CSCI-1680
DNS

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Based partly on lecture notes by Scott Shenker and John Jannotti

Host names and IP Addresses

- **Host names**
  - Mnemonics appreciated by humans
  - Variable length, ASCII characters
  - Provide little (if any) information about location
  - Examples: www.cs.brown.edu, bbc.co.uk
- **IP Addresses**
  - Numerical address appreciated by routers
  - Fixed length, binary numbers
  - Hierarchical, related to host location (in the network)
  - Examples: 128.148.32.110, 212.58.224.138

Separating Naming and Addressing

- **Names are easier to remember**
  - www.cnn.com vs 157.166.224.26
- **Addresses can change underneath**
  - e.g, renumbering when changing providers
- **Name could map to multiple addresses**
  - www.cnn.com maps to at least 6 ip addresses
  - Enables
    - Load balancing
    - Latency reduction
    - Tailoring request based on requester's location/device/identity
- **Multiple names for the same address**
  - Aliases: www.cs.brown.edu and cs.brown.edu
  - Multiple servers in the same node (e.g., apache virtual servers)

Scalable Address <-> Name Mappings

- **Originally kept in a local file, `hosts.txt`**
  - Flat namespace
  - Central administrator kept master copy (for the Internet)
  - To add a host, emailed admin
  - Downloaded file regularly
- **Completely impractical today**
  - File would be huge (gigabytes)
  - Traffic implosion (lookups and updates)
    - Some names change mappings every few days (dynamic IP)
  - Single point of failure
  - Impractical politics (repeated names, ownership, etc…)

Goals for an Internet-scale name system

- **Scalability**
  - Must handle a huge number of records
    - With some software synthesizing names on the fly
  - Must sustain update and lookup load
- **Distributed Control**
  - Let people control their own names
- **Fault Tolerance**
  - Minimize lookup failures in face of other network problems

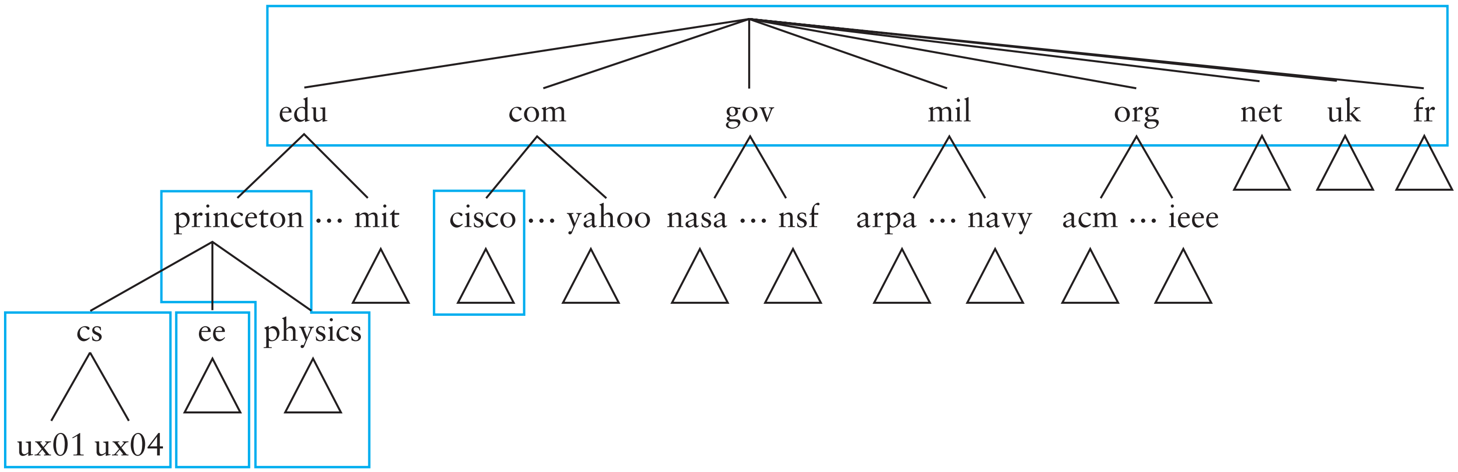
The good news

- **Properties that make these goals easier to achieve**
  1. Read-mostly database

     Lookups MUCH more frequent than updates
  2. Loose consistency

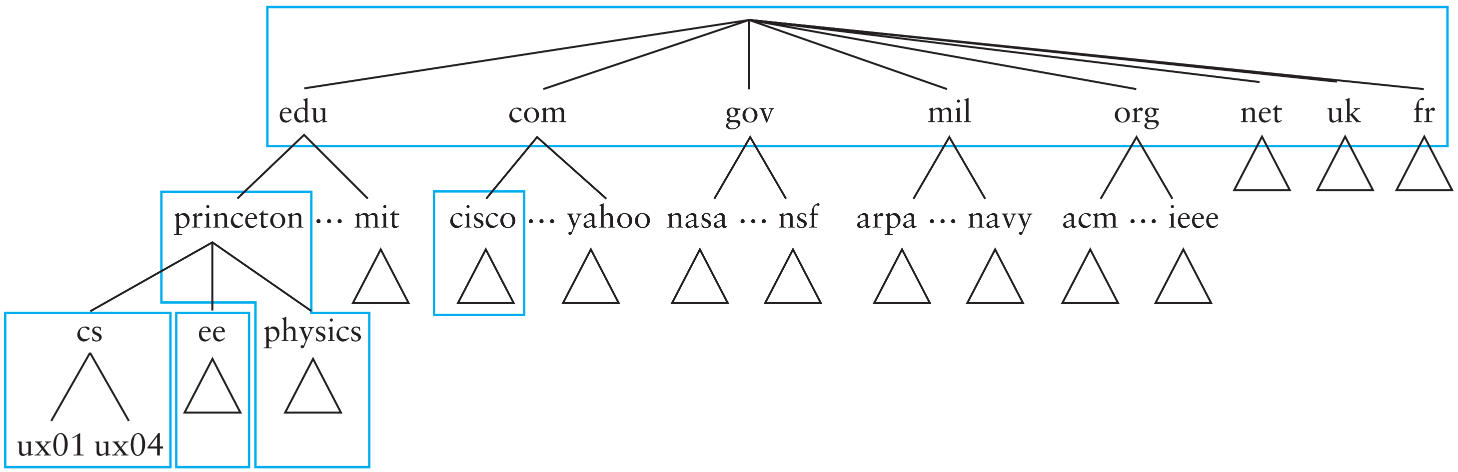
     When adding a machine, not end of the world if it takes minutes or hours to propagate
- **These suggest aggressive caching**
  – Once you've lookup up a hostname, remember
  – Don't have to look again in the near future

Domain Name System (DNS)



- **Hierarchical namespace broken into *zones***
  - root (.), edu., brown.edu., cs.brown.edu.,
  - Zones separately administered :: delegation
  - Parent zone tells you how to find servers for subdomains
- **Each zone served from multiple replicated servers**

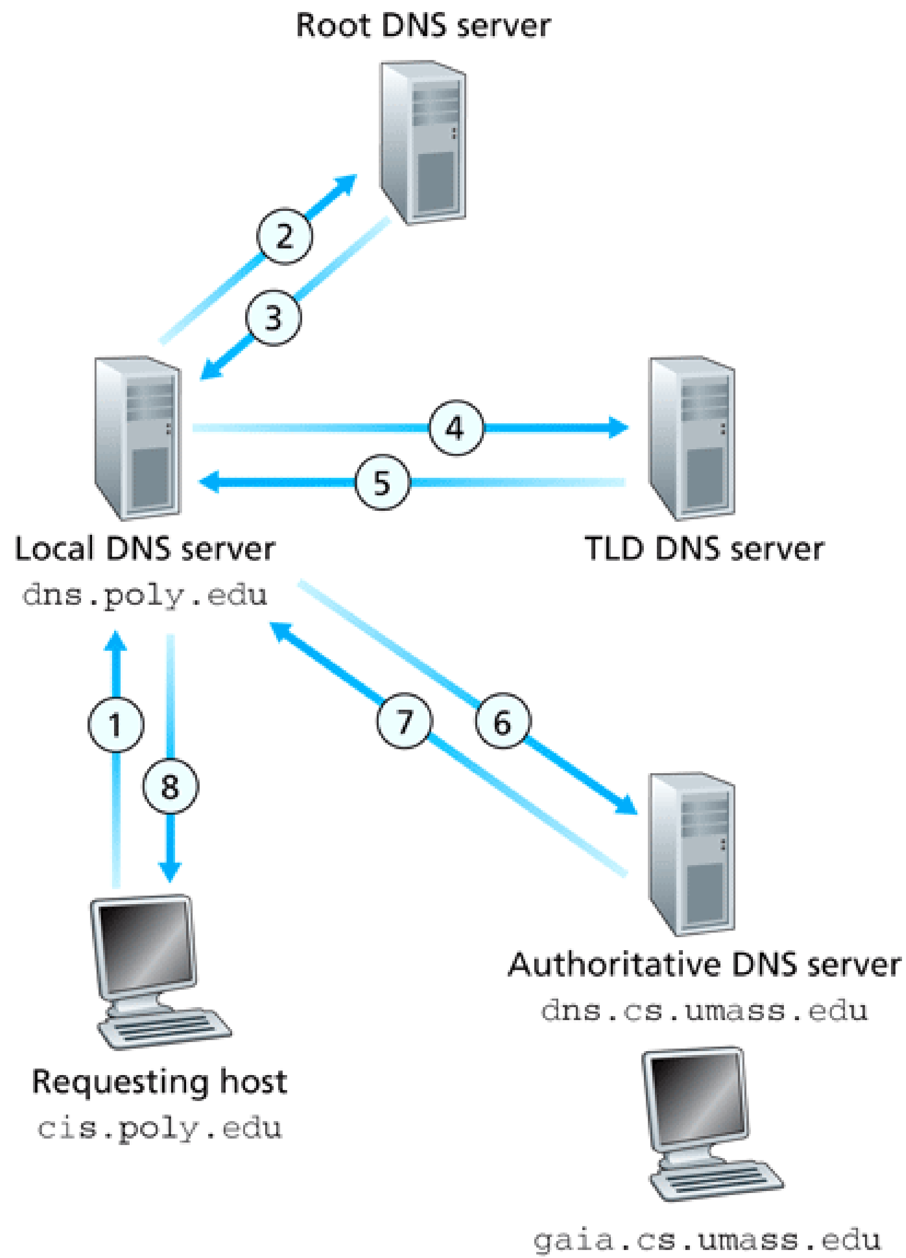
DNS Architecture



- **Hierarchy of DNS servers**
  - Root servers
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- **Performing the translation**
  - Local DNS servers
  - Resolver software

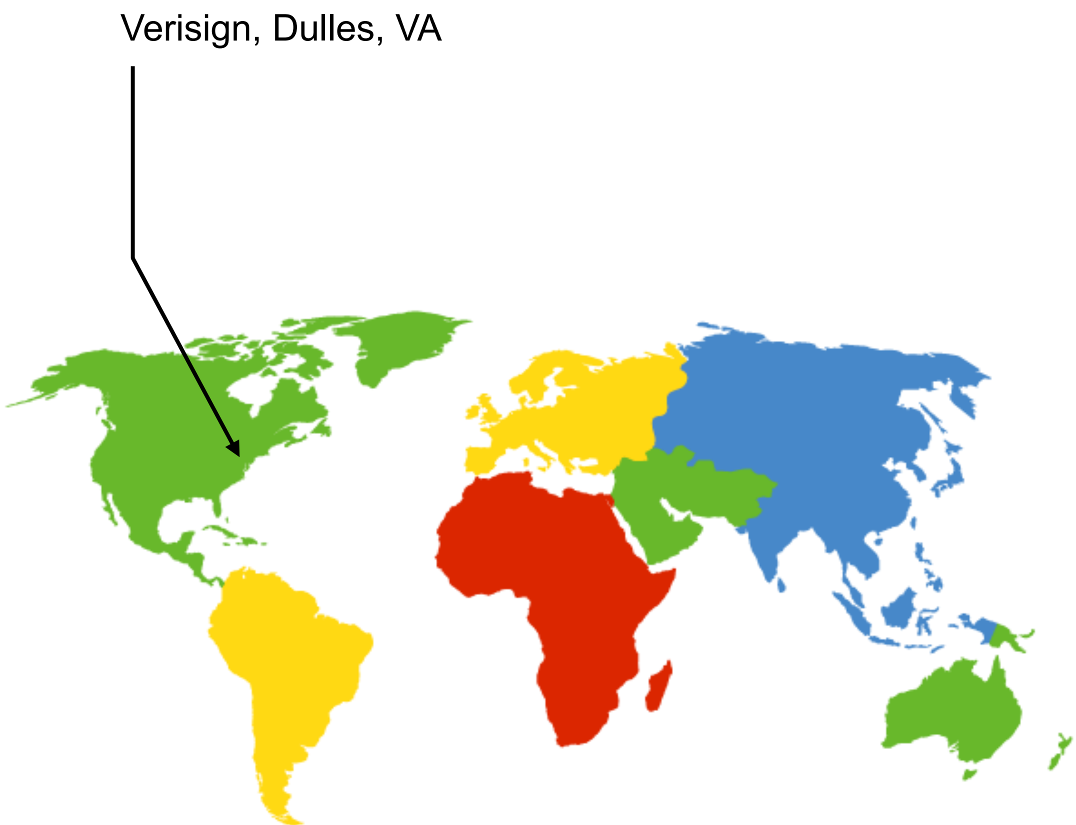
Resolver operation

- Apps make recursive queries to local DNS server (1)
  - Ask server to get answer for you
- Server makes iterative queries to remote servers (2,4,6)
  - Ask servers who to ask next
  - Cache results aggressively



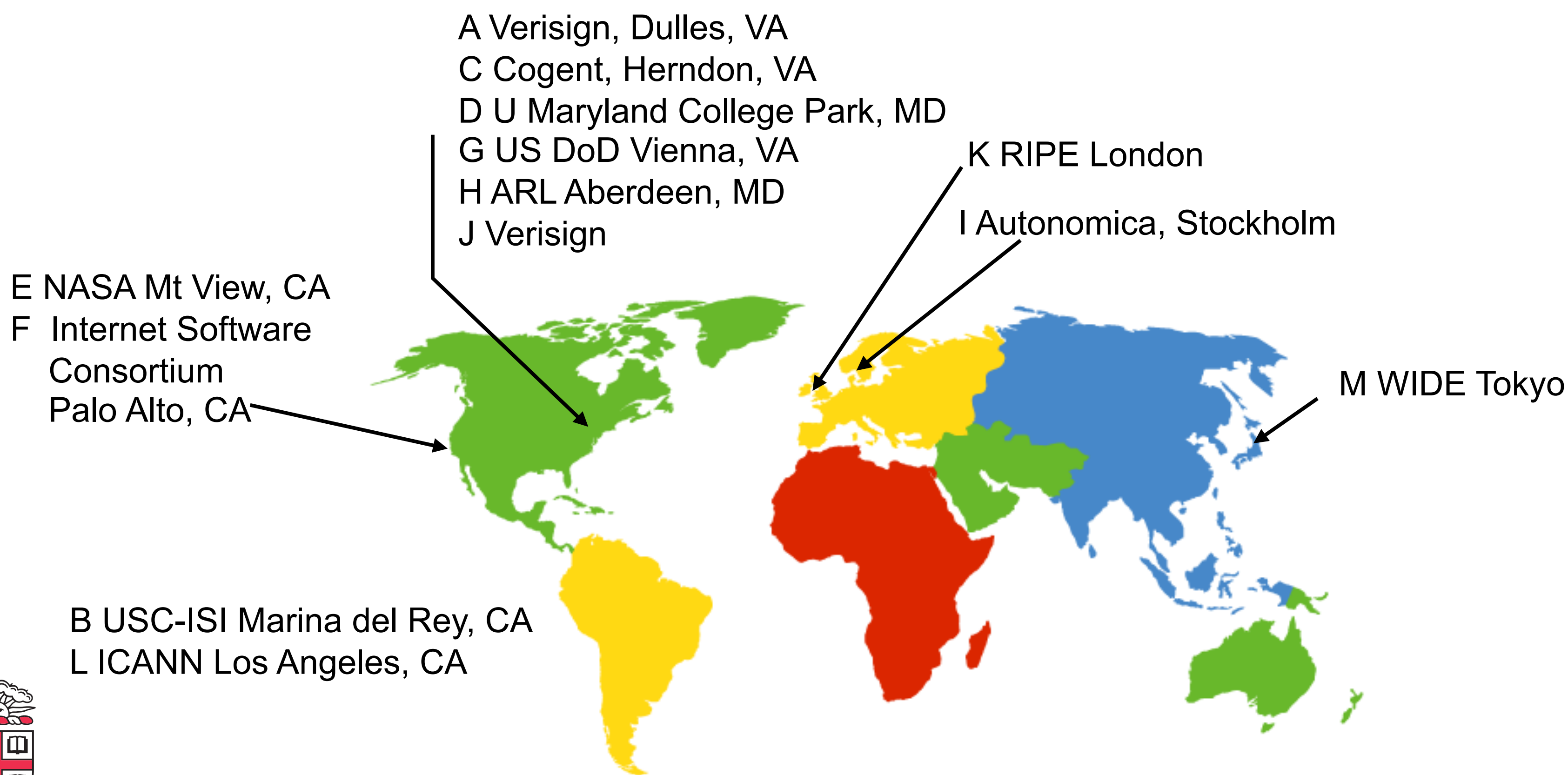
DNS Root Server

- Located in Virginia, USA
- How do we make the root scale?



DNS Root Servers

- **13 Root Servers (www.root-servers.org)**
  - Labeled A through M (e.g, A.ROOT-SERVERS.NET)
- **Does this scale?**



DNS Root Servers

- **13 Root Servers (www.root-servers.org)**
  - Labeled A through M (e.g, A.ROOT-SERVERS.NET)
- **Replication via anycasting**

TLD and Authoritative DNS Servers

- **Top Level Domain (TLD) servers**
  - Generic domains (e.g., com, org, edu)
  - Country domains (e.g., uk, br, tv, in, ly)
  - Special domains (e.g., arpa)
  - Typically managed professionally
- **Authoritative DNS servers**
  - Provides public records for hosts at an organization
    - e.g, for the organization's own servers (www, mail, etc)
  - Can be maintained locally or by a service provider

Reverse Mapping

- **How do we get the other direction, IP address to name?**
- **Addresses have a natural hierarchy:**
  - 128.148.34.7
- **But, most significant element comes first**
- **Idea: reverse the numbers: 7.34.148.128 …**
  - and look that up in DNS
- **Under what TLD?**
  - Convention: in-addr.arpa
  - Lookup 7.34.148.128.in-addr.arpa
  - in6.arpa for IPv6

DNS Caching

- **All these queries take a long time!**
  - And could impose tremendous load on root servers
  - This latency happens before any real communication, such as downloading your web page
- **Caching greatly reduces overhead**
  - Top level servers very rarely change
  - Popular sites visited often
  - Local DNS server caches information from many users
- **How long do you store a cached response?**
  - Original server tells you: TTL entry
  - Server deletes entry after TTL expires

Negative Caching

- **Remember things that don't work**
  - Misspellings like www.cnn.comm, ww.cnn.com
- **These can take a long time to fail the first time**
  - Good to cache negative results so it will fail faster next time

- **But negative caching is optional, and not widely implemented**

DNS Protocol

- **TCP/UDP port 53**
- **Most traffic uses UDP**
  - Lightweight protocol has 512 byte message limit
  - Retry using TCP if UDP fails (e.g., reply truncated)
- **TCP requires messages boundaries**
  - Prefix all messages with 16-bit length
- **Bit in query determines if query is recursive**

Resource Records

- **All DNS info represented as resource records (RR)**

  name [ttl] [class] type rdata

  – name: domain name
  – TTL: time to live in seconds
  – class: for extensibility, normally IN (1) "Internet"
  – type: type of the record
  – rdata: resource data dependent on the type
- **Two important RR types**
  – A – Internet Address (IPv4)
  – NS – name server
- **Example RRs**

```
www.cs.brown.edu.   86400  IN  A   128.148.32.110
cs.brown.edu.    86400  IN  NS  dns.cs.brown.edu.
cs.brown.edu.    86400  IN  NS  ns1.ucsb.edu.
```

Some important details

- **How do local servers find root servers?**
  - DNS lookup on a.root-servers.net ?
  - Servers configured with *root cache* file
  - Contains root name servers and their addresses

```
.                         3600000  IN  NS    A.ROOT-SERVERS.NET.
A.ROOT-SERVERS.NET.       3600000      A     198.41.0.4
...
```

- **How do you get addresses of other name servers?**
  - To obtain the address of www.cs.brown.edu, ask a.edu-servers.net, says a.root-servers.net
  - How do you find a.edu-servers.net?
  - Glue records: A records in parent zone

Example

```
dig +norec www.cs.brown.edu @a.root-servers.net

dig +norec www.cs.brown.edu @a.edu-servers.net

dig +norec www.cs.brown.edu @bru-ns1.brown.edu

    www.cs.brown.edu.   86400 IN A  128.148.32.110
```

Structure of a DNS Message

```
+---------------------+
|        Header       |
+---------------------+
|       Question      | the question for the name server
+---------------------+
|        Answer       | RRs answering the question
+---------------------+
|      Authority      | RRs pointing toward an authority
+---------------------+
|      Additional     | RRs holding additional information
+---------------------+
```

- **Same format for queries and replies**
  - Query has 0 RRs in Answer/Authority/Additional
  - Reply includes question, plus has RRs
- **Authority allows for delegation**
- **Additional for glue, other RRs client might need**

Header format

```
                                  1  1  1  1  1  1
    0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  |                      ID                       |
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  |QR|   Opcode  |AA|TC|RD|RA|   Z    |   RCODE   |
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  |                    QDCOUNT                    |
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  |                    ANCOUNT                    |
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  |                    NSCOUNT                    |
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  |                    ARCOUNT                    |
  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

- Id: match response to query; QR: 0 query/1 response
- RCODE: error code.
- AA: authoritative answer, TC: truncated,
- RD: recursion desired, RA: recursion available

Other RR Types

- **CNAME (canonical name): specifies an alias**

```
www.google.com.      446199  IN  CNAME   www.l.google.com.
www.l.google.com.    300 IN  A   72.14.204.147
```

- **MX record: specifies servers to handle mail for a domain (the part after the @ in email addr)**
  - Different for historical reasons
- **SOA (start of authority)**
  - Information about a DNS zone and the server responsible for the zone
- **PTR (reverse lookup)**

```
7.34.148.128.in-addr.arpa. 86400 IN   PTR quanto.cs.brown.edu.
```

Reliability

- **Answers may contain several alternate servers**
- **Try alternate servers on timeout**
  - Exponential backoff when retrying same server
- **Use same identifier for all queries**
  - Don't care which server responds

Inserting a Record in DNS

- **Your new startup helpme.com**
- **Get a block of addresses from ISP**
  - Say 212.44.9.128/25
- **Register helpme.com at GoDaddy.com (for ex.)**
  - Provide name and address of your authoritative name server (primary and secondary)
  - Registrar inserts RR pair into the com TLD server:
    - helpme.com NS dns1.helpme.com
    - dns1.helpme.com A 212.44.9.129
- **Configure your authoritative server (dns1.helpme.com)**
  - Type A record for www.helpme.com
  - Type MX record for foobar.com

Inserting a Record in DNS, cont

- **Need to provide reverse PTR bindings**
  - E.g., 212.44.9.129 -> dns1.helpme.com
- **Normally, these would go into the 9.44.212.in-addr.arpa zone**
- **Problem: you can't run the name server for that domain. Why not?**
  - Your block is 212.44.9.128/25, not 212.44.9.0/24
  - Whoever has 212.44.9.0/25 wouldn't be happy with you setting their PTR records
- **Solution: [RFC2317, Classless Delegation]**
  - Install CNAME records in parent zone, e.g:

129.9.44.212.in-addr.arpa CNAME 129.ptr.helpme.com

DNS Measurements (Data from MIT, 2000)

- **What is being looked up?**
  - 60% A, 25% PTR, 5% MX, 6% ANY
- **Latency**
  - Median ~100ms (90th percentile ~500ms)
- **Query packets per lookup: ~2.4**
- **Top 10% of domains → ~70% of lookups**
  - Great for caching!
- **9% of lookups are unique**
  - Caching can't hit more than 91%
- **Cache hit rates actually ~75%**

DNS Measurements (Data from MIT, 2000)

- **Does DNS give back answers?**
  - ~23% of queries do not elicit an answer
  - ~13% return NXDOMAIN (or similar)
    - Mostly reverse lookups
  - Only ~64% of queries are successful
- **~63% of DNS packets in unanswered queries**
  - Failing queries are frequently retransmitted
  - 99.9% successful queries have <= 2 retransmissions

DNS Security

- **You go to starbucks, how does your browser find www.google.com?**
  - Ask local name server, obtained from DHCP
  - You implicitly trust this server
  - Can return any answer for google.com, including a malicious IP that poses as a man in the middle
- **How can you know you are getting correct data?**
  - Today, you can't
  - HTTPS can help
  - DNSSEC extension will allow you to verify

DNS Security 2 – Cache Poisoning

- Suppose you control evil.com. You receive a query for www.evil.com and reply:

```
;; QUESTION SECTION:
;www.evil.com.                  IN      A

;; ANSWER SECTION:
www.evil.com.           300     IN      A       212.44.9.144

;; AUTHORITY SECTION:
evil.com.               600     IN      NS      dns1.evil.com.
evil.com.               600     IN      NS      google.com.

;; ADDITIONAL SECTION:
google.com.               5     IN      A       212.44.9.155
```

- Glue record pointing to your IP, not Google's
- Gets cached!

Cache Poisoning # 2

- **But how do you get a victim to look up evil.com?**
- **You might connect to their mail server and send**
  - HELO www.evil.com
  - Which their mail server then looks up to see if it corresponds to your IP address (SPAM filtering)
- **Mitigation (bailiwick checking)**
  - Only accept glue records from the domain you asked for

Cache Poisoning

- **Another possibility: bad guy at Starbucks, can sniff or guess the ID field the local server will use**
  - Not hard if DNS server generates ID numbers sequentially
  - Can be done if you force the DNS server to look up something in *your* name server
  - Guessing has 1 in 65535 chance (Or does it?)
- **Now:**
  - Ask the local server to lookup google.com
  - Spoof the response from google.com using the correct ID
  - Bogus response arrives before legit one (maybe)
- **Local server caches first response it receives**
  - Attacker can set a long TTL

Kaminsky Exploit

- **If good guy wins the race, you have to wait until the TTL to race again**
- **But…**
  - What if you start a new race, for AAAA.google.com, AAAB.google.com, …?
  - Forge CNAME responses for each
  - Circumvents bailiwick checking

Countermeasures

- **Randomize id**
  - Used to be sequential
- **Randomize source port number**
  - Used to be the same for all requests from the server
- **Offers some protection, but attack still possible**

Solution: signatures

- Signature: cryptographic way to prove a party is who they say they are
- Requires a chain of trust
- DNSSEC deployment is underway

Some more DNS fun

- **You can use DNS to tunnel data!**
- **Steps:**
  - Start up a Name Server for a domain you control
  - Send info encoding data in the domain name part of a query
  - Server encodes response in a TXT record
- **Why? DNS is often *not* blocked in airports, etc**
- **This has been a final project in this class!**