

Computer Networks and Applications

COMP 3331/COMP 9331

Week 3

Application Layer (Email, DNS, CDN,
Socket Programming)

Reading Guide: Chapter 2, Sections 2.3, 2.4, 2.6, 2.7

Application Layer: outline

2.1 principles of network applications

- app architectures
- app requirements

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

2.7 socket programming with UDP and TCP

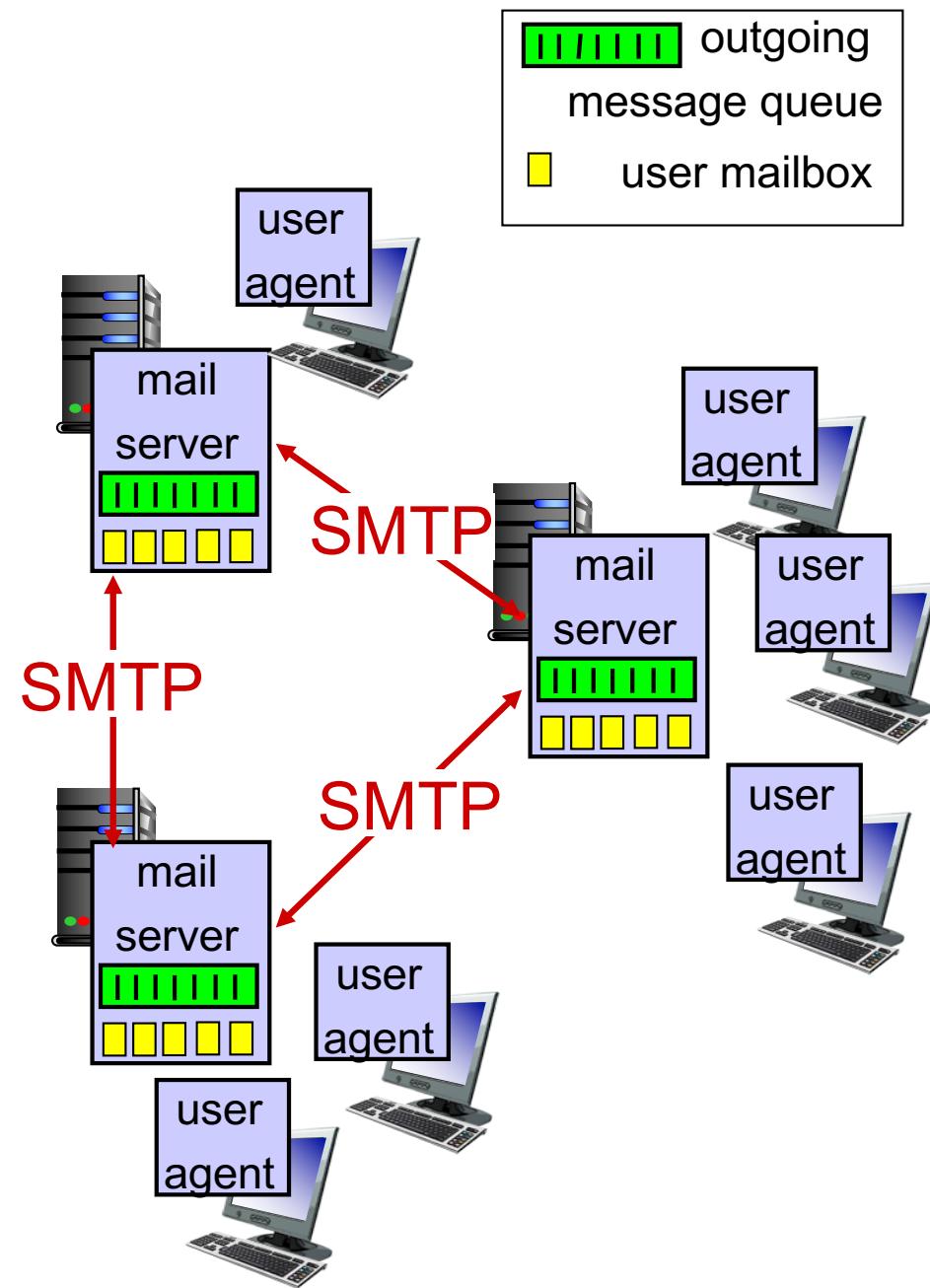
Electronic mail

Three major components:

- ❖ user agents
- ❖ mail servers
- ❖ simple mail transfer protocol: SMTP

User Agent

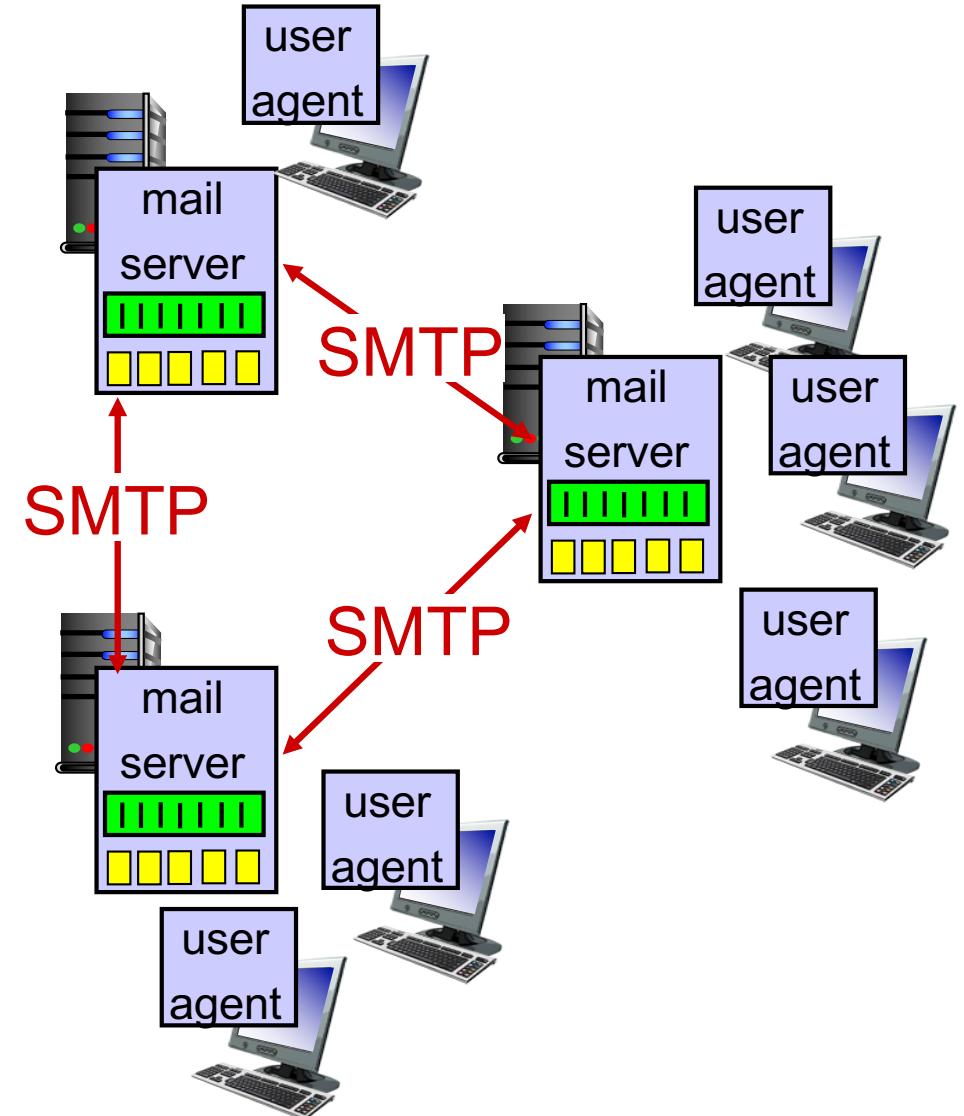
- ❖ a.k.a. “mail reader”
- ❖ composing, editing, reading mail messages
- ❖ e.g., Outlook, Thunderbird, iPhone mail client
- ❖ outgoing, incoming messages stored on server



Electronic mail: mail servers

mail servers:

- ❖ *mailbox* contains incoming messages for user
- ❖ *message queue* of outgoing (to be sent) mail messages
- ❖ *SMTP protocol* between mail servers to send email messages
 - client: sending mail server
 - “server”: receiving mail server

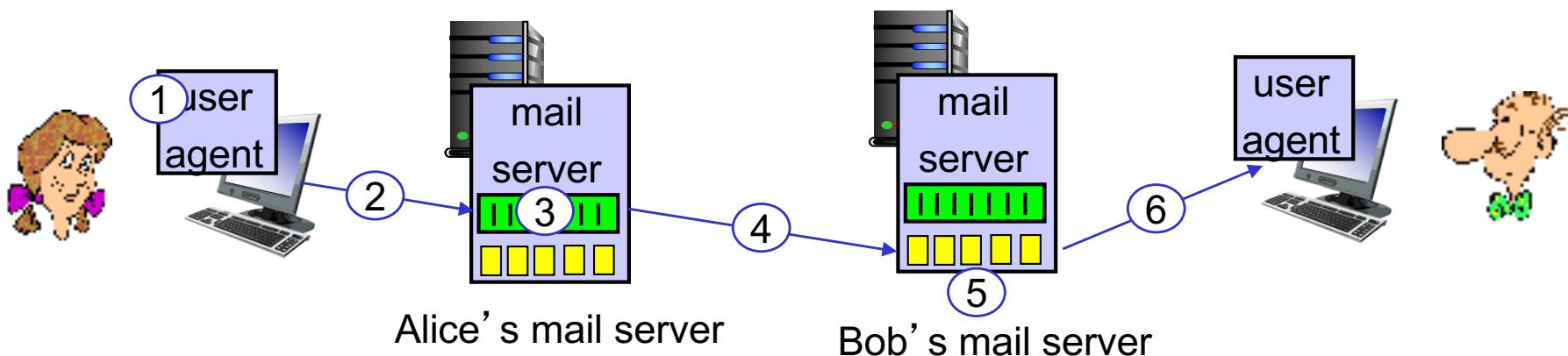


Electronic Mail: SMTP [RFC 2821]

- ❖ uses TCP to reliably transfer email message from client to server, port 25
- ❖ direct transfer: sending server to receiving server
- ❖ three phases of transfer
 - handshaking (greeting)
 - transfer of messages
 - closure
- ❖ command/response interaction (like HTTP, FTP)
 - **commands:** ASCII text
 - **response:** status code and phrase
- ❖ messages must be in 7-bit ASCII

Scenario: Alice sends message to Bob

- 1) Alice uses UA to compose message “to” bob@someschool.edu
- 2) Alice’s UA sends message to her mail server; message placed in 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 mailbox
- 6) Bob invokes his user agent to read message



Sample SMTP interaction

S: 220 hamburger.edu

C: HELO crepes.fr

S: 250 Hello crepes.fr, pleased to meet you

C: MAIL FROM: <alice@crepes.fr>

S: 250 alice@crepes.fr... Sender ok

C: RCPT TO: <bob@hamburger.edu>

S: 250 bob@hamburger.edu ... Recipient ok

C: DATA

S: 354 Enter mail, end with "." on a line by itself

C: Do you like ketchup?

C: How about pickles?

C: .

S: 250 Message accepted for delivery

C: QUIT

S: 221 hamburger.edu closing connection

How to tell a fake email?

star sheldon.cooper@bigbang.com

To: salilk@cse.unsw.edu.au
(No Subject)

11 March 2013 11:44 AM



Helo Salil

BAZINGA !!

best
Dr. Sheldon Cooper

Examine Long Headers or Raw Source

sheldon.cooper@bigbang.com

To: salilk@cse.unsw.edu.au

11 March 2013 11:44 AM

[Hide Details](#)

Return-Path: <sheldon.cooper@bigbang.com>

Received: From bigbang.com ([129.94.242.19] == wagner orchestra.cse.unsw.EDU.AU) (ident-user cs3331) (cse-authentic-sender cs3331) (for <salilk@cse.unsw.edu.au>) By note With Smtip ; Mon, 11 Mar 2013 11:44:05 +1100

Message-Id: <1130311004405.4478@cse.unsw.edu.au>

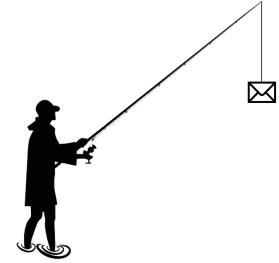
(No Subject)

Helo Salil

BAZINGA !!

best
Dr. Sheldon Cooper

Phishing



❖ Spear phishing

- Phishing attempts directed at specific individuals or companies
- Attackers may gather personal information (social engineering) about their targets to increase their probability of success
- Most popular and accounts for over 90% of attacks

❖ Clone phishing

- A type of phishing attack whereby a legitimate, and previously delivered email containing an attachment or link has had its content and recipient address(es) taken and used to create an almost identical or cloned email.
- The attachment or link within the email is replaced with a malicious version and then sent from an email address spoofed to appear to come from the original sender.



SMTP: final words

- ❖ SMTP uses persistent connections
- ❖ SMTP requires message (header & body) to be in 7-bit ASCII
- ❖ SMTP server uses CRLF .CRLF to determine end of message

comparison 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

Mail message format

SMTP: protocol for
exchanging email msgs

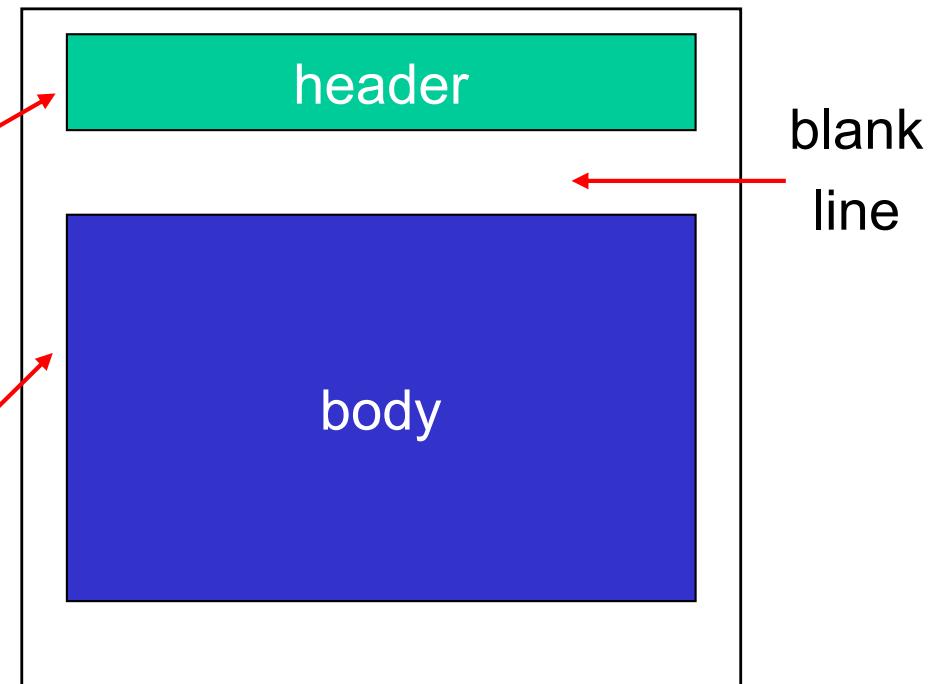
RFC 2822 (5322): standard
for text message format:

- ❖ header lines, e.g.,

- To:
- From:
- Subject:

*different from SMTP MAIL
FROM, RCPT TO:
commands!*

- ❖ Body: the “message”
 - ASCII characters only

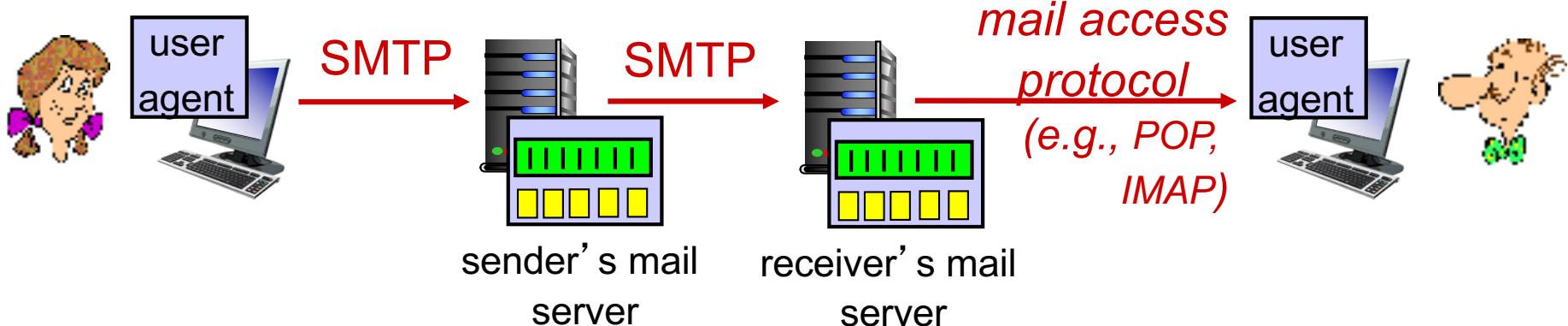


Quiz: E-mail attachments?



- ❖ IF SMTP only allows 7-bit ASCII, how do we send pictures/videos/files via email?
 - A: We use a different protocol instead of SMTP
 - B: We encode these objects as 7-bit ASCII
 - C: We're really sending links to the objects, rather than the objects themselves
 - D: We don't !! You have been lied to !!

Mail access protocols



- ❖ **SMTP:** delivery/storage to receiver's server
- ❖ mail access protocol: retrieval from server
 - **POP:** Post Office Protocol [RFC 1939]: authorization, download
 - **IMAP:** Internet Mail Access Protocol [RFC 1730]: more features, including manipulation of stored msgs on server
 - **HTTP(S):** Gmail, Yahoo! Mail, etc.

Read about POP and IMAP on [OpenLearning](#)

Quiz: HTTP vs SMTP



- ❖ Which of the following is not true?
 - A. HTTP is pull-based, SMTP is push-based
 - B. HTTP uses a separate header for each object, SMTP uses a multipart message format
 - C. SMTP uses persistent connections
 - D. HTTP uses client-server communication but SMTP does not

2. Application Layer: outline

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A nice overview: <https://webhostinggeeks.com/guides/dns/>

DNS is a rather important concept. Make sure you take the time to complete all activities on OpenLearning

DNS: domain name system

people: many identifiers:

- TFN, name, passport #

Internet hosts, routers:

- IP address (32 bit) - used for addressing datagrams
- “name”, e.g., www.yahoo.com - used by humans

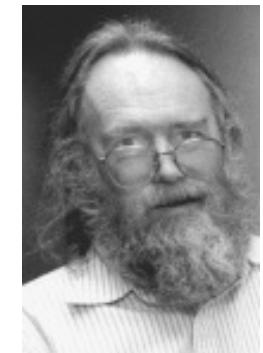
Q: how to map between IP address and name, and vice versa ?

Domain Name System:

- ❖ *distributed database* implemented in hierarchy of many *name servers*
- ❖ *application-layer protocol:* hosts, name servers communicate to *resolve* names (address/name translation)
 - note: core Internet function, implemented as application-layer protocol
 - complexity at network’s “edge”

DNS: History

- ❖ Initially all host-address mappings were in a hosts.txt file (in /etc/hosts):
 - Maintained by the Stanford Research Institute (SRI)
 - Changes were submitted to SRI by email
 - New versions of hosts.txt periodically FTP'd from SRI
 - An administrator could pick names at their discretion
- ❖ As the Internet grew this system broke down:
 - SRI couldn't handle the load; names were not unique; hosts had inaccurate copies of hosts.txt
- ❖ The Domain Name System (DNS) was invented to fix this



Jon Postel

<http://www.wired.com/2012/10/joe-postel/>

DNS: services, structure

DNS services

- ❖ hostname to IP address translation
- ❖ host aliasing
 - canonical, alias names
- ❖ mail server aliasing
- ❖ load distribution
 - replicated Web servers: many IP addresses correspond to one name
 - Content Distribution Networks: use IP address of requesting host to find best suitable server
 - Example: closest, least-loaded, etc

why not centralize DNS?

- ❖ single point of failure
- ❖ traffic volume
- ❖ distant centralized database
- ❖ maintenance

A: doesn't scale!

Goals

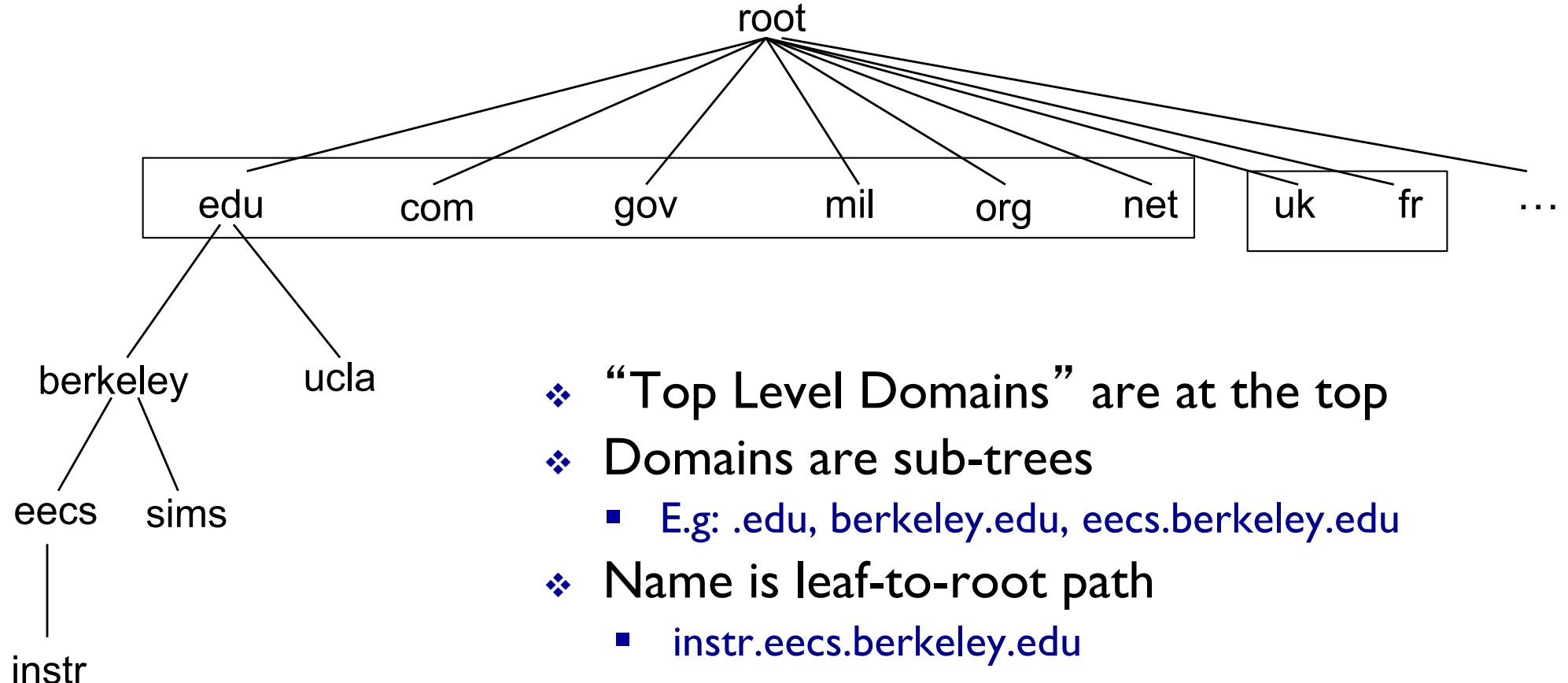
- ❖ No naming conflicts (uniqueness)
- ❖ Scalable
 - many names
 - (secondary) frequent updates
- ❖ Distributed, autonomous administration
 - Ability to update my own (machines') names
 - Don't have to track everybody's updates
- ❖ Highly available
- ❖ Lookups should be fast

Key idea: Hierarchy

Three intertwined hierarchies

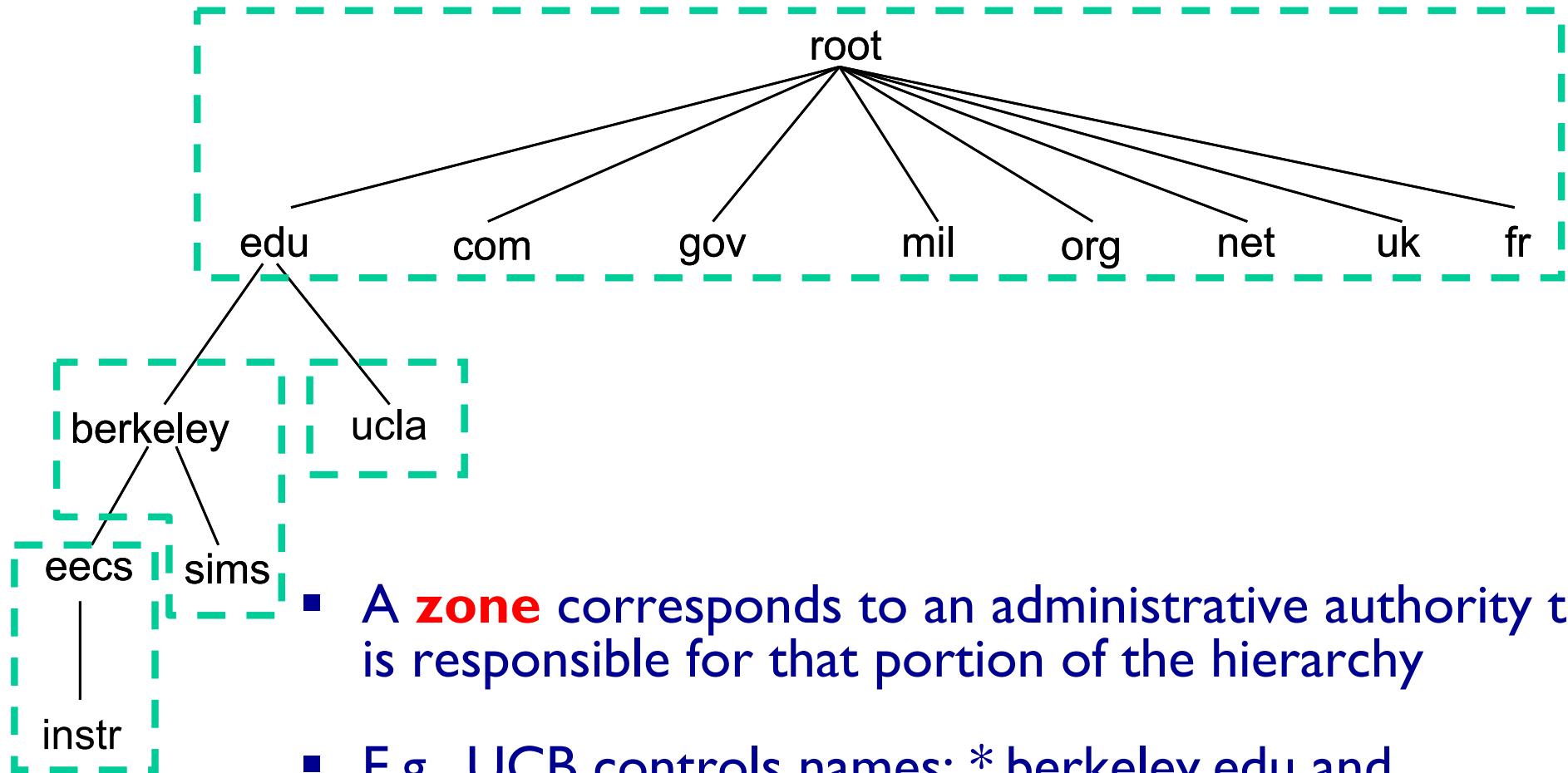
- Hierarchical namespace
 - As opposed to original flat namespace
- Hierarchically administered
 - As opposed to centralised
- (Distributed) hierarchy of servers
 - As opposed to centralised storage

Hierarchical Namespace



- ❖ “Top Level Domains” are at the top
- ❖ Domains are sub-trees
 - E.g: [.edu](#), [berkeley.edu](#), [eecs.berkeley.edu](#)
- ❖ Name is leaf-to-root path
 - [instr.eecs.berkeley.edu](#)
- ❖ Depth of tree is arbitrary (limit 128)
- ❖ Name collisions trivially avoided
 - each domain is responsible

Hierarchical Administration



- A **zone** corresponds to an administrative authority that is responsible for that portion of the hierarchy
- E.g., UCB controls names: *.berkeley.edu and *.sims.berkeley.edu
- ❖ E.g., EECS controls names: *.eeecs.berkeley.edu

Server Hierarchy

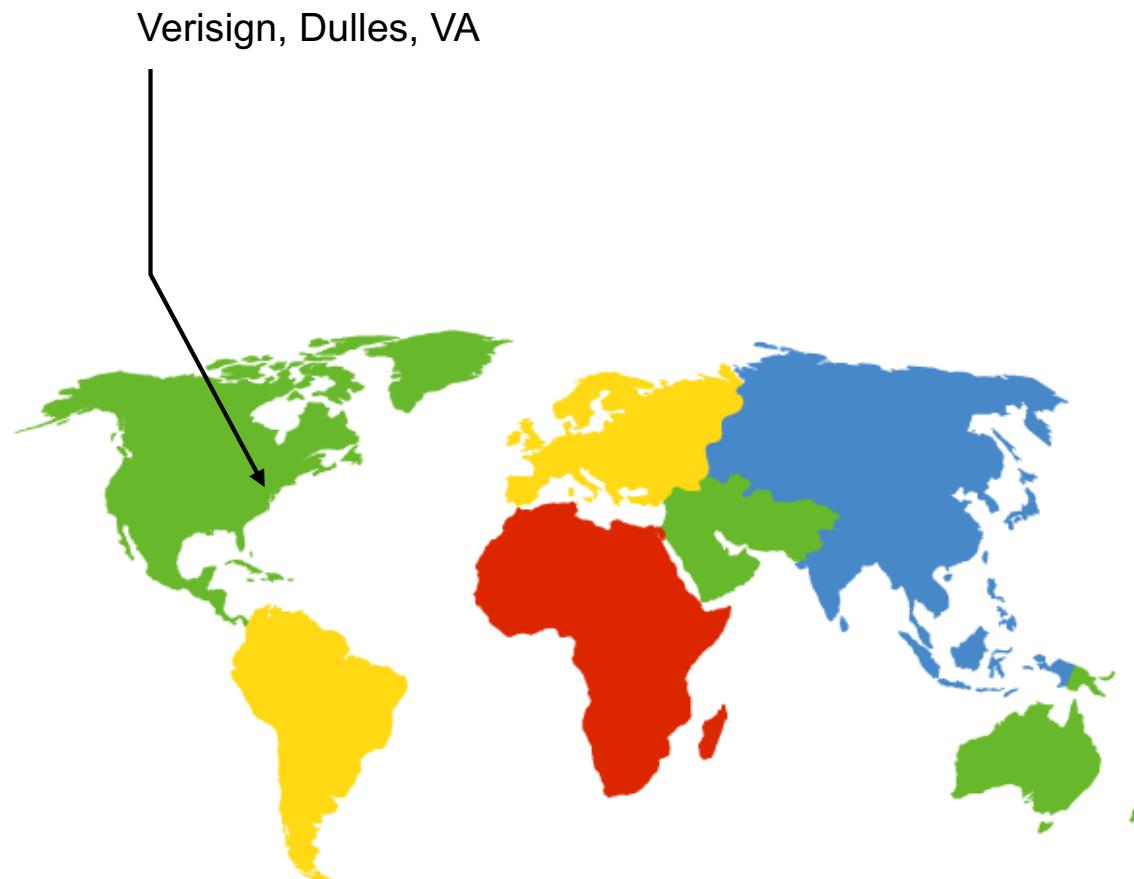
- ❖ Top of hierarchy: Root servers
 - Location hardwired into other servers
- ❖ Next Level: Top-level domain (TLD) servers
 - .com, .edu, etc.
 - Managed professionally
- ❖ Bottom Level: **Authoritative** DNS servers
 - Actually store the name-to-address mapping
 - Maintained by the corresponding administrative authority

Server Hierarchy

- ❖ Each server stores a (small!) subset of the total DNS database
- ❖ An authoritative DNS server stores “resource records” for all DNS names in the domain that it has authority for
- ❖ Each server needs to know other servers that are responsible for the other portions of the hierarchy
 - Every server knows the root
 - Root server knows about all top-level domains

DNS Root

- ❖ Located in Virginia, USA
- ❖ How do we make the root scale?



DNS Root Servers

- ❖ 13 root servers (labeled A-M; see <http://www.root-servers.org/>)



DNS Root Servers

- 13 root servers (labeled A-M; see <http://www.root-servers.org/>)
- Replicated via any-casting



Root Server health: <https://www.ultratools.com/tools/dnsRootServerSpeed>

TLD, authoritative servers

top-level domain (TLD) servers:

- responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, ca, jp
- Network Solutions maintains servers for .com TLD
- Educause for .edu TLD

authoritative DNS servers:

- organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
- can be maintained by organization or service provider

Local DNS name server

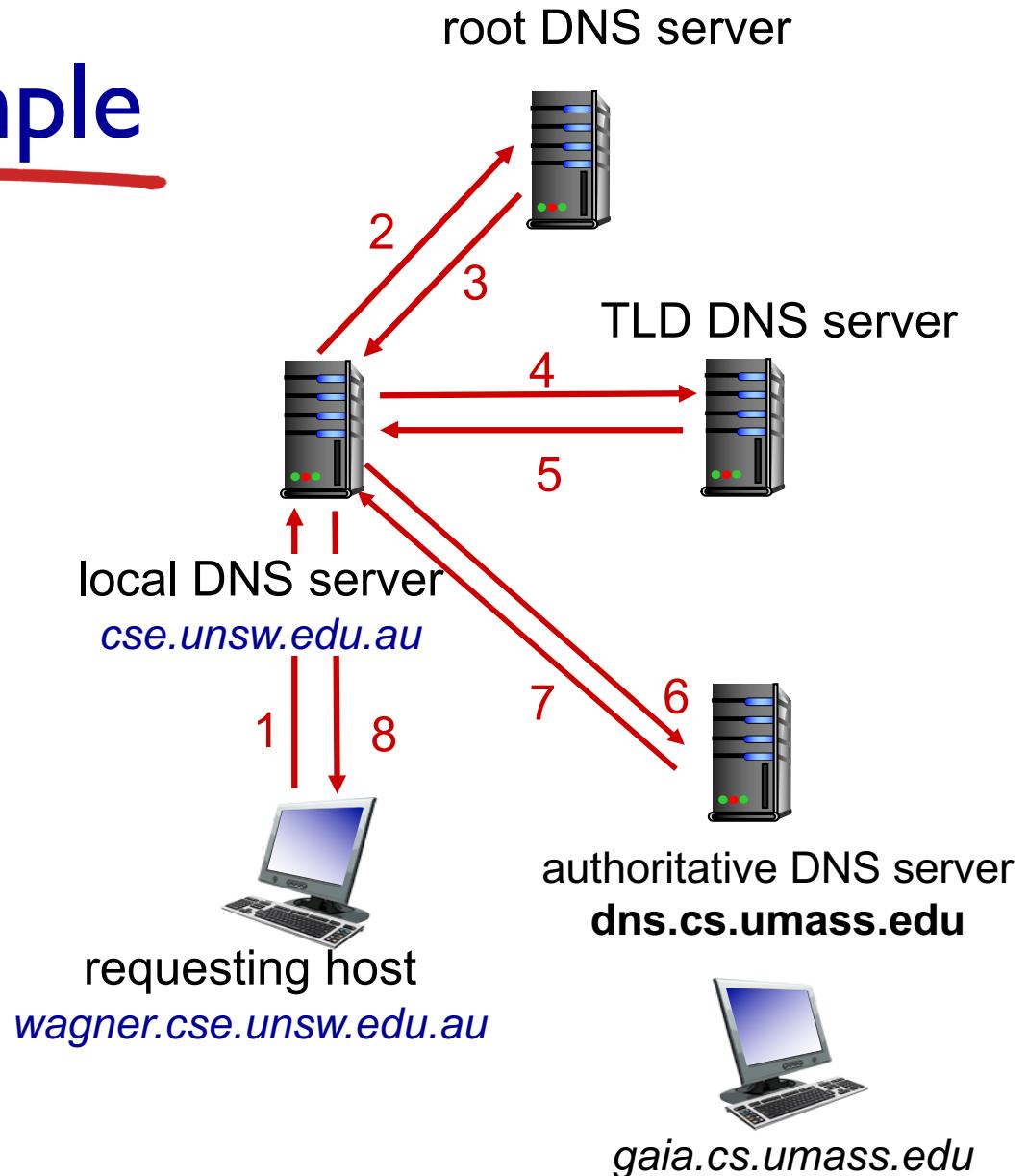
- ❖ does not strictly belong to hierarchy
- ❖ each ISP (residential ISP, company, university) has one
 - also called “default name server”
- ❖ Hosts configured with local DNS server address (e.g.,
`/etc/resolv.conf`) or learn server via a host configuration protocol (e.g., DHCP)
- ❖ Client application
 - Obtain DNS name (e.g., from URL)
 - Do `gethostbyname()` to trigger DNS request to its local DNS server
- ❖ when host makes DNS query, query is sent to its local DNS server
 - has local cache of recent name-to-address translation pairs (but may be out of date!)
 - acts as proxy, forwards query into hierarchy

DNS name resolution example

- ❖ host at `wagner.cse.unsw.edu.au` wants IP address for `gaia.cs.umass.edu`

iterated query:

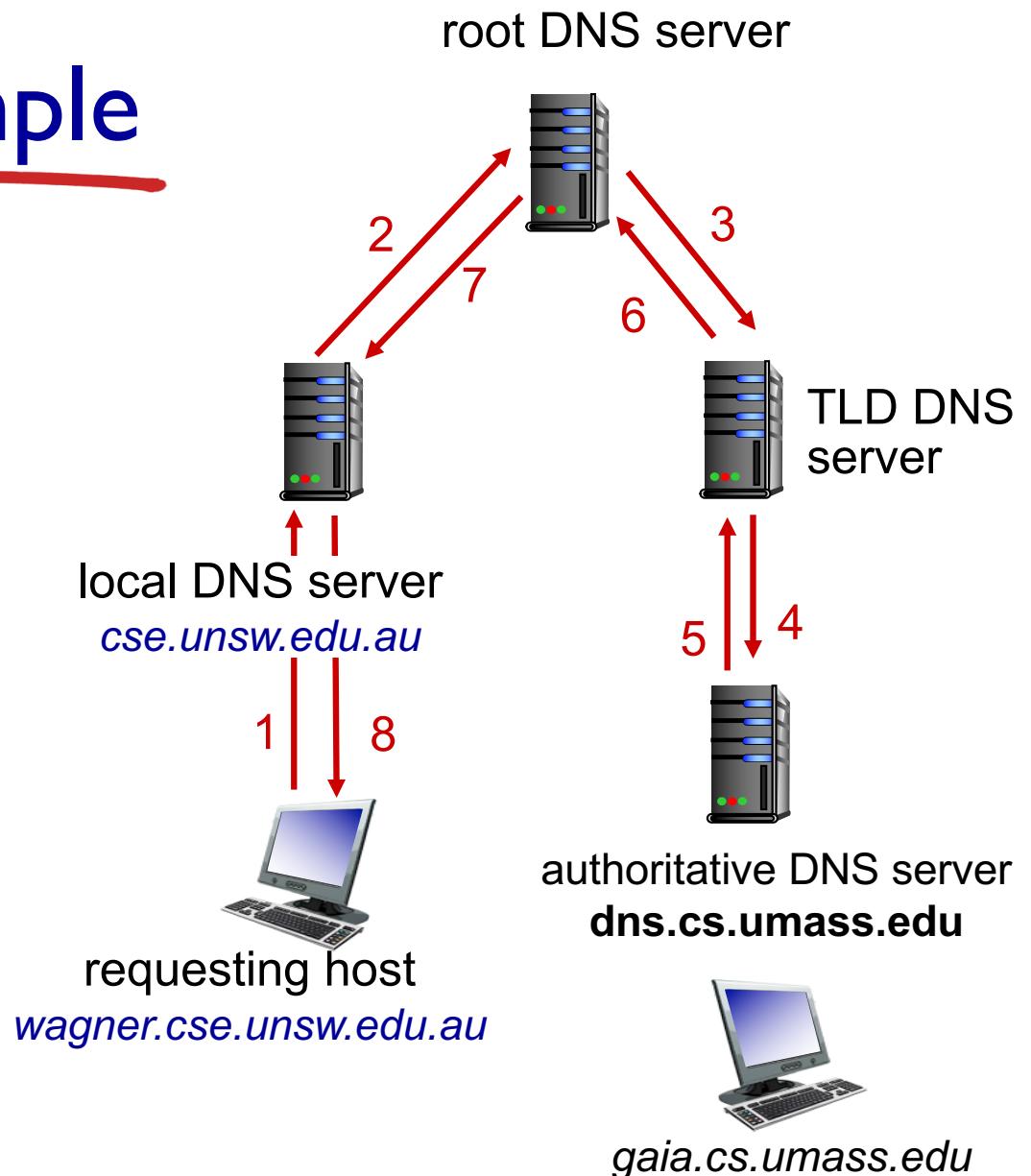
- ❖ contacted server replies with name of server to contact
- ❖ “I don’t know this name, but ask this server”



DNS name resolution example

recursive query:

- ❖ puts burden of name resolution on contacted name server



Note: Complete related activities on OpenLearning

DNS: caching, updating records

- ❖ once (any) name server learns mapping, it *caches* mapping
 - cache entries timeout (disappear) after some time (TTL)
 - TLD servers typically cached in local name servers
 - thus root name servers not often visited
- ❖ Subsequent requests need not burden DNS
- ❖ cached entries may be *out-of-date* (best effort name-to-address translation!)
 - if name host changes IP address, may not be known Internet-wide until all TTLs expire

DNS records

DNS: distributed db storing resource records (**RR**)

RR format: `(name, value, type, ttl)`

type=A

- **name** is hostname
- **value** is IP address

type=NS

- **name** is domain (e.g.,
foo.com)
- **value** is hostname of
authoritative name
server for this domain

type=CNAME

- **name** is alias name for some
“canonical” (the real) name
- `www.ibm.com` is really
`servereast.backup2.ibm.com`
- **value** is canonical name

type=MX

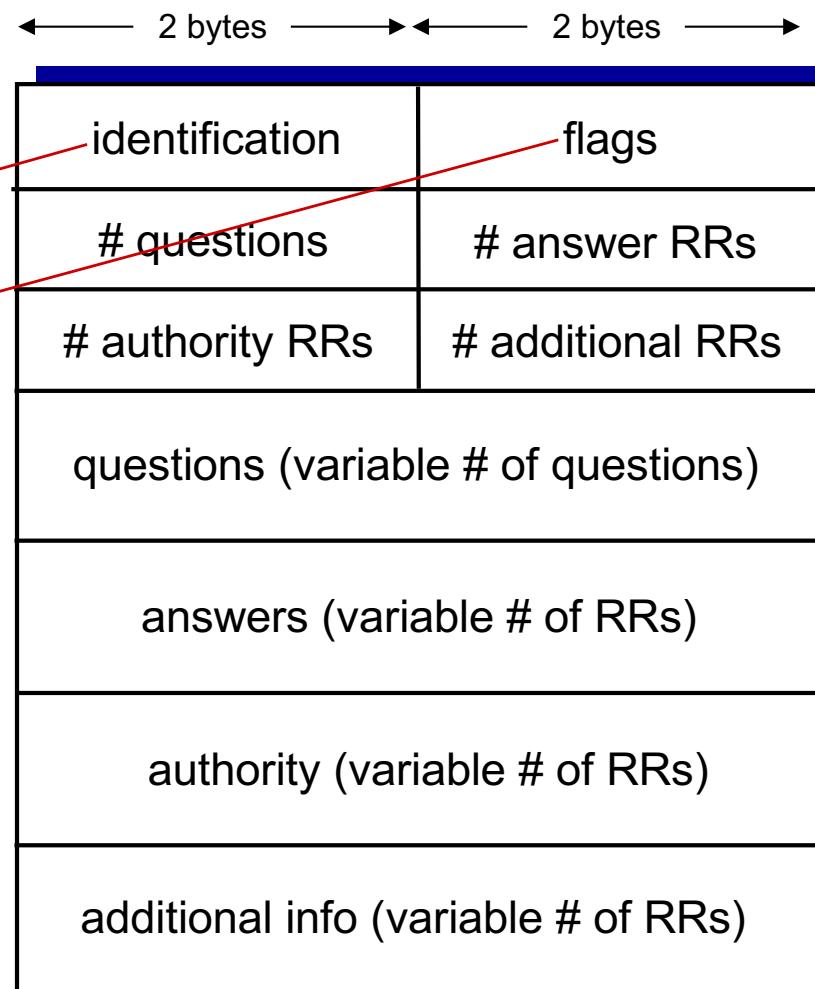
- **value** is name of mailserver
associated with **name**

DNS protocol, messages

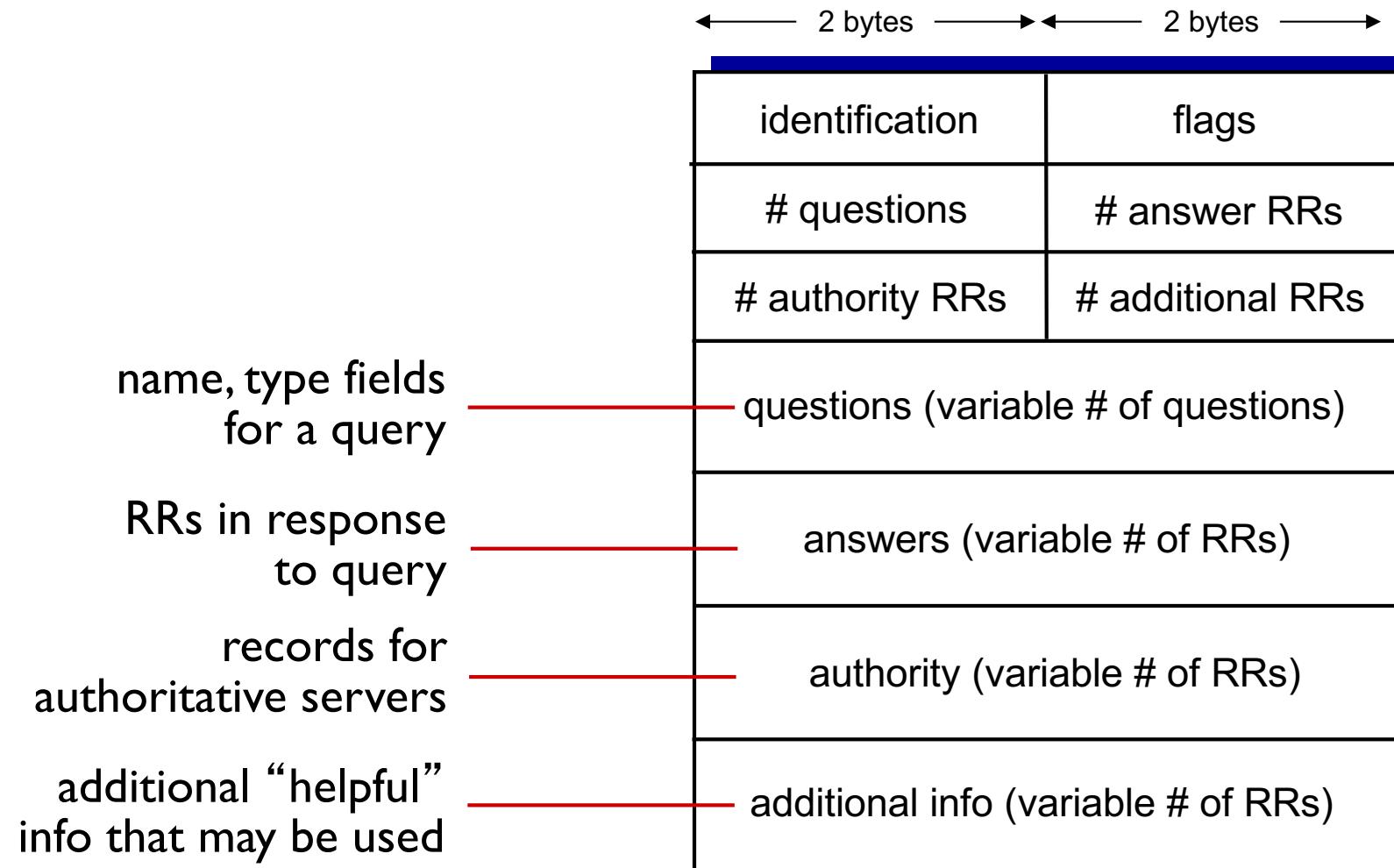
- ❖ *query* and *reply* messages, both with same *message format*

msg header

- ❖ **identification:** 16 bit # for query, reply to query uses same #
- ❖ **flags:**
 - query or reply
 - recursion desired
 - recursion available
 - reply is authoritative



DNS protocol, messages



An Example

```
bash-3.2$ dig www.oxford.ac.uk

; <>> DiG 9.8.3-P1 <>> www.oxford.ac.uk
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 35102
;; flags: qr rd ra; QUERY: 1, ANSWER: 2, AUTHORITY: 4, ADDITIONAL: 5

;; QUESTION SECTION:
;www.oxford.ac.uk.           IN      A

;; ANSWER SECTION:
www.oxford.ac.uk.        300     IN      A      129.67.242.154
www.oxford.ac.uk.        300     IN      A      129.67.242.155

;; AUTHORITY SECTION:
oxford.ac.uk.            86399   IN      NS      dns2.ox.ac.uk.
oxford.ac.uk.            86399   IN      NS      dns1.ox.ac.uk.
oxford.ac.uk.            86399   IN      NS      ns2.ja.net.
oxford.ac.uk.            86399   IN      NS      dns0.ox.ac.uk.

;; ADDITIONAL SECTION:
ns2.ja.net.              33560   IN      A      193.63.105.17
ns2.ja.net.              33560   IN      AAAA    2001:630:0:45::11
dns0.ox.ac.uk.          48090   IN      A      129.67.1.190
dns1.ox.ac.uk.          86399   IN      A      129.67.1.191
dns2.ox.ac.uk.          54339   IN      A      163.1.2.190

;; Query time: 589 msec
;; SERVER: 129.94.172.11#53(129.94.172.11)
;; WHEN: Thu Mar  9 17:53:52 2017
;; MSG SIZE  rcvd: 242
```

Try this out
yourself. Part of
your lab next
week.

Inserting records into DNS

- ❖ example: new startup “Network Utopia”
- ❖ register name networkuptopia.com at *DNS registrar* (e.g., Network Solutions)
 - provide names, IP addresses of authoritative name server (primary and secondary)
 - registrar inserts two RRs into .com TLD server:
(`networkutopia.com`, `dns1.networkutopia.com`, NS)
(`dns1.networkutopia.com`, `212.212.212.1`, A)
- ❖ create authoritative server type A record for `www.networkuptopia.com`; type MX record for `networkutopia.com`
- ❖ **Q:** Where do you insert these type A and type MX records?

A: ??

Reliability

- ❖ DNS servers are **replicated** (primary/secondary)
 - Name service available if at least one replica is up
 - Queries can be load-balanced between replicas
- ❖ Usually, UDP used for queries
 - Need reliability: must implement this on top of UDP
 - Spec supports TCP too, but not always implemented
- ❖ Try alternate servers on timeout
 - **Exponential backoff** when retrying same server
- ❖ Same identifier for all queries
 - Don't care which server responds

DNS provides Indirection

- ❖ Addresses can **change** underneath
 - Move www.cnn.com to 4.125.91.21
 - Humans/Apps should be unaffected
- ❖ Name could map to **multiple** IP addresses
 - Enables
 - Load-balancing
 - Reducing latency by picking nearby servers
- ❖ **Multiple names** for the same address
 - E.g., many services (mail, www, ftp) on same machine
 - E.g., aliases like www.cnn.com and cnn.com
- ❖ But, this flexibility applies only within domain!

Reverse DNS

- ❖ IP address -> domain name
- ❖ Special PTR record type to store reverse DNS entries
- ❖ Where is reverse DNS used?
 - Troubleshooting tools such as traceroute and ping
 - “Received” trace header field in SMTP e-mail
 - SMTP servers for validating IP addresses of originating servers
 - Internet forums tracking users
 - System logging or monitoring tools
 - Used in load balancing servers/content distribution to determine location of requester



Attacking DNS



DDoS attacks

- ❖ Bombard root servers with traffic
 - Not successful to date
 - Traffic Filtering
 - Local DNS servers cache IPs of TLD servers, allowing root server to be bypassed
- ❖ Bombard TLD servers
 - Potentially more dangerous

Redirect attacks

- ❖ Man-in-middle
 - Intercept queries
- ❖ DNS poisoning
 - Send bogus replies to DNS server, which caches

Exploit DNS for DDoS

- ❖ Send queries with spoofed source address: target IP
- ❖ Requires amplification

Want to dig deeper?

<http://www.networkworld.com/article/2886283/security0/top-10-dns-attacks-likely-to-infiltrate-your-network.html>



Schneier on Security

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IoT Attack Against a University Network

Verizon's *Data Brief Digest 2017* describes [an attack](#) against an unnamed university by attackers who hacked a variety of IoT devices and had them spam network targets and slow them down:

Analysis of the university firewall identified over 5,000 devices making hundreds of Domain Name Service (DNS) look-ups every 15 minutes, slowing the institution's entire network and restricting access to the majority of internet services.

In this instance, all of the DNS requests were attempting to look up seafood restaurants -- and it wasn't because thousands of students all had an overwhelming urge to eat fish -- but because devices on the network had been instructed to repeatedly carry out this request.

"We identified that this was coming from their IoT network, their vending machines and their light sensors were actually looking for seafood domains; 5,000 discreet systems and they were nearly all in the IoT infrastructure," says Laurance Dine, managing principal of investigative response at Verizon.

The actual Verizon document doesn't appear to be available online yet, but there is an advance version that only discusses the incident above, available [here](#).

Detailed Report at - http://www.verizonenterprise.com/resources/reports/rp_data-breach-digest-2017-sneak-peek_xg_en.pdf

DNS Cache Poisoning



- ❖ Suppose you are a bad guy and you control the name server for drevil.com. Your name server receives a request to resolve www.drevil.com. and you respond as follows:

;; QUESTION SECTION:

;www.drevil.com. IN A

;; ANSWER SECTION:

www.drevil.com 300 IN A 129.45.212.42

;; AUTHORITY SECTION:

drevil.com 86400 IN NS dns1.drevil.com.

drevil.com 86400 IN NS google.com

;; ADDITIONAL SECTION:

google.com 600 IN A 129.45.212.222

A drevil.com machine, **not** google.com

- ❖ Solution: Do not allow DNS servers to cache IP address mappings unless they are from authoritative name servers

Dig deeper?

DNS Cache Poisoning Test

<https://www.grc.com/dns/dns.htm>



DNSSEC: DNS Security Extensions,

<http://www.dnssec.net>

Quiz: DNS



- ❖ If a name server has no clue about where to find the address for a hostname then
 - A. Server asks its adjacent name server
 - B. Server asks its root name server
 - C. Request is not processed
 - D. Server explodes

Quiz: DNS



- ❖ Which of the following is an example of a Top Level Domain?
 - A. yoda.jedi.starwars.com
 - B. jedi.starwars.com
 - C. starwars.com
 - D. .com

Quiz: DNS



- ❖ A web browser needs to contact www.cse.unsw.edu.au. The minimum number of DNS requests sent is:
 - A. 0
 - B. 1
 - C. 2
 - D. 3

Application Layer: outline

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2.2 Web and HTTP

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2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

2.7 socket programming with UDP and TCP

Video Streaming and CDNs: context

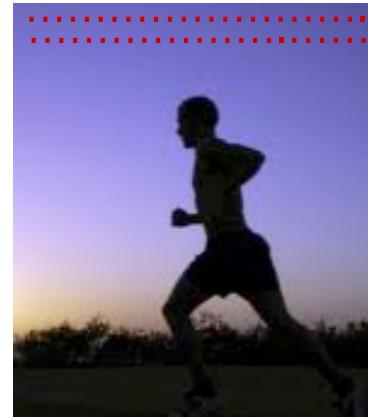
- video traffic: major consumer of Internet bandwidth
 - Netflix, YouTube: 37%, 16% of downstream residential ISP traffic
 - ~1B YouTube users, ~75M Netflix users
- challenge: scale - how to reach ~1B users?
 - single mega-video server won't work (why?)
- challenge: heterogeneity
 - different users have different capabilities (e.g., wired versus mobile; bandwidth rich versus bandwidth poor)
- **solution:** distributed, application-level infrastructure



Multimedia: video

- ❖ video: sequence of images displayed at constant rate
 - e.g., 24 images/sec
- ❖ digital image: array of pixels
 - each pixel represented by bits
- ❖ coding: use redundancy *within* and *between* images to decrease # bits used to encode image
 - spatial (within image)
 - temporal (from one image to next)

spatial coding example: instead of sending N values of same color (all purple), send only two values: color value (*purple*) and number of repeated values (N)



frame i

temporal coding example: instead of sending complete frame at $i+1$, send only differences from frame i

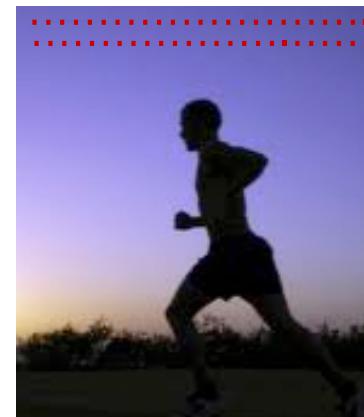


frame $i+1$

Multimedia: video

- **CBR: (constant bit rate):**
video encoding rate fixed
- **VBR: (variable bit rate):**
video encoding rate changes
as amount of spatial,
temporal coding changes
- **examples:**
 - MPEG I (CD-ROM) 1.5 Mbps
 - MPEG2 (DVD) 3-6 Mbps
 - MPEG4 (often used in Internet, < 1 Mbps)

spatial coding example: instead of sending N values of same color (all purple), send only two values: color value (*purple*) and number of repeated values (N)



frame i

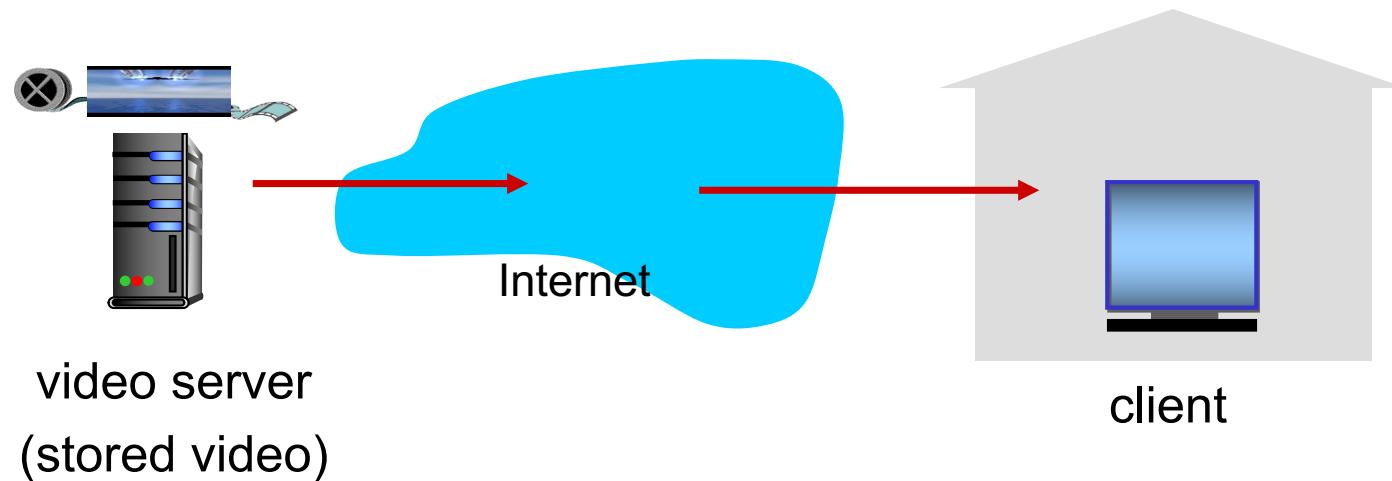
temporal coding example:
instead of sending complete frame at $i+1$,
send only differences from frame i



frame $i+1$

Streaming stored video:

simple scenario:

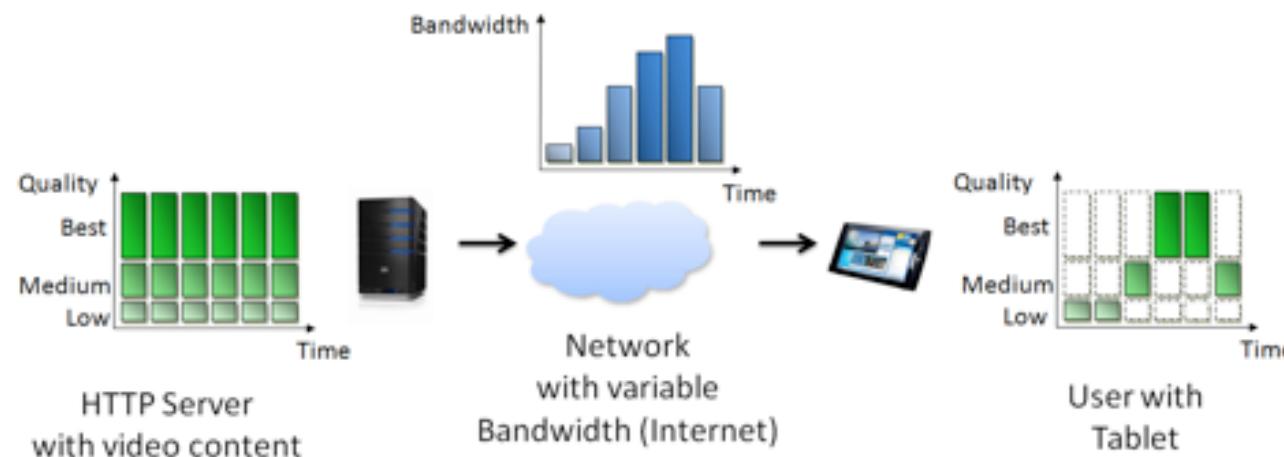


Streaming multimedia: DASH

- ❖ *DASH: Dynamic, Adaptive Streaming over HTTP*
- ❖ *server:*
 - divides video file into multiple chunks
 - each chunk stored, encoded at different rates
 - *manifest file:* provides URLs for different chunks
- ❖ *client:*
 - periodically measures server-to-client bandwidth
 - consulting manifest, requests one chunk at a time
 - chooses maximum coding rate sustainable given current bandwidth
 - can choose different coding rates at different points in time (depending on available bandwidth at time)

Streaming multimedia: DASH

- ❖ *DASH: Dynamic, Adaptive Streaming over HTTP*
- ❖ “*intelligence*” at client: client determines
 - *when* to request chunk (so that buffer starvation, or overflow does not occur)
 - *what encoding rate* to request (higher quality when more bandwidth available)
 - *where* to request chunk (can request from URL server that is “close” to client or has high available bandwidth)

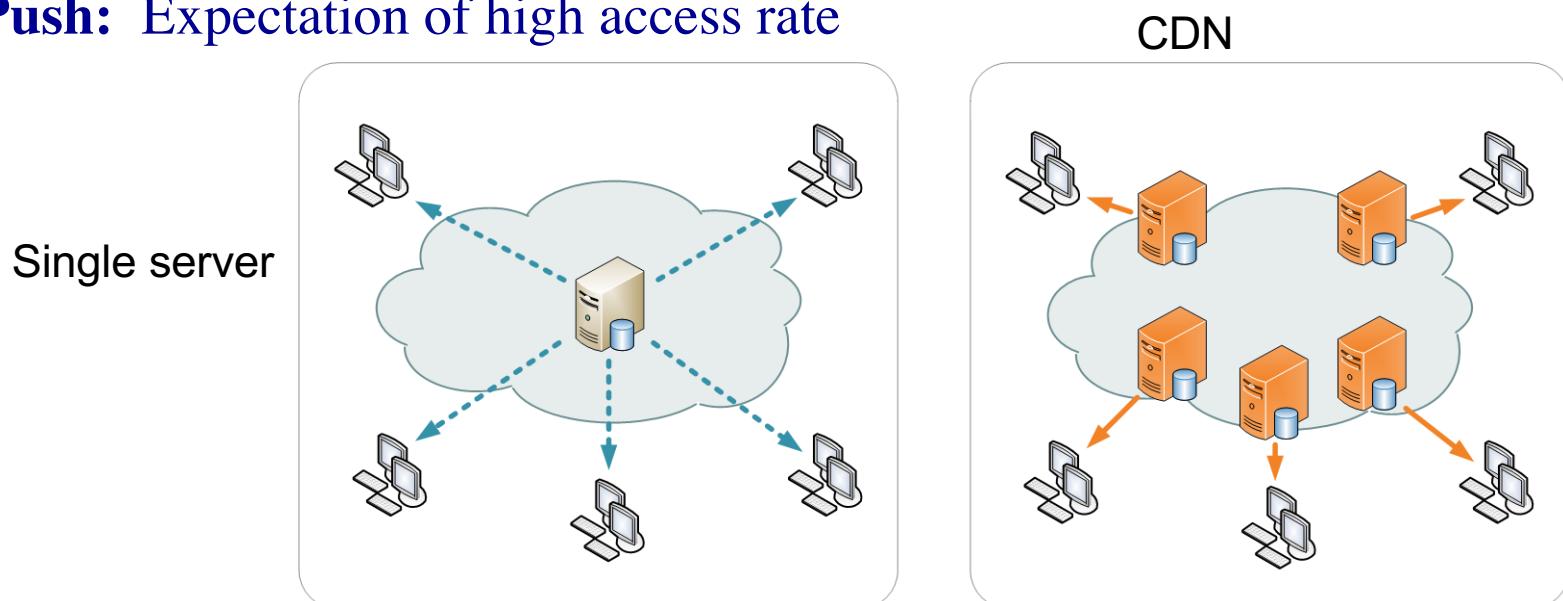


DASH implementations

- ❖ Android through ExoPlayer
- ❖ Samsung, LG, Sony, Philips Smart TVs
- ❖ Youtube
- ❖ Netflix
- ❖ JavaScript Implementation for HTML5
- ❖

Content distribution networks

- ❖ Caching and replication as a service (amortise cost of infrastructure)
- ❖ Goal: bring content close to the user
- ❖ Large-scale distributed storage infrastructure (usually) administered by one entity
 - *e.g.*, Akamai has servers in 20,000+ locations
- ❖ Combination of (pull) caching and (push) replication
 - **Pull:** Direct result of clients' requests
 - **Push:** Expectation of high access rate



An example

```
bash-3.2$ dig www.mit.edu

; <>> DiG 9.8.3-P1 <>> www.mit.edu
;; global options: +cmd
;; Got answer:
;; ->>HEADER<- opcode: QUERY, status: NOERROR, id: 27387
;; flags: qr rd ra; QUERY: 1, ANSWER: 3, AUTHORITY: 9, ADDITIONAL: 9

;; QUESTION SECTION:
;www.mit.edu.           IN      A

;; ANSWER SECTION:
www.mit.edu.          1800    IN      CNAME   www.mit.edu.edgekey.net.
www.mit.edu.edgekey.net. 60      IN      CNAME   e9566.dscb.akamaiedge.net.
e9566.dscb.akamaiedge.net. 20    IN      A       23.77.150.125

;; AUTHORITY SECTION:
dscb.akamaiedge.net. 681     IN      NS      n4dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n5dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      a0dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n6dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n1dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n3dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n0dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n7dscb.akamaiedge.net.
dscb.akamaiedge.net. 681     IN      NS      n2dscb.akamaiedge.net.

;; ADDITIONAL SECTION:
a0dscb.akamaiedge.net. 7144   IN      AAAA   2600:1480:e800::c0
n0dscb.akamaiedge.net. 3048   IN      A       88.221.81.193
n1dscb.akamaiedge.net. 2752   IN      A       88.221.81.194
n2dscb.akamaiedge.net. 1380   IN      A       104.72.70.167
n3dscb.akamaiedge.net. 3048   IN      A       88.221.81.195
n4dscb.akamaiedge.net. 2810   IN      A       104.71.131.100
n5dscb.akamaiedge.net. 1326   IN      A       104.72.70.166
n6dscb.akamaiedge.net. 49     IN      A       104.72.70.174
n7dscb.akamaiedge.net. 2554   IN      A       104.72.70.175

;; Query time: 246 msec
;; SERVER: 129.94.172.11#53(129.94.172.11)
;; WHEN: Thu Mar  9 18:04:37 2017
;; MSG SIZE  rcvd: 463
```

Many well-known sites are hosted by CDNs. A simple way to check is using dig as shown here.

Can you find more examples?

Content distribution networks

- *challenge*: how to stream content (selected from millions of videos) to hundreds of thousands of simultaneous users?
- *option 1*: single, large “mega-server”
 - single point of failure
 - point of network congestion
 - long path to distant clients
 - multiple copies of video sent over outgoing link

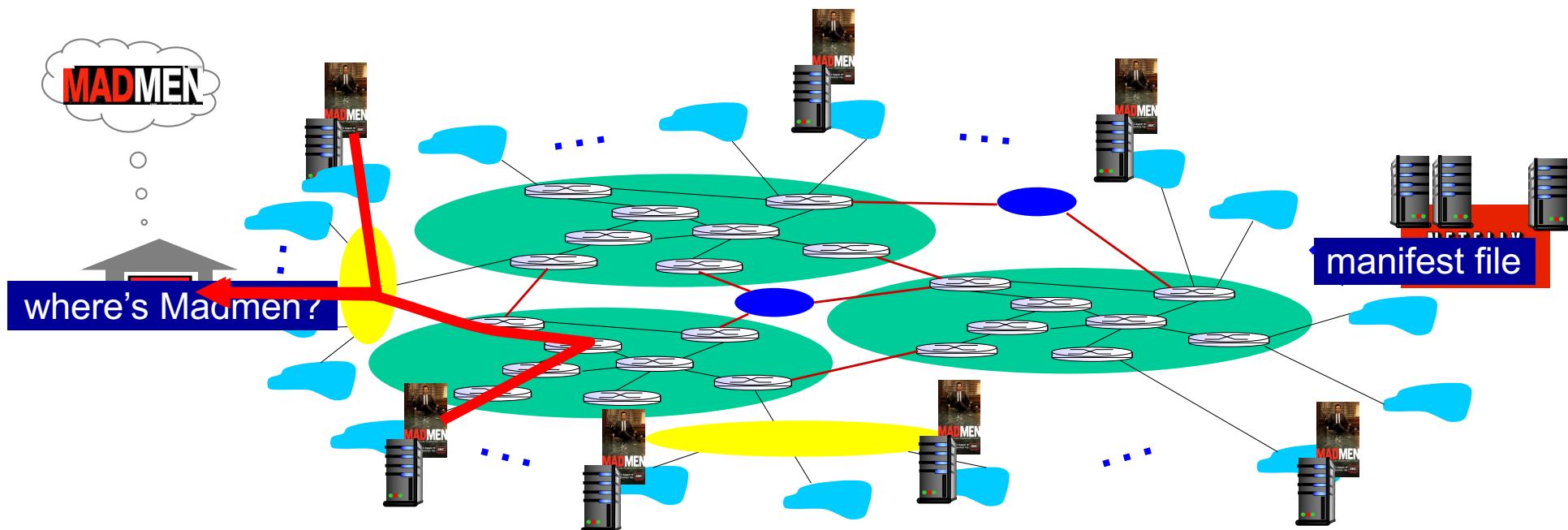
....quite simply: this solution *doesn't scale*

Content distribution networks

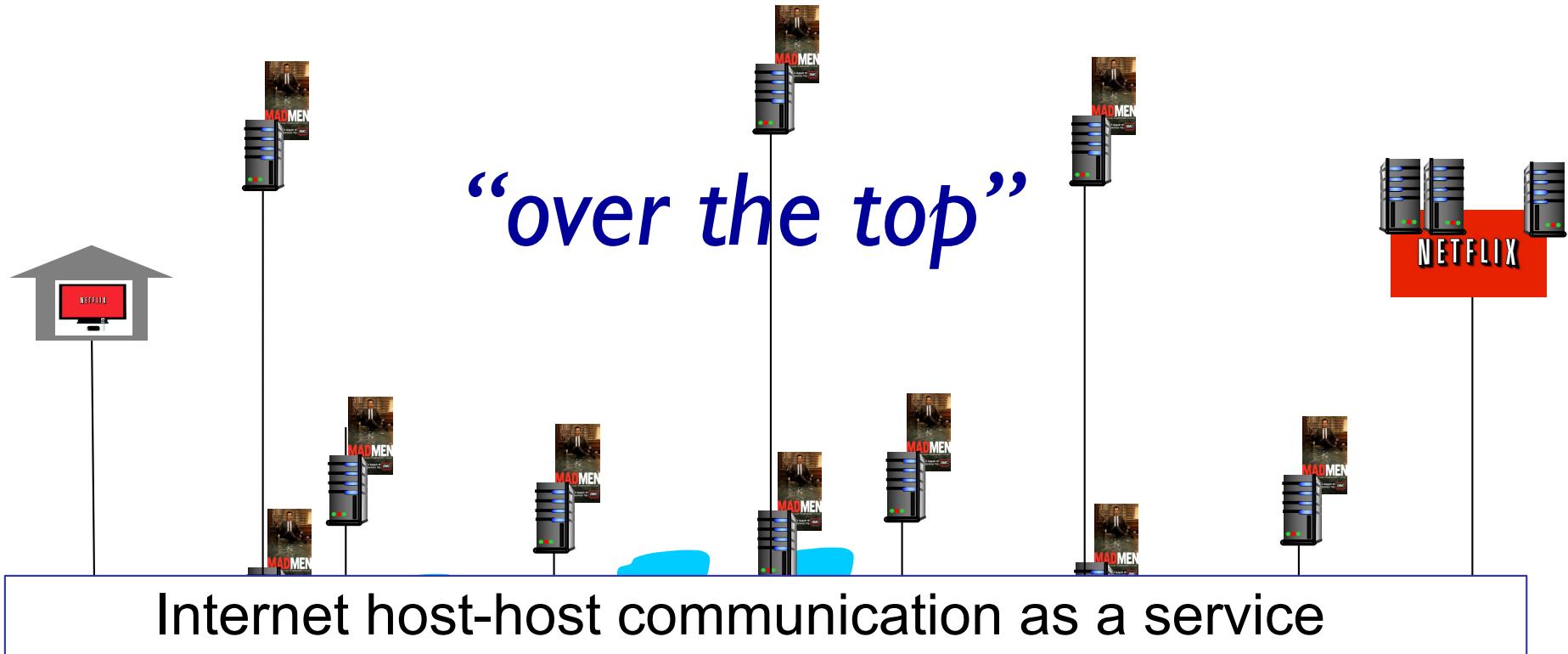
- ❖ *challenge*: how to stream content (selected from millions of videos) to hundreds of thousands of simultaneous users?
- ❖ *option 2*: store/serve multiple copies of videos at multiple geographically distributed sites (*CDN*)
 - *enter deep*: push CDN servers deep into many access networks
 - close to users
 - used by Akamai, thousands of locations
 - *bring home*: smaller number (10's) of larger clusters in POPs near (but not within) access networks
 - used by Limelight

Content Distribution Networks (CDNs)

- CDN: stores copies of content at CDN nodes
 - e.g. Netflix stores copies of MadMen
- subscriber requests content from CDN
 - directed to nearby copy, retrieves content
 - may choose different copy if network path congested



Content Distribution Networks (CDNs)



OTT challenges: coping with a congested Internet

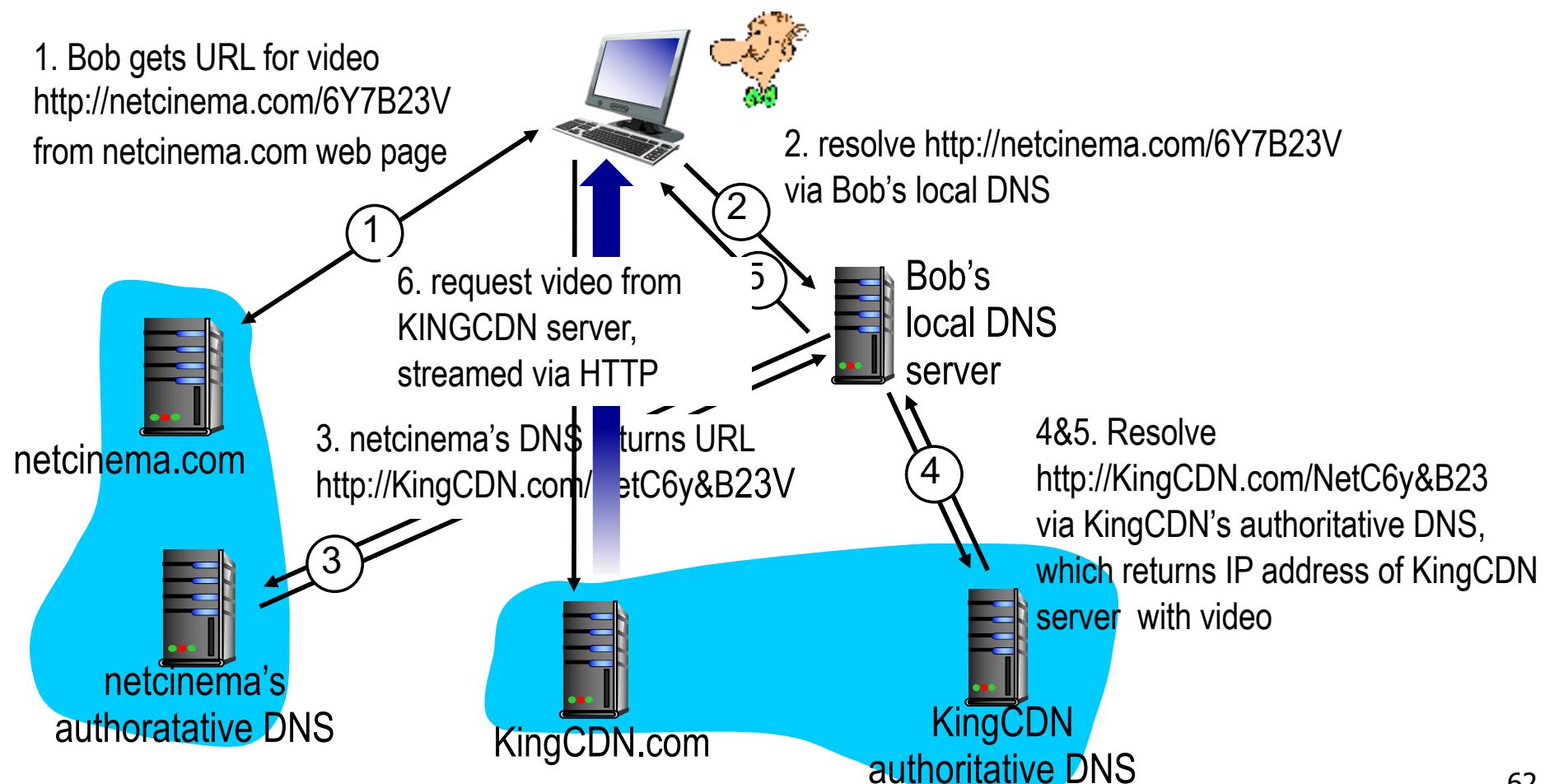
- from which CDN node to retrieve content?
- viewer behavior in presence of congestion?
- what content to place in which CDN node?

More later time permitting

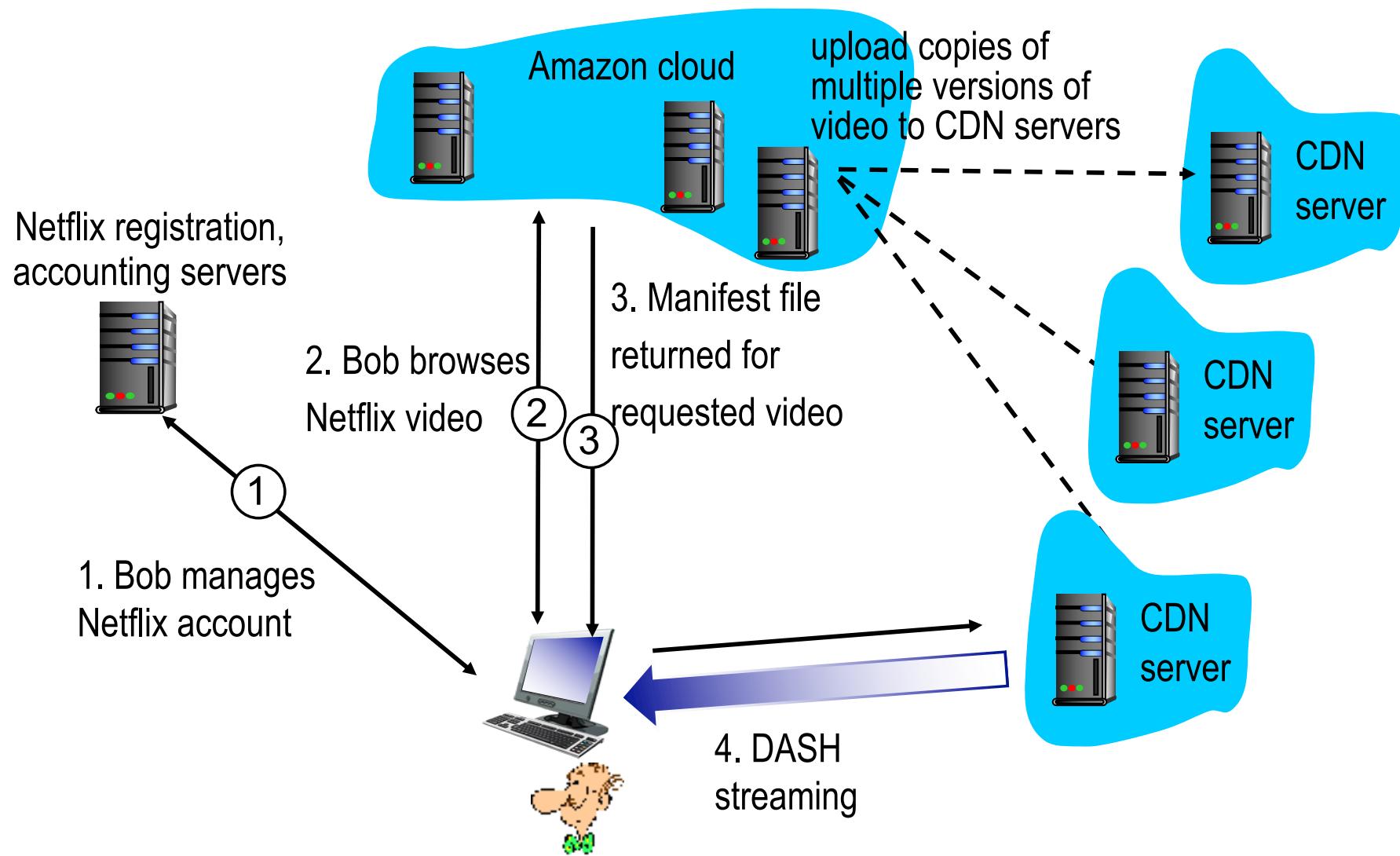
CDN content access: a closer look

Bob (client) requests video <http://netcinema.com/6Y7B23V>

- video stored in CDN at <http://KingCDN.com/NetC6y&B23V>



Case study: Netflix



Quiz: CDN



- ❖ The role of the CDN provider’s authoritative DNS name server in a content distribution network, simply described, is:
 - a) to provide an alias address for each browser access to the “origin server” of a CDN website
 - b) to map the query for each CDN object to the CDN server closest to the requestor (browser)
 - c) to provide a mechanism for CDN “origin servers” to provide paths for clients (browsers)
 - d) none of the above, CDN networks do not use DNS

2. Application Layer: outline

2.1 principles of network applications

- app architectures
- app requirements

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

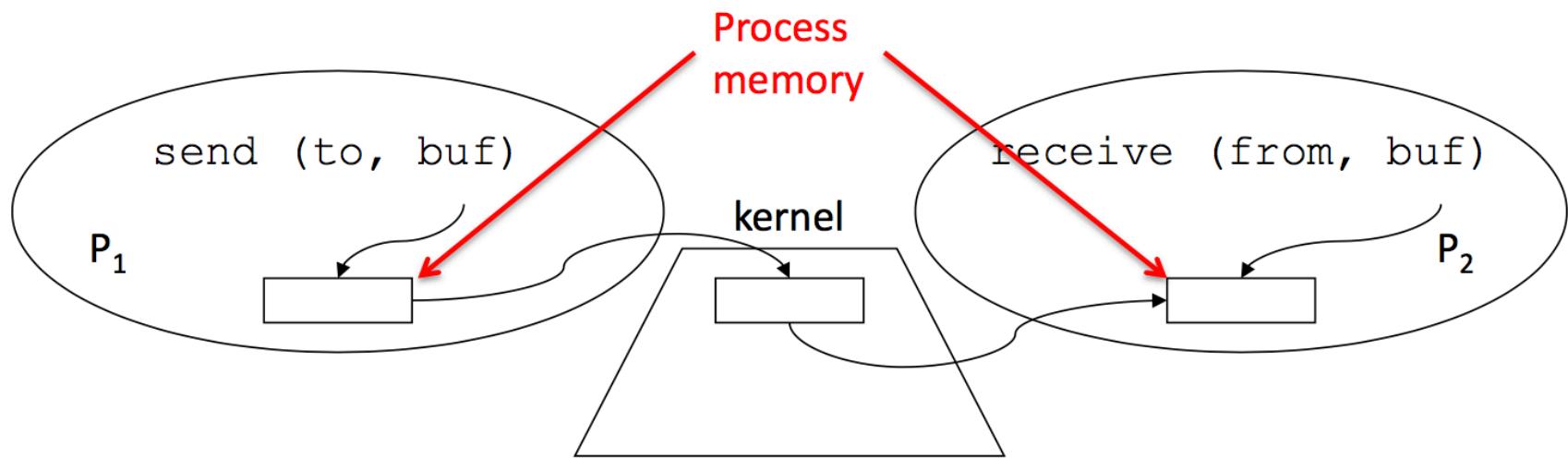
2.7 socket programming with UDP and TCP

Note: 6th & 7th Edition uses Python.

OpenLearning show examples of both Java and Python

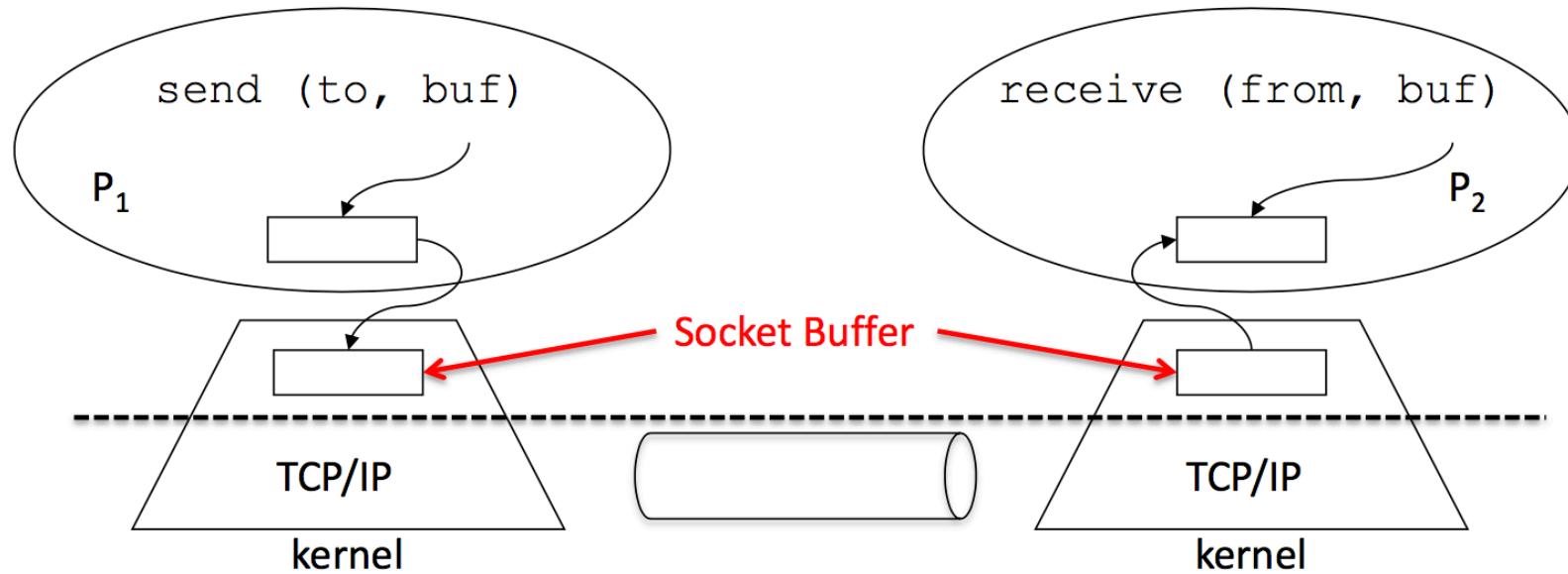
Please see example code on OpenLearning
In your lab this week you will write a simple UDP client

Message Passing (local)



- ❖ Operating system mechanism for IPC
 - `send (destination, message_buffer)`
 - `receive (source, message_buffer)`
- ❖ Data transfer: in to and out of kernel message buffer

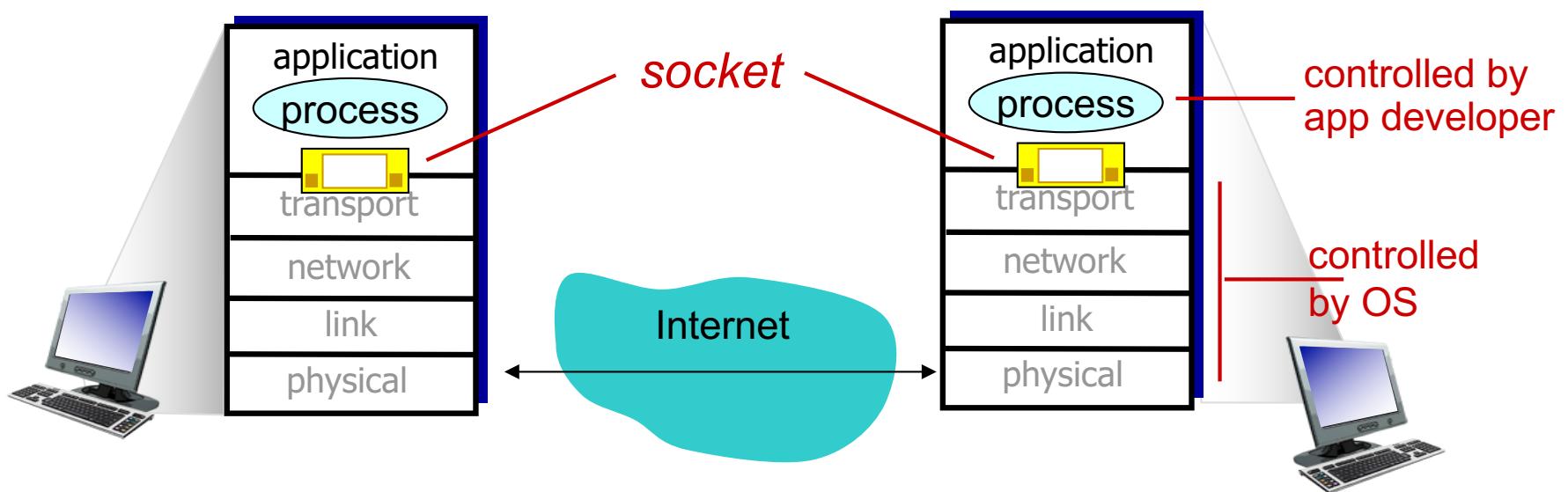
Message Passing (network)



- ❖ Data transfer
 - Copy to/from OS socket buffer
 - Extra step across network: hidden from applications

Socket programming

Socket: a door between application process and end-end-transport protocol (UDP or TCP)



Sockets Specify Transport Services

- ❖ Sockets define the interfaces between an application and the transport layer
- ❖ Applications choose the type of transport layer by choosing the type of socket
 - UDP Sockets – called DatagramSocket in Java, SOCK_DGRAM in C
 - TCP Sockets – called Socket/ServerSocket in Java, SOCK_STREAM in C
- ❖ Client and server agree on the type of socket, the server port number and the protocol

How do clients and servers communicate?

API: application programming interface

- ❖ defines interface between application and transport layer
- ❖ socket: Internet API
 - two processes communicate by sending data into socket, reading data out of socket

Q: how does a process “identify” the other process with which it wants to communicate?

- **IP address** of host running other process
- “**port number**” - allows receiving host to determine to which local process the message should be delivered

Languages and Platforms

Socket API is available for many languages on many platforms:

- ❖ C, Java, Perl, Python,...
- ❖ *nix, Windows,...

Socket Programs written in any language and running on any platform can communicate with each other!

Writing communicating programs in different languages is a good exercise

Learn how to build client/server application that communicate using sockets

Socket Programming is Easy

- ❖ Create socket much like you open a file
- ❖ Once open, you can read from it and write to it
- ❖ Operating System hides most of the details

System calls for a socket:

Socket()	Read()
Bind()	Write()
Connect()	Close()
Listen()	
Accept()	

Decisions

- ❖ Before you go to write socket code, decide
 - Do you want a **TCP**-style reliable, full duplex, connection oriented channel? Or do you want a **UDP**-style, unreliable, message oriented channel?
 - Will the code you are writing be the **client** or the **server**?
 - Client: you assume that there is a process already running on another machines that you need to connect to.
 - Server: you will just start up and wait to be contacted

OVERVIEW: TCP vs UDP

TCP service:

- ❖ *connection-oriented*: setup required between client, server
- ❖ *reliable transport* between sending and receiving process
- ❖ *flow control*: sender won't overwhelm receiver
- ❖ *congestion control*: throttle sender when network overloaded
- ❖ *does not provide*: timing or minimum bandwidth guarantees

UDP service:

- ❖ unreliable data transfer between sending and receiving process
- ❖ does not provide: connection setup, reliability, flow control, congestion control, timing, or bandwidth guarantee

OVERVIEW: TCP vs UDP



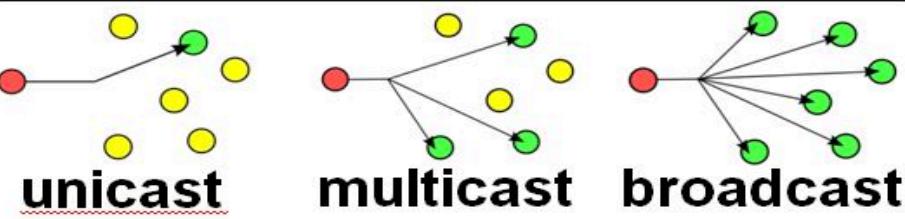
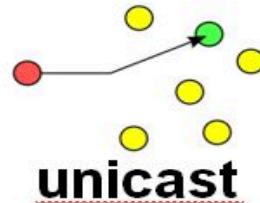
TCP



UDP

- **Slower but reliable transfers**
- **Typical applications:**
 - Email
 - Web browsing

- **Fast but non-guaranteed transfers (“best effort”)**
- **Typical applications:**
 - VoIP
 - Music streaming



Pseudo code TCP server

Create socket (doorbellSocket)

Bind socket to a specific port where clients can contact you

Register with the kernel your willingness to listen that on
socket for client to contact you

Loop

 Listen to doorbell Socket for an incoming connection,
 get a connectSocket

 Read and Write Data Into connectSocket to
 Communicate with client

 Close connectSocket

End Loop

Close doorbellSocket

Pseudo code TCP client

Create socket, connectSocket

Do an active connect specifying the IP address and port number of server

Read and Write Data Into connectSocket to Communicate with server

Close connectSocket

Example: Java server (TCP)

```
import java.io.*;
import java.net.*;

class TCPServer {

    public static void main(String argv[]) throws Exception
    {
        String clientSentence;
        String capitalizedSentence;

        ServerSocket doorbellSocket = new ServerSocket(6789);

        while(true) {
            Socket connectSocket = doorbellSocket.accept();

            BufferedReader inFromClient =
                new BufferedReader(new
                    InputStreamReader(connectSocket.getInputStream()));

            // Create output stream, attached to socket
            DataOutputStream outToClient =
                new DataOutputStream(connectSocket.getOutputStream());
        }
    }
}
```

Create welcoming socket at port 6789

Wait, on welcoming socket for contact by client

Create input stream, attached to socket

Example: Java server (TCP), cont

The diagram illustrates a Java code snippet for a TCP server with annotations explaining the steps:

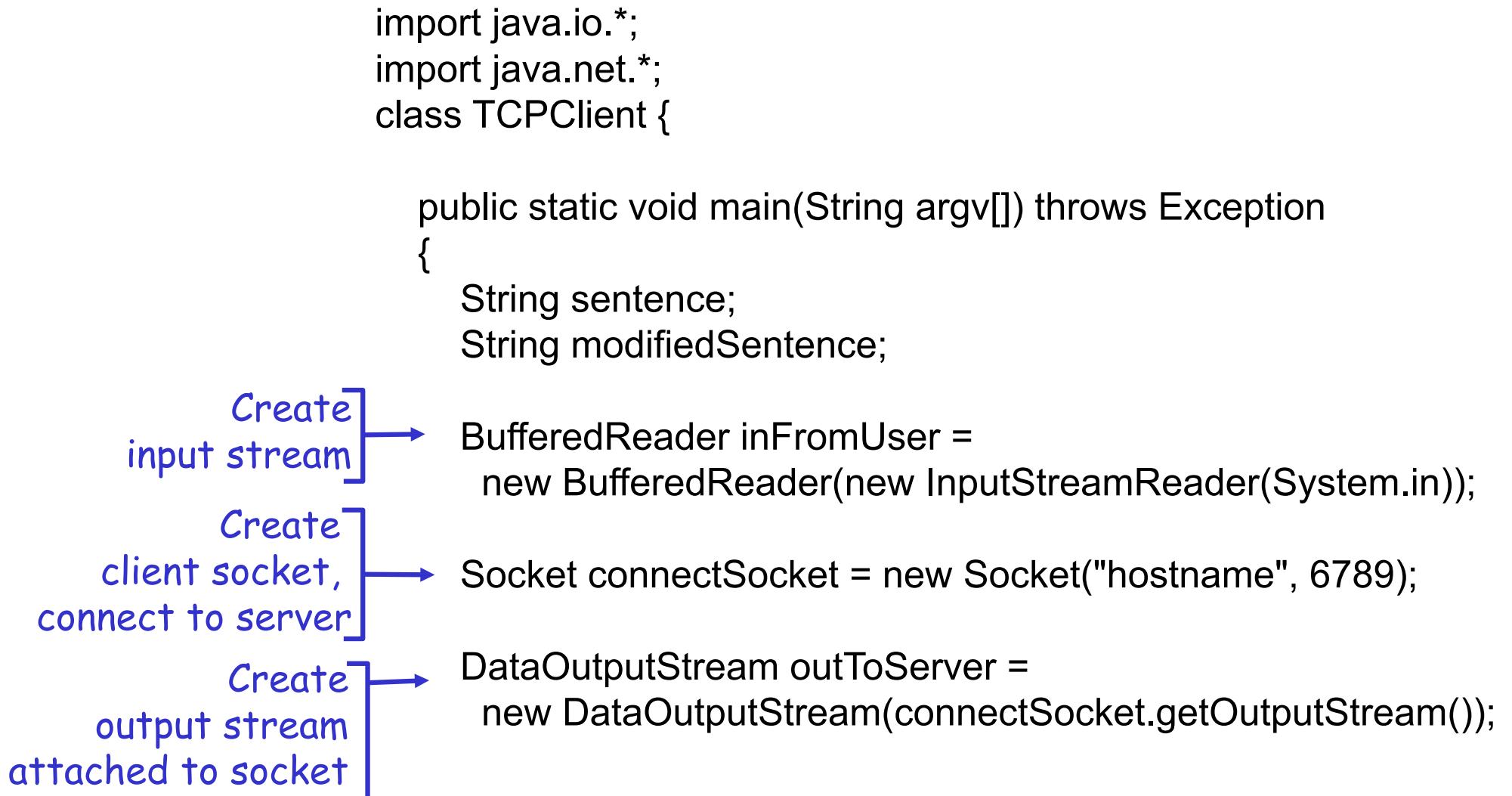
- Create output stream, attached to socket**: Points to the line `DataOutputStream outToClient = new DataOutputStream(connectSocket.getOutputStream());`.
- Read in line from socket**: Points to the line `clientSentence = inFromClient.readLine();`.
- Write out line to socket**: Points to the line `outToClient.writeBytes(capitalizedSentence);`.
- End of while loop, loop back and wait for another client connection**: Points to the closing brace of the while loop.

```
DataOutputStream outToClient =  
    new DataOutputStream(connectSocket.getOutputStream());  
  
clientSentence = inFromClient.readLine();  
  
capitalizedSentence = clientSentence.toUpperCase() + '\n';  
  
outToClient.writeBytes(capitalizedSentence);  
  
}  
}  
  
} // End of while loop, loop back and wait for another client connection
```

Example: Java client (TCP)

```
import java.io.*;
import java.net.*;
class TCPClient {

    public static void main(String argv[]) throws Exception
    {
        String sentence;
        String modifiedSentence;


        BufferedReader inFromUser =
            new BufferedReader(new InputStreamReader(System.in));
        Socket connectSocket = new Socket("hostname", 6789);
        DataOutputStream outToServer =
            new DataOutputStream(connectSocket.getOutputStream());
    }
}
```

Example: Java client (TCP), cont.

```
        Create  
        input stream  
        attached to socket } BufferedReader inFromServer =  
                                new BufferedReader(new  
                                InputStreamReader(connectSocket.getInputStream()));  
  
                                sentence = inFromUser.readLine();  
  
        Send line  
        to server } outToServer.writeBytes(sentence + '\n');  
  
        Read line  
        from server } modifiedSentence = inFromServer.readLine();  
                                System.out.println("FROM SERVER: " + modifiedSentence);  
  
                                connectSocket.close();  
  
    }  
}
```

Client/server socket interaction: TCP (Java)

Server (running on `hostid`)

```
create socket,  
port=x, for  
incoming request:  
doorbellSocket =  
    ServerSocket()
```

```
wait for incoming  
connection request  
connectSocket =  
    welcomeSocket.accept()
```

```
read request from  
connectSocket  
write reply to  
connectSocket
```

```
close  
connectSocket
```

Client

```
create socket,  
connect to hostid, port=x  
connectSocket =  
    Socket()
```

```
send request using  
connectSocket
```

```
read reply from  
connectSocket  
close  
connectSocket
```

TCP
connection setup

```
graph TD; Client[Client] -- "create socket, connect to hostid, port=x" --> CS[connectSocket = Socket()]; CS -- "send request using connectSocket" --> R1[read reply from connectSocket]; R1 -- "TCP connection setup" --> WS[welcomeSocket.accept()]; WS -- "read request from connectSocket" --> R2[read request from connectSocket]; R2 -- "write reply to connectSocket" --> CS; CS -- "close connectSocket" --> Client; Server[Server<br>(running on hostid)] -- "create socket, port=x, for incoming request:<br>doorbellSocket = ServerSocket()" --> WS; WS -- "wait for incoming connection request" --> CS;
```

Concurrent/Multithreaded TCP Servers

- ❖ What good is the doorbell socket? Can't accept new connections until call accept again anyway?
- ❖ Benefit comes in ability to hand off processing to another process or thread
 - Parent process creates the “door bell” or “welcome” socket on well-known port and waits for clients to request connection
 - When a client does connect, fork off a child process or pass to another thread to handle that connection so that parent can return to waiting for connections as soon as possible

Pseudo code concurrent TCP server

Create socket doorbellSocket

Bind

Listen

Loop

 Accept the connection, connectSocket

 Fork

 If I am the child

 Read/Write connectSocket

 Close connectSocket

 exit

EndLoop

Close doorbellSocket

Socket programming with UDP

UDP: very different mindset than TCP

- ❖ no connection just independent messages sent
- ❖ no handshaking
- ❖ sender explicitly attaches IP address and port of destination to each packet
- ❖ server must extract IP address, port of sender from received datagram to know who to respond to

UDP: transmitted data may be received out of order, or lost

Pseudo code UDP client

Create socket

Loop

(Send Message To Well-known port of server)+

(Receive Message From Server)

Close Socket

Pseudo code UDP server

Create socket

Bind socket to a specific port where clients can contact you

Loop

(Receive UDP Message from client x)+

(Send UDP Reply to client x)*

Close Socket

Example: Java server (UDP)

```
import java.io.*;
import java.net.*;

class UDPServer {
    public static void main(String args[]) throws Exception
    {
        DatagramSocket serverSocket = new DatagramSocket(9876);

        byte[] receiveData = new byte[1024];
        byte[] sendData = new byte[1024];

        while(true)
        {
            DatagramPacket receivePacket =
                new DatagramPacket(receiveData, receiveData.length);
            serverSocket.receive(receivePacket);
        }
    }
}
```

Create datagram socket at port 9876

Create space for received datagram

Receive datagram

Example: Java server (UDP), cont

```
String sentence = new String(receivePacket.getData());  
Get IP addr  
port #, of  
sender } → InetAddress IPAddress = receivePacket.getAddress();  
int port = receivePacket.getPort();  
  
String capitalizedSentence = sentence.toUpperCase();  
  
sendData = capitalizedSentence.getBytes();  
Create datagram  
to send to client } → DatagramPacket sendPacket =  
new DatagramPacket(sendData, sendData.length, IPAddress,  
port);  
Write out  
datagram  
to socket } → serverSocket.send(sendPacket);  
}  
} } ← End of while loop,  
loop back and wait for  
another datagram
```

Example: Java client (UDP)

```
import java.io.*;
import java.net.*;

class UDPClient {
    public static void main(String args[]) throws Exception
    {

        BufferedReader inFromUser =
            new BufferedReader(new InputStreamReader(System.in));

        DatagramSocket clientSocket = new DatagramSocket();

        InetAddress IPAddress = InetAddress.getByName("hostname");

        byte[] sendData = new byte[1024];
        byte[] receiveData = new byte[1024];

        String sentence = inFromUser.readLine();
        sendData = sentence.getBytes();
```

Create input stream → BufferedReader inFromUser =
Create client socket, DatagramSocket, but no port → DatagramSocket clientSocket = new DatagramSocket();
Translate hostname to IP address using DNS → InetAddress IPAddress = InetAddress.getByName("hostname");

Example: Java client (UDP), cont.

```
Create datagram  
with data-to-send,  
length, IP addr, port] DatagramPacket sendPacket =  
new DatagramPacket(sendData, sendData.length, IPAddress, 9876);  
  
Send datagram  
to server] clientSocket.send(sendPacket);  
  
Read datagram  
from server] DatagramPacket receivePacket =  
new DatagramPacket(receiveData, receiveData.length);  
clientSocket.receive(receivePacket);  
String modifiedSentence =  
new String(receivePacket.getData());  
  
System.out.println("FROM SERVER:" + modifiedSentence);  
clientSocket.close();  
}  
}
```

Client/server socket interaction: UDP

Server (running on `hostid`)

```
create socket,  
port=x, for  
incoming request:  
serverSocket =  
DatagramSocket()
```



Client

```
create socket,  
clientSocket =  
DatagramSocket()
```

```
Create, address (hostid, port=x),  
send datagram request  
using clientSocket
```

```
read reply from  
clientSocket  
close  
clientSocket
```

Socket programming

Application Example:

1. Client reads a line of characters (data) from its keyboard and sends the data to the server.
2. The server receives the data and converts characters to uppercase.
3. The server sends the modified data to the client.
4. The client receives the modified data and displays the line on its screen.