The Application Layer:
HTTP, SMTP

Lecture 6
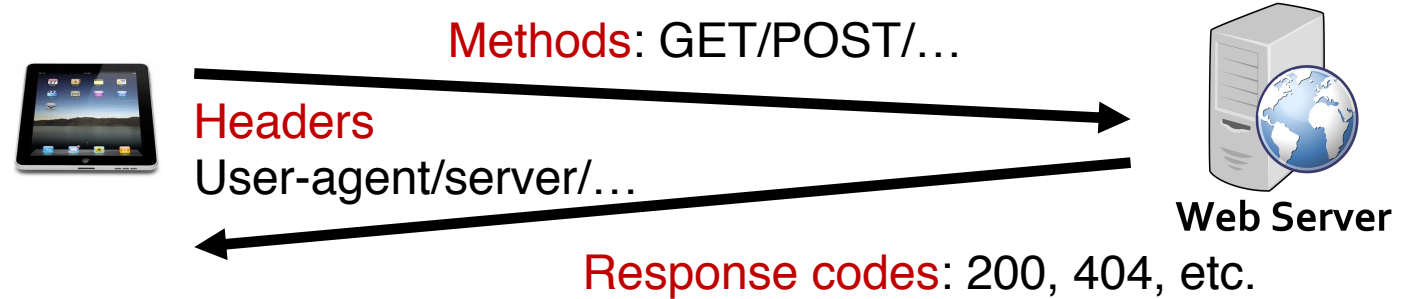http://www.cs.rutgers.edu/~sn624/352-S22

Srinivas Narayana

RUTGERS
UNIVERSITY | NEW BRUNSWICK

Quick recap of concepts

App layer

HyperText Transfer Protocol (HTTP)

HTTP is a client/server application

Methods: GET/POST/...

Headers
User-agent/server/...

Response codes: 200, 404, etc.

Web Server

Persistence

Connection

RTT

HTTP req

Web Server

RTT HTTP resp

Cookies

Set-cookie: XXX

Cookie: XXX

Web Server

Cookie file
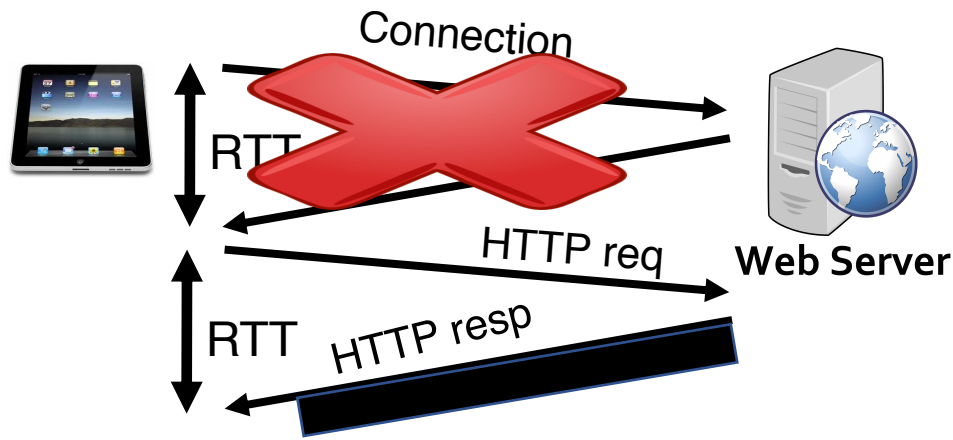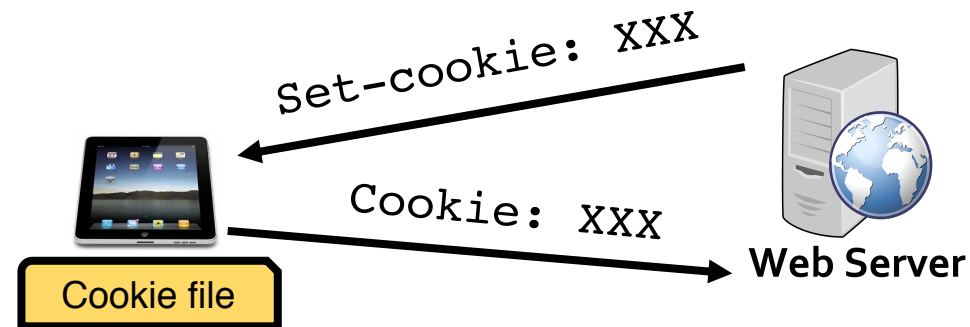
Caching

e.g., proxy server

Web caches

Web caches: Machines that remember web responses for a network

Why cache web responses?

- Reduce response time for client requests

- Reduce traffic on an institution's access link

Last lecture: Caches implemented in the form of a proxy server

3

Content Distribution Networks (CDNs)
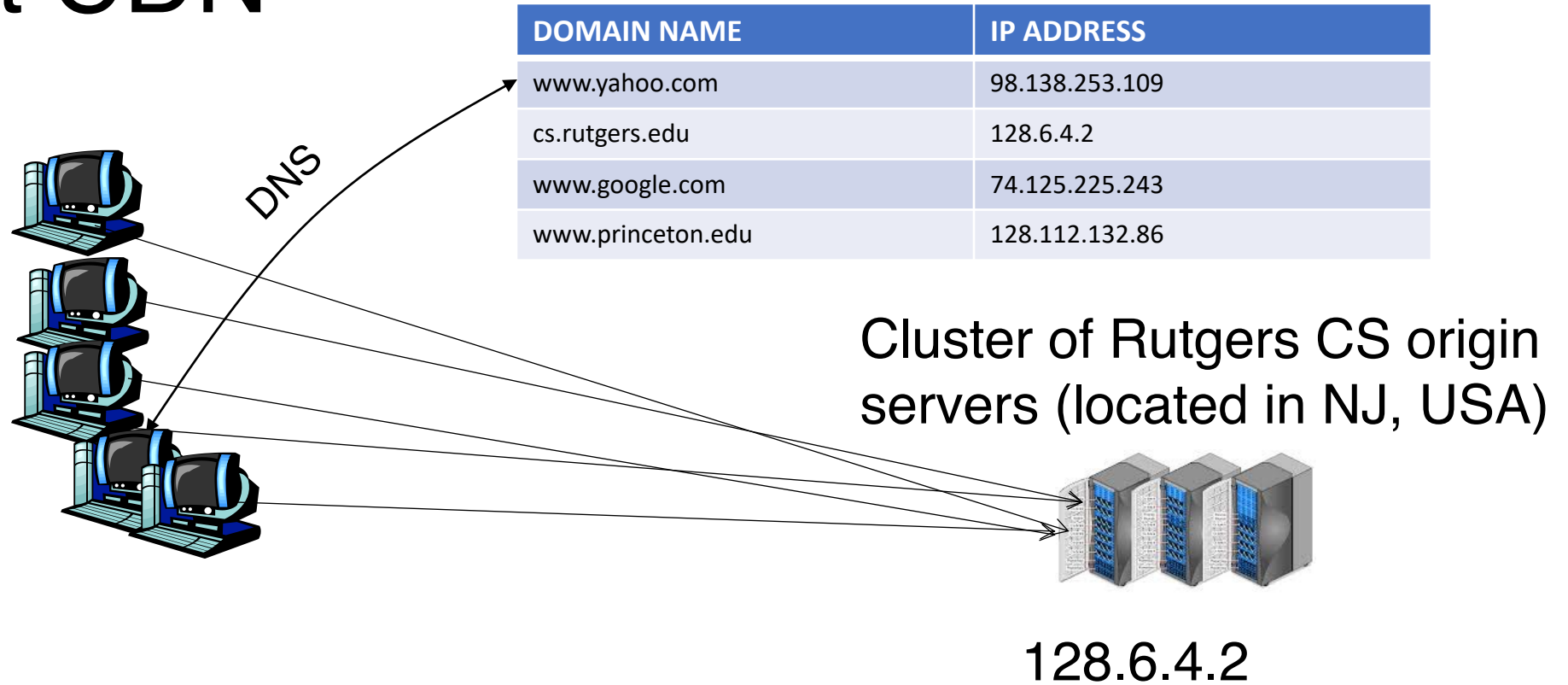
A global network of web caches
- Provisioned by ISPs and network operators
- Or content providers, like Netflix, Google, etc.

Uses (overlaps with uses of web caching in general)
- Reduce traffic on a network's Internet connection, e.g., Rutgers
- Improve response time for users: CDN nodes are closer to most users than origin servers
- Reduce bandwidth requirements on content provider
- Reduce $$ to maintain origin servers

Without CDN

DOMAIN NAME	IP ADDRESS
www.yahoo.com	98.138.253.109
cs.rutgers.edu	128.6.4.2
www.google.com	74.125.225.243
www.princeton.edu	128.112.132.86

Clients distributed all over the world

DNS

Cluster of Rutgers CS origin servers (located in NJ, USA)

128.6.4.2

- Problems:
- Huge bandwidth requirements for Rutgers
- Large propagation delays to reach users

Where the CDN comes in

- Distribute content of the origin server over geographically distributed CDN servers

- But how will users get to these CDN servers?

- Use DNS!
  - DNS provides an additional layer of indirection
  - Instead of returning IP address, return another DNS server (NS record)
  - The second DNS server (run by the CDN) returns IP address to client

- The CDN runs its own DNS servers (CDN name servers)
  - Custom logic to send users to the "closest" CDN web server

With CDN

| DOMAIN NAME	IP ADDRESS
www.yahoo.com	98.138.253.109
cs.rutgers.edu	124.8.9.8 (NS record pointing to CDN name server)
www.google.com	74.125.225.243

NS record delegates the choice of IP address to the CDN name server.

DNS reply

CDN Name Server (124.8.9.8)

DOMAIN NAME	IP ADDRESS
Cs.Rutgers.edu	12.1.2.3
Cs.Rutgers.edu	12.1.2.4
Cs.Rutgers.edu	12.1.2.5
Cs.Rutgers.edu	12.1.2.6

Custom logic to map ONE domain name to one of many IP addresses!

Using CDN

Popular CDNs:
CloudFlare
Akamai
Level3
…

12.1.2.3

12.1.2.4

CDN servers

12.1.2.6

12.1.2.5

Client

128.6.4.2
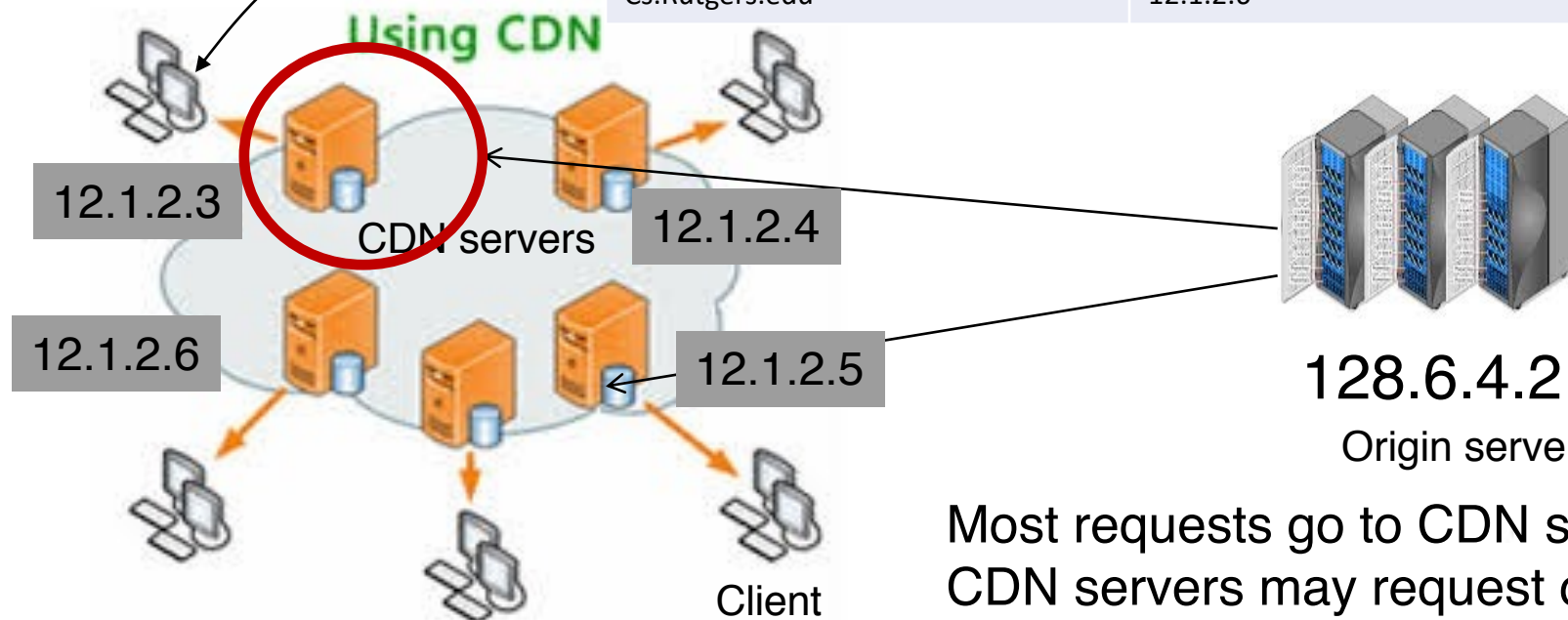
Origin server

Most requests go to CDN servers (caches).
CDN servers may request object from origin
Few client requests go directly to origin server

Summary of HTTP

- Request/response protocol
- ASCII-based human-readable message structures
- Improve performance using connection persistence, caching, and CDN
- Enhanced stateful functionality using cookies
- Simple, highly-customizable protocol
  - Just add headers
- Protocol that forms of the basis of the web we enjoy today!

Simple Mail Transfer Protocol
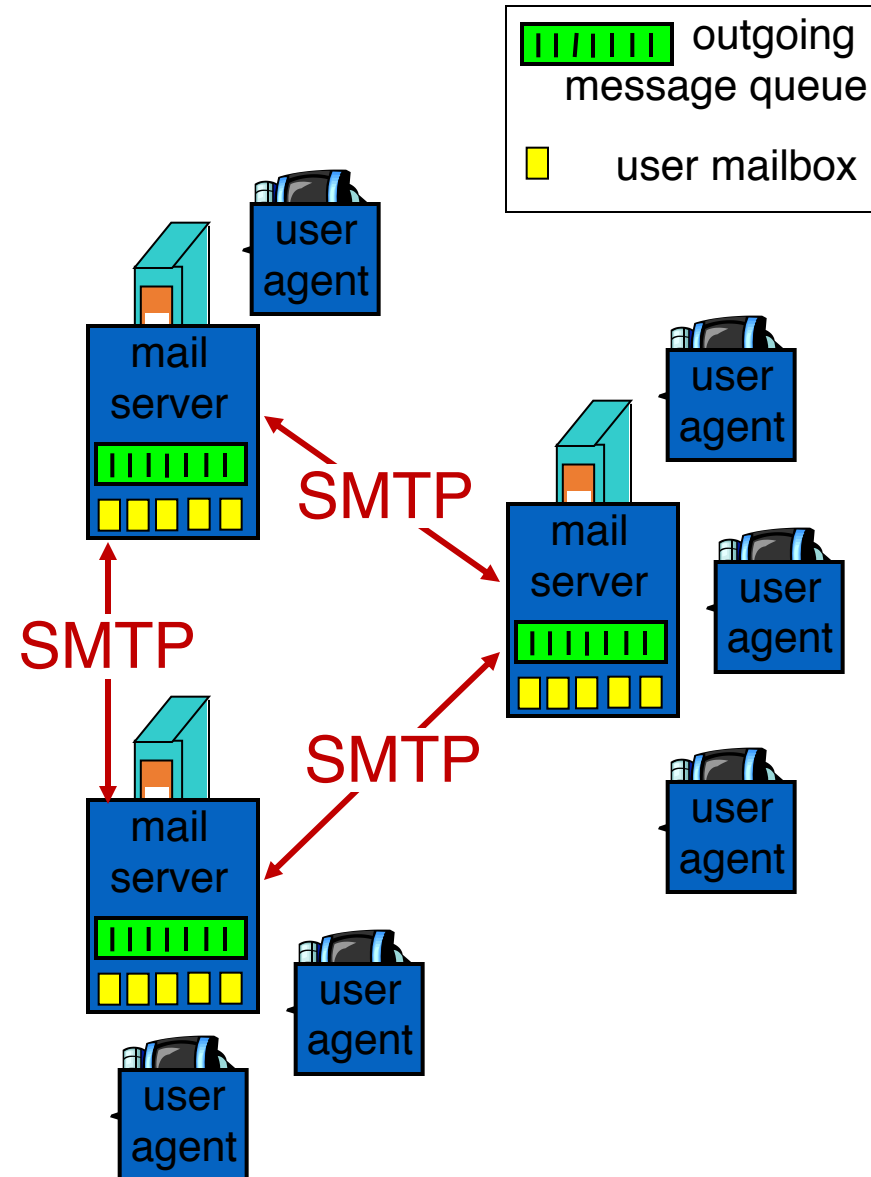
We're all familiar with email.
How does it work?
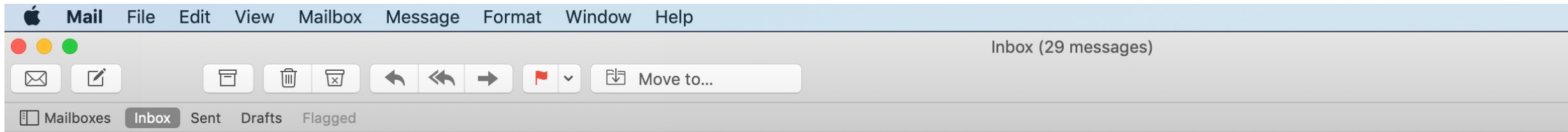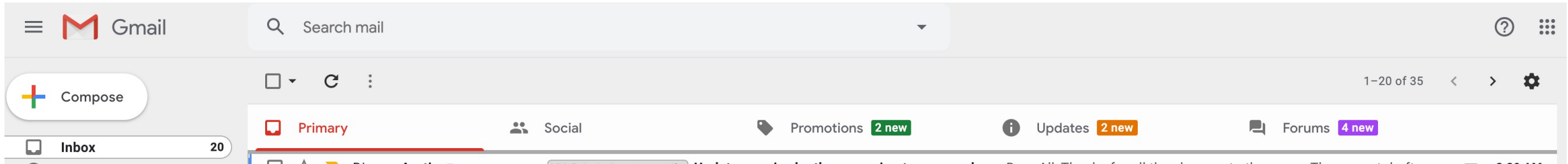
Electronic Mail

Three major components:

1. **User agents**
   - a.k.a. "mail reader"
   - e.g., Applemail, Outlook
   - Web-based user agents (ex: gmail)

# Electronic Mail: Mail servers

2. Mail Servers

- Mailbox contains incoming messages for user

- Message queue of outgoing (to be sent) mail messages

- Sender's mail server makes connection to Receiver's mail server
  - IP address, port 25
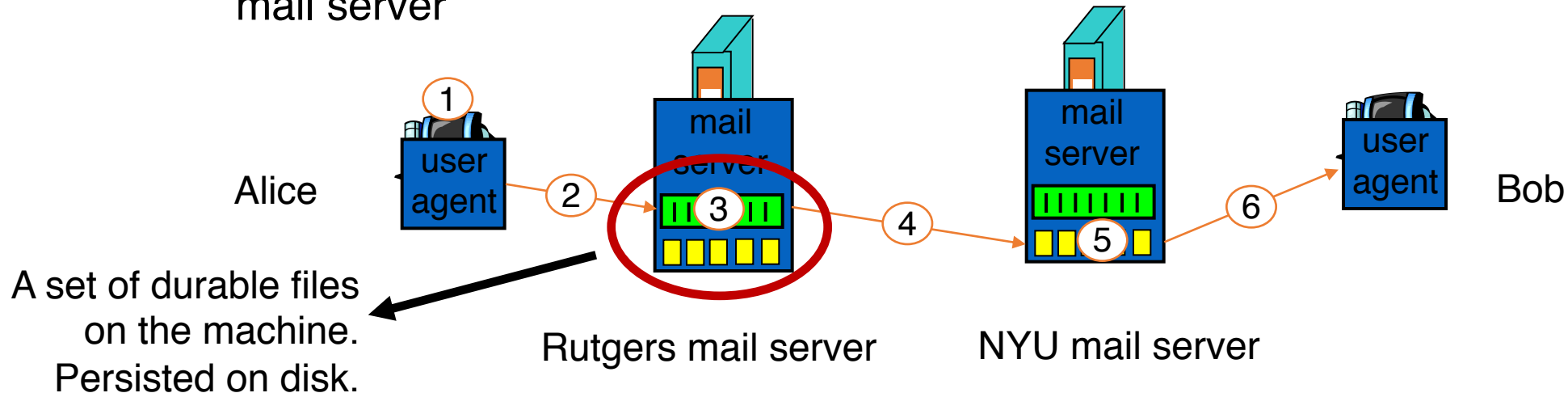
3. SMTP protocol: client/server protocol

- Used to send messages

- Client: sending user agent or sending mail server

- server: receiving mail server
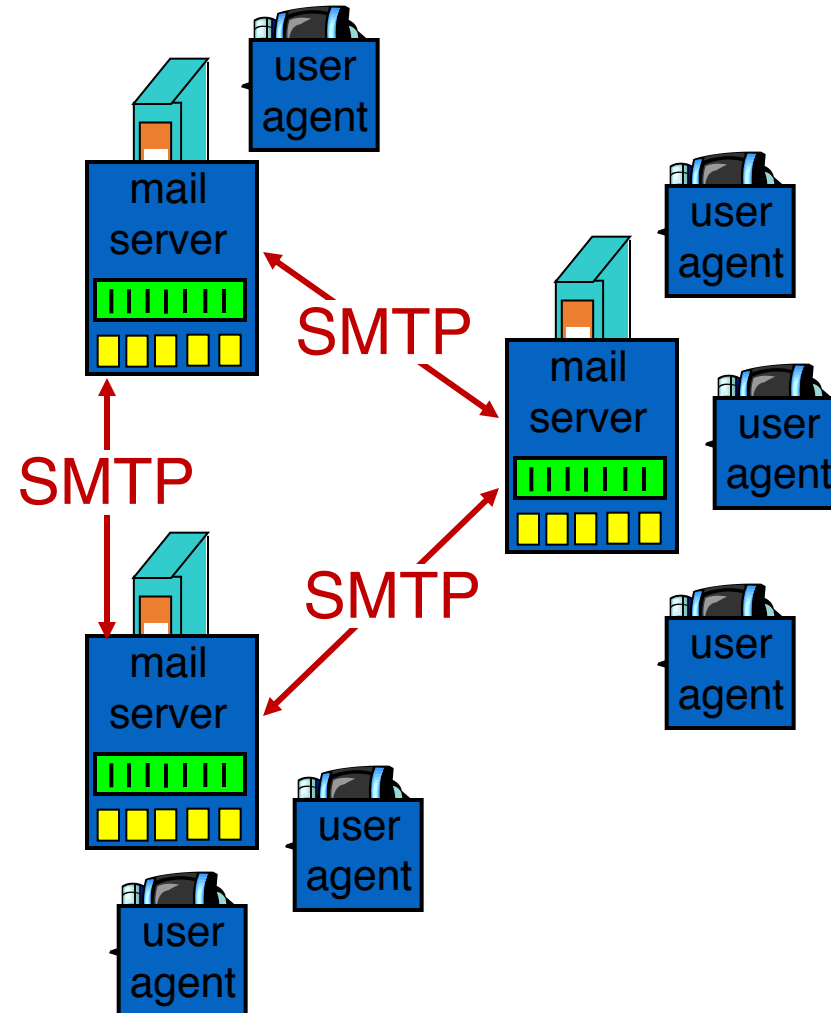
Scenario: Alice sends message to Bob

1) Alice (`alice@rutgers.edu`) uses UA to compose message to `bob@nyu.edu`

2) Alice's UA sends message to her mail server; message placed in outgoing message queue

3) Client side of SMTP opens TCP connection with Bob's mail server

4) SMTP client sends Alice's message over the TCP connection

5) Bob's mail server places the message in Bob's incoming mailbox

6) Sometime later, Bob invokes his user agent to read message

Alice

mail server

Bob

user agent

1

2

3

4

5

6

A set of durable files on the machine. Persisted on disk.

Rutgers mail server

NYU mail server

14

Observations on these exchanges

- Mail servers are the "infrastructure" for email functionality
  - Receiving the email on behalf of Bob, should Bob's machine be turned off
  - Retrying the delivery of the email to Bob on behalf of Alice, should Bob's mail server be unavailable in the first attempt

- The same machine can act as client or server based on context
  - Rutgers's mail server is the server when Alice sends the mail
  - It is the client when it sends mail to Bob's mail server

- SMTP is push-based: info is pushed from client to server
  - Contrast to HTTP or DNS where info is pulled from the server

Sample SMTP interaction

- `telnet <mail-server> 25`

- `HELO <sender-domain>`

- `MAIL FROM:` `<name>@<sender-domain>`

- `RCPT TO: <user>@<mail-server-domain>`

- `DATA`

- Put data in, then [enter].[enter] Don't forget the "."

- You can add mail headers (later) to make your email look good

MAIL command response codes

Code	Description
Positive Completion Reply	
211	System status or help reply
214	Help message
220	Service ready
221	Service closing transmission channel
250	Request command completed
251	User not local; the message will be forwarded
Positive Intermediate Reply	
354	Start mail input
Transient Negative Completion Reply	
421	Service not available
450	Mailbox not available
451	Command aborted: local error
452	Command aborted; insufficient storage
Permanent Negative Completion Reply	
500	Syntax error; unrecognized command
501	Syntax error in parameters or arguments
502	Command not implemented
503	Bad sequence of commands
504	Command temporarily not implemented
550	Command is not executed; mailbox unavailable
551	User not local
552	Requested action aborted; exceeded storage location
553	Requested action not taken; mailbox name not allowed
554	Transaction failed

220: Service ready

250: Request command complete

354: Start mail input

421: Service not available

500: Unrecognized command

17

Mail message format (stored on server)

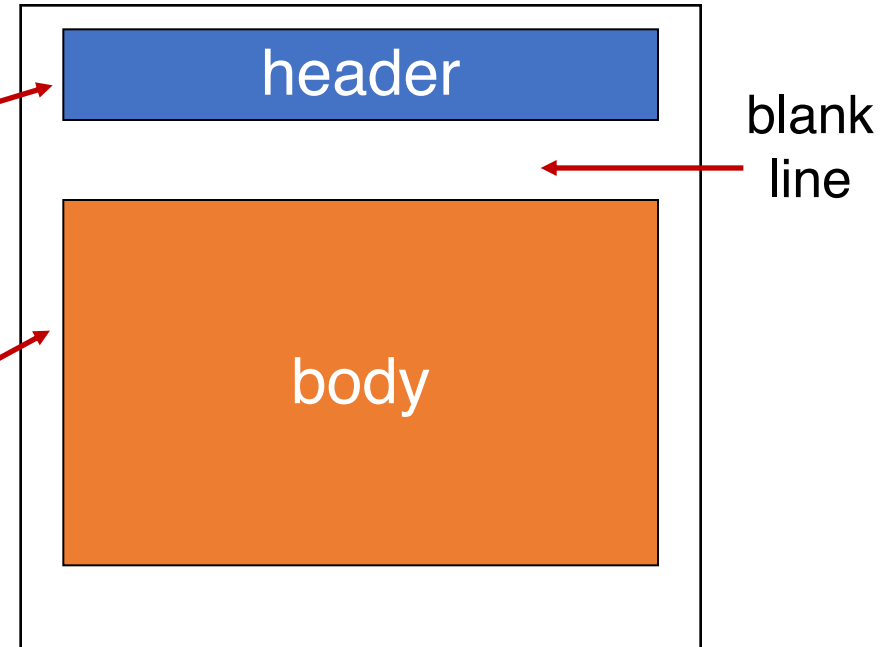SMTP text message exchange standardized in RFC 822

- Header lines, e.g.,
  - To:
  - From:
  - Subject:

  These are different from SMTP commands!
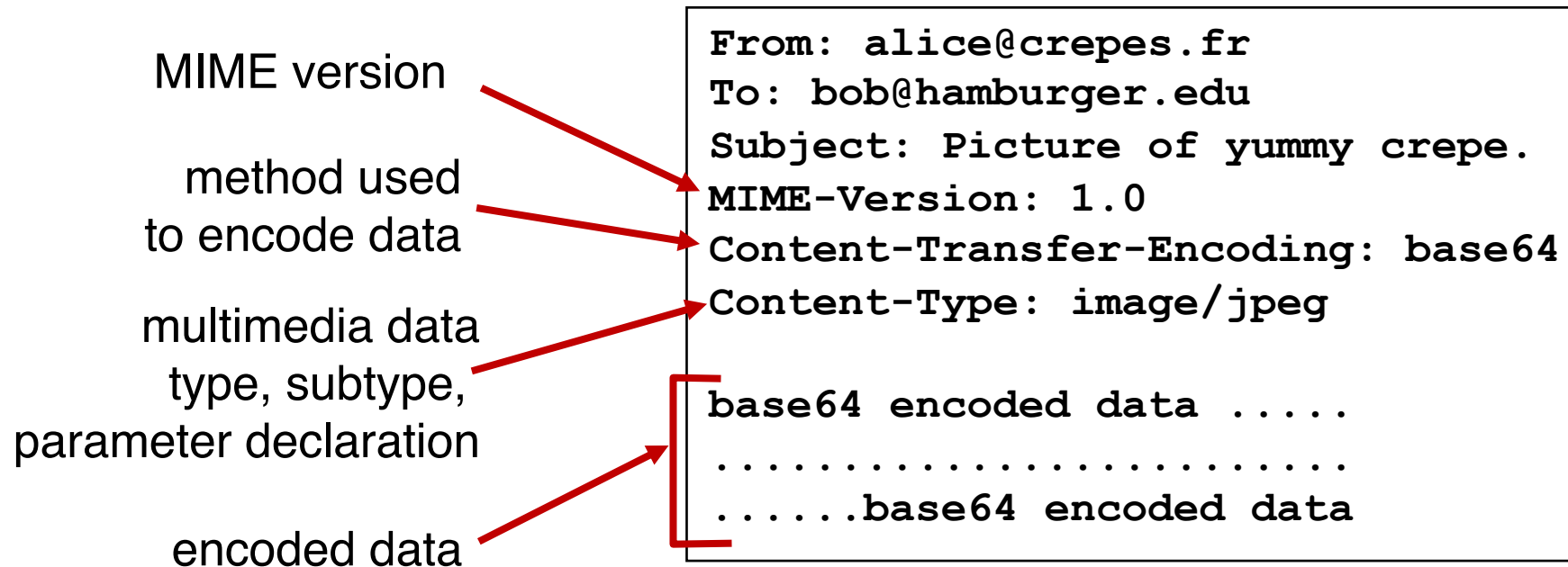
  (these would still be under "DATA")

- body
  - the "message".
  - ASCII characters only

header

blank
line

body

Message format: multimedia extensions

- MIME: multimedia mail extension, RFC 2045, 2056
- additional headers in DATA header declare MIME content type
- A message can have many parts

MIME version

method used
to encode data

multimedia data
type, subtype,
parameter declaration

encoded data

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

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

Vote for New Brunswick's Favorite Restaurants ⤳ Inbox ×

🖨 ⧉

@NBCityCenter citymarket@newbrunswick.com <u>via</u> newbrunswick.ccsend.com

to me ▾

1:17 AM (8 hours ago) ☆ ↩ ⋮

- ↩ Reply
- ➡ Forward
- Filter messages like this
- Print
- Add The Morning Paper to Contacts list
- Delete this message
- Block "The Morning Paper"
- Report spam
- Report phishing
- Show original
- Translate message
- Download message
- Mark as unread

NEW BRUNSWICK
CITY CENTER

LIFESTYLE & EVENTS

Upcoming Fun in New Brunswick

Newbrunswick.com

Message-ID: <1138527284182.1100462763056.2128912358.0.1561738JL.2002@scheduler.constantcontact.com>
Date: Wed, 2 Feb 2022 17:41:43 -0500 (EST)
From: "@NBCityCenter" <citymarket@newbrunswick.com>
Reply-To: citymarket@newbrunswick.com
Sender: "@NBCityCenter" <pamela@newbrunswick.ccsend.com>
To: ███████████████████
Subject: Vote for New Brunswick's Favorite Restaurants
MIME-Version: 1.0
Content-Type: multipart/alternative; boundary="----=_Part_550097535_1238800096.1643841703083"
List-Unsubscribe: <https://visitor.constantcontact.com/do?
p=un&m=001HGjyDxPJyPKvJg5rDoRs1g%3D%3D&se=001BAprMYzSEJkLWw3FBEdL0g%3D%3D&t=001EkZLEx15CcE%3D&llr=qblcl7aab>
List-Unsubscribe-Post: List-Unsubscribe=One-Click
X-Campaign-Activity-ID: 7af9b840-b29e-4db4-8870-83aaf3a5e6a0
X-250ok-CID: 7af9b840-b29e-4db4-8870-83aaf3a5e6a0
X-Channel-ID: f1703300-eb85-11e8-8729-d4ae5275b3f6
X-Mailer: Roving Constant Contact 2012 (http://www.constantcontact.com)
X-Return-Path-Hint: Aevm4QLKeTbSIcIOq86XmoA==_1100462763056_8XAzAOuFEeiHKdSuUnWz9g==@in.constantcontact.com
X-Roving-Campaignid: 1138527284182
X-Roving-Id: 1100462763056.2128912358
X-Feedback-ID: f1703300-eb85-11e8-8729-d4ae5275b3f6:7af9b840-b29e-4db4-8870-83aaf3a5e6a0:1100462763056:CTCT
X-CTCT-ID: f15ea6d0-eb85-11e8-8729-d4ae5275b3f6

------=_Part_550097535_1238800096.1643841703083
Content-Type: text/plain; charset=utf-8
Content-Transfer-Encoding: quoted-printable

Dine, Shop, Play & Stay... It All Happens Here! VALENTINE'S WEEKEND =EF=BB=
=BFLive music & theater entertainment, comedy shows, a variety of activitie=
s, chocolate shops, and high-end restaurants make New Brunswick an excellen=
t choice for couples on Valentine's Day! It's easy to see why this city is=
 romantic with so many fun date night options, luxurious spas, and deliciou=
s dining selections. Book Your Reservations Now Jersey's Choice Restaurant =
Poll Presented by New Brunswick's Performing Arts Center, it's your time to=
 show your support for your favorite spots in New Brunswick as NJ Monthly h=
osts their 39th Annual Restaurants of NJ Poll! New Brunswick is represented=
 strongly with many of your favorites including, Roosterspin, Stage Left St=

Constant Contact Data Notice Sent by citymarket@newbrunswick.com powered b=
y Try email marketing for free today!
------=_Part_550097535_1238800096.1643841703083
Content-Type: text/html; charset=utf-8
Content-Transfer-Encoding: quoted-printable

```
<!DOCTYPE html>
<html>
<head>
<meta content=3D"text/html; charset=3Dutf-8" http-equiv=3D"Content-Type">
<meta content=3D"width=3Ddevice-width, initial-scale=3D1.0" name=3D"viewpor=
t">
<meta charset=3D"UTF-8">
<meta name=3D"viewport" content=3D"width=3Ddevice-width, initial-scale=3D1,=
 maximum-scale=3D1">
<!--[if gte mso 9]>
<style id=3D"ol-styles">
/* OUTLOOK-SPECIFIC STYLES */
li {
text-indent: -1em;
padding: 0;
margin: 0;
line-height: 1.2;
}
ul, ol {
padding: 0;
margin: 0 0 0 40px;
}
p {
```

```html
o  style=3D color: #3d3d3d; text-decoration: none >Try email market
free today!</a>
                    </div>
                  =20
                  =20
                </td>
              </tr>
            </table>
          </td>
        </tr>
      </table>
    </div>
  </td>
</tr>
</table></body>
</html>

------=_Part_550097535_1238800096.1643841703083--
```

Date: Wed, 2 Feb 2022 17:41:43 -0500 (EST)
From: "@NBCityCenter" <citymarket@newbrunswick.com>
To:
Subject: Vote for New Brunswick's Favorite Restaurants
X-Mailer: Roving Constant Contact 2012 (http://www.constantcontact.com)

[-- Autoview using lynx -assume_charset='utf-8' -display_charset=utf-8 -collapse_br_tags -dump
+'/var/folders/6r/g2lff0zd62q8p_4sm8h14mqh0000gp/T//mutt.html' --]
    Dine, Shop, Play & Stay... It All Happens Here!

    [1]Valentine's Day in New Brunswick - Weekend Specials & Events
    VALENTINE'S WEEKEND

        Live music & theater entertainment, comedy shows, a variety of
        activities, chocolate shops, and high-end restaurants make New
         Brunswick an excellent choice for couples on Valentine's Day!

    It's easy to see why this city is romantic with so many fun date night
            options, luxurious spas, and delicious dining selections.

    [2]Book Your Reservations Now

    Jersey's Choice Restaurant Poll

    Presented by [3]New Brunswick's Performing Arts Center, it's your time
                                     to

        show your support for your favorite spots in New Brunswick as NJ

            Monthly hosts their 39th Annual Restaurants of NJ Poll!

        New Brunswick is represented strongly with many of your favorites
         including, [4]Roosterspin, [5]Stage Left Steak, [6]Harvest Moon
            Brewery, [7]The Frog & The Peach, [8]Delta's, [9]Cambo Box,

--00000000000013d53505d7114793
Content-Type: image/png; name="screenshot.png"
Content-Disposition: attachment;
        filename="screenshot.png"
Content-Transfer-Encoding: base64
X-Attachment-Id: f_kz66ba9k0
Content-ID: <f_kz66ba9k0>

iVBORw0KGgoAAAANSUhEUgAABSgAAAGCCAYAAADjWS0TAAAKC2lDQ1BJQ0MgUHJvZmlsZQAASImF
lgdUFFkWhl9V50RqaHLOOUMDknOSHEWlaXKyaaKICREVGFFEREARZIgKjkqQQUREQWUQUMCADsgg
oIyDAVBRewuY0ZndPbu3zj3vq9vv/XXfqz6nfgBILgwWKxbmASAuPontaW8l5R8QKIWbBihABgAQ
gS6DmciydHd3Qe7AX+M/Y2kUQKvjffVVrf/8/X8Gb2hYIhMAyB1hOpPFTkL4IMeqUmsVR5HmJ+N
NIXwwipHrDGXuWQdRZam+PtaY2wGgbB4MoPBjkCapyN1qRRmBKJD9EdYKz40Kh7hVX0zZiQjFOE+
hNXCY5/OicubhtSJ8krLGUWQFFAPhQAPE
gmSQBqqQAC7DBNqQShVTCkLP/7+voa+uskZkssB1ZEQUiQCRIQtbb/U3La00pCaQCBjInDKm4IJf1
6ntcl3xHW1OFaHe+1zKRvZqGcjicju81F2TPl/cje3nxvabYCQCXIAB9ucxkdsp6bfXoAQb5b3AD
fiAMJIAsUALqQAcYABNgAWyBE3AD3iAAbAFMpN84pKtUkAH2gmyQC46A46AElIOzoBpcBBdBK+gA
18EtcBcMghHwBEyAafAKLIAlsAJBEA6iQFRIGJKE5CFVSAeiQ2aQLeQCeQCeUIBUDAUDAUDAUAcVDyVAGtA/K
hOqqFaqCooN+gC3aE5aE5qC30CcYBZNhfLacVoPA1YTpsCTvvQXJhf

Mail Access Protocols

Mail access protocols
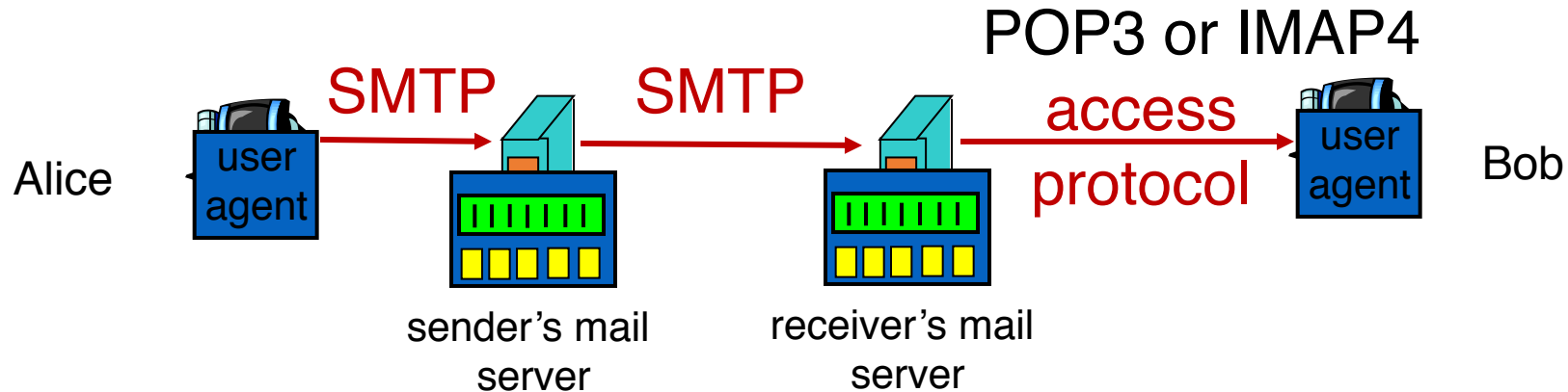
- SMTP: delivery/storage to receiver's server. Focused on push

- Mail access protocol: retrieval from server
  - POP: Post Office Protocol [RFC 1939]
    - Client connects to POP3 server on TCP port 110
  - IMAP: Internet Mail Access Protocol [RFC 1730]
    - Client connects to TCP port 143
  - HTTP: gmail, outlook, etc.

POP vs IMAP

- POP3
- Stateless server
- UA-heavy processing
- UA retrieves email from server, then typically deleted from server
- Latest changes are at the UA
- Simple protocol (`list, retr, del` within a POP session)

- IMAP4
- Stateful server
- UA and server processing
- Server sees folders, etc. which are visible to UAs
- Latest changes are at the server
- Complex protocol
- Heavily used: email sync across devices, reliable, …

What about web-based email?

- Connect to mail servers via web browser
  - Ex: gmail, scarletmail, etc.

- Browsers speak HTTP

- Email servers speak SMTP

- Need to bridge these two

Web based email

Alice
`alice@scarletmail.rutgers.edu`

HTTP

Application process on the web server machine uses SMTP to push mail

HTTP server
`scarletmail.rutgers.edu`

May run on the same or different machines (owned by your webmail provider)

SMTP Client/Server
`aspmx4.googlemail.com`

Alice's mail provider's server(s)

Internet

HTTP

Bob

HTTP server
`outlook.com`

App process on the web server uses access protocol to pull email

SMTP server
`outlook-com.olc.protection.outlook.com`

IMAP

Bob
`bob@outlook.com`

Bob's mail provider's server(s)

30

Comparing SMTP with HTTP

- HTTP: pull
- SMTP: push

- both have ASCII command/response interaction, status codes

- HTTP: each object encapsulated in its own response msg
- SMTP: multiple objects sent in multipart msg

- HTTP: can put non-ASCII data directly in response (dedicated entity body for binary data)
- SMTP: need ASCII-based encoding (base64)

More themes from app-layer protocols

- Keep it simple until you really need complexity
  - Start with ASCII-based design; stateless servers. Then introduce:
  - Cookies for HTTP state
  - Stateful mail (IMAP, folders, etc.) for email organization
  - Security extensions (e.g., TLS)
  - Performance optimizations: persistence, caching, indirection, …
  - Use headers as much as possible to non-intrusively evolve functionality
- Partition functions based on what's done best at the user (app) and protocol. Examples:
  - Content rendering for users (browser, UA) separate from protocol operations (mail server)
  - mail UA doesn't need to be "always on" to send or receive email reliably. That's the mail server's job