Communication Networks

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Communication Networks

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

Last Monday on
Communication Networks

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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

name	DNS	IP address
www.ethz.ch		129.132.19.216

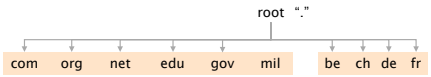
To scale,
DNS adopt three intertwined hierarchies

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

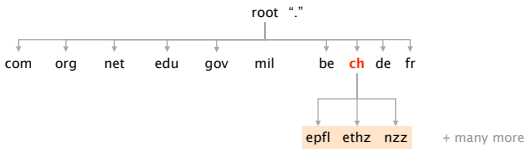
naming structure addresses are hierarchical

www.ee.ethz.ch

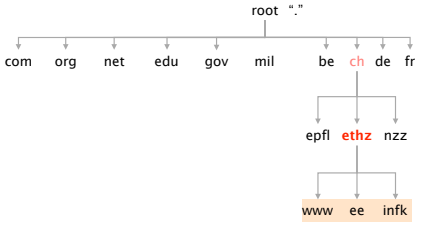
Top Level Domain (TLDs) sit at the top



Domains are subtrees



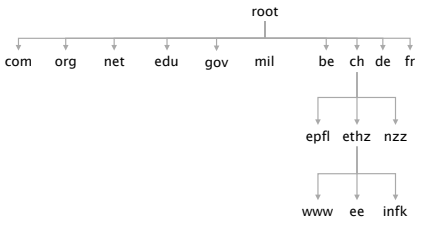
A name, *e.g.* ee.ethz.ch, represents
a leaf-to-root path in the hierarchy



management

hierarchy of authority
over names

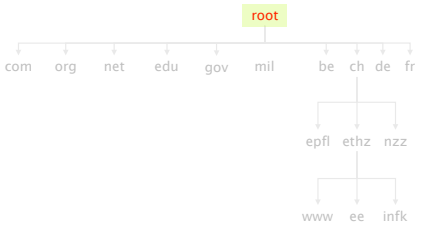
The DNS system is
hierarchically administered



infrastructure

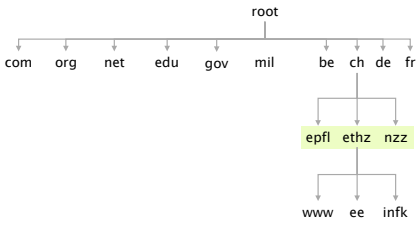
hierarchy of DNS servers

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

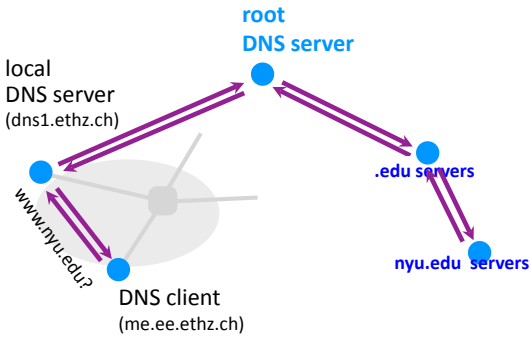
Using DNS relies on two components

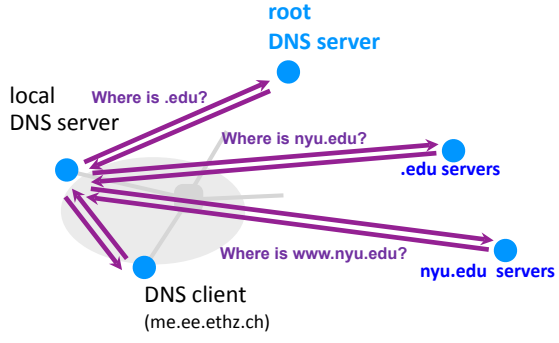
trigger resolution process
send request to local DNS server

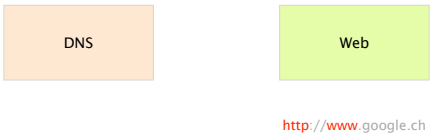
usually, near the endhosts
configured statically (resolv.conf)
or dynamically (DHCP)

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



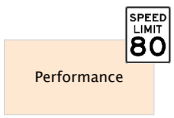




http://www.google.ch

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	



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

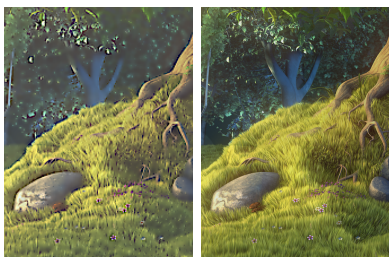
HTTP is stateless
it maintains *no info* about past client requests

Today on Communication Networks

Video Streaming	E-mail
HTTP-based	MX, SMTP, POP, IMAP

Video Streaming	E-mail
HTTP-based	

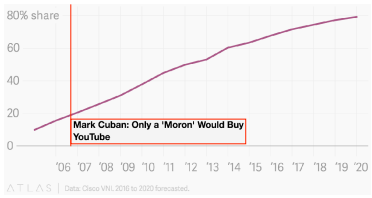
We want the highest video quality



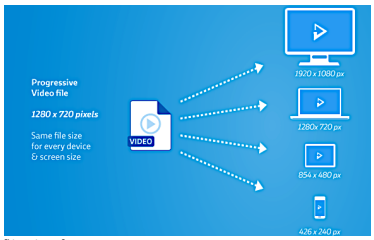
(c) copyright 2008, Blender Foundation / www.bigbuckbunny.org, CC-BY-3.0

Without seeing this …

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

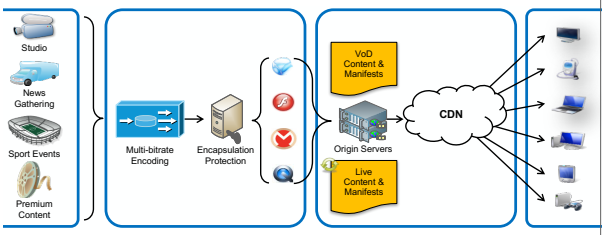


A naive approach: one-size-fits-all



[bitmovin.com]

In practice, things are slightly more complex



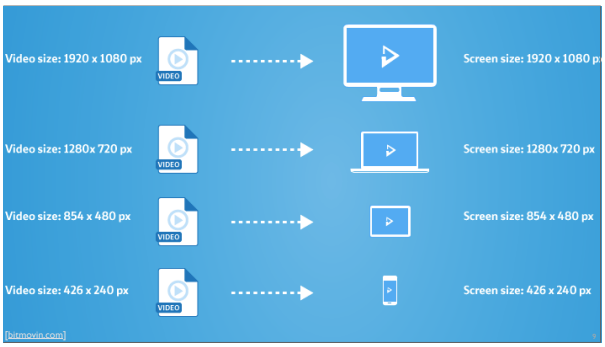
[Adapted from: Adaptive Streaming of Traditional and Omnidirectional Media, Begen & Timmerer, ACM SIGCOMM Tutorial, 2017]

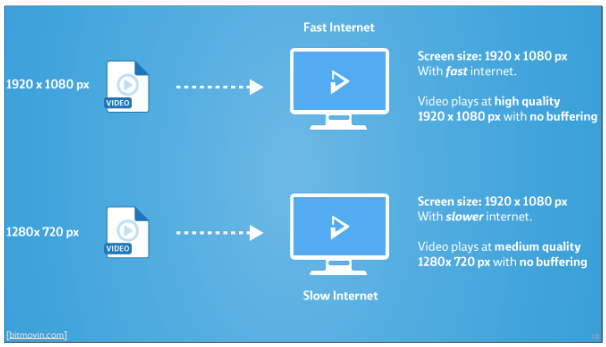
The three steps behind most contemporary solutions

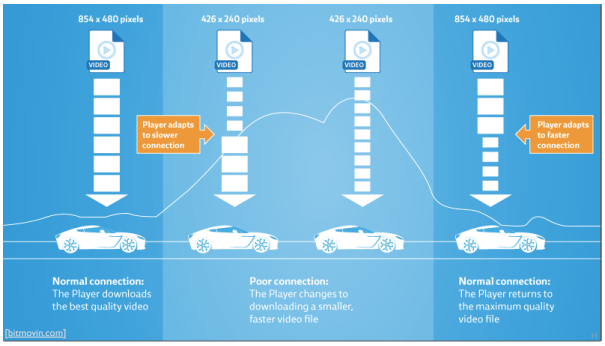
- Encode video in multiple bitrates
- Replicate using a content delivery network
- Video player picks bitrate adaptively
  - Estimate connection's available bandwidth
  - Pick a bitrate ≤ available bandwidth

Encoding | Replication | Adaptation

Encoding | Replication | Adaptation







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]

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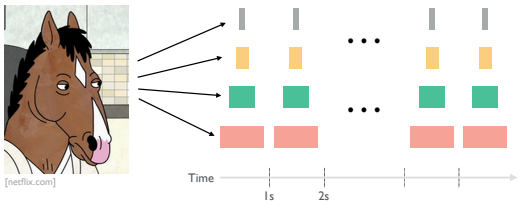
Your player download “chunks” of video at different bitrates



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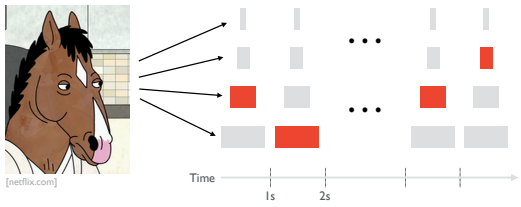
Depending on your network connectivity, your player fetches chunks of different qualities



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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]

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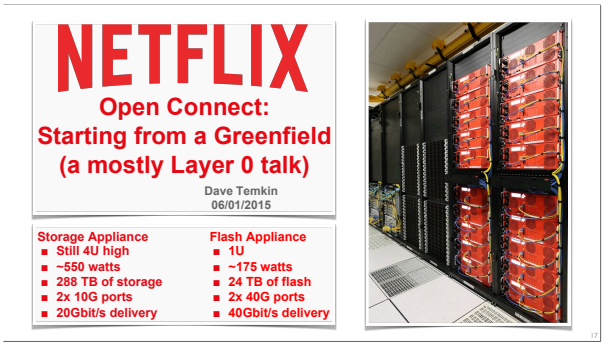

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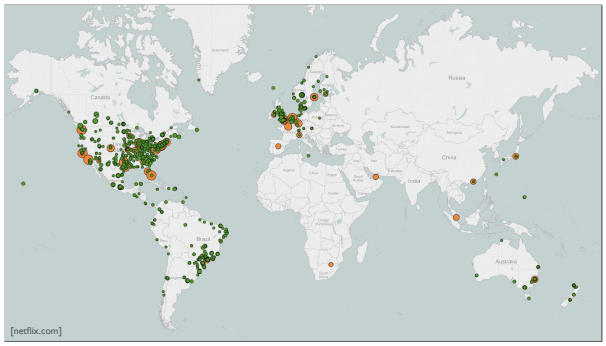
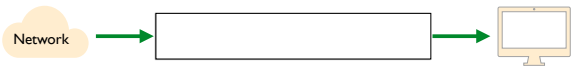


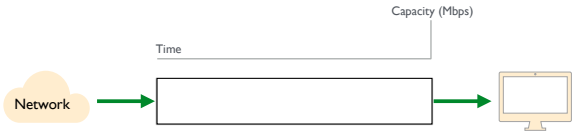
[netflix.com]

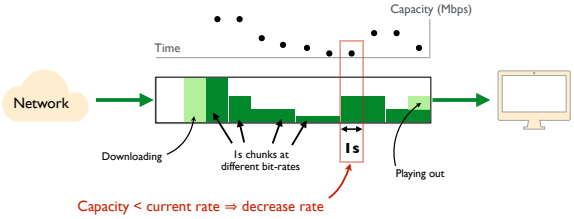
Encoding

Replication

Adaptation



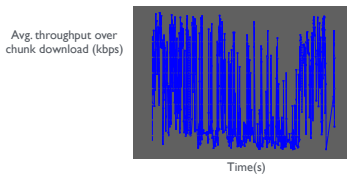




Common solution approach

- 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



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

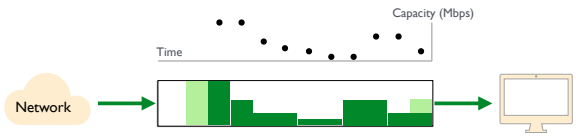
Estimating available capacity

"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"

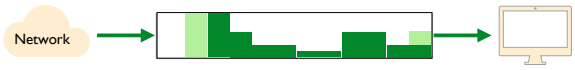
[A Buffer-Based Approach to Rate Adaptation: Evidence from a Large Video Streaming Service, Huang et al., ACM SIGCOMM 2014]

Capacity estimation



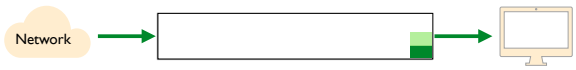
Decide based on the buffer alone?

Buffer-based adaptation



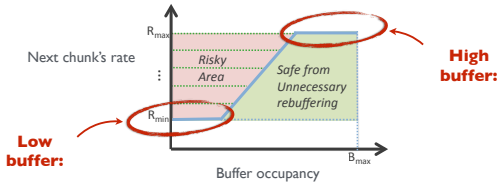
Nearly full buffer ⇒ large rate

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 Encoding: MIME	SMTP: Simple Mail Transfer Protocol Infrastructure mail servers	POP: Post Office Protocol IMAP: Internet Message Access Protocol

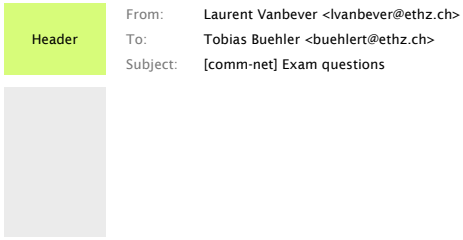
Content | Infrastructure/ Transmission | Retrieval

Format: Header/Content

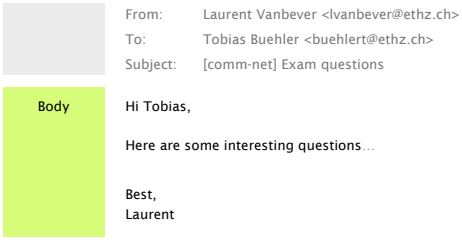
Encoding: MIME

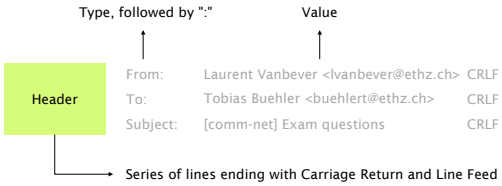
An e-mail is composed of two parts

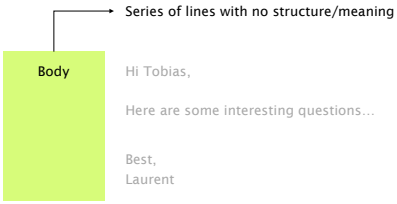
A header, in 7-bit U.S. ASCII text

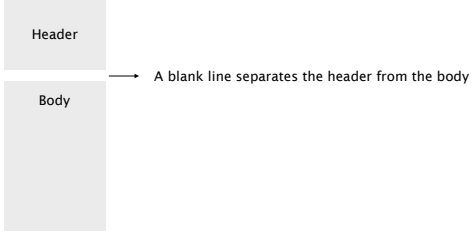


A body, also in 7-bit U.S. ASCII text









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

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

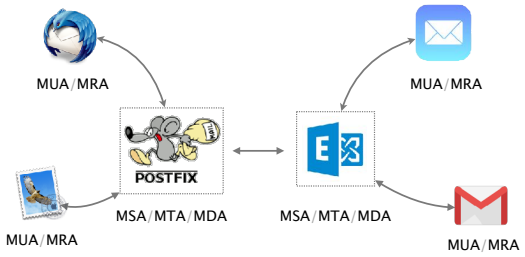
local mailbox — domain name

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

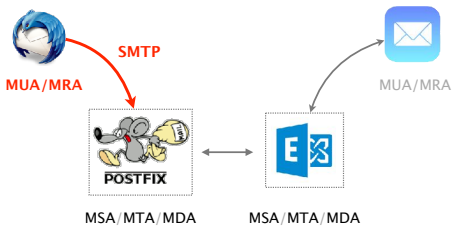
SMTP uses reliable data transfer
built on top of TCP (port 25 and 465 for SSL/TLS)

SMTP is a push-like protocol
sender pushes the file to the receiving server (no pull)

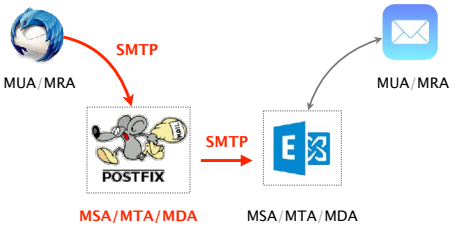
	SMTP 3 digit response code			comment
Status	2XX	success	220	Service ready
			250	Requested mail action completed
	3XX	input needed	354	Start mail input
	4XX	transient error	421	Service not available
			450	Mailbox unavailable
			452	Insufficient space
	5XX	permanent error	500	Syntax error
			502	Unknown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

```
server ── 220 hamburger.edu
          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
```

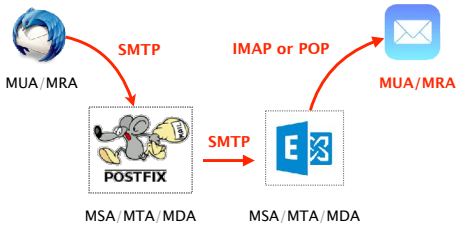
The sender MUA uses SMTP to transmit the e-mail first to a local MTA (e.g. mail.ethz.ch, gmail.com, hotmail.com)



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

authentication required

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

Communication Networks

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