15-440 Distributed Systems

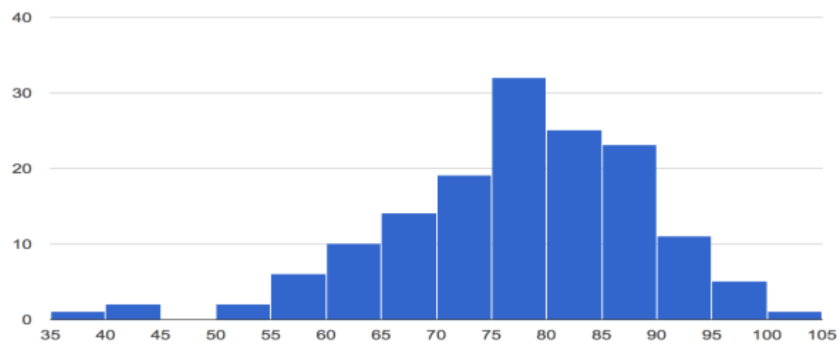
DNS

Midterm Exam

- Avg/Med/StdDev → 76.9/78/11.3
  - Q1 – 15.7/21
  - Q2 – 12.9/16
  - Q3 – 11.9/18
  - Q4 – 16.7/20
  - Q5 – 8.5/11
  - Q6 – 9.2/12

Midterm Exam

- Solutions – will be posted soon
- Regrade policy
  - Return exam to course secretary by Friday @ 5pm
  - Attach sheet explaining why regrade is requested



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Midsemester Grades

- 46.1% of total
  - 3.75% for HW1
  - 3.75% for HW2
  - 20% for midterm
  - 9% for P0
  - 9.6% (.12 * .8) for P1 Checkpoint + Part A

Outline

- DNS Design
- DNS Today

Naming

- How do we efficiently locate resources?
  - DNS: name → IP address
- Challenge
  - How do we scale this to the wide area?

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Obvious Solutions (1)

Why not use /etc/hosts?

- Original Name to Address Mapping
  - Flat namespace
  - /etc/hosts
  - SRI kept main copy
  - Downloaded regularly
- Count of hosts was increasing: machine per domain → machine per user
  - Many more downloads
  - Many more updates

Obvious Solutions (2)

Why not centralize DNS?

- Single point of failure
- Traffic volume
- Distant centralized database
- Single point of update

- Doesn't *scale!*

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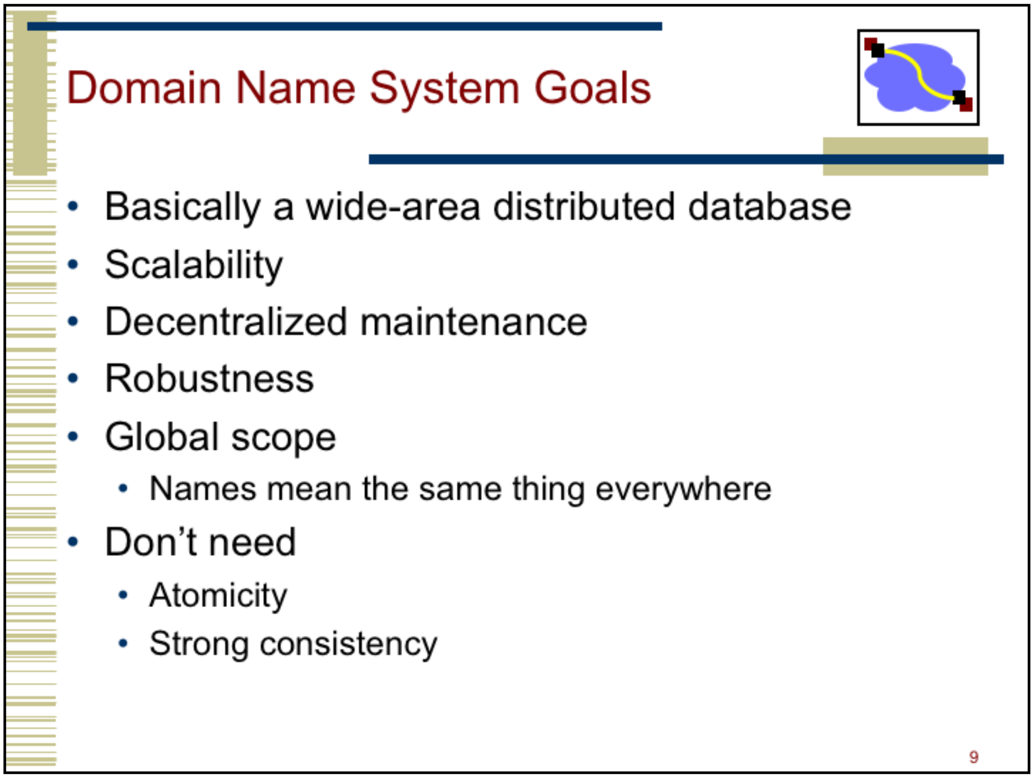

ACID

Atomic

Consistent

Isolated

Durable

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 addrinfo {
        int     ai_family;              /* host address type (AF_INET) */
        size_t  ai_addrlen;             /* length of an address, in bytes */
        struct sockaddr *ai_addr;       /* address! */
        char    *ai_canonname;          /* official domain name of host */
        struct addrinfo *ai_next;       /* other entries for host */
};
```

- Functions for retrieving host entries from DNS:
  - `getaddrinfo`: query key is a DNS host name.
  - `getnameinfo`: query key is an IP address.

DNS Message Format

12 bytes	Identification	Flags
	No. of Questions	No. of Answer RRs
	No. of Authority RRs	No. of Additional RRs
Name, type fields for a query	Questions (variable number of answers)	
RRs in response to query	Answers (variable number of resource records)	
Records for authoritative servers	Authority (variable number of resource records)	
Additional "helpful info that may be used	Additional Info (variable number of resource records)	

DNS Header Fields

- Identification
  - Used to match up request/response
- Flags
  - 1-bit to mark query or response
  - 1-bit to mark authoritative or not
  - 1-bit to request recursive resolution
  - 1-bit to indicate support for recursive resolution

DNS Records

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

- DB contains tuples called resource records (RRs)
  - Classes = Internet (IN), Chaosnet (CH), etc.
  - Each class defines value associated with type

FOR IN class:

- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is name of authoritative name server for this domain
- Type=CNAME
  - **name** is an alias name for some “canonical” (the real) name
  - **value** is canonical name
- Type=MX
  - **value** is hostname of mailserver associated with **name**

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Properties of DNS Host Entries

- Different kinds of mappings are possible:
  - Simple case: 1-1 mapping between domain name and IP addr:
    - `kittyhawk.cmcl.cs.cmu.edu` maps to `128.2.194.242`
  - Multiple domain names maps to the same IP address:
    - `eecs.mit.edu` and `cs.mit.edu` both map to `18.62.1.6`
  - Single domain name maps 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: `cmcl.cs.cmu.edu`

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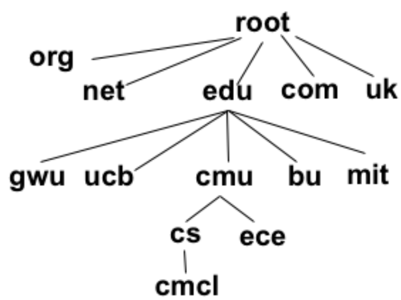
DNS Design: Hierarchy Definitions



- Each node in hierarchy stores a list of names that end with same suffix
  - Suffix = path up tree
- E.g., given this tree, where would following be stored:
  - Fred.com
  - Fred.edu
  - Fred.cmu.edu
  - Fred.cmcl.cs.cmu.edu
  - Fred.cs.mit.edu

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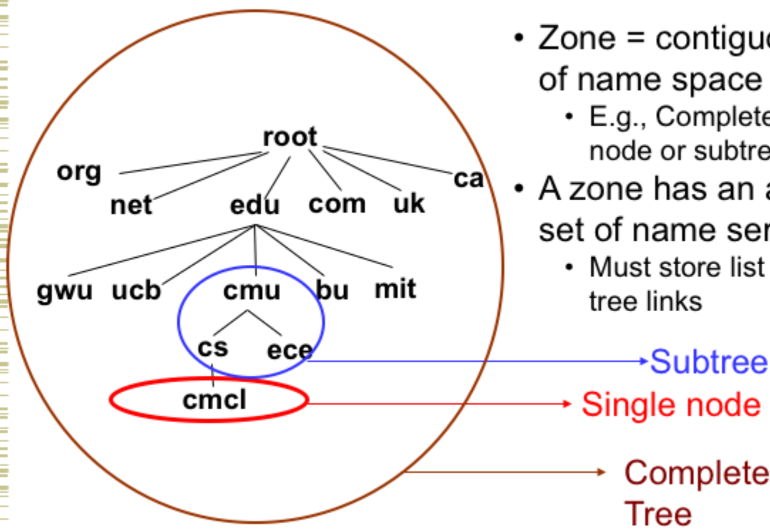
DNS Design: Zone Definitions

- Zone = contiguous section of name space
  - E.g., Complete tree, single node or subtree
- A zone has an associated set of name servers
  - Must store list of names and tree links



DNS Design: Cont.

- Zones are created by convincing owner node to create/delegate a subzone
  - Records within zone stored multiple redundant name servers
  - Primary/master name server updated manually
  - Secondary/redundant servers updated by zone transfer of name space
    - Zone transfer is a bulk transfer of the "configuration" of a DNS server – uses TCP to ensure reliability
- Example:
  - CS.CMU.EDU created by CMU.EDU administrators
  - Who creates CMU.EDU or .EDU?

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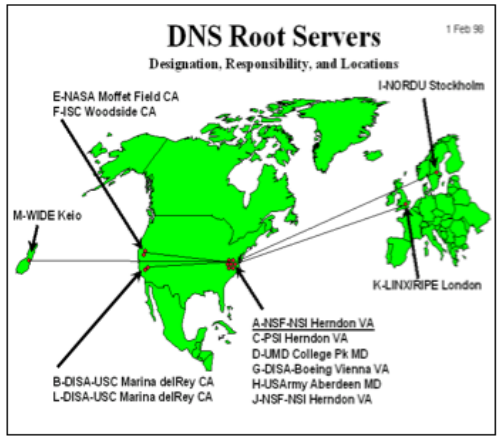
DNS: Root Name Servers

- Responsible for “root” zone
- Approx. 13 root name servers worldwide
  - Currently {a-m}.root-servers.net
- Local name servers contact root servers when they cannot resolve a name
  - Configured with well-known root servers
  - Newer picture → www.root-servers.org



Physical Root Name Servers

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

Servers/Resolvers

- Each host has a resolver
  - Typically a library that applications can link to
  - Local name servers hand-configured (e.g. /etc/resolv.conf)
- Name servers
  - Either responsible for some zone or…
  - Local servers
    - Do lookup of distant host names for local hosts
    - Typically answer queries about local zone

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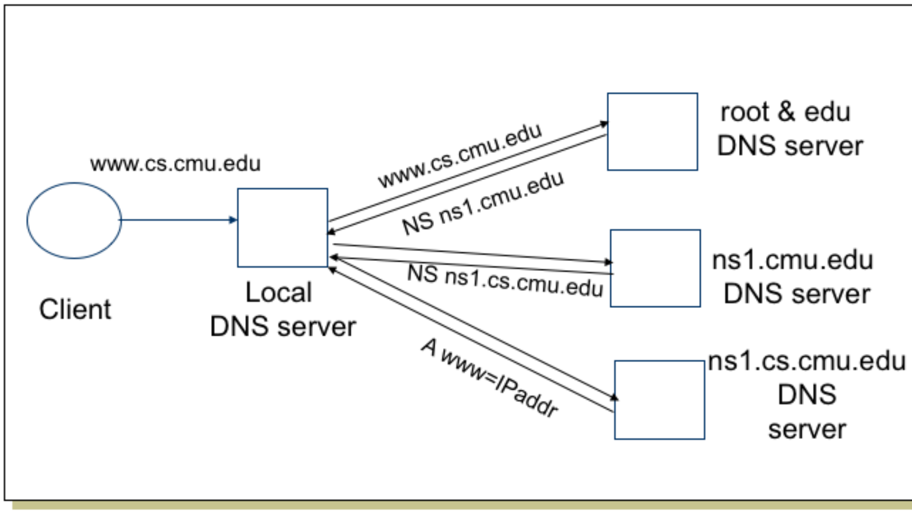
Typical Resolution



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Typical Resolution

- Steps for resolving www.cmu.edu
  - Application calls gethostbyname() (RESOLVER)
  - Resolver contacts local name server (S_1)
  - S_1 queries root server (S_2) for (www.cmu.edu)
  - S_2 returns NS record for cmu.edu (S_3)
  - What about A record for S_3?
    - This is what the additional information section is for (PREFETCHING)
  - S_1 queries S_3 for www.cmu.edu
  - S_3 returns A record for www.cmu.edu

Lookup Methods

Recursive query:

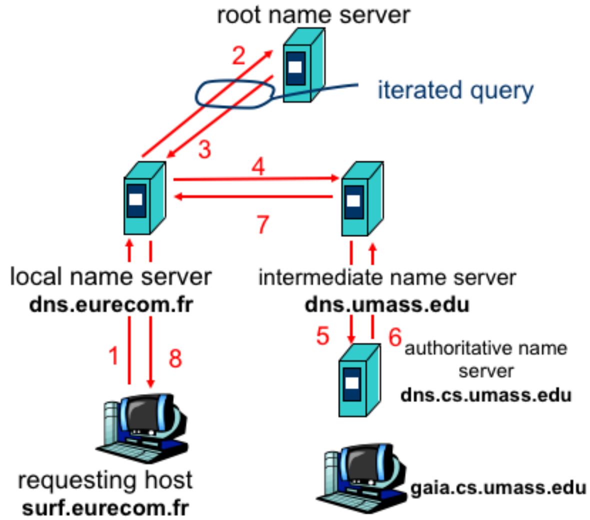
- Server goes out and searches for more info (recursive)
- Only returns final answer or "not found"

Iterative query:

- Server responds with as much as it knows (iterative)
- "I don't know this name, but ask this server"

Workload impact on choice?

- Local server typically does recursive
- Root/distant server does iterative



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Workload and Caching

- Are all servers/names likely to be equally popular?
  - Why might this be a problem? How can we solve this problem?
- DNS responses are cached
  - Quick response for repeated translations
  - Other queries may reuse some parts of lookup
    - NS records for domains
- DNS negative queries are cached
  - Don't have to repeat past mistakes
  - E.g. misspellings, search strings in resolv.conf
- Cached data periodically times out
  - Lifetime (TTL) of data controlled by owner of data
  - TTL passed with every record

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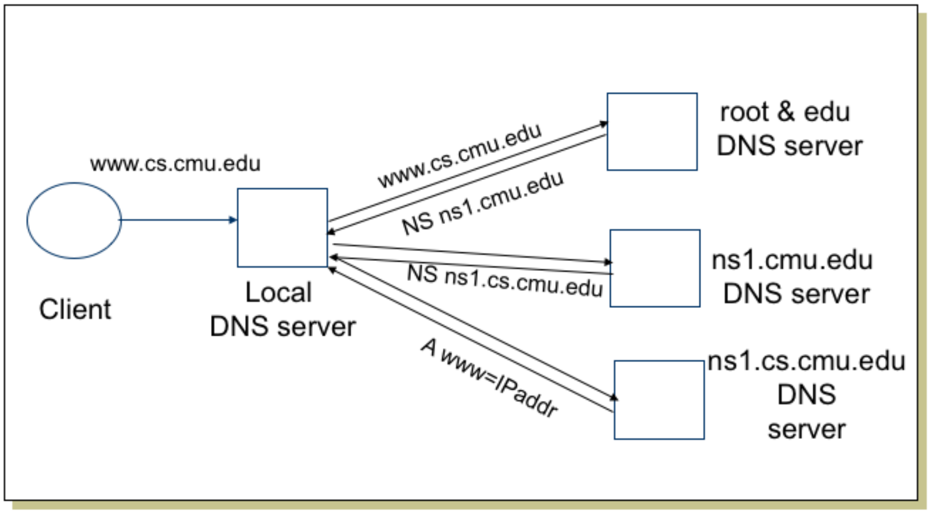
Typical Resolution



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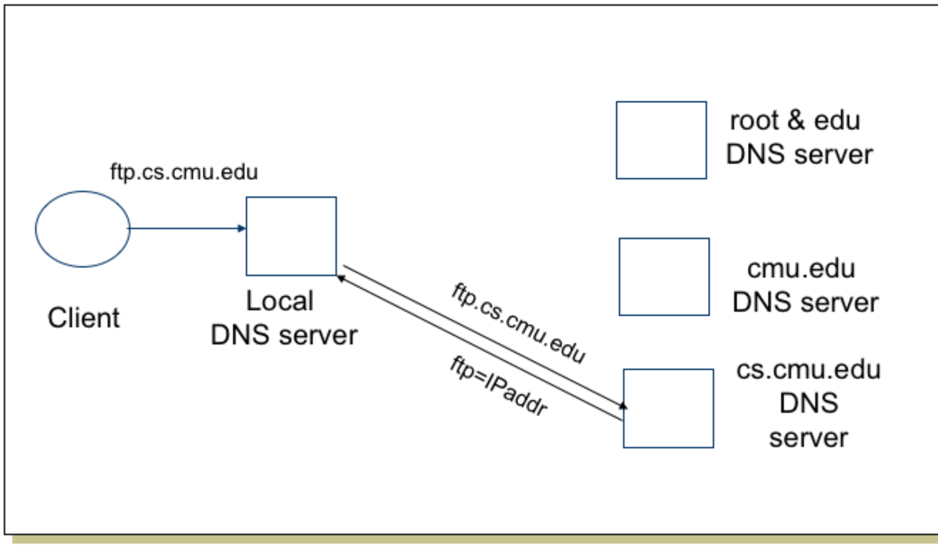
Subsequent Lookup Example



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Reliability

- DNS servers are replicated
  - Name service available if ≥ one replica is up
  - Queries can be load balanced between replicas
- UDP used for queries
  - Need reliability → must implement this on top of UDP!
  - Why not just use TCP?
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don't care which server responds

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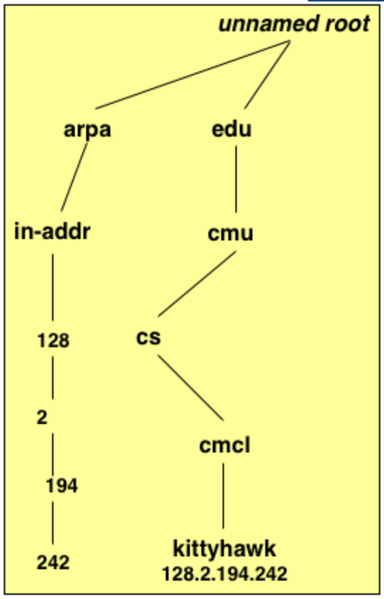
Reverse DNS



- Task
  - Given IP address, find its name
- Method
  - Maintain separate hierarchy based on IP names
  - Write 128.2.194.242 as 242.194.2.128.in-addr.arpa
    - Why is the address reversed?
- Managing
  - Authority manages IP addresses assigned to it
  - E.g., CMU manages name space 128.2.in-addr.arpa

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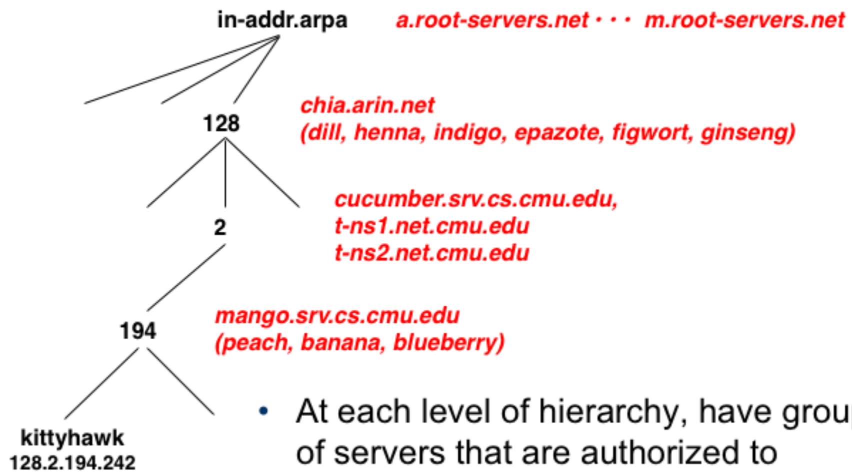
.arpa Name Server Hierarchy



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

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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

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Prefetching

- Name servers can add additional data to response
- Typically used for prefetching
  - CNAME/MX/NS typically point to another host name
  - Responses include address of host referred to in "additional section"

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.
```

```
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.
```

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DNS Hack #1

- Can return multiple A records → what does this mean?

- Load Balance
  - Server sends out multiple A records
  - Order of these records changes per-client

Server Balancing Example

- DNS Tricks

```
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
```

Outline

- DNS Design
- DNS Today

Protecting the Root Nameservers

Attack On Internet Called Largest Ever

By David McGuire and Brian Krebs
washingtonpost.com Staff Writers
Tuesday, October 22, 2002; 5:40 PM

The heart of the Internet sustained its largest and most sophisticated attack ever, starting late Monday, according to officials at key online backbone organizations.

Around 5:00 p.m. EDT on Monday, a "distributed denial of service" (DDOS) attack struck the 13 "root servers" that provide the primary roadmap for almost all Internet communications. Despite the scale of the attack, which lasted about an hour, Internet users worldwide were largely unaffected, experts said.

Sophisticated?
Why did nobody notice?

seshan.org. 13759 NS www.seshan.org.

Defense Mechanisms

- Redundancy: 13 root nameservers
- IP Anycast for root DNS servers {c,f,i,j,k}.root-servers.net
  - RFC 3258
  - Most *physical* nameservers lie outside of the US

Defense: Replication and Caching

Letter	Old name	Operator	Location
A	ns.internic.net	VeriSign	Dulles, Virginia, USA
B	ns1.isi.edu	ISI	Marina Del Rey, California, USA
C	c.psi.net	Cogent Communications	distributed using anycast
D	terp.umd.edu	University of Maryland	College Park, Maryland, USA
E	ns.nasa.gov	NASA	Mountain View, California, USA
F	ns.isc.org	ISC	distributed using anycast
G	ns.nic.ddn.mil	U.S. DoD NIC	Columbus, Ohio, USA
H	aos.arl.army.mil	U.S. Army Research Lab	Aberdeen Proving Ground, Maryland, USA
I	nic.nordu.net	Autonomica	distributed using anycast
J		VeriSign	distributed using anycast
K		RIPE NCC	distributed using anycast
L		ICANN	Los Angeles, California, USA
M		WIDE Project	distributed using anycast

source: wikipedia

What Happened on Oct 21st?

- DDoS attack on Dyn
- Dyn provides core Internet services for Twitter, SoundCloud, Spotify, Reddit and a host of other sites
- Why didn't DNS defense mechanisms work in this case?
- Let's take a look at the DNS records

What was the source of attack?

- Mirai botnet
  - Used in 620Gbps attack last month

- Source: bad IoT devices, e.g.,
  - White-labeled DVR and
    IP camera electronics
  - username: root and password: **xc3511**
  - password is hardcoded into the device firmware

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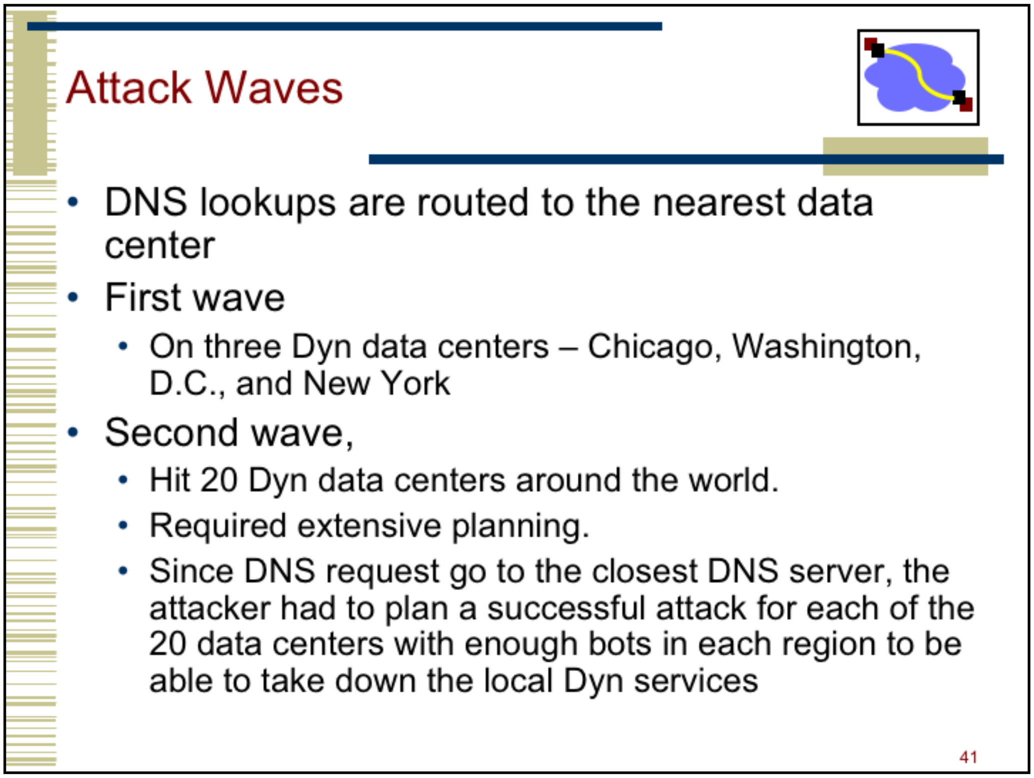

Drew says the attack consisted mainly of TCP SYN floods aimed directly at against port 53 of Dyn's DNS servers, but also a prepend attack, which is also called a subdomain attack. That's when attackers send DNS requests to a server for a domain for which they know the target is authoritative. But they tack onto the front of the domain name random prepends or subnet designations. The server won't have these in its cache so will have to look them up, sapping computational resources and effectively preventing the server from handling legitimate traffic, he says.

Solutions?

- Dyn customers
  - Going to backup DNS providers, as Amazon did
  - Signing up with an alternative today after the attacks, as PayPal did
- Lowering their time-to-life settings on their DNS servers
  - Redirect traffic faster to another DNS service that is still available

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Root Zone

- Generic Top Level Domains (gTLD) = .com, .net, .org, etc…
- Country Code Top Level Domain (ccTLD) = .us, .ca, .fi, .uk, etc…
- Root server ({a-m}.root-servers.net) also used to cover gTLD domains
  - Load on root servers was growing quickly!
  - Moving .com, .net, .org off root servers was clearly necessary to reduce load → done Aug 2000

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gTLDs

- Unsponsored
  - .com, .edu, .gov, .mil, .net, .org
  - .biz → businesses
  - .info → general info
  - .name → individuals
- Sponsored (controlled by a particular association)
  - .aero → air-transport industry
  - .cat → catalan related
  - .coop → business cooperatives
  - .jobs → job announcements
  - .museum → museums
  - .pro → accountants, lawyers, and physicians
  - .travel → travel industry
- Starting up
  - .mobi → mobile phone targeted domains
  - .post → postal
  - .tel → telephone related
- Proposed
  - .asia, .cym, .geo, .kid, .mail, .sco, .web, .xxx

New Registrars

- Network Solutions (NSI) used to handle all registrations, root servers, etc…
  - Clearly not the democratic (Internet) way
  - Large number of registrars that can create new domains → However NSI still handles A root server

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Do you trust the TLD operators?

- Wildcard DNS record for all .com and .net domain names not yet registered by others
  - September 15 – October 4, 2003
  - February 2004: Verisign sues ICANN
- Redirection for these domain names to Verisign web portal (SiteFinder)
- What services might this break?

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DNS (Summary)

- Motivations → large distributed database
  - Scalability
  - Independent update
  - Robustness
- Hierarchical database structure
  - Zones
  - How is a lookup done
- Caching/prefetching and TTLs
- Reverse name lookup
- What are the steps to creating your own domain?