Computer Networks and Applications

COMP 3331/COMP 9331

Week 3

Application Layer (DNS, P2P, Video Streaming and CDN)

Reading Guide: Chapter 2, Sections 2.4 -2.7

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

A nice overview https://www.thegeeksearch.com/beginners-guide-to-dns/

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

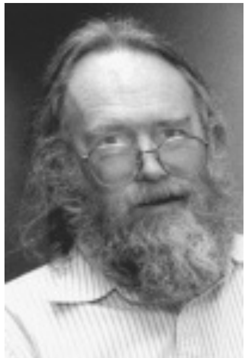
Q: how to map between IP address and name, and vice versa ?

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



Jon Postel

- 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

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

DNS: services, structure

DNS services

- hostname to IP address translation
- Indirection
- 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

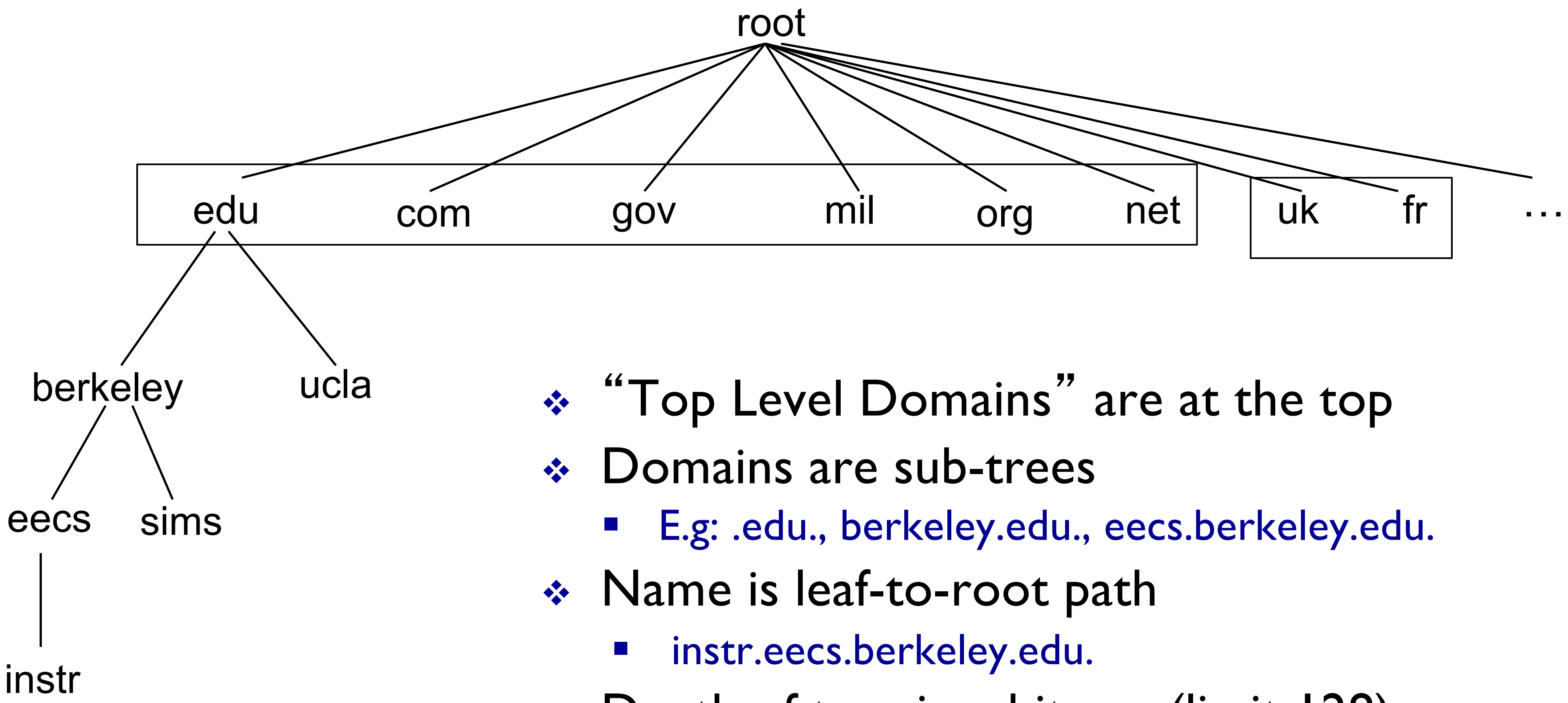
- No naming conflicts (uniqueness)
- Scalable
  - many names
  - (secondary) frequent updates
- Distributed, autonomous administration
  - Ability to update my own (domains') names
  - Don't have to track everybody's updates
- Highly available
- Lookups should be fast

Key idea: Hierarchy

Three intertwined hierarchies

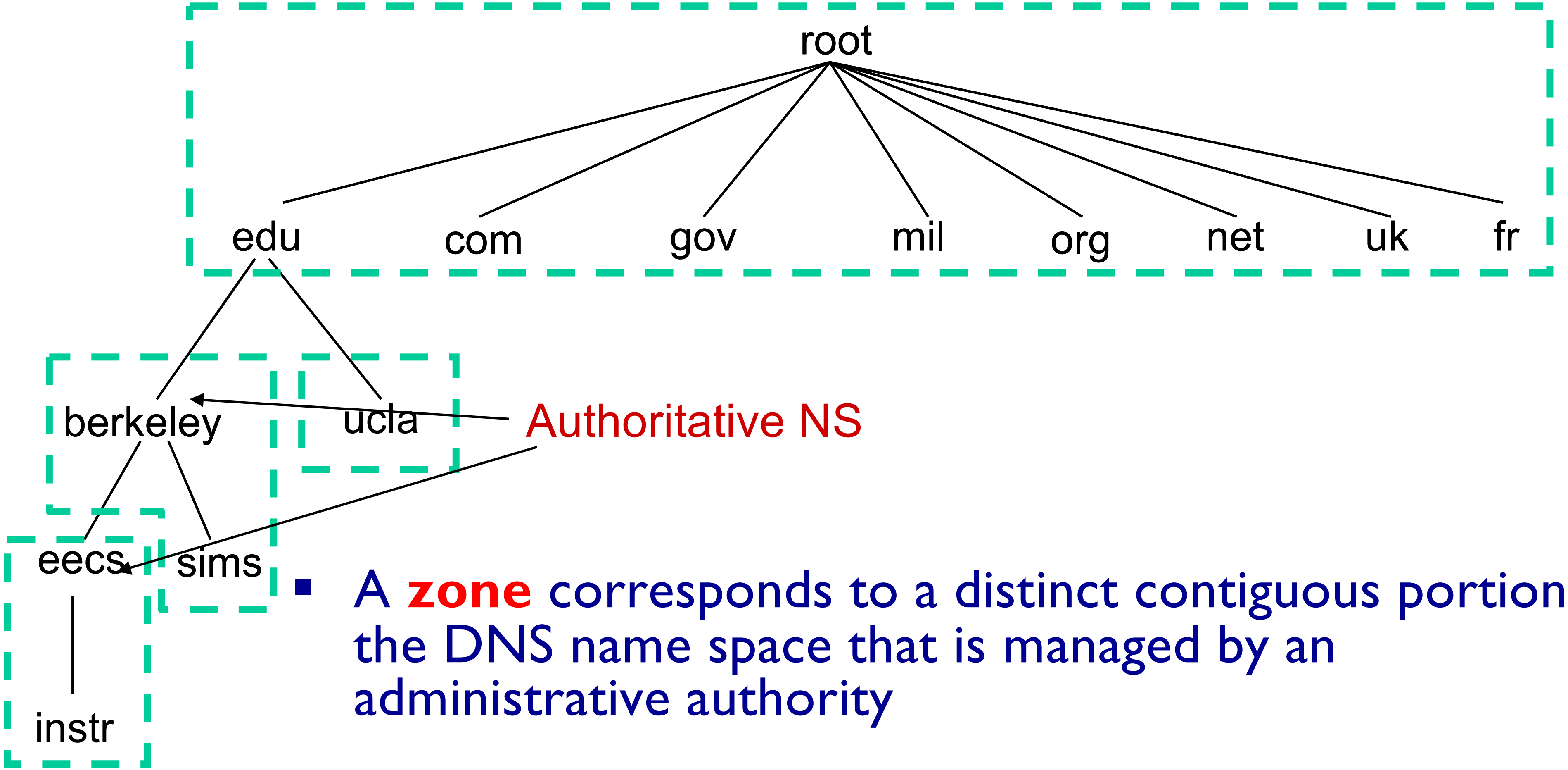
- Hierarchical namespace
  - As opposed to original flat namespace
- Hierarchically administered
  - As opposed to centralised
- (Distributed) hierarchy of servers
  - As opposed to centralised storage

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 a distinct contiguous portion of the DNS name space that is managed by an administrative authority

- E.g., UCB controls names: *.berkeley.edu and *.sims.berkeley.edu

- E.g., EECS controls names: *.eecs.berkeley.edu

Server Hierarchy

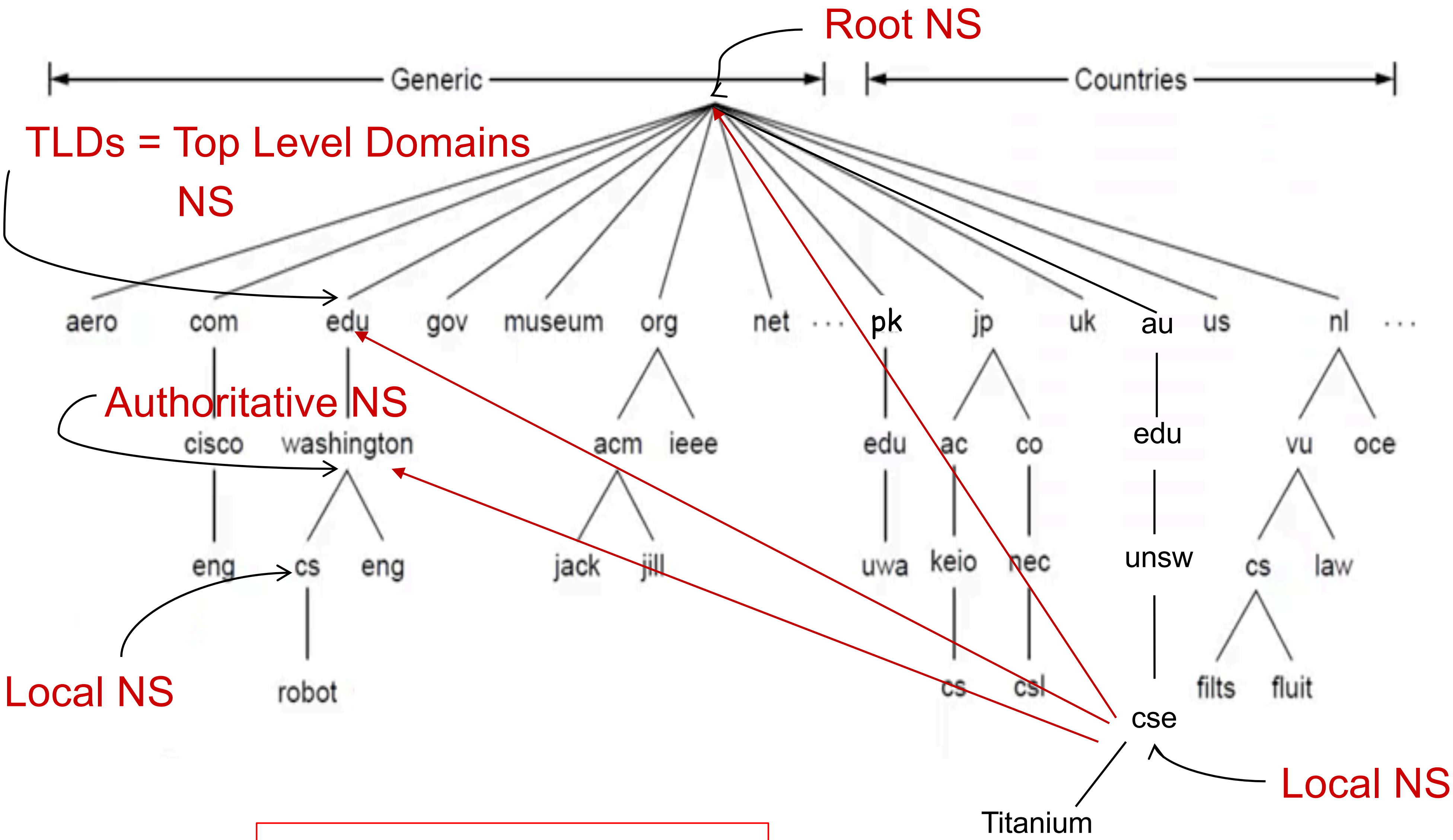
- Top of hierarchy: Root servers
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, etc. (several new TLDs introduced recently)
  - Managed professionally
- Bottom Level: Authoritative DNS servers
  - Store the name-to-address mapping
  - Maintained 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 can discover the server(s) that are responsible for the other portions of the hierarchy
  - Every server knows the root server(s)
  - Root server(s) knows about all top-level domains

Credits: Prof David Wetherall, UoW

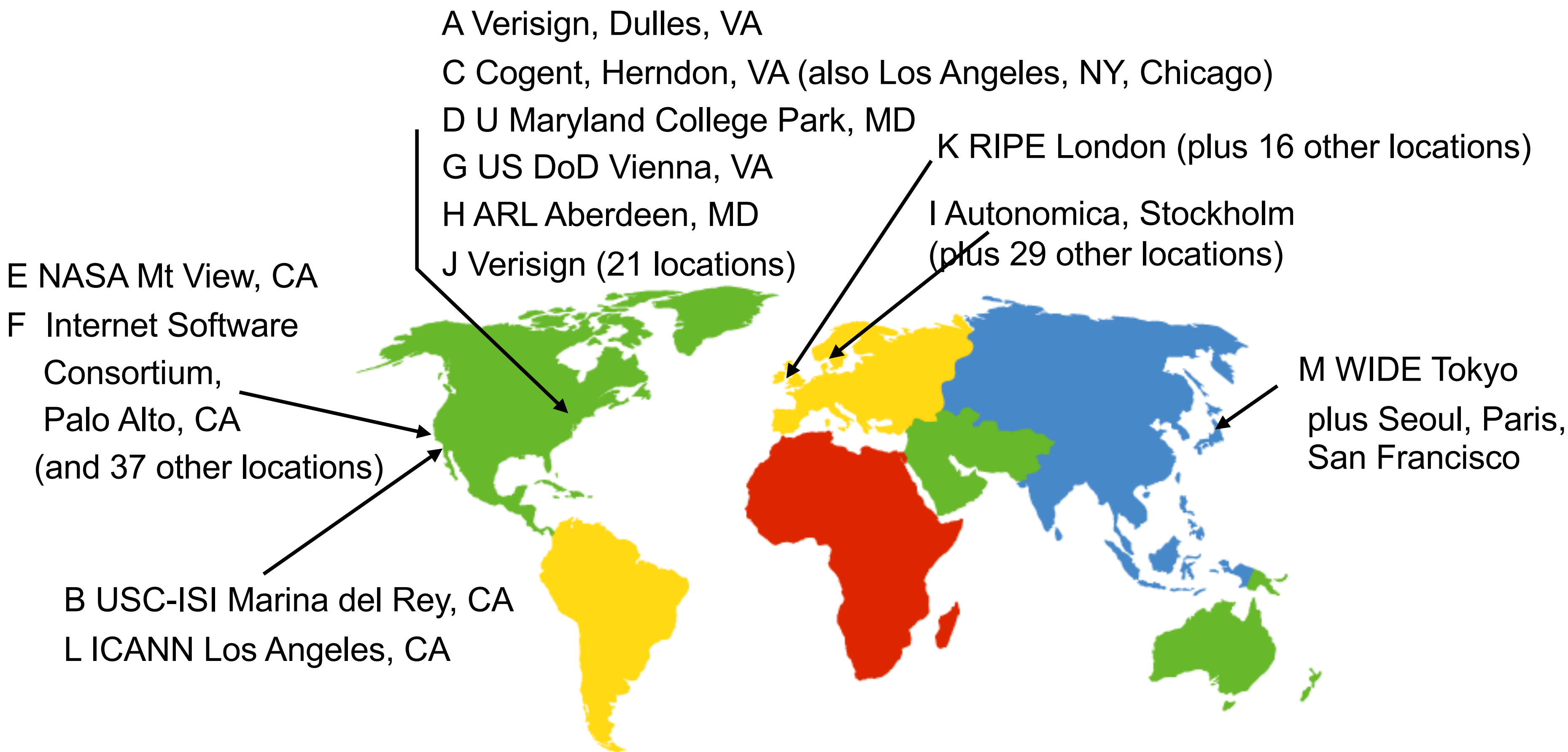
DNS: a distributed, hierarchical database



robot.cs.washington.edu.

DNS Root Servers

- 13 root servers (labeled A-M; see http://www.root-servers.org/)
- Replicated via any-casting (network will deliver DNS messages to the closest replica)



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

DNS: root name servers

As of 2018-08-01, the root server system consists of 931 instances operated by the 12 independent root server operators.

www.root-servers.org

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

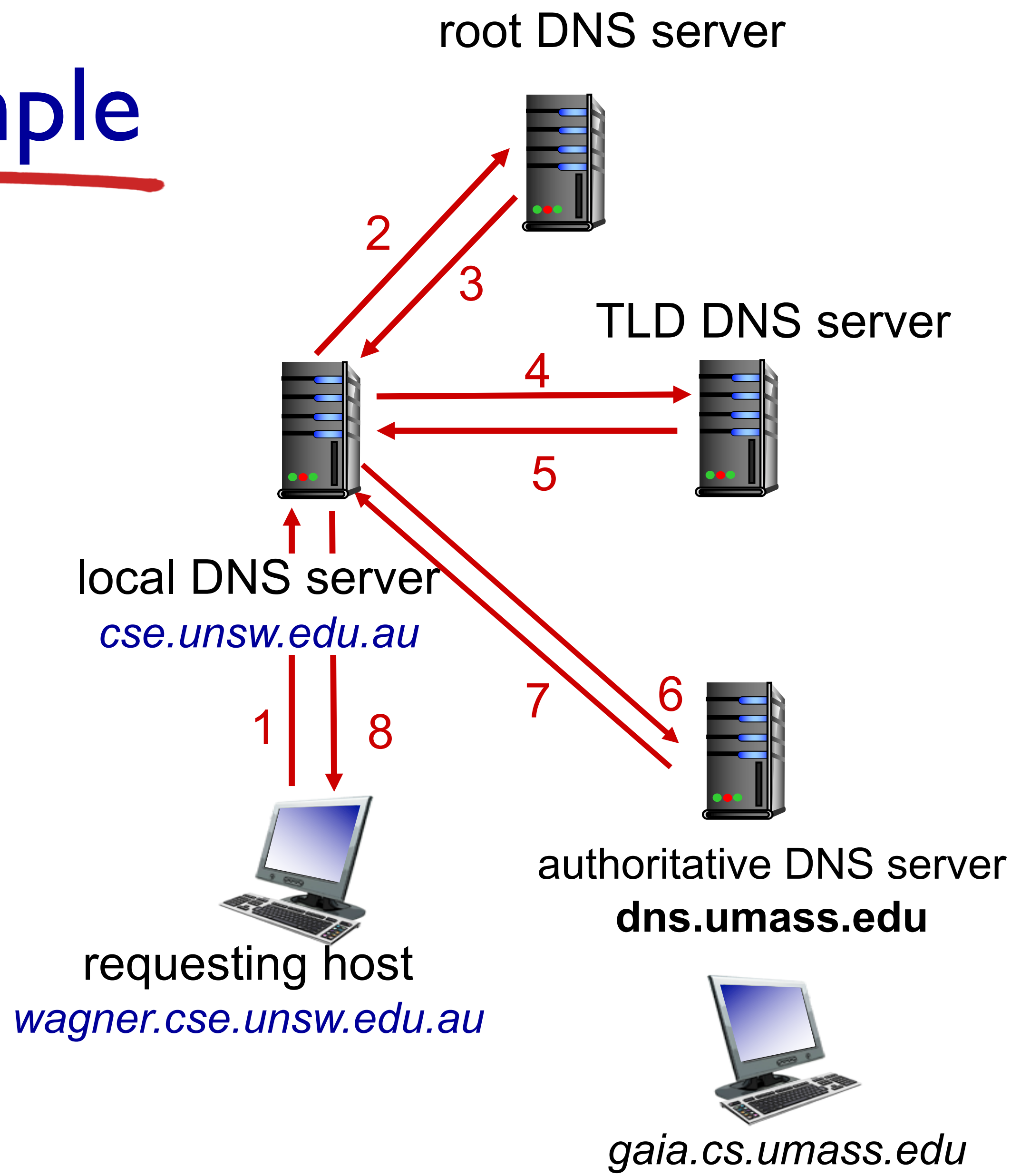
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
  - also called "default name server" or "DNS resolver"
- Hosts configured with local DNS server address (e.g., /etc/resolv.conf) or learn server via a host configuration protocol (e.g., DHCP)
- Client application
  - Obtain DNS name (e.g., from URL)
  - Do **gethostbyname()** to trigger DNS request to its local DNS server
- when host makes DNS query, the 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:

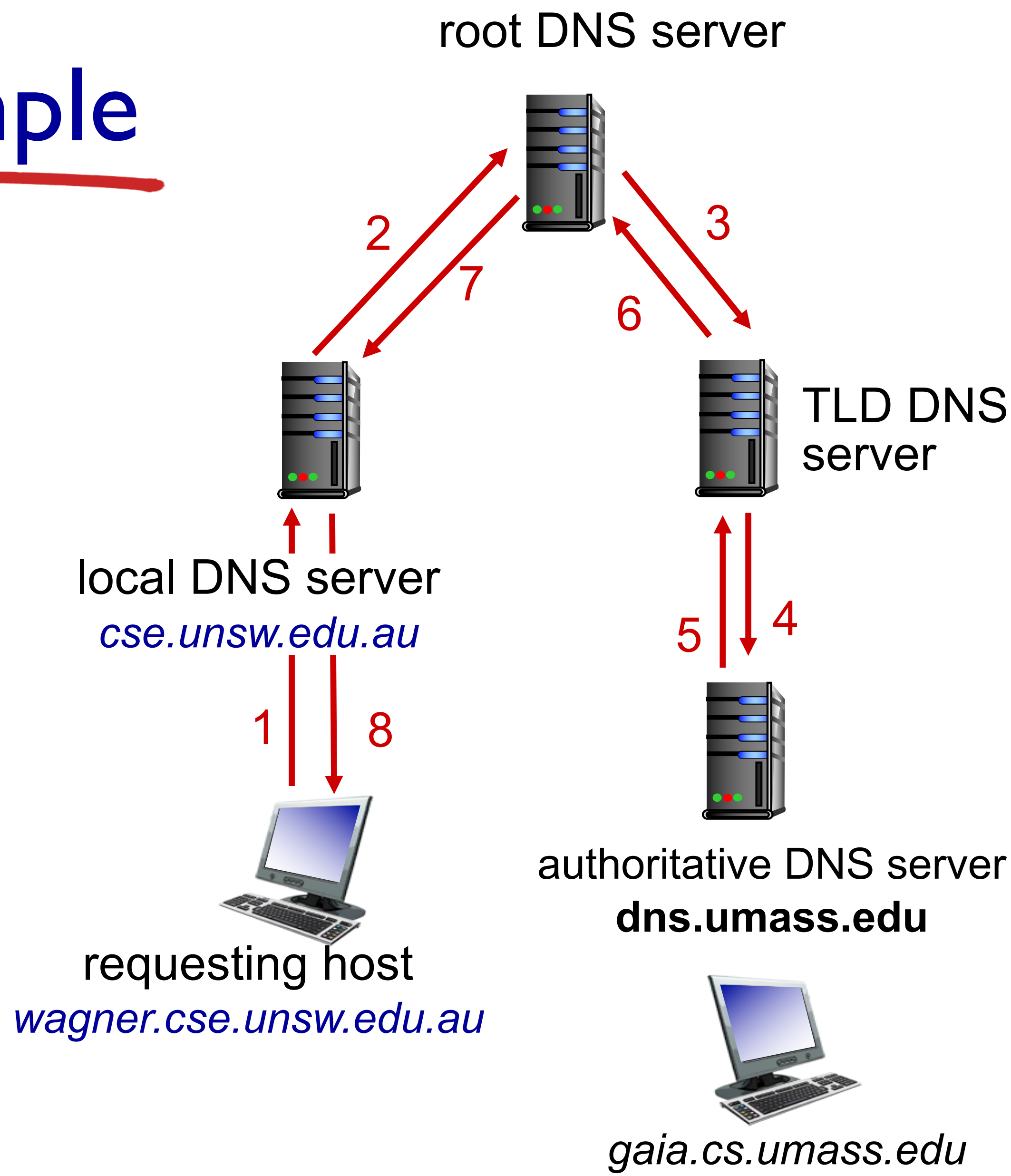
- contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”



DNS name resolution example

recursive query:

- puts burden of name resolution on contacted name server



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
- Negative caching (optional)
  - Remember things that don't work
  - E.g., misspellings like www.cnn.comm and www.cnnn.com
  - These can take a long time to fail for the first time
  - Good to remember that they don't work

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

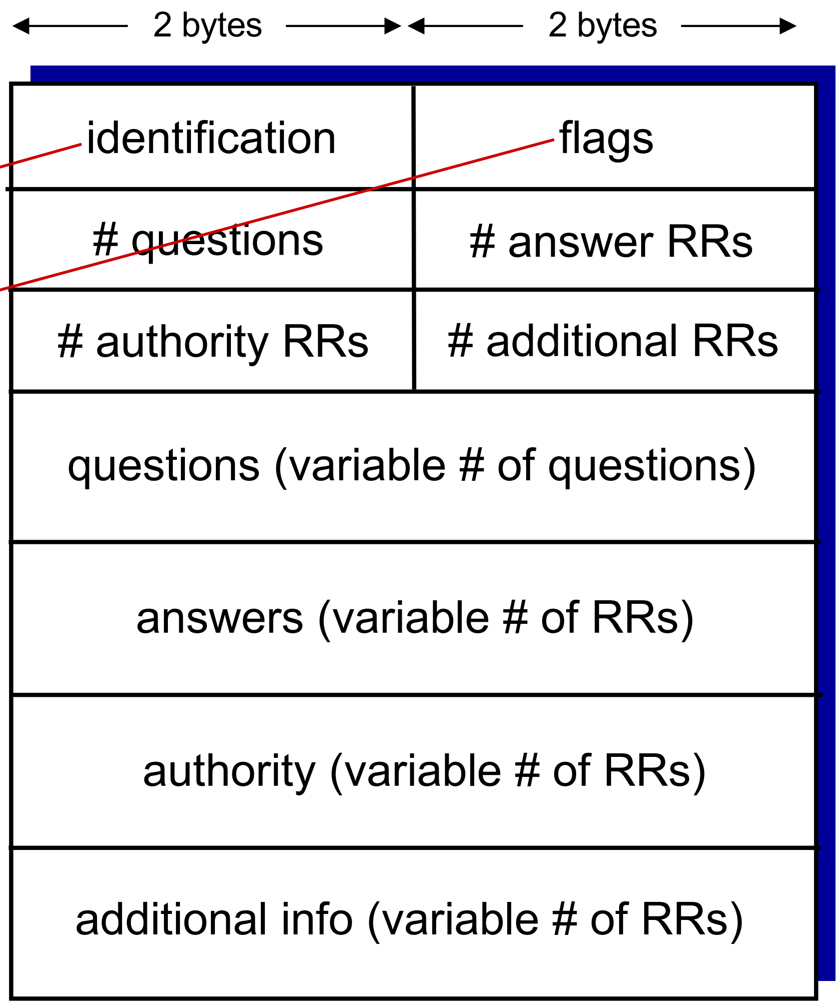
- **`value`** is name of mailserver associated with **`name`**

DNS protocol, messages

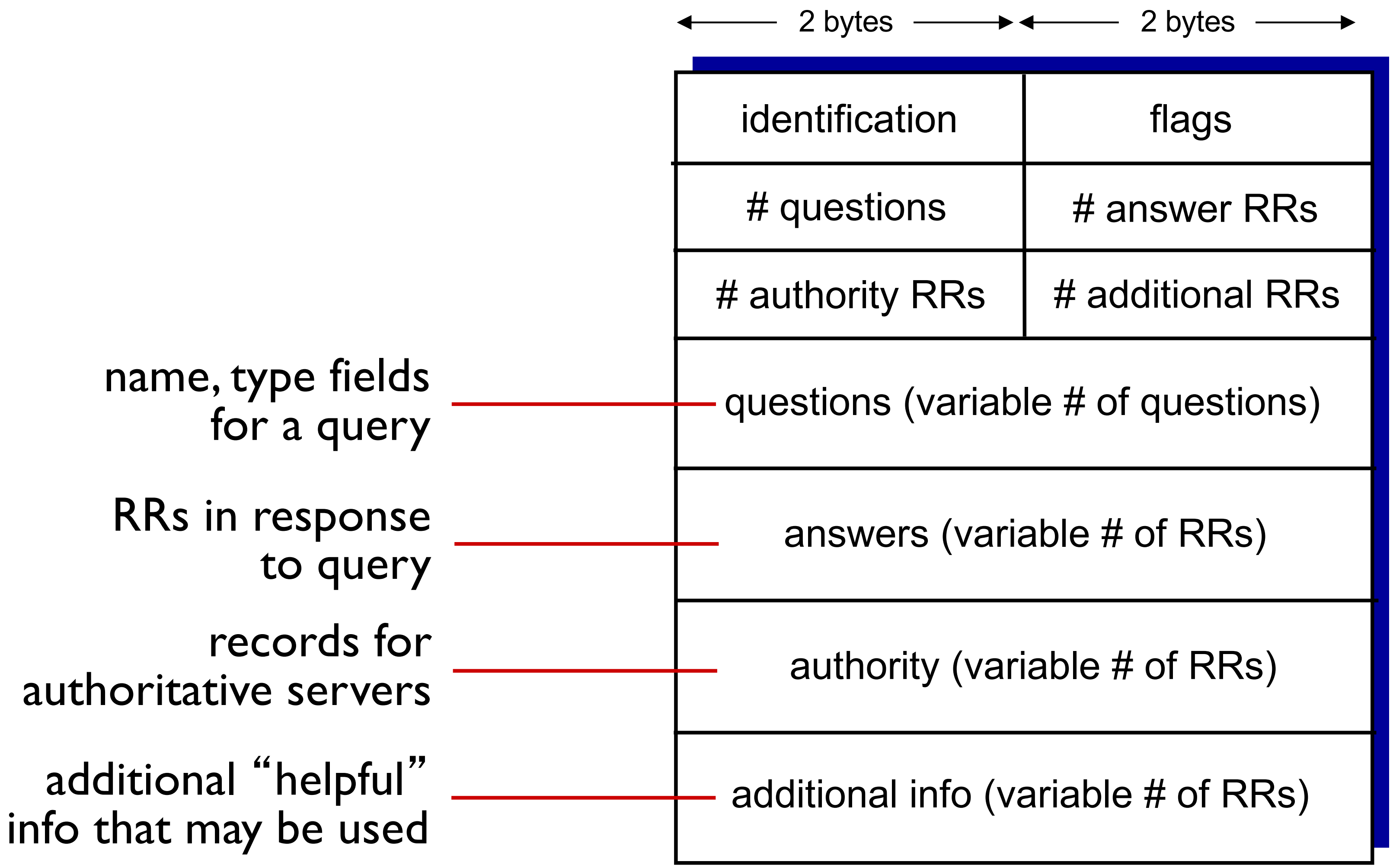
- *query* and *reply* messages, both with same *message format*

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

```
salilk@wagner:~$ dig www.oxford.ac.uk

; <<>> DiG 9.9.5-9+deb8u19-Debian <<>> www.oxford.ac.uk
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 23390
;; flags: qr rd ra; QUERY: 1, ANSWER: 4, AUTHORITY: 4, ADDITIONAL: 6

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;www.oxford.ac.uk.              IN      A

;; ANSWER SECTION:
www.oxford.ac.uk.       300     IN      A       151.101.194.133
www.oxford.ac.uk.       300     IN      A       151.101.2.133
www.oxford.ac.uk.       300     IN      A       151.101.66.133
www.oxford.ac.uk.       300     IN      A       151.101.130.133

;; AUTHORITY SECTION:
oxford.ac.uk.           86400   IN      NS      dns2.ox.ac.uk.
oxford.ac.uk.           86400   IN      NS      dns0.ox.ac.uk.
oxford.ac.uk.           86400   IN      NS      dns1.ox.ac.uk.
oxford.ac.uk.           86400   IN      NS      ns2.ja.net.

;; ADDITIONAL SECTION:
ns2.ja.net.             81448   IN      A       193.63.105.17
ns2.ja.net.             17413   IN      AAAA    2001:630:0:45::11
dns0.ox.ac.uk.          42756   IN      A       129.67.1.190
dns1.ox.ac.uk.          908     IN      A       129.67.1.191
dns2.ox.ac.uk.          908     IN      A       163.1.2.190

;; Query time: 544 msec
;; SERVER: 129.94.242.2#53(129.94.242.2)
;; WHEN: Mon Sep 28 10:55:27 AEST 2020
;; MSG SIZE  rcvd: 285
```

Try this out yourself. Part of one of the lab

Inserting records into DNS

- example: new startup "Network Utopia"
- register name networkutopia.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: ??

Updating DNS records

- Remember that old records may be cached in other DNS servers (for up to TTL)
- General guidelines
  - Record the current TTL value of the record
  - Lower the TTL of the record to a low value (e.g., 30 seconds)
  - Wait the length of the previous TTL
  - Update the record
  - Wait for some time (e.g. 1 hour)
  - Change the TTL back to your previous time

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
- DNS uses port 53
- 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

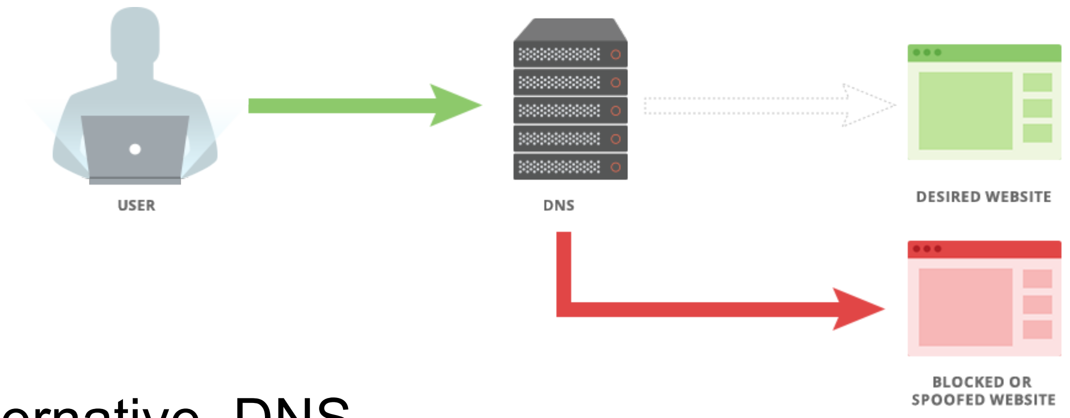
- Addresses can change underneath
  - Move www.cnn.com to 4.125.91.21
  - Humans/Apps should be unaffected
- Name could map to multiple IP addresses
  - Enables
    - Load-balancing
    - Reducing latency by picking nearby servers
- Multiple names for the same address
  - E.g., many services (mail, www, 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

Do you trust your DNS server?

- Censorship



https://wikileaks.org/wiki/Alternative_DNS

- Logging
  - IP address, websites visited, geolocation data and more
  - E.g., Google DNS:

    https://developers.google.com/speed/public-dns/privacy

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

Want to dig deeper?

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

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IoT Attack Against a University Network

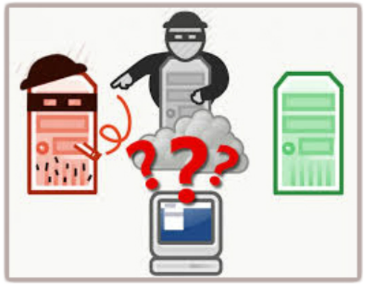
Verizon's *Data Brief Digest 2017* describes an attack against an unnamed university by attackers who hacked a variety of IoT devices and had them spam network targets and slow them down:

> 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 it responds 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

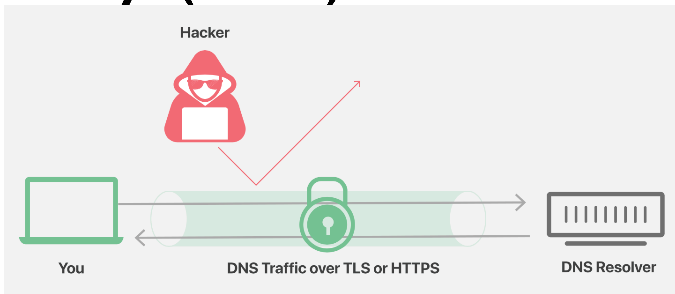
DNS Cache Poisoning Test - https://www.grc.com/dns/dns.htm

DNSSEC

- Extension to improve DNS security
- Allows DNS clients to cryptographically authenticate DNS data and data integrity
- Does not guarantee availability or confidentiality
- Further details: https://www.dnssec.net
- Stats: https://stats.labs.apnic.net/dnssec

DoH (RFC 8484) and DoT (RFC 7858)

- DoT: DNS over Transport Layer Security (TLS)
- DoH: DNS over HTTPS (or HTTP2)
- Increase user privacy and security
- DoT: port 853, DoH: port 443



- DoH traffic masked with other HTTPS traffic
- Cloudflare, Google, etc. have publicly accessible DoT resolvers and OS support is also available
- Chrome and Mozilla support DoH, OS support coming soon (or already there)
- DoT: https://developers.google.com/speed/public-dns/docs/dns-over-tls
- DoH: https://developers.cloudflare.com/1.1.1.1/dns-over-https

Quiz: DNS

❖ If a local DNS server has no clue about where to find the address for a hostname then the

a) Server starts crying

b) Server asks the root DNS server

c) Server asks its neighbouring DNS server

d) Request is not processed

ANSWER: b)

www.zeetings.com/salil

Quiz: DNS

- Which of the following are respectively maintained by the client-side ISP and the domain name owner?

  a) Root DNS server, Top-level domain DNS server
  b) Root DNS server, Local DNS server
  c) Local DNS server, Authoritative DNS server
  d) Top-level domain DNS server, Authoritative DNS server
  e) Authoritative DNS server, Top-level domain DNS server

ANSWER: c)

www.zeetings.com/salil

Quiz: DNS

- Suppose you open your email program and send an email to salil@unsw.edu.au, your email program will trigger which type of DNS query?

a) A
b) NS
c) CNAME
d) MX
e) All of the above

ANSWER: d)

www.zeetings.com/salil

Quiz: DNS

- You open your browser and type www.zeetings.com. The minimum number of DNS requests sent by your local DNS server to obtain the corresponding IP address is:

A. 0

B. 1

C. 2

D. 3

E. 42

ANSWER: a)

Application Layer: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

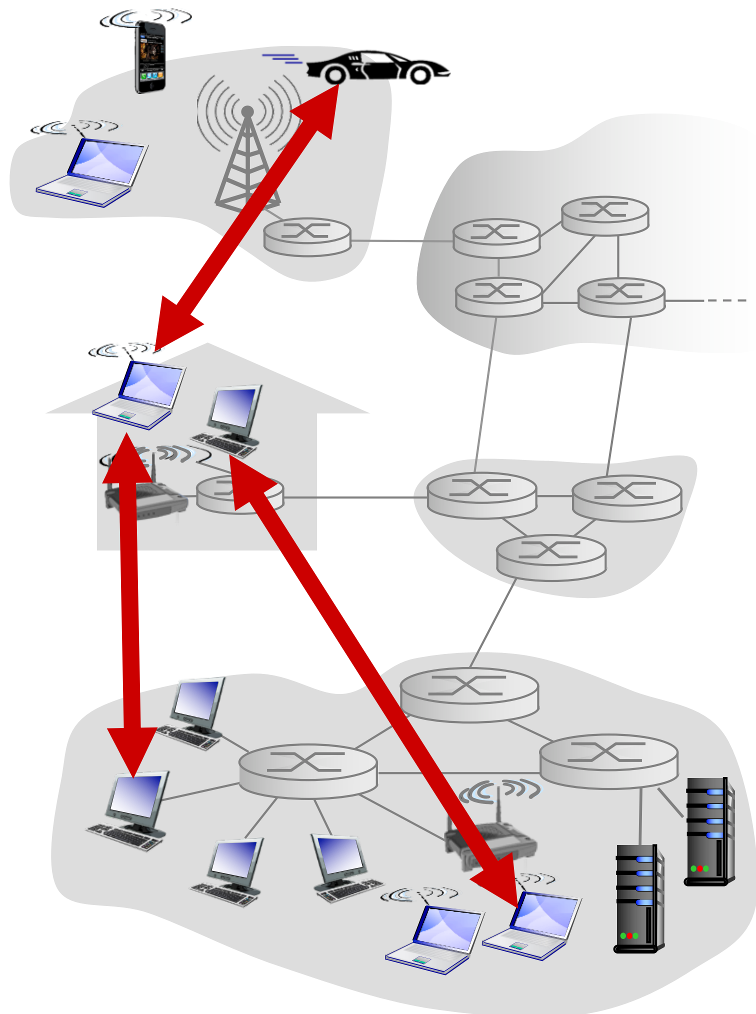
2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

2.7 socket programming with UDP and TCP

Pure P2P architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and change IP addresses



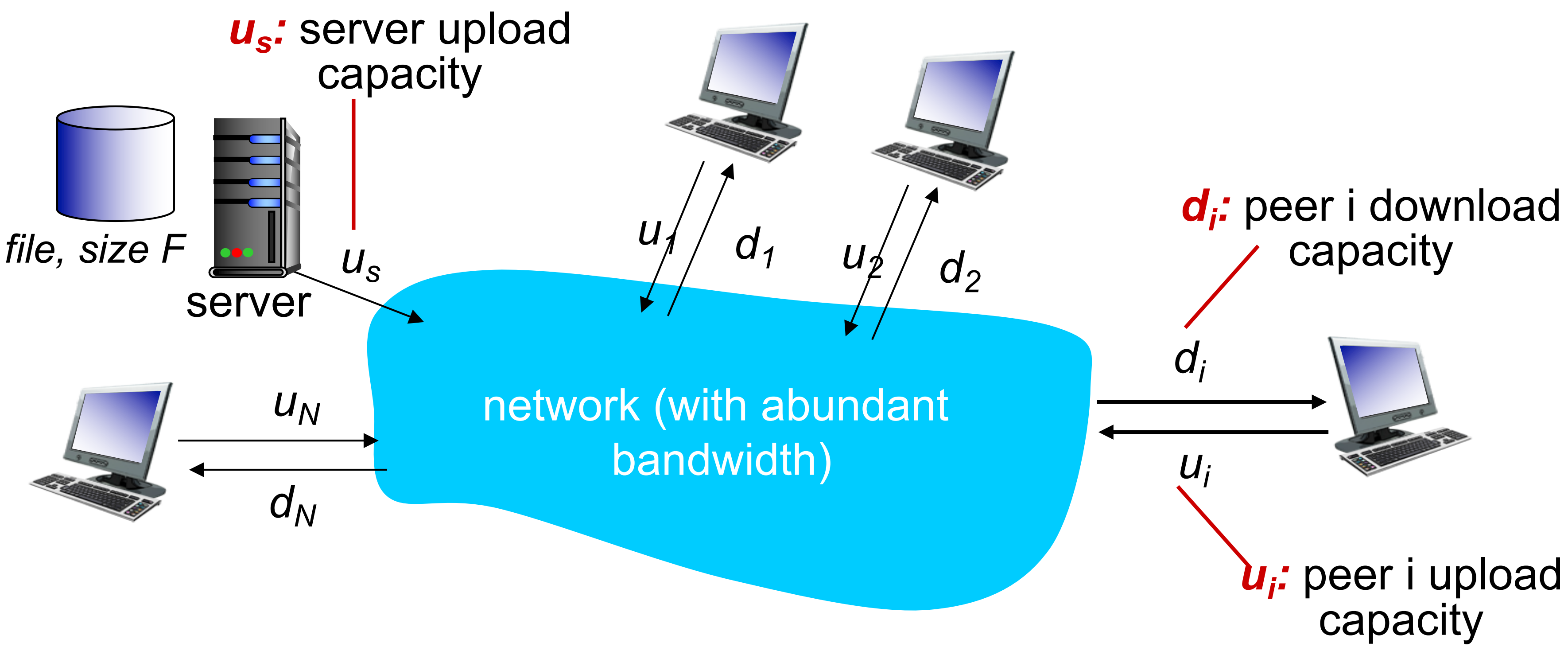
examples:

- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)
- Cryptocurrency (BitCoin)

File distribution: client-server vs P2P

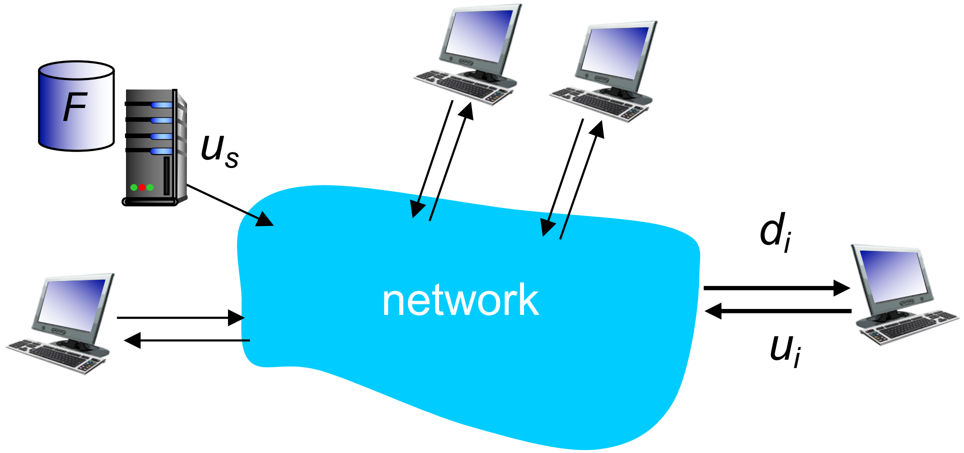
Question: how much time to distribute file (size *F*) from one server to *N* *peers*?

- peer upload/download capacity is limited resource



File distribution time: client-server

- *server transmission:* must send (upload) *N* file copies:
  - time to send one copy: F/u_s
  - time to send N copies: NF/u_s



- *client:* each client must download file copy
  - d_{min} = min client download rate
  - client download time: F/d_{min}

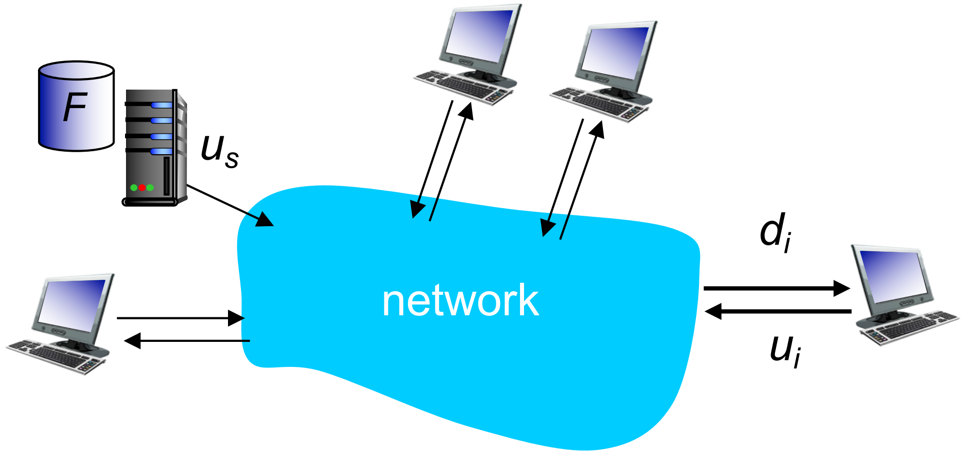
time to distribute F to N clients using client-server approach

$$D_{c\text{-}s} \geq max\{NF/u_{s,},F/d_{min}\}$$

increases linearly in N

File distribution time: P2P

- *server transmission:* must upload at least one copy
  - time to send one copy: F/u_s
- *client:* each client must download file copy
  - client download time: F/d_{min}



- *clients:* as aggregate must download *NF* bits
  - max upload rate (limiting max download rate) is $u_s + \sum u_i$

time to distribute F to N clients using P2P approach

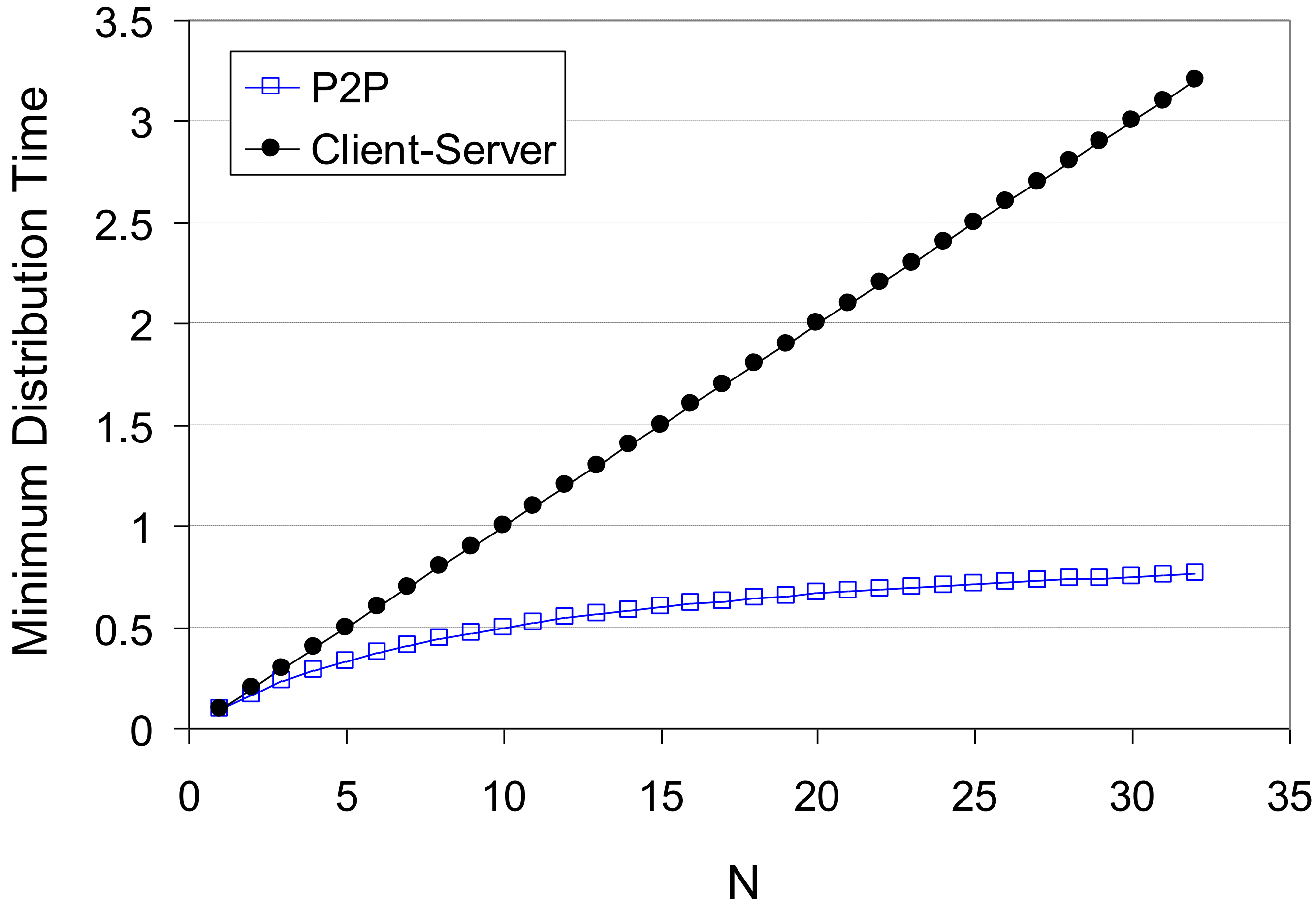
$$D_{P2P} \geq \max\{F/u_s, F/d_{min}, NF/(u_s + \sum_{i=1}^{N} u_i)\}$$

increases linearly in *N* …

… but so does this, as each peer brings service capacity

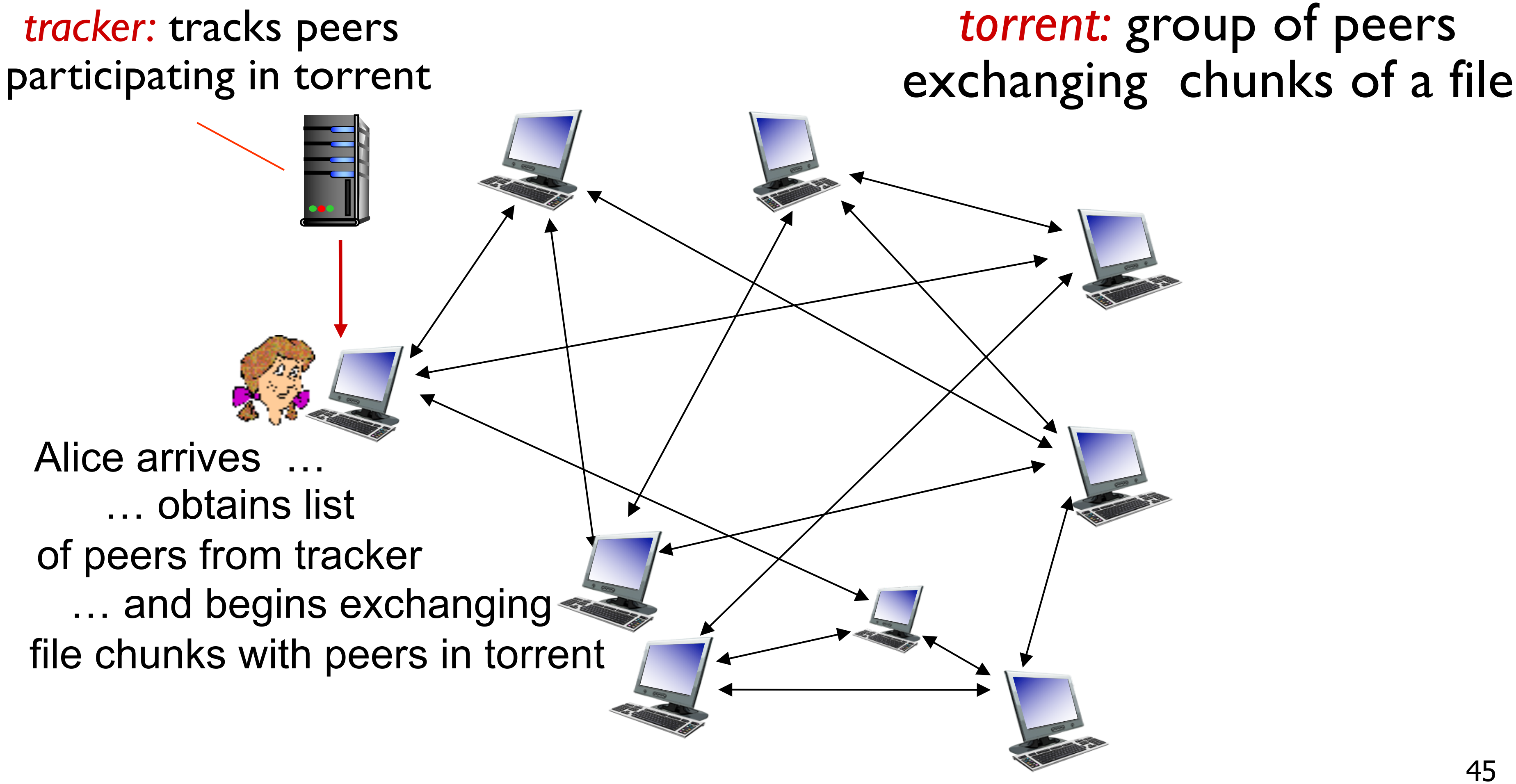
Client-server vs. P2P: example

client upload rate = *u*, *F/u* = 1 hour, $u_s = 10u$



P2P file distribution: BitTorrent

- file divided into 256KB chunks
- peers in torrent send/receive file chunks



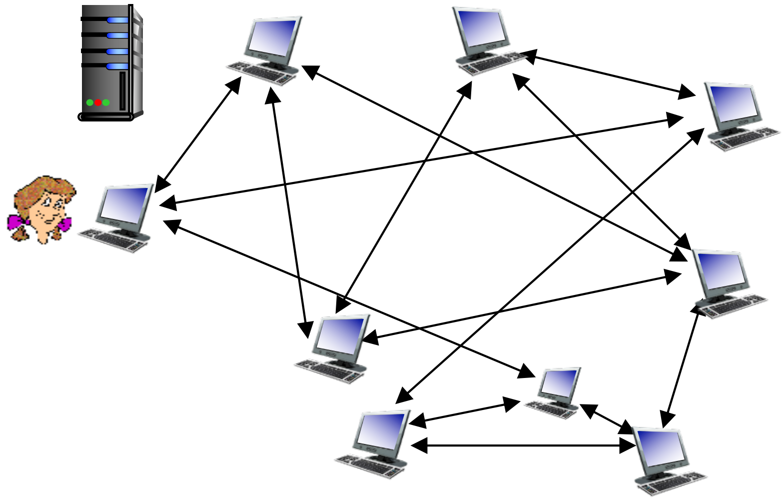
.torrent files

- Contains address of trackers for the file
  - Where can I find other peers?
- Contain a list of file chunks and their cryptographic hashes
  - This ensures that chunks are not modified

Title	Trackers
The Boys Season 2	Tracker1-url
Walking Dead Season 10	Tracker2-url
Game of Thrones Season 8	Tracker2-url,Tracker3-url

P2P file distribution: BitTorrent

- peer joining torrent:
  - has no chunks, but will accumulate them over time from other peers
  - registers with tracker to get list of peers, connects to subset of peers ("neighbours")



- while downloading, peer uploads chunks to other peers
- peer may change peers with whom it exchanges chunks
  - *churn:* peers may come and go
- once peer has entire file, it may (selfishly) leave or (altruistically) remain in torrent

BitTorrent: requesting, sending file chunks

requesting chunks:

- at any given time, different peers have different subsets of file chunks
- periodically, Alice asks each peer for list of chunks that they have
- Alice requests missing chunks from peers, rarest first
- **Q:** Why rarest first?

sending chunks: tit-for-tat

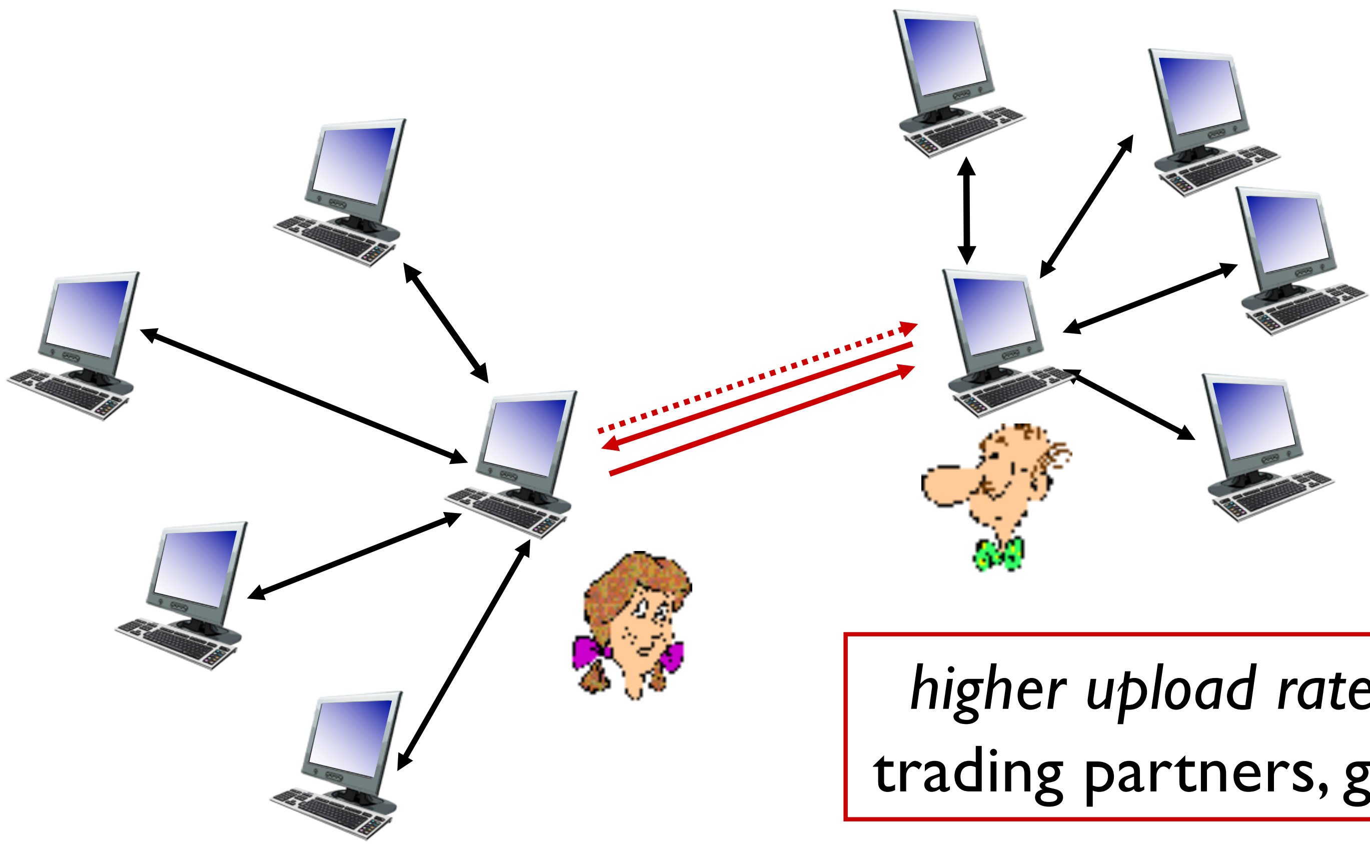
- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
  - other peers are choked by Alice (do not receive chunks from her)
  - re-evaluate top 4 every10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

BitTorrent: tit-for-tat

(1) Alice "optimistically unchokes" Bob

(2) Alice becomes one of Bob's top-four providers; Bob reciprocates

(3) Bob becomes one of Alice's top-four providers



higher upload rate: find better trading partners, get file faster !

Original Research Paper on BitTorrent added to lecture notes: NOT MANDATORY READING

Getting rid of the server/tracker

- Distribute the tracker information using a Distributed Hash Table (DHT)

- A DHT is a lookup structure
  - Maps keys to an arbitrary value
  - Works a lot like, well …. hash table

Content available in 6th Edition of the textbook Section 2.6.2, Added to Lecture Notes

Hash table - review

- (key,value) pairs
- Centralised hash table – all (key, value) pairs on one node
- Distributed hash tables – each node has a "section" of (key, value) pairs

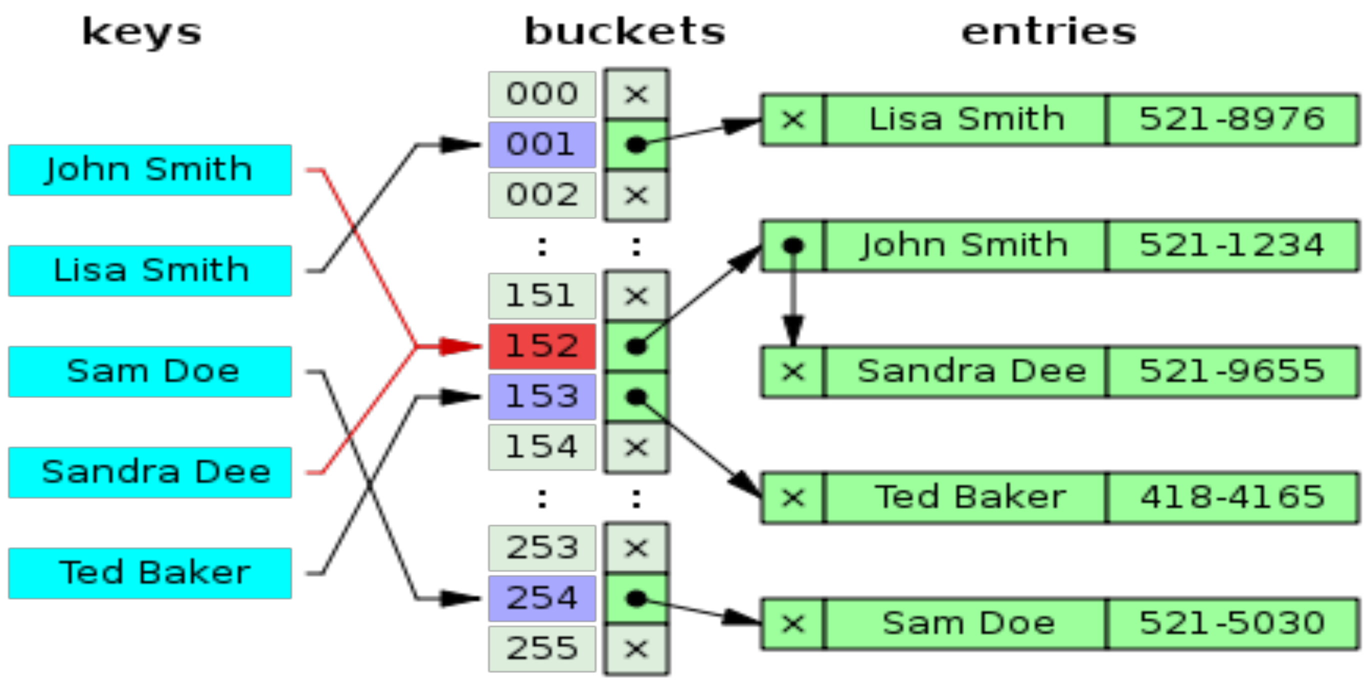


Figure src: http://en.wikipedia.org/wiki/Hash_table

Distributed Hash Table (DHT)

- DHT: a *distributed P2P database*
- database has (key, value) pairs; examples:
  - key: TFN number; value: human name
  - key: file name; value: BT tracker(s)
- Distribute the (key, value) pairs over many peers
- a peer queries DHT with key
  - DHT returns values that match the key
- peers can also insert (key, value) pairs

Q: how to assign keys to peers?

- basic idea:
  - convert each key to an integer
  - Assign integer value to each peer
  - put (key, value) pair in the peer that is closest to the key

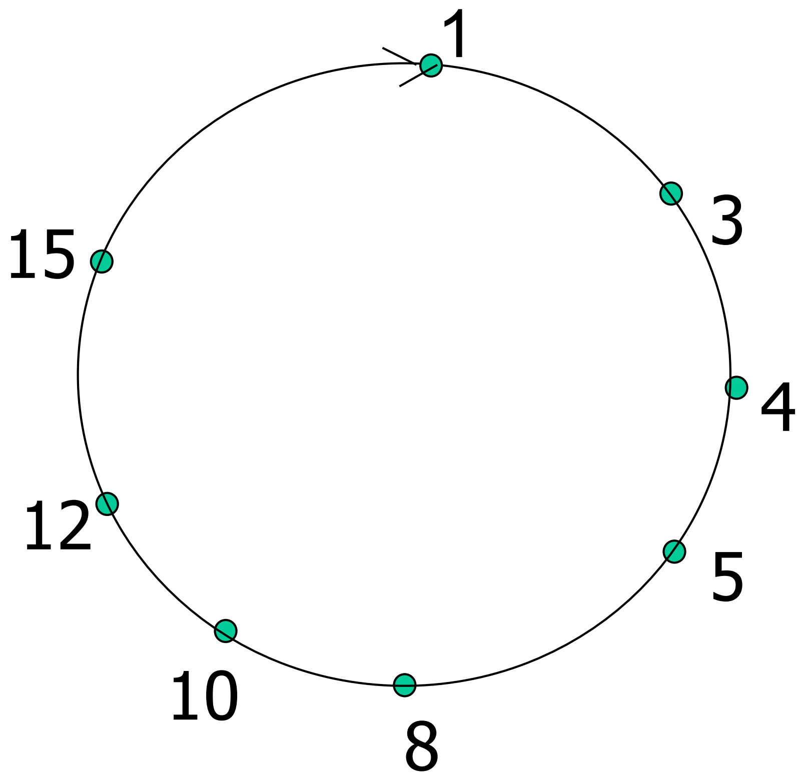
DHT identifiers: Consistent Hashing

- assign integer identifier to each peer in range $[0,2^n-1]$ for some *n*-bit hash function
  - E.g., node ID is hash of its IP address
- require each key to be an integer in same range
- to get integer key, hash original key
  - e.g., key = hash("The Boys Season 2")
  - this is why its is referred to as a *distributed "hash" table*

Assign keys to peers

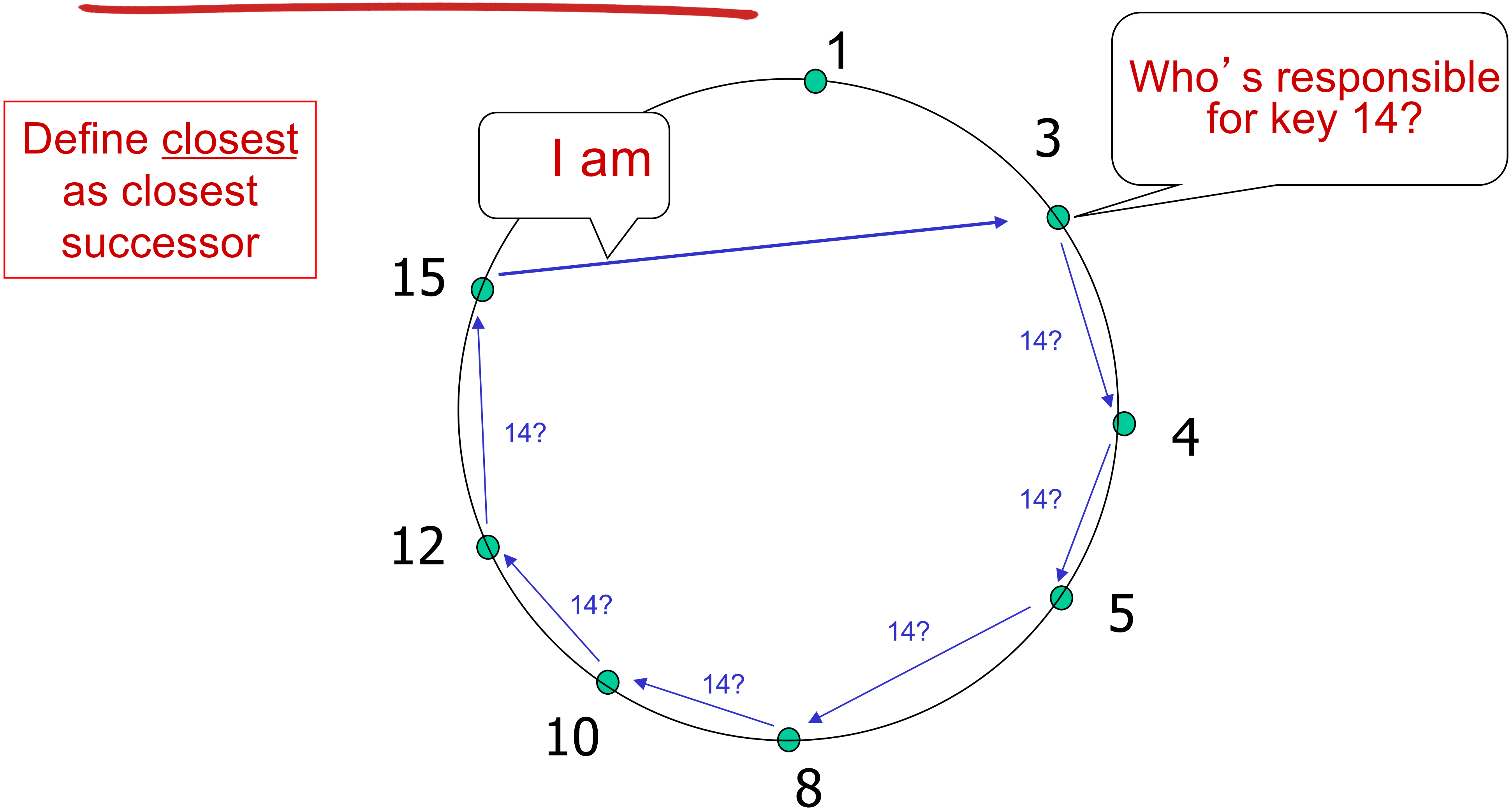
- rule: assign key to the peer that has the *closest* ID.
- common convention: closest is the *immediate successor* of the key.
- e.g., n=4; all peers & key identifiers are in the range [0-15], peers: 1,3,4,5,8,10,12,14;
  - key = 13, then successor peer = 14
  - key = 15, then successor peer = 1

Circular DHT (I)



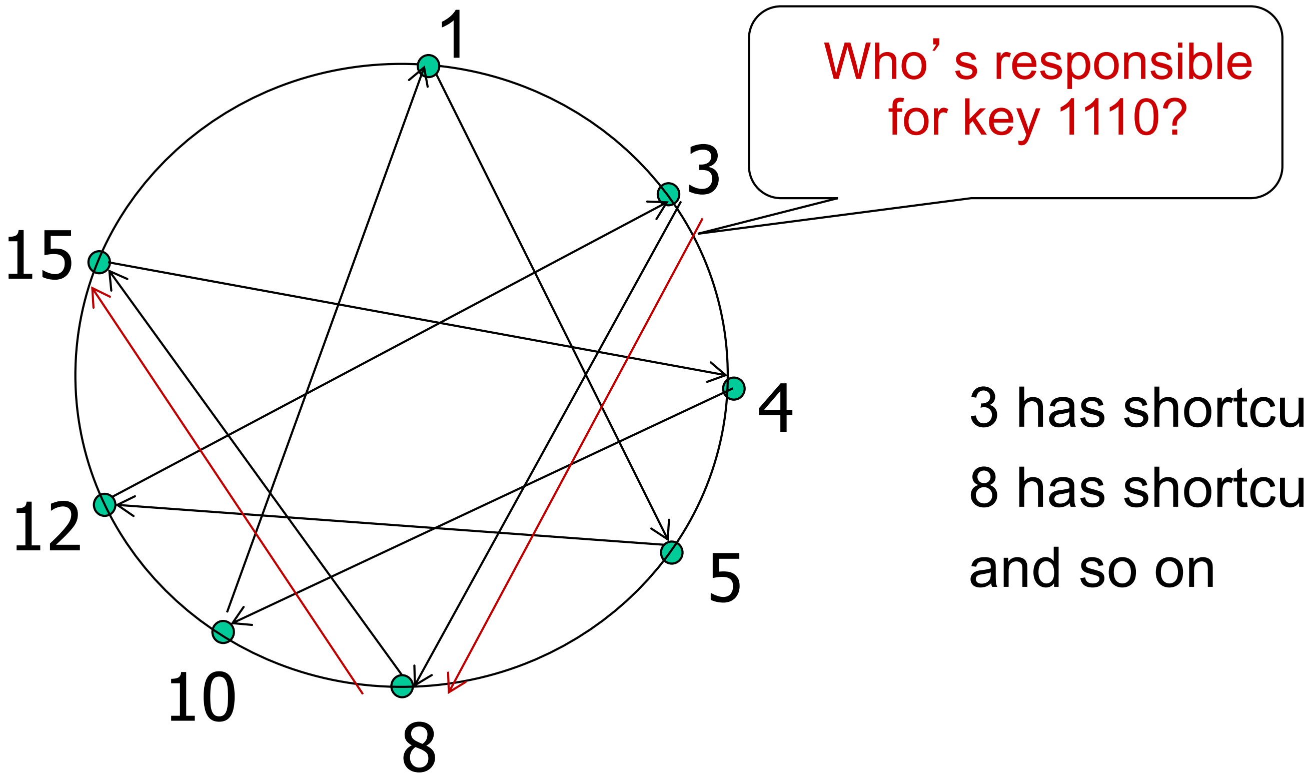
- each peer *only* aware of immediate successor and predecessor.
- "overlay network"

Circular DHT (2)



- Each peer maintains 2 neighbours
- In this example, 6 query messages are sent
- Worst case: N messages, Average: N/2 messages

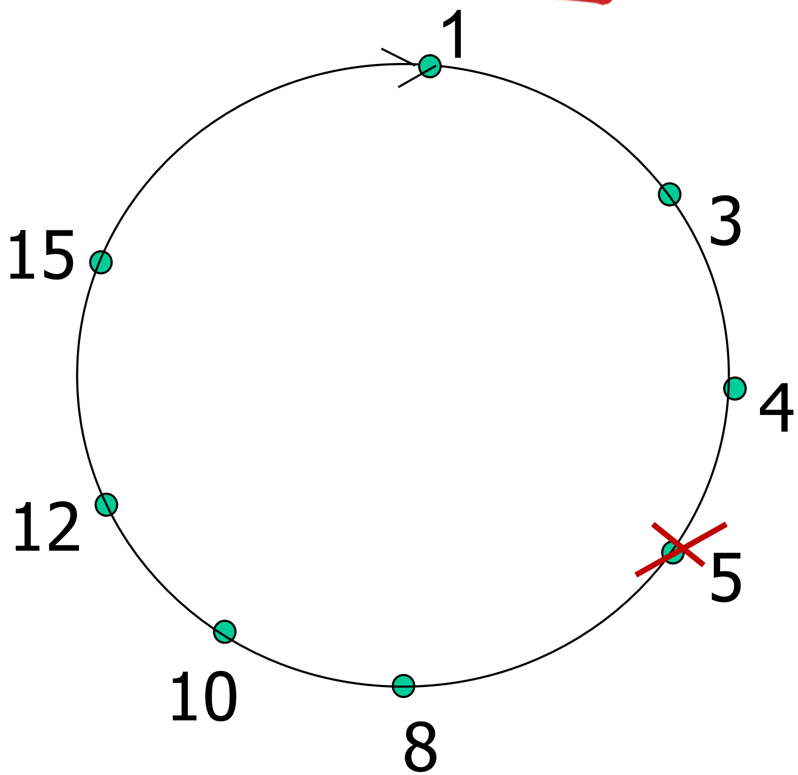
Circular DHT with shortcuts



3 has shortcut to 8
8 has shortcut to 15
and so on

- each peer keeps track of IP addresses of predecessor, successor, short cuts
- reduced from 6 to 2 messages.
- possible to design shortcuts so *O(log N)* neighbours, *O(log N)* messages in query

Peer churn



handling peer churn:

- peers may come and go (churn)
- each peer knows address of its two successors
- each peer periodically pings its two successors to check aliveness
- if immediate successor leaves, choose next successor as new immediate successor

example: peer 5 abruptly leaves

- peer 4 detects peer 5 departure; makes 8 its immediate successor; asks 8 who its immediate successor is; makes 8's immediate successor its second successor.

More DHT info

- How do nodes join?
- How does cryptographic hashing work?
- How much state does each node store?

Research Papers (on the webpage):
Chord: A Scalable Peer-to-Peer Lookup Service for Internet Applications
NOT MANDATORY READING

Quiz: BitTorrent

- BitTorrent uses tit-for-tat in each round to

a) Determine which chunks to download
b) Determine from which peers to download chunks
c) Determine to which peers to upload chunks
d) Determine which peers to report to the tracker as uncooperative
e) Determine whether or how long it should stay after completing download

ANSWER: c)

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Quiz: BitTorent

- Suppose Todd joins a BitTorrent torrent, but he does not want to upload any data to any other peers. Todd claims that he can receive a complete copy of the file that is shared by the swarm. Is Todd's claim possible? Why or Why not (one short sentences)?

ANSWER: Yes. Todd may receive chunks through the optimistic unchoke process. However, it will take Todd a much longer time to obtain the file.

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Application Layer: outline

2.1 principles of network applications

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

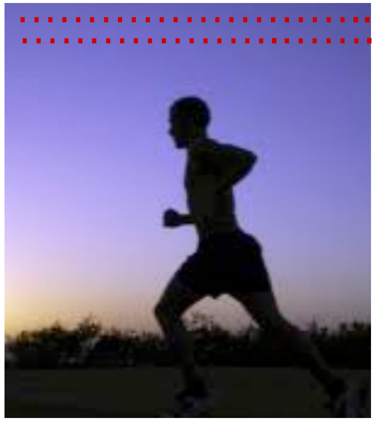
Video Streaming and CDNs: context

- video traffic: major consumer of Internet bandwidth
  - Netflix, YouTube: 37%, 16% of downstream residential ISP traffic
  - ~1.8B YouTube users, ~140M Netflix users
- challenge: scale - how to reach ~2B 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*

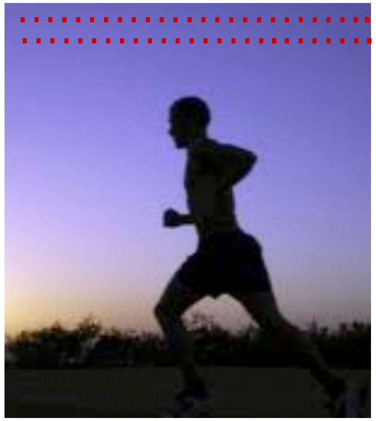
temporal coding example: instead of sending complete frame at i+1, send only differences from frame i

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 1 (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)



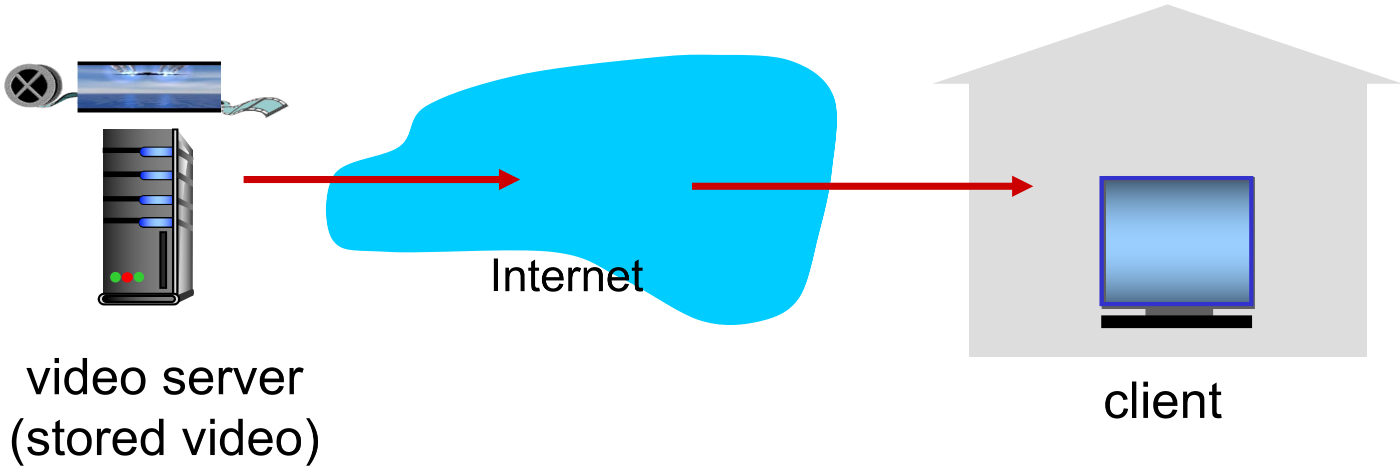
frame *i*

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:

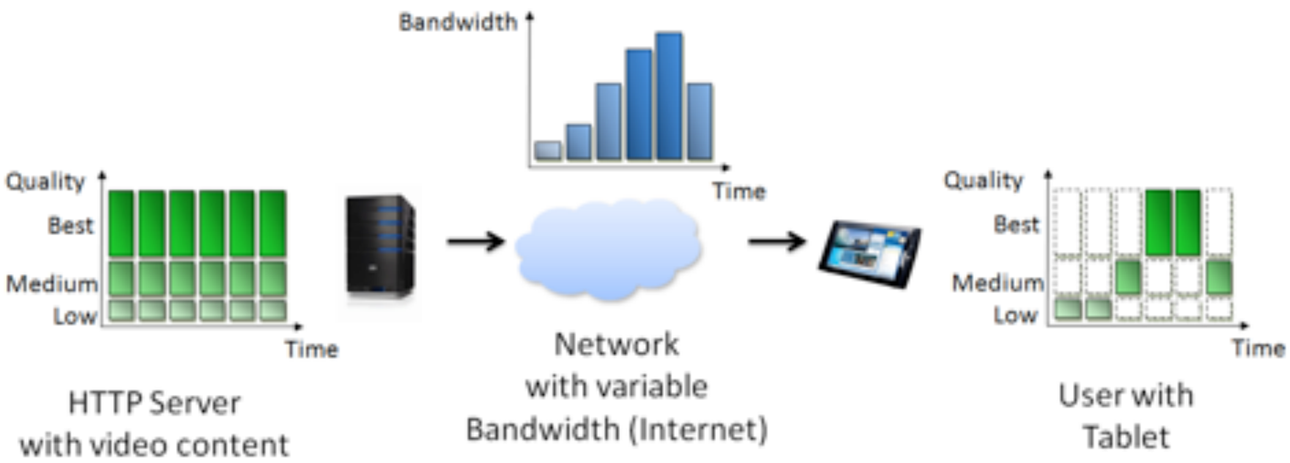


Streaming multimedia: DASH

- *DASH: D*ynamic, *A*daptive *S*treaming over *H*TTP
- *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 from (can request from URL server that is "close" to client or has high available bandwidth)



Content Distribution Networks (CDNs)

- *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 (CDNs)

- *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

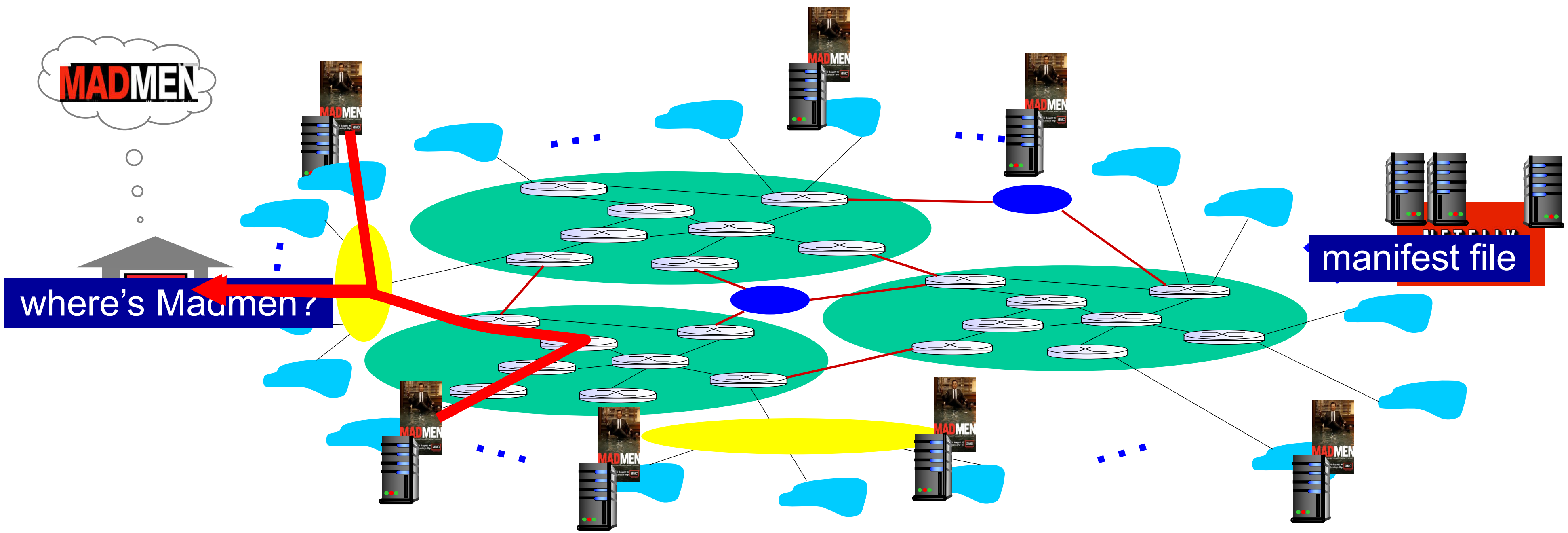
An example

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

; <<>> DiG 9.10.6 <<>> www.mit.edu
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 17913
;; flags: qr rd ra; QUERY: 1, ANSWER: 3, AUTHORITY: 8, ADDITIONAL: 8

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;www.mit.edu.                   IN      A

;; ANSWER SECTION:
www.mit.edu.            924     IN      CNAME   www.mit.edu.edgekey.net.
www.mit.edu.edgekey.net. 54     IN      CNAME   e9566.dscb.akamaiedge.net.
e9566.dscb.akamaiedge.net. 14   IN      A       23.77.154.132

;; AUTHORITY SECTION:
dscb.akamaiedge.net.    623     IN      NS      n0dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n2dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n7dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n6dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n1dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n3dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n5dscb.akamaiedge.net.
dscb.akamaiedge.net.    623     IN      NS      n4dscb.akamaiedge.net.

;; ADDITIONAL SECTION:
n0dscb.akamaiedge.net.  1241    IN      A       88.221.81.192
n0dscb.akamaiedge.net.  1124    IN      AAAA    2600:1480:e800::c0
n1dscb.akamaiedge.net.  842     IN      A       23.32.5.76
n2dscb.akamaiedge.net.  749     IN      A       23.32.5.84
n4dscb.akamaiedge.net.  1399    IN      A       23.32.5.177
n6dscb.akamaiedge.net.  702     IN      A       23.32.5.98
n7dscb.akamaiedge.net.  1208    IN      A       23.206.243.54

;; Query time: 46 msec
;; SERVER: 129.94.172.11#53(129.94.172.11)
;; WHEN: Mon Sep 28 13:15:28 AEST 2020
;; MSG SIZE  rcvd: 421
```

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

Content Distribution Networks (CDNs)

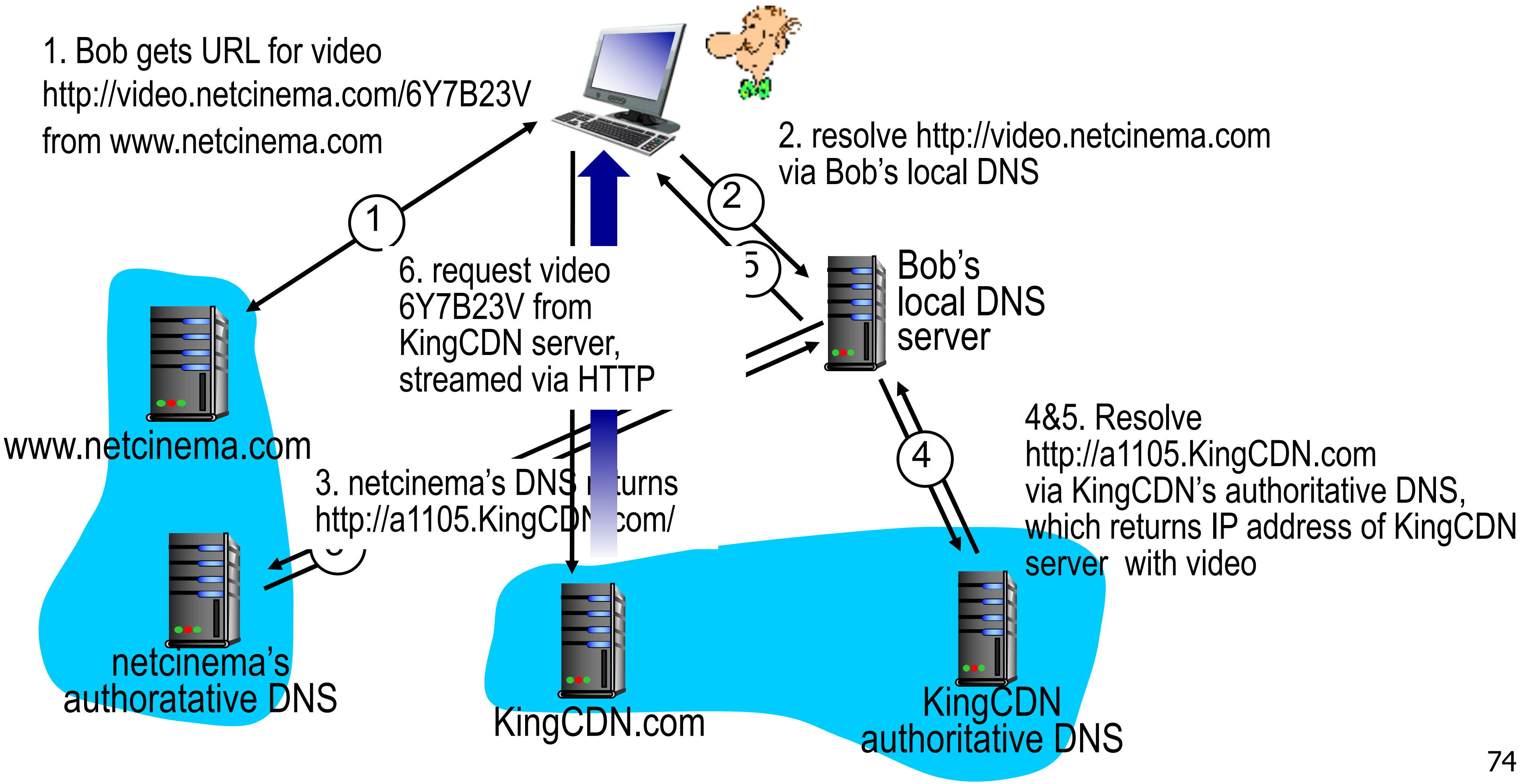
- CDN: stores copies of content at CDN nodes
  - e.g. Netflix stores copies of MadMen
- subscriber requests content from CDN
  - directed to nearby copy, retrieves content
  - may choose different copy if network path congested



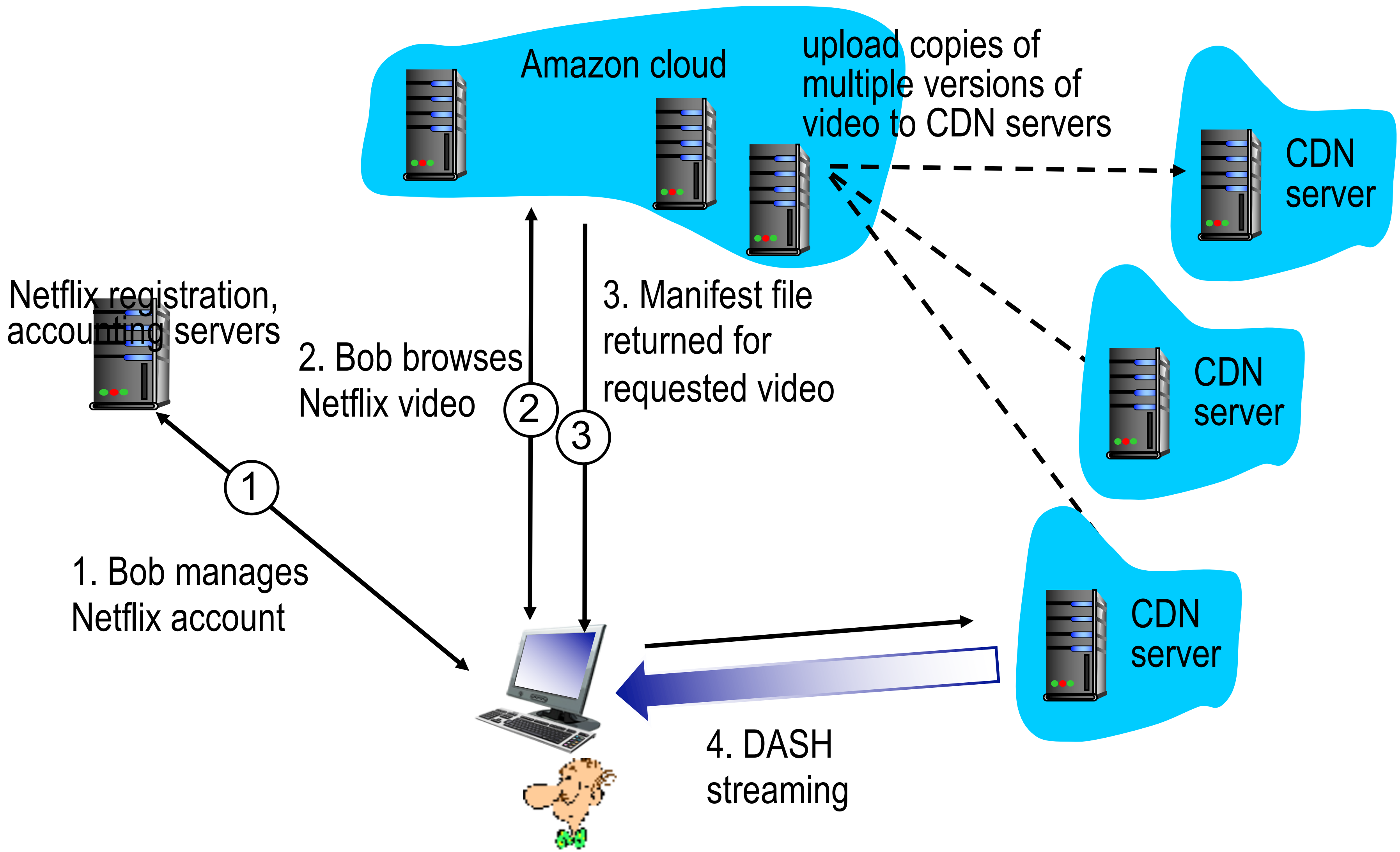
CDN content access: a closer look

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

- video stored in CDN at managed by KingCDN.com

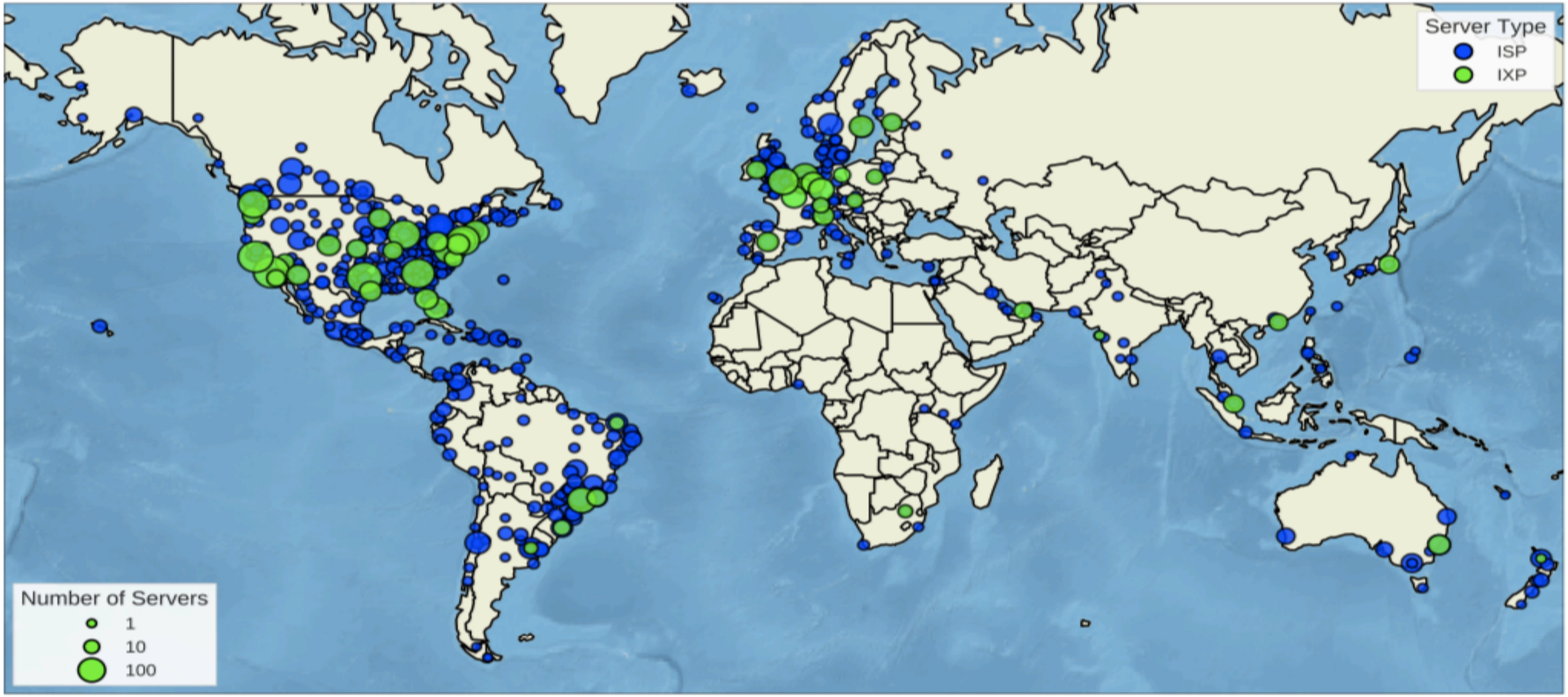


Case study: Netflix



Uses Push caching (during offpeak)
Preference to "deep inside" followed by "bring home"

NetFlix servers (snap shot from Jan 2018)



Researchers from Queen Mary University of London (QMUL) traced server names that are sent to a user's computer every time they play content on Netflix to find the location of the 8492 servers (4152 ISP, 4340 IXP).They have been found to be scattered across 578 locations around the world.

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

ANSWER: b)

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2. Application Layer: outline

2.1 principles of network applications
- app architectures
- app requirements

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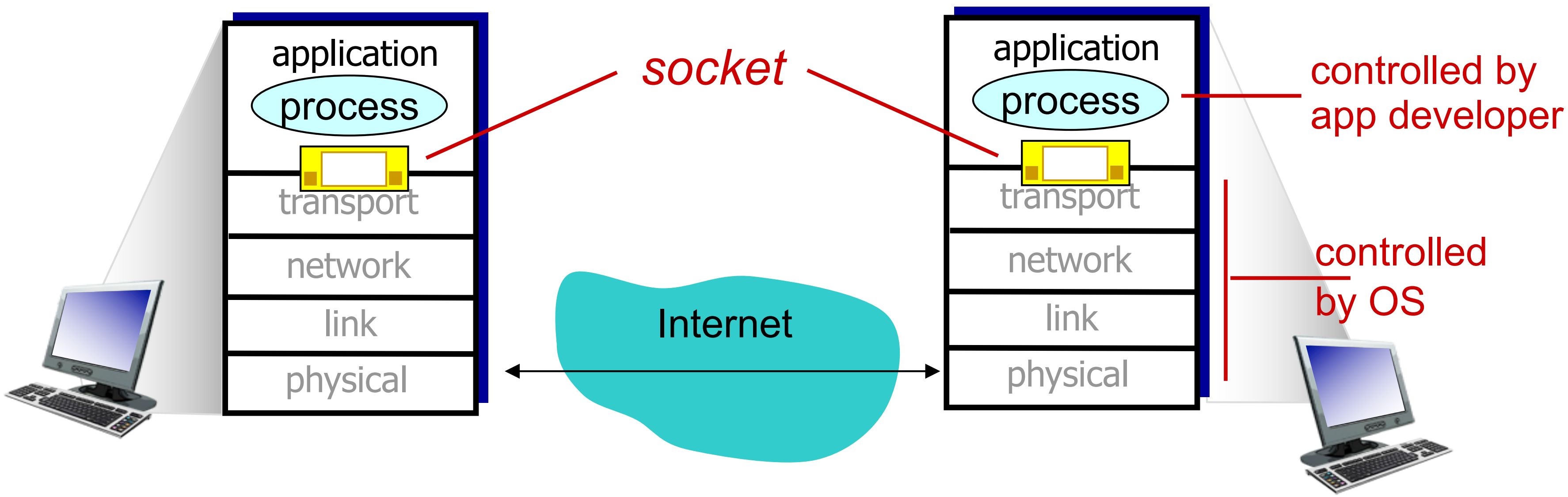
2.7 socket programming with UDP and TCP

Please see example code (C, Java, Python) on course website
Labs 2 & 3 will include a socket programming exercise

Socket programming

goal: learn how to build client/server applications that communicate using sockets

socket: door between application process and end-end-transport protocol



Socket programming *with UDP*

UDP: no "connection" between client & server

- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- rcvr extracts sender IP address and port# from received packet

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

Application viewpoint:

- UDP provides *unreliable* transfer of groups of bytes ("datagrams") between client and server

Pseudo code UDP client

- Create socket
- Loop
  - (Send UDP datagram to known port and IP addr of server)

  - (Receive UDP datagram as a response from server)
- Close socket

Pseudo code UDP server

- Create socket
- Bind socket to a specific port where clients can contact you
- Loop
  - (Receive UDP datagram from client X)

  - (Send UDP datagram as reply to client X)
- Close socket

Note: The IP address and port number of the client must be extracted from the client's message

Socket programming *with TCP*

client must contact server

- server process must first be running
- server must have created socket (door) that welcomes client's contact

client contacts server by:

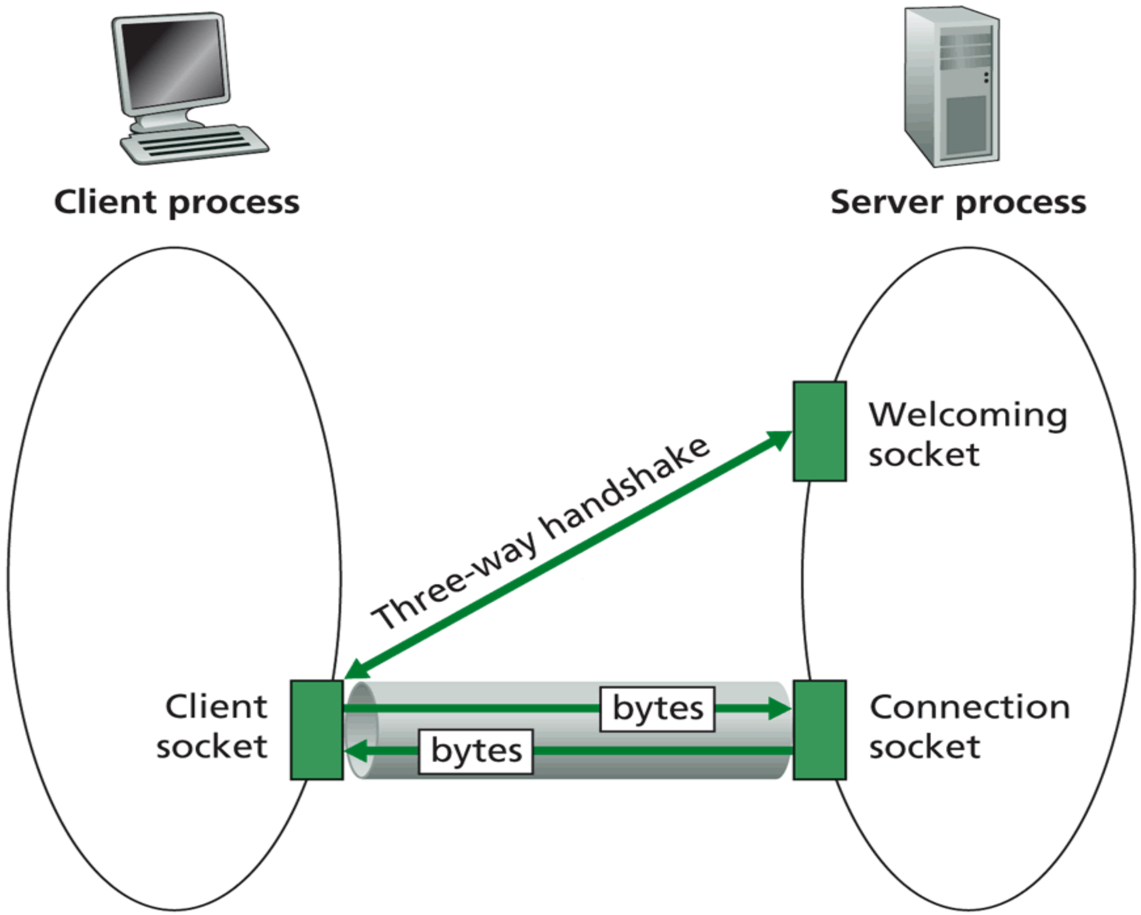
- Creating TCP socket, specifying IP address, port number of server process
- *when client creates socket:* client TCP establishes connection to server TCP

- when contacted by client, *server TCP creates new socket* for server process to communicate with that particular client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients (more later)

application viewpoint:

TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server

TCP Sockets



Client process
Server process
Welcoming socket
Three-way handshake
Client socket
bytes
bytes
Connection socket

Pseudo code TCP client

- Create socket (ConnectionSocket)
- Do an active connect specifying the IP address and port number of server
- Read and write data into ConnectionSocket to communicate with client
- Close ConnectionSocket

Pseudo code TCP server

- Create socket (WelcomingSocket)
- Bind socket to a specific port where clients can contact you
- Register with the OS your willingness to listen on that socket for clients to contact you
- Loop
  - Accept new connection(ConnectionSocket)
  - Read and write data into ConnectionSocket to communicate with client
  - Close ConnectionSocket
- Close WelcomingSocket

Queues

- While the server socket is busy, incoming connection requests are stored in a queue
- Once the queue fills up, further incoming connections are refused
- This is clearly a problem
  - Example: HTTP servers
- Solution
  - Concurrency

Concurrent TCP Servers

- Benefit comes in ability to hand off interaction with a client to another process
- Parent process creates the WelcomingSocket and waits for clients to request connection
- When a connection request is received, fork off a child process to handle that connection so that the parent process can return to waiting for connections as soon as possible
- Multithreaded server: same idea, just spawn off another thread rather than a process

Summary

our study of network apps now complete!

- application architectures
  - client-server
  - P2P
- application service requirements:
  - reliability, bandwidth, delay
- Internet transport service model
  - connection-oriented, reliable: TCP
  - unreliable, datagrams: UDP
- specific protocols:
  - HTTP
  - SMTP, POP, IMAP
  - DNS
  - P2P: BitTorrent, DHT
- video streaming, CDNs
- socket programming:

  TCP, UDP sockets