Communication Networks

Spring 2019

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Materials inspired from Scott Shenker and Jennifer Rexford

Last Monday on

Communication Networks

Web

Video Streaming

http://www.google.ch

HTTP-based

Web

Video Streaming

http://www.google.ch

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 files, pictures, videos, …	URL: name content
Servers	*organized* in	HTTP: transport content
Proxies	Web sites a collection of objects	

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

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

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

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	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 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

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

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	

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

	# RTTS
one-at-a-time	~2*n*
M concurrent	~2*n*/M
persistent	~*n*+1
pipelined	2

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

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

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

Web

Video Streaming

HTTP-based

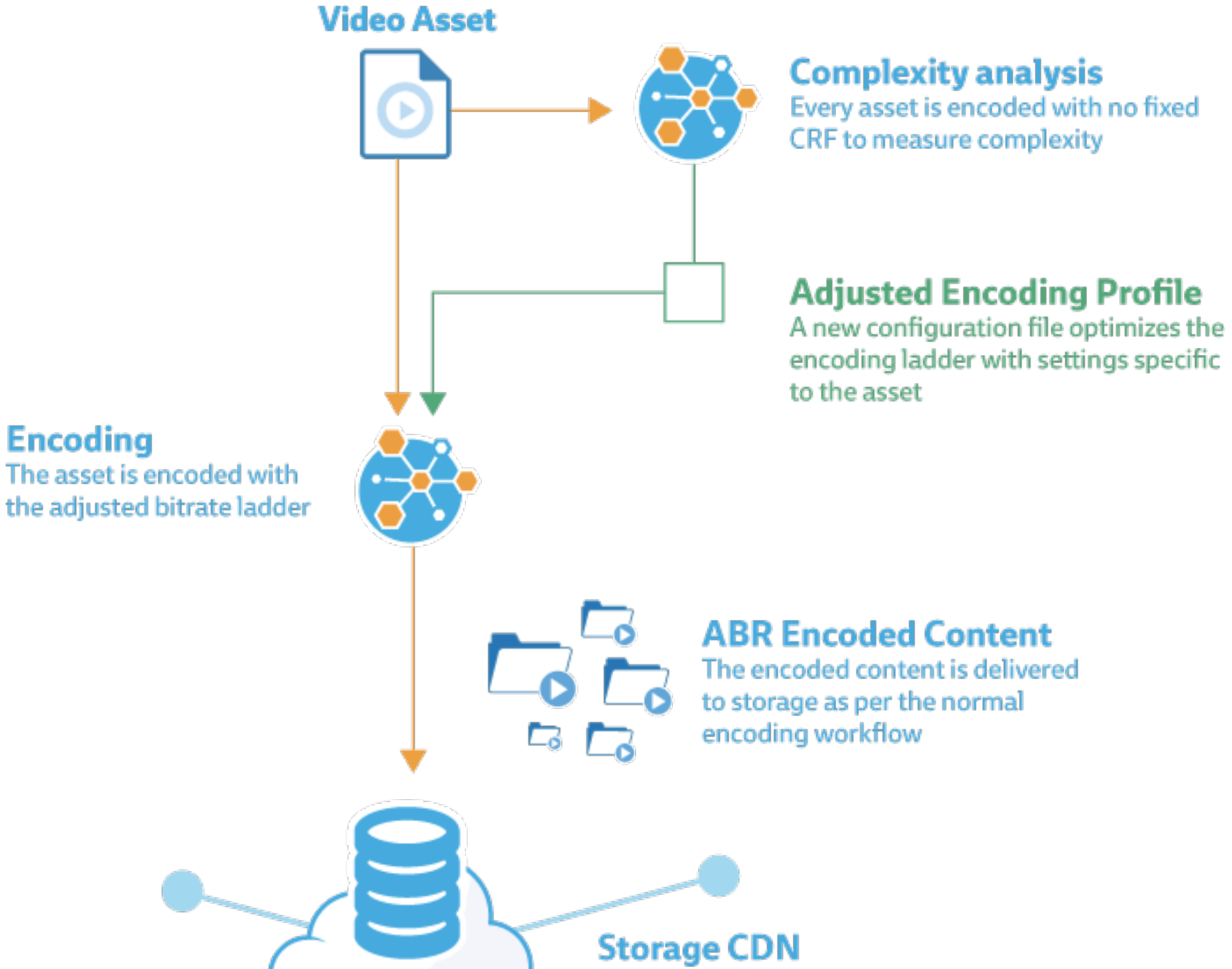
We want the highest video quality

Without seeing this …

The three steps behind most contemporary solutions

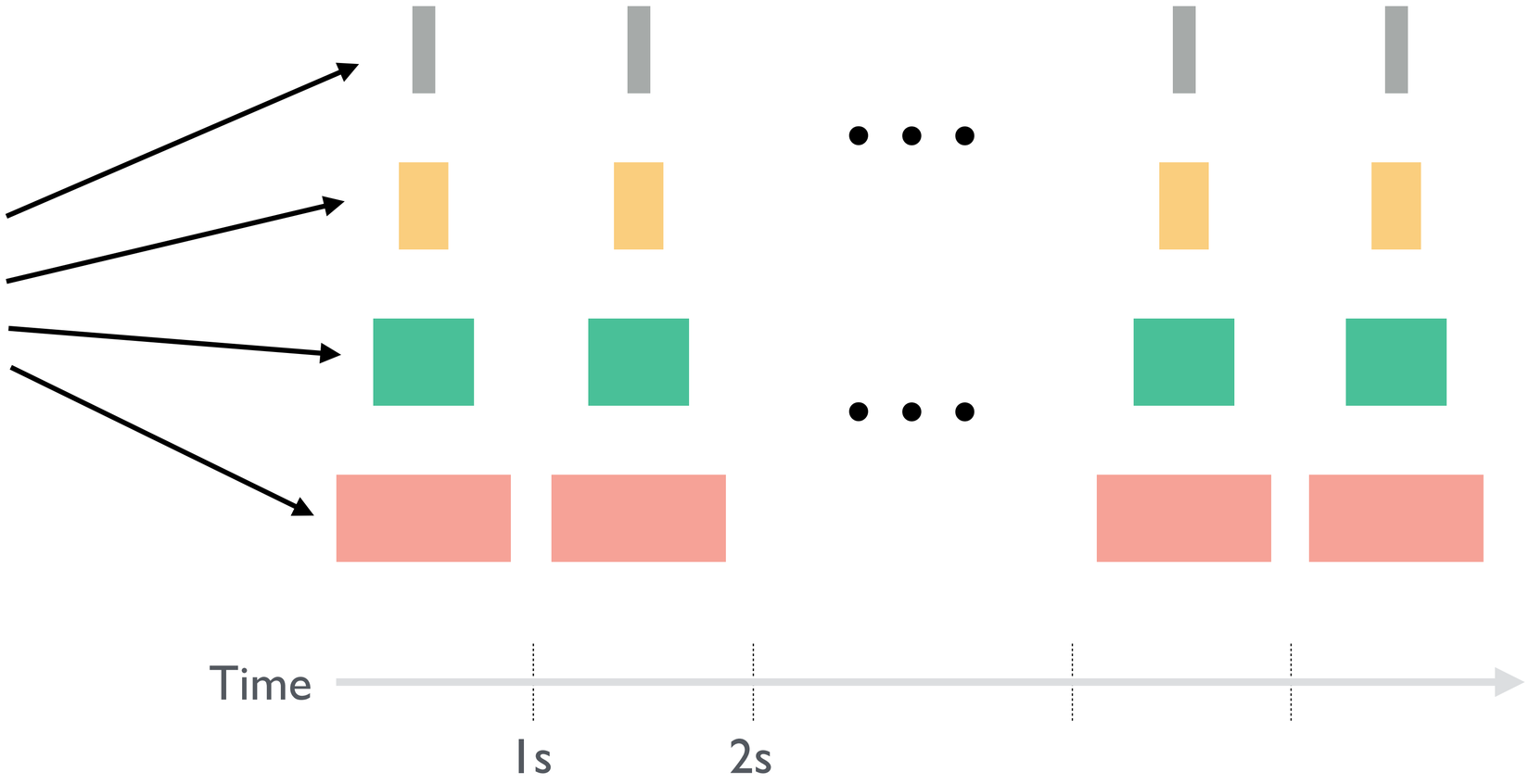
- Encode video in multiple bitrates
- Replicate using a content delivery network
- Video player picks bitrate adaptively
  - Estimate connection's available bandwidth
  - Pick a bitrate $\leq$ available bandwidth

Encoding


Video Asset
Complexity analysis
Every asset is encoded with no fixed CRF to measure complexity
Adjusted Encoding Profile
A new configuration file optimizes the encoding ladder with settings specific to the asset
Encoding
The asset is encoded with the adjusted bitrate ladder
ABR Encoded Content
The encoded content is delivered to storage as per the normal encoding workflow
Storage CDN

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]

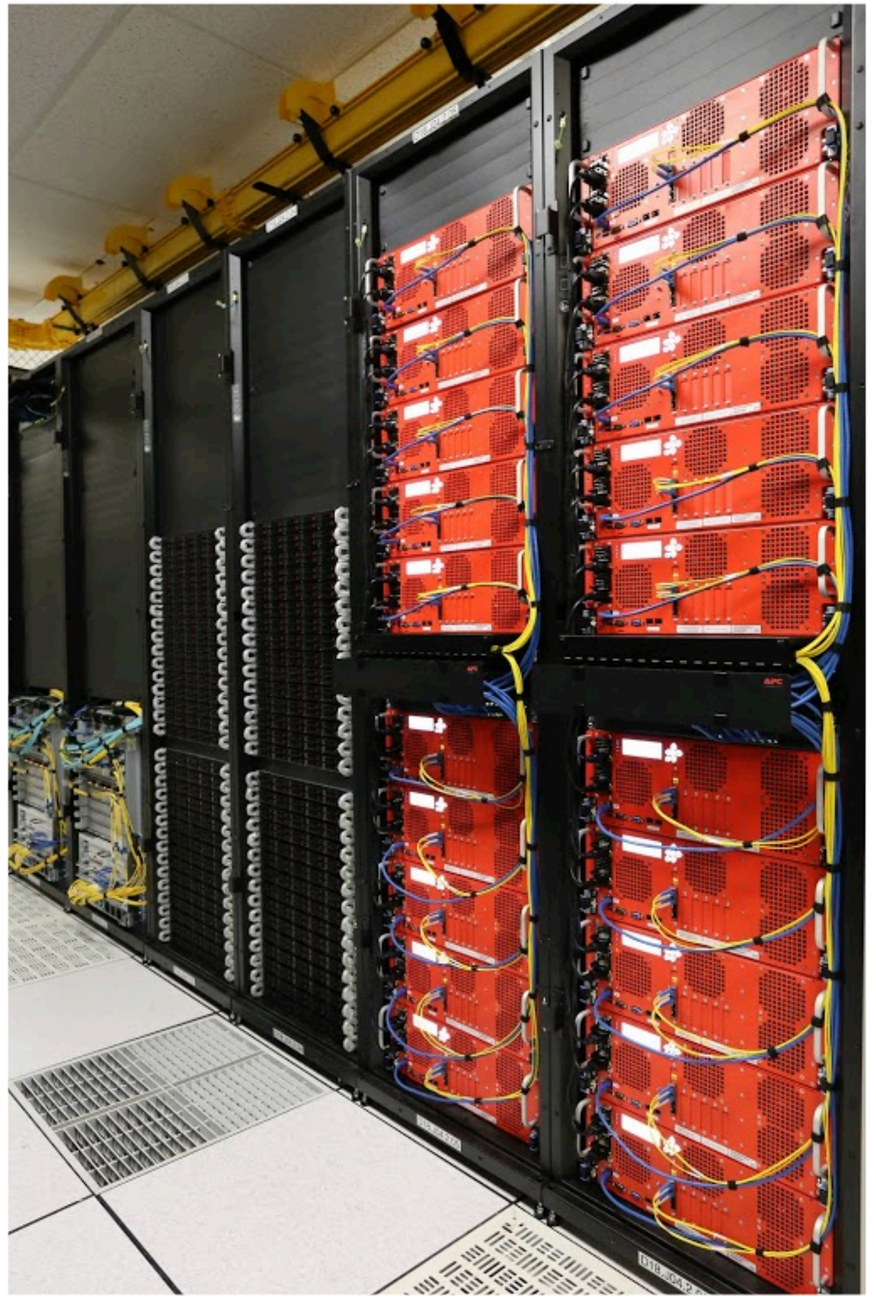
NETFLIX

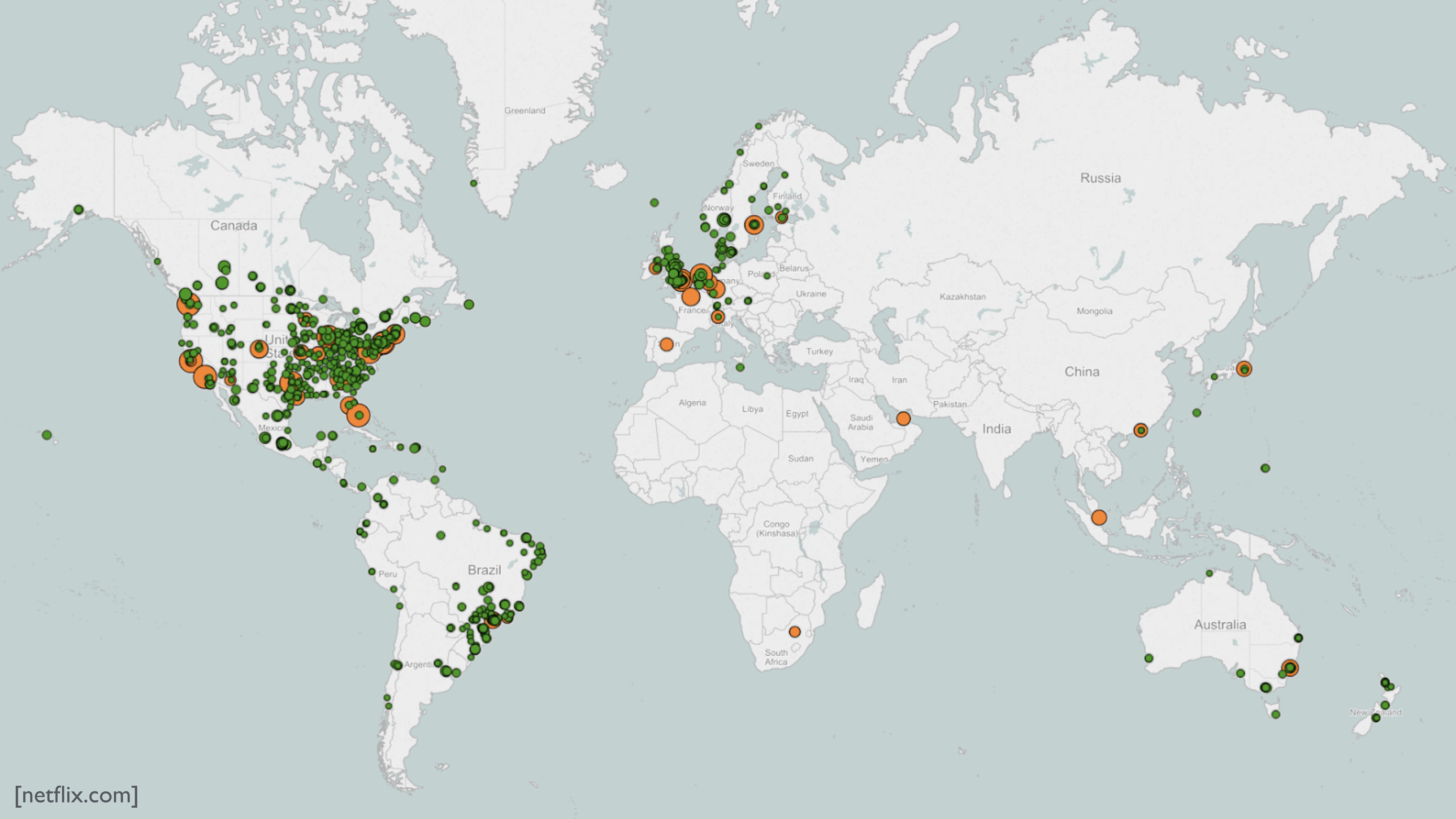
Open Connect: Starting from a Greenfield (a mostly Layer 0 talk)

Dave Temkin
06/01/2015

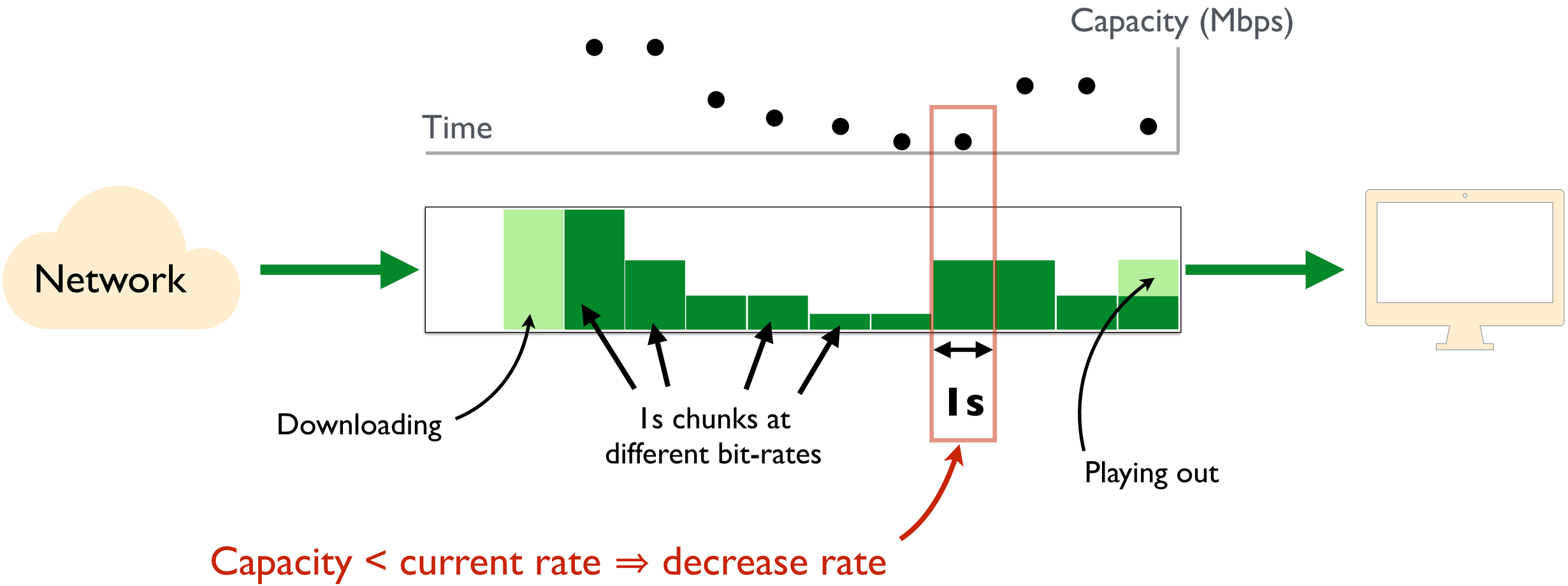
Storage Appliance
- Still 4U high
- ~550 watts
- 288 TB of storage
- 2x 10G ports
- 20Gbit/s delivery

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

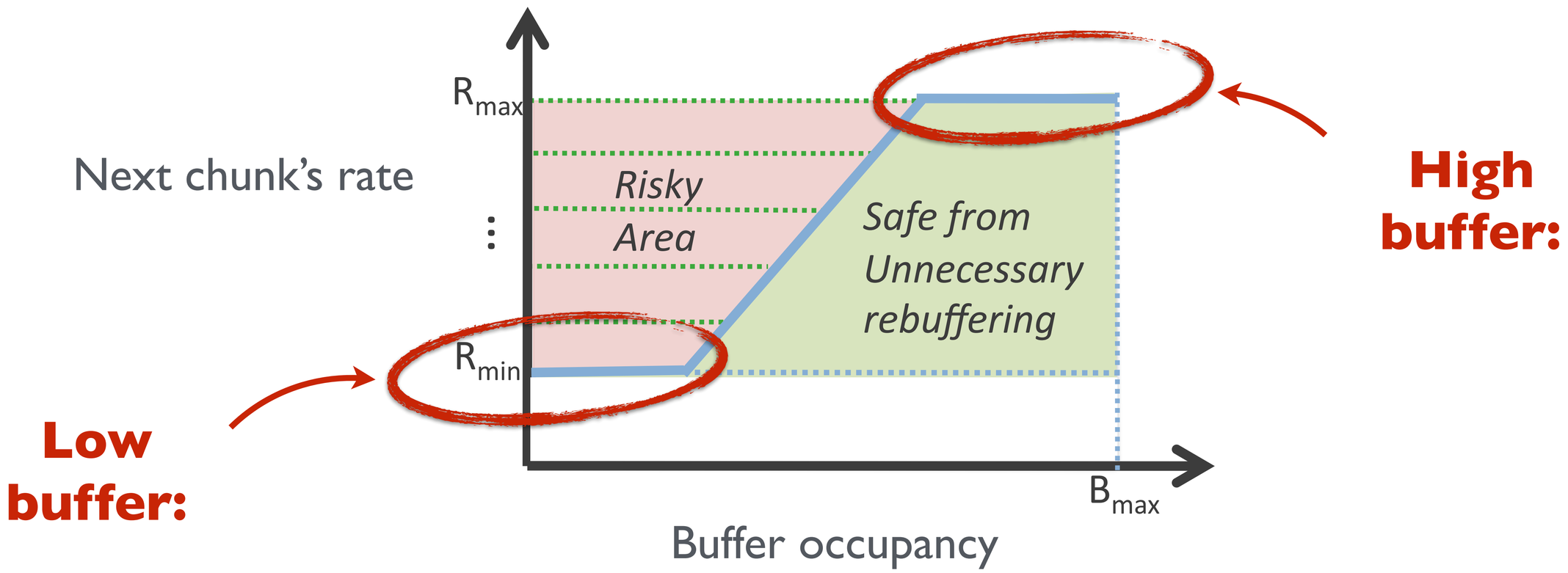



Greenland
Canada
Sweden
Finland
Norway
Russia
Belarus
Ukraine
Kazakhstan
Mongolia
China
Turkey
Iraq
Iran
Pakistan
India
Algeria
Libya
Egypt
Saudi Arabia
Yemen
Sudan
Congo (Kinshasa)
South Africa
Brazil
Peru
Australia

[netflix.com]


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

Buffer-based adaptation



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

Today on

Communication Networks

E-mail

MX, SMTP, POP, IMAP

2nd project

Introduction

E-mail

2nd project

MX, SMTP, POP, IMAP

We'll study e-mail from three different perspectives

Content	Infrastructure/ Transmission	Retrieval
Format: Header/Content Encoding: MIME	SMTP: Simple Mail Transfer Protocol Infrastructure mail servers	POP: Post Office Protocol 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

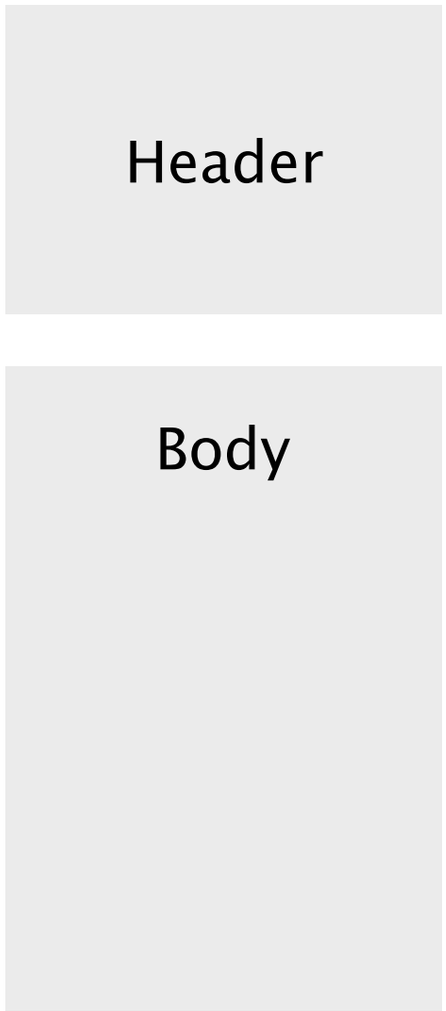
Series of lines with no structure/meaning

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 e.g. plain text *and* a binary file
multipart/alternative	multiple representation of the same content 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

What kind of delimiter do we use?

multipart/mixed — **multiple** independent parts

multipart/alternative — **multiple** representation of the same content

Content-Type contains a parameter that specifies
a string delimiter (usually chosen randomly by the client)

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` `00000011 11011001 01111110`
6-bits	`000101 001111 101110 011100` `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

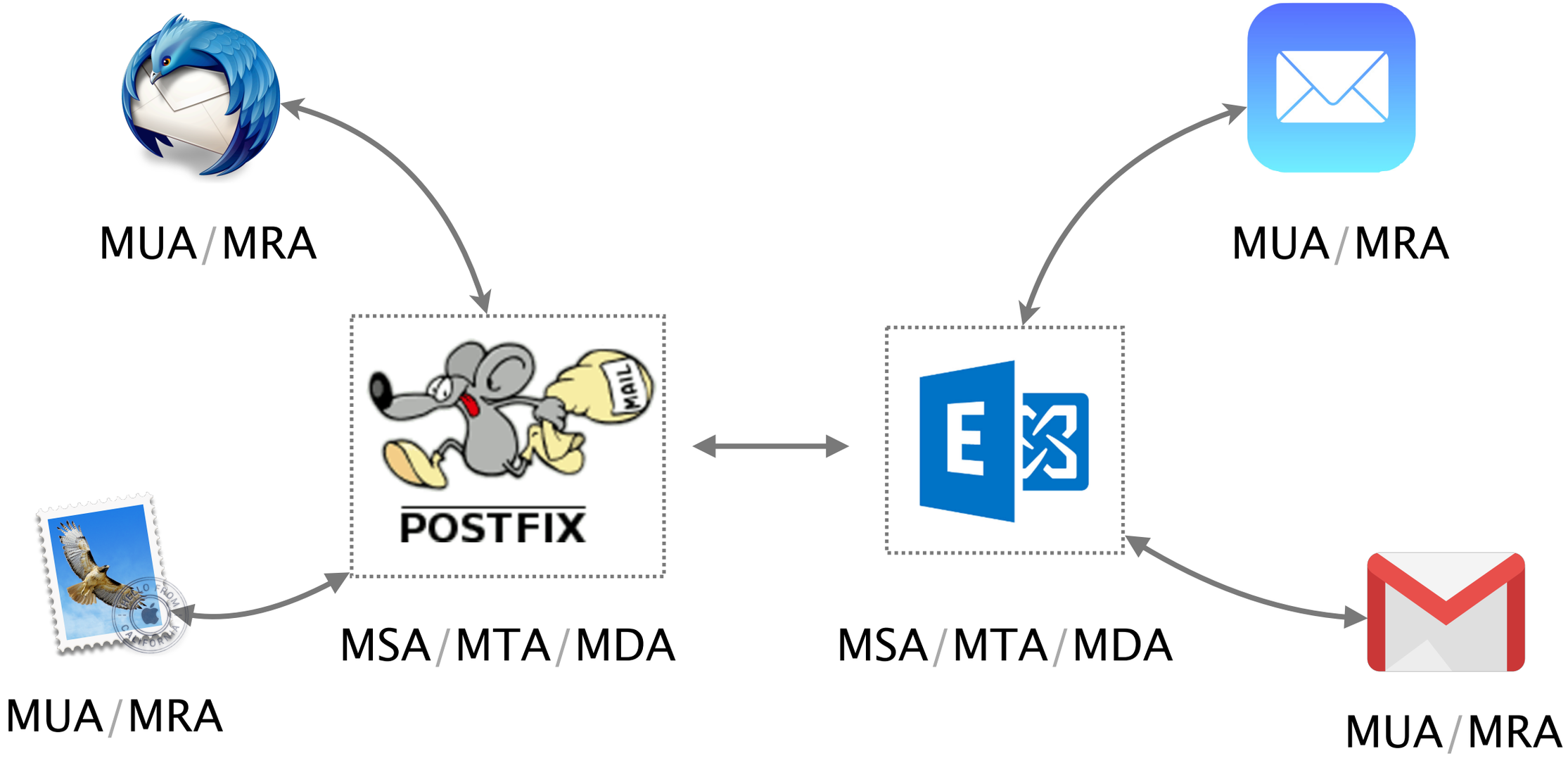
domain name

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)

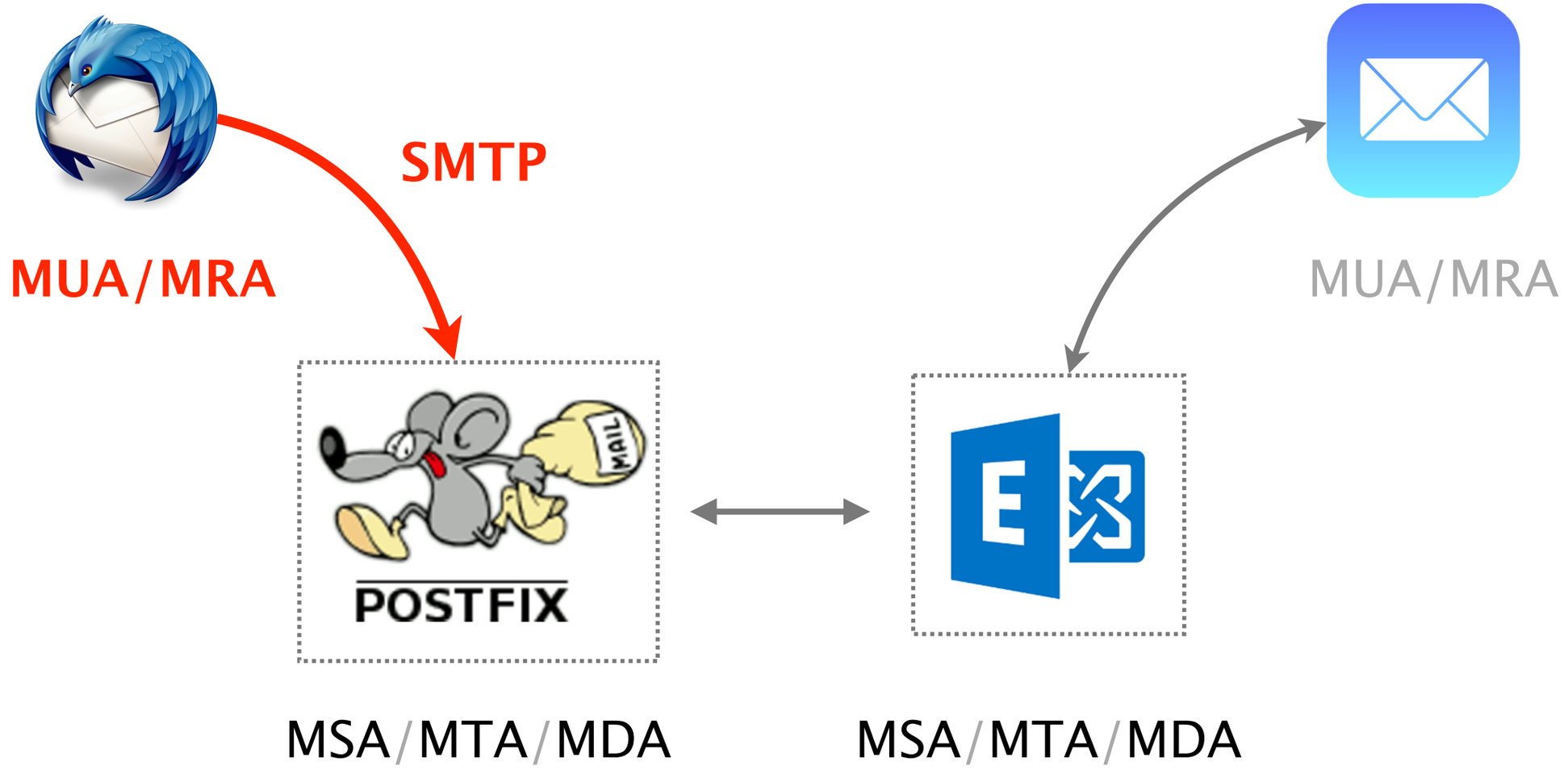
SMTP is a push-like protocol

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

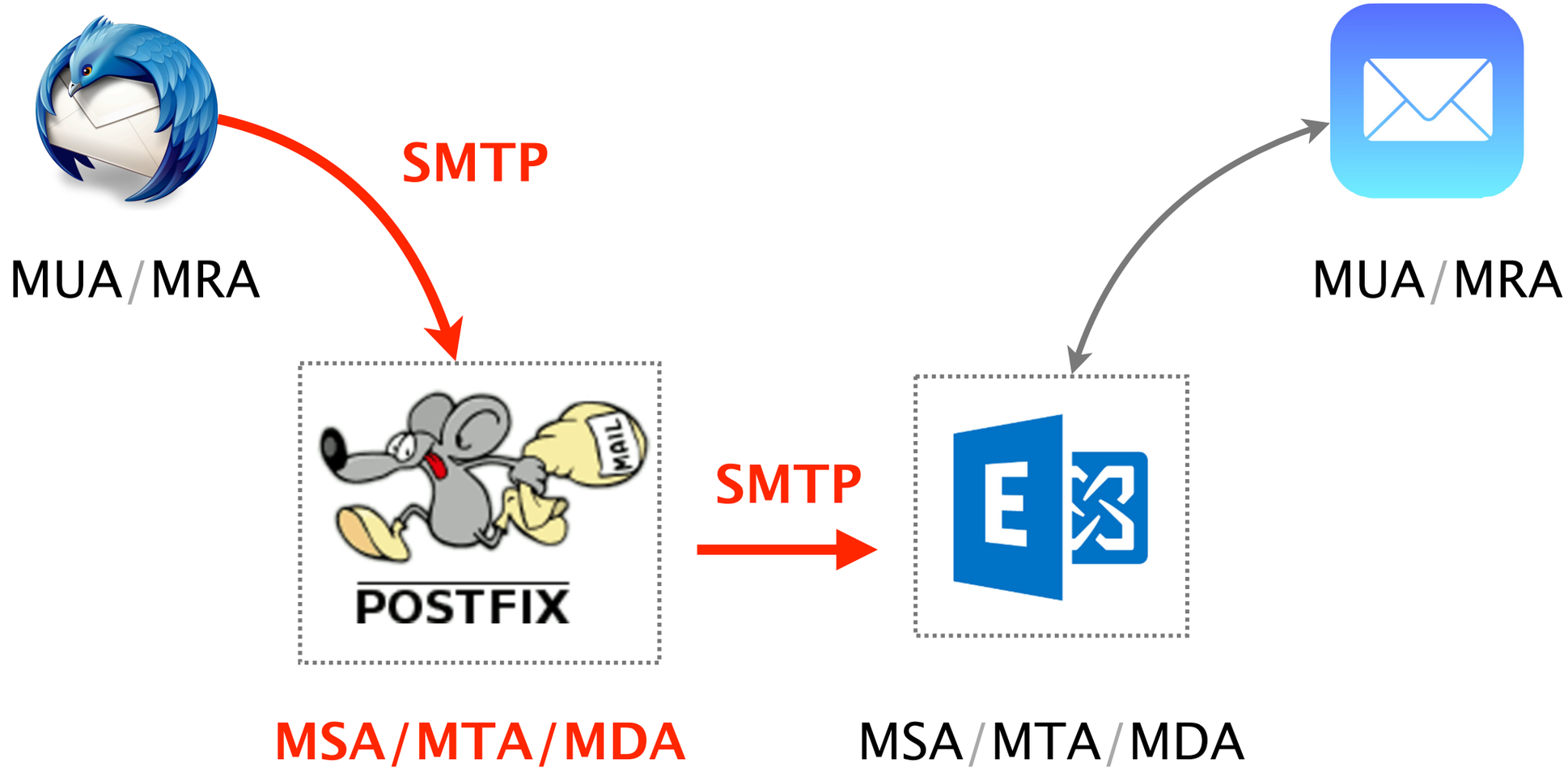
	SMTP 3 digit response code			comment
Status	2XX	success	220	Service ready
			250	Requested mail action completed
	3XX	input needed	354	Start mail input
	4XX	transient error	421	Service not available
			450	Mailbox unavailable
			452	Insufficient space
	5XX	permanent error	500	Syntax error
			502	Unknown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

```
server ——— 220 hamburger.edu
           EHLO 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
```

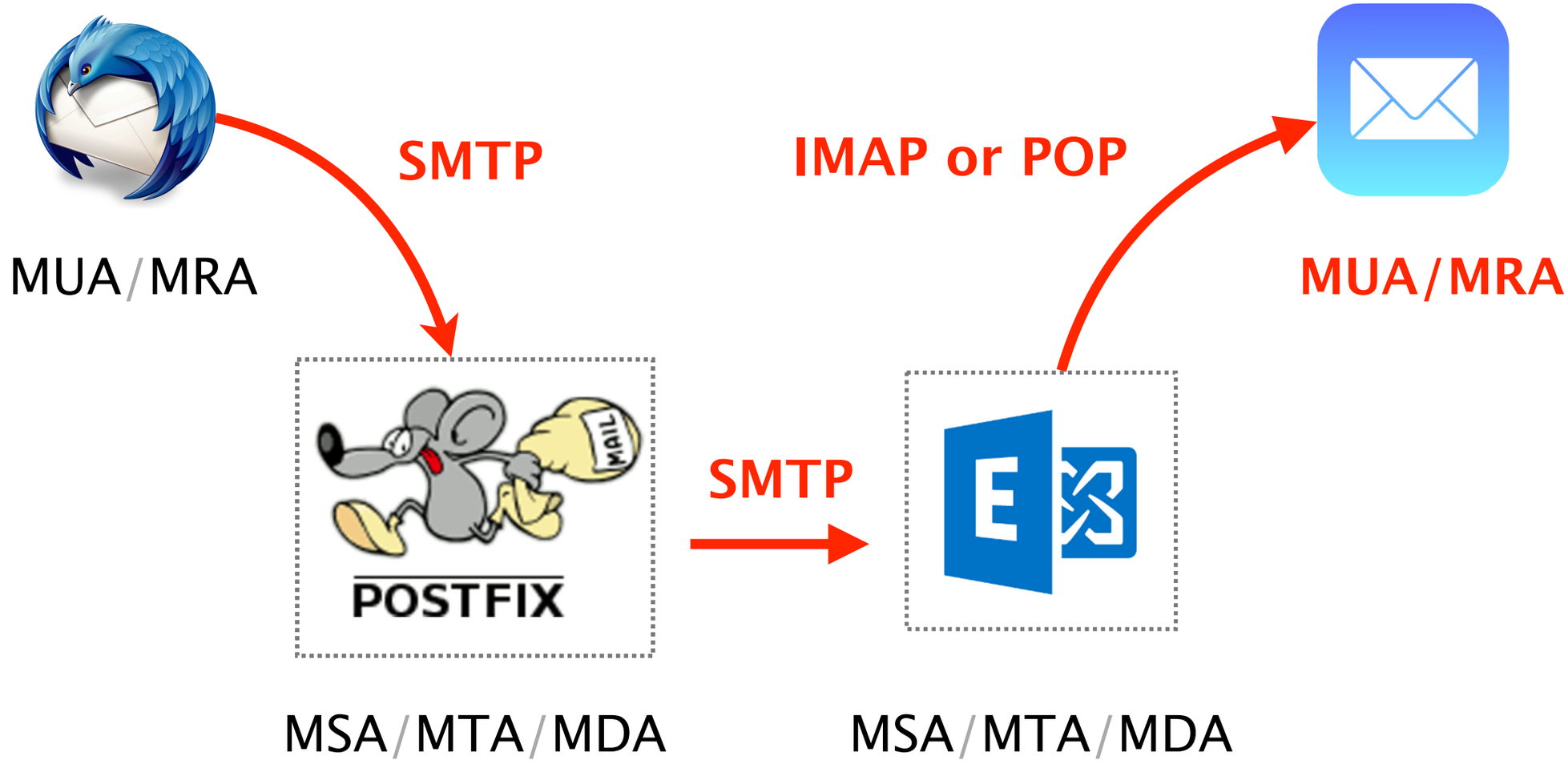
The sender MUA uses SMTP to transmit the e-mail first to a local MTA (e.g. mail.ethz.ch, gmail.com, hotmail.com)



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

Infrastructure/
Transmission

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)

E-mail

MX, SMTP, POP, IMAP

2nd project

Introduction

Communication Networks

Spring 2019

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May 6 2019