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://webhostinggeeks.com/guides/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:

Match the name to the server

- *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"

ip address is hard to remember, that is why we have DNS

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
- 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

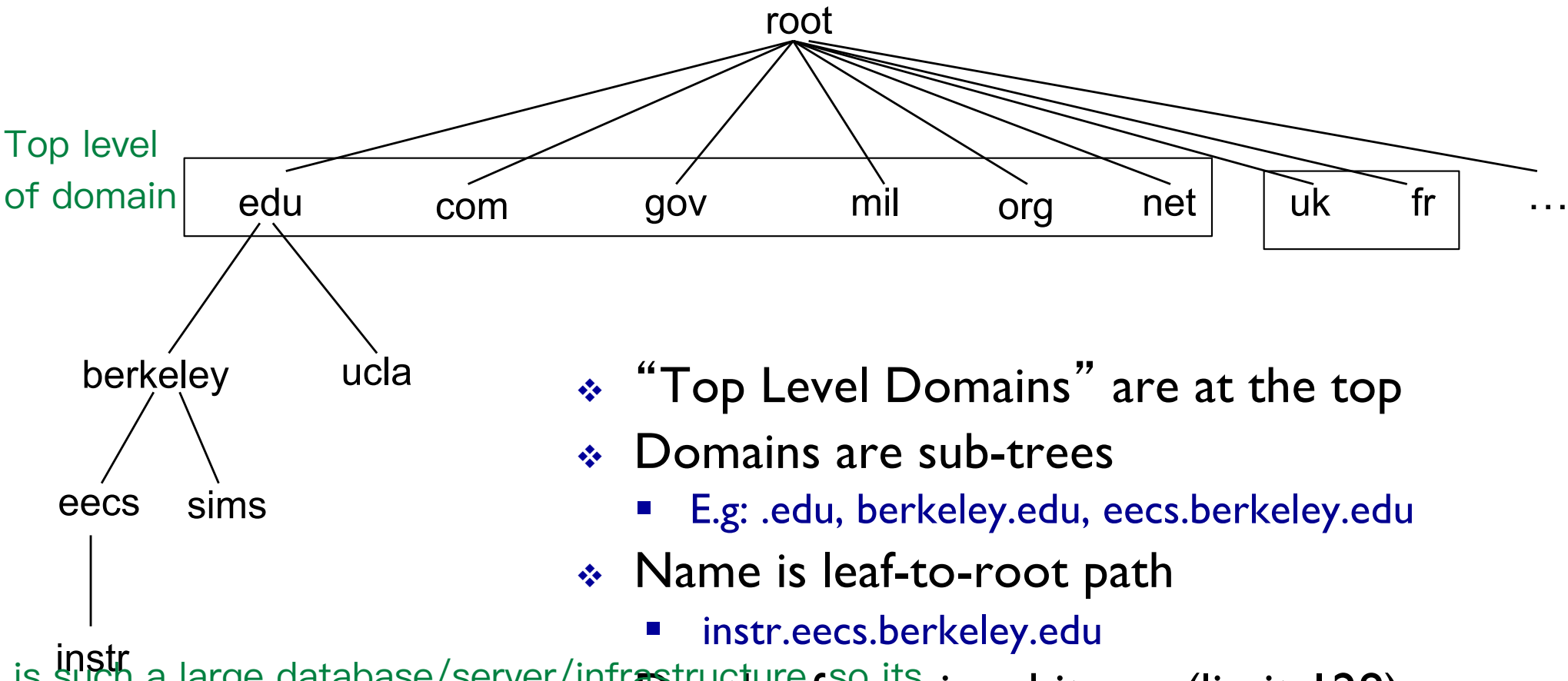
- No naming conflicts (uniqueness)
- Scalable
  - many names
  - (secondary) frequent updates
- Distributed, autonomous 自主的 administration
  - Ability to update my own (machines') names
  - Don't have to track everybody's updates
- Highly available
- Lookups should be fast

Key idea: Hierarchy

Three intertwined hierarchies

- Hierarchical namespace
  - As opposed to original flat namespace
- Hierarchically administered 分层次管理
  - As opposed to centralised
- (Distributed) hierarchy of servers 层次结构的服务器
  - As opposed to centralised storage

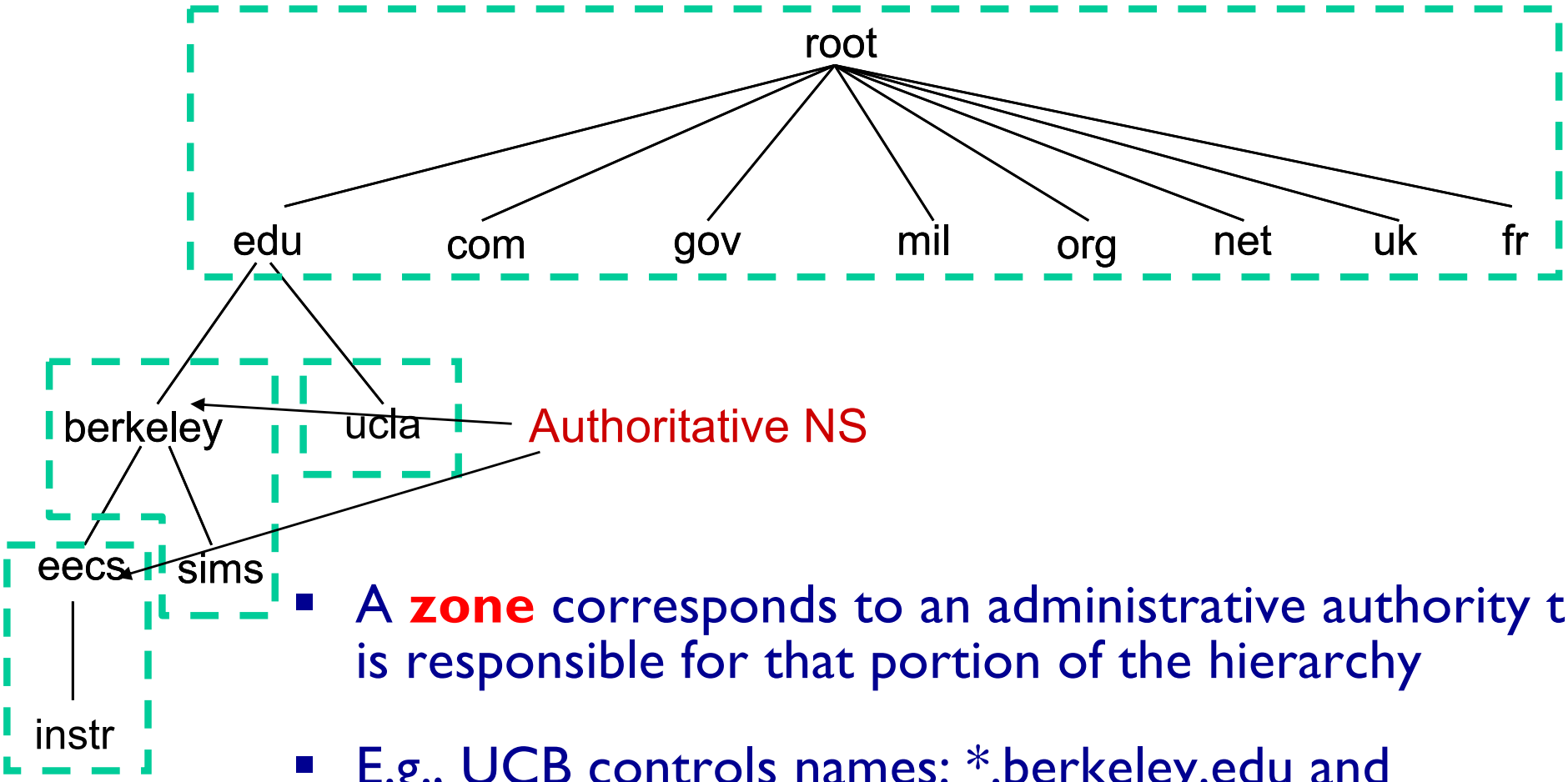
Hierarchical Namespace



- "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

dns is such a large database/server/infrastructure, so its administration should be hierarchical and different administrative organization should be responsible for a certain part of the DNS server.(such as unsw should be responsible for the hostname unsw.)

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

different department take charge of different level(part) of the server

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

The top level just know where to go and find it

Server Hierarchy

- Top of hierarchy: Root servers
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, etc.
  - Managed professionally

Because it's the actual situation.for example, CSE take charge of the VLAB imformation

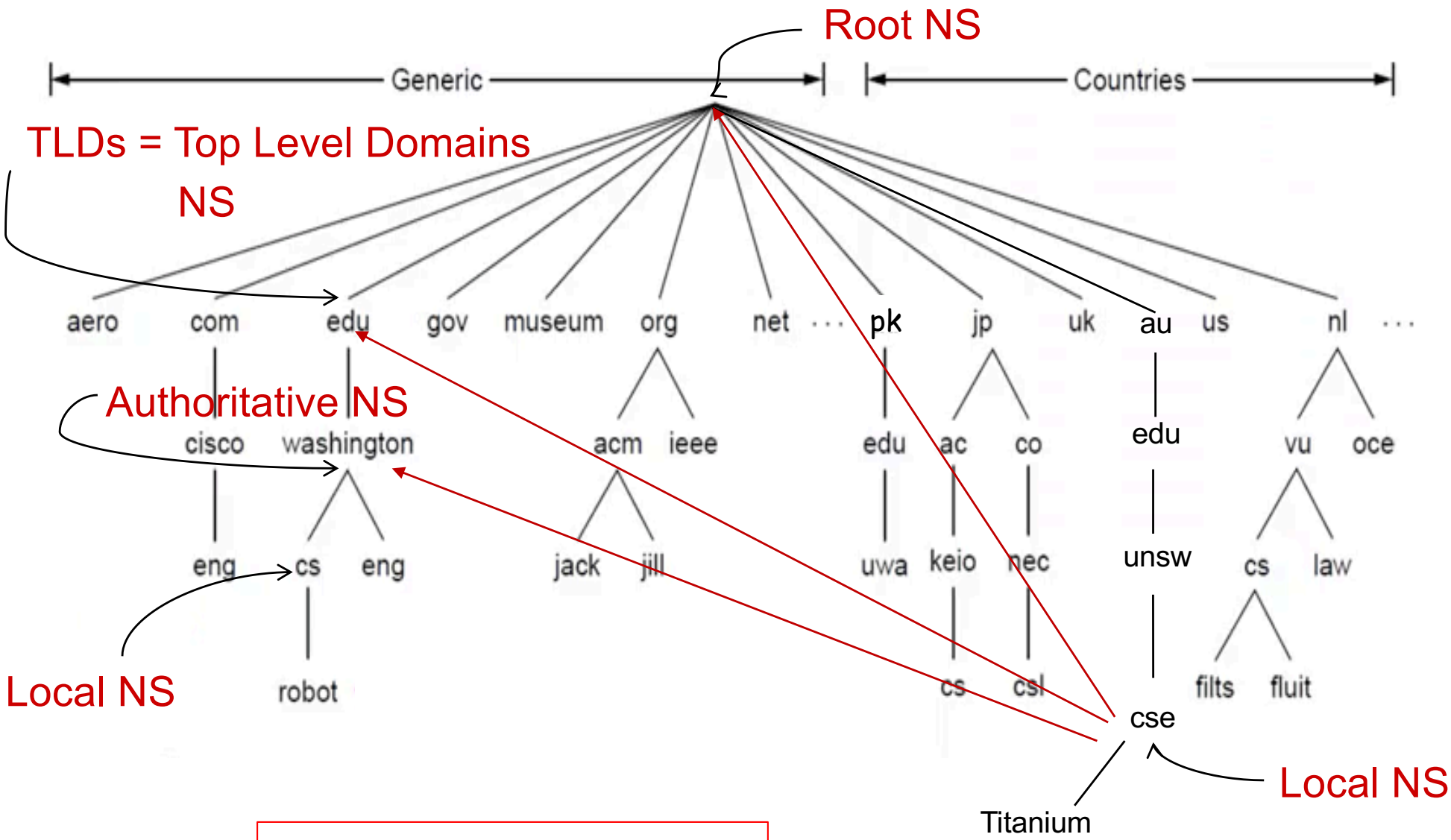
- Bottom Level: Authoritative DNS servers
  - Actually store the name-to-address mapping
  - Maintained by the corresponding administrative authority

The top one is not the authoritative one. Because that's the leaves take charge of the facilities, service, decision and etc.

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: a distributed, hierarchical database



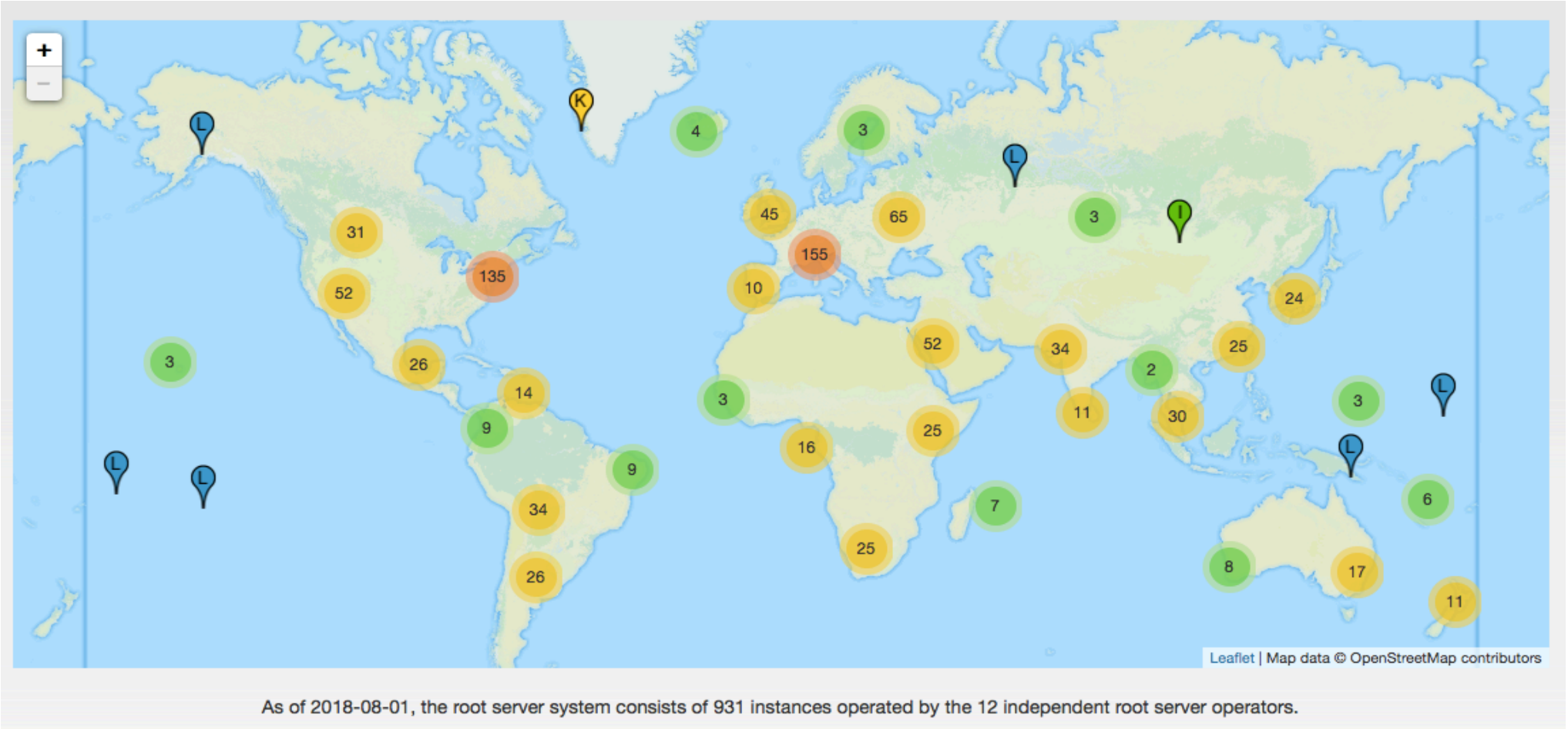
robot.cs.**washington**.edu

DNS Root Servers

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

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 is out of the hirearchy

Local DNS name server

Domain network system

Browser cache(chrome) hold some DNS cache. But this is not a DNS cache.

- 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 **getaddrinfo()** 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

But the DNS has no authority to control the DNS server

Traffic and response time are two essential issue. And local DNS act as a proxy

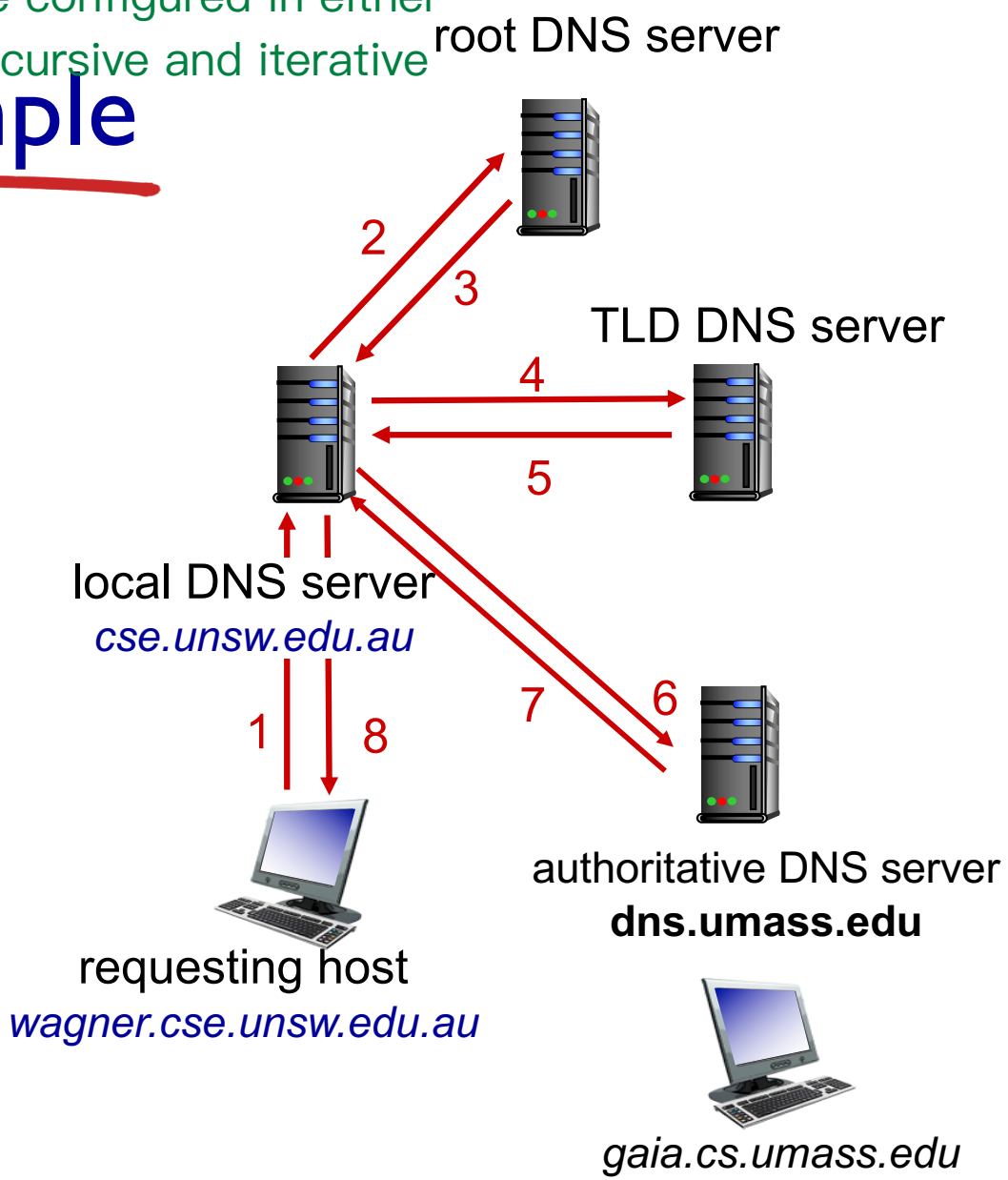
DNS name resolution example

The DNS name server can be configured in either recursive and iterative

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

iterated query:

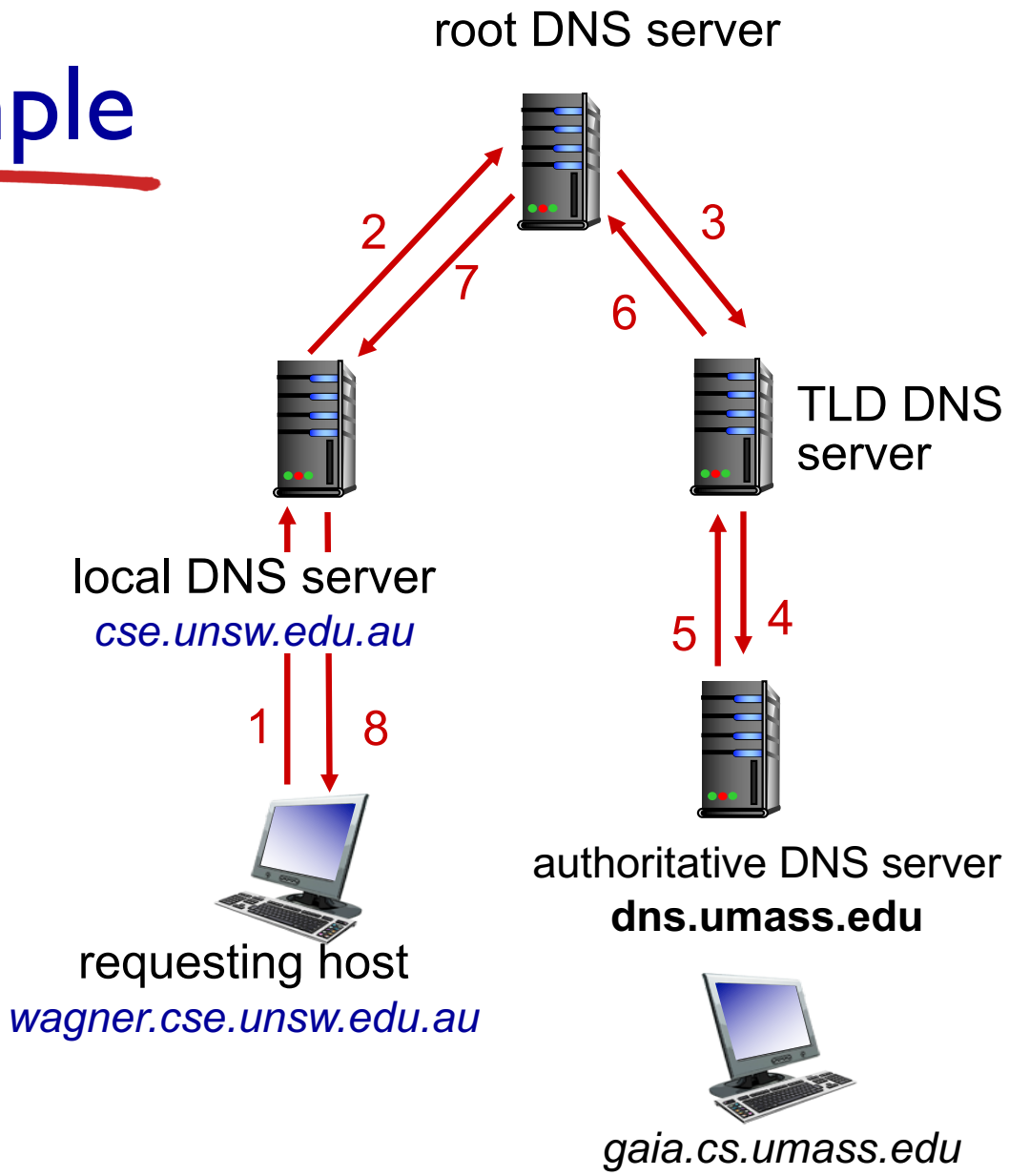
- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"



DNS name resolution example

recursive query:

- puts burden of name resolution on contacted name server



Caching can be done in any hierarchy

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

top–level domain

- 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

sometimes more than one domain name resolves to the same IP address, and this is where the CNAME is useful

DNS records

Value is something that can be used to find the IP address

DNS: distributed db storing resource records (RR)

Decide the meaning of name and value

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

time to live

Domain name(name of the machine)

type=A

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

type=NS

Authoritative name server

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

Responsible for that domain

type=CNAME

- **name** is alias name for some "canonical" (the real) name
- **www.ibm.com** is really Name **servereast.backup2.ibm.com**
- **value** is canonical name 规范名

type=MX

Mail server

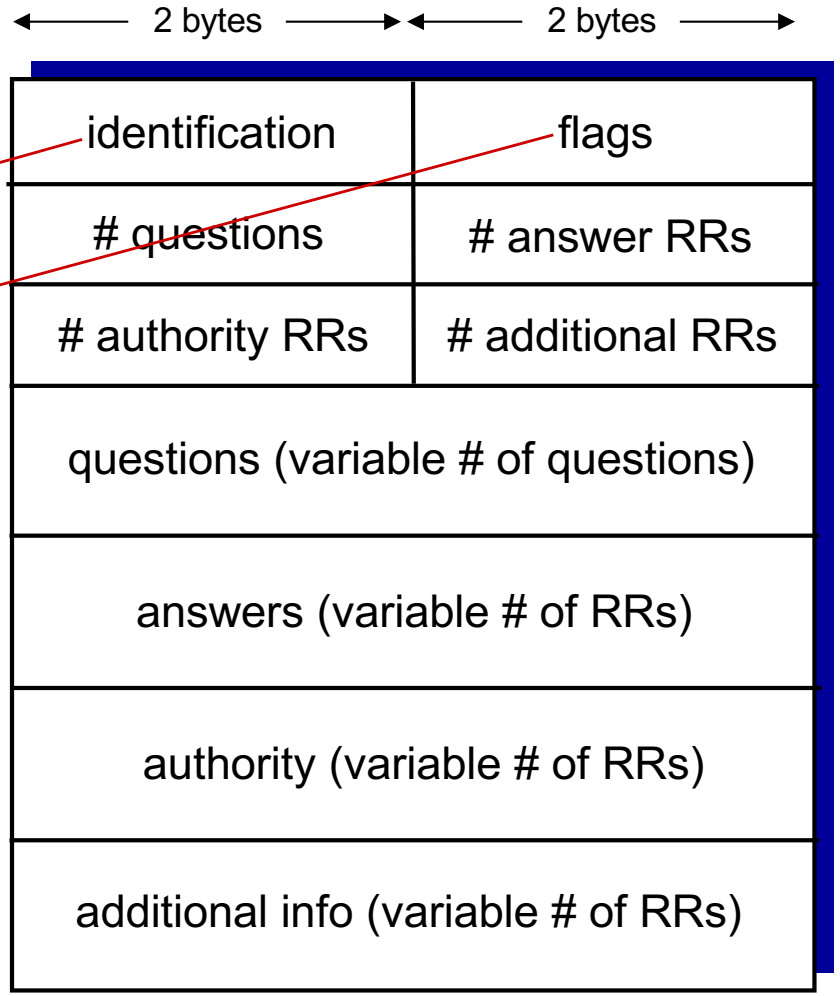
- **value** is name of mailserver associated with **name**

DNS protocol, messages

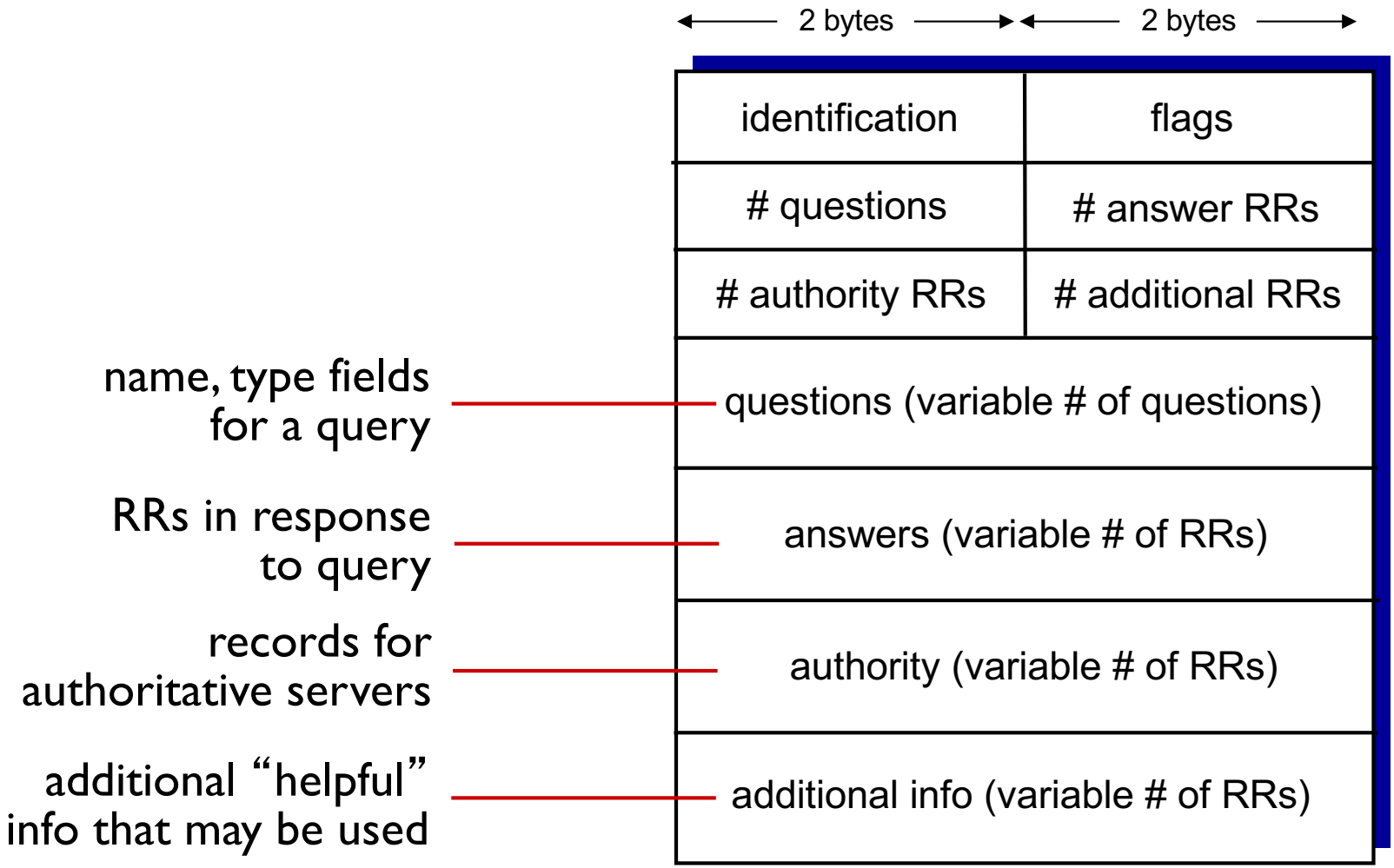
- *query* and *reply* messages, both with same *message format*

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

Try this out yourself. Part of one of the lab

```
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
oxford.ac.uk.           86399   IN
oxford.ac.uk.           86399   IN
oxford.ac.uk.           86399   IN

;; ADDITIONAL SECTION:
ns2.ja.net.             33560   IN
ns2.ja.net.             33560   IN
dns0.ox.ac.uk.          48090   IN
dns1.ox.ac.uk.          86399   IN
dns2.ox.ac.uk.          54339   IN

;; Query time: 589 msec
;; SERVER: 129.94.172.11#53(129.94.
;; WHEN: Thu Mar  9 17:53:52 2017
;; MSG SIZE  rcvd: 242
```

- 如果Type=A，则Name是主机名，Value是该主机名的IP地址。因此，一条类型为A的资源记录提供了标准的主机名到IP地址的映射。例如，(relay1.bar.foo.com, 145.37.93.126, A) 就是一条类型A的记录。
- 如果Type=NS，则Name是域（如foo.com），而Value是知道如何获得该域中主机IP地址的权威DNS服务器的主机名。这个记录用于沿着查询链路进一步路由DNS查询。例如，(foo.com, dns.foo.com, NS) 就是一条类型NS的记录。
- 如果Type=CNAME，则Value是别名为Name的主机对应的规范主机名。该记录能够向请求主机提供一个主机名对应的规范主机名，例如，(foo.com, relay1.bar.foo.com, CNAME) 就是一条CNAME类型的记录。
- 如果Type=MX，则Value是别名为Name的邮件服务器的规范主机名。例如，(foo.com, mail.bar.foo.com, MX) 就是一条MX记录。MX记录允许邮件服务器的主机名具有简单的别名。注意，通过使用MX记录，一个公司的邮件服务器和其他服务器（如它的Web服务器）可以使用相同的别名。为了获得邮件服务器的规范主机名，DNS客户机应当请求一条MX记录；而为了获得其他服务器的规范主机名，DNS客户机应当请求一条CNAME记录。

you're a new company and assume that you have so many server, (http, mail server, etc)you want people to find your server for service. But how? As the main server name would not change.

Inserting records into DNS

- example: new startup "Network Utopia"
- register name networkutopia.com at *DNS registrar* (e.g., Network Solutions)

Multiple nowadays

  - provide names, IP addresses of authoritative name server (primary and secondary)

Name of the authority name server for your domain

  - registrar inserts two RRs into .com TLD server:

Domain name of company

```
(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

Udp is used for DNS because it's faster and the message used for communication is small–sized

- 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

Flexibility

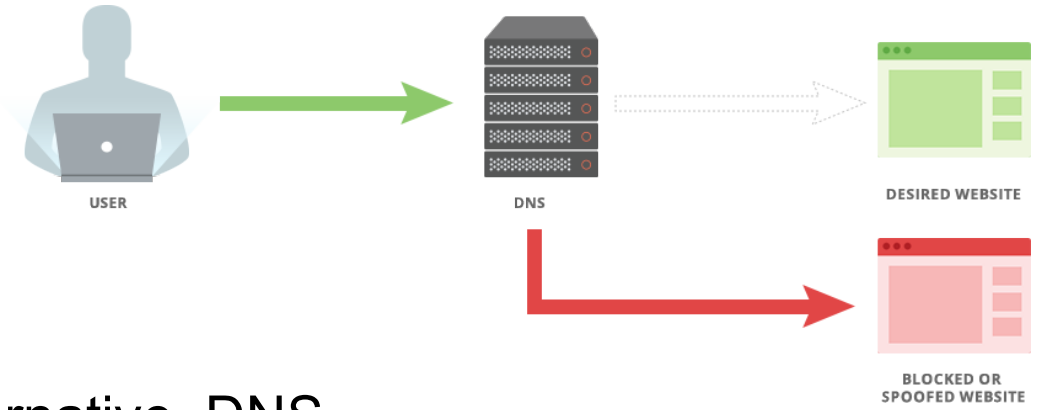
- Addresses can change underneath
  - Move www.cnn.com to 4.125.91.21
  - Humans/Apps should be unaffected
- Name could map to multiple IP addresses
  - Enables
    - Load-balancing
    - Reducing latency by picking nearby servers
- Multiple names for the same address
  - E.g., many services (mail, www,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



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
- 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

IoT Attack Against a University Network

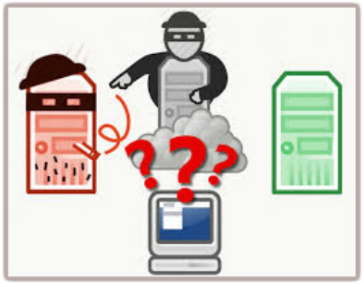
Verizon's *Data Brief Digest 2017* describes an attack against an unnamed university by attackers who hacked a variety of IoT devices and had them spam network targets and slow them down:

> 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

Dig deeper?

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

DNSSEC: DNS Security Extensions,
https://www.dnssec.net

DNS over HTTPs (DoH):
https://developers.cloudflare.com/1.1.1.1/dns-over-https/

Quiz: DNS

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

c

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

Quiz: DNS

- Which of the following DNS resource record types return an IP address as the answer (i.e. in the answer field of the DNS response message)?

a) A
b) A and NS
c) A, NS and CNAME
d) NS and CNAME
e) NS, CNAME and MX

NS doesn't store an IP address, but if sending a request with IP address. The return would contain a IP address

B

Application Layer: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

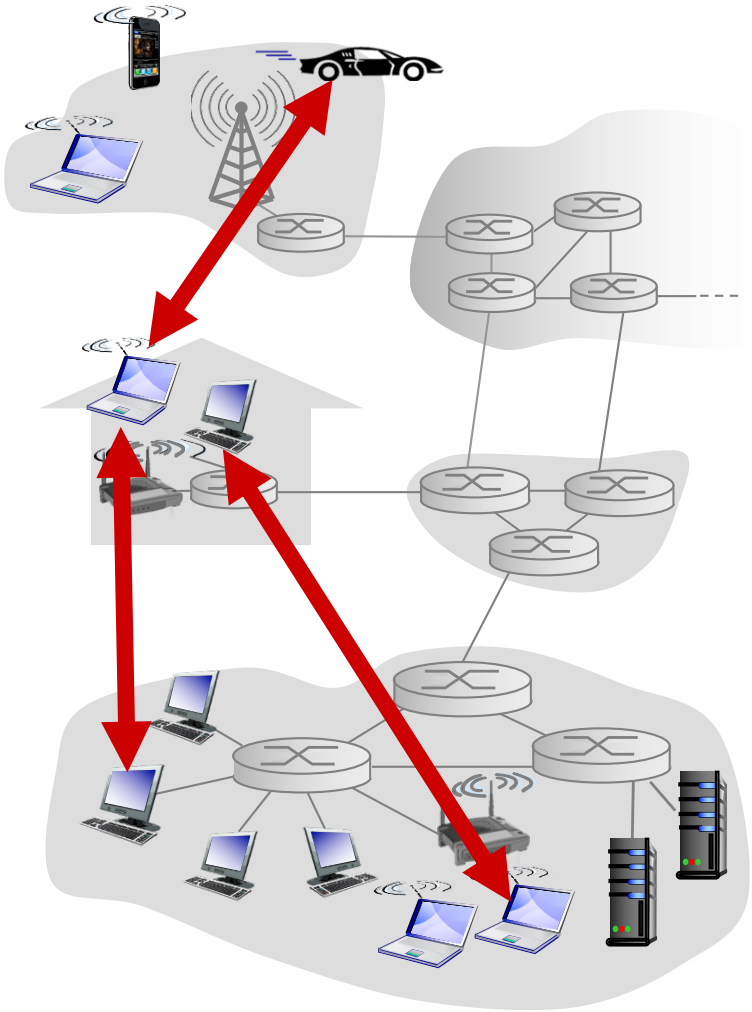
2.5 P2P applications

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



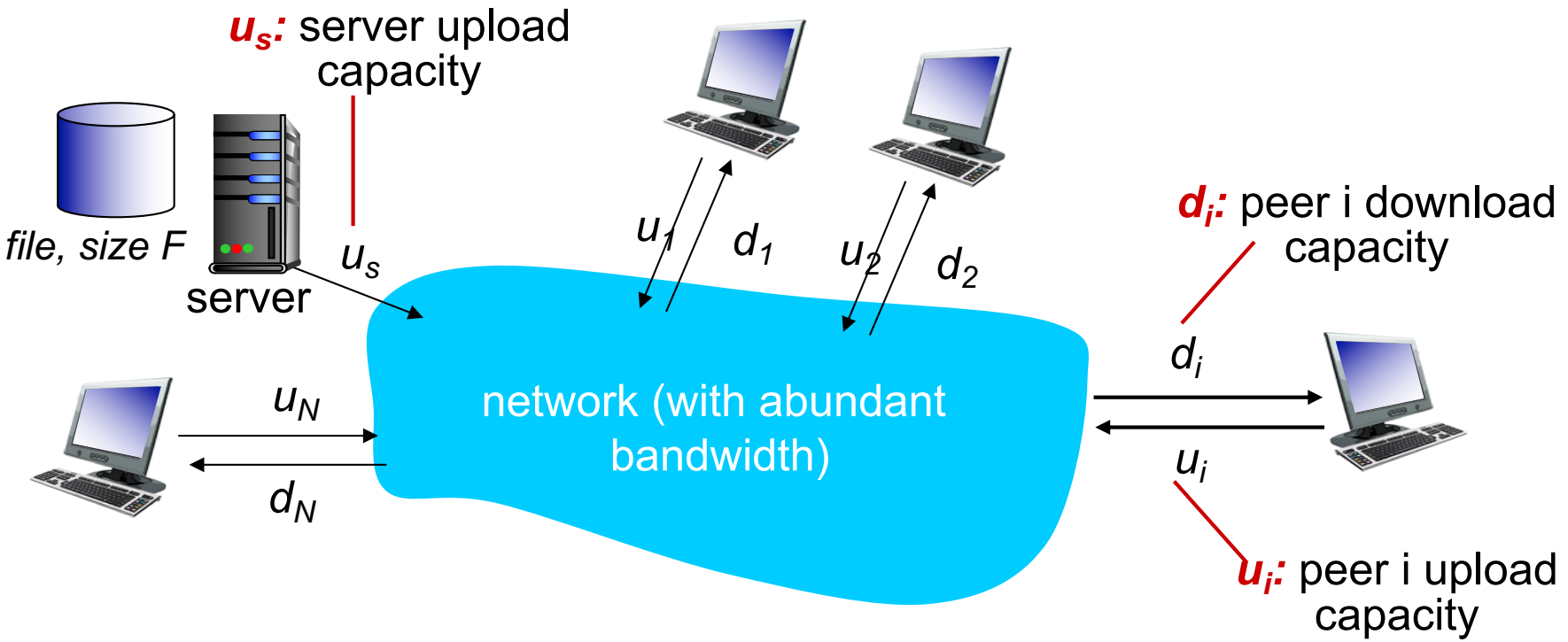
examples:

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

File distribution: client-server vs P2P

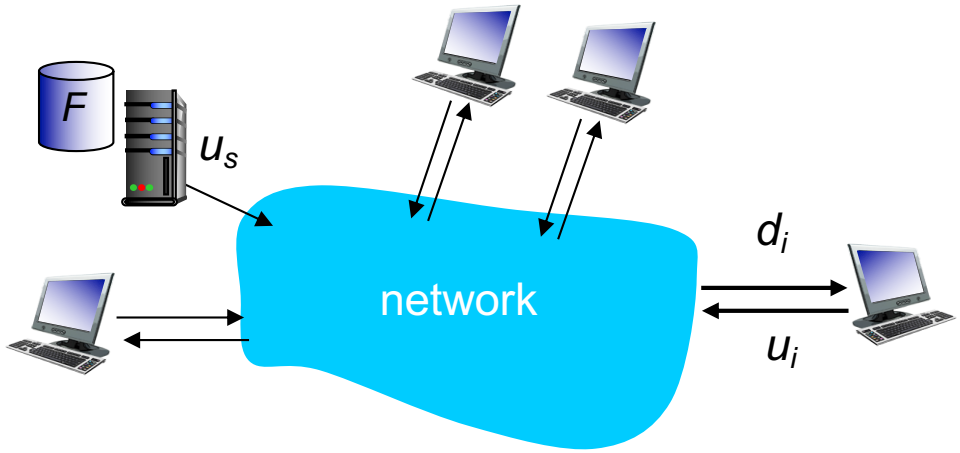
Question: how much time to distribute file (size *F*) from one server to *N* peers?

- 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}

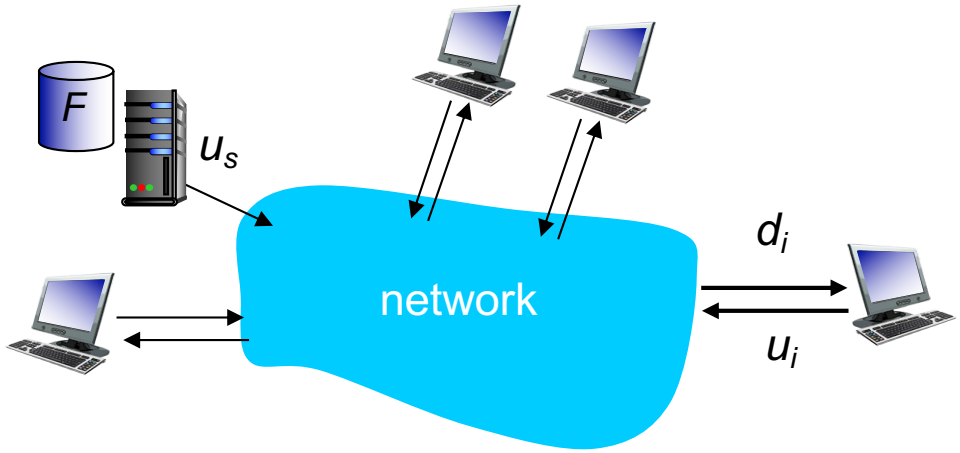
time to distribute F to N clients using client-server approach

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

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

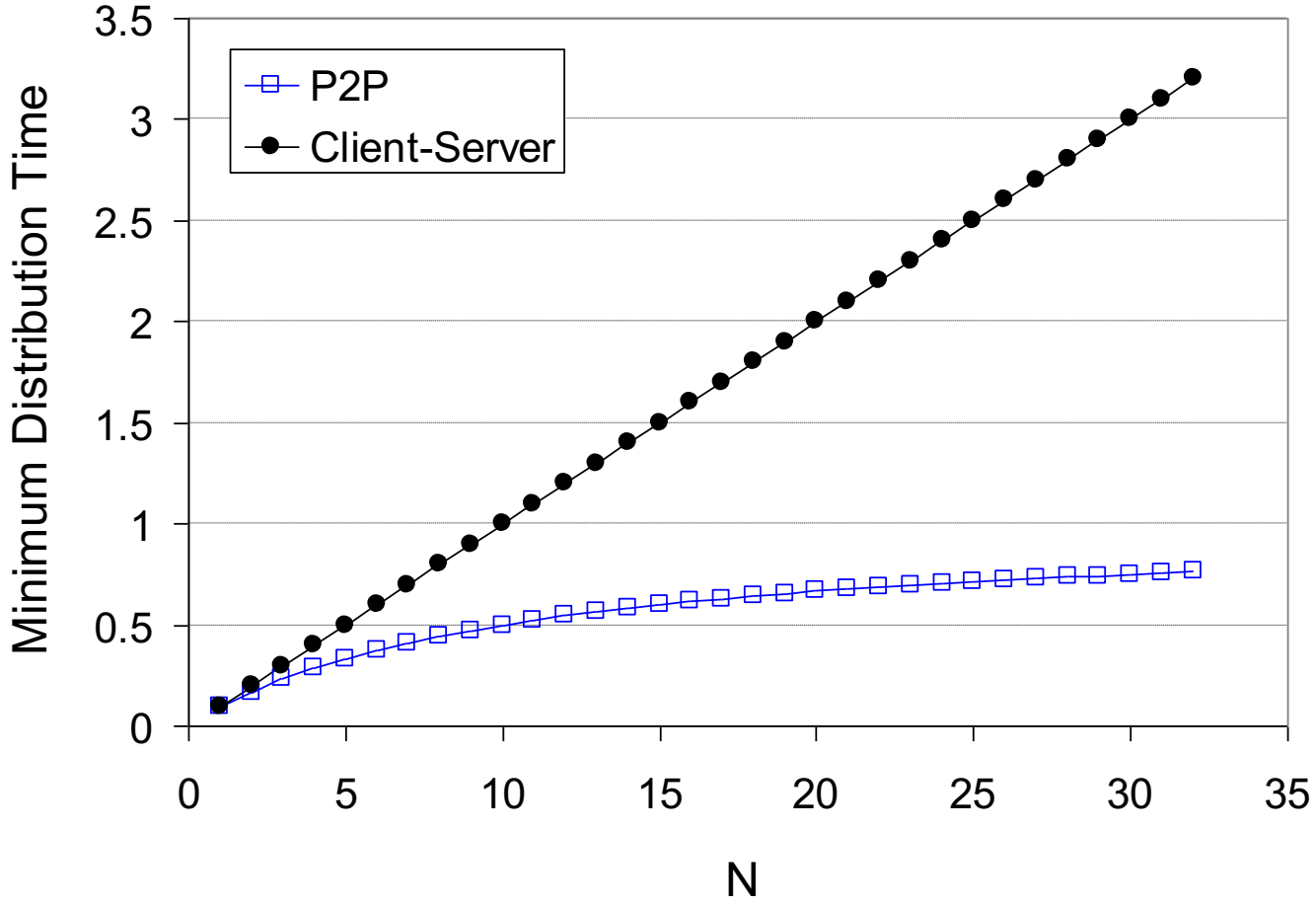
Client-server vs. P2P: ex

client upload rate = u, F/u = 1

- 在分发的开始，只有服务器拥有文件。为了使这些对等方得到该文件，服务器必须经其接入链路至少发送一次该文件的每个比特。因此，最小分发时间至少是F/u_s。（与客户机/服务器方案不同，服务器发送过一次的比特可能就不用再次发送了，因为对等方可以互相重新分发这些比特。）
- 与客户机/服务器体系结构相同，下载速率最小的对等方不可能在F/d_{min}秒之内获得所有F比特。因此，最小分发时间至少为F/d_{min}。
- 最后，系统的总上载能力等于服务器的上载速率加上每个对等方的上载速率，即$u_{total} = u_s + u_1 + \ldots + u_N$。系统必须向$N$个对等方的每个交付（上载）$F$比特，因此总共交付$NF$比特。这不可能以快于$u_{total}$的速率完成。所以，最小分发时间至少是$NF/(u_s + u_1 + \ldots + u_N)$。

将这三个观察结合起来，我们获得了P2P的最小分发时间，记为D_{P2P}。

$$D_{P2P} \geq \max\left\{\frac{F}{u_s}, \frac{F}{d_{min}}, \frac{NF}{u_s + \sum_{i=1}^{N} u_i}\right\} \quad (2\text{-}2)$$



No need to go through the server. Everyone can share individual resources

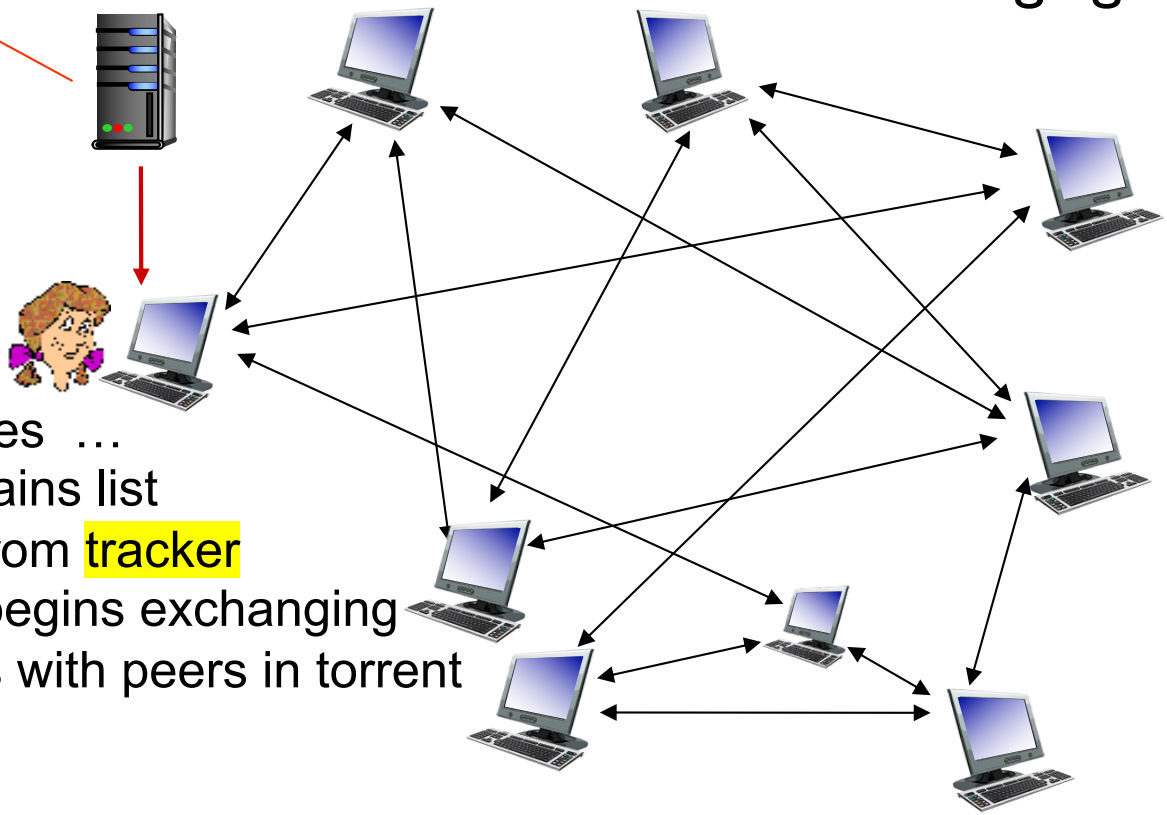
P2P file distribution: BitTorrent

Before started, it is necessary to send a request to sever to get the resource. After that, client simply download file from peers

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

tracker: tracks peers participating in torrent

torrent: group of peers exchanging chunks of a file



When a peer join in a torrent, it register for the tracker and notify the tracker periodically that it is still in the tracker

Note:
1. each torrent has only one tracker
2. The connection between peers is TCP

Alice arrives …
… obtains list of peers from tracker
… and begins exchanging file chunks with peers in torrent

.torrer

给她的哪些邻居？在决定请求哪些块的过程中，Alice使用一种称为**最稀罕优先**（rarest first）的技术。这种技术的思路是，根据她没有的块从她的邻居中确定最稀罕的块（最稀罕的块就是在她的邻居中拷贝数量最少的那些块），并优先请求那些最稀罕的块。按照此方式，最稀罕的块更迅速地重新分发，其目标（大致）是均衡每个块在洪流中的拷贝数量。

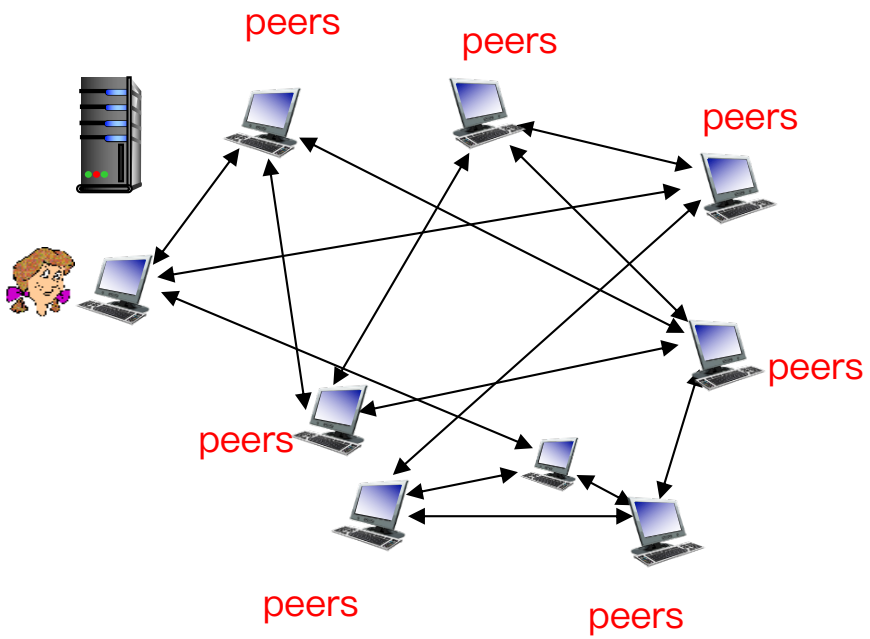
- Contains address of trackers for the file
  - Where can I find other peers?
- Contain a list of file chunks and their cryptographic hashes
  - This ensures that chunks are not modified

For a single peer, the connected peers (neiborhoods) are dynamically changing in a torrent

Title	Trackers
House of Cards Season 4	Tracker1-url
Walking Dead Season 6	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")



We not alway directly select a certain peer

- 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

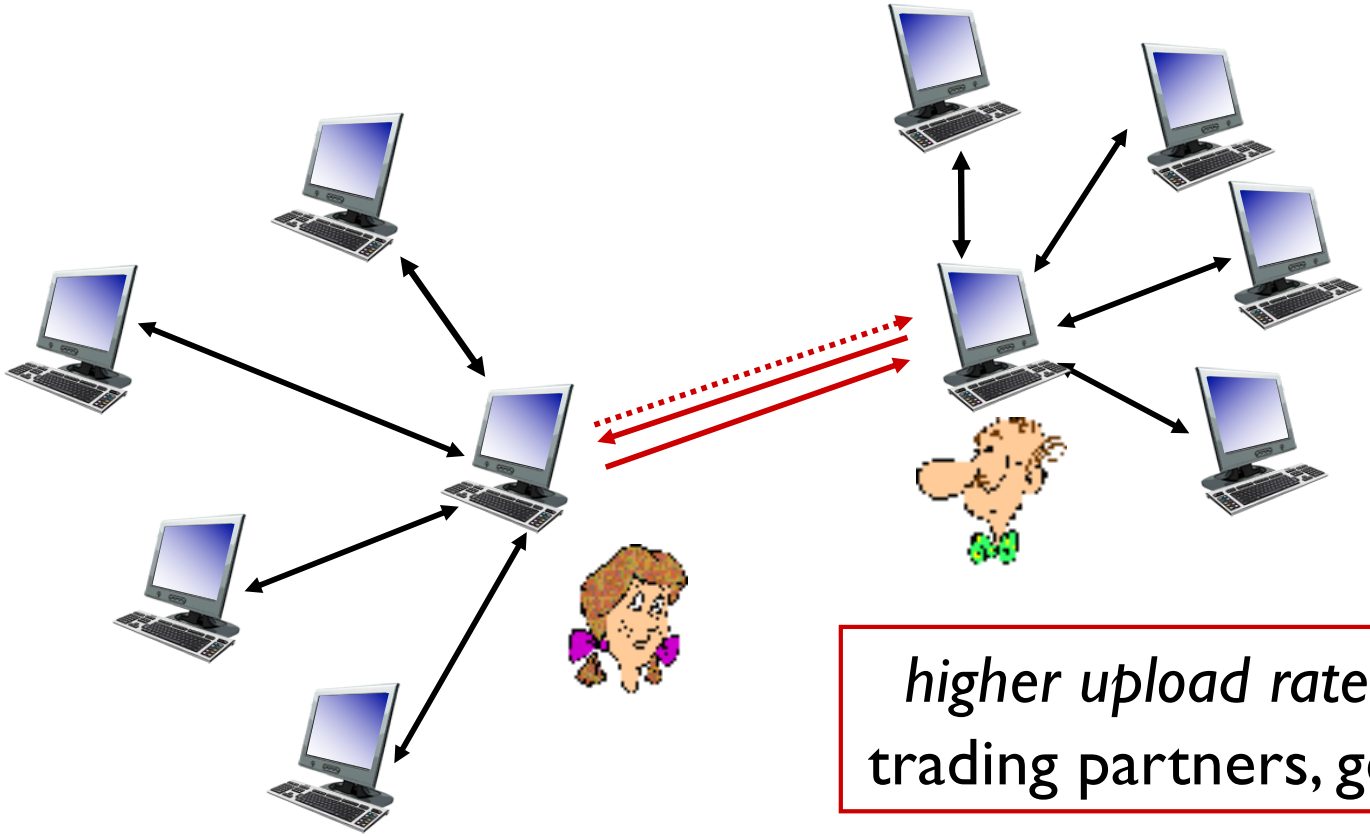
Help to maintain the balance of the number of chunks. Prevent that some chunks may much more than others.

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 linked to WebCMS

Getting rid of the server/tracker

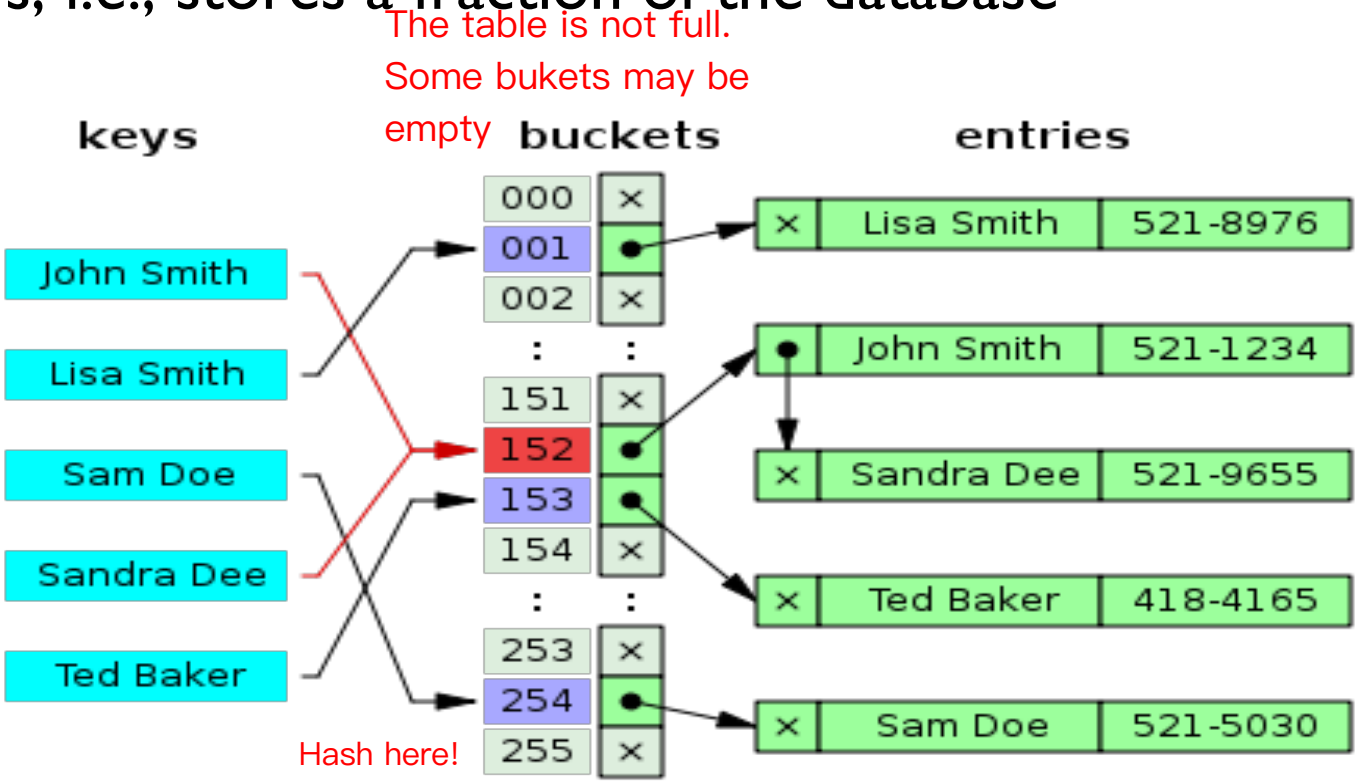
- Distribute the tracker information using a Distributed Hash Table (DHT)

- 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

Hash table - review

- Database stores (key,value) pairs
- Centralised hash table – all (key,value) pairs stored on a single node
- Distributed hash table – each node has a "section" of (key,value) pairs, i.e., stores a fraction of the database



e.g., Hash(Lisa Smith) = 001

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: *movie name* (e.g., Led Zeppelin IV);
  - value: *IP address* the movie is stored (e.g., 128.17.123.38)
- Distribute the (key, value) pairs over many peer nodes
- A peer queries DHT with key
  - DHT returns values that match the key
- Peers can also insert (key, value) pairs

Challenges

- How do we assign (key, value) pairs to nodes?
  - i.e., what fraction of the database should be stored in which node?
- How do we find them again quickly?
- What happens if nodes join/leave?

Q: how to assign keys to peers?

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

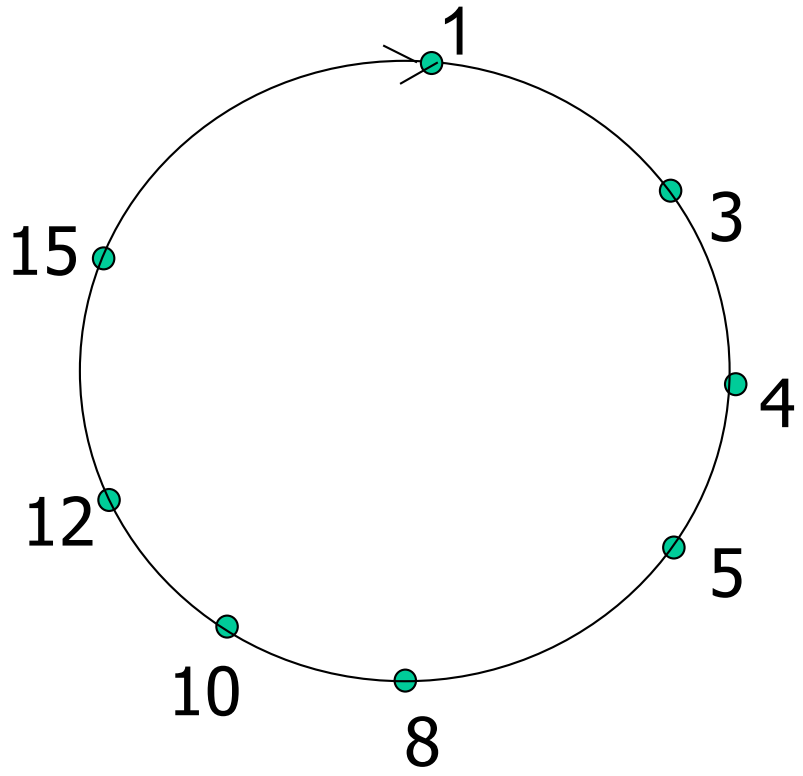
DHT identifiers: Consistent Hashing

- 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("House of Cards Season 4")
  - 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

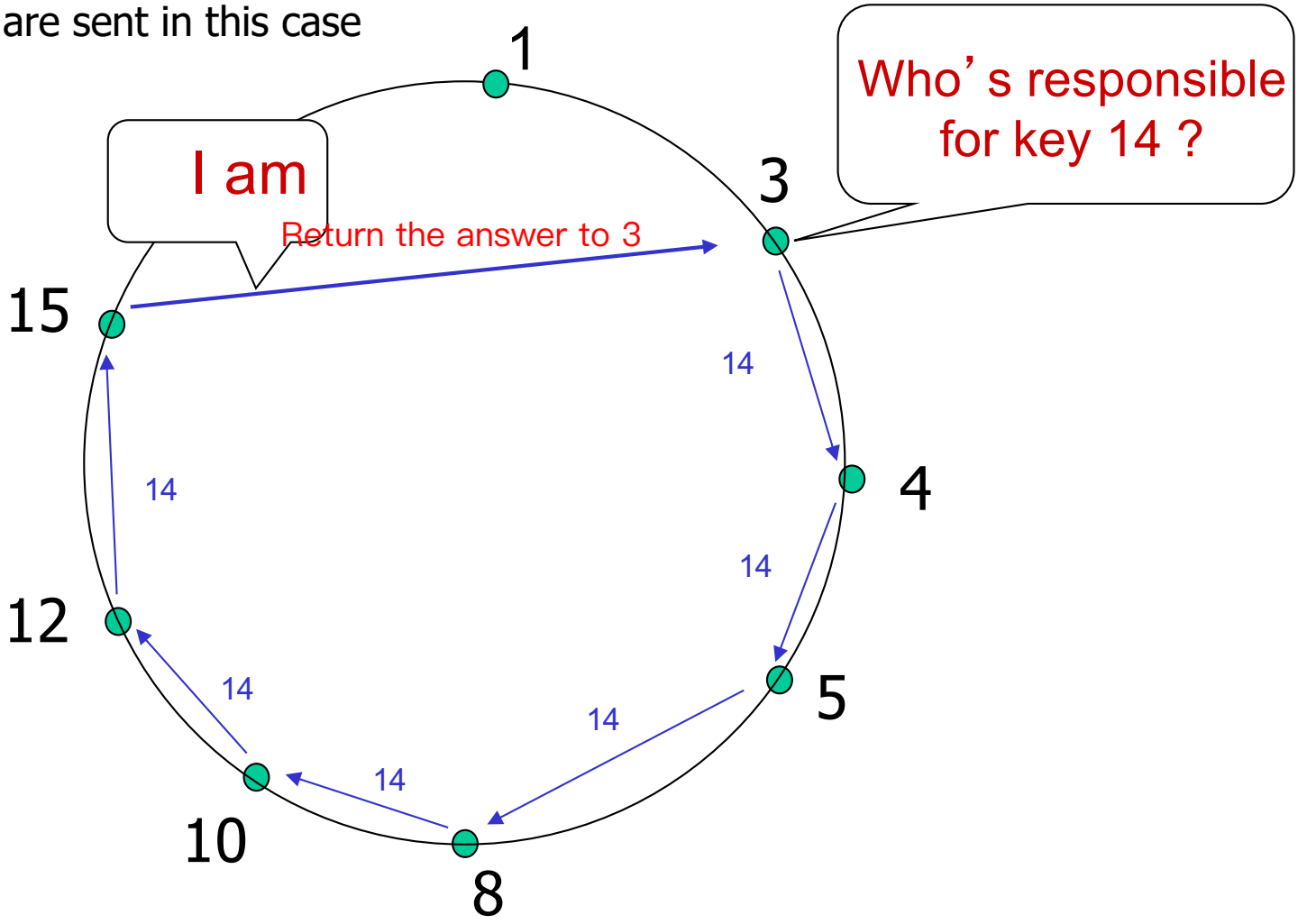
Circular DHT (1)



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

Circular DHT (2)

- Each peer maintains 2 neighbours
- 6 query messages are sent in this case

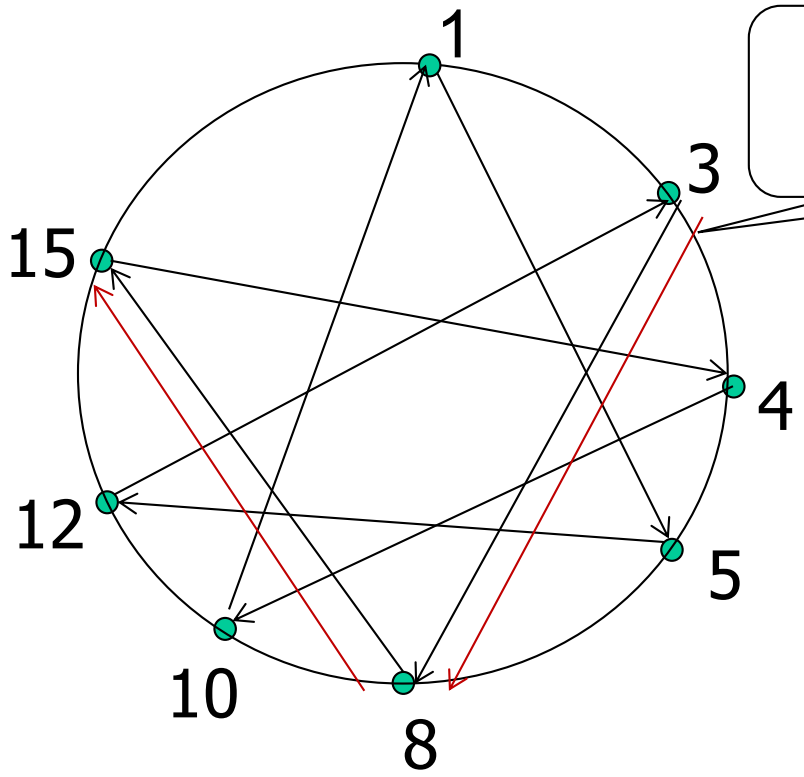


Define closest as closest successor

Tradeoff: #of neighbours vs. #of messages

- The smaller the number of neighbours to maintain, the larger the number of messages have to be sent;
- Previous example: 2 neighbours, 6 messages
- Worst case: N messages
- Average: N/2 messages

Circular DHT with shortcuts



Who's responsible for key 14?

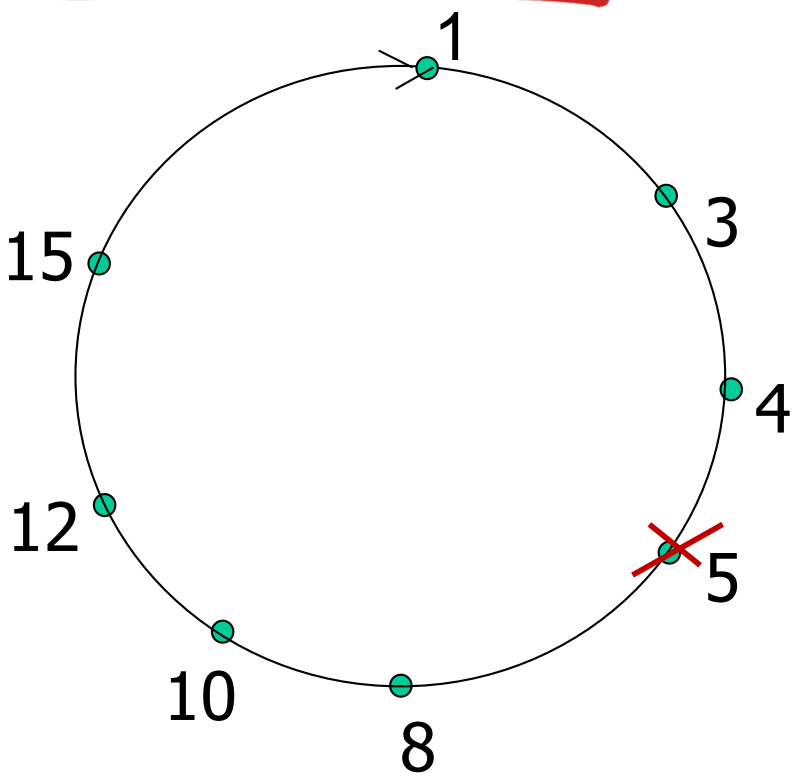
3 has shortcut to 8

8 has shortcut to 15

And so on

- each peer keeps track of IP addresses of predecessor, successor, and *shortcuts*
- 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.
- 8 makes 4 its new predecessor

More DHT info

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

Research Article
CHORD: A Scalable Peer-to-Peer Lookup Service for Internet Applications

DHT: Applications

- File sharing and backup [CFS, Ivy, OceanStore, PAST, Pastiche …]
- Web cache and replica [Squirrel, Croquet Media Player]
- Censor-resistant stores [Eternity]
- DB query and indexing [PIER, Place Lab, VPN Index]
- Event notification [Scribe]
- Naming systems [ChordDNS, Twine, INS, HIP]
- Distributed BitTorrent tracker [Kademlia, Vuze]
- Communication primitives [I3, …]
- Host mobility [DTN Tetherless Architecture]

Quiz: BitTorrent

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

c

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

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?

Feasible

In the process of downloading, as u getting some chunk, the algorithm is saying you have to give chunks to someone, that is built-in in the protocol

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

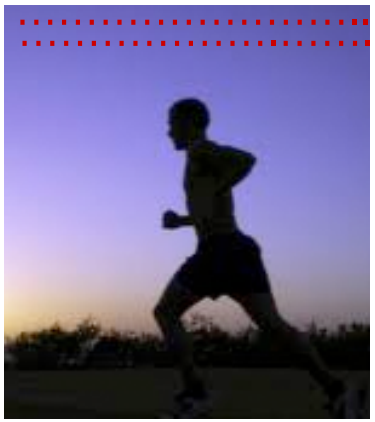
Video Streaming and CDNs: context

- 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*

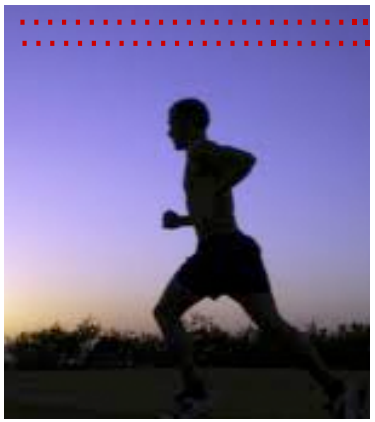
frame *i+1*

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

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)



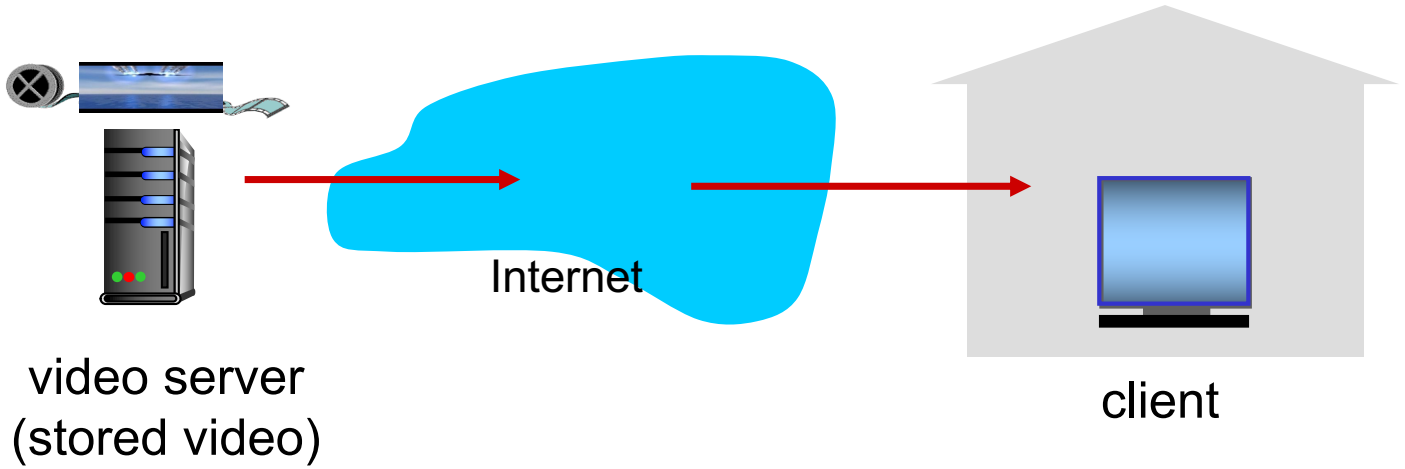
frame *i*

frame *i+1*

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

Streaming stored video:

simple scenario:

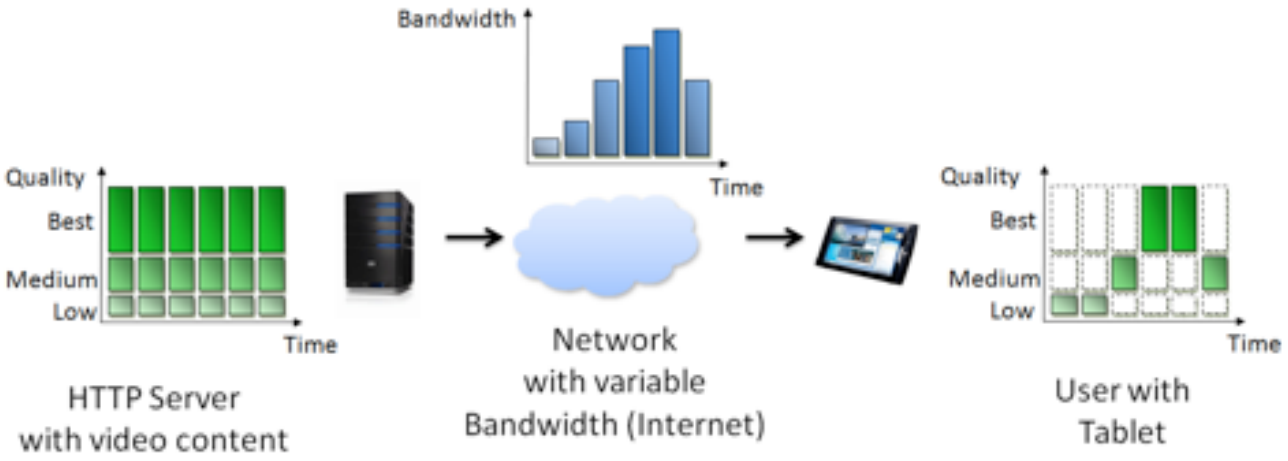


Streaming multimedia: DASH

- *DASH: Dynamic, Adaptive Streaming* 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 (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

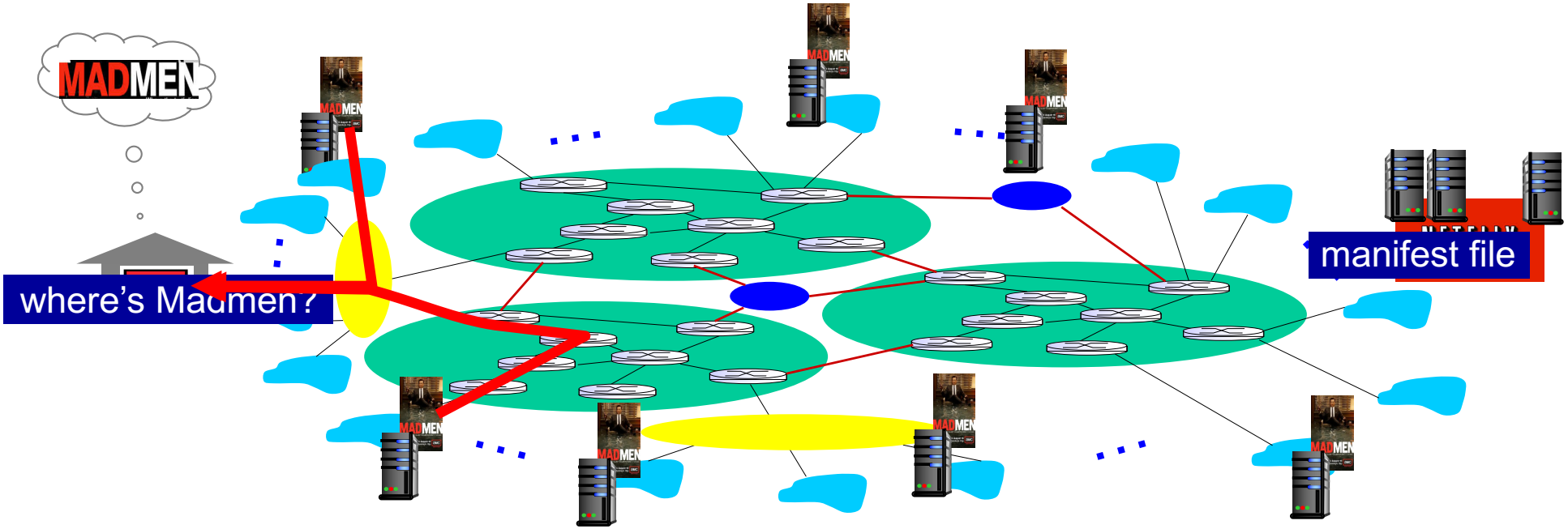
An example

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

; <<>> DiG 9.8.3-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 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



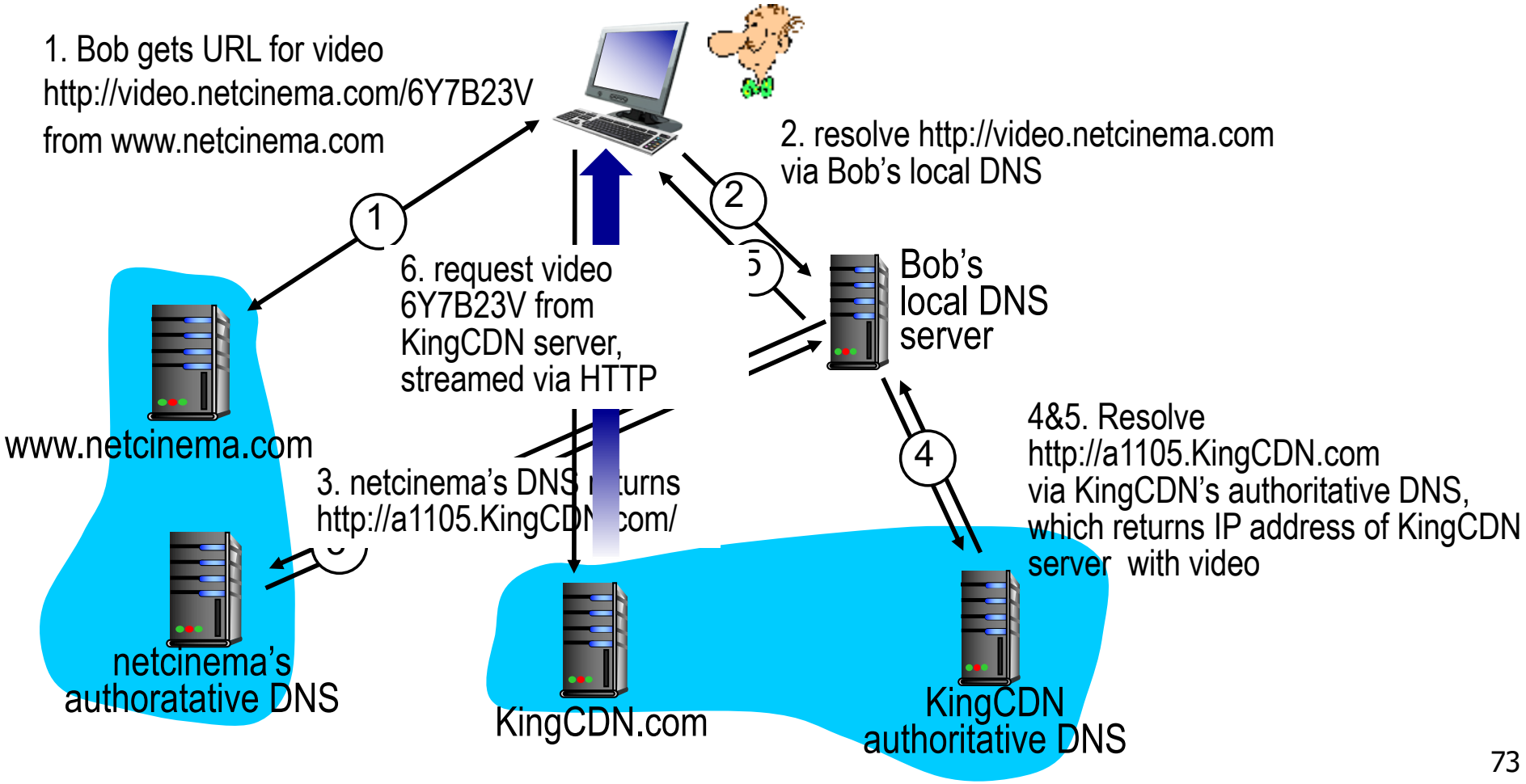
Cnd extend the flexibilty of DNS

CDN content access: a closer look

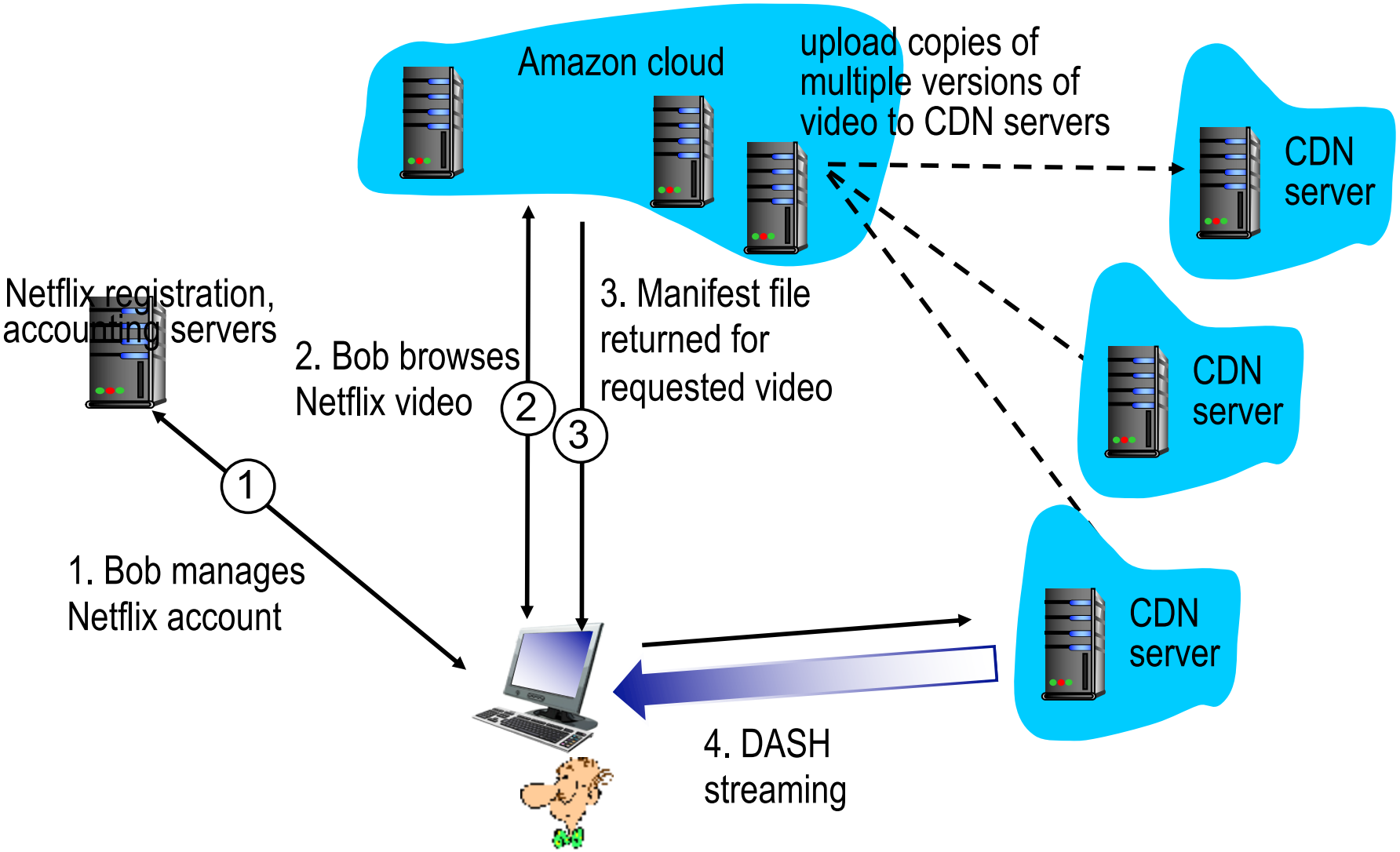
Content Delivery Network

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

- video stored in CDN at managed by KingCDN.com

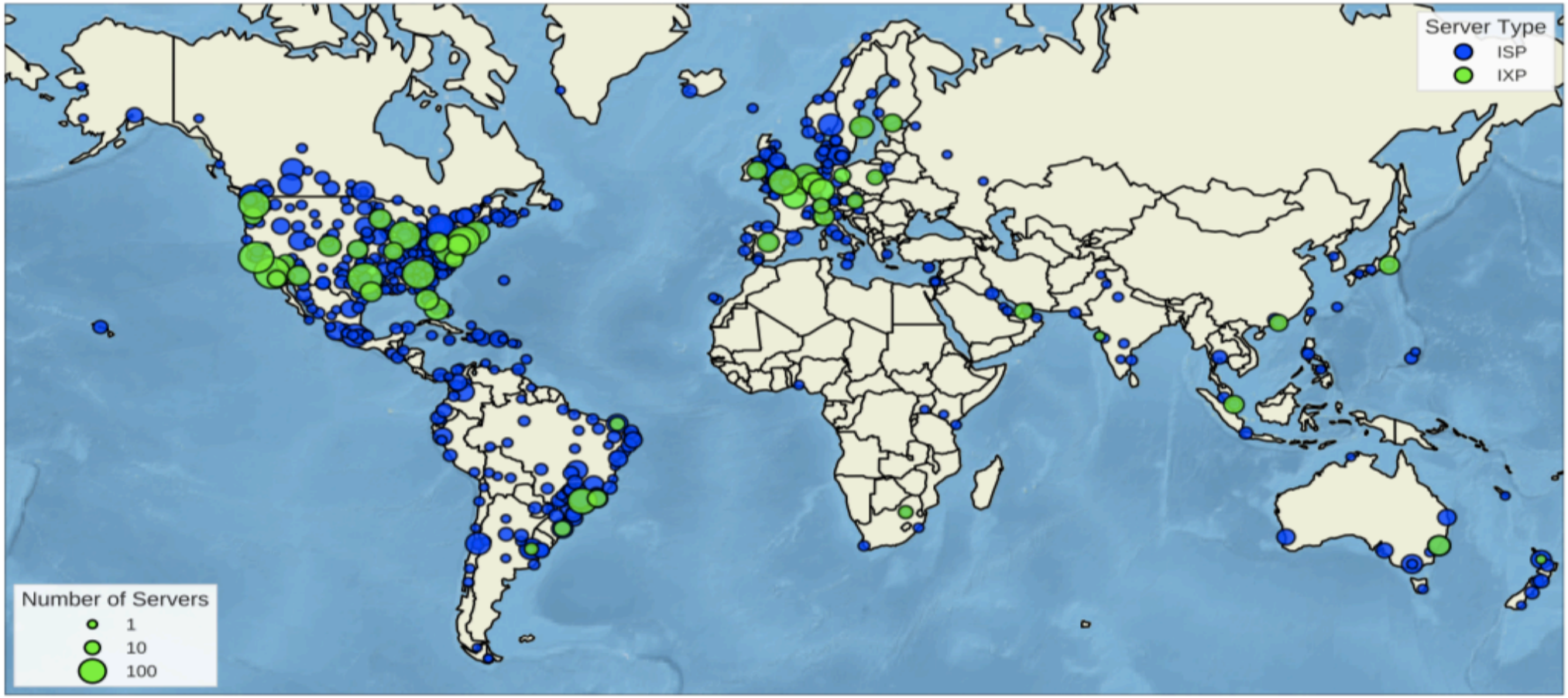


Case study: Netflix



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: B
  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)

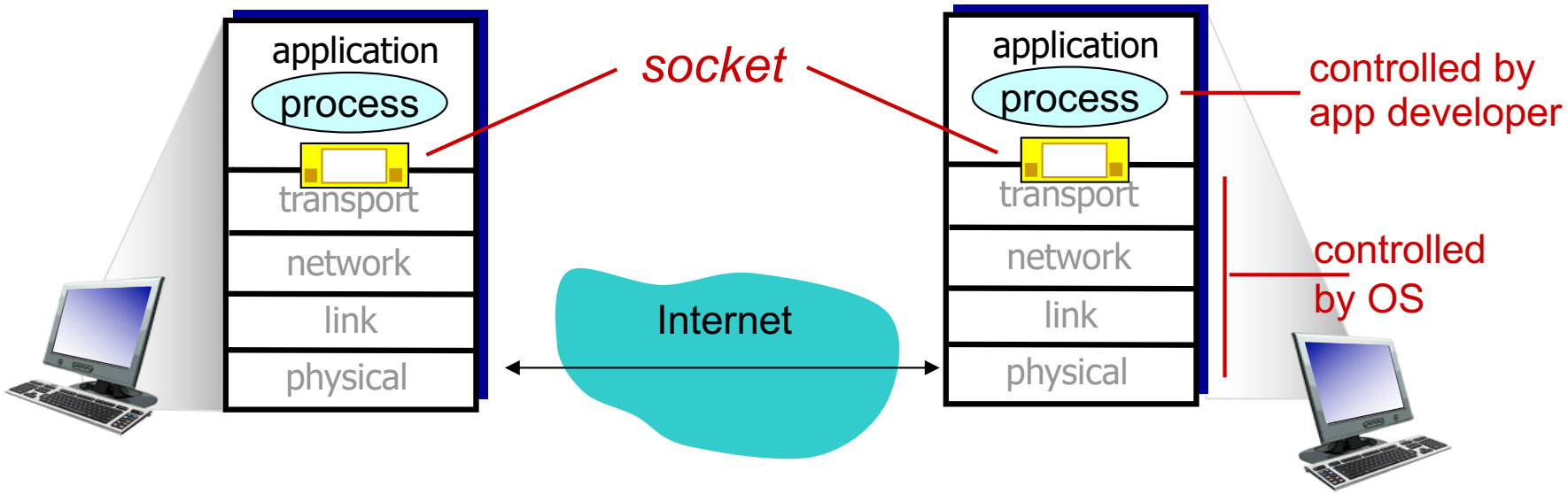
2.7 socket programming with UDP and TCP

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 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

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:

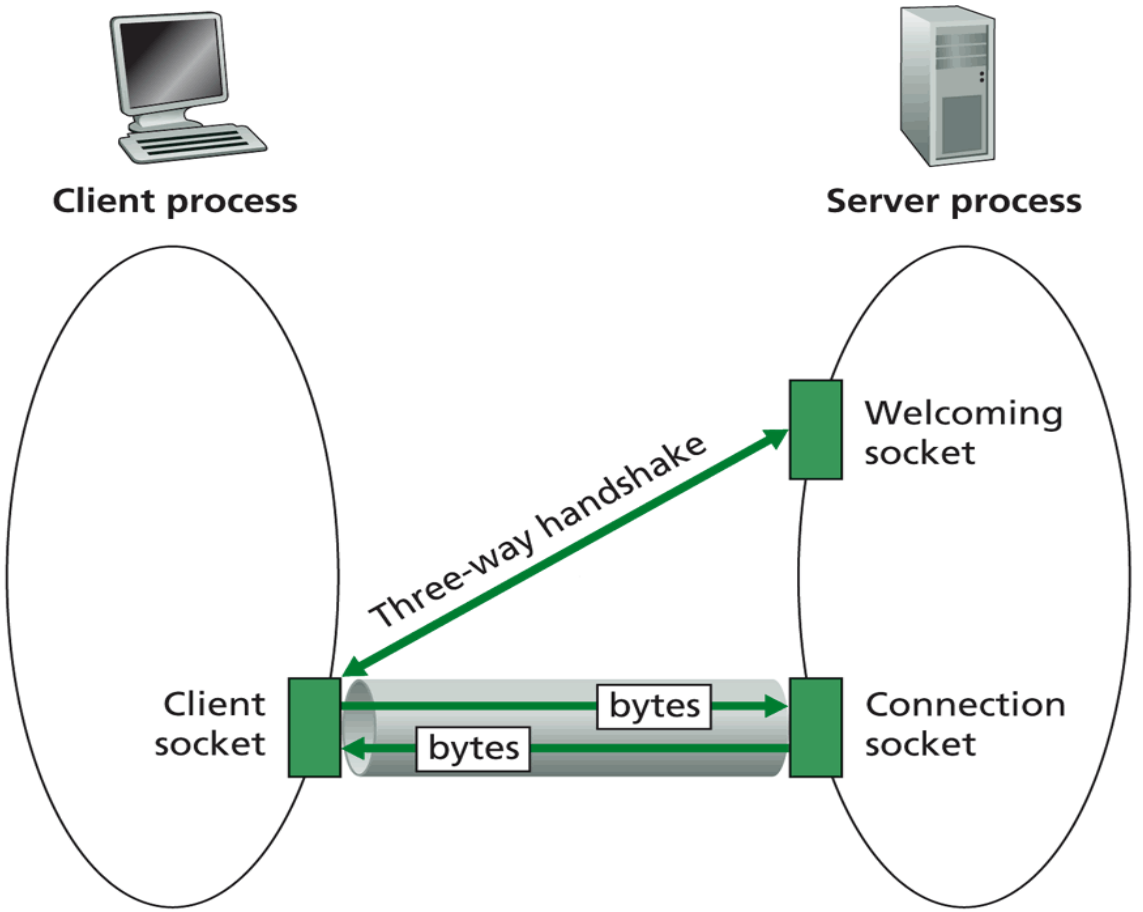
- Creating TCP socket, specifying IP address, port number of server process
- *when client creates socket:* client TCP establishes connection to server TCP

- 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