Freie Universität Berlin

TI III: Operating Systems & Computer Networks
Applications

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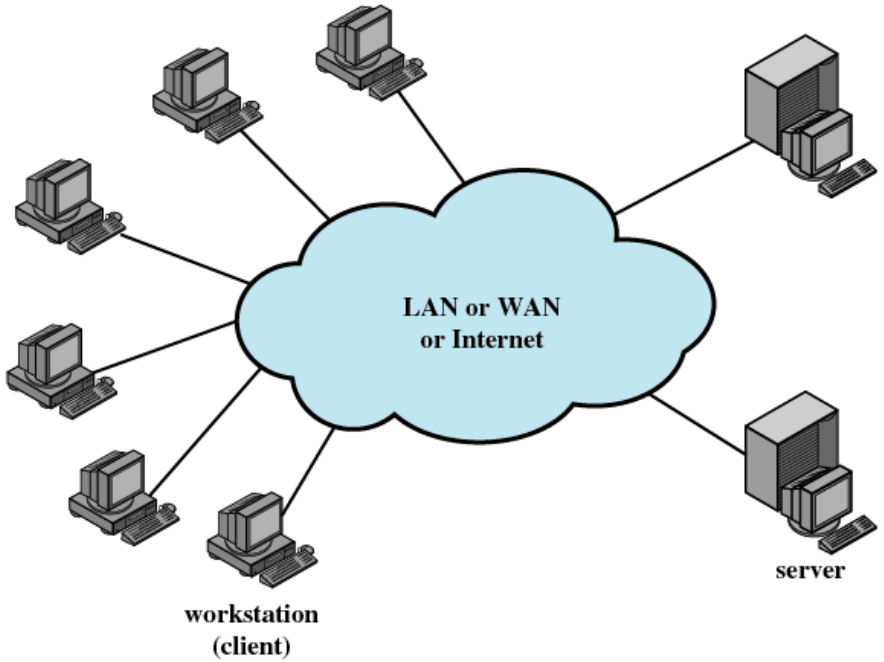
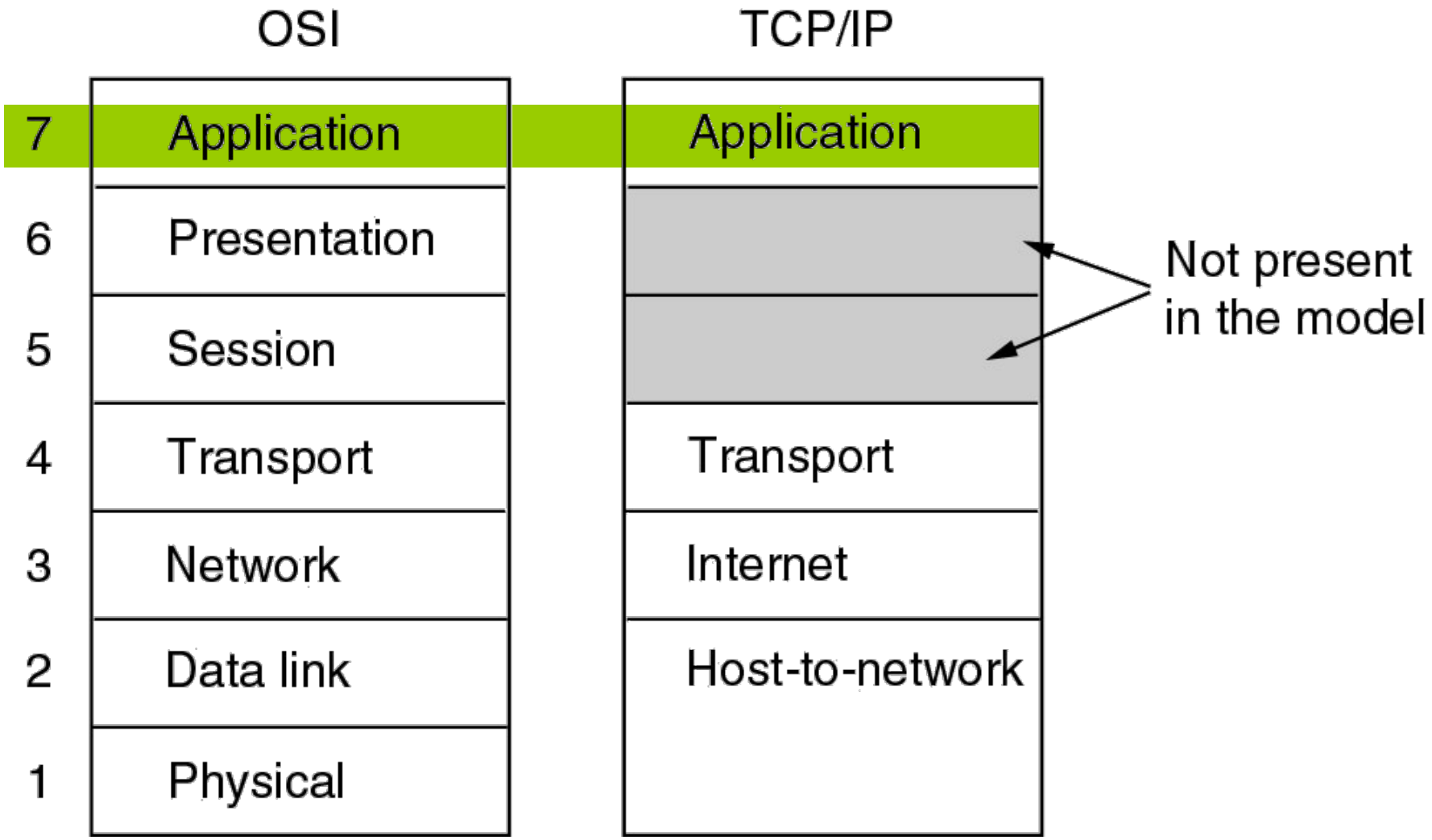


Content

Application



Goals of this Chapter

With the transport layer in place, all essential functionality to build a network is available

- Anything else is up to the application programmer

Nonetheless, there are some services that are almost essential for a practical network but that actually belong to the application layer

- More recent additions to the networking infrastructure
- Services that are naturally implemented as processes
- Prime example: Domain Name System (DNS)

Moreover, some applications are important enough to be discussed in more detail

- Classical “Killer applications” of the Internet: Email, WWW

Domain Name System (DNS)

Addressing in the Internet uses 4 bytes (IPv4)
- Commonly represented in dotted decimal notation

Nice for machines, impractical for human beings
- Do you recognize (or remember) 160.145.117.199?
  - Internet “phonebook” tries to solve this
- More convenient: Mnemonic names for communication peers
  - E.g. www.mi.fu-berlin.de

Domain Name System (DNS) provides name to address mapping
- Additionally, layer of indirection allows IP addresses to change while preserving the name

Example: DNS Query

Who is responsible for handling the following email receiver: j.schiller@ieee.org?

- How can I reach the mail server of ieee.org? (example > 10 years old)

MX-Record

NS-Records

A-Records

```
nslookup -q=mx ieee.org
Server:  einstein.abc.com
Address:  123.45.67.89

ieee.org        preference = 0, mail exchanger = gemini.ieee.org
ieee.org        nameserver = auth01.ieee.org
ieee.org        nameserver = dns.ieee.org
ieee.org        nameserver = ns.uu.net
ieee.org        nameserver = krypton.ieee.org
ieee.org        nameserver = deepthought.ieee.org
gemini.ieee.org internet address = 199.172.136.14
auth01.ieee.org internet address = 199.172.136.2
dns.ieee.org    internet address = 199.172.136.6
ns.uu.net       internet address = 137.39.1.3
krypton.ieee.org        internet address = 199.172.136.2
deepthought.ieee.org    internet address = 199.172.136.6
```

Example: DNS Query - redone

Who is responsible for handling the following email receiver: j.schiller@ieee.org?

- How can I reach the mail server of ieee.org? (example 2016)

```
Z:\>nslookup -q=mx ieee.org
Server:  impdc1.imp.fu-berlin.de
Address:  160.45.41.8

Non-authoritative answer:
ieee.org        MX preference = 100, mail exchanger = aspmx2.googlemail.com
ieee.org        MX preference = 50, mail exchanger = alt1.aspmx.l.google.com
ieee.org        MX preference = 50, mail exchanger = alt2.aspmx.l.google.com
ieee.org        MX preference = 10, mail exchanger = aspmx.l.google.com
ieee.org        MX preference = 100, mail exchanger = aspmx3.googlemail.com

aspmx2.googlemail.com   internet address = 74.125.130.27
aspmx2.googlemail.com   AAAA IPv6 address = 2404:6800:4003:c01::1b
alt1.aspmx.l.google.com internet address = 74.125.130.27
alt1.aspmx.l.google.com AAAA IPv6 address = 2404:6800:4003:c01::1b
alt2.aspmx.l.google.com internet address = 64.233.188.26
alt2.aspmx.l.google.com AAAA IPv6 address = 2404:6800:4008:c06::1b
aspmx.l.google.com      internet address = 74.125.136.27
aspmx.l.google.com      AAAA IPv6 address = 2a00:1450:4013:c01::1b
aspmx3.googlemail.com   internet address = 64.233.188.27
aspmx3.googlemail.com   AAAA IPv6 address = 2404:6800:4008:c06::1a
```

MX-Records

A- and AAAA-Records

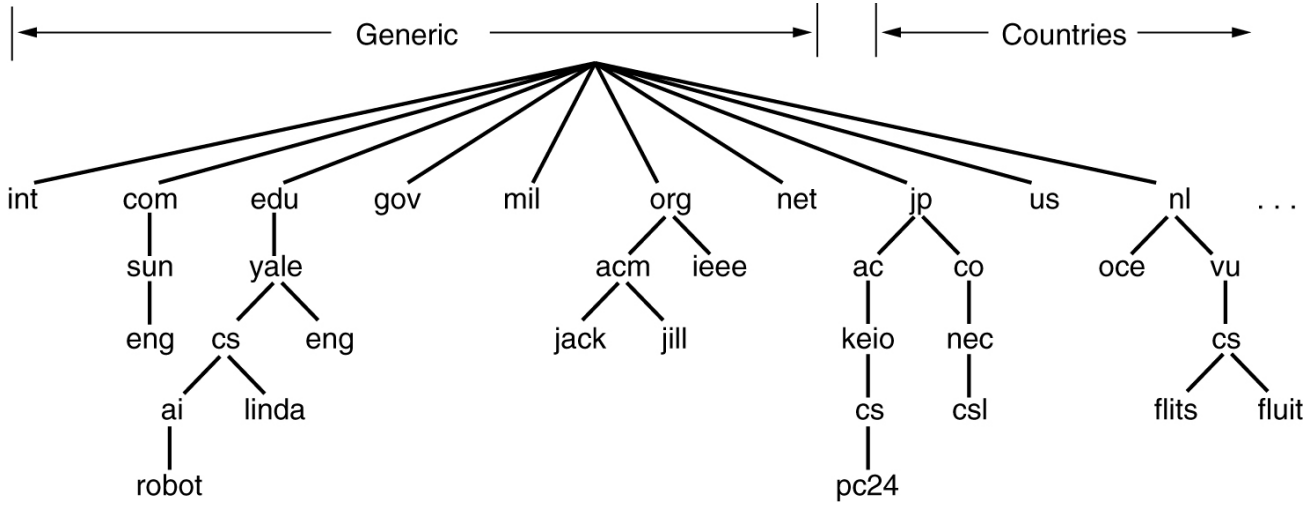
Architecture of DNS

DNS maps names to addresses

- Actually, maps names to multi-valued resource records

Names are structured hierarchically into a name space

- Max. 63 characters per component
- Max. 255 characters total
- Domains, each domain owner controls name space below it:

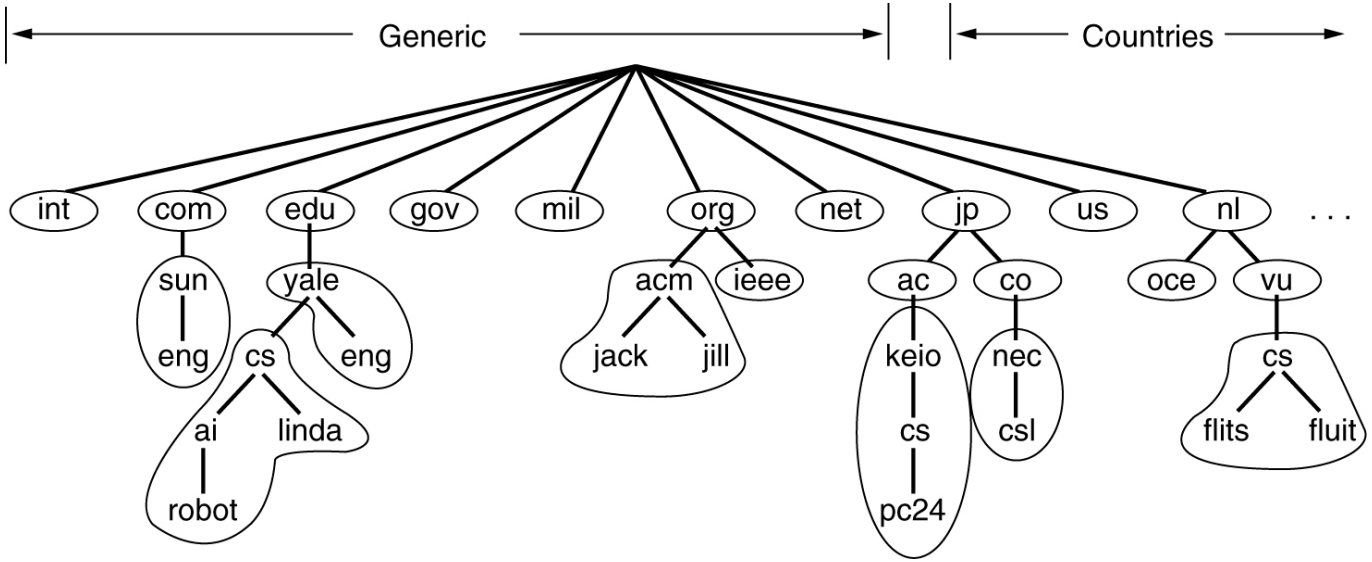


Mapping done by well known, hierarchical name servers

DNS Name Servers

Name space divided into zones with one primary name server with authoritative information per zone
- Also secondary name server for dependability

Each name server holds information about:
- Mappings in its own zone
- Addresses of name servers of all its children zones
  - Their siblings or about some server that knows about the siblings



➢DNS is a distributed database with weak consistency

DNS Query Resolution

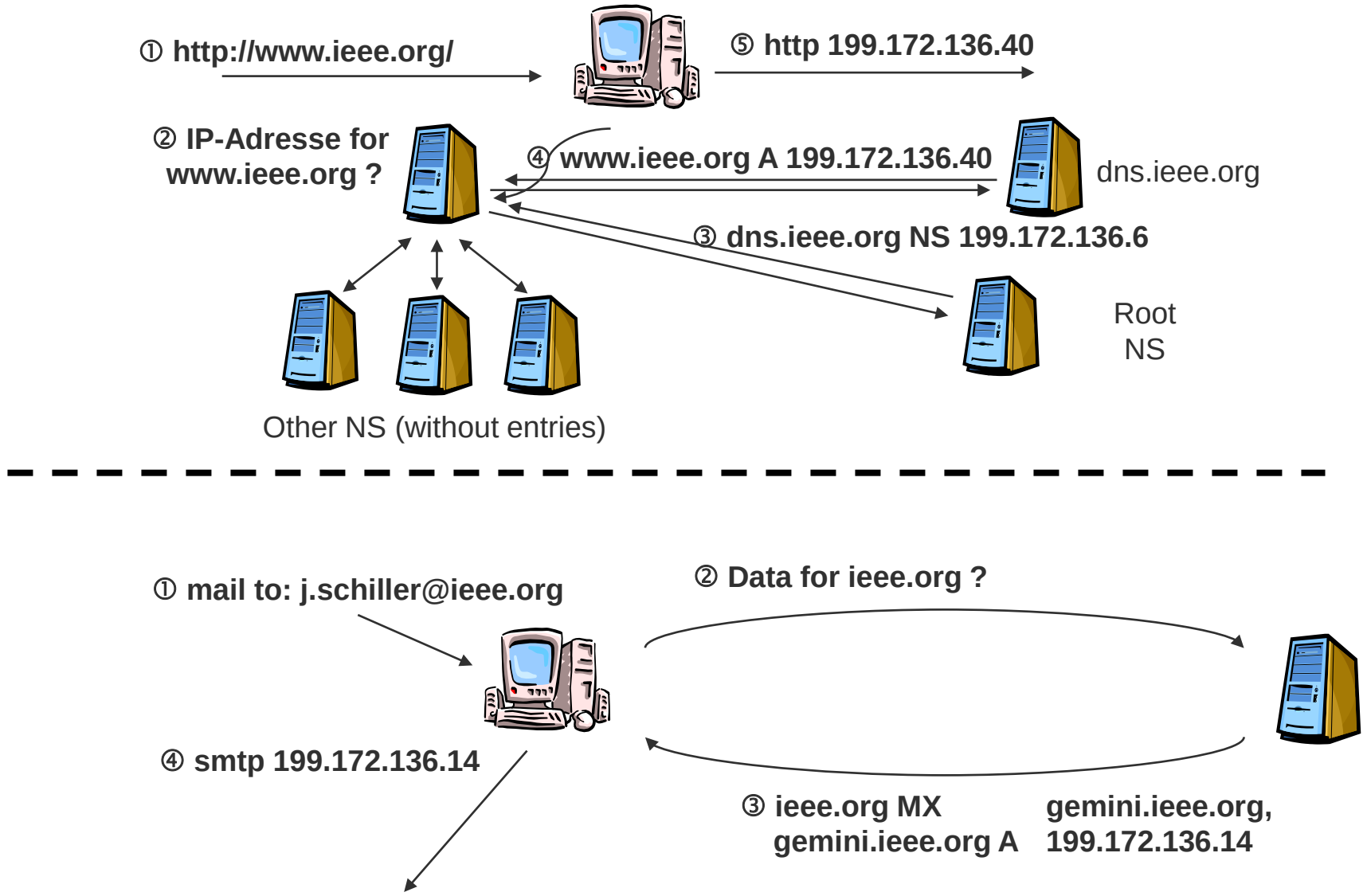
Queries by end system are sent to pre-configured name server (either through manual configuration or DHCP)

If possible, that name server answers query

If not, it will forward query to the “most suitable” name server in the zone hierarchy it is aware of
- Continues recursively (or iteratively, in case of root servers)

Answer sent back through intermediate servers
- Servers may cache replies

Example: DNS A-/MX-Records



DNS Root Servers

13 original DNS root servers, mostly located in the US:

Root Name Server: Many Replications – over 1000 servers in 2020

DNS Security Issues

Typeface Attacks

- Example: What's the difference between the following?
  - www.paypal.com
  - www.paypal.com
  - www.paypal.com
- ➢ Similar letters can mislead users to trust domain addresses
  - Especially problematic since Internationalized Domain Names (IDNs) were standardized (see IDN homograph attack)

DNS Cache Poisoning

- Place harmful data in DNS server cache
  - ➢ Example: `www.paypal.com.  3600  IN  A  160.45.114.34`
- Two alternatives:
  - Corrupt DNS server: Add additional data to any query
  - Man-in-the-middle: Flood client, try to guess 16-bit query ID
- *Real* solution: Use certificates for name servers (DNSSEC)

Questions & Tasks

- What is the basic idea of DNS?
- Can the Internet transport data without DNS?
- Is it possible to create an alternative DNS? If yes, what is needed? If no, why not?
- What are top level domains (classical and today)? Ok, there are > 1500 now …
- Why are root servers needed? What do they know?
- Why is security for DNS an important issue?

Email – Architecture and Services

"Email" as described in RFC 821/822

Main components:
- User agents (UA) and message transfer agents (MTA)
- Simple Mail Transfer Protocol (SMTP)

Main services:
- Composition, transfer, reporting, displaying and disposition of messages
- Optionally: Forwarding, auto-reply, vacation functions, mailing lists, BCC, …

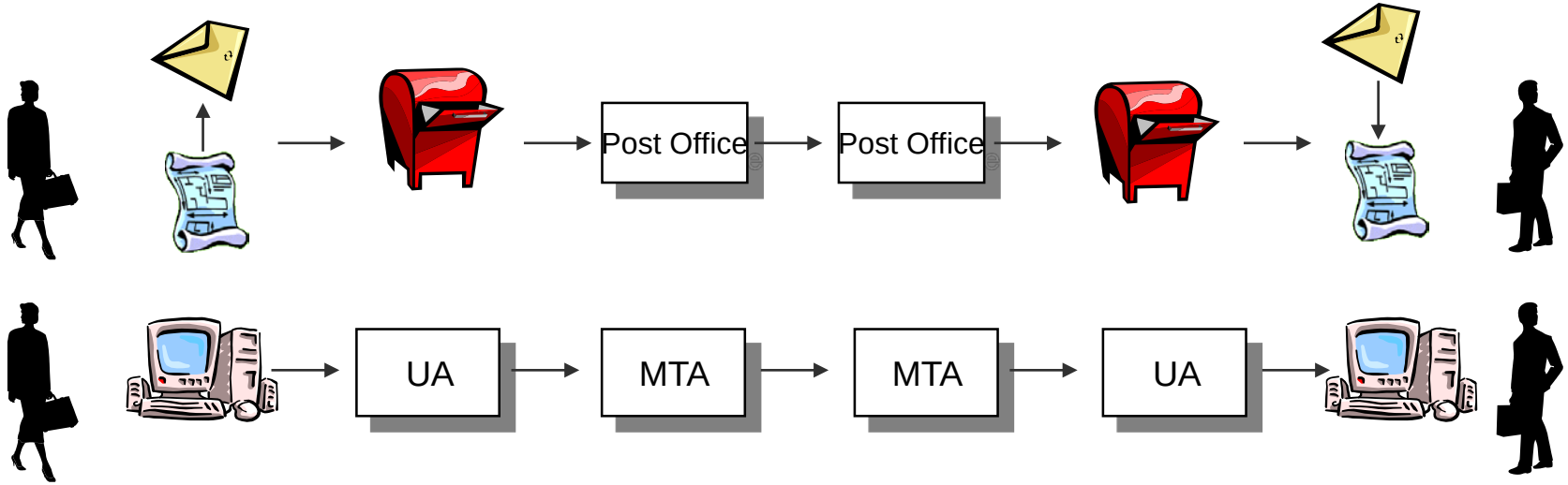
Main structure of an email:
- Envelope: Information required for transport
- Content: Information required for local processing and viewing

Remark: Merging email/IM/SMS/posts in the 2010s
- Social networks are currently trying to "swallow" email (and everything else too)

Email: System Model

User Agent (UA)
- Local text-oriented/graphical program
- Reading, writing, sending and receiving of email on local machine
- Examples: Integrated into browser, Outlook, pine, ..., ...

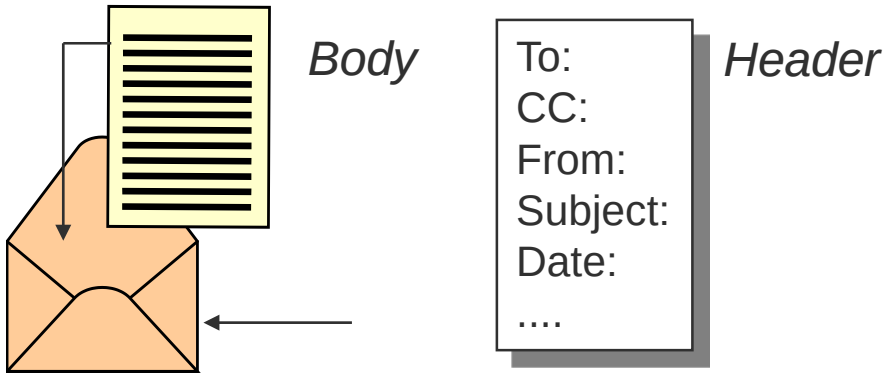
Message Transfer Agent (MTA)
- Background process
- Responsible for forwarding of emails towards receiver
- Example MTAs: sendmail, qmail, Exchange, ...



Email: Transmission Format (RFC 5322, was 2822, updated by 6854…)

Envelope:
- Contains all transport-relevant information (“To:”)
- Addressing based on DNS, e.g. schiller@computer.org
- Interpreted by MTAs

Content:
- Header:
  - Contains additional meta-information, e.g. “Subject:”, “CC:”, ...
  - Interpreted by UAs
- Body:
  - Contains actual message (originally ASCII only)

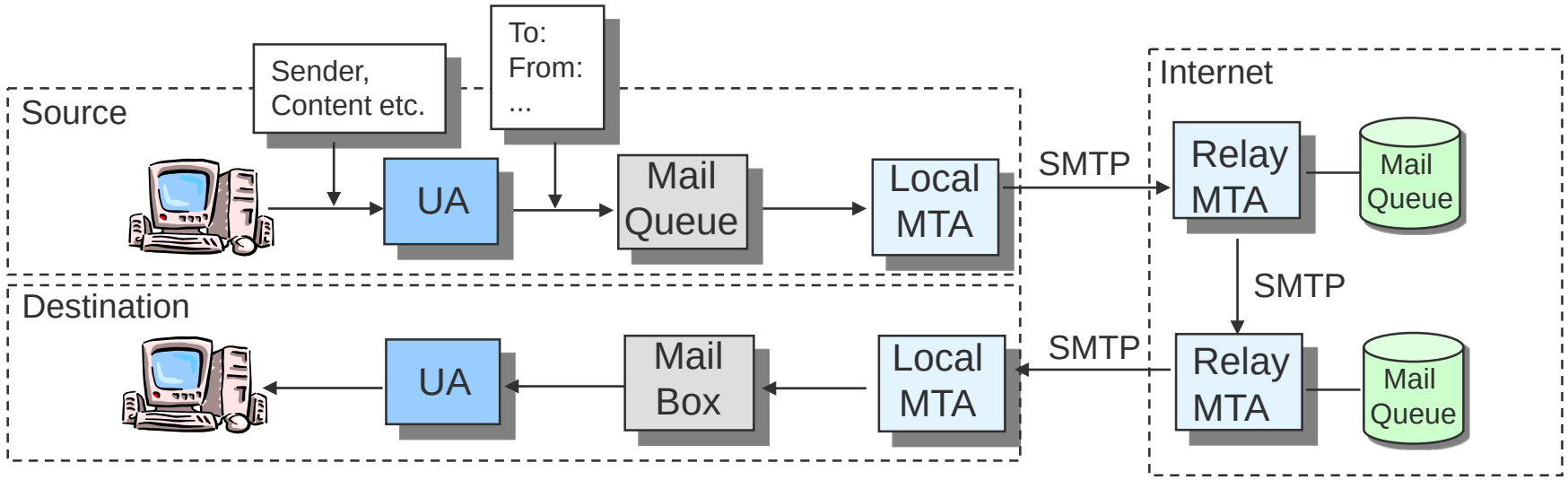


Simple Mail Transfer Protocol (SMTP, RFC 5321, updated by 7504)

SMTP transmits messages over TCP connections (port 25; port 587 with authentication, RFC 6409)
- Text-oriented protocol, originally 7 bit ASCII
- Few, simple commands, e.g. HELO, MAIL, RCPT, DATA, ...

UA gets all necessary information from user
- Sends message via local mail queue to pre-configured local MTA

MTAs transfer message to receiver
- Transfer via TCP, relays possible
  - E.g. campus relay plus MTAs for each institute



Example: SMTP Session

“Old” example, few mail servers allow this nowadays:

```
> telnet mailer.inf.fu-berlin.de 25

E:      220 mailer.inf.fu-berlin.de ESMTP
        Sendmail 8.9.3/8.9.3; Wed, 22 Sep 1999 10:41:34 +0200 (MET DST)
S:      HELO laptop.inf.fu-berlin.de
E:      250 mailer Hello laptop [123.45.67.89], pleased to meet you

S:      MAIL FROM: whoever
E:      250 whoever... Sender ok

S:      RCPT TO: webadmin@inf.fu-berlin.de
E:      250 whoever .. Recipient ok

S:      DATA
E:      354 Enter mail, end with "." on a line by itself
S:      Dear administrator, good to see that this does not work any longer...
S:      .
E:      250 KAA12526 Message accepted for delivery

S:      QUIT
E:      221 blackfoot closing connection
```

- No authentication of sender
- Anybody could request this MTA to send emails (open relay)

➢ Spam

Multipurpose Internet Mail Extensions

Original SMTP only supports data encoded in ASCII
- How to transfer images, sound, arbitrary data attachments?

Multipurpose Internet Mail Extensions (MIME) adds formatting/type information to content:
- Content-Type: Defines type of message body
  - Exemplary types: Text, multipart, message, application (binary), image, audio, video, X-private…
- Content-Transfer-Encoding: Defines transfer syntax for body (part) encoding
  - Examples: Base 64, quoted printable, 7 bit, 8 bit, binary, …

Still compatible to classical email:
- Base 64 encoding allows to transfer of binary data though 7 bit ASCII only MTAs
- Quoted printable supports national special characters

Example Email Header: The Trail of MTAs

Microsoft Mail Internet Headers Version 2.0
Received: from mail.math.fu-berlin.de ([160.45.40.10]) by spree.pcpool.mi.fu-berlin.de with Microsoft SMTPSVC(6.0.3790.3959);
Thu, 24 Jan 2008 17:48:26 +0100
Received: (qmail 9044 invoked by alias); 24 Jan 2008 17:48:26 +0100
Delivered-To: schiller@inf.fu-berlin.de
Received: (qmail 9038 invoked from network); 24 Jan 2008 17:48:26 +0100
Received: from lusin.mi.fu-berlin.de (HELO mi.fu-berlin.de) (160.45.117.141)
by leibniz.math.fu-berlin.de with SMTP; 24 Jan 2008 17:48:26 +0100
Received: (qmail 8626 invoked by uid 9804); 24 Jan 2008 17:48:26 +0100
Received: from localhost (HELO mi.fu-berlin.de) (127.0.0.1)
by localhost with SMTP; 24 Jan 2008 17:48:06 +0100
Received: (qmail 23135 invoked by uid 9804); 24 Jan 2008 17:15:01 +0100
Received: from leibniz.math.fu-berlin.de (HELO math.fu-berlin.de) (160.45.40.10)
by lusin.mi.fu-berlin.de with SMTP; 24 Jan 2008 17:15:01 +0100
Received: (qmail 152 invoked from network); 24 Jan 2008 17:15:01 +0100
Received: from sigma.informatik.hu-berlin.de (HELO mailslv1.informatik.hu-berlin.de) (141.20.20.51)
by leibniz.math.fu-berlin.de with (DHE-RSA-AES256-SHA encrypted) SMTP; 24 Jan 2008 16:15:01 -0000

MTA used by email recipient

Loop! Spam/virus filter running on lusin

from Math server to MI server

from HU to FU

Example Email Header: Continued

Source email server

Received: from ex.sar.informatik.hu-berlin.de (sar.informatik.hu-berlin.de [141.20.23.63])
by mailslv1.informatik.hu-berlin.de (8.13.8+Sun/8.13.8/INF-2.0-MA-SOLARIS-2.10-25) with ESMTP id m0OGEabt015579 for <schiller@inf.fu-berlin.de>; Thu, 24 Jan 2008 17:14:36 +0100 (CET)
X-Envelope-Sender: mm@informatik.hu-berlin.de
X-Virus-Scanned: by AMaViS 0.3.12pre7-L41+ClamAV[8175](NAI-uvscan@mi.fu-berlin.de)
X-Remote-IP: 141.20.20.51
Content-class: urn:content-classes:message
MIME-Version: 1.0
Content-Type: multipart/alternative;
boundary="----_=_NextPart_001_01C85EA4.35AB5B2E"
Subject: RE: Frohes neues Jahr
X-MimeOLE: Produced By Microsoft Exchange V6.5
Date: Thu, 24 Jan 2008 17:14:33 +0100
Message-ID: <BD8398D4C88E2C458083D1D2B04C4DA3207F4A@ex.sar.informatik.hu-berlin.de>
In-Reply-To: <6FE71171187F564EA019A177D00043B230418A@spree.pcpool.mi.fu-berlin.de>
X-MS-Has-Attach:
X-MS-TNEF-Correlator:
Thread-Topic: Frohes neues Jahr

Virus scan information

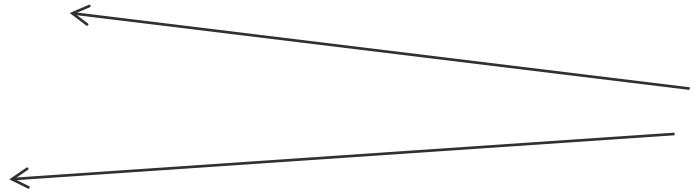
Subject and Date

Example Email Header: Continued

Thread-Index: AchNIy4Op6zY/HruSXS/HroQsbGWmgBgaQBwApbvmuABYRONYAAGTKOgAAF20KA=
References: <6FE71171187F564EA019A177D00043B2304027@spree.pcpool.mi.fu-berlin.de>
<BD8398D4C88E2C458083D1D2B04C4DA3207E49@ex.sar.informatik.hu-berlin.de>
<6FE71171187F564EA019A177D00043B2304108@spree.pcpool.mi.fu-berlin.de>
<BD8398D4C88E2C458083D1D2B04C4DA3207F47@ex.sar.informatik.hu-berlin.de>
<6FE71171187F564EA019A177D00043B230418A@spree.pcpool.mi.fu-berlin.de>
From: "Max Mustermann" <mm@informatik.hu-berlin.de>
To: "Jochen Schiller" <schiller@inf.fu-berlin.de>

From and To

X-Greylist: Sender IP whitelisted, not delayed by milter-greylist-3.0 (mailslv1.informatik.hu-berlin.de [141.20.20.51]); Thu, 24 Jan 2008 17:14:36 +0100 (CET)
X-Virus-Status: No (sigma)
Return-Path: mm@informatik.hu-berlin.de
X-OriginalArrivalTime: 24 Jan 2008 16:48:26.0547 (UTC) FILETIME=[F0AD6030:01C85EA8]
------_=_NextPart_001_01C85EA4.35AB5B2E
Content-Type: text/plain; charset="iso-8859-1"
Content-Transfer-Encoding: quoted-printable
------_=_NextPart_001_01C85EA4.35AB5B2E
Content-Type: text/html; charset="iso-8859-1"
Content-Transfer-Encoding: quoted-printable
------_=_NextPart_001_01C85EA4.35AB5B2E--



2 parts to follow:
- a plain text part
- an HTML part

Example Email Header: MIME Parts

MIME-Version: 1.0

Content-Type: MULTIPART/MIXED;
BOUNDARY= "8323328-2120168431-824156555=:325"

--8323328-2120168431-824156555=:325

Content-Type: TEXT/PLAIN; charset=US-ASCII

A picture is in the appendix

--8323328-2120168431-824156555=:325

Content-Type: IMAGE/JPEG; name="picture.jpg"

Content-Transfer-Encoding: BASE64

Content-ID: <PINE.LNX.3.91.960212212235.325B@localhost>

Content-Description:

/9j/4AAQSkZJRgABAQEAlgCWAAD/2wBDAAEBAQEBAQEBAQEBAQEBAQIBAQEBAQIBAQECAgICAgICAgID
AwQDAwMDAwICAwQDAwQEBAQEAgMFBQQEBQQEBAT/2wBDAQEBAQEBAQIBAQIEAwIDBAQEBA […]

KKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAoo
ooAKKKKACiiigAooooAKKKKACiiigAooooAD//Z

---8323328-2120168431-824156555=:325 —

MIME substructure starts

Content of type Text

Content of type Image
(picture.jpg)

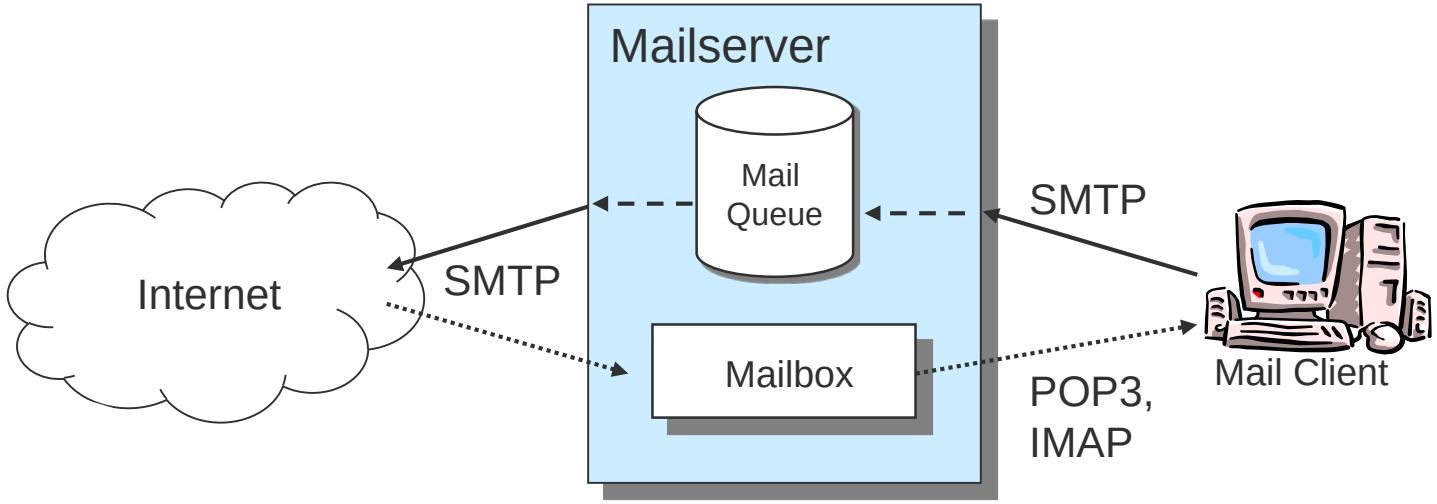
JPEG encoding

Advantage: emails can feature more varied content, multimedia etc.
Drawback: complexity w.r.t. command line mechanism from the 80s

Management of Emails

Typically, central mail server handles all email (always online)
Clients are not always online, need to pull email (SMTP pushes only):

- POP3 (Post Office Protocol 3)
  - Very simple pull protocol, client pulls email from server
  - Messages can stay on server or server deletes messages
  - With/without authentication, secure transmission
- IMAP (Interactive Mail Access Protocol)
  - Management of emails on central server, support of several clients
  - Many commands for filtering, forwarding, online/offline operation, ...



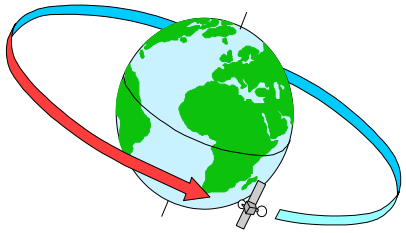
Questions & Tasks

- What is the role of MTAs and SMTP in Email-Systems?
- Email is text-based. How can we send multimedia content?
- Why are special protocols like POP or IMAP needed?
- Why is it easy to fake a sender address?

World Wide Web (WWW) – Development

Started as project of British computer scientist Tim Berners-Lee at CERN research center
- Goal: Simple, world-wide exchange of documents among researchers (first ideas in 1989)

First browser prototype in 1990
- Graphical (based on NEXTStep) and text-oriented



Break-through based on client Mosaic
- Developed by Marc Andreesen and Eric Bina (University of Illinois)
- Originally for X-Windows systems
- Available as source code via FTP, thus rapid dissemination

End of 1993: 500 known web servers generating 1% of the Internet traffic

July 1994: Foundation of the W3 Consortium
- Goal: Further development of WWW, standardization of HTML
- ➢http://www.w3.org

End of 1994:
- 10000 servers, 2000 commercial
- 10 million users
- Traffic generated equaled roughly complete works of Shakespeare – every second

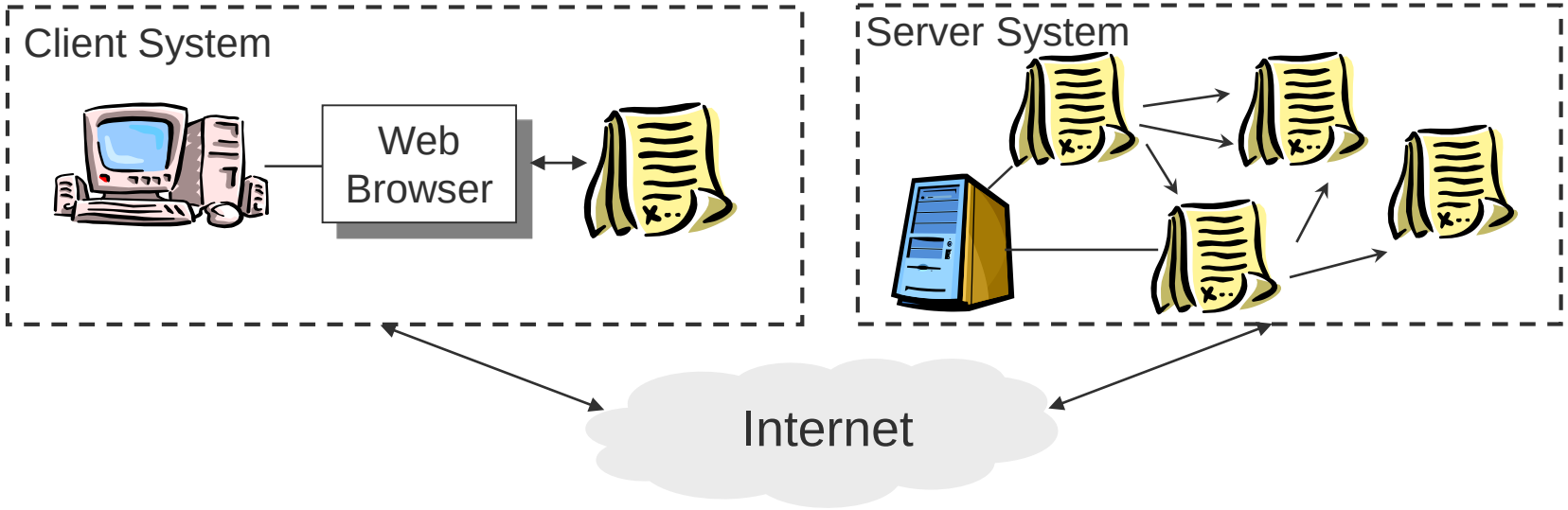
1995: Marc Andreesen founds Netscape

And then we all know the story:
- Rise & fall of the .coms, Web 2.0 hype, ...
- Today everyone/everything is on/in the Web creating a large portion of Internet traffic

WWW: Client/Server Architecture

Client:
- Runs web browser for displaying hypertext documents, hypermedia object
- Interprets hyperlinks for navigation, loading of objects

Server:
- Stores pages as files, runs database which generate pages

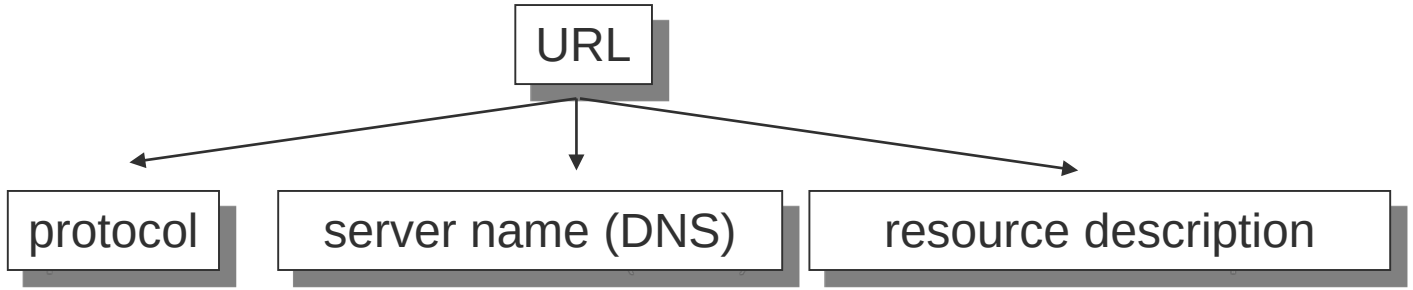


Open issues:
- Addressing of web pages, resources
- Transport of web pages, content
- Content description, syntax of links

Addressing of Web Resources

Uniform Resource Locator (URL)

- Directs client software to a certain resource
- Also applicable for content of other services (FTP, Email, ...)
- Examples: http://www.mi.fu-berlin.de/index.html



Identification of objects on a server via resource description

- WWW: Web page, or rather content to be transferred over HTTP
- FTP: File
- Mail: Receiver of email

Web browsers support different protocols/applications

- Examples: http://, ftp://, mailto://, telnet://, soap://, ...

HyperText Transfer Protocol (HTTP)

HTTP (HyperText Transfer Protocol)
- Versions 0.9 and 1.0 described in RFC1945
- Since January 1997 version 1.1 (RFC2068, RFC2616 since 99)
- HTTP/2 (originally HTTP/2.0), published as standard May 2015, RFC7540
- Primarily used for transfer of web pages
  - However, almost everything can be transferred over HTTP

Characteristics:
- ASCII-based application layer protocol
- Uses a reliable TCP connection (default: port 80)
- Short-lived connections with version 1.0 (one connection per request), persistent connections since version 1.1
  - Optimization as web pages commonly consist of multiple objects

Exemplary commands:
- GET: Request a certain resource
- HEAD: Request the header information of a resource
- POST: Submits data to a resource
- PUT: Uploads a new resource

HTTP Request / Response

- Request from client to server
- Command line: <command> <URL> <version>
- Client request most current version of the resource, not cached

- TCP connection was already established

- Response line
- Date
- Server
- Coding information
- Type of content
- Main part

HTTP-Client

```
GET /index.html HTTP/1.1
Host:www.abc.com
Pragma: no-cache
....
```

HTTP-Server

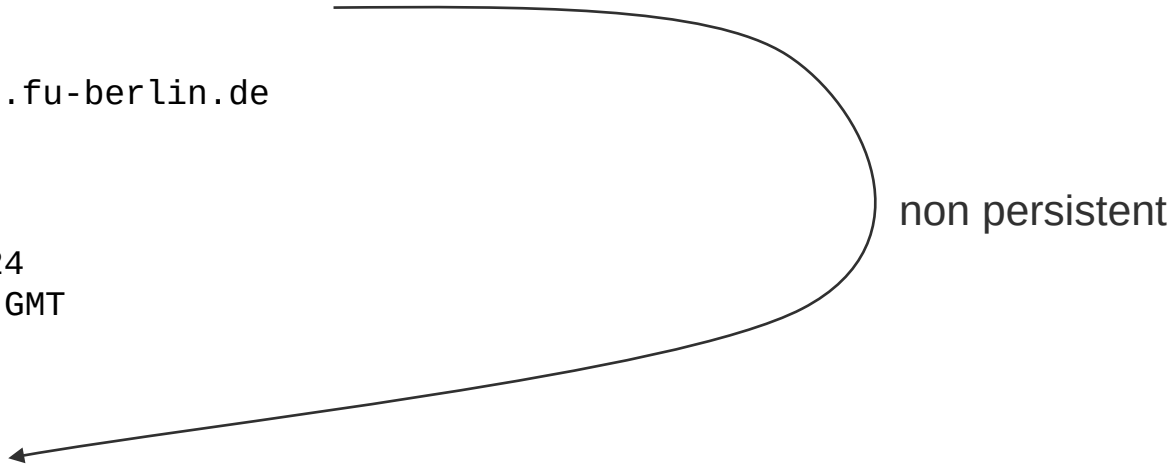
```
HTTP/1.1 200 OK
Date: Fri, 24 Sep 1999 09:45:51 GMT
Server: Apache/1.3.6 (Unix)
Transfer-Encoding: chunked
Content-Type: text/html

<HTML>
Document according to HTML
</HTML>
```

Example: HTTP Request / Response

Request to port 80:
```
GET / HTTP/1.0
```
or:
```
GET / HTTP/1.1
Host: www.inf.fu-berlin.de
```

Response from server




```
HTTP/1.1 200 OK
Date: Wed, 30 Oct 2002 19:44:26 GMT
Server: Apache/1.3.12 (Unix) mod_perl/1.24
Last-Modified: Wed, 30 Oct 2002 13:16:31 GMT
ETag: "2d8190-2322-3dbfdbaf"
Accept-Ranges: bytes
Content-Length: 8994
Connection: close
Content-Type: text/html

<DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN">
<html>
  <head>
    <title>FU-Berlin: Institut f&uuml;r Informatik</TITLE>
    <base href="http://www.inf.fu-berlin.de">
    <link rel="stylesheet" type="text/css" href="http://www.inf.fu-berlin.de/styles/homepage.css">
    <!--script language="JavaScript" src="fuinf.js"-->
    <!--/script-->
  </head>

  <body onResize="self.location.reload();">
...
```

HyperText Markup Language (HTML)

HyperText Markup Language (HTML):

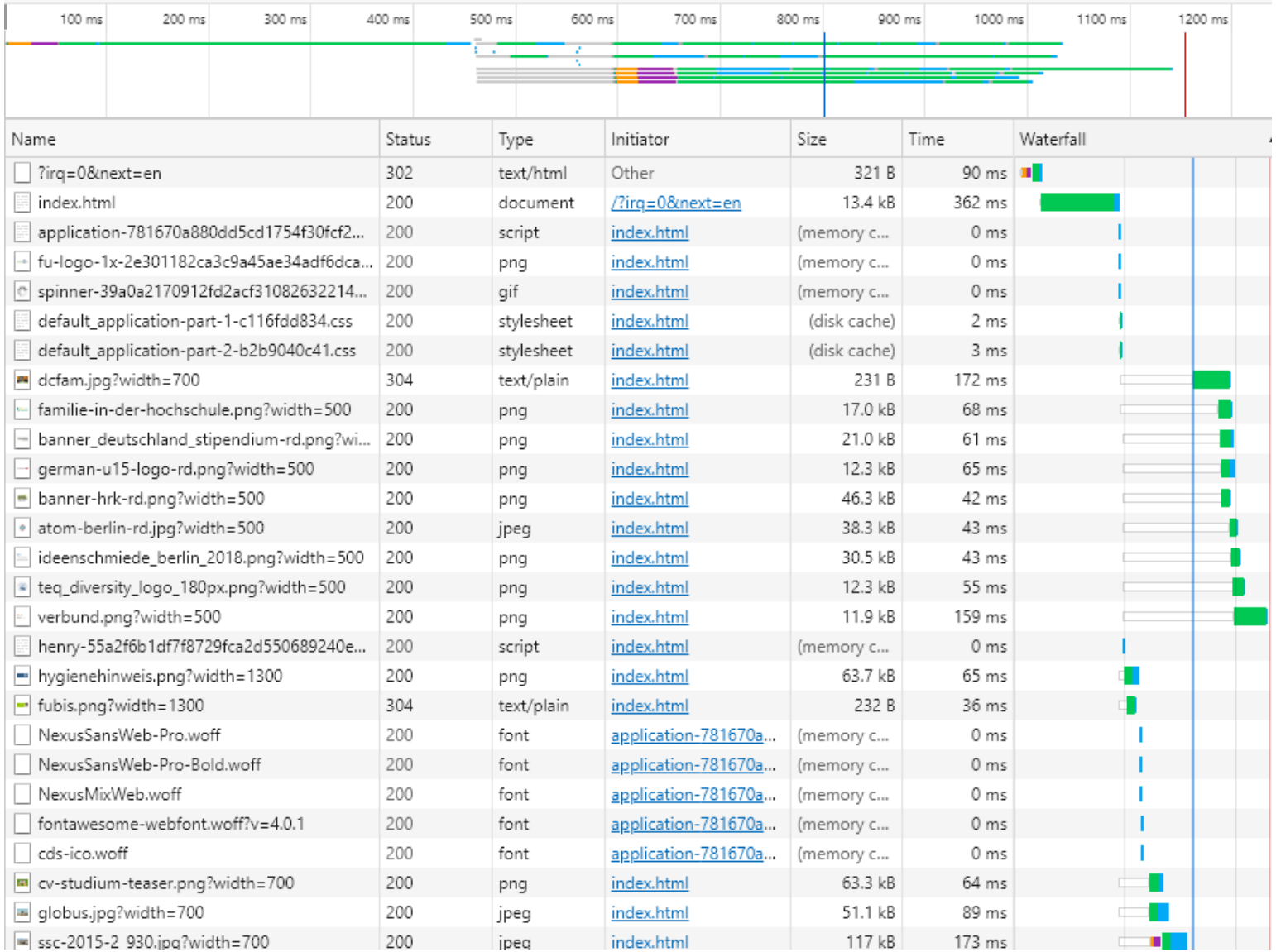
- Document description language
- HTML documents are structured text documents (similar to XML)
- HTML tags describe the presentation/meaning (cf. TEX)
  - HTML tags in plain text
  - Example: Bold Font
- Documents contain header and body
  - Header defines general properties of the document
  - Body contains content, i.e. the web page
    - Subdivided into headings, paragraphs, ...
- Hyperlinks refer to labels or other resources
- Integration of arbitrary non-text elements, e.g. graphics, videos, ...
- Browser can adapt (within certain limits) presentation to local capabilities

Standardization has reached HTML 5

- Integration of scripting (JavaScript) and Cascading Style Sheets (CSS)
- Includes audio, video, 2/3D…

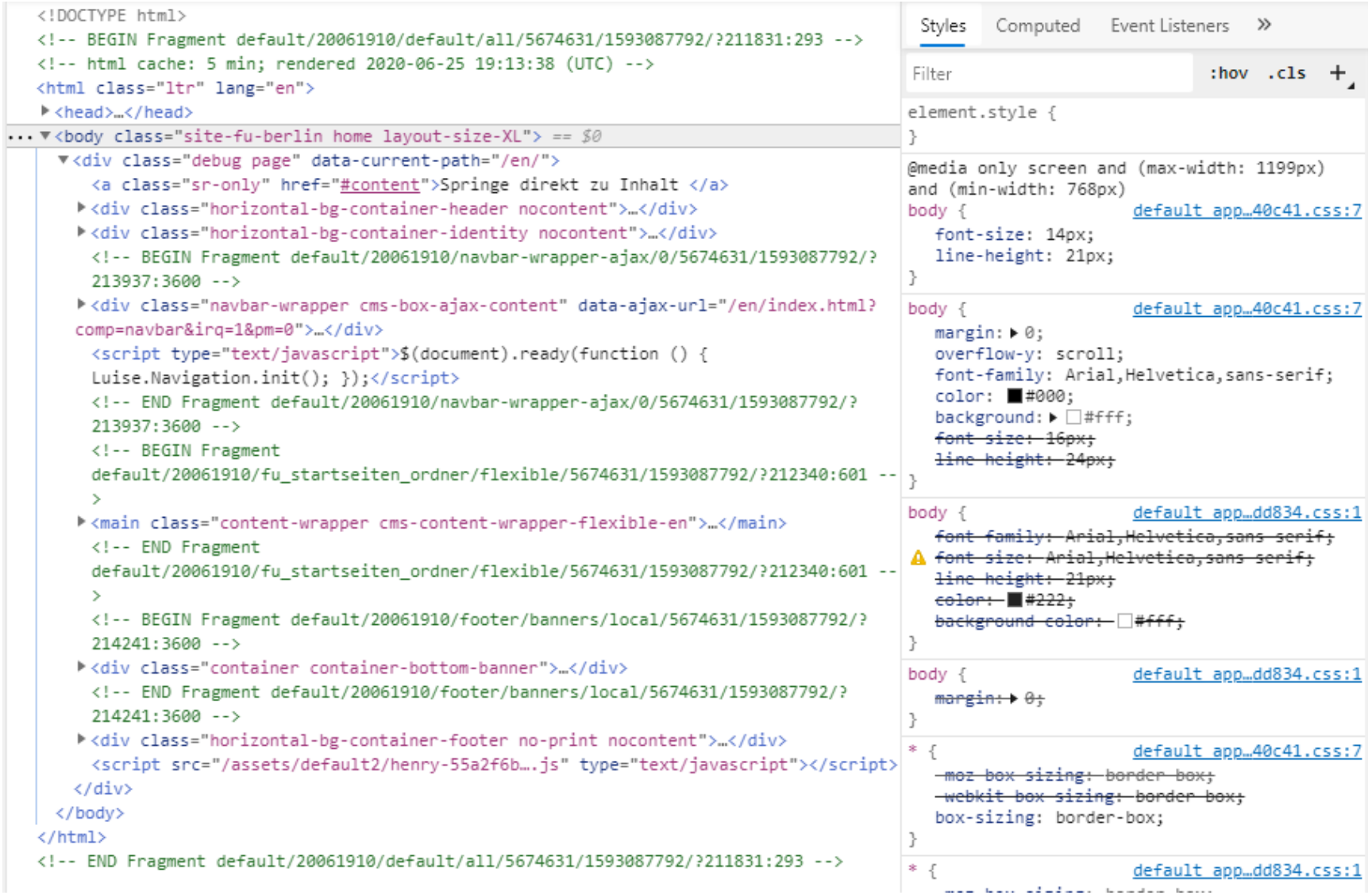
Example Webpage

Example Webpage – and what is going on in the background I



Name	Status	Type	Initiator	Size	Time	Waterfall
?irq=0&next=en	302	text/html	Other	321 B	90 ms	
index.html	200	document	/?irq=0&next=en	13.4 kB	362 ms	
application-781670a880dd5cd1754f30fcf2...	200	script	index.html	(memory c...	0 ms	
fu-logo-1x-2e301182ca3c9a45ae34adf6dca...	200	png	index.html	(memory c...	0 ms	
spinner-39a0a2170912fd2acf31082632214...	200	gif	index.html	(memory c...	0 ms	
default_application-part-1-c116fdd834.css	200	stylesheet	index.html	(disk cache)	2 ms	
default_application-part-2-b2b9040c41.css	200	stylesheet	index.html	(disk cache)	3 ms	
dcfam.jpg?width=700	304	text/plain	index.html	231 B	172 ms	
familie-in-der-hochschule.png?width=500	200	png	index.html	17.0 kB	68 ms	
banner_deutschland_stipendium-rd.png?wi...	200	png	index.html	21.0 kB	61 ms	
german-u15-logo-rd.png?width=500	200	png	index.html	12.3 kB	65 ms	
banner-hrk-rd.png?width=500	200	png	index.html	46.3 kB	42 ms	
atom-berlin-rd.jpg?width=500	200	jpeg	index.html	38.3 kB	43 ms	
ideenschmiede_berlin_2018.png?width=500	200	png	index.html	30.5 kB	43 ms	
teq_diversity_logo_180px.png?width=500	200	png	index.html	12.3 kB	55 ms	
verbund.png?width=500	200	png	index.html	11.9 kB	159 ms	
henry-55a2f6b1df7f8729fca2d550689240e...	200	script	index.html	(memory c...	0 ms	
hygienehinweis.png?width=1300	200	png	index.html	63.7 kB	65 ms	
fubis.png?width=1300	304	text/plain	index.html	232 B	36 ms	
NexusSansWeb-Pro.woff	200	font	application-781670a...	(memory c...	0 ms	
NexusSansWeb-Pro-Bold.woff	200	font	application-781670a...	(memory c...	0 ms	
NexusMixWeb.woff	200	font	application-781670a...	(memory c...	0 ms	
fontawesome-webfont.woff?v=4.0.1	200	font	application-781670a...	(memory c...	0 ms	
cds-ico.woff	200	font	application-781670a...	(memory c...	0 ms	
cv-studium-teaser.png?width=700	200	png	index.html	63.3 kB	64 ms	
globus.jpg?width=700	200	jpeg	index.html	51.1 kB	89 ms	
ssc-2015-2_930.jpg?width=700	200	jpeg	index.html	117 kB	173 ms	

Example Webpage – and what is going on in the background II



Content

Questions & Tasks

- What do many application layer protocols have in common?
- What is the idea of a URL? What are elements of a URL?
- What are the typical components of a web page today?
- Go to your favorite browser and enable the developer tools – this opens up the world behind web pages!