# Communication Networks

## Spring 2018


Laurent Vanbever

nsg.ee.ethz.ch

ETH Zürich (D-ITET)


May 24 2018

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

Last Monday on

# Communication Networks

DNS

Web

google.ch ⟷ 172.217.16.131

http://www.google.ch

DNS

Web

google.ch ⟷ 172.217.16.131

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


www.ethz.ch 129.132.19.216

To scale,

DNS adopt three intertwined hierarchies

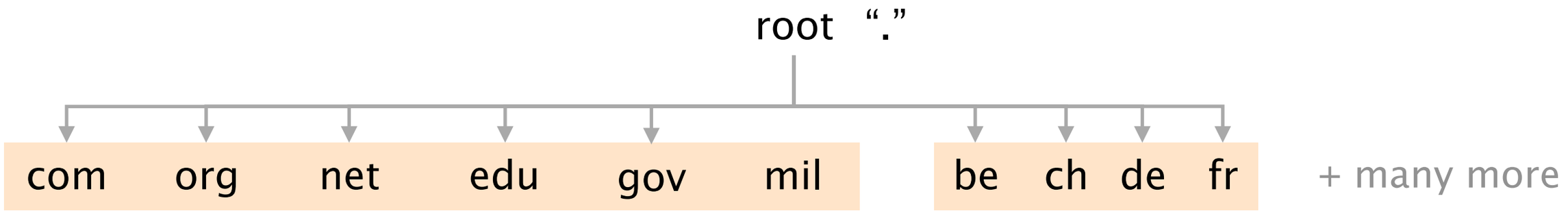
| | |
|---|---|
| naming structure | addresses are hierarchical<br>www.ee.ethz.ch |
| management | hierarchy of authority<br>over names |
| infrastructure | hierarchy of DNS servers |

naming structure

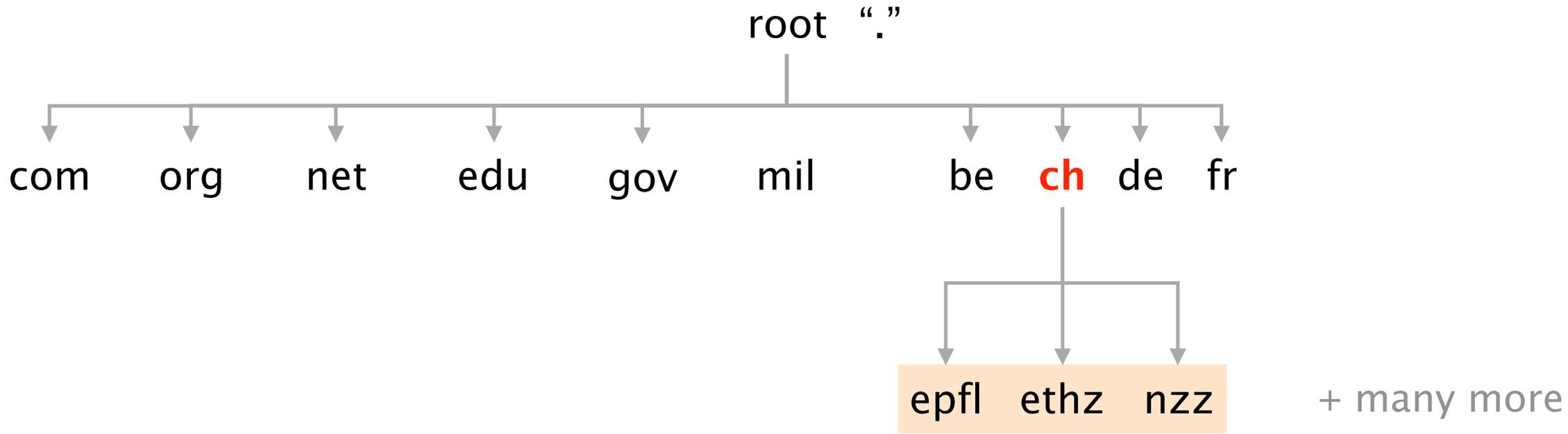
addresses are hierarchical

www.ee.ethz.ch

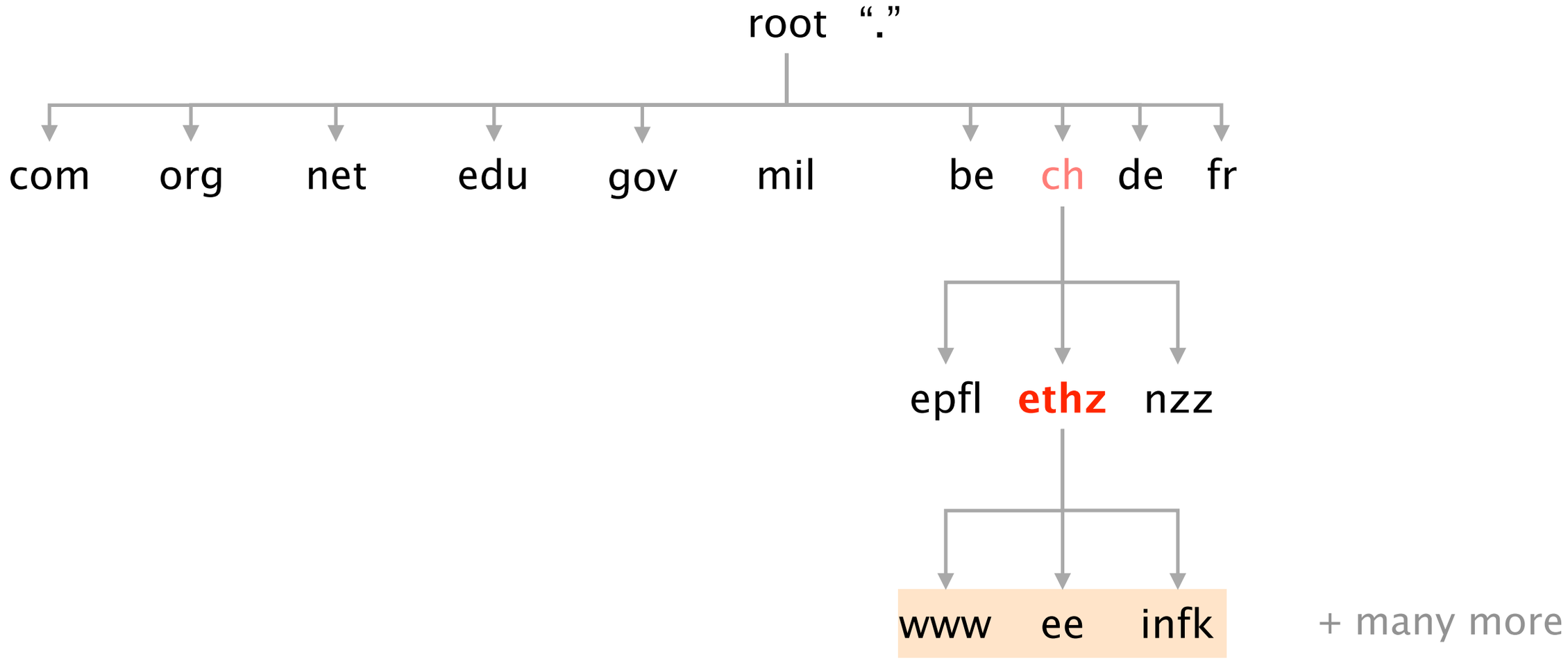
# Top Level Domain (TLDs) sit at the top



# Domains are subtrees



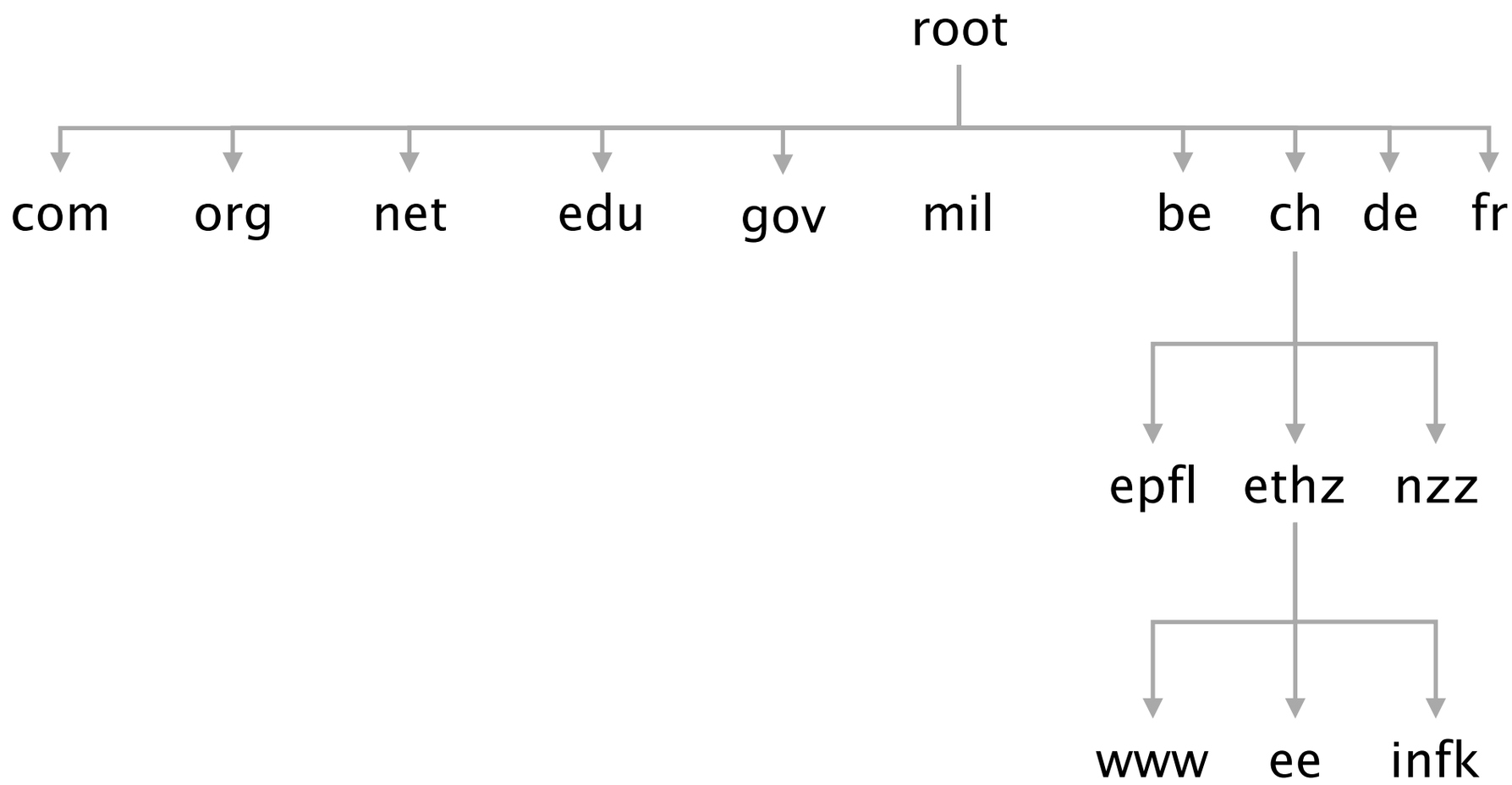
A name, *e.g.* ee.ethz.ch, represents
a leaf-to-root path in the hierarchy



management

hierarchy of authority
over names

# The DNS system is hierarchically administered

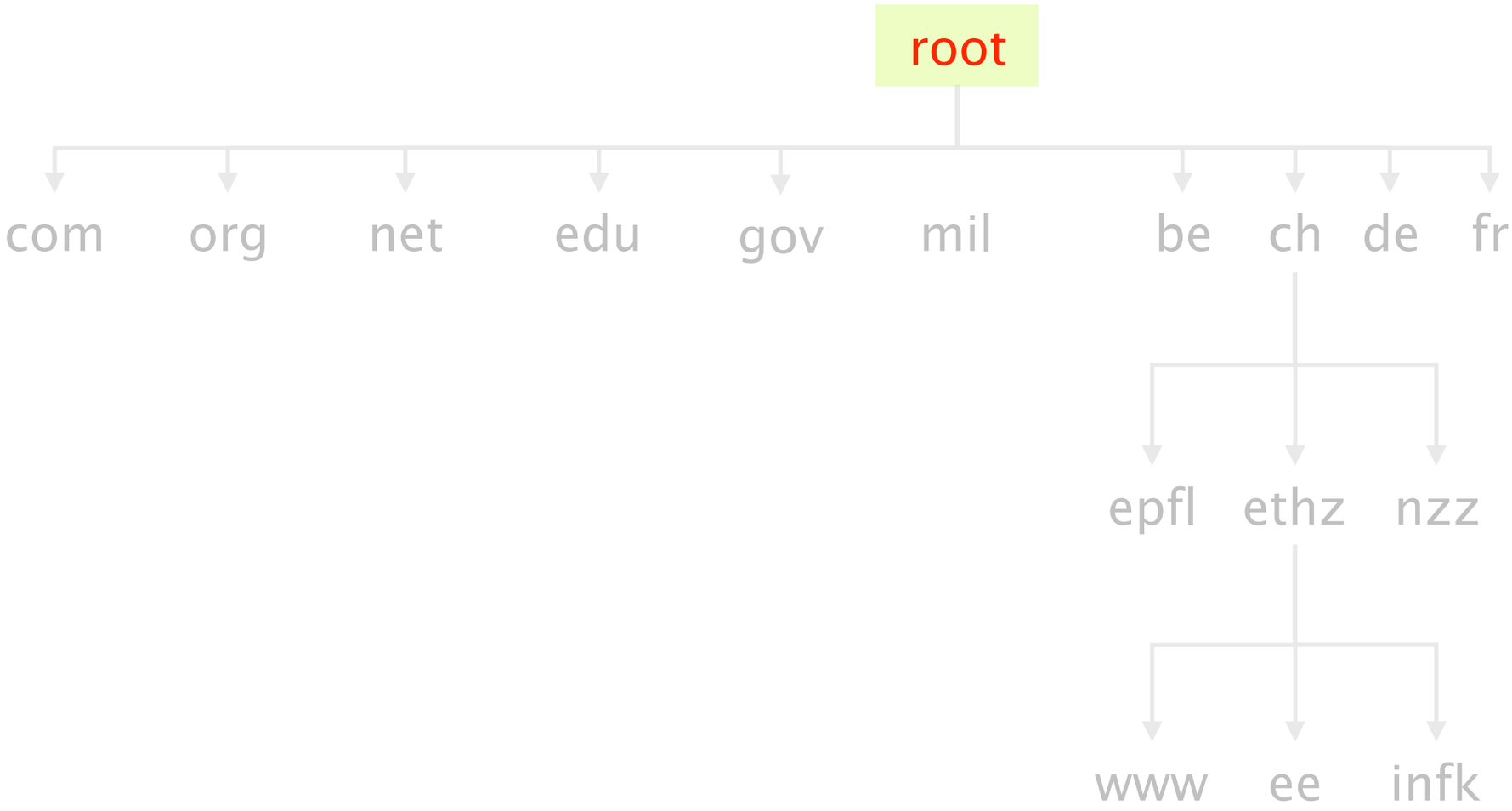


infrastructure

hierarchy of DNS servers

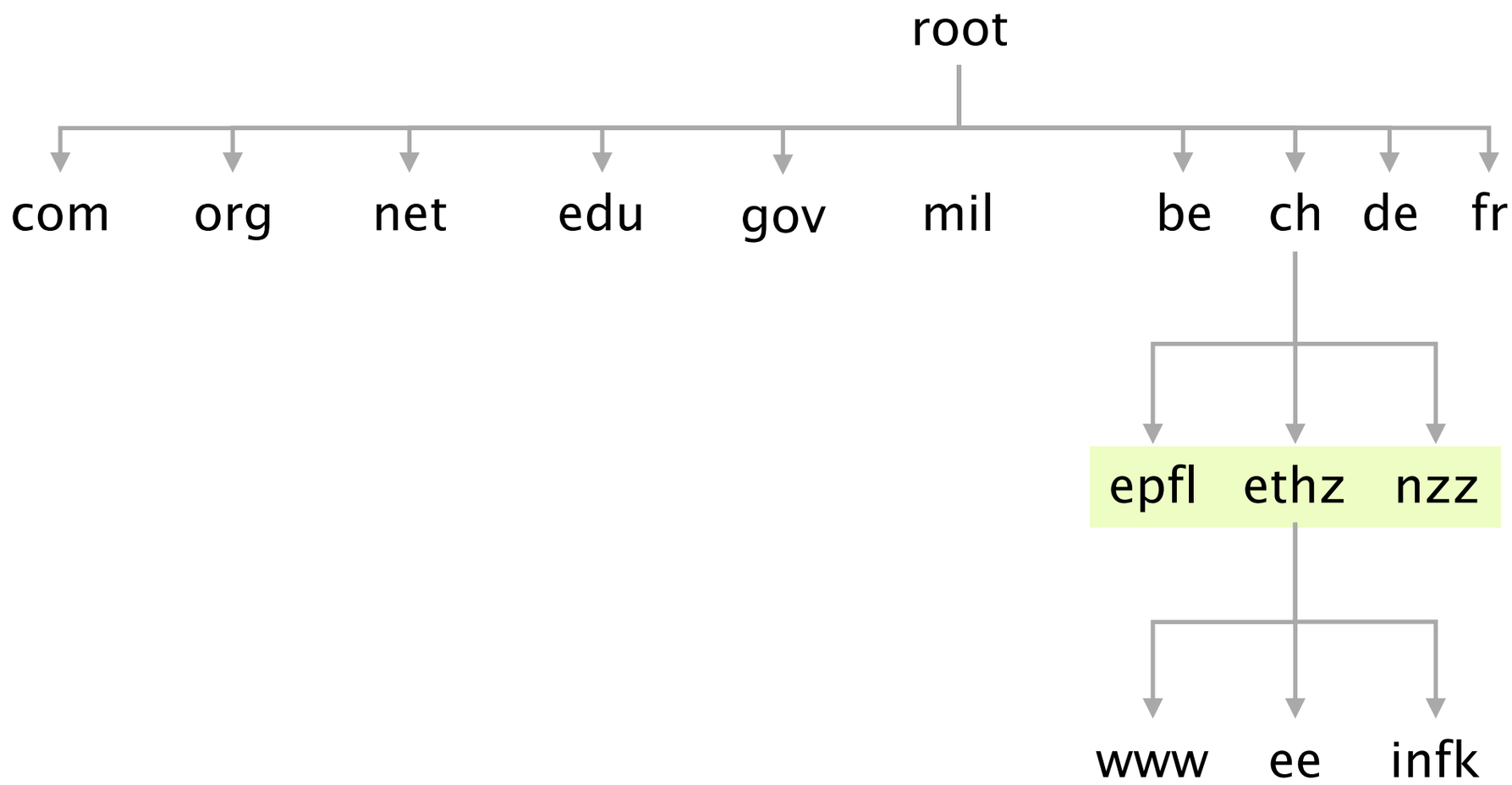
13 root servers (managed professionally)

serve as root (*)




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

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



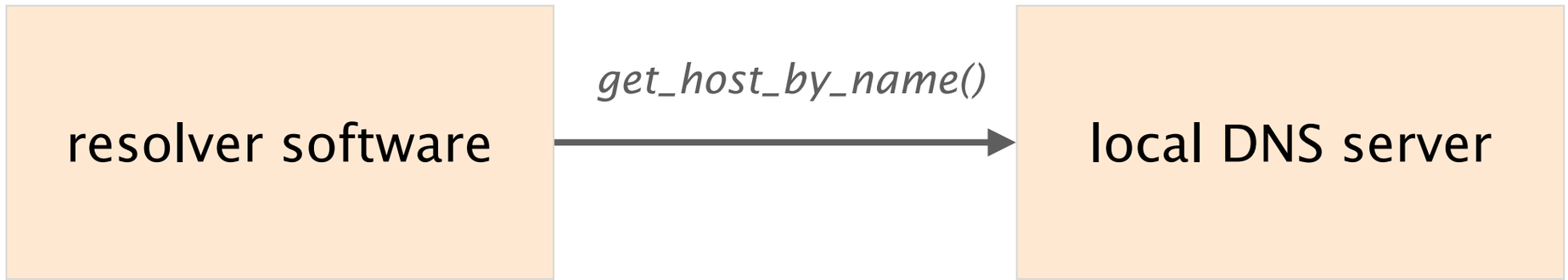
Every server knows the address of the root servers (*)

required for bootstrapping the systems

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

Each server knows the address of all children

# Using DNS relies on two components




trigger resolution process

send request to local DNS server

usually, near the endhosts

configured statically (resolv.conf)

or dynamically (DHCP)

| Records | Name | Value |
| --- | --- | --- |
| A | hostname | IP address |
| NS | domain | DNS server name |
| MX | domain | Mail server name |
| CNAME | alias | canonical name |
| PTR | IP address | corresponding hostname |

DNS resolution can either be recursive or iterative

root
DNS server

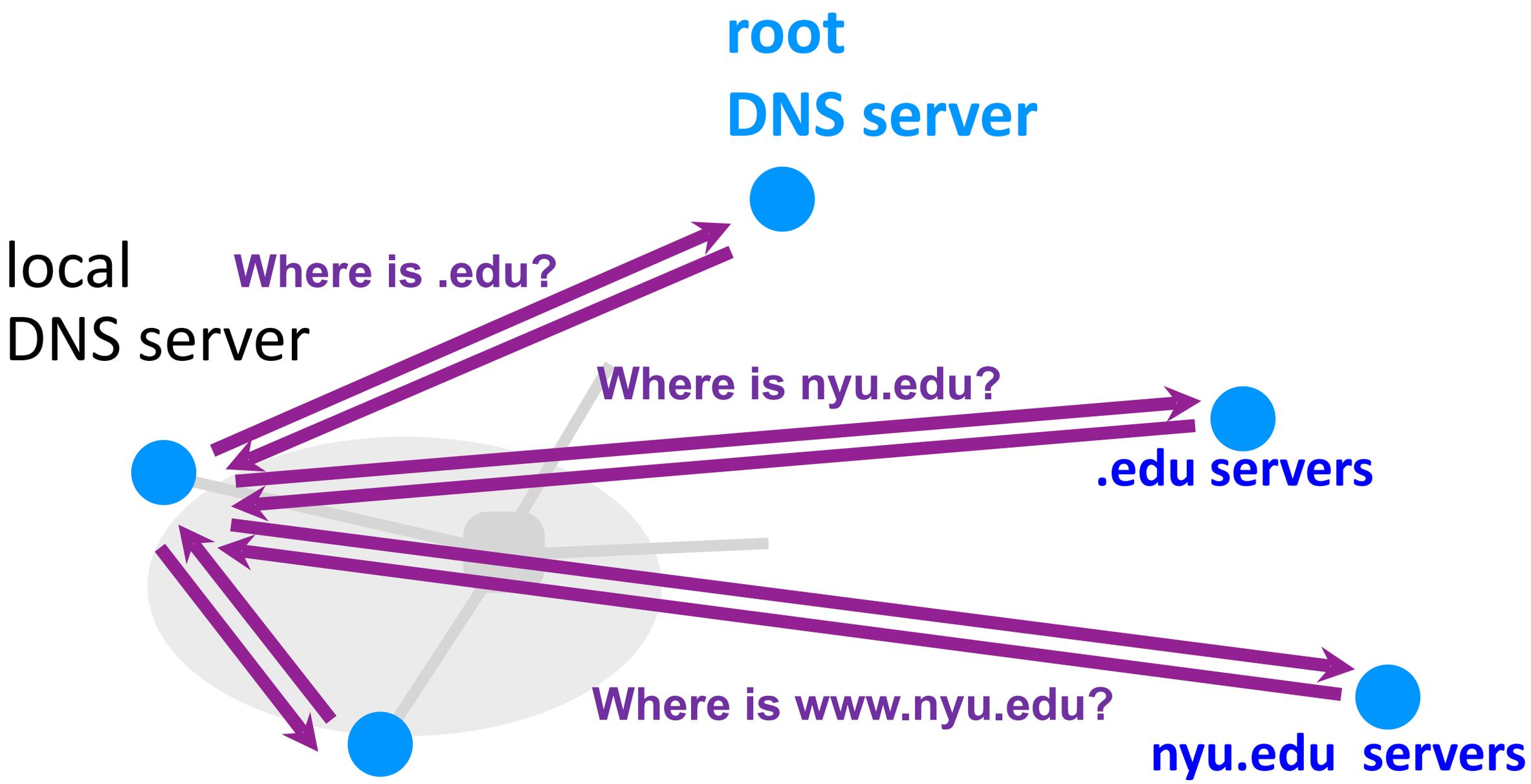
local
DNS server
(dns1.ethz.ch)

.edu servers

nyu.edu servers

www.nyu.edu?

DNS client
(me.ee.ethz.ch)


root
DNS server
local
DNS server
Where is .edu?
Where is nyu.edu?
.edu servers
Where is www.nyu.edu?
nyu.edu servers
DNS client
(me.ee.ethz.ch)

DNS

Web

http://www.google.ch

# The WWW is made of three key components

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

http://

Protocol


Performance

# HTTP is a rather simple synchronous request/reply protocol

HTTP is layered over a bidirectional byte stream

almost always TCP

HTTP is text-based (ASCII)

human readable, easy to reason about

HTTP is stateless

it maintains *no info* about past client requests

Today on

# Communication Networks

Video Streaming

E-mail

HTTP-based

MX, SMTP, POP, IMAP

Video Streaming

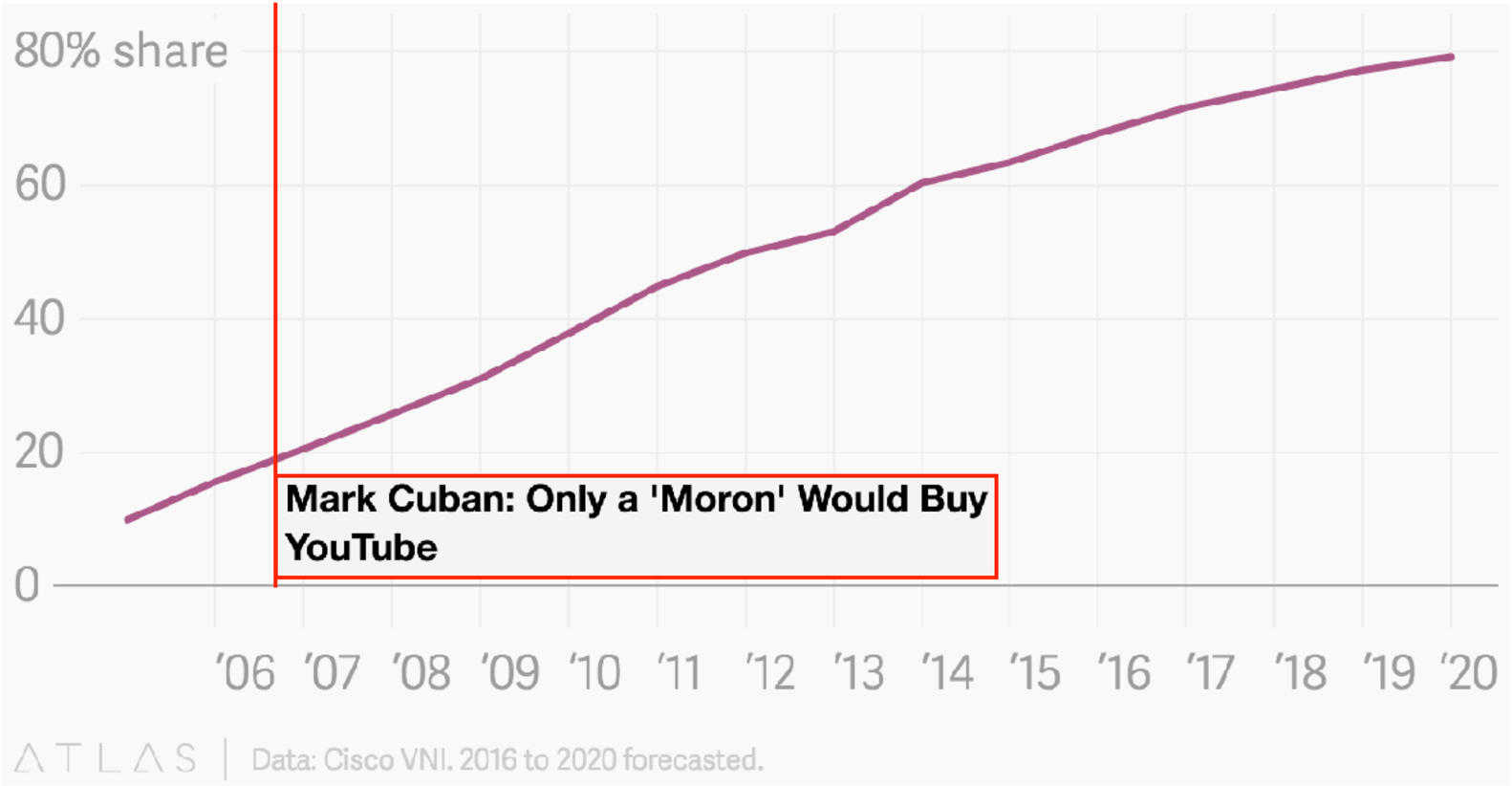
E-mail

HTTP-based

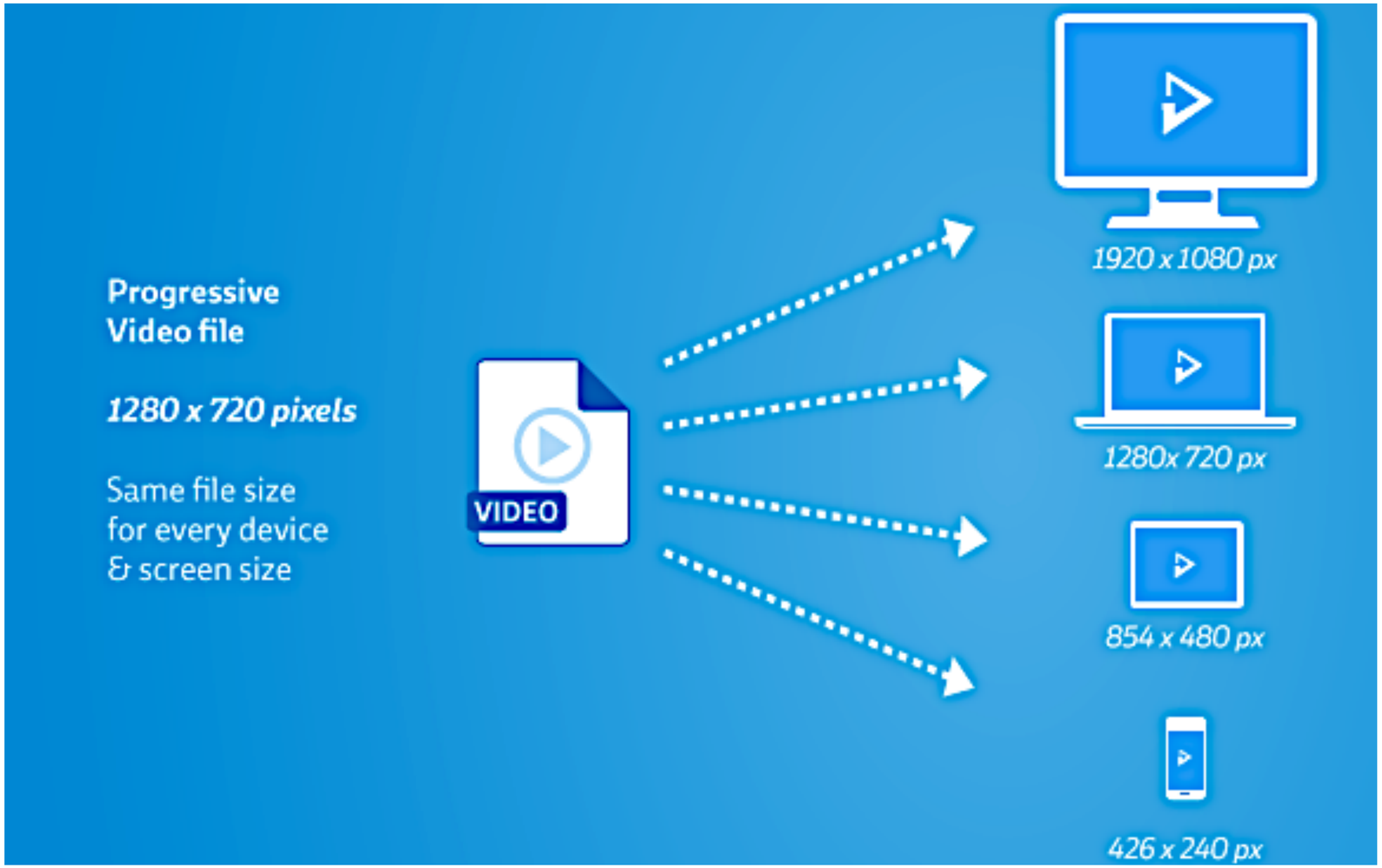
# We want the highest video quality

# Without seeing this …

# Why should you care? Just look at this: video's share of global internet traffic

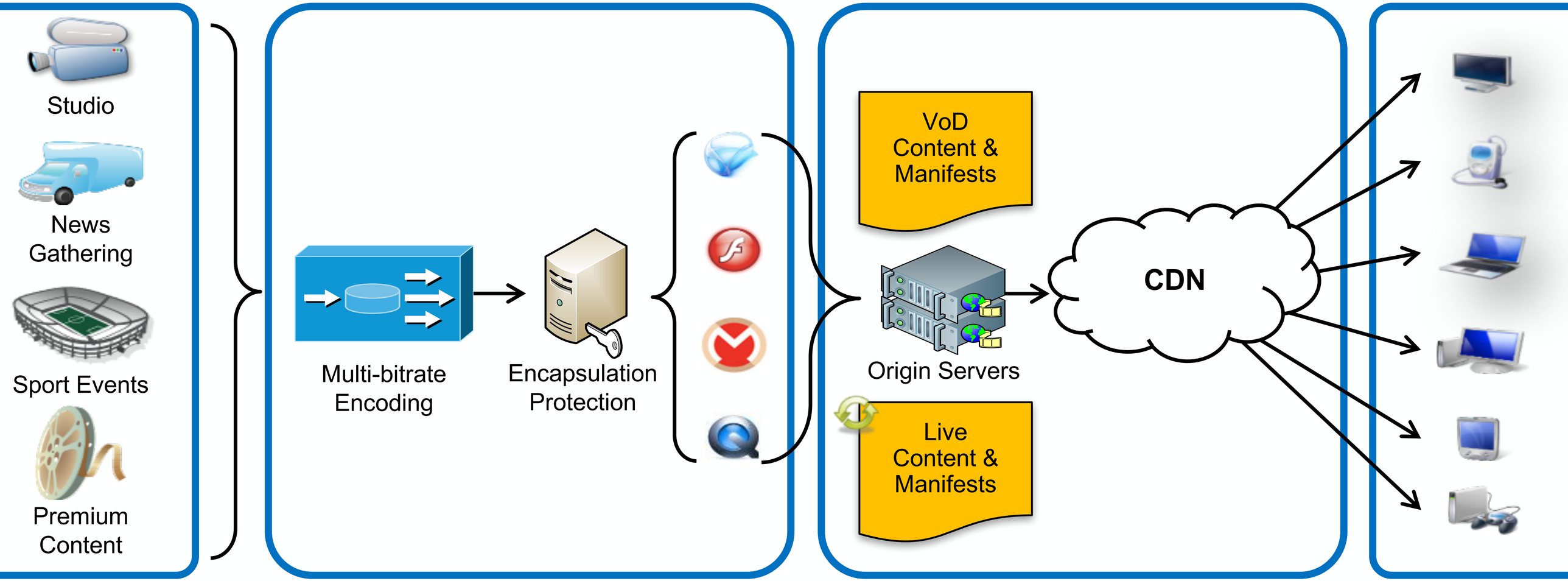


# A naive approach: one-size-fits-all




[bitmovin.com]

# In practice, things are slightly more complex




[Adapted from: Adaptive Streaming of Traditional and Omnidirectional Media, Begen & Timmerer, ACM SIGCOMM Tutorial, 2017]

# The three steps behind most contemporary solutions

- Encode video in multiple bitrates
- Replicate using a content delivery network
- Video player picks bitrate adaptively
  - Estimate connection's available bandwidth
  - Pick a bitrate $\leq$ available bandwidth

Encoding

Replication

Adaptation

Encoding

Replication

Adaptation

Video size: 1920 x 1080 px


Screen size: 1920 x 1080 px

Video size: 1280x 720 px


Screen size: 1280x 720 px

Video size: 854 x 480 px


Screen size: 854 x 480 px

Video size: 426 x 240 px


Screen size: 426 x 240 px

Fast Internet

1920 x 1080 px


**Screen size: 1920 x 1080 px**
With ***fast*** internet.

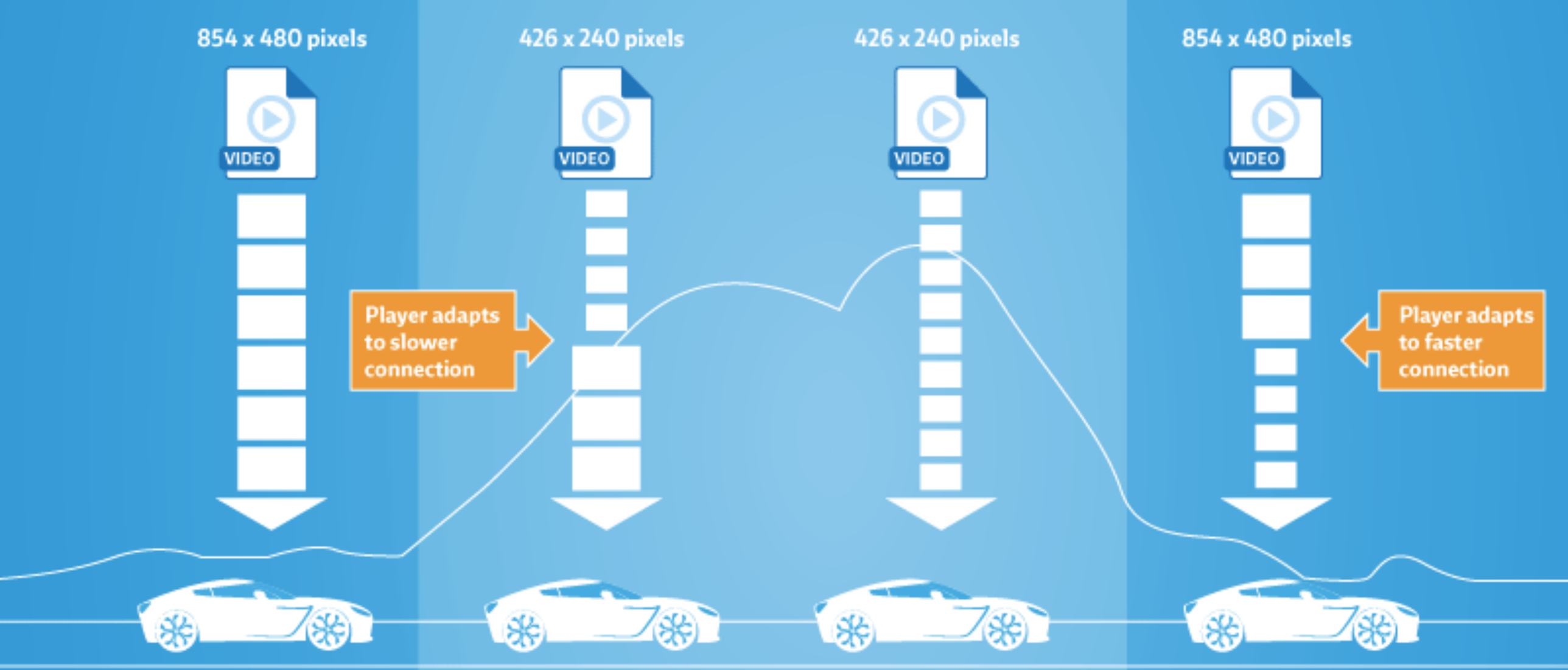
Video plays at **high quality**
**1920 x 1080 px** with **no buffering**

1280x 720 px


**Screen size: 1920 x 1080 px**
With ***slower*** internet.

Video plays at **medium quality**
**1280x 720 px** with **no buffering**

Slow Internet




[bitmovin.com]

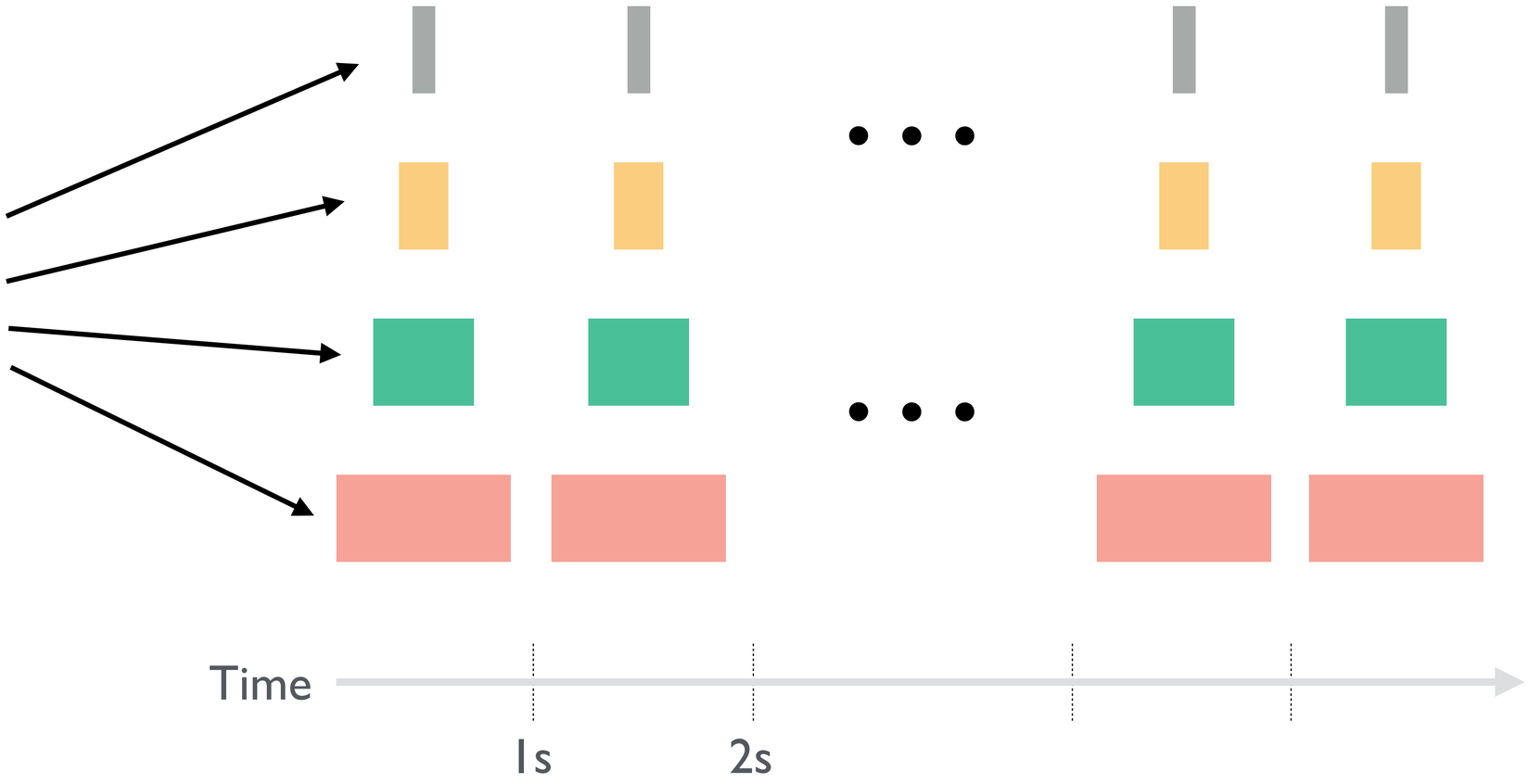
# Simple solution for encoding: use a “bitrate ladders”

| Bitrate (kbps) | Resolution |
|---|---|
| 235 | 320x240 |
| 375 | 384x288 |
| 560 | 512x384 |
| 750 | 512x384 |
| 1050 | 640x480 |
| 1750 | 720x480 |
| 2350 | 1280x720 |
| 3000 | 1280x720 |
| 4300 | 1920x1080 |
| 5800 | 1920x1080 |

[netflix.com]

# Your player download “chunks” of video at different bitrates

[netflix.com]



# Depending on your network connectivity, your player fetches chunks of different qualities

[netflix.com]

# Your player gets metadata about chunks via “Manifest”

```
<?xml version="1.0" encoding="UTF-8"?>
<MPD xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns="urn:mpeg:DASH:schema:MPD:2011"
    xsi:schemaLocation="urn:mpeg:DASH:schema:MPD:2011"
    profiles="urn:mpeg:dash:profile:isoff-main:2011"
    type="static"
    mediaPresentationDuration="PT0H9M56.46S"
    minBufferTime="PT15.0S">
  <BaseURL>http://witestlab.poly.edu/~ffund/video/2s_480p_only/</BaseURL>
  <Period start="PT0S">
        <AdaptationSet bitstreamSwitching="true">
     <Representation id="0" codecs="avc1" mimeType="video/mp4"
        width="480" height="360" startWithSAP="1" bandwidth="101492">
       <SegmentBase>
         <Initialization sourceURL="bunny_2s_100kbit/bunny_100kbit.mp4"/>
       </SegmentBase>
       <SegmentList duration="2">
         <SegmentURL media="bunny_2s_100kbit/bunny_2s1.m4s"/>
         <SegmentURL media="bunny_2s_100kbit/bunny_2s2.m4s"/>
         <SegmentURL media="bunny_2s_100kbit/bunny_2s3.m4s"/>
         <SegmentURL media="bunny_2s_100kbit/bunny_2s4.m4s"/>
         <SegmentURL media="bunny_2s_100kbit/bunny_2s5.m4s"/>
         <SegmentURL media="bunny_2s_100kbit/bunny_2s6.m4s"/>
```

[witestlab.poly.edu]

Encoding

Replication

Adaptation

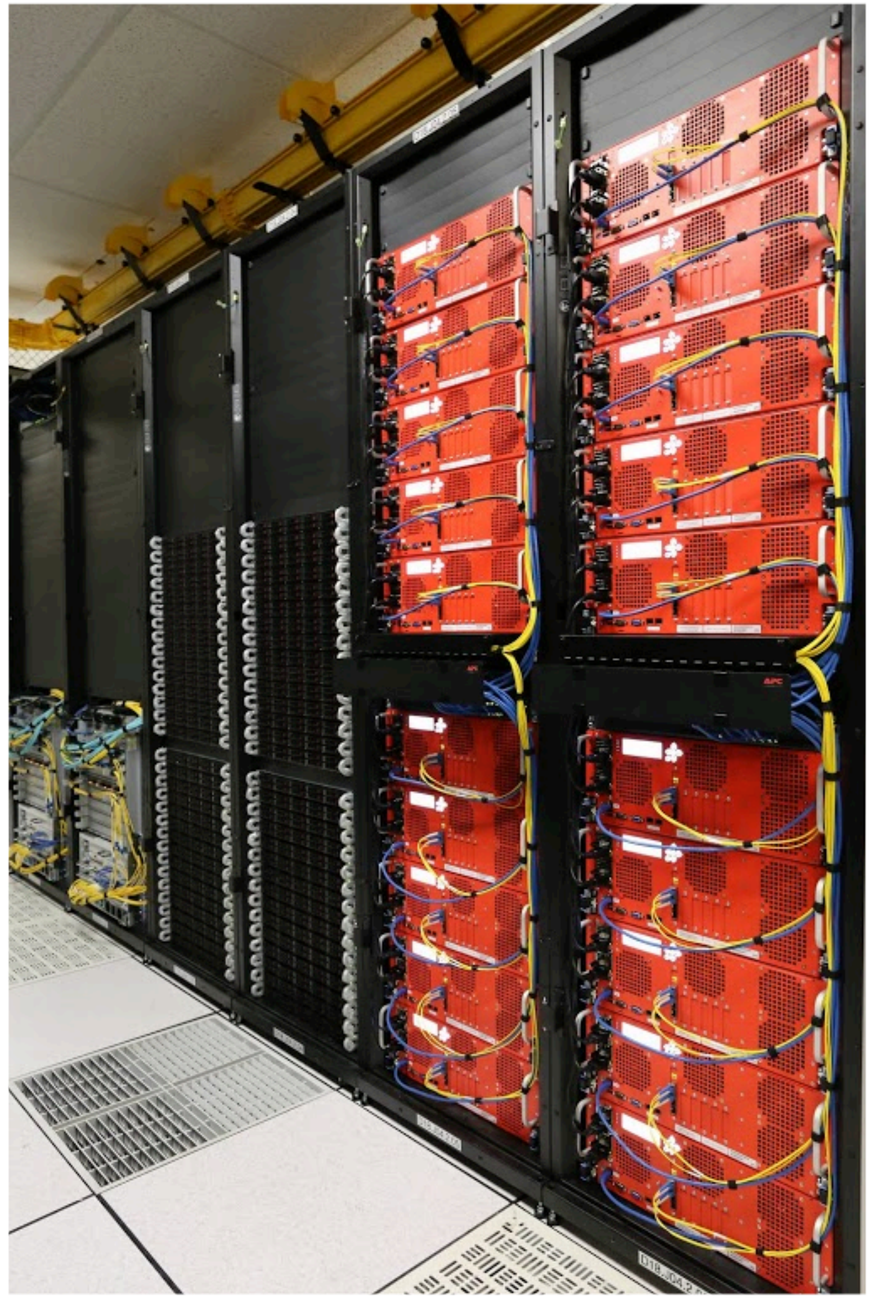
# NETFLIX

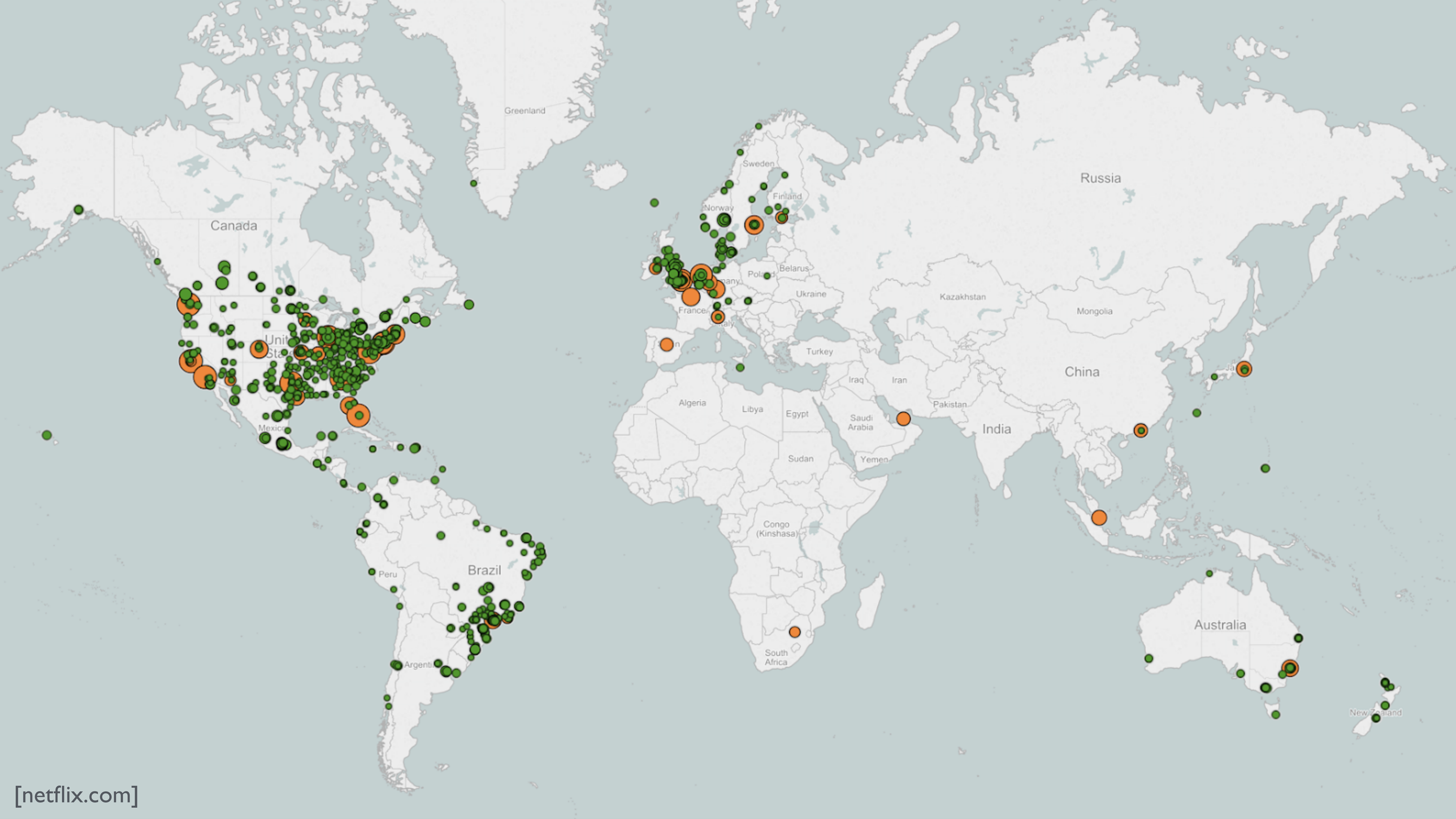
## Open Connect: Starting from a Greenfield (a mostly Layer 0 talk)

Dave Temkin
06/01/2015

**Storage Appliance**
- Still 4U high
- ~550 watts
- 288 TB of storage
- 2x 10G ports
- 20Gbit/s delivery

**Flash Appliance**
- 1U
- ~175 watts
- 24 TB of flash
- 2x 40G ports
- 40Gbit/s delivery




Greenland
Canada
Sweden
Finland
Norway
Russia
Belarus
Ukraine
Kazakhstan
Mongolia
China
Turkey
Iraq
Iran
Pakistan
India
Algeria
Libya
Egypt
Saudi Arabia
Yemen
Sudan
Congo (Kinshasa)
South Africa
Brazil
Peru
Australia
New Zealand

[netflix.com]


WEST COAST US
DAREDEVIL
DAREDEVIL
DAREDEVIL
DAREDEVIL
AUSTRALIA

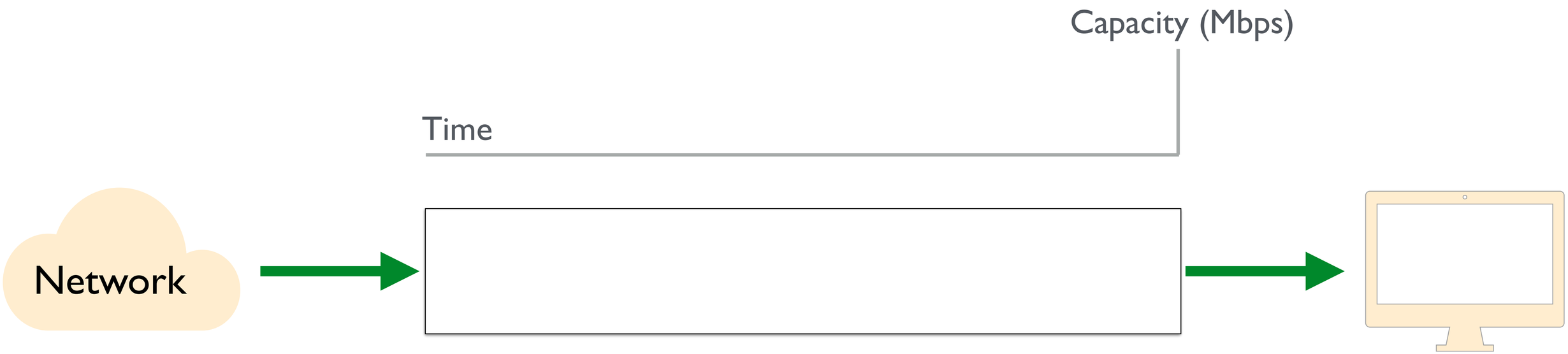
[netflix.com]

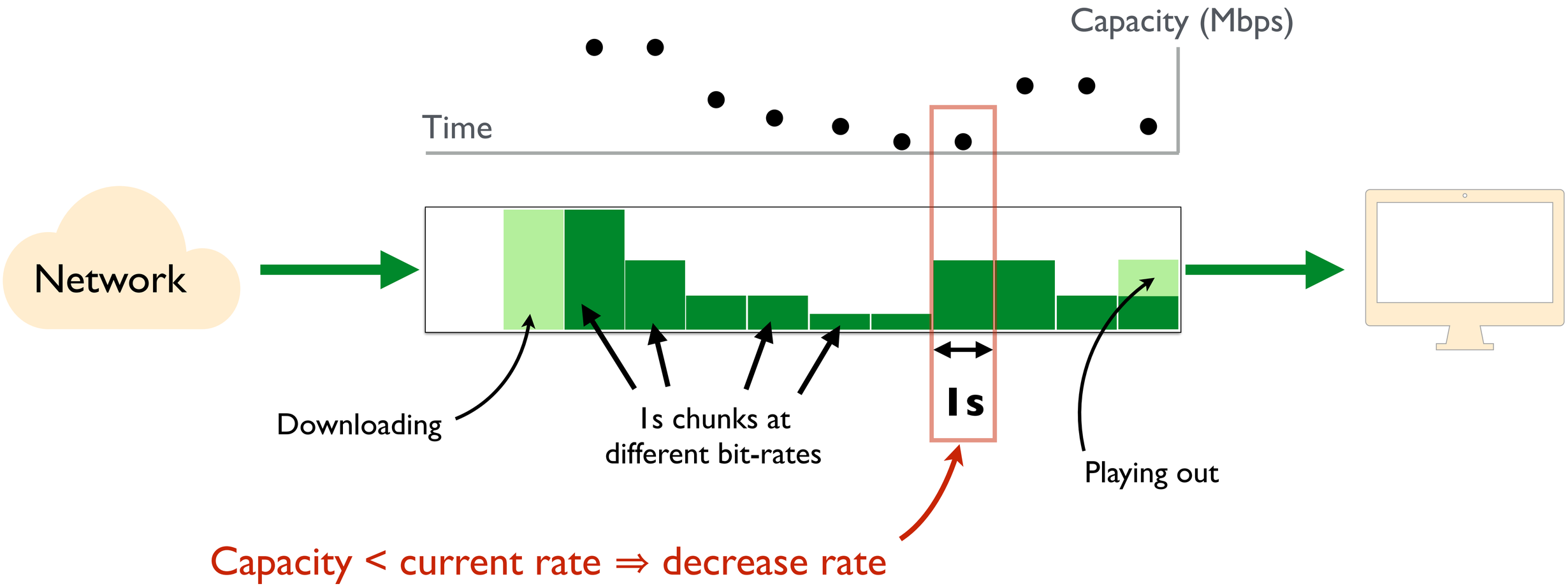
Encoding

Replication

Adaptation


Network


Capacity (Mbps)
Time
Network

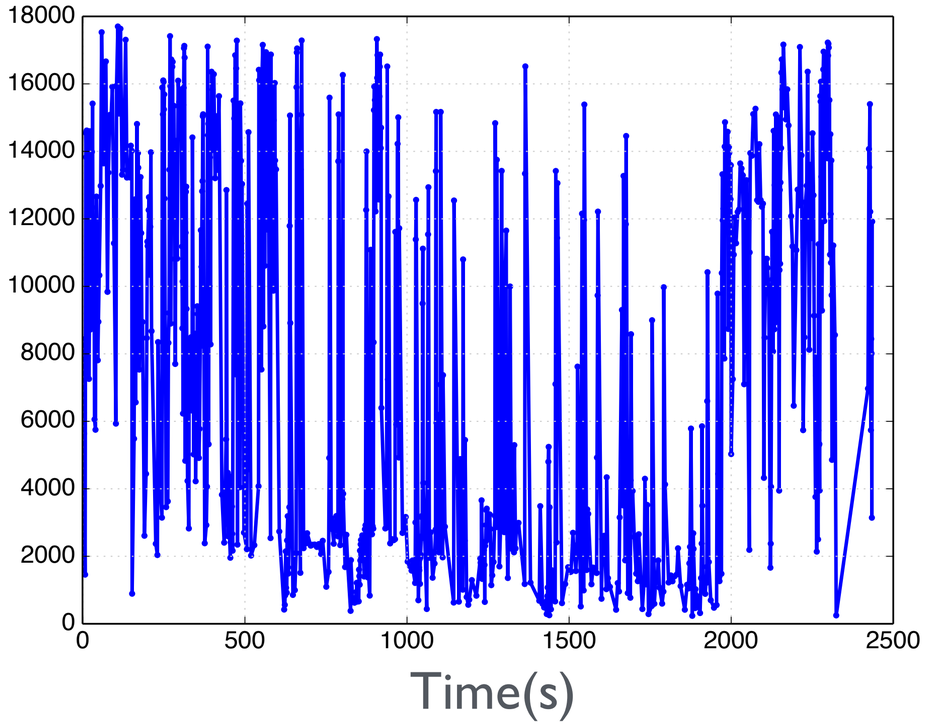

Capacity (Mbps)
Time
Network
Downloading
1s chunks at
different bit-rates
1s
Playing out
Capacity < current rate ⇒ decrease rate

# Common solution approach

- Encode video in multiple bitrates
- Replicate using a content delivery network
- Video player picks bitrate adaptively
  - Estimate connection's available bandwidth
  - Pick a bitrate ≤ available bandwidth

# Estimating available capacity

Avg. throughput over chunk download (kbps)




[A Buffer-Based Approach to Rate Adaptation: Evidence from a Large Video Streaming Service, Huang et al., ACM SIGCOMM 2014]

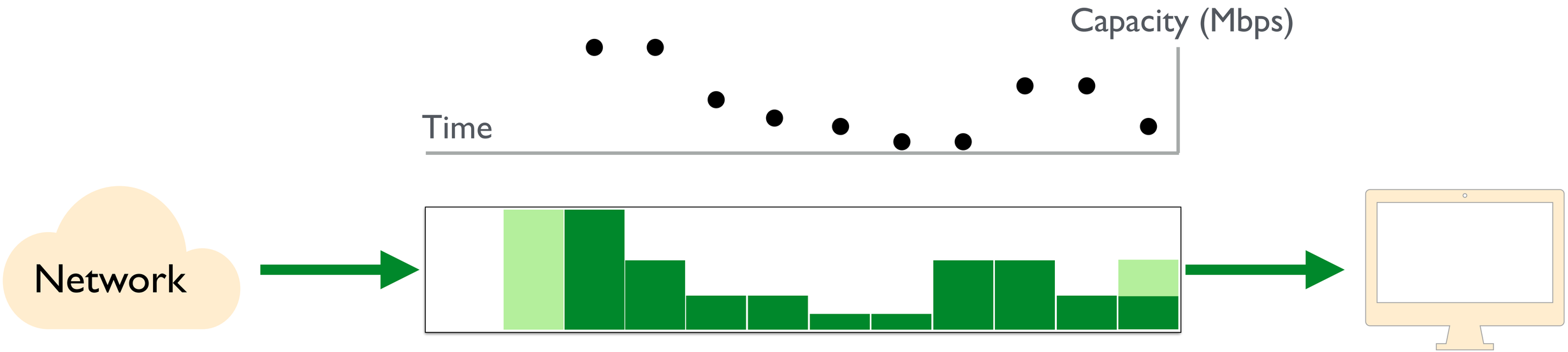
# Estimating available capacity

***"A random sample of 300,000 Netflix sessions shows that roughly 10% of sessions experience a median throughput less than half of the 95th percentile throughput."***

***"20–30% of rebuffers are unnecessary"***

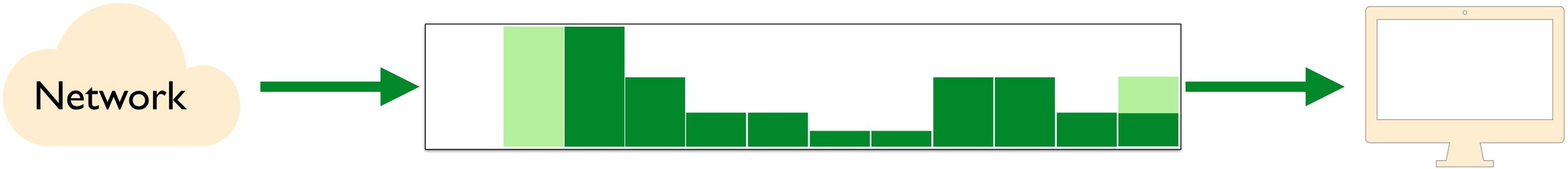
[A Buffer-Based Approach to Rate Adaptation: Evidence from a Large Video Streaming Service, Huang et al., ACM SIGCOMM 2014]

# Capacity estimation




**Decide based on the buffer alone?**

# Buffer-based adaptation

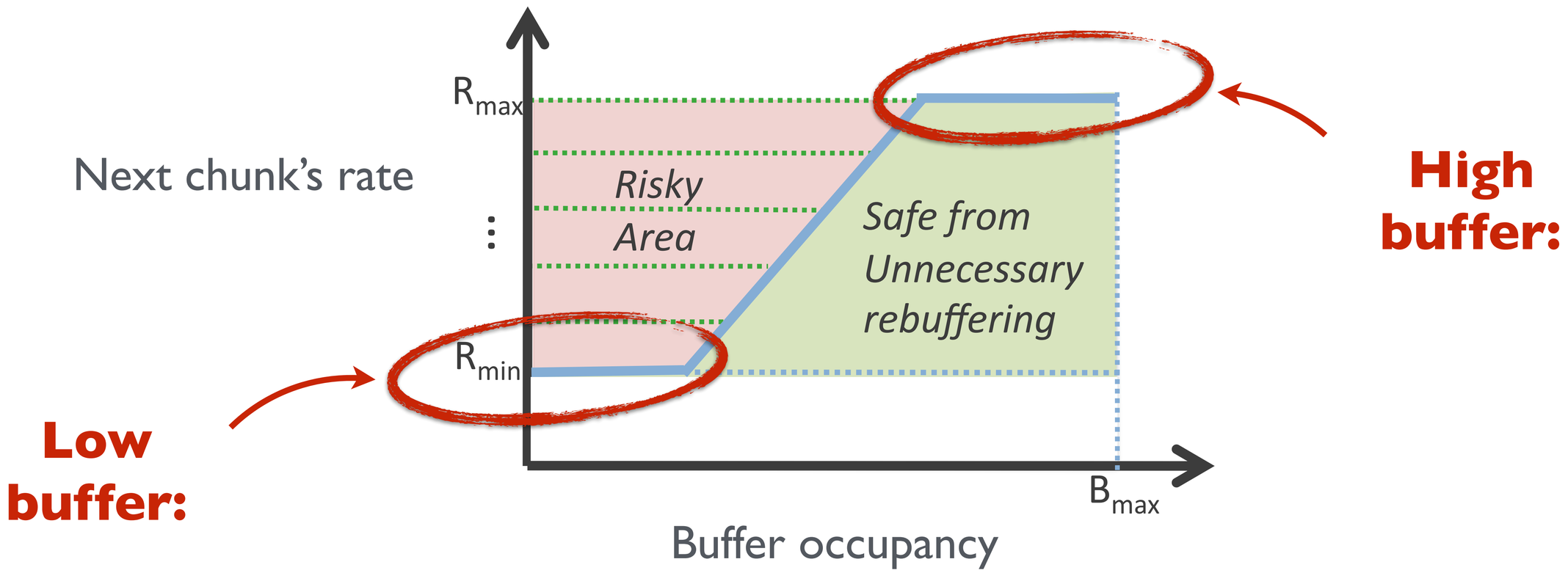



**Nearly full buffer ⇒ large rate**

# Buffer-based adaptation


**Nearly empty buffer ⇒ small rate**

# Buffer-based adaptation




[A Buffer-Based Approach to Rate Adaptation: Evidence from a Large Video Streaming Service, Huang et al., ACM SIGCOMM 2014]

Problem: startup phase?

**Pick a rate based on immediate past throughput**

# Summary

- Encode video in multiple bitrates
- Replicate using a content delivery network
- Video player picks bitrate adaptively
- Problem of active research interest, many competing algorithms and objectives

Video Streaming

E-mail

MX, SMTP, POP, IMAP

# We'll study e-mail from three different perspectives

| Content | Infrastructure/ Transmission | Retrieval |
| --- | --- | --- |
| Format: Header/Content<br>Encoding: MIME | SMTP: Simple Mail Transfer Protocol<br>Infrastructure<br>mail servers | POP: Post Office Protocol<br>IMAP:Internet Message Access Protocol |

Content

Infrastructure/
Transmission

Retrieval

Format: Header/Content

Encoding: MIME

# An e-mail is composed of two parts

E-mail

# A header, in 7-bit U.S. ASCII text

Header

From: Laurent Vanbever <lvanbever@ethz.ch>

To: Tobias Buehler <buehlert@ethz.ch>

Subject: [comm-net] Exam questions

# A body, also in 7-bit U.S. ASCII text

From: Laurent Vanbever <lvanbever@ethz.ch>

To: Tobias Buehler <buehlert@ethz.ch>

Subject: [comm-net] Exam questions

Body

Hi Tobias,

Here are some interesting questions...

Best,
Laurent

Type, followed by ":"

Value

Header

From: Laurent Vanbever <lvanbever@ethz.ch> CRLF

To: Tobias Buehler <buehlert@ethz.ch> CRLF

Subject: [comm-net] Exam questions CRLF

Series of lines ending with Carriage Return and Line Feed

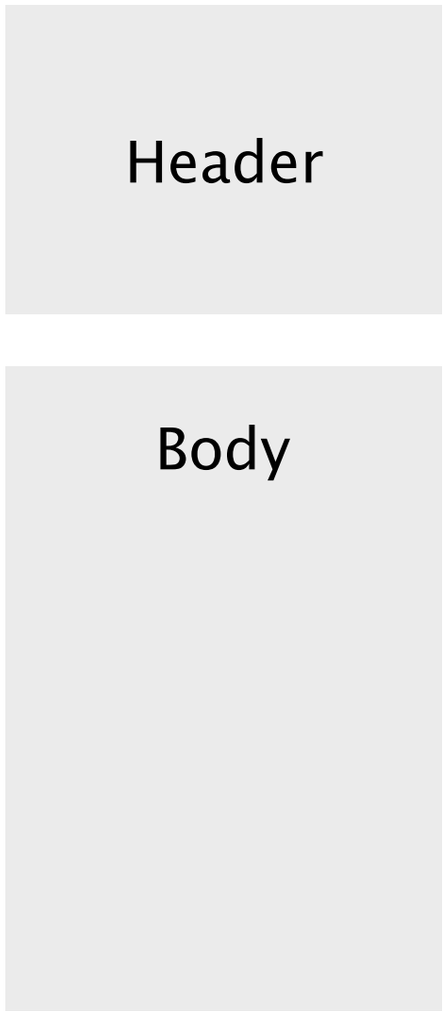
Series of lines with no structure/meaning

Body

Hi Tobias,

Here are some interesting questions…

Best,
Laurent




A blank line separates the header from the body

Email relies on 7-bit U.S. ASCII…

How do you send non-English text? Binary files?

Solution

Multipurpose Internet Mail Extensions

commonly known as MIME, standardized in RFC 822

MIME defines

- additional headers for the email body
- a set of content types and subtypes
- base64 to encode binary data in ASCII

MIME defines

- additional headers for the email body

  MIME-Version: the version of MIME being used

  Content-Type: the type of data contained in the message

  Content-Transfer-Encoding: how the data are encoded

MIME defines

- additional headers for the email body
- a set of content types and subtypes

  e.g. image with subtypes gif or jpeg

  text with subtypes plain, html, and rich text

  application with subtypes postscript or msword

  multipart with subtypes mixed or alternative

The two most common types/subtypes for MIME are:
*multipart/mixed* and *multipart/alternative*

| Content-Type | indicates that the message contains |
| --- | --- |
| multipart/mixed | multiple independent parts<br>e.g. plain text *and* a binary file |
| multipart/alternative | multiple representation of the same content<br>e.g. plain text *and* HTML |

MIME defines

- additional headers for the email body
- a set of content types and subtypes
- base64 to encode binary data in ASCII

# MIME relies on Base64 as binary-to-text encoding scheme

Relies on 64 characters out of the 128 ASCII characters

the most common *and* printable ones, i.e. A-Z, a-z, 0-9, +, /

Divides the bytes to be encoded into sequences of 3 bytes

each group of 3 bytes is then encoded using 4 characters

Uses padding if the last sequence is partially filled

i.e. if the |sequence| to be encoded is not a multiple of 3

| | |
|---|---|
| Binary input | `0x14fb9c03d97e` |
| 8-bits | `00010100 11111011 10011100`<br>`00000011 11011001 01111110` |
| 6-bits | `000101 001111 101110 011100`<br>`000000 111101 100101 111110` |
| Decimal | `5 15 46 28 0 61 37 62` |
| base64 | `F P u c A 9 l +` |

| Value | Char | Value | Char | Value | Char | Value | Char |
|---|---|---|---|---|---|---|---|
| 0 | A | 16 | Q | 32 | g | 48 | w |
| 1 | B | 17 | R | 33 | h | 49 | x |
| 2 | C | 18 | S | 34 | i | 50 | y |
| 3 | D | 19 | T | 35 | j | 51 | z |
| 4 | E | 20 | U | 36 | k | 52 | 0 |
| 5 | F | 21 | V | 37 | l | 53 | 1 |
| 6 | G | 22 | W | 38 | m | 54 | 2 |
| 7 | H | 23 | X | 39 | n | 55 | 3 |
| 8 | I | 24 | Y | 40 | o | 56 | 4 |
| 9 | J | 25 | Z | 41 | p | 57 | 5 |
| 10 | K | 26 | a | 42 | q | 58 | 6 |
| 11 | L | 27 | b | 43 | r | 59 | 7 |
| 12 | M | 28 | c | 44 | s | 60 | 8 |
| 13 | N | 29 | d | 45 | t | 61 | 9 |
| 14 | O | 30 | e | 46 | u | 62 | + |
| 15 | P | 31 | f | 47 | v | 63 | / |

If the length of the input is not a multiple of three, Base64 uses "=" as padding character

| | |
|---|---|
| Binary input | 0x14 |
| 8-bits | 00010100 |
| 6-bits | 000101 000000 |
| Decimal | 5 0 |
| base64 | F A = = |

```
From: Laurent Vanbever <lvanbever@ethz.ch>
To: Tobias Buehler <buehlert@ethz.ch>
Subject: [comm-net] Final exam
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: multipart/mixed;
        boundary="123boundary"

This is a multipart message in MIME format.

--123boundary
Content-Type: text/plain

Hi Tobias, Please find the exam enclosed. Laurent

--123boundary
Content-Type: application/pdf;
Content-Disposition: attachment;
        filename="exam_2018.pdf"

base64 encoded data .....
.........................
......base64 encoded data
```

Content

Infrastructure/
Transmission

Retrieval

SMTP: Simple Mail
Transfer Protocol

Infrastructure
mail servers

An e-mail address is composed of two parts identifying the local mailbox and the domain

lvanbever @ ethz.ch

local mailbox

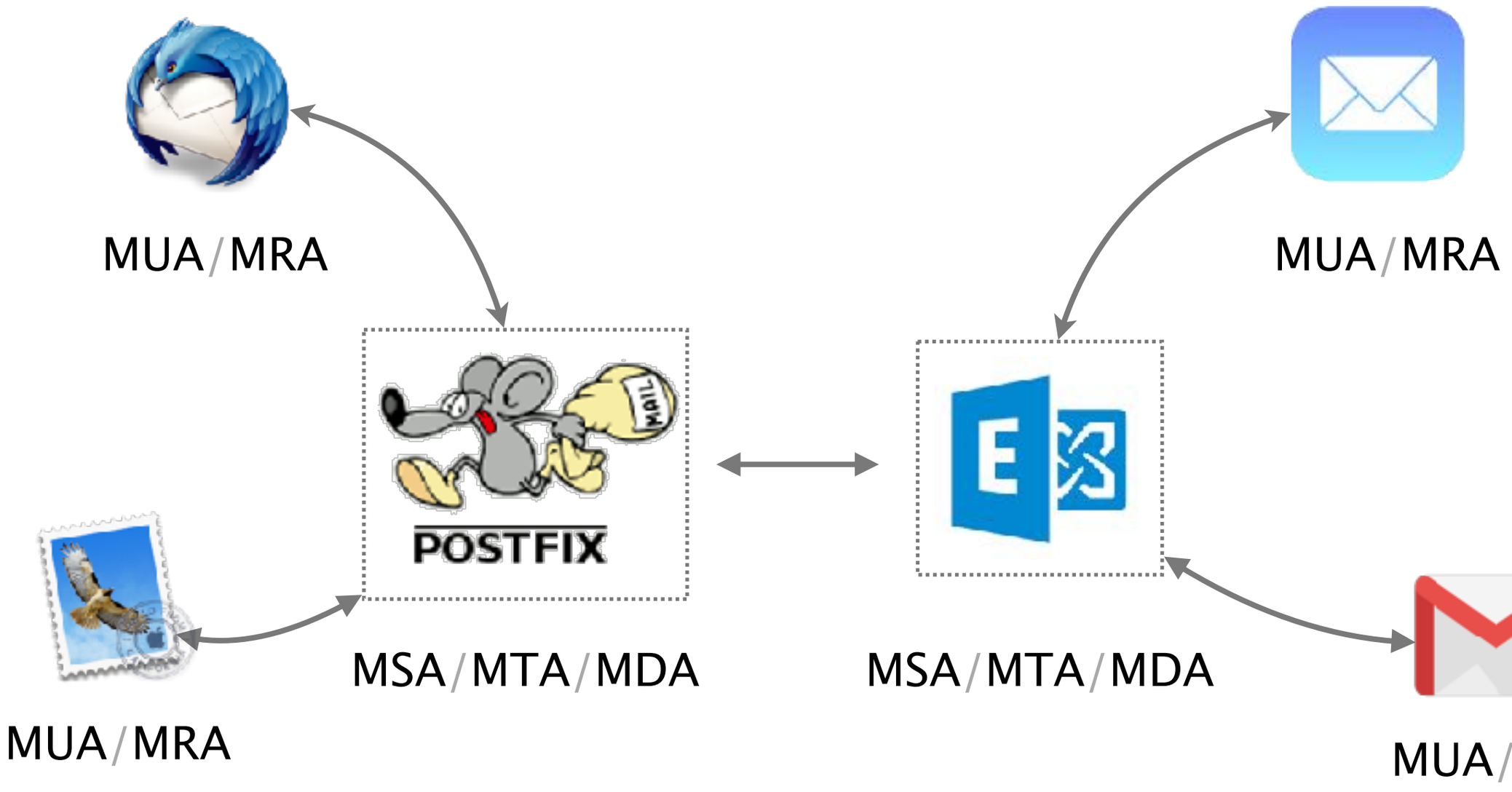
domain name

actual mail server is identified using a DNS query asking for MX records

We can divide the e-mail infrastructure into five functions

| | | | |
|---|---|---|---|
| Mail | User | Agent | Use to read/write emails (mail client) |
| Mail | Submission | Agent | Process email and forward to local MTA |
| Mail | Transmission | Agent | Queues, receives, sends mail to other MTAs |
| Mail | Delivery | Agent | Deliver email to user mailbox |
| Mail | Retrieval | Agent | Fetches email from user mailbox |

MSA/MTA/MDA and MRA/MUA are often packaged together leading to simpler workflows



# Simple Mail Transfer Protocol (SMTP) is the current standard for transmitting e-mails

SMTP is a text-based, client-server protocol

client sends the e-mail, server receives it

SMTP uses reliable data transfer

built on top of TCP (port 25 and 465 for SSL/TLS)

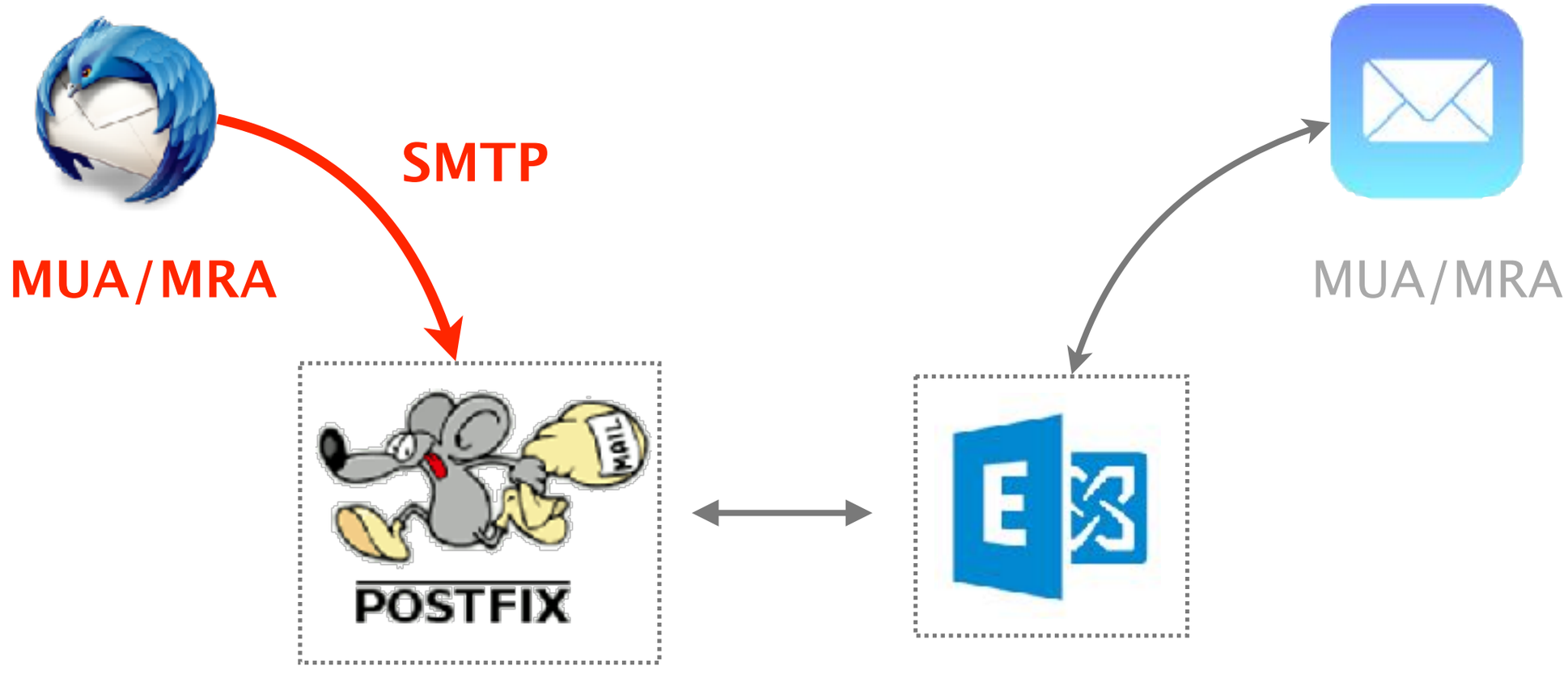
SMTP is a push-like protocol

sender pushes the file to the receiving server (no pull)

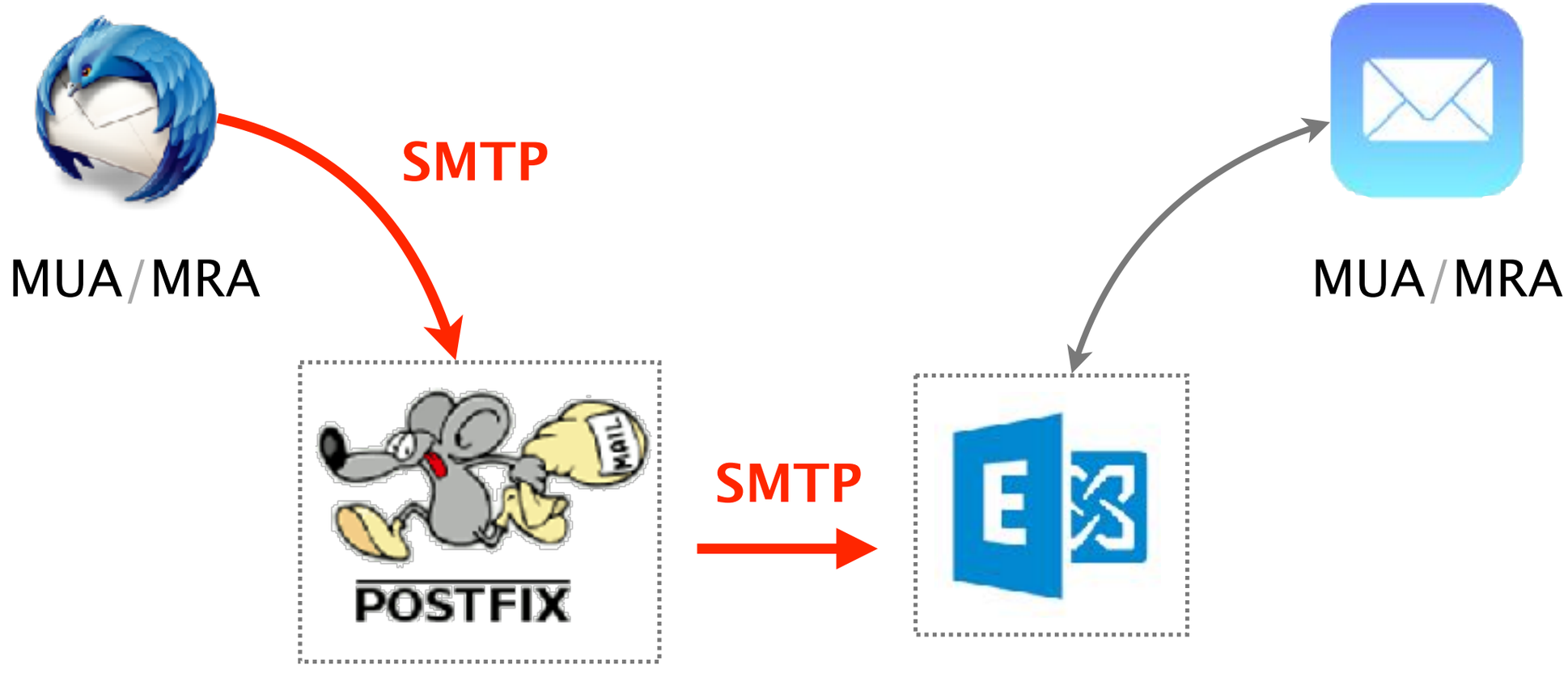
| | SMTP 3 digit response code | | | comment |
|---|---|---|---|---|
| Status | 2XX | success | 220 | Service ready |
| | | | 250 | Requested mail action completed |
| | 3XX | input needed | 354 | Start mail input |
| | 4XX | transient error | 421 | Service not available |
| | | | 450 | Mailbox unavailable |
| | | | 452 | Insufficient space |
| | 5XX | permanent error | 500 | Syntax error |
| | | | 502 | Unknown command |
| | | | 503 | Bad sequence |

```
server ——— 220 hamburger.edu
           HELO crepes.fr
           250  Hello crepes.fr, pleased to meet you
client ——— MAIL FROM: <alice@crepes.fr>
           250 alice@crepes.fr... Sender ok
           RCPT TO: <bob@hamburger.edu>
           250 bob@hamburger.edu ... Recipient ok
           DATA
           354 Enter mail, end with "." on a line by
           itself
           Do you like ketchup?
           How about pickles?
           .
           250 Message accepted for delivery
           QUIT
           221 hamburger.edu closing connection
```

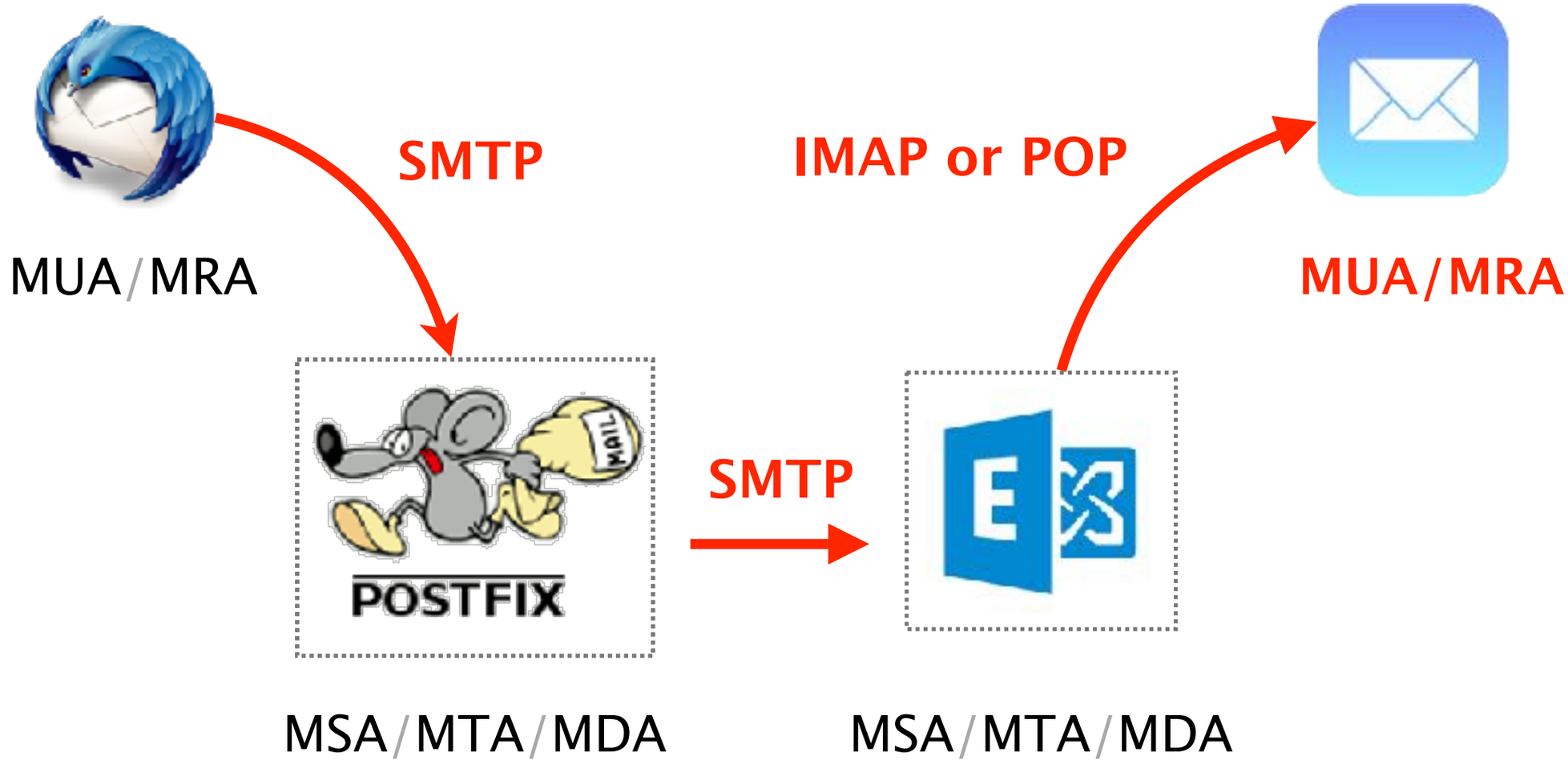
The sender MUA uses SMTP to transmit the e-mail first to a local MTA (e.g. mail.ethz.ch, gmail.com, hotmail.com)



The local MTA then looks up the MTA of the recipient domain (DNS MX) and transmits the e-mail further



Once the e-mail is stored at the recipient domain, IMAP or POP is used to retrieve it by the recipient MUA



E-mails typically go through at least 2 SMTP servers,
but often way more

sending and receiving sides

Each SMTP server/MTA hop adds its identity to the e-mail header by prepending a "Received" entry

8 Received: from edge20.ethz.ch (82.130.99.26) by CAS10.d.ethz.ch (172.31.38.210) with Microsoft SMTP Server (TLS) id 14.3.361.1; Fri, 23 Feb 2018 01:48:56 +0100

7 Received: from phil4.ethz.ch (129.132.183.133) by edge20.ethz.ch (82.130.99.26) with Microsoft SMTP Server id 14.3.361.1; Fri, 23 Feb 2018 01:48:57 +0100

6 Received: from outprodmail02.cc.columbia.edu ([128.59.72.51]) by phil4.ethz.ch with esmtps (TLSv1:AES256-SHA:256) (Exim 4.69) (envelope-from <ethan@ee.columbia.edu>) id 1ep1Xg-0002s3-FH for lvanbever@ethz.ch; Fri, 23 Feb 2018 01:48:55 +0100

5 Received: from hazelnut (hazelnut.cc.columbia.edu [128.59.213.250]) by outprodmail02.cc.columbia.edu (8.14.4/8.14.4) with ESMTP id w1N0iAu4026008 for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:51 -0500

4 Received: from hazelnut (localhost.localdomain [127.0.0.1]) by hazelnut (Postfix) with ESMTP id 421126D for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:52 -0500 (EST)

3 Received: from sendprodmail01.cc.columbia.edu (sendprodmail01.cc.columbia.edu [128.59.72.13]) by hazelnut (Postfix) with ESMTP id 211526D for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:52 -0500 (EST)

2 Received: from mail-pl0-f43.google.com (mail-pl0-f43.google.com [209.85.160.43]) (user=ebk2141 mech=PLAIN bits=0) by sendprodmail01.cc.columbia.edu (8.14.4/8.14.4) with ESMTP id w1N0mnlx052337 (version=TLSv1/SSLv3 cipher=AES128-GCM-SHA256 bits=128 verify=NOT) for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:50 -0500

1 Received: by mail-pl0-f43.google.com with SMTP id u13so3927207plq.1 for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 16:48:50 -0800 (PST)

E-mails typically go through at least 2 SMTP servers, but often way more

Separate SMTP servers for separate functions

SPAM filtering, virus scanning, data leak prevention, etc.

Separate SMTP servers that redirect messages

e.g. from lvanbever@tik.ee.ethz.ch to lvanbever@ethz.ch

Separate SMTP servers to handle mailing-list

mail is delivered to the list server and then expanded

# Try it out yourself!

SMTP-MTA

plaintext (!),
hard to find

```
telnet server_name 25
```

SMTP-MSA

rely on TLS
encryption

```
openssl s_client -starttls smtp
   -connect mail.ethz.ch:587
   -crlf -ign_eof (*)
```

authentication
required

```
perl -MMIME::Base64 -e 'print encode_base64("username");'
perl -MMIME::Base64 -e 'print encode_base64("password");'
```

(*) https://www.ndchost.com/wiki/mail/test-smtp-auth-telnet

# As with most of the key Internet protocols, security is an afterthought

SMTP Headers

MAIL FROM: no checks are done to verify that the sending MTA is authorized to send e-mails on behalf of that address

Email content (DATA)

From: no checks are done to verify that the sending system is authorized to send e-mail on behalf of that address

Reply-to: ditto

In short, *none* of the addresses in an email are typically reliable

# Let's spoof some e-mails!

And, as usual, multiple countermeasures have been proposed with various level of deployment success

Example* Sender Policy Framework (SPF)

Enables a domain to explicitly authorize a set of hosts that are allowed to send emails using their domain names in "MAIL FROM".

How? using a DNS TXT resource record

look for "v=spf1" in the results of "dig TXT google.com"

* if you are interested, also check out Sender ID, DKIM, and DMARC

Content

Infrastructure/
Transmission

Retrieval

POP: Post Office Protocol

IMAP:Internet Message
Access Protocol

Content

Infrastructure/
Transmission

Retrieval

**POP: Post Office Protocol**

IMAP:Internet Message
Access Protocol

POP is a simple protocol which was designed to support users with intermittent network connectivity

POP enables e-mail users to

- retrieve e-mails locally — when connected
- view/manipulate e-mails — when disconnected

and that's pretty much it…

# Example

POP server ——— +OK POP3 server ready
user bob
+OK
client ——— pass hungry
+OK user successfully logged on

list
1 498
2 912
.
retr 1
<message 1 contents>
.
dele 1
retr 2
<message 1 contents>
.
dele 2
quit
+OK POP3 server signing off

## Authorization phase

Clients declares username

password

Server answers +OK/-ERR

```
+OK POP3 server ready
user bob
+OK
pass hungry
+OK user successfully logged on
```

```
list
1 498
2 912
.
retr 1
<message 1 contents>
.
dele 1
retr 2
<message 1 contents>
.
dele 2
quit
+OK POP3 server signing off
```

## Transaction phase

| | |
|---|---|
| `list` | get message numbers |
| `retr` | retrieve message X |
| `dele` | delete message X |
| `quit` | exit session |

```
+OK POP3 server ready
user bob
+OK
pass hungry
+OK user successfully logged on

list
1 498
2 912
.
retr 1
<message 1 contents>
.
dele 1
retr 2
<message 1 contents>
.
dele 2
quit
+OK POP3 server signing off
```

POP is heavily limited. Among others, it does not go well with multiple clients or always-on connectivity

Cannot deal with multiple mailboxes

designed to put incoming emails in one folder

Not designed to keep messages on the server

designed to download messages to the client

Poor handling of multiple-client access

while many (most?) users have now multiple devices

Content

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Retrieval

POP: Post Office Protocol

**IMAP:Internet Message Access Protocol**

# Unlike POP, Internet Message Access Protocol (IMAP) was designed with multiple clients in mind

Support multiple mailboxes and searches on the server

client can create, rename, move mailboxes & search on server

Access to individual MIME parts and partial fetch

client can download only the text content of an e-mail

Support multiple clients connected to one mailbox

server keep state about each message (e.g. read, replied to)

# Communication Networks

## Spring 2018

Laurent Vanbever

nsg.ee.ethz.ch

ETH Zürich (D-ITET)

May 24 2018