DNS

Host Names vs. IP addresses

- Host names
  - Mnemonic name appreciated by humans
  - Variable length, full alphabet of characters
  - Provide little (if any) information about physical location
  - Examples: `www.cnn.com` and `bbc.co.uk`

- IP addresses
  - Numerical address appreciated by routers
  - Fixed length, binary number
  - Hierarchical, related to host location
  - Examples: `64.236.16.20` and `212.58.224.131`

Separating Naming and Addressing

- Names are easier to remember
  - `cnn.com` vs. `64.236.16.20` (but not shortened urls)
- Addresses can change underneath
  - Move `www.cnn.com` to `4.125.91.21`
  - e.g., renumbering when changing providers

Separating Naming and Addressing

- Name could map to multiple IP addresses
  - **www.cnn.com** may refer to multiple (8) replicas of the Web site
  - Enables
    - Load-balancing
    - Reducing latency by picking nearby servers
    - Tailoring content based on requester's location/identity
- Multiple names for the same address
  - e.g., aliases like **www.cnn.com** and **cnn.com**

Scalable (Name ↔ Address) Mappings

- Originally: per-host file
  - Flat namespace
  - `/etc/hosts`
  - SRI (Menlo Park) kept master copy
  - Downloaded regularly

Scalable (Name ↔ Address) Mappings

- Why not centralize DNS?
  - Single point of failure
  - Traffic volume
  - Distant centralized database
  - Maintenance
- Doesn't scale!

- Root name server
  - Contacted by local name server that can not resolve name
  - Contacts authoritative name server if mapping not known
  - Gets mapping and returns it to local name server

Domain Name Service (DNS)

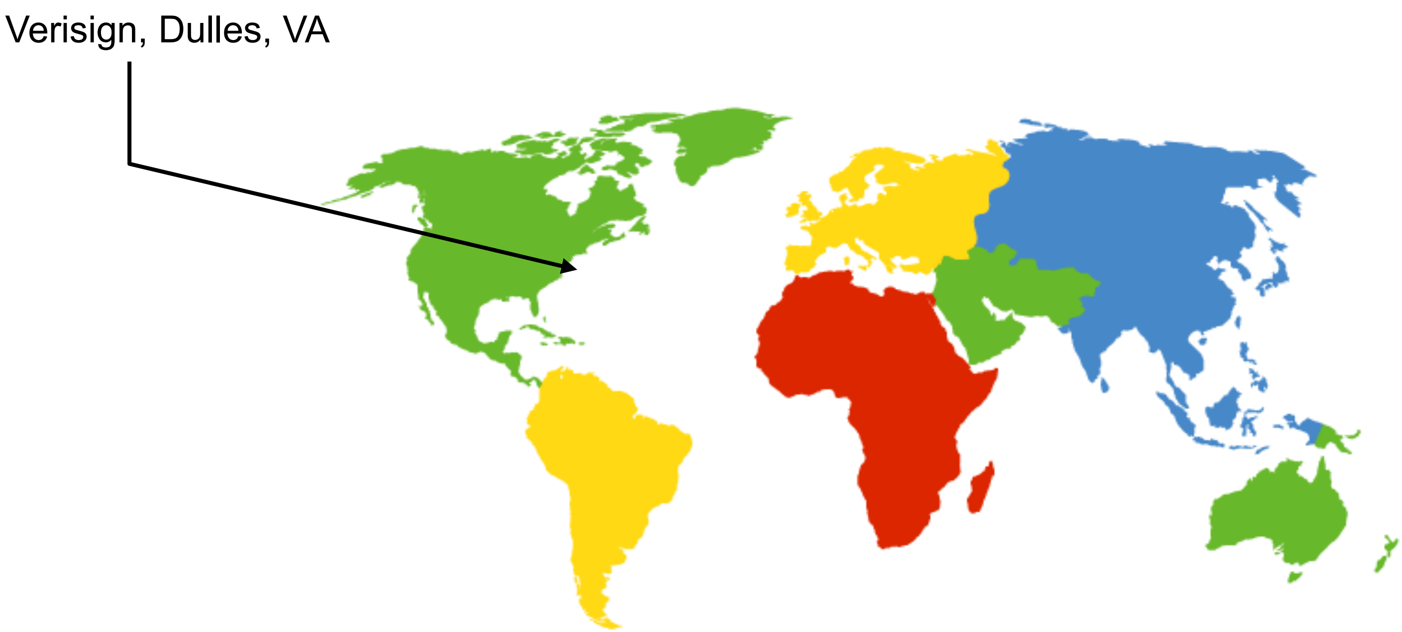
- Large scale dynamic, distributed application
  - Replaced Network Information Center (NIC)
- RFC 1034 and 1035
- Name space
  - Set of possible names
- Bindings
  - Maps internet domain names into IP addresses
- Name server
  - Resolution mechanism

Applications' use of DNS

- Local DNS server ("default name server")
  - Usually near the endhosts that use it
  - Local hosts configured with local server (e.g., `/etc/resolv.conf`) or learn server via DHCP
- Client application
  - Extract server name (e.g., from the URL)
  - Do `getaddrinfo()` to trigger resolver code, sending message to server
- Server application
  - Extract client IP address from socket
  - Optional `getnameinfo()` to translate into name

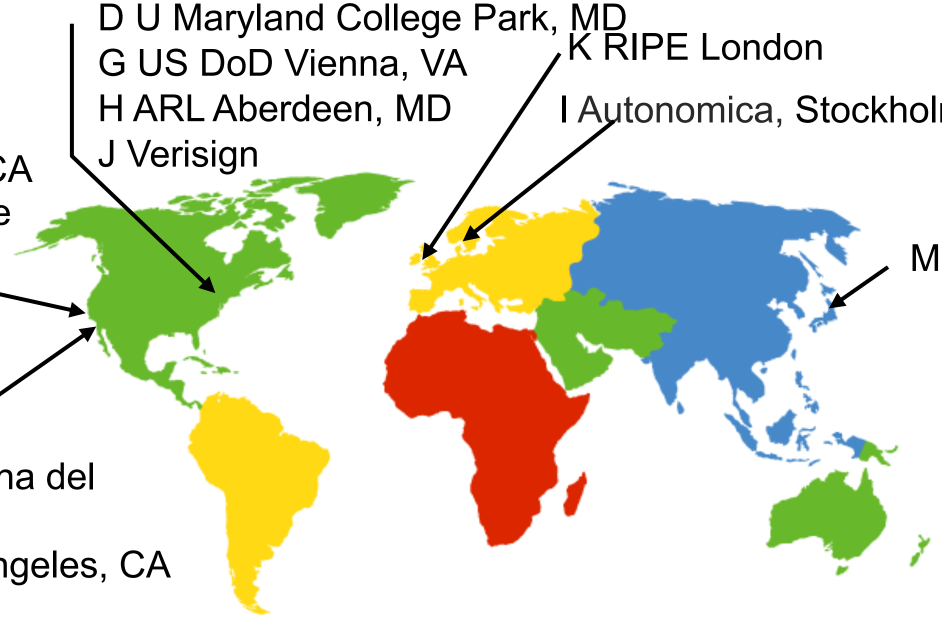
DNS Root

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



DNS Root Servers

- 13 root servers (see `http://www.root-servers.org/`)
  - Labeled A through M
- Does this scale?



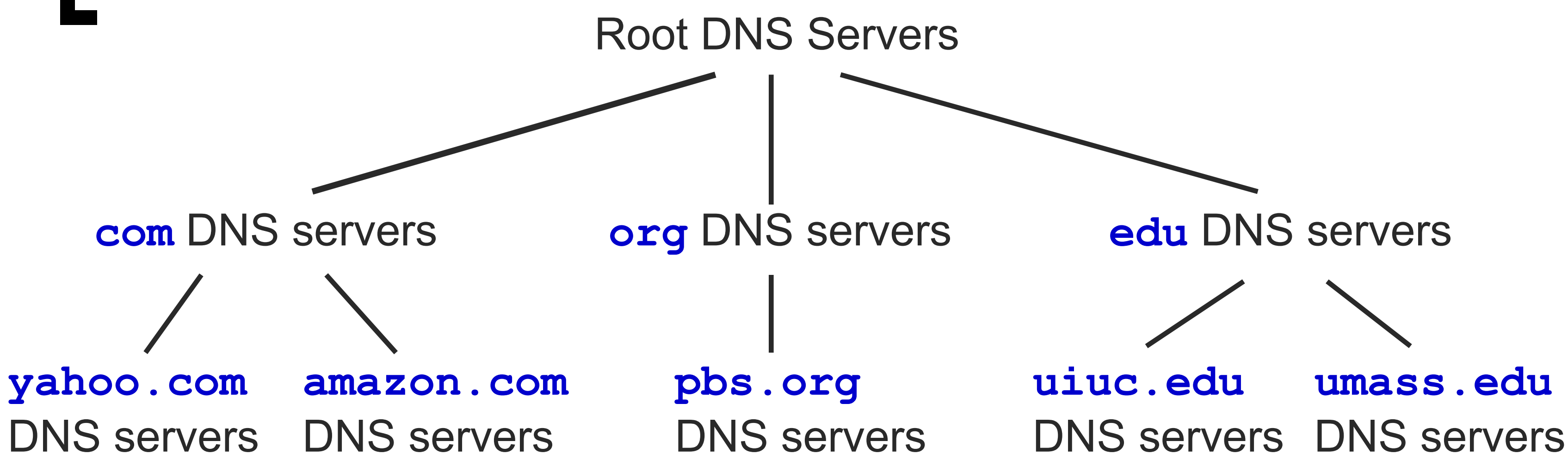
TLD and Authoritative Servers

- Top-level domain (TLD) servers
  - Responsible for **`com`**, **`org`**, **`net`**, **`edu`**, etc, and all top-level country domains **`uk`**, **`fr`**, **`ca`**, **`jp`**.
    - Network Solutions maintains servers for **`com`** TLD
    - Educause for **`edu`** TLD
- Authoritative DNS servers
  - Organization's DNS servers
  - Provide authoritative hostname to IP mappings for organization's servers (e.g., Web, mail).
  - Can be maintained by organization or service provider

Local Name Server

- One per ISP (residential ISP, company, university)
  - Also called "default name server"
- When host makes DNS query, query is sent to its local DNS server
  - Acts as proxy, forwards query into hierarchy
  - Reduces lookup latency for commonly searched hostnames

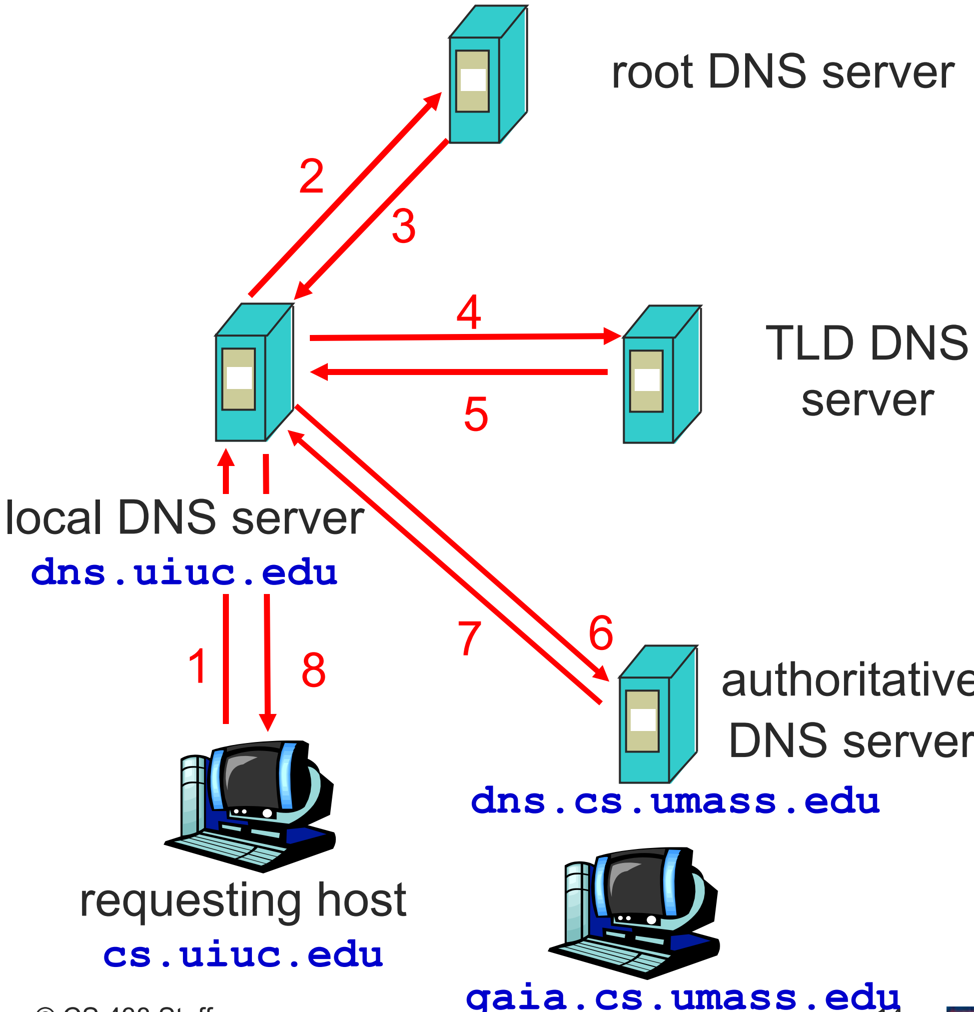
Distributed, Hierarchical Database



- Client wants IP for **`www.amazon.com`**
  - 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`**

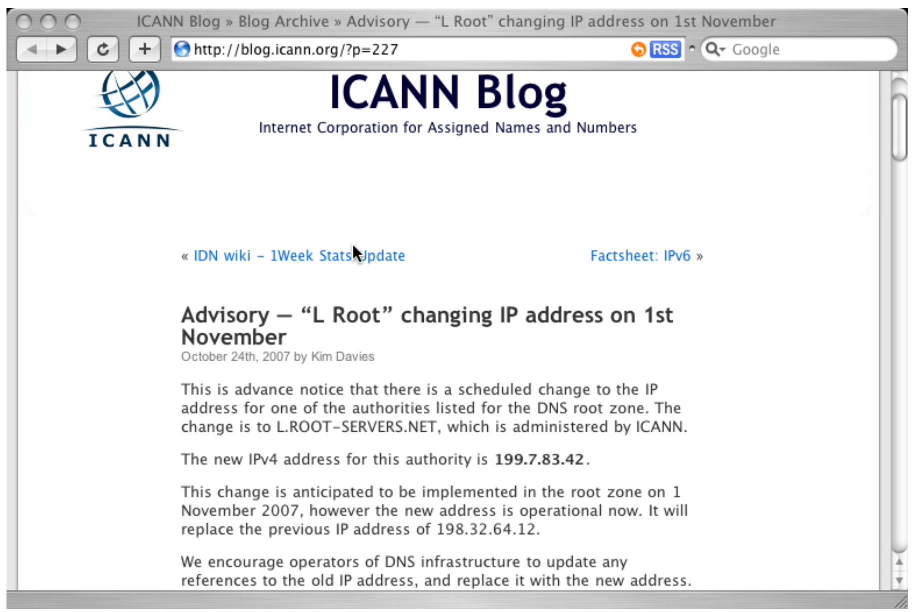
DNS – Name Server

- Host at **cs.uiuc.edu**
  - Wants IP address for **gaia.cs.umass.edu**
- Recursive query
  - Ask server to get answer for you
  - e.g., request 1 and response 8
- Iterated query
  - Contacted server replies with name of server to contact
  - "I don't know this name, but ask this server"



But how did it know the root server IP?

- Hard-coded
- What if it changes?



ICANN Blog » Blog Archive » Advisory — "L Root" changing IP address on 1st November

http://blog.icann.org/?p=227

ICANN

ICANN Blog

Internet Corporation for Assigned Names and Numbers

« IDN wiki – 1Week Stats Update

Factsheet: IPv6 »

Advisory — "L Root" changing IP address on 1st November

October 24th, 2007 by Kim Davies

This is advance notice that there is a scheduled change to the IP address for one of the authorities listed for the DNS root zone. The change is to L.ROOT-SERVERS.NET, which is administered by ICANN.

The new IPv4 address for this authority is **199.7.83.42**.

This change is anticipated to be implemented in the root zone on 1 November 2007, however the new address is operational now. It will replace the previous IP address of 198.32.64.12.

We encourage operators of DNS infrastructure to update any references to the old IP address, and replace it with the new address.

DNS: Caching

- Performing all these queries takes time
  - And all this before actual communication takes place
  - e.g., 1-second latency before starting Web download
- Caching can greatly 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

DNS: Caching

- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a “time to live” (TTL) field
- Once (any) name server learns mapping, it caches mapping
  - Cache entries timeout (disappear) after some time
  - TLD servers typically cached in local name servers
    - Thus root name servers not often visited

DNS Resource 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=PTR
  - `name` is reversed IP quads
    - e.g. `78.56.34.12.in-addr.arpa`
  - `value` is corresponding hostname
- Type=CNAME
  - `name` is alias name for some "canonical" name
  - e.g., `www.cs.mit.edu` is really `eecsweb.mit.edu`
  - `value` is canonical name
- Type=MX
  - `value` is name of mailserver associated with name
  - Also includes a weight/preference

DNS Protocol

DNS protocol: *query* and *reply* messages, both with same *message format*

- Message header
- Identification
  - 16 bit # for query, reply to query uses same #
- Flags
  - Query or reply
  - Recursion desired
  - Recursion available
  - Reply is authoritative
- Plus fields indicating size (0 or more) of optional header elements

16 bits	*16 bits*
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Reliability

- DNS servers are replicated
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Usually, UDP used for queries
  - Need reliability: must implement this on top of UDP
  - Spec supports TCP too, but not always implemented
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don't care which server responds

Inserting Resource Records into DNS

- Example: just created startup "FooBar"
- Get a block of address space from ISP
  - Say **`212.44.9.128/25`**
- Register foobar.com at Network Solutions (say)
  - Provide registrar with names and IP addresses of your authoritative name server (primary and secondary)
  - Registrar inserts RR pairs into the **`com`** TLD server:
    - **`(foobar.com, dns1.foobar.com, NS)`**
    - **`(dns1.foobar.com, 212.44.9.129, A)`**
- Put in your (authoritative) server **`dns1.foobar.com`**:
  - Type A record for **`www.foobar.com`**
  - Type MX record for **`foobar.com`**

Setting up foobar.com

- In addition, need to provide reverse PTR bindings
  - e.g., **`212.44.9.129`** → **`dns1.foobar.com`**
- Normally, these go in **`9.44.212.in-addr.arpa`**
- Problem
  - You can't run the name server for that domain. Why not?
  - Because your block is **`212.44.9.128/25`**, not **`212.44.9.0/24`**
  - Whoever has **`212.44.9.0/25`** won't be happy with you owning their PTR records
- Solution: ISP runs it for you
  - Now it's more of a headache to keep it up-to-date :-(

DNS Measurements (MIT data from 2000)

- What is being looked up?
  - ~60% requests for A records
  - ~25% for PTR records
  - ~5% for MX records
  - ~6% for ANY records
- How long does it take?
  - Median ~100msec (but 90th percentile ~500msec)
  - 80% have no referrals; 99.9% have fewer than four
- Query packets per lookup: ~2.4

DNS Measurements (MIT data from 2000)

- Top 10% of names accounted for ~70% of lookups
  - Caching should really help!
- 9% of lookups are unique
  - Cache hit rate can never exceed 91%
- Cache hit rates ~ 75%
  - But caching for more than 10 hosts doesn't add much

DNS Measurements (MIT data from 2000)

- Does DNS give answers?
  - ~23% of lookups fail to elicit an answer!
  - ~13% of lookups result in NXDOMAIN (or similar)
    - Mostly reverse lookups
  - Only ~64% of queries are successful!
    - How come the web seems to work so well?

- ~ 63% of DNS packets in unanswered queries!
  - Failing queries are frequently retransmitted
  - 99.9% successful queries have ≤2 retransmissions

Moral of the Story

- If you design a highly resilient system, many things can be going wrong without you noticing it!

Security Analysis of DNS

- What security issues does the design & operation of the Domain Name System raise?

16 bits	*16 bits*
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Security Problem #1: Starbucks (and China…)

- As you sip your latte and surf the Web, how does your laptop find `google.com`?
- Answer: it asks the local name server per Dynamic Host Configuration Protocol (DHCP) …
  - … which is run by Starbucks or their contractor
  - … and can return to you any answer they please
  - … including a "man in the middle" site that forwards your query to Google, gets the reply to forward back to you, yet can change anything they wish in either direction
- How can you know you're getting correct data?
  - Today, you can't. (Though if site is HTTPS, that helps)
  - One day soon: DNSSEC extensions to DNS

Security Problem #2: Cache Poisoning

- Suppose you are a Bad Guy and you control the name server for **foobar.com**. You receive a request to resolve **www.foobar.com** and reply:

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

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

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

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

Evidence of the attack disappears 5 seconds later!

A **foobar.com** machine, *not* **google.com**

Cache Poisoning

- Okay, but how do you get the victim to look up `www.foobar.com` in the first place?
- Perhaps you connect to their mail server and send
  - `HELO www.foobar.com`
  - Which their mail server then looks up to see if it corresponds to your source address (anti-spam measure)
- Note, with compromised name server we can also lie about PTR records (address → name mapping)
  - e.g., for `212.44.9.155` = `155.44.9.212.in-addr.arpa` return `google.com` (or `whitehouse.gov`, or whatever)
    - If our ISP lets us manage those records as we see fit, or we happen to directly manage them

Cache Poisoning

- Suppose Bad Guy is at Starbucks and they can sniff (or even guess) the identification field the local server will use in its next request.
- They:
  - Ask local server for a (recursive) lookup of `google.com`
  - Locally spoof subsequent reply from correct name server using the identification field
  - Bogus reply arrives sooner than legit one
- Local server duly caches the bogus reply!
  - Now: every future Starbucks customer is served the bogus answer out of the local server's cache
    - In this case, the reply uses a **large** TTL

Summary

- Domain Name System (DNS)
  - Distributed, hierarchical database
  - Distributed collection of servers
  - Caching to improve performance

- DNS currently lacks authentication
  - Can't tell if reply comes from the correct source
  - Can't tell if correct source tells the truth
  - Malicious source can insert extra (mis)information
  - Malicious bystander can spoof (mis)information
  - Playing with caching lifetimes adds extra power to attacks