15-440

Distributed Systems

Distributed Systems Within the Internet
Nov. 6, 2012

Topics

- Domain Name System
  - Finding IP address
- Content Delivery Networks
  - Caching content within the network

Domain Name System (DNS)

- Mapping from Host Names to IP Addresses

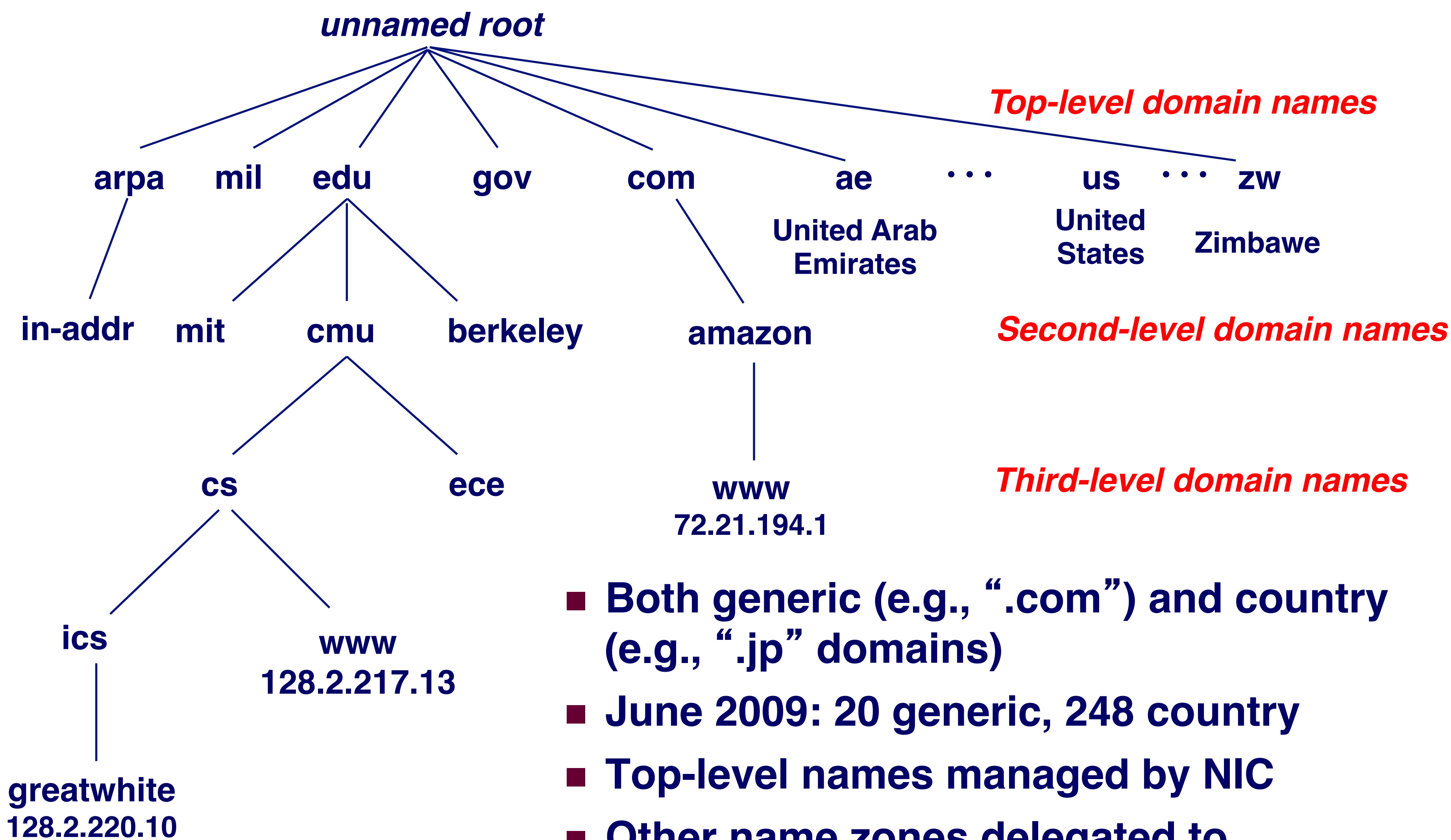
Distributed database

- Each site (university, large company, ISP, ...) maintains database with its own entries
- Provide server for others to query

Implemented at Application Layer

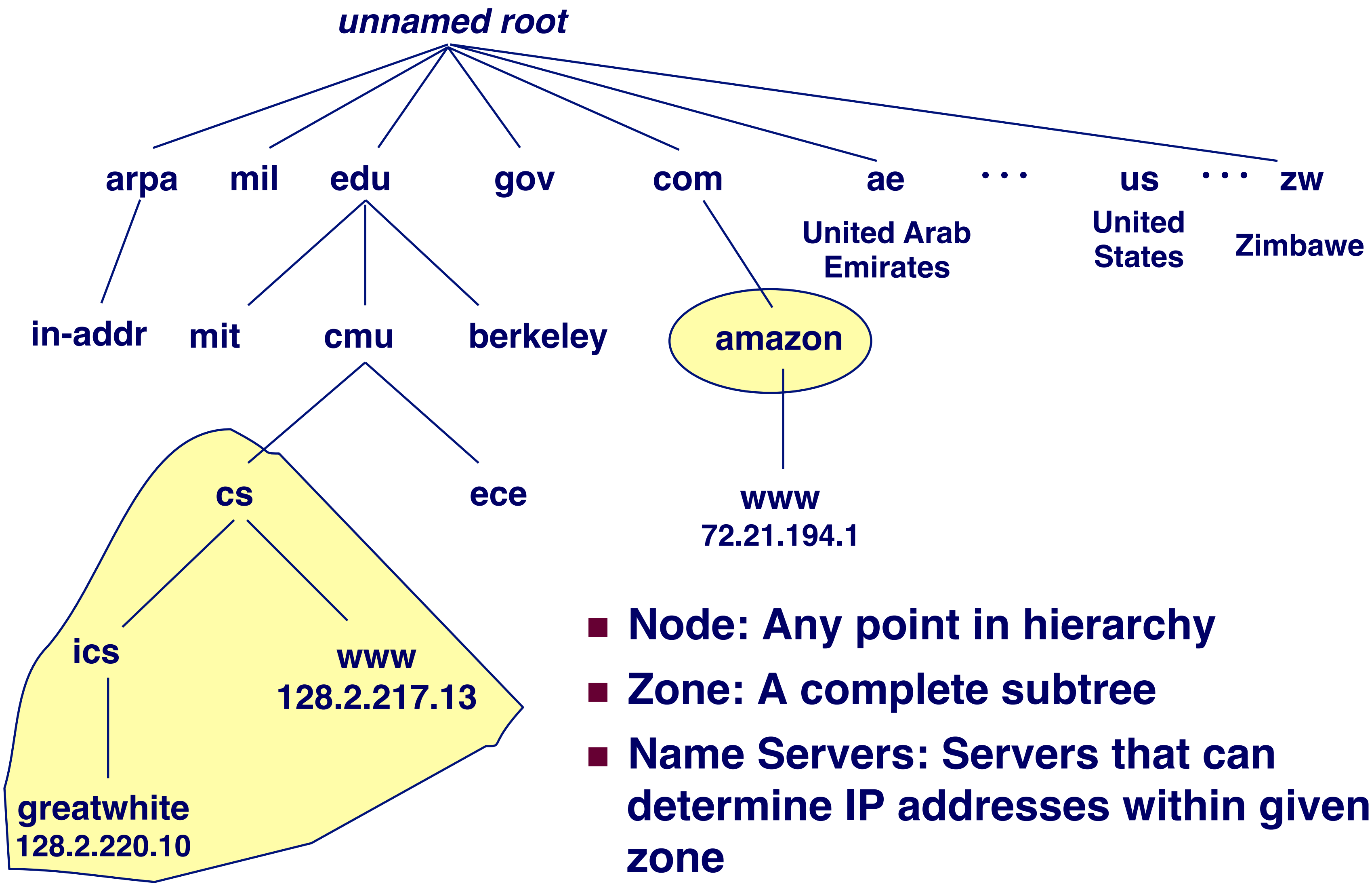
- Runs over UDP (normally) or TCP

DNS Name Hierarchy



- Both generic (e.g., ".com") and country (e.g., ".jp" domains)
- June 2009: 20 generic, 248 country
- Top-level names managed by NIC
- Other name zones delegated to different entities

DNS Name Terminology



- Node: Any point in hierarchy
- Zone: A complete subtree
- Name Servers: Servers that can determine IP addresses within given zone
  - With help from other servers

Programmer’s View of DNS

- Conceptually, programmers can view the DNS database as a collection of millions of *host entry structures*:

```
/* DNS host entry structure */
struct hostent {
   char   *h_name;       /* official domain name of host */
   char   **h_aliases;   /* null-terminated array of domain names */
   int    h_addrtype;    /* host address type (AF_INET) */
   int    h_length;      /* length of an address, in bytes */
   char   **h_addr_list; /* null-terminated array of in_addr structs */
};
```

- in_addr is a struct consisting of 4-byte IP address

Functions for retrieving host entries from DNS:

- `gethostbyname`: query key is a DNS domain name.
- `gethostbyaddr:` query key is an IP address.

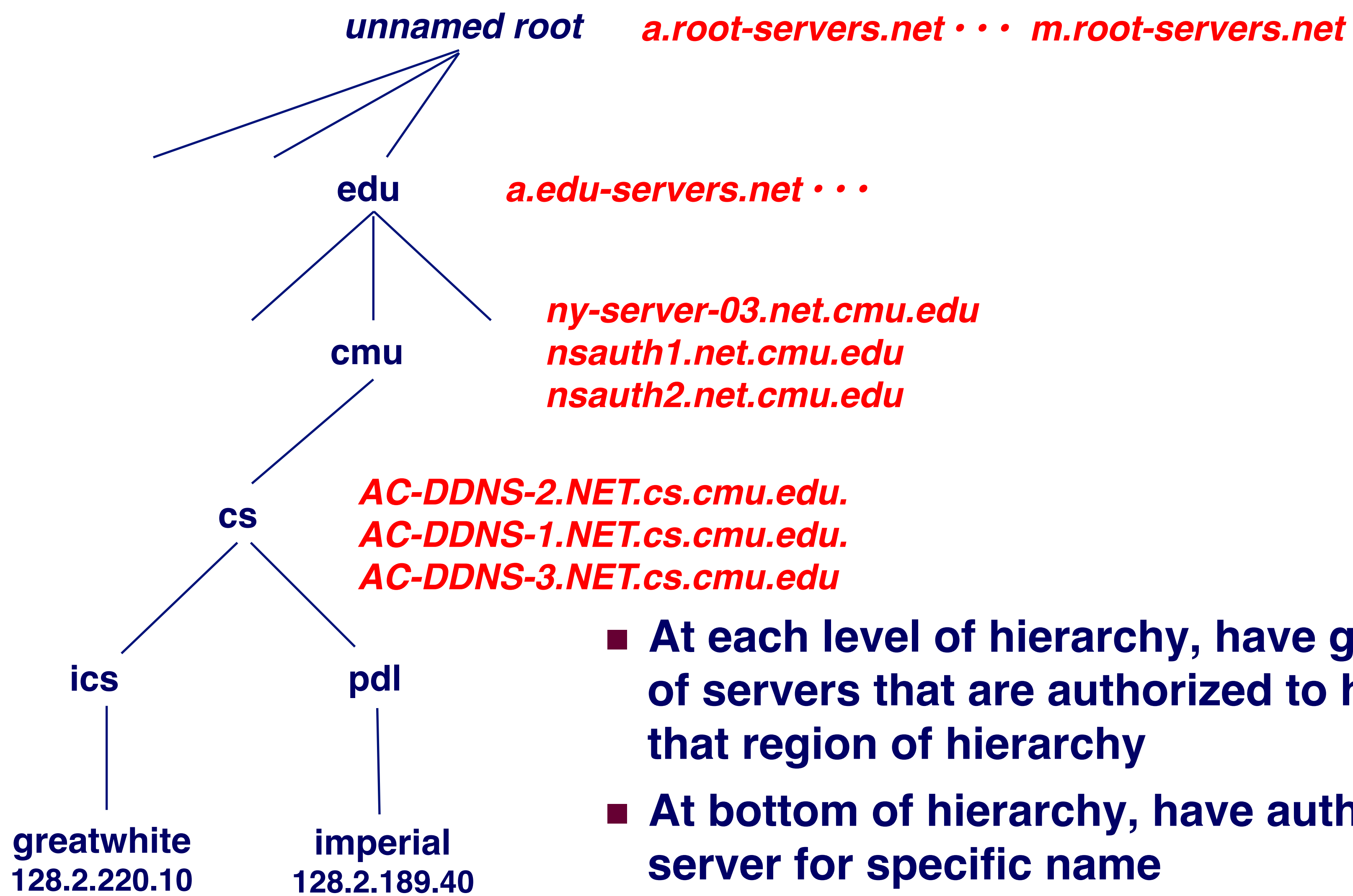
Properties of DNS Host Entries

- **Each host entry is an equivalence class of domain names and IP addresses.**

Different kinds of mappings are possible:

- **Simple case: 1-1 mapping between domain name and IP addr:**
  - `greatwhite.ics.cs.cmu.edu` maps to `128.2.220.10`
- **Multiple domain names mapped to the same IP address:**
  - `eecs.mit.edu, cs.mit.edu`, and `ee.mit.edu` map to `18.62.1.6`
- **Multiple domain names mapped to multiple IP addresses:**
  - `aol.com` and `www.aol.com` map to multiple IP addrs.
- **Some valid domain names don't map to any IP address:**
  - for example: `ics.cs.cmu.edu`

DNS Name Server Hierarchy



- At each level of hierarchy, have group of servers that are authorized to handle that region of hierarchy
- At bottom of hierarchy, have authority server for specific name

Nominal Root Name Servers

- **13 total**

Physical Root Name Servers

- Several root servers have multiple physical servers
- Packets routed to "nearest" server by "Anycast" protocol
- 346 servers total

DNS Records

Format: (class, name, value, type, TTL)

Database of Resource Records (RRs)

- Classes: IN = Internet
- Each class defines value associated with type

IN Class Types

- A   Address
  - Name = hostname, Value = IP address
- NS   Name Server
  - Name = domain (e.g., cs.cmu.edu)
  - Value = authoritative name server for this domain
- CNAME   Canonical Name (alias)
  - Name = alias name
  - Value = canonical name
- MX   Mail server
  - Value = mail server hostname

Getting DNS Information with `dig`

```
unix> dig greatwhite.ics.cs.cmu.edu

;; ANSWER SECTION:
greatwhite.ics.cs.cmu.edu. 2966 IN      A       128.2.220.10

;; AUTHORITY SECTION:
cs.cmu.edu.                593      IN      NS      AC-DDNS-3.NET.cs.cmu.edu.
cs.cmu.edu.                593      IN      NS      AC-DDNS-1.NET.cs.cmu.edu.
cs.cmu.edu.                593      IN      NS      AC-DDNS-2.NET.cs.cmu.edu.
```

Perform DNS lookup as would for `gethostbyname`

- Lots of command-line options

Tracing Hierarchy (1)

Dig Program

- Use flags to find name server (NS)
- Disable recursion so that operates one step at a time

```
unix> dig +norecurse @a.root-servers.net NS greatwhite.ics.cs.cmu.edu

;; ADDITIONAL SECTION:
a.edu-servers.net.      172800  IN      A       192.5.6.30
c.edu-servers.net.      172800  IN      A       192.26.92.30
d.edu-servers.net.      172800  IN      A       192.31.80.30
f.edu-servers.net.      172800  IN      A       192.35.51.30
g.edu-servers.net.      172800  IN      A       192.42.93.30
g.edu-servers.net.      172800  IN      AAAA    2001:503:cc2c::2:36
l.edu-servers.net.      172800  IN      A       192.41.162.30
```

IP v6 address

- All .edu names handled by set of servers

Tracing Hierarchy (2)

- **3 servers handle CMU names**

```
unix> dig +norecurse @g.edu-servers.net NS greatwhite.ics.cs.cmu.edu

;; AUTHORITY SECTION:
cmu.edu.                172800  IN      NS      ny-server-03.net.cmu.edu.
cmu.edu.                172800  IN      NS      nsauth1.net.cmu.edu.
cmu.edu.                172800  IN      NS      nsauth2.net.cmu.edu.
```

Tracing Hierarchy (3 & 4)

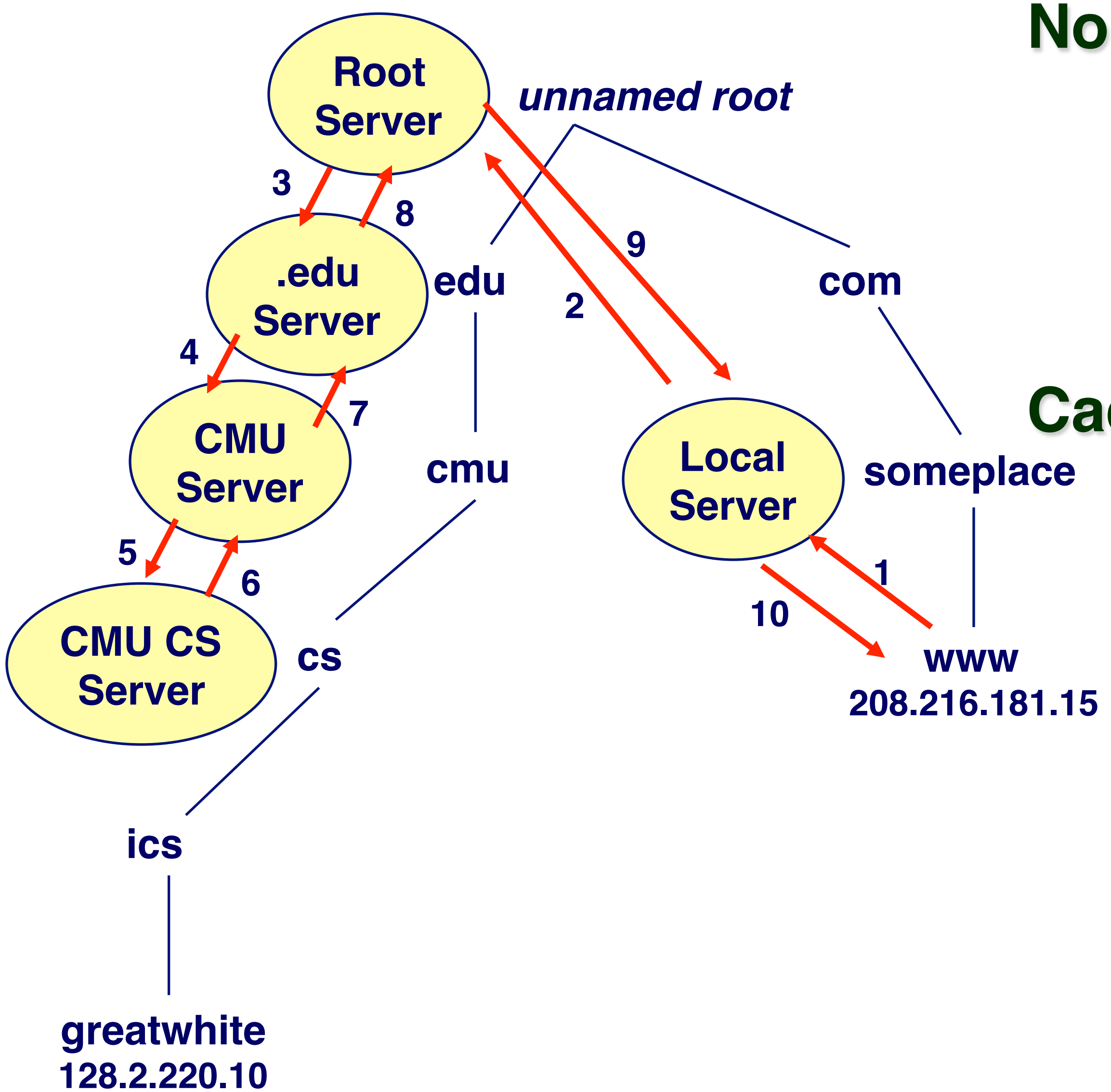
- **3 servers handle CMU CS names**

```
unix> dig +norecurse @nsauth1.net.cmu.edu NS greatwhite.ics.cs.cmu.edu

;; AUTHORITY SECTION:
cs.cmu.edu.                 600     IN      NS      AC-DDNS-2.NET.cs.cmu.edu.
cs.cmu.edu.                 600     IN      NS      AC-DDNS-1.NET.cs.cmu.edu.
cs.cmu.edu.                 600     IN      NS      AC-DDNS-3.NET.cs.cmu.edu.
```

- **Server within CS is "start of authority" (SOA) for this name**

```
unix>dig +norecurse @AC_DDNS-2.NET.cs.cmu.edu NS
        greatwhite.ics.cs.cmu.edu

;; AUTHORITY SECTION:
cs.cmu.edu.                 300     IN      SOA   PLANISPHERE.FAC.cs.cmu.edu.
```

Recursive DNS Name Resolution



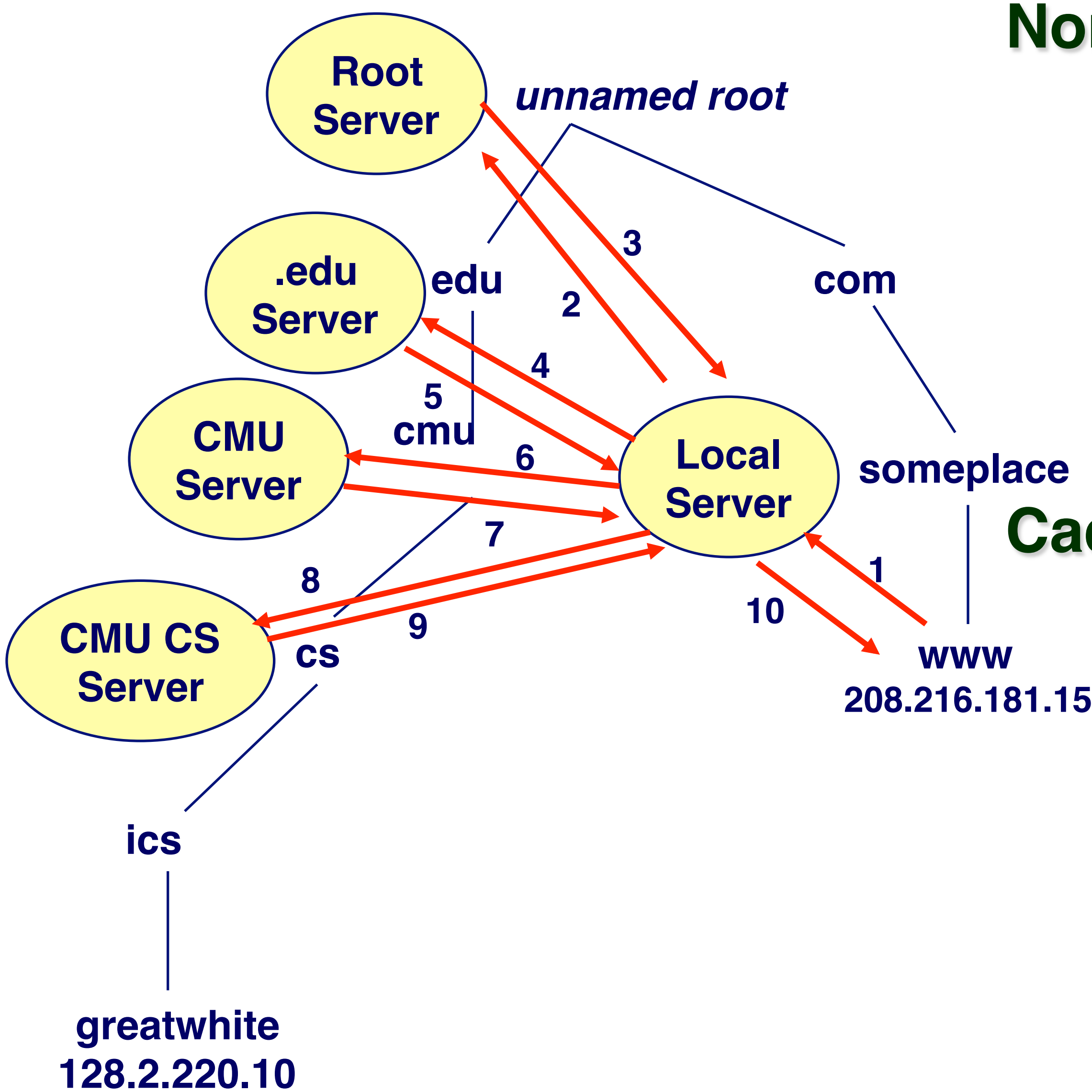
Nonlocal Lookup

- Recursively from root server downward
- Results passed up

Caching

- Results stored in caches along each hop
- Can shortcircuit lookup when cached entry present

Iterative DNS Name Resolution



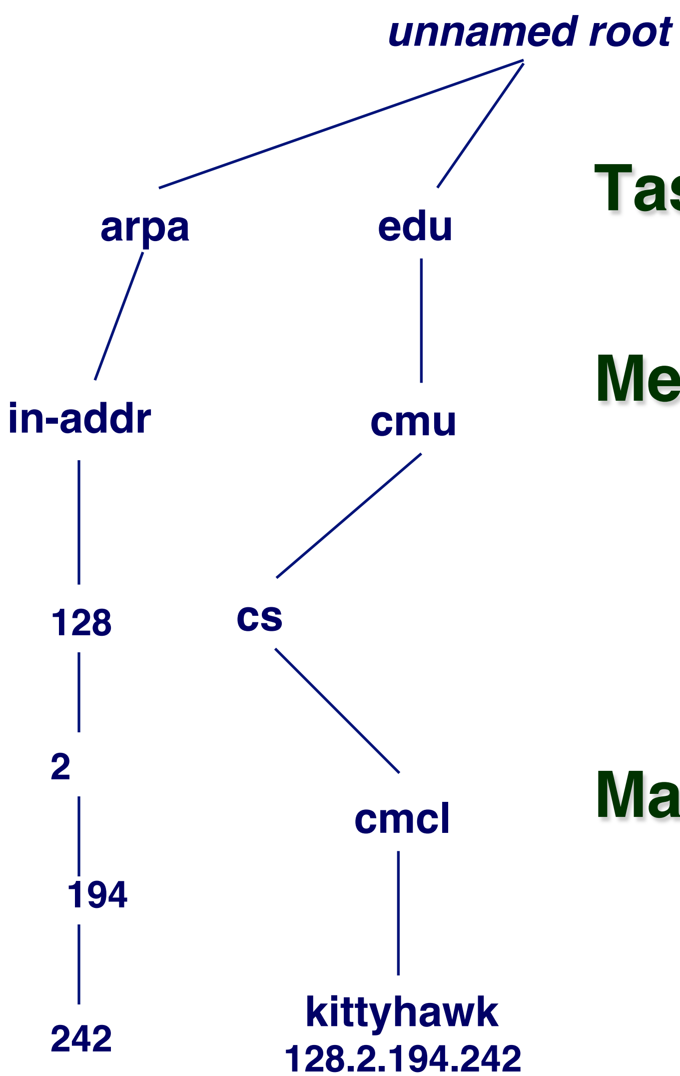
Nonlocal Lookup

- At each step, server returns name of next server down
- Local server directly queries each successive server

Caching

- Local server builds up cache of intermediate translations
- Helps in resolving names xxx.cs.cmu.edu, yy.cmu.edu, and z.edu

Reverse DNS



Task

- Given IP address, find its name

Method

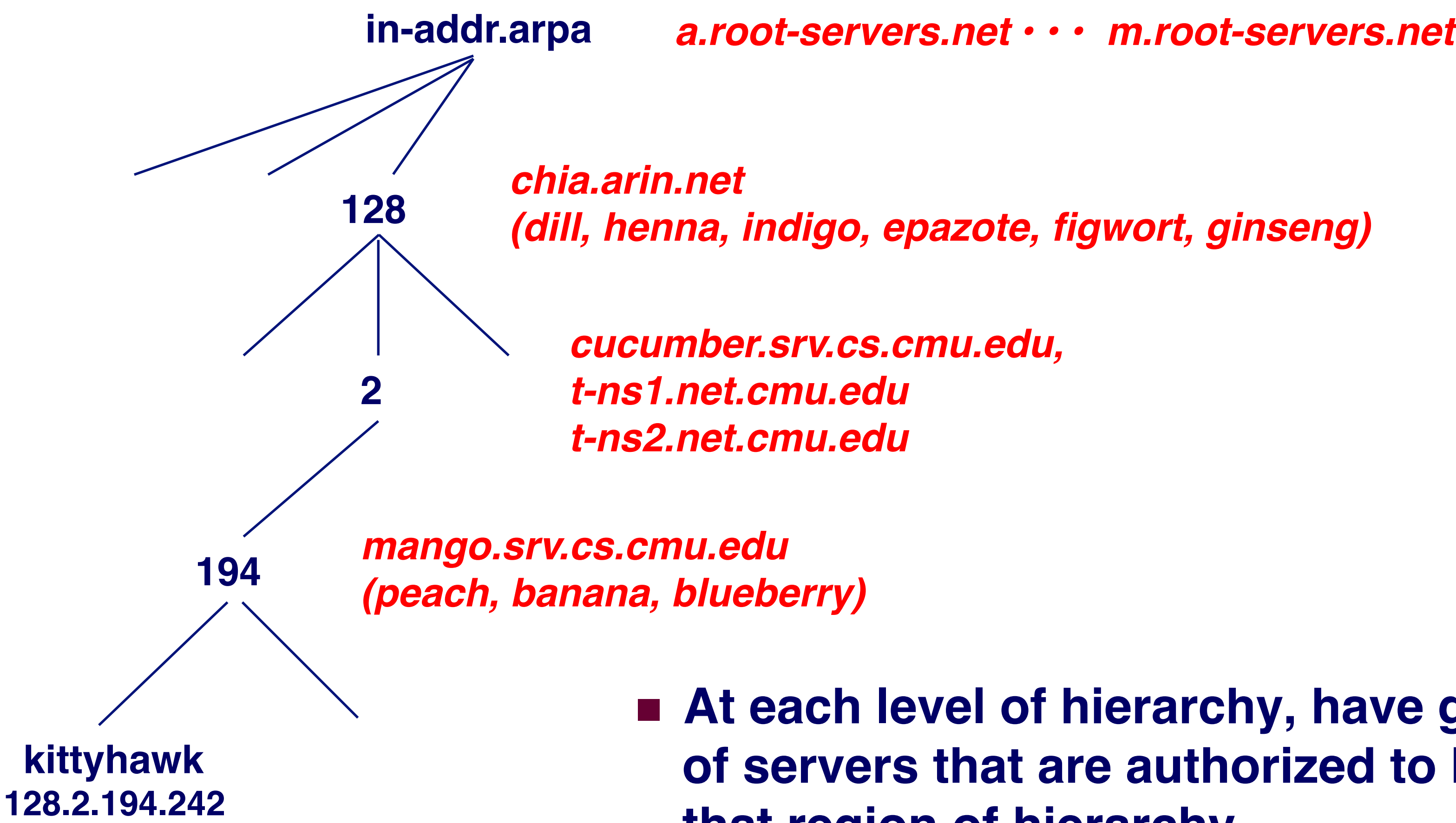
- Maintain separate hierarchy based on IP names
- Write 128.2.194.242 as

  242.194.128.2.in-addr.arpa

Managing

- Authority manages IP addresses assigned to it
- E.g., CMU manages name space 128.2.in-addr.arpa

.arpa Name Server Hierarchy



- At each level of hierarchy, have group of servers that are authorized to handle that region of hierarchy

Performance Issues

Challenge

- There's way too much traffic on the Internet
- Popular sites (Google, Amazon, Facebook, …) get huge amounts of traffic
  - Could become "hot spot"
- It takes much longer to route packets around world than next door

Opportunities

- Services can be replicated
  - Multiple servers / data center
  - Multiple data centers around world
- Content can be cached

How Can this Work?

- Compare to original Internet model
  - IP address designates unique host

Server Balancing

DNS Tricks

- Customize DNS response to location
  - Allows distribution by geography
- Return multiple host names / query
  - Client (could) choose one at random
- Update DNS entries with new servers
  - Rotate loading

Within Data Center

- Keep changing binding between IP address and host

Server Balancing Example

DNS Tricks

- Different responses to different servers, short TTL's

```
unix1> dig www.google.com

;; ANSWER SECTION:
www.google.com.          87775   IN      CNAME   www.l.google.com.
www.l.google.com.        81      IN      A       72.14.204.104
www.l.google.com.        81      IN      A       72.14.204.105
www.l.google.com.        81      IN      A       72.14.204.147
www.l.google.com.        81      IN      A       72.14.204.99
www.l.google.com.        81      IN      A       72.14.204.103
```

```
unix2> dig www.google.com

;; ANSWER SECTION:
www.google.com.          603997  IN      CNAME   www.l.google.com.
www.l.google.com.        145     IN      A       72.14.204.99
www.l.google.com.        145     IN      A       72.14.204.103
www.l.google.com.        145     IN      A       72.14.204.104
www.l.google.com.        145     IN      A       72.14.204.105
www.l.google.com.        145     IN      A       72.14.204.147
```

CDN Motivation

Typical Workload:

- Multiple (typically small) objects per page
- Frame, body, ads, logos, …

File sizes

- Heavy-tailed
  - Pareto distribution for tail
  - Lognormal for body of distribution

Embedded references

- Number of embedded objects also pareto
  $Pr(X>x) = (x/x^m)^{-k}$

This plays havoc with performance. Why?

Solutions?

- Lots of small objects & TCP yields:
  - 3-way handshake
  - Lots of slow starts
  - Extra connection state

Content Distribution Networks (CDNs)

The content providers are the CDN customers.

<u>Content replication</u>

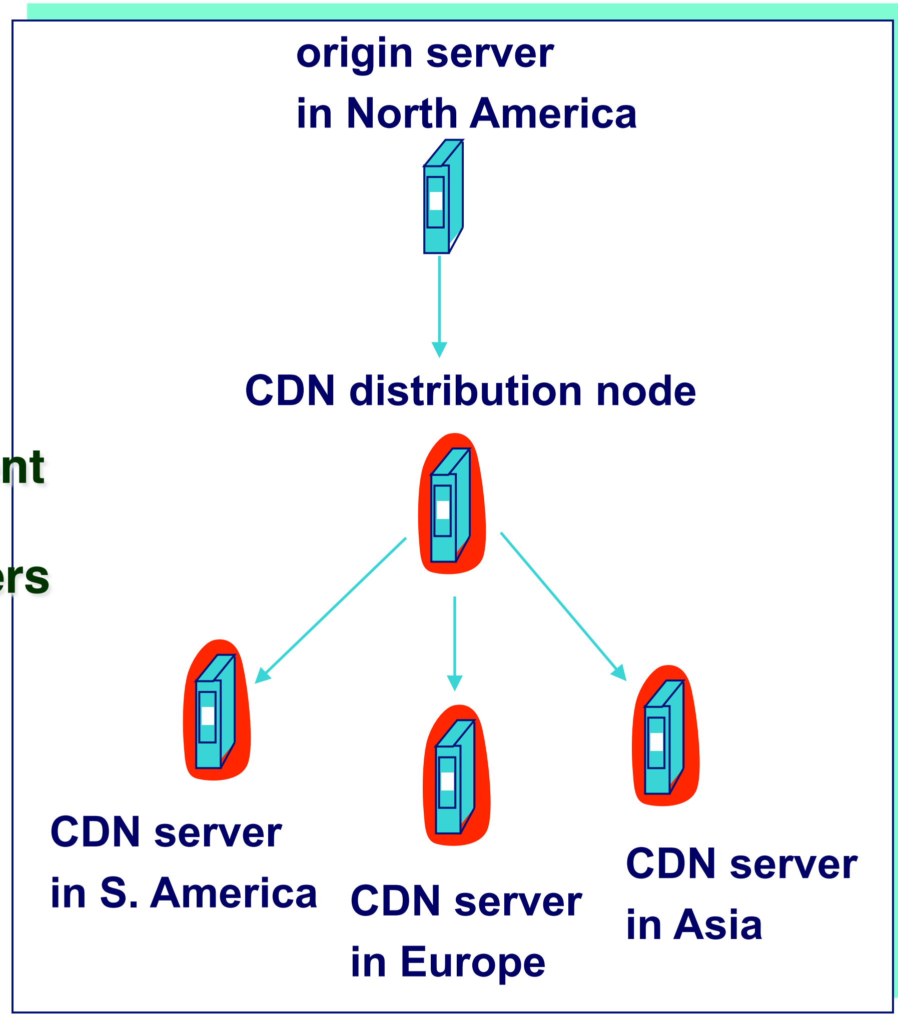
CDN company installs hundreds of CDN servers throughout Internet

- Close to users

CDN replicates its customers' content in CDN servers. When provider updates content, CDN updates servers

CDNs:

- Akamai
- Major ISPs



Serving Through CDN

Requirement

- Route HTTP request to CDN node, rather than to original server

Methods

- CDN provider manipulates DNS tables

```
unix1> dig www.nfl.com

;; ANSWER SECTION:
www.nfl.com.              300     IN      CNAME   www.nfl.com.edgesuite.net.
www.nfl.com.edgesuite.net. 13778 IN      CNAME   a989.g.akamai.net.
a989.g.akamai.net.        20      IN      A       96.7.40.32
a989.g.akamai.net.        20      IN      A       96.7.40.33
```

- Rewrite HTML pages
  - <a href="http://www.nfl.com/images/ben_roethlisberger">
- With
  - <a href="http://a989.g.akamai.net/nfl/images/ben_roethlisberger">

Caching Content in CDN

Simplistic

- Each CDN server caches content that flows through it

Better

- Create DHT among cluster of servers
- Origin of Chord led to founding of Akamai

Challenges

- Usual ones of staleness / consistency / replication
- Handled by TTLs

Effectiveness

- Can't cache dynamic content
  - Responses to individual queries
  - But, even dynamic pages contain static links
- Great for streaming content
  - If multiple clients viewing same programs ~ simultaneously

Summary

DNS one of world's largest distributed system

- Operation and authority delegated hierarchically
- Huge number of queries / second

Many Ways to Reduce / Balance Traffic

- Contrary to simple unique address / host model
- Time & location varying DNS entries
- CDNs