15-441 Lecture 7

DNS

Based on slides from previous 441 lectures

Outline

- DNS Design
- DNS Today

(Extra credit, remind me at end)

What is DNS?

- DNS (Domain Name Service) is primarily used to translate human readable names into machine usable addresses, e.g., IP addresses.
- DNS goal:
  - Efficiently locate resources.
    E.g., Map name → IP address
  - Scale to many users over a large area
  - Scale to many updates

How resolve name → IP addr?

Obvious Solutions (1)

Why not centralize DNS?

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

- Doesn't *scale!*

Obvious Solutions (2)

Why not use /etc/hosts?

- Original Name to Address Mapping
  - Flat namespace
  - /etc/hosts
  - SRI kept main copy
  - Downloaded regularly
- Mid 80's this became untenable. Why?
- Count of hosts was increasing: machine per domain → machine per user
  - Many more downloads
  - Many more updates

/etc/hosts still exists.

Domain Name System Goals

- Basically a wide-area distributed database (The biggest in the world!)
- Scalability
- Decentralized maintenance
- Robustness
- Global scope
  - Names mean the same thing everywhere
- Don't need all of ACID
  - Atomicity
  - Strong consistency
- Do need: distributed update/query & Performance

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-termed array of in_addr structs */
};
```

  - in_addr is a struct consisting of 4-byte IP addr
- Functions for retrieving host entries from DNS:
  - **gethostbyname**: query key is a DNS host name.
  - **gethostbyaddr**: query key is an IP address.

DNS Message Format

Identification	Flags
No. of Questions	No. of Answer RRs
No. of Authority RRs	No. of Additional RRs
Questions (variable number of answers)	
Answers (variable number of resource records)	
Authority (variable number of resource records)	
Additional Info (variable number of resource records)	

12 bytes

Name, type fields for a query

RRs in response to query

Records for authoritative servers

Additional "helpful info that may be used

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:

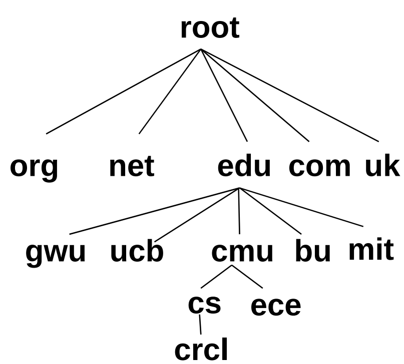
- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is name of authoritative name server for this domain
- Type=CNAME
  - **name** is an alias name for some "canonical" name
  - **value** is canonical name
- Type=MX
  - **value**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

Properties of DNS Host Entries

Different kinds of mappings are possible:

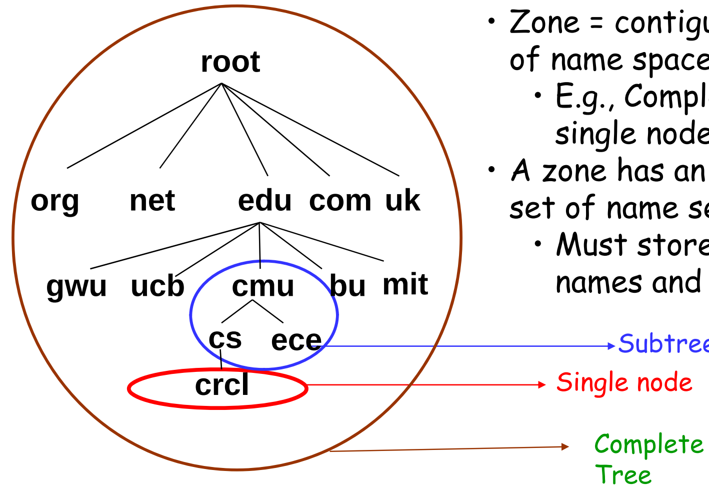
- 1-1 mapping between domain name and IP addr:
  `provolone.crcl.cs.cmu.edu` maps to `128.2.218.81`
- Multiple domain names maps to the same IP addr:
  `www.scs.cmu.edu` and `www.cs.cmu.edu` both map to `128.2.203.164`
- Single domain name maps to multiple IP addresses:
  `aol.com` and `www.aol.com` map to multiple IP addrs.
- Some valid domain names don't map to any IP addr:
  `crcl.cs.cmu.edu` doesn't have a host

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.crcl.cs.cmu.edu
  - Fred.cs.mit.edu

DNS Design: Zone Definitions



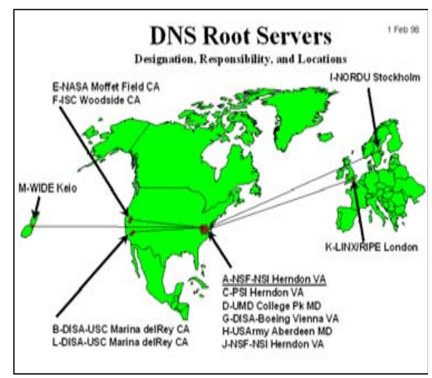
- Zone = contiguous section of name space
  - E.g., Complete tree, single node or subtree
- A zone has an associated set of name servers
  - Must store list of names and tree links

DNS Design: Cont.

- Zones are created by convincing owner node to create/delegate a subzone
  - Records within zone stored in 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 admins
  - Who creates CMU.EDU or .EDU?

DNS: Root Name Servers

- Responsible for "root" zone
- 13 root name servers
  - Currently {a-m}.root-servers.net
- Local name servers contact root servers when they cannot resolve a name
- Why 13?



Not really 13!

Check out anycast)

10/08, from www.root-servers.org

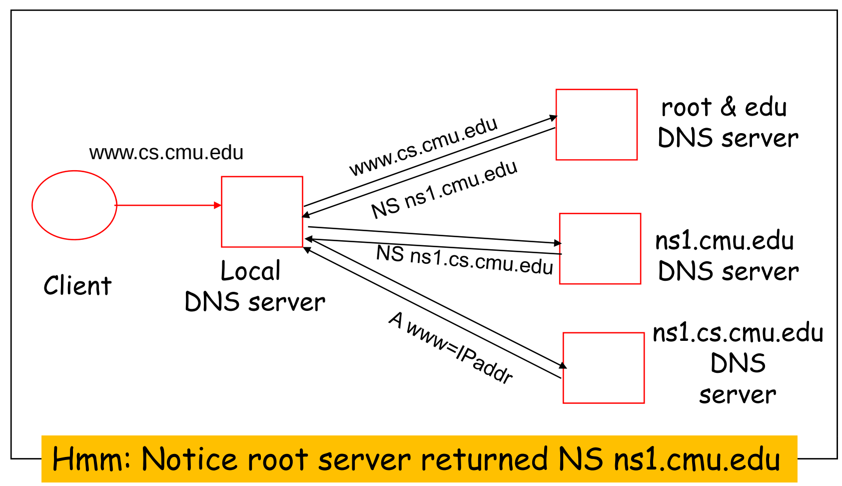
So Far

- Database structure
  - Hierarchy of labels x.y.z
  - Organized into zones
  - Zones have nameservers (notice plural!)
- Database layout
  - Records which map
    names→names,
    names→ip,
    etc.
- Programmer API: gethostbyname, …

Servers/Resolvers

- Each host has a resolver
  - Typically a library that applications can link to
  - Local name servers hand-configured (or DHCP) (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

Typical Resolution



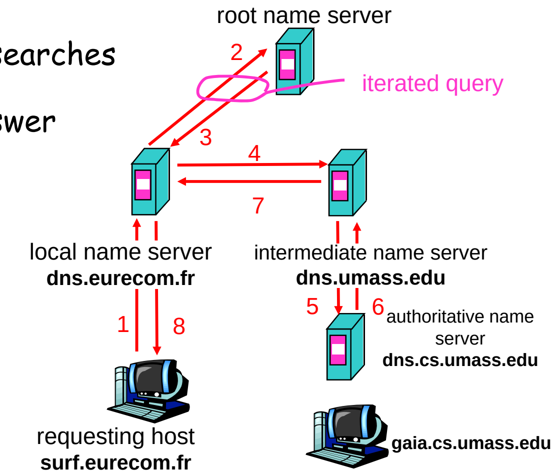
Typical Resolution

- 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 info section is for (PREFETCHING)
  - S_1 queries S_3 for www.cmu.edu
  - S_3 returns A record for www.cmu.edu
- Can return multiple A records → What does this mean?

Lookup Methods

Recursive query:
- Server goes out and searches for more info
- Only returns final answer or "not found"

Iterative query:
- Server responds with as much as it knows.
- "I don't know this name, but ask this server"



Workload impact on choice?
- Root/distant server does iterative
- Local server typically does recursive

How to manage workload?

- Does root nameserver do recursive lookups?
- What about other zones?
- What about imbalance in popularity?
  - .com versus .dj
  - google.com versus bleu.crcl.cs.cmu.edu?
- How do we scale query workload?

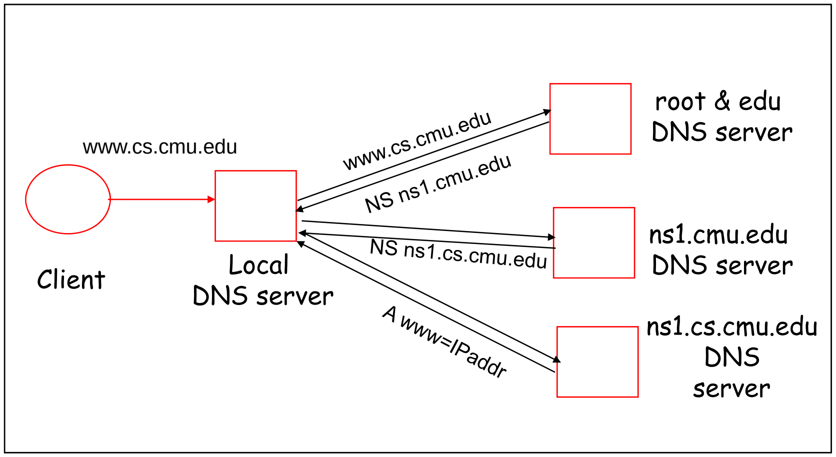
Workload and Caching

- DNS responses are cached
  - Quick response for repeated translations
  - Other queries may reuse some parts of lookup
    - E.g., NS records for domains
- DNS negative queries are cached
  - Don't have to repeat past mistakes
  - E.g., misspellings, search strings in resolv.conf
- How do you handle updates?

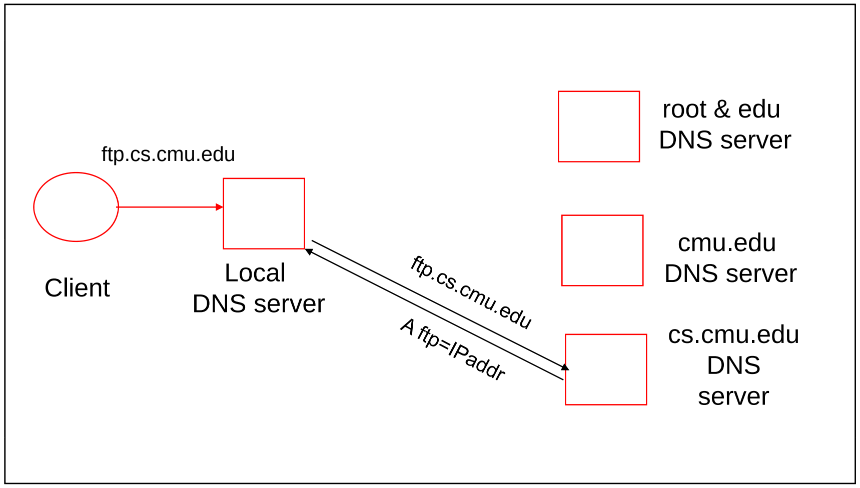
Workload and Caching

- DNS responses are cached
  - Quick response for repeated translations
  - Other queries may reuse some parts of lookup
    - E.g., 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

Typical Resolution



Subsequent Lookup Example



Reliability

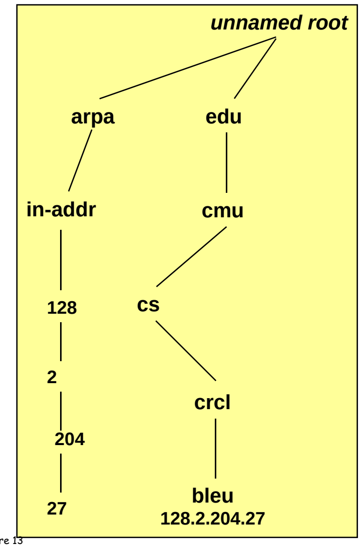
- DNS servers are replicated
  - Name service available if ≥ one replica is up
  - Queries can be load balanced between replicas
- UDP used for queries
  - Need reliability → must implement this on top of UDP!
  - Why not just use TCP?
- Try alternate servers on timeout
  - Exponential backoff when retrying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

So far

- Hierarchial name space

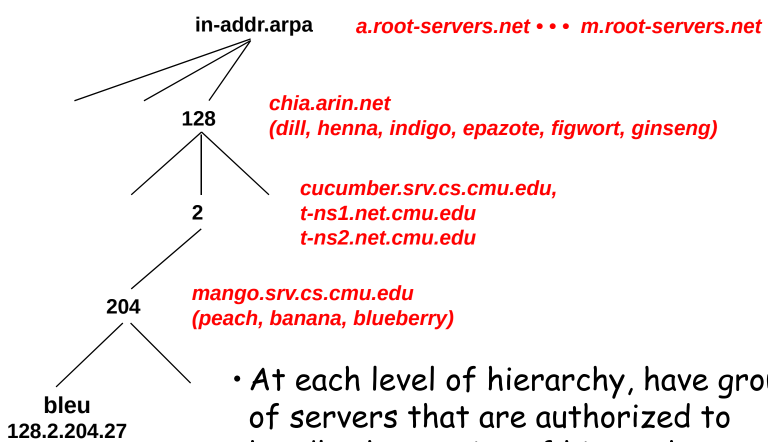
Reverse DNS

Arpa: backronym → Address and Routing Parameter Area



- Task
  - Given IP address, find its name
- Method
  - Maintain separate hierarchy based on IP names
  - Write 128.2.204.27 as 27.204.2.128.in-addr.arpa
    - Why is the address reversed?
- Managing
  - Authority manages IP addresses assigned to it
  - E.g., CMU manages name space 2.128.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

Prefetching

- Name servers can add additional data to response
- Why would they?

Prefetching

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

Mail Addresses

- MX records point to mail exchanger for a name
  - E.g.

```
cmu.edu.     2590     IN     MX     10 CMU-MX4.ANDREW.cmu.edu.
cmu.edu.     2590     IN     MX     10 CMU-MX5.ANDREW.cmu.edu.
```

- Addition of MX record type proved to be a challenge
  - How to get mail programs to lookup MX record for mail delivery?
  - Needed critical mass of such mailers
  - Could we add a new one now?

Outline

- DNS Design
- DNS Today

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
  - How significant an effect would this have?
    - On load?
    - On performance?

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 → bu
  - .jobs → jol
  - .museum →
  - .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
  - Whatever you want!

Is there anything special about .com?
What about adding .goldstein as a gTLD?

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

Measurements of DNS

- No centralized caching per site
  - Each machine runs own caching local server
  - Why is this a problem?
  - How many hosts do we need to share cache? → recent studies suggest 10-20 hosts
- "Hit rate for DNS:1 - (#DNS/#connections)→80%
  - Is this good or bad?
- Lower TTLs for A records does not affect performance
- DNS performance really relies more on NS-record caching

Measurements of DNS

- No centralized caching per site
  - Each machine runs own caching local server
  - Why is this a problem?
  - How many hosts do we need to share cache? → recent studies suggest 10-20 hosts
- "Hit rate for DNS:1 - (#DNS/#connections)→80%
  - Is this good or bad?
  - Most Internet traffic was Web with HTTP 1.0
    - What does a typical page look like? → average of 4-5 imbedded objects → needs 4-5 transfers
    - This alone accounts for 80% hit rate!
- Lower TTLs for A records does not affect performance
- DNS performance really relies more on NS-record caching

Tracing Hierarchy (1)

- Dig Program
  - Allows querying of DNS system
  - Use flags to find name server (NS)
  - Disable recursion so that operates one step at a time

Zone TTL Type Class Value

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

;; A[illegible]HORITY [illegible]N:
edu.            [illegible]  IN   NS   L3.NSTLD.COM.
edu.            172800  IN   NS   D3.NSTLD.COM.
edu.            172800  IN   [illegible] A3.NSTLD.COM.
edu.            172800  IN   [illegible] E3.NSTLD.COM.
edu.            172800  IN   NS   C3.NSTLD.COM.
edu.            172800  IN   NS   F3.NST[illegible]
edu.            172[illegible]  NS   G3.NS[illegible]
edu.            172[illegible]  NS   B3.NS[illegible]
edu.            172[illegible]  NS   M3.NSTLD.COM.
```

  - All .edu names handled by set of servers

Tracing Hierarchy (2)

- 3 servers handle CMU names

```
unix> dig +norecurse @e3.nstld.com NS kittyhawk.cmcl.cs.cmu.edu

;; AUTHORITY SECTION:
cmu.edu.        172800  IN   NS   CUCUMBER.SRV.cs.cmu.edu.
cmu.edu.        172800  IN   NS   T-NS1.NET.cmu.edu.
cmu.edu.        172800  IN   NS   T-NS2.NET.cmu.edu.
```


Tracing Hierarchy (3 & 4)

- 4 servers handle CMU CS names

```
unix> dig +norecurse @t-ns1.net.cmu.edu NS kittyhawk.cmcl.cs.cmu.edu

;; AUTHORITY SECTION:
cs.cmu.edu.     86400   IN   NS   MANGO.SRV.cs.cmu.edu.
cs.cmu.edu.     86400   IN   NS   PEACH.SRV.cs.cmu.edu.
cs.cmu.edu.     86400   IN   NS   BANANA.SRV.cs.cmu.edu.
cs.cmu.edu.     86400   IN   NS   BLUEBERRY.SRV.cs.cmu.edu.
```

- Quasar is master NS for this zone

```
unix>dig +norecurse @blueberry.srv.cs.cmu.edu NS
        kittyhawk.cmcl.cs.cmu.edu

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


DNS (Summary)

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