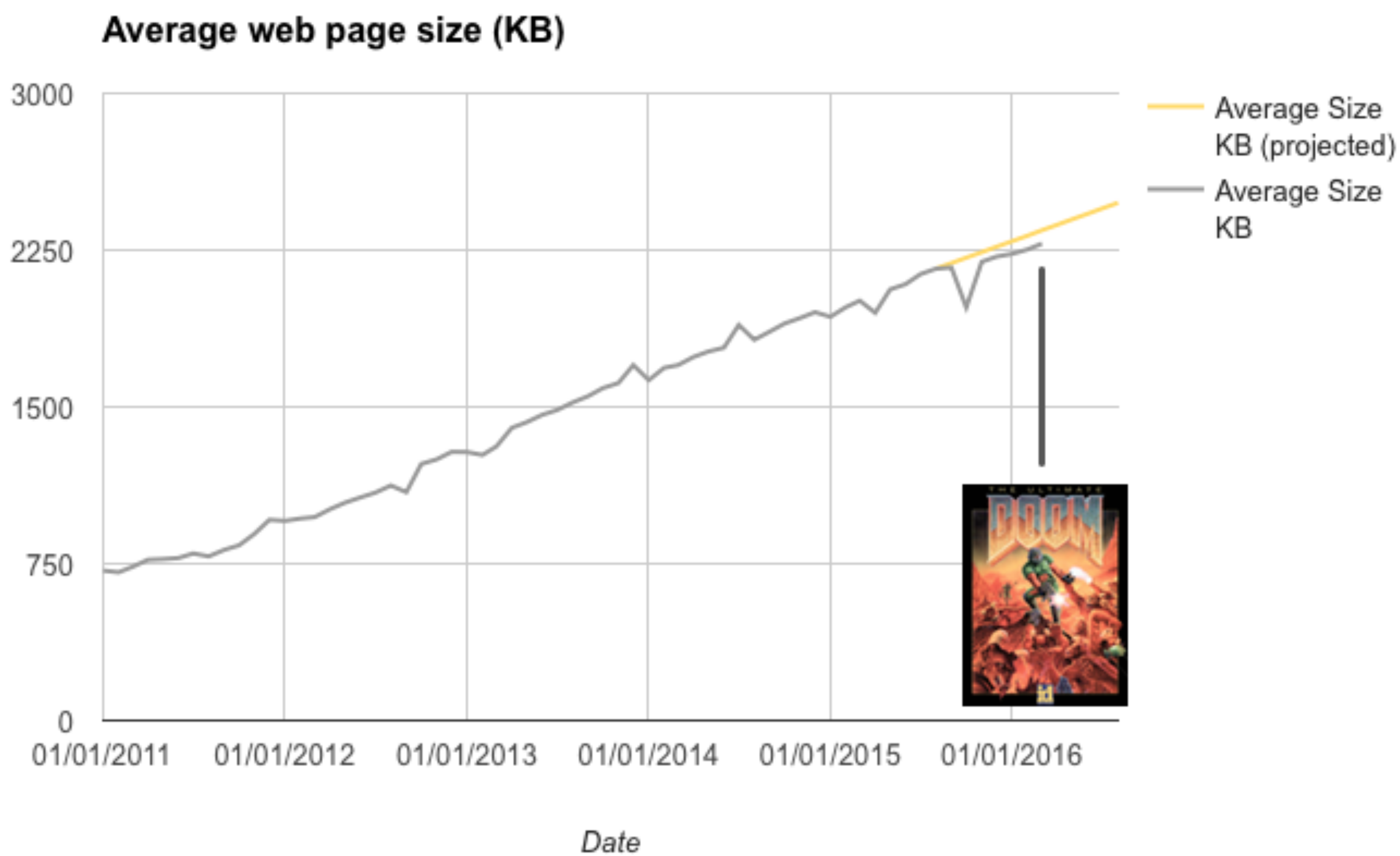
Considering the time to retrieve *n* big objects, there is no clear winner as bandwidth matters more

\# RTTS

$$\frac{\sim n * \text{avg. file size}}{\text{bandwidth}}$$

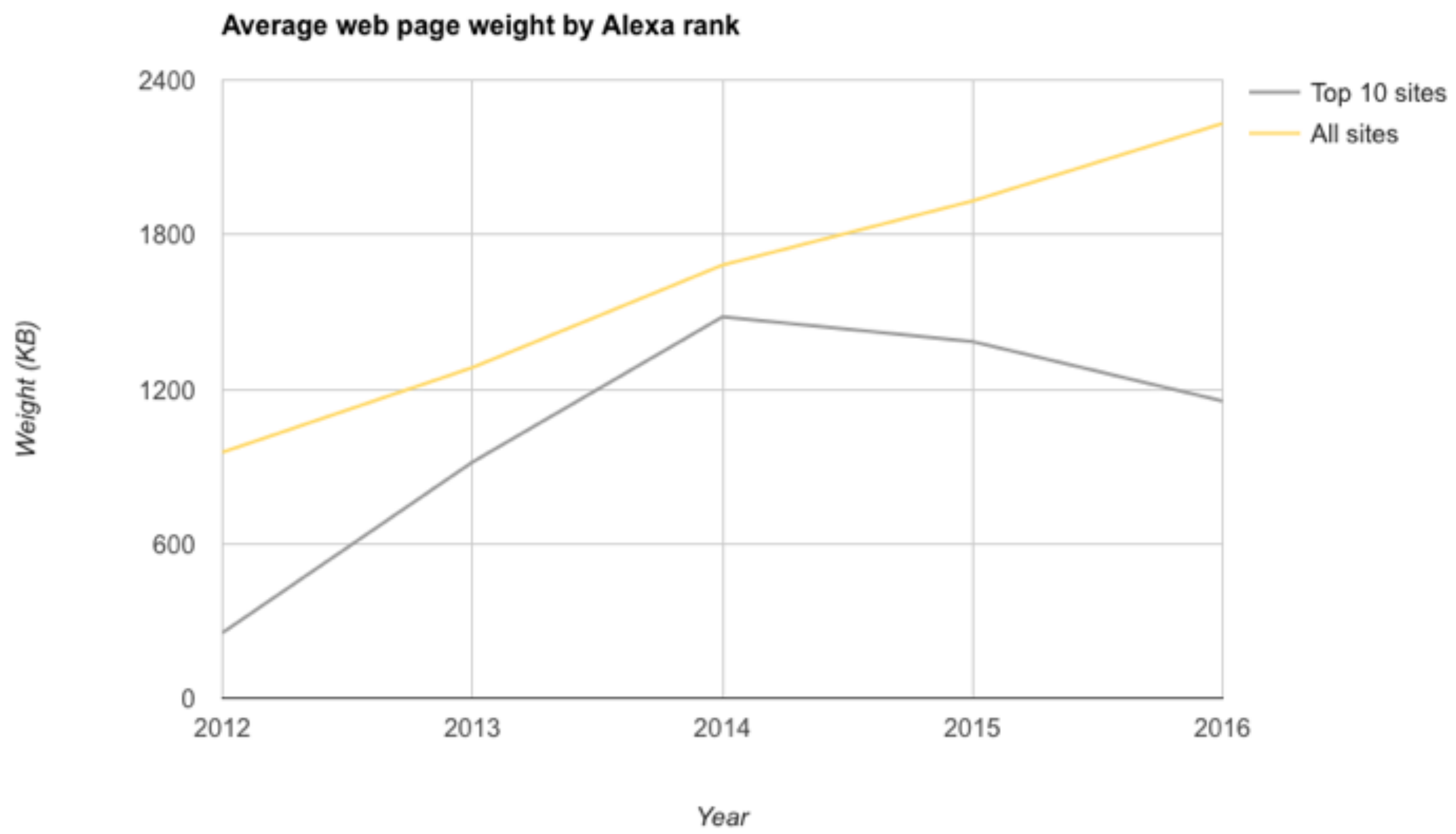
The average webpage size nowadays is 2.3 MB

as much as the original DOOM game…



(*) see https://mobiforge.com/research-analysis/the-web-is-doom

Top web sites have decreased in size though because they care about TCP performance



(*) see https://mobiforge.com/research-analysis/the-web-is-doom

User

Network operators

Content provider

NETFLIX

wish

no overload

happy users

cost-effective infrastructure

solution

Caching and Replication

Caching leverages the fact that highly popular content largely overlaps

Just think of how many times
you request the logo
per day

vs

how often it *actually* changes

Caching it save time for your browser
and decrease network and server load

Yet, a significant portion of the HTTP objects are “uncachable"

Examples	dynamic data	stock prices, scores, ...
	scripts	results based on parameters
	cookies	results may be based on passed data
	SSL	cannot cache encrypted data
	advertising	wants to measure # of hits ($$$)

To limit staleness of cached objects, HTTP enables a client to validate cached objects

Server hints when an object expires (kind of TTL)

as well as the last modified date of an object

Client conditionally requests a ressources

using the “if-modified-since” header in the HTTP request

Server compares this against “last modified” time

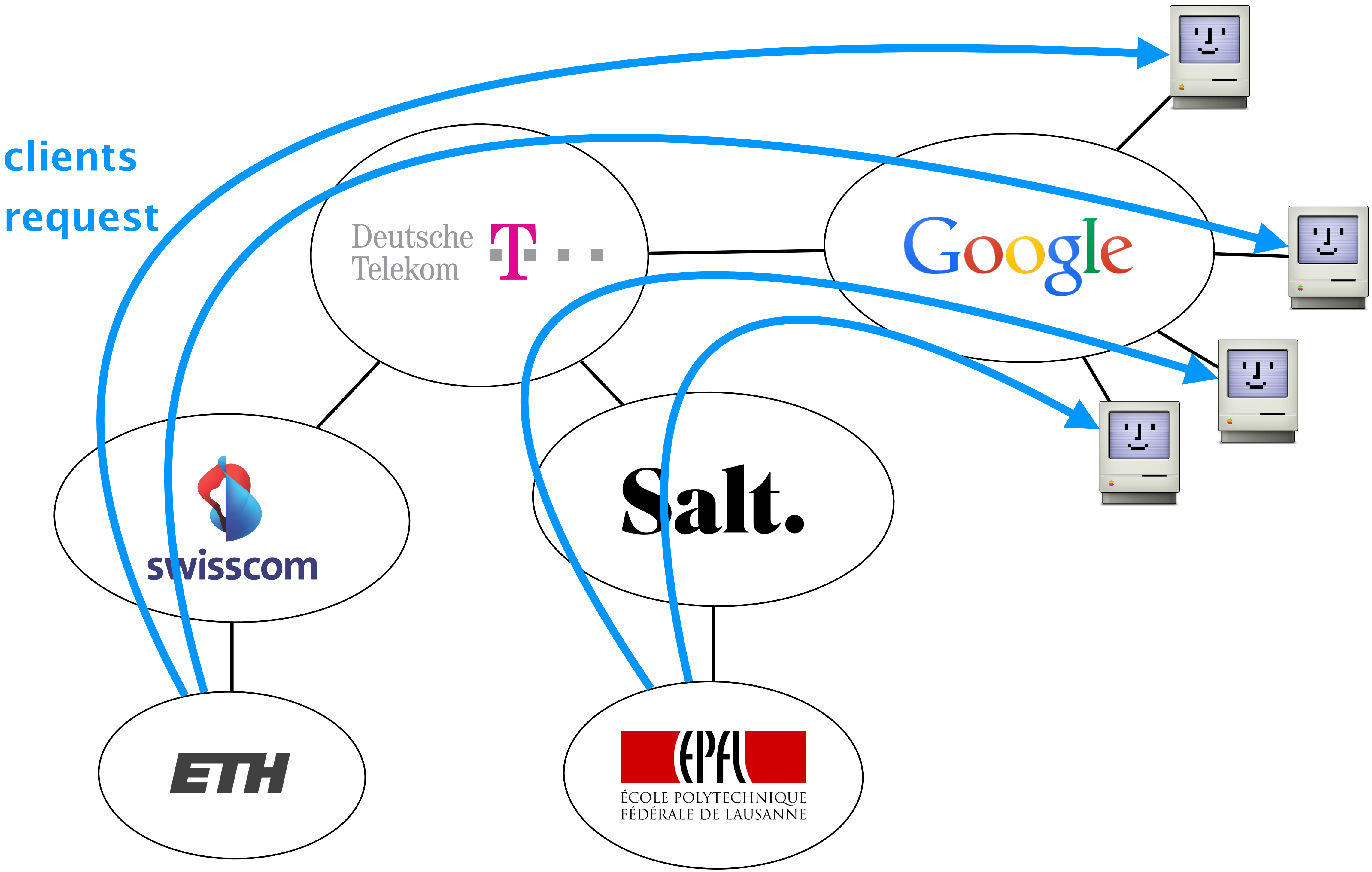
of the resource and returns:

- Not Modified if the resource has not changed
- OK with the latest version

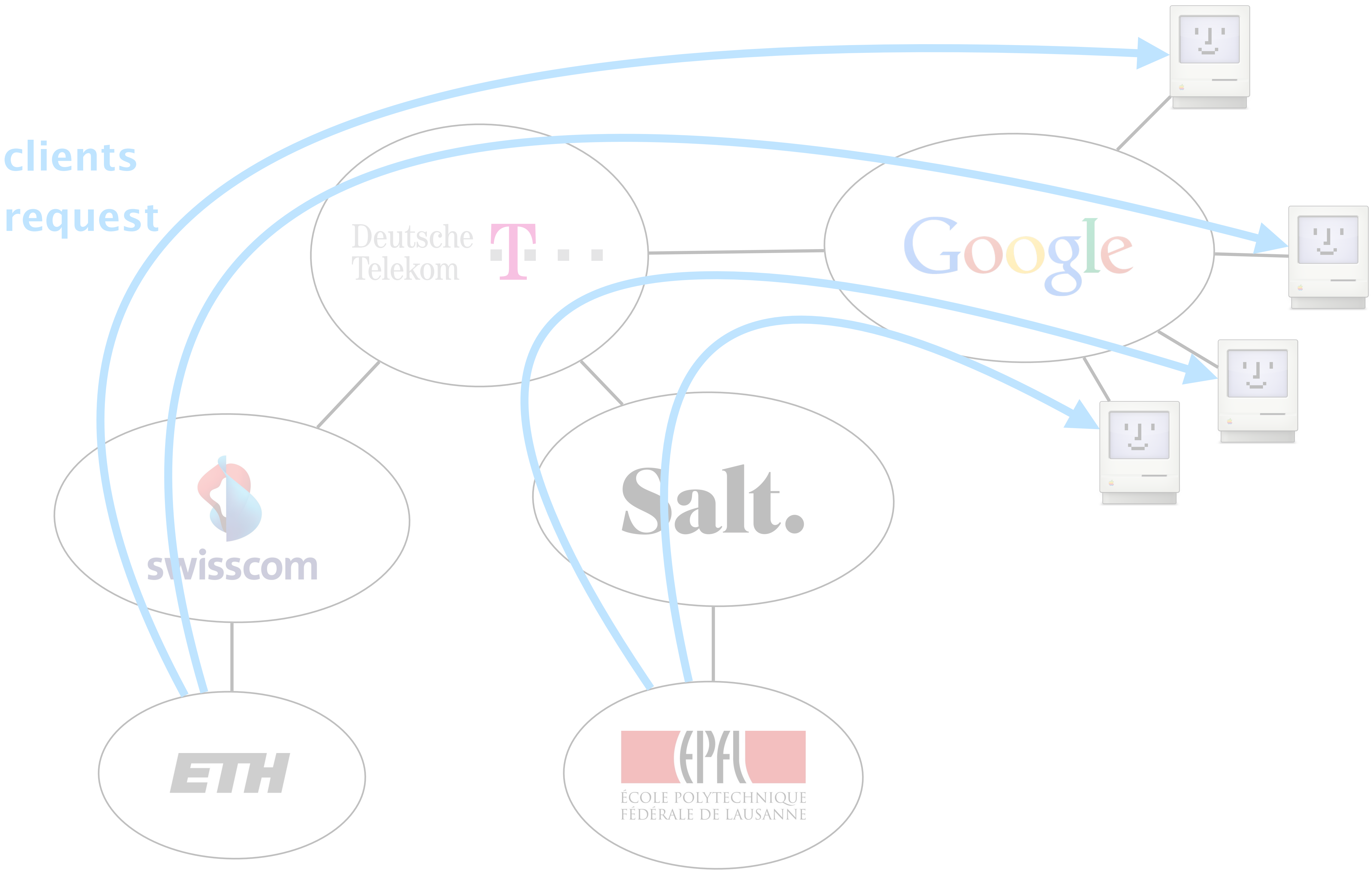
Caching can and is performed at different locations

client	browser cache
close to the client	forward proxy
	Content Distribution Network (CDN)
close to the destination	reverse proxy

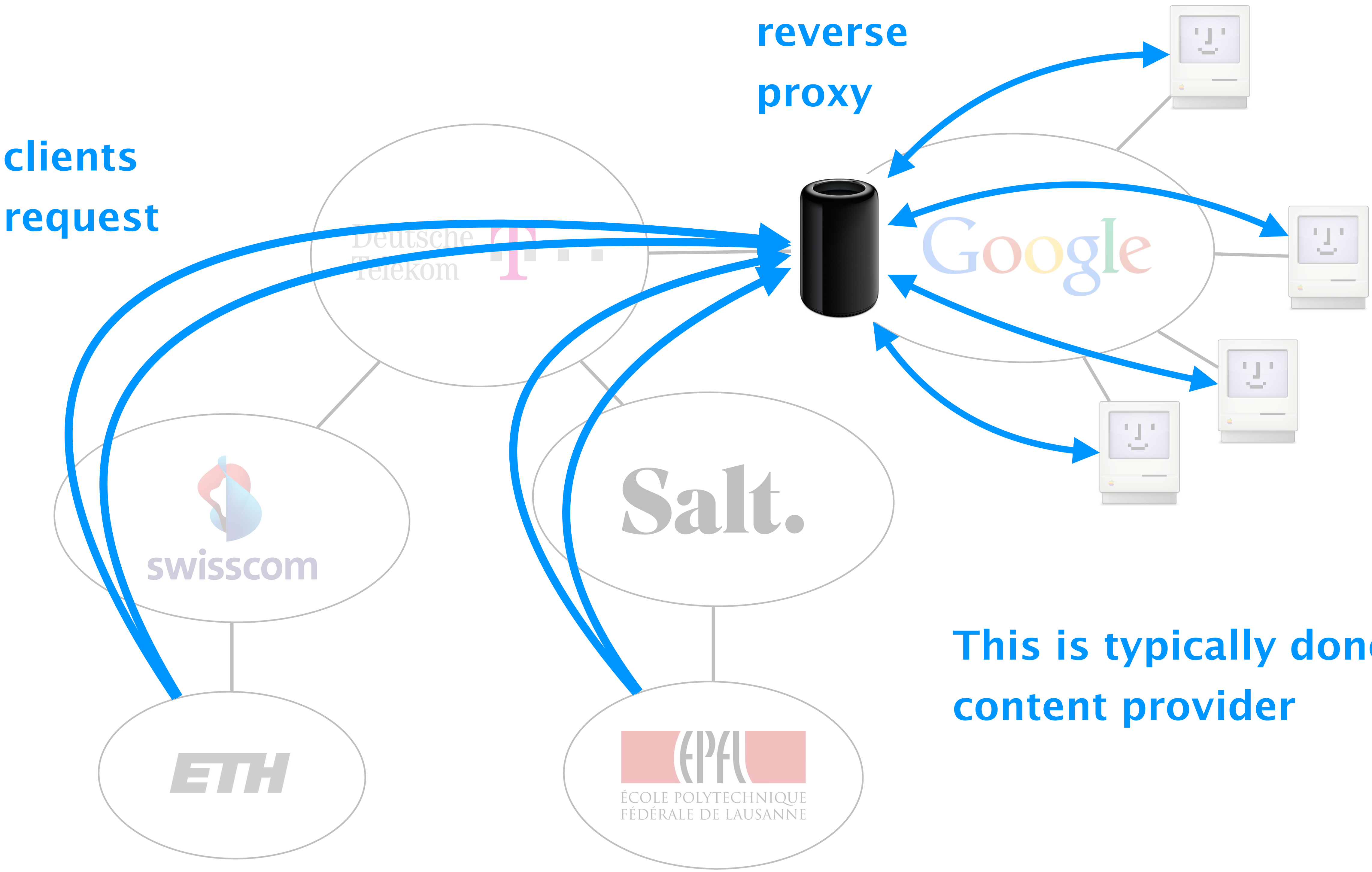
Many clients request the same information



This increases servers and network's load, while clients experience unnecessary delays

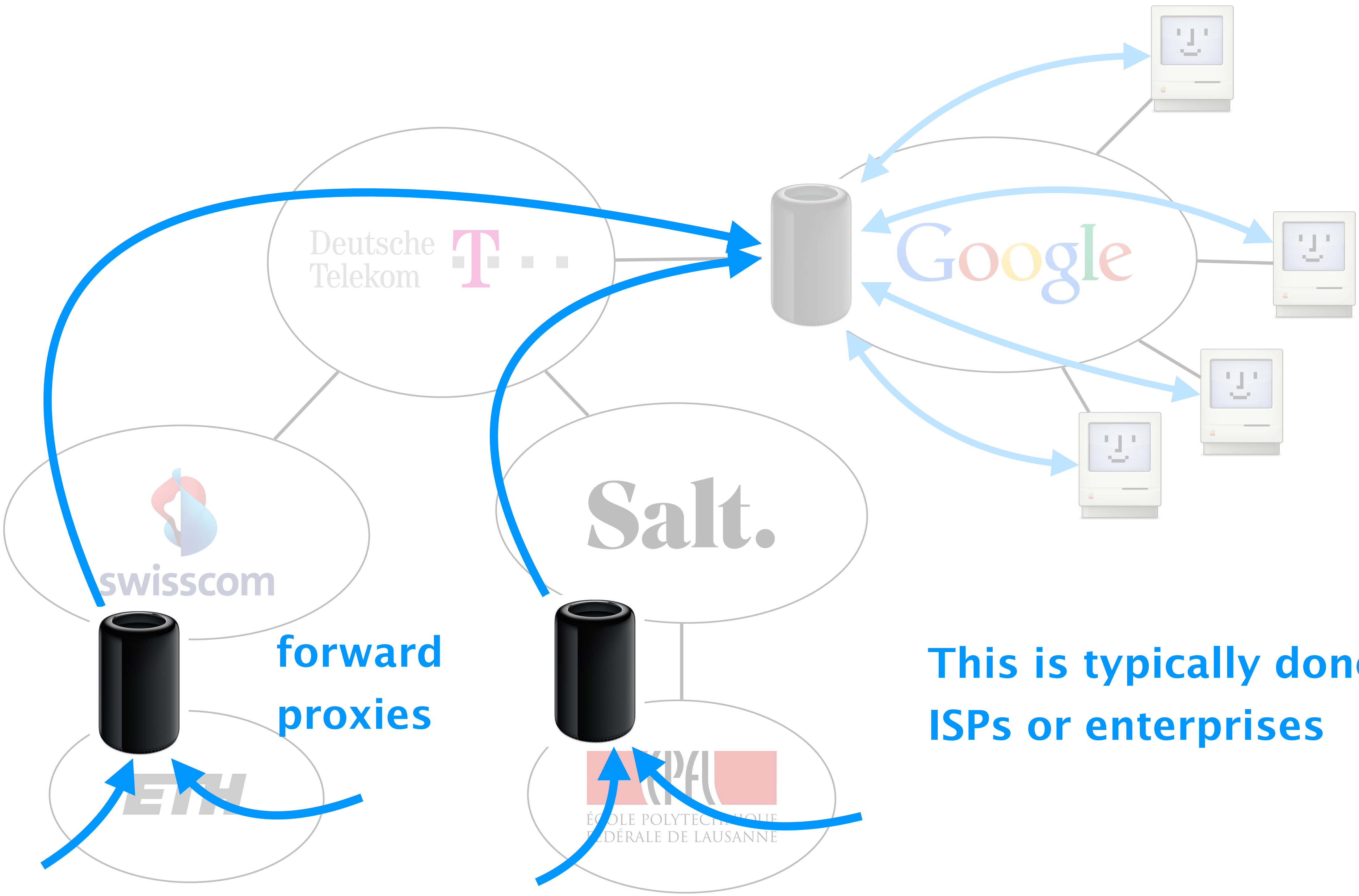


Reverse proxies cache documents close to servers, decreasing their load



This is typically done by content provider

Forward proxies cache documents close to clients, decreasing network traffic, server load and latencies



This is typically done by ISPs or enterprises

Network operators

Content provider

NETFLIX

wish

no overload

happy users

cost-effective infrastructure

solution

Caching and Replication

The idea behind replication is to duplicate popular content all around the globe

Spreads load on server

e.g., across multiple data-centers

Places content closer to clients

only way to beat the "speed-of-light"

Helps speeding up uncachable content

still have to pull it, but from closer

The problem of CDNs is to direct and serve your requests from a close, non-overloaded replica

DNS–based

returns ≠ IP addresses
based on

- client geo-localization
- server load

BGP Anycast

advertise the same IP prefix from different locations

avoided in practice, any idea why?

Akamai is one of the largest CDNs in the world, boasting servers in more than 20,000 locations

http://wwwnui.akamai.com/gnet/globe/index.html

Akamai uses a combination of

- *pull* caching

  direct result of clients requests

- *push* replication

  when expecting high access rate

together with some dynamic processing

dynamic Web pages, transcoding,…

"Akamaizing" content is easily done by modifying content to reference the Akamai's domains

Akamai creates domain names for each client

a128.g.akamai.net for cnn.com

Client modifies its URL to refer to Akamai's domain

http://www.cnn.com/image-of-the-day.gif
becomes
http://a128.g.akamai.net/image-of-the-day.gif

Requests are now sent to the CDN infrastructure

Communication Networks

Spring 2020

Laurent Vanbever

nsg.ee.ethz.ch

ETH Zürich (D-ITET)

May 4 2020