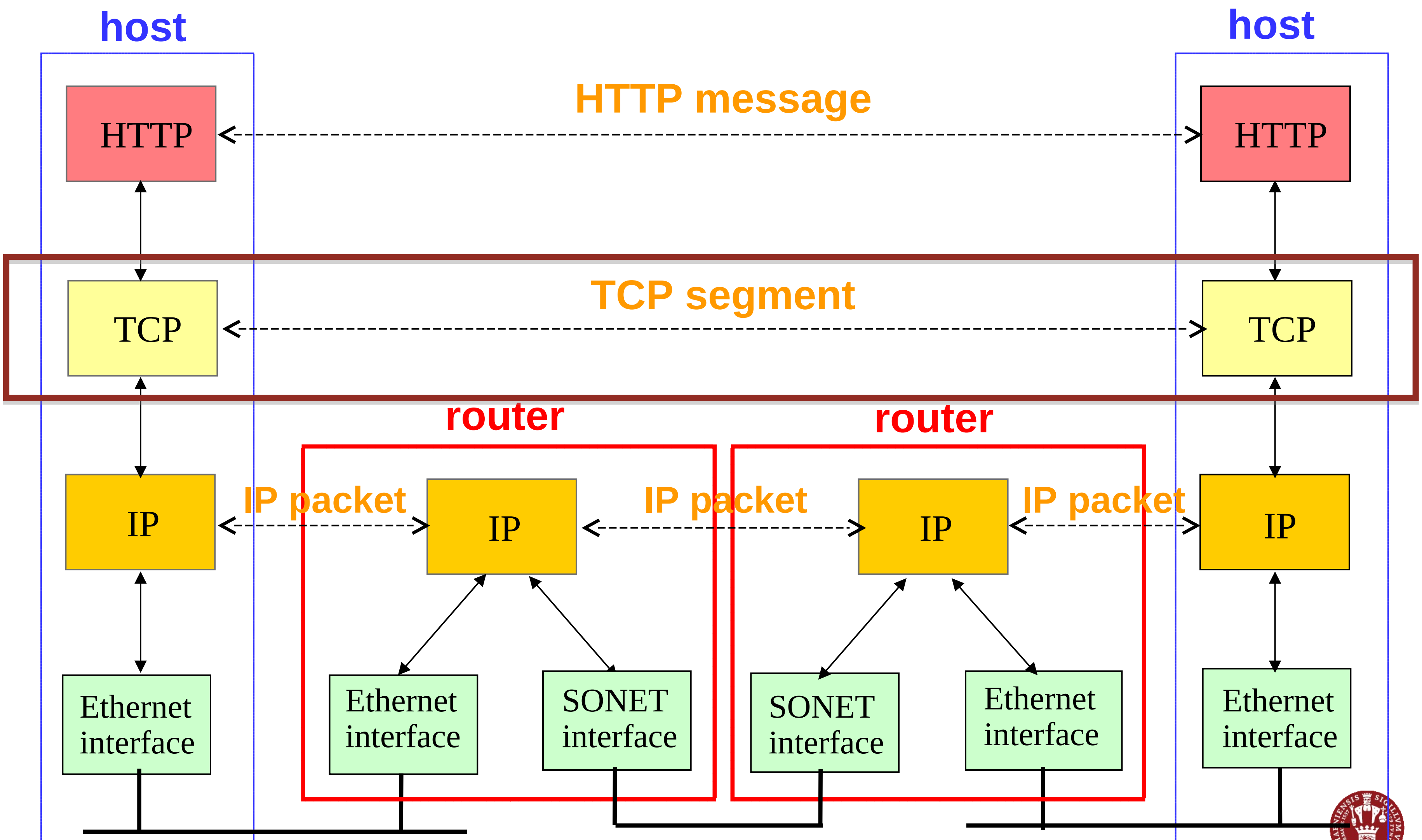
# Transport Layer: UDP Application Layer: DNS & Peer to Peer File Sharing

David Marchant

Based on slides compiled by Marcos Vaz Salles, adaptions by Vivek Shah and Michael Kirkedal Thomsen

# Recap: Internet Layering Model




Source: Freedman

# Transport Layer

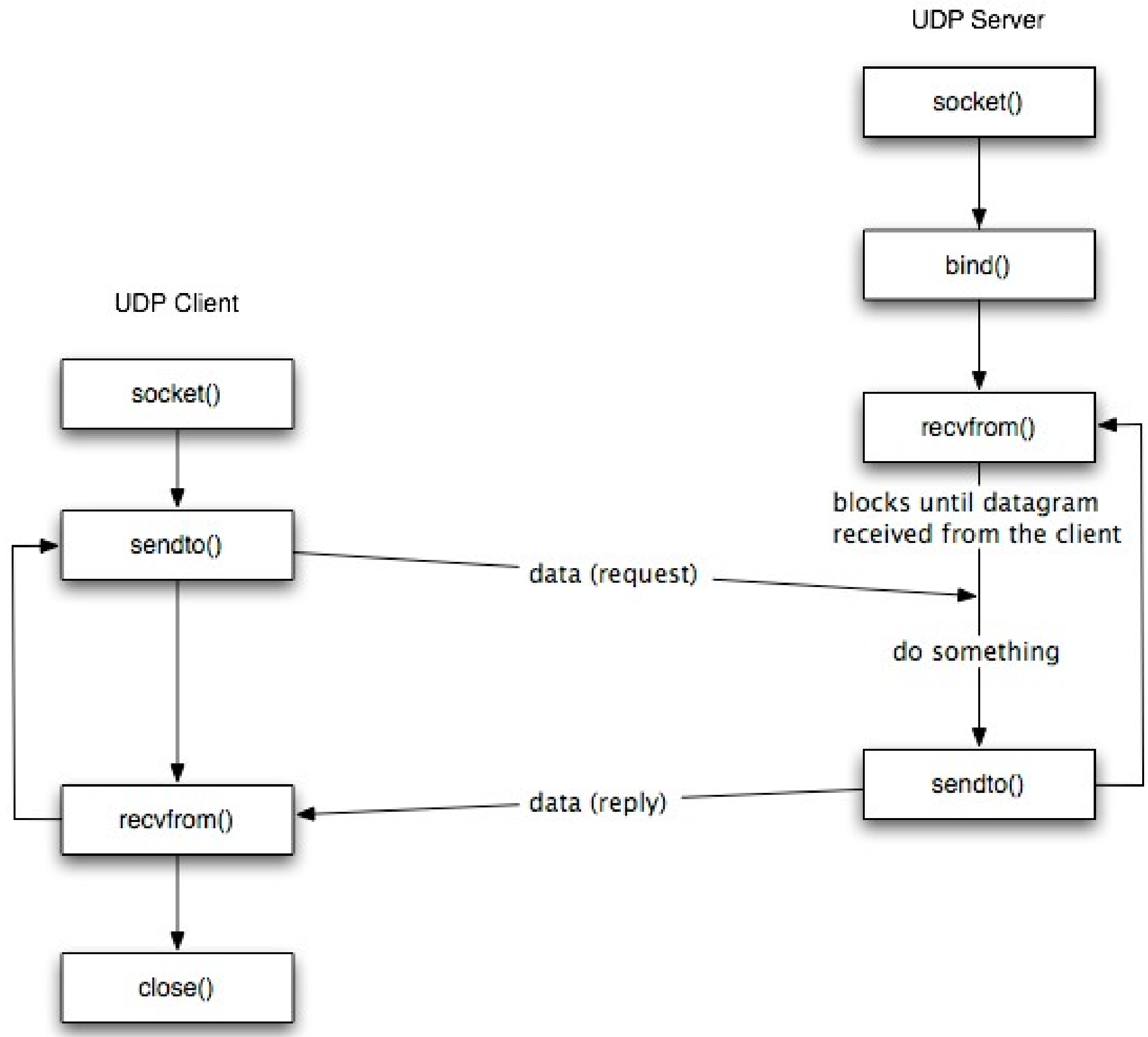
- Logical Communication between processes
  - Sender divides messages into segments.
  - Receiver re-assembles messages into segments.

- Principles underlying transport-layer services
  - (De)multiplexing
  - Detecting corruption
  - Optional: Reliable delivery, Flow control, Congestion control

- Transport-layer protocols in the Internet
  - User Datagram Protocol (UDP)
    - Simple (unreliable) message delivery
  - Transmission Control Protocol (TCP)
    - Reliable bidirectional stream of bytes

Source: Freedman

# Socket Programming Using UDP




Source: Campbell

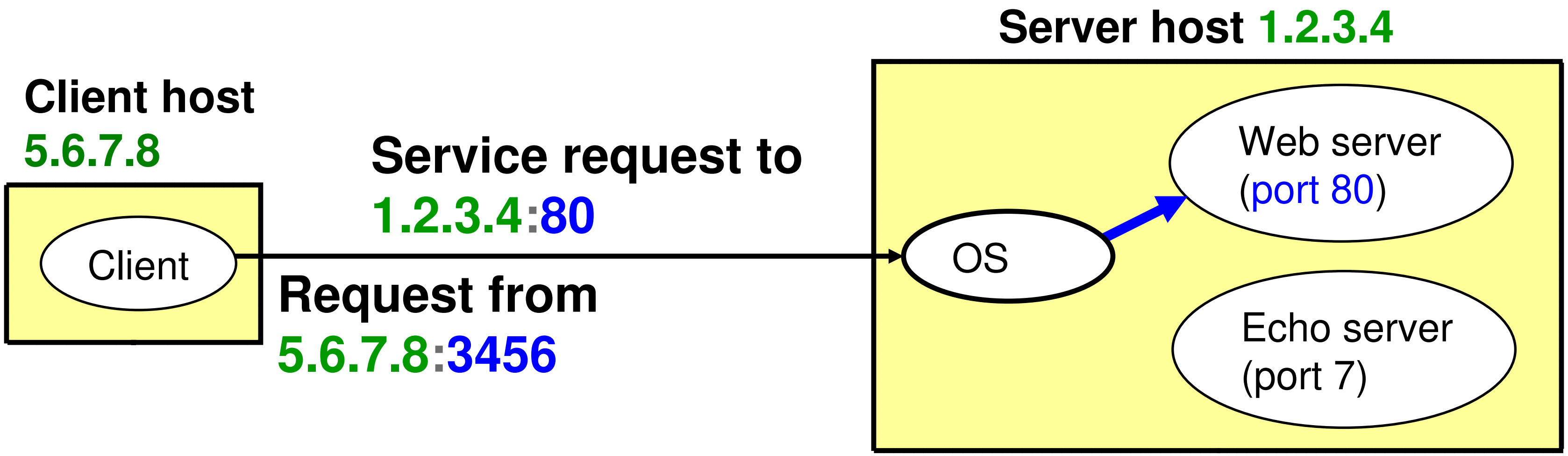
# Socket Programming Using UDP

```
ssize_t recvfrom(int sockfd, void* buff,
  size_t nbytes, int flags, struct sockaddr* from,
socklen_t *addrlen);
```

```
ssize_t sendto(int sockfd, const void *buff,
  size_t nbytes, int flags,
const struct sockaddr *to, socklen_t addrlen);
```

# Two Basic Transport Features

- **Demultiplexing:** port numbers

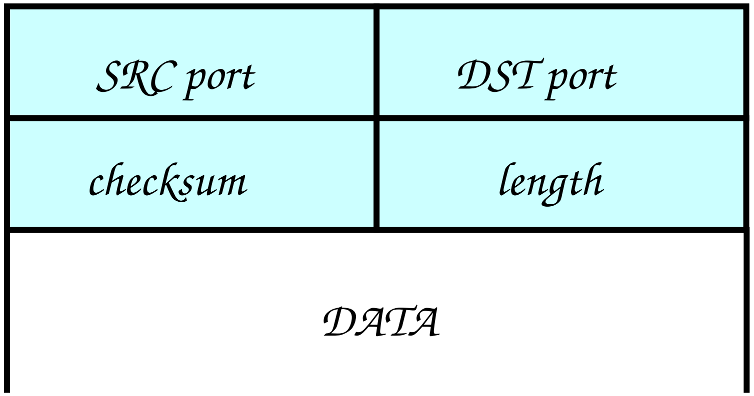



- **Error detection:** checksums

Source: Freedman

# User Datagram Protocol (UDP)

- Datagram messaging service
  - Demultiplexing of messages: port numbers
  - Detecting corrupted messages: checksum
- Lightweight communication between processes
  - Send messages to and receive them from a socket
  - Avoid overhead and delays of ordered, reliable delivery




Source: Freedman

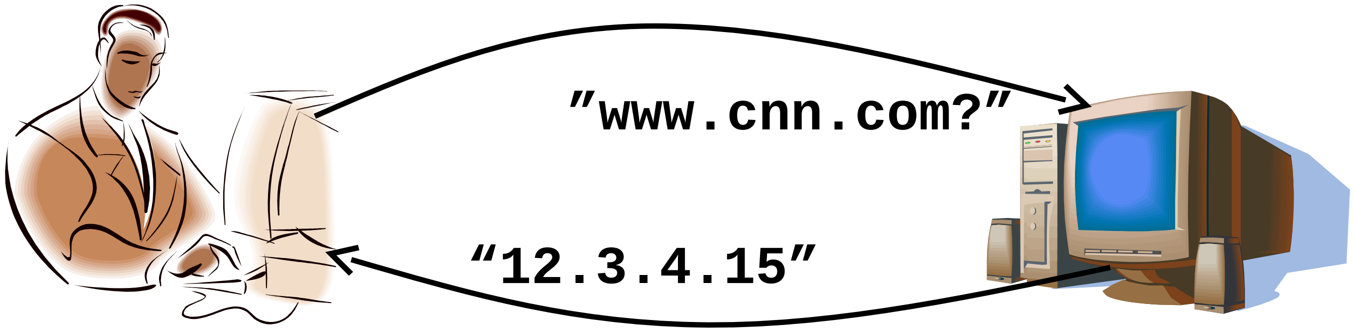
# Why Would Anyone Use UDP?

- Fine control over what data is sent and when
  - As soon as app process writes into socket
  - … UDP will package data and send packet
- No delay for connection establishment
  - UDP blasts away without any formal preliminaries
  - … avoids introducing unnecessary delays
- No connection state (no buffers, sequence #'s, etc.)
  - Can scale to more active clients at once
- Small packet header overhead (header only 8B long)

Source: Freedman

# Popular Applications That Use UDP

- Simple query protocols like DNS
  - Overhead of connection establishment is overkill
  - Easier to have the application retransmit if needed

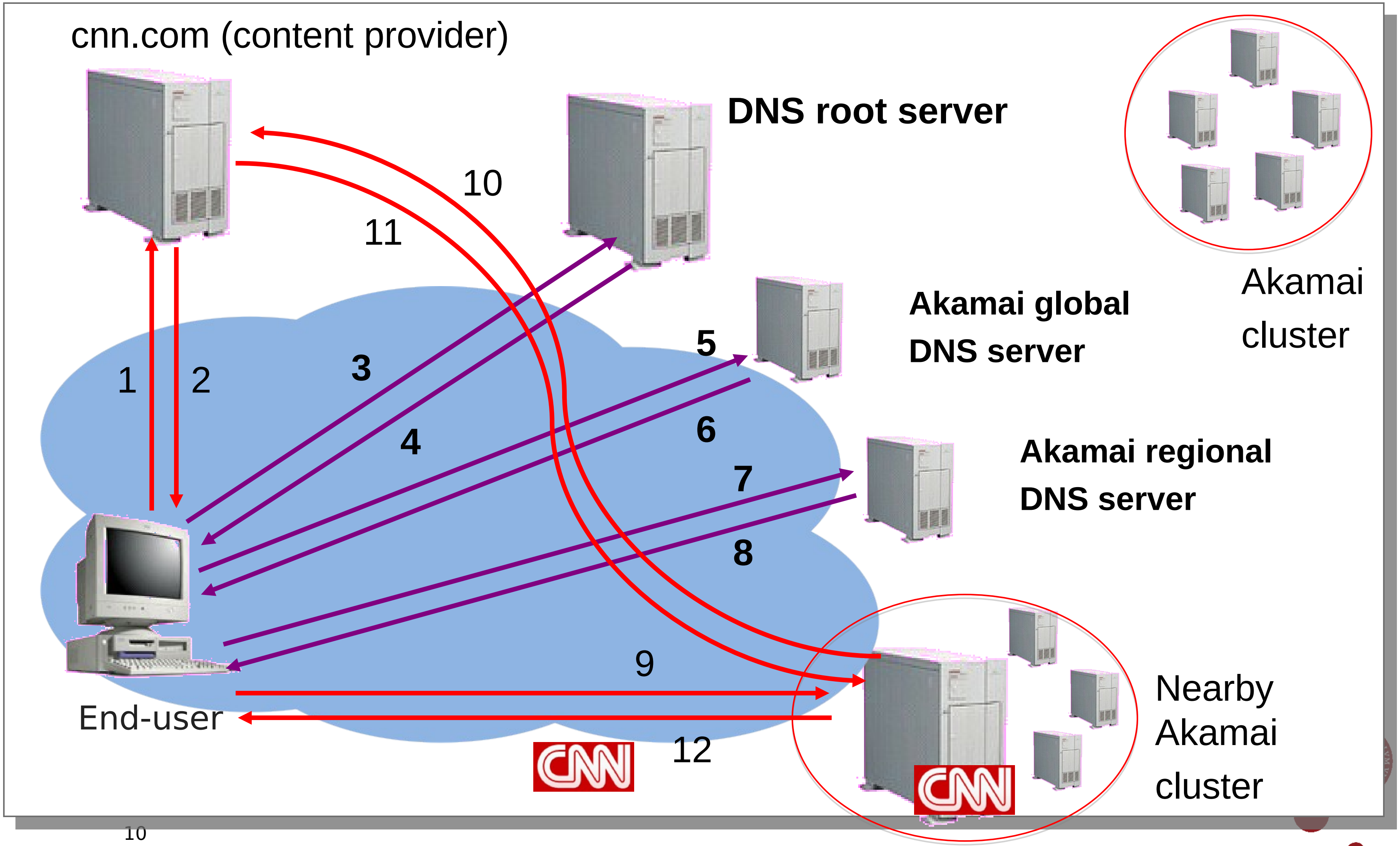



- Multimedia streaming (VoIP, video conferencing, …)
  - Retransmitting lost/corrupted packets is not worthwhile
  - By time packet is retransmitted, it's too late

Source: Freedman

# Recap: How Akamai Works

Source: Freedman (partial)



# Hierarchical Names

- **Host name:** www.cs.princeton.edu
  - Domain: registrar for each top-level domain (e.g., .edu)
  - Host name: local administrator assigns to each host

- **IP addresses:** 128.112.7.156
  - Prefixes: ICANN, regional Internet registries, and ISPs
  - Hosts: static configuration, or dynamic using DHCP

  (more on DHCP later in the course ☺)

Source: Freedman (partial)

# Aside: IPvX versions

| | |
|---|---|
| IPv0 | Reserved |
| IPv1-3 | Initial attempts, became IPv4 and TCP('73-'79) |
| IPv4 | First actually deployed protocol ('81) |
| 5 | Experiment ('90 -'95) into video streaming protocol |
| IPv6 | Improvement on IPv4 ('95) |
| IPv7 | Incorrectly assigned when IPv6 was assumed to already be in use('88) |
| 8 | PIP, obsolete replacement for IPv4 ('94) |
| 9<br>IPv9<br>IPv9 | TUBA, obsolete replacement for IPv4 ('92),<br>April Fools Joke by IETF ('94),<br>Chinese research project, seemingly abandoned ('04) |
| IPv10-14 | Unassigned |
| IPv15 | Reserved |

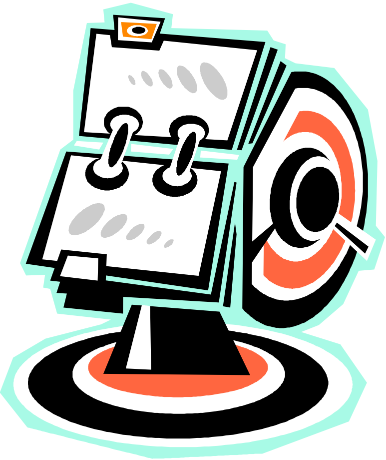
# Separating Names and IP Addresses

- Names are easier (for us!) to remember
  - www.cnn.com vs. 64.236.16.20
- IP addresses can change underneath
  - Move www.cnn.com to 173.15.201.39
  - E.g., renumbering when changing providers
- Name could map to multiple IP addresses
  - www.cnn.com to multiple replicas of the Web site
- Map to different addresses in different places
  - Address of a nearby copy of the Web site
  - E.g., to reduce latency, or return different content
- Multiple names for the same address
  - E.g., aliases like ee.mit.edu and cs.mit.edu

Source: Freedman

# Outline: Domain Name System

- Computer science concepts underlying DNS
  - Indirection: names in place of addresses
  - Hierarchy: in names, addresses, and servers
  - Caching: of mappings from names to/from addresses



- DNS software components
  - DNS resolvers
  - DNS servers
- DNS queries
  - Iterative queries
  - Recursive queries
- DNS caching based on time-to-live (TTL)

Source: Freedman

# Strawman Solution: Central Server

- All you need is to map names!
- Central server
  - One place where all mappings are stored
  - All queries go to the central server

- Is this a good solution?
- What would be the potential drawbacks?

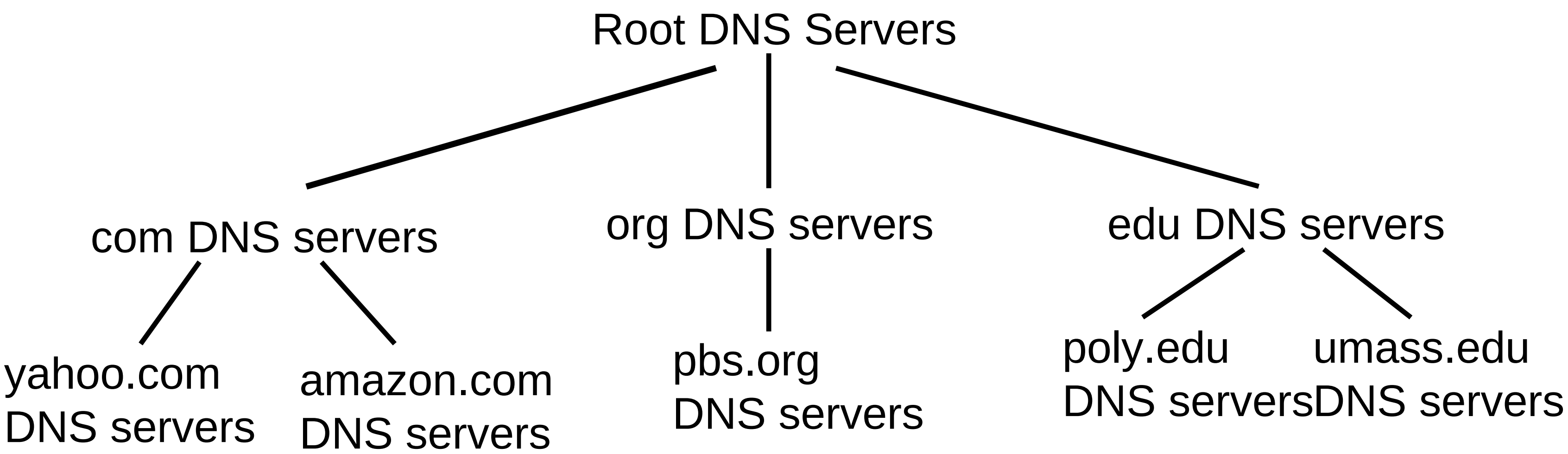
Source: Freedman (partial)

# Domain Name System (DNS)

- Properties of DNS
  - Hierarchical name space divided into zones
  - Distributed over a collection of DNS servers
- Hierarchy of DNS servers
  - Root servers
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- Performing the translations
  - Local DNS servers
  - Resolver software

Source: Freedman

# Distributed, Hierarchical Database



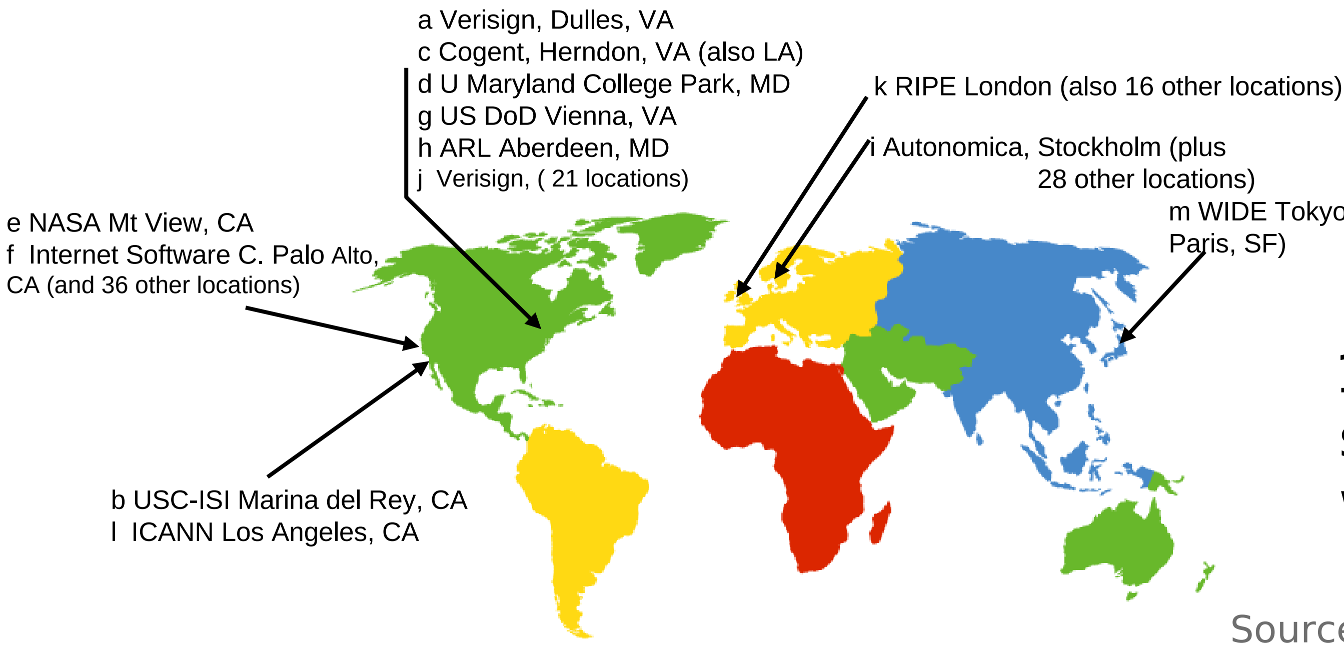

client wants IP for www.amazon.com; 1st approx:

- client queries a root server to find com DNS server
- client queries com DNS server to get amazon.com DNS server
- client queries amazon.com DNS server to get IP address for www.amazon.com

Source: Kurose & Ross

# DNS: Root name servers

- contacted by local name server that can not resolve name
- root name server



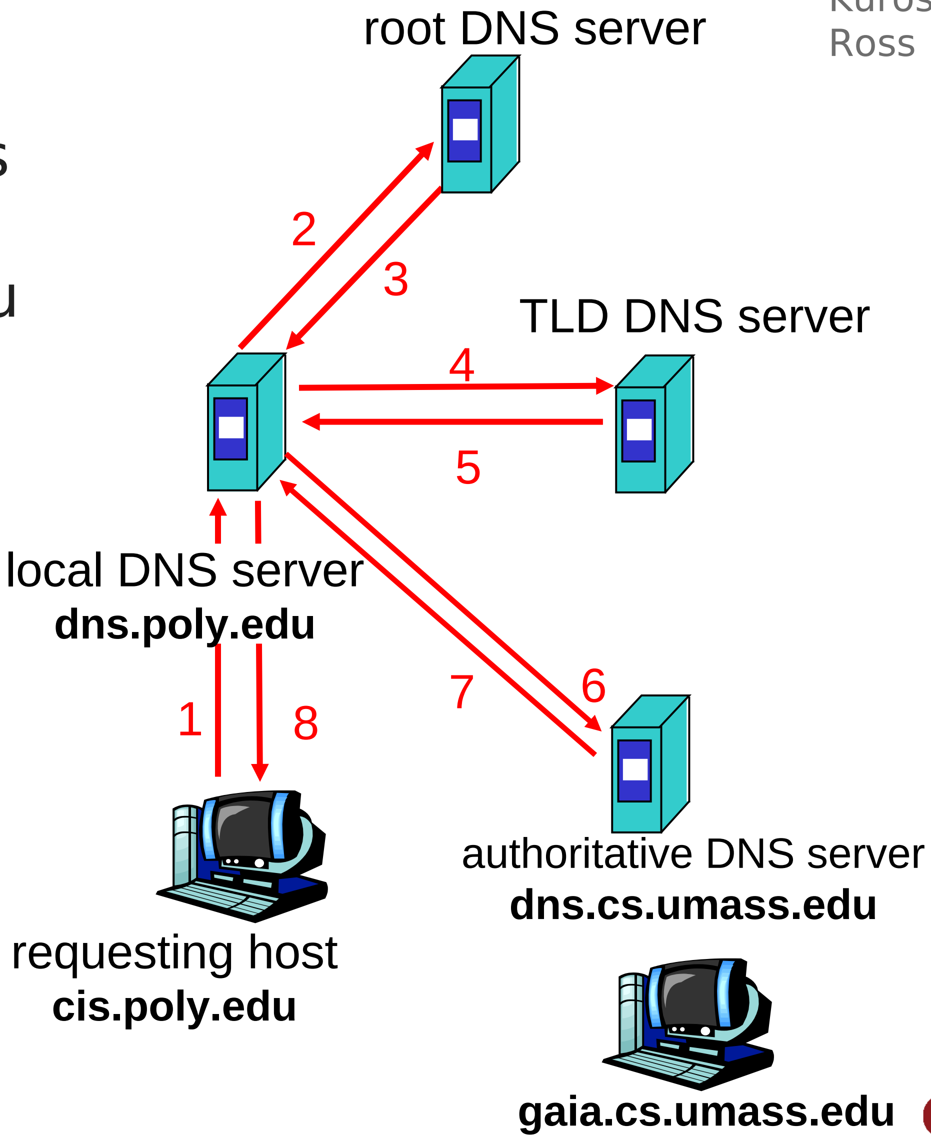

13 root name server organizers worldwide

Source: Kurose & Ross

# DNS Name Resolution Example

Source: Kurose & Ross

- host at cis.poly.edu wants IP address for gaia.cs.umass.edu




## Iterated query

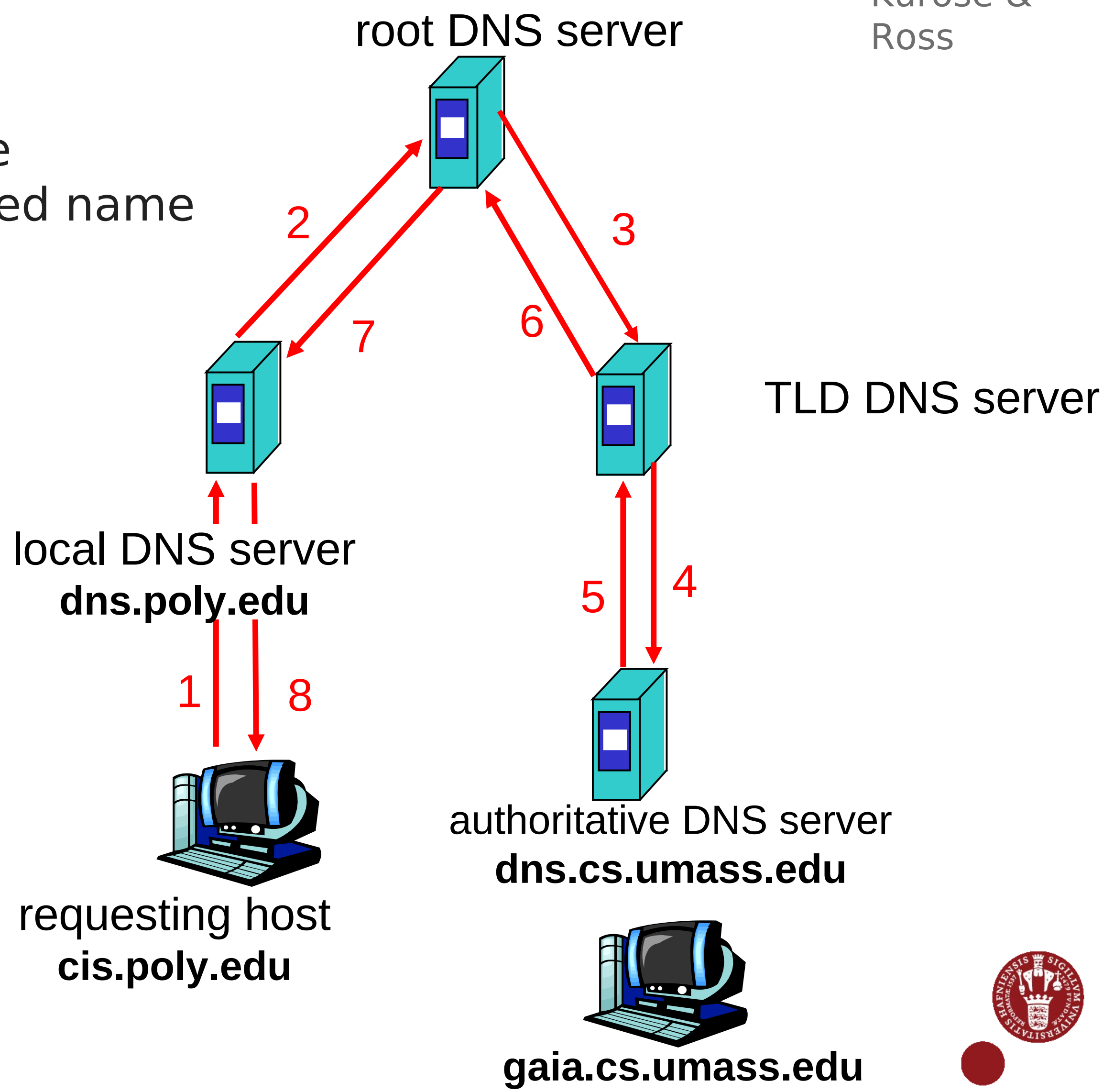
- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"

# DNS Name Resolution Example

Source: Kurose & Ross

## Recursive query

- puts burden of name resolution on contacted name server
- heavy load?



# DNS Caching

- Performing all these queries take time
  - And all this before the actual communication takes place
  - E.g., 1-second latency before starting Web download

- Caching can substantially reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., www.cnn.com) visited often
  - Local DNS server often has the information cached

Source: Freedman (partial)

# Time to Live & Negative Caching

- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a "time to live" (TTL) field
  - Server deletes the cached entry after TTL expires

- Negative Caching: Remember things that do not work
  - Misspellings like www.cnn.comm and www.cnnn.com
  - These can take a long time to fail the first time
  - Good to remember that they don't work
  - … so the failure takes less time the next time around

Source: Freedman (partial)

# 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

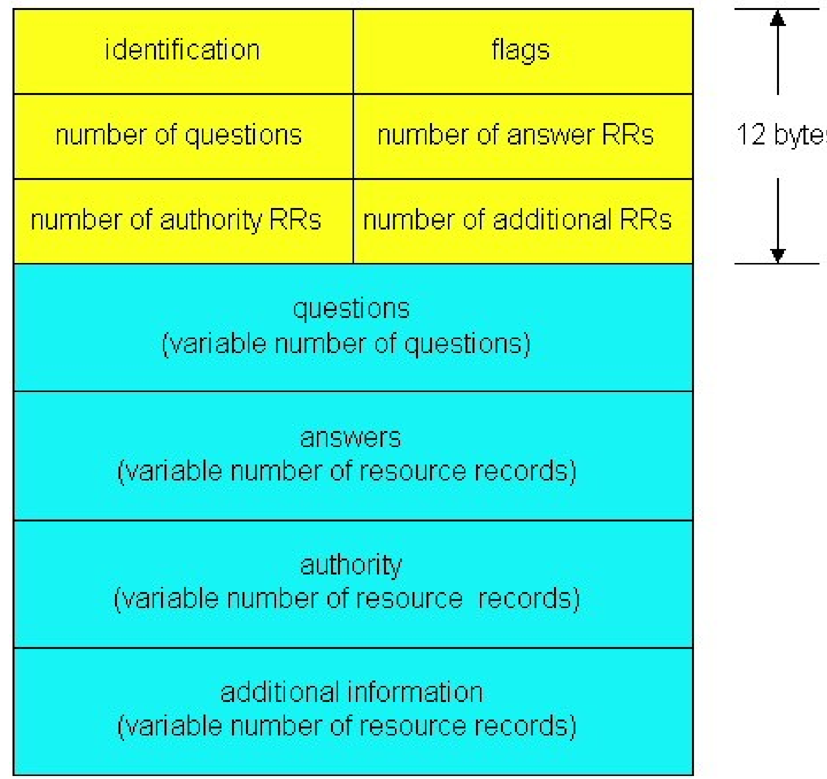
- **value** is name of mailserver associated with **name**

Source: Kurose & Ross

# DNS protocol, messages

DNS protocol : *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




Source: Kurose & Ross

# 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
- How do people get IP address of your Web site?

Source: Kurose & Ross

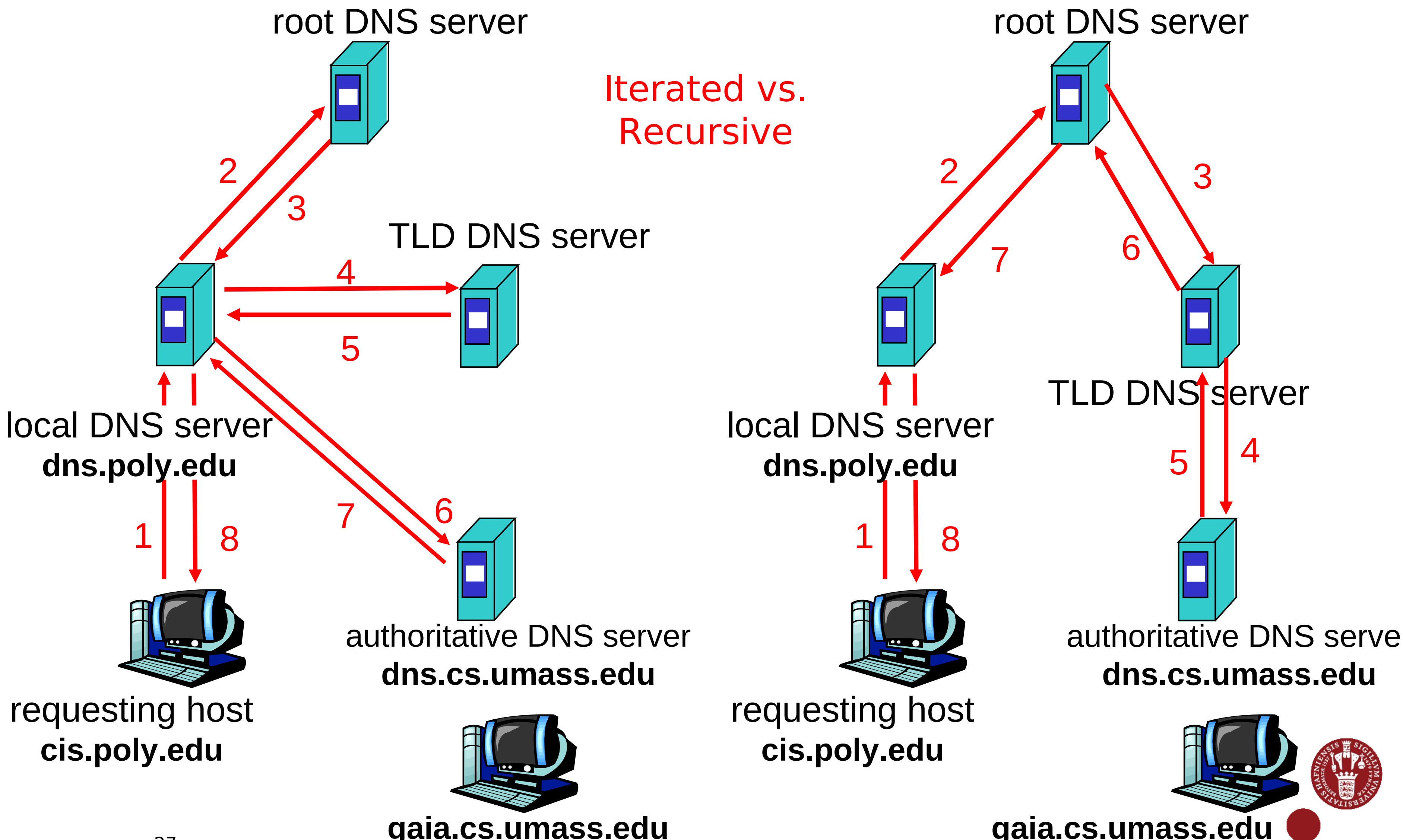
# DNS security

- DNS cache poisoning
  - Ask for www.evil.com
  - Additional section for (www.cnn.com, 1.2.3.4, A)
  - Thanks! I won't bother check what I asked for

- DNS hijacking
  - Let's remember the domain. And the UDP ID (source port + transaction ID).
  - 16 bits: 65K possible transaction IDs
    - What rate to enumerate all in 1 sec? 64B/packet
    - 64*65536*8 / 1024 / 1024 = 32 Mbps
  - Prevention: Also randomize the DNS source port
    - E.g., Windows DNS alloc's 2500 DNS ports: ~164M possible IDs
    - Would require 80 Gbps
    - Kaminsky attack: this source port…wasn't random after all

Source: Freedman (partial)

# How does caching affect each variant? In which one do you expect caching to work best?



# Use `dig` and nslookup with what you learned today

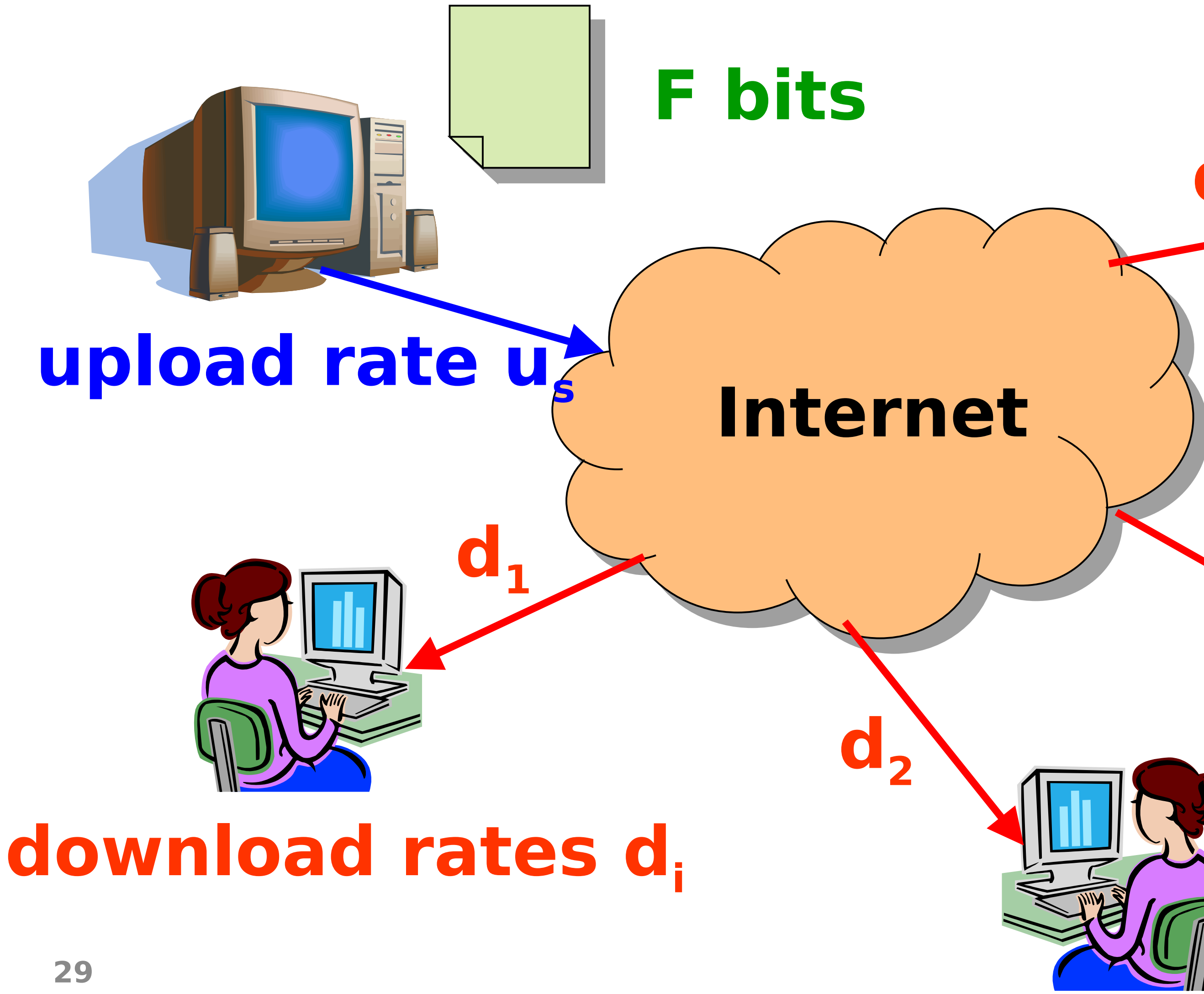
```
bonii@Bigbang@14:21:50 ~ $nslookup www.diku.dk
Server:		192.38.118.220
Address:	192.38.118.220#53

Non-authoritative answer:
www.diku.dk	canonical name = web-aggregator.diku.dk.
Name:	web-aggregator.diku.dk
Address: 130.226.14.83

bonii@Bigbang@14:25:04 ~ $dig +trace www.diku.dk

; <<>> DiG 9.10.4-P3 <<>> +trace www.diku.dk
;; global options: +cmd
.			185772	IN	NS	g.root-servers.net.
.			185772	IN	NS	e.root-servers.net.
.			185772	IN	NS	c.root-servers.net.
.			185772	IN	NS	k.root-servers.net.
.			185772	IN	NS	d.root-servers.net.
.			185772	IN	NS	l.root-servers.net.
.			185772	IN	NS	m.root-servers.net.
.			185772	IN	NS	a.root-servers.net.
.			185772	IN	NS	i.root-servers.net.
.			185772	IN	NS	h.root-servers.net.
.			185772	IN	NS	f.root-servers.net.
.			185772	IN	NS	j.root-servers.net.
.			185772	IN	NS	b.root-servers.net.
;; Received 824 bytes from 192.38.118.220#53(192.38.118.220) in 0 ms
```

# Server Distributing a Large File




Source: Freedman

# Server Distributing a Large File

- Sending an $F$-bit file to $N$ receivers
  - Transmitting $NF$ bits at rate $u_s$
  - … takes at least $NF/u_s$ time
- Receiving the data at the slowest receiver
  - Slowest receiver has download rate $d_{min} = min_i\{d_i\}$
  - … takes at least $F/d_{min}$ time
- Download time: $max\{NF/u_s, F/d_{min}\}$

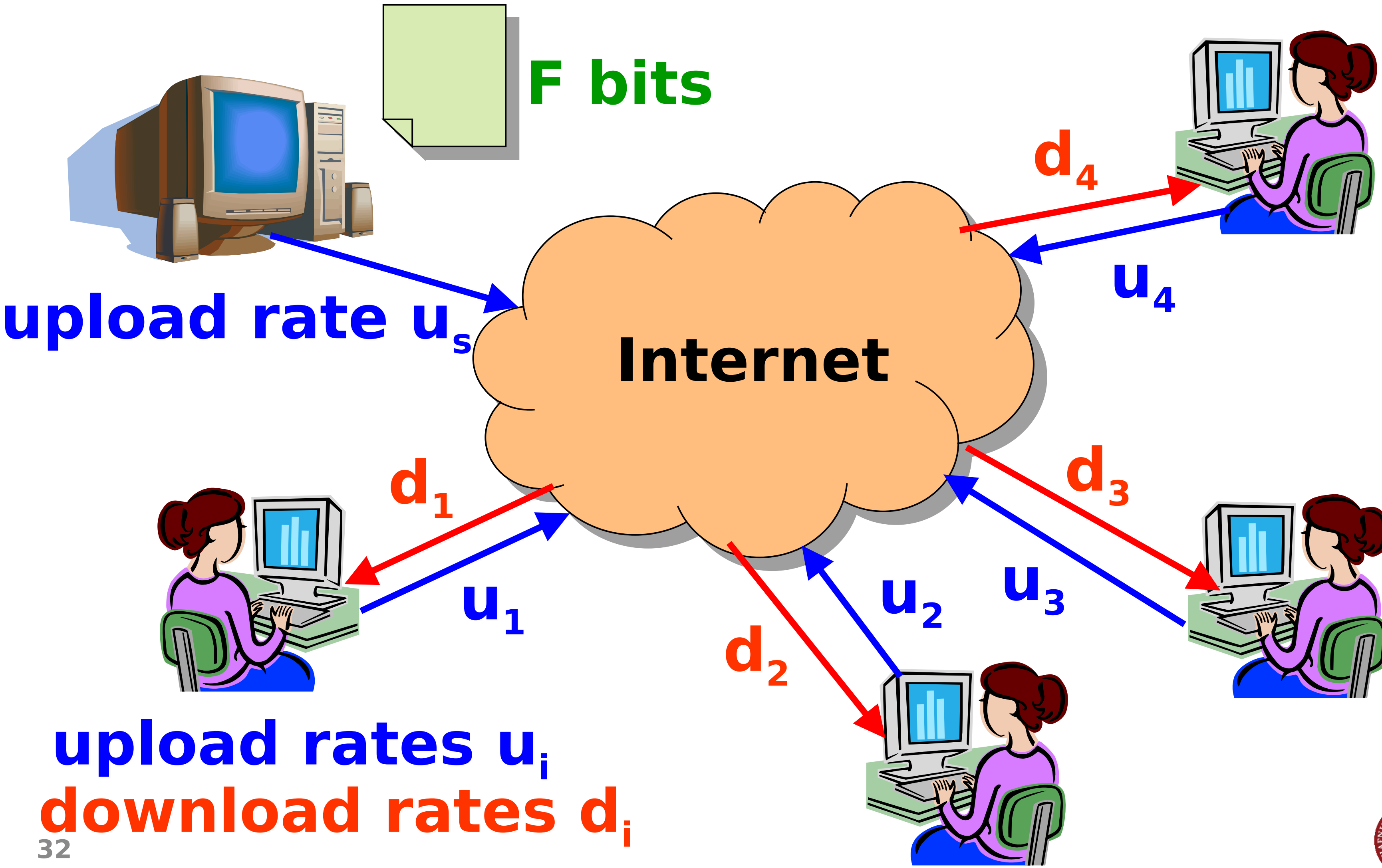
**Source: Freedman**

# Speeding Up the File Distribution

- Increase the server upload rate
  - Higher link bandwidth at the server
  - Multiple servers, each with their own link
- Alternative: have the receivers help
  - Receivers get a copy of the data
  - … and redistribute to other receivers
  - To reduce the burden on the server

Source: Freedman

# Peers Help Distributing a Large File






Source: Freedman

# Peers Help Distributing a Large File

- Components of distribution latency
  - Server must send each bit: min time $F/u_s$
  - Slowest peer must receive each bit: min time $F/d_{min}$
- Upload time using all upload resources
  - Total number of bits: $NF$
  - Total upload bandwidth $u_s + sum_i(u_i)$
- Total: $max\{F/u_s, F/d_{min}, NF/(u_s+sum_i(u_i))\}$
- *Peer to peer is self-scaling*
  - *Download time grows slowly with N*
    - Client-server: $max\{NF/u_s, F/d_{min}\}$
    - Peer-to-peer: $max\{F/u_s, F/d_{min}, NF/(u_s+sum_i(u_i))\}$

Source: Freedman

# Peer-to-Peer Networks: BitTorrent

- BitTorrent history
  - 2002: B. Cohen debuted BitTorrent
- Emphasis on efficient fetching, not searching
  - Distribute same file to many peers
  - Single publisher, many downloaders
- Preventing free-loading
  - Incentives for peers to contribute

**Source: Freedman**

# BitTorrent: Tracker

- Infrastructure node
  - Keeps track of peers participating in the torrent
  - Peers register with the tracker when it arrives
- Tracker selects peers for downloading
  - Returns a random set of peer IP addresses
  - So the new peer knows who to contact for data
- Can have “trackerless” system
  - Using distributed hash tables (DHTs)

Source: Freedman

# BitTorrent: Chunk Request Order

- Which chunks to request?
  - Could download in order
  - Like an HTTP client does
- Problem: many peers have the early chunks
  - Peers have little to share with each other
  - Limiting the scalability of the system
- Problem: eventually nobody has rare chunks
  - E.g., the chunks need the end of the file
  - Limiting the ability to complete a download
- Solutions: random selection and rarest first

Source: Freedman

# BitTorrent: Rarest Chunk First

- Which chunks to request first?
  - Chunk with fewest available copies (i.e., rarest chunk)
- Benefits to the peer
  - Avoid starvation when some peers depart
- Benefits to the system
  - Avoid starvation across all peers wanting a file
  - Balance load by equalizing # of copies of chunks

Source: Freedman

# Free-Riding in P2P Networks

- Vast majority of users are free-riders
  - Most share no files and answer no queries
  - Others limit # of connections or upload speed
- A few “peers” essentially act as servers
  - A few individuals contributing to the public good
  - Making them hubs that basically act as a server
- BitTorrent prevent free riding
  - Allow the fastest peers to download from you
  - Occasionally let some free loaders download

Source: Freedman

# Bit-Torrent: Preventing Free-Riding

- Peer has limited upload bandwidth
  - And must share it among multiple peers
  - Tit-for-tat: favor neighbors uploading at highest rate
- Rewarding the top four neighbors
  - Measure download bit rates from each neighbor
  - Reciprocate by sending to the top four peers
- Optimistic unchoking
  - Randomly try a new neighbor every 30 seconds
  - So new neighbor has a chance to be a better partner
  - Compatible peers find each other

Source: Freedman

# Peer-to-Peer Naming

- But…
  - Peers may come and go
  - Peers need to find each other
  - Peers need to be willing to help each other

Source: Freedman

# Locating the Relevant Peers

- Three main approaches
  - Central directory (Napster)
  - Query flooding (Gnutella)
  - Hierarchical overlay (Kazaa, modern Gnutella)

- Design goals
  - Scalability
  - Simplicity
  - Robustness
  - Plausible deniability

Source: Freedman

# Summary

- UDP
  - basic multiplexing, checksums
- DNS
  - Hierarchical names
  - Recursive vs. iterative name resolution, caching
  - Addresses, aliases, resource records
- P2P applications
  - Self scalability
  - BitTorrent – Popular P2P file sharing protocol
    - Rarest chunk first, fair trading + optimistic unchoking

# What’s next ? Reliable Data Transfer & TCP