Week 7: Distributed Lookup
Part 3: Domain Name System (DNS)
How are IP addresses assigned?

IP addresses are distributed hierarchically

- Internet Assigned Numbers Authority (IANA) at the top
  - IANA is currently run by ICANN
- Internet Corporation for Assigned Names and Numbers

Allocate blocks of addresses to ISPs

Your computer (or Internet gateway)
- Permanent (static) or temporary (dynamic)
How are machine names assigned?

• Early ARPANET
  – Globally unique names per machine (e.g., UCBVAX)
  – Kept track at the Network Information Center (NIC) at the Stanford Research Institute (SRI)

• That doesn’t scale!

• A domain hierarchy was created in 1984 (RFC 920)
  – Domains are administrative entities: divide name management
  – Tree-structured global name space
  – Textual representation of domain names
    
    www.cs.rutgers.edu
Domain Name Hierarchy

Root

- com
- edu
- gov
- info
- net
- org

- ac
- ae
- nl
- us
- zw

generic TLDs

country-code TLDs

rutgers

- cs
- nb
- www
Top Level Domains (TLDs)

There are currently 1,591 top-level domains (as of October 26, 2022)

Each top-level domain has an administrator assigned to it

Assignment is delegated to various organizations by the Internet Assigned Numbers Authority (IANA)

IANA keeps track of the root servers  
See http://www.iana.org/domains/root/db for the latest count
Shared registration

- **Domain name registry:** this is the database
  - Keeps track of all domain names registered under a top-level domain

- **Domain name registry operator:** this is the company that runs the DB
  - NIC = Network Information Center – organization that keeps track of the registration of domain names under a top-level domain
    - Keeps the database of domain names
    - See https://www.icann.org/resources/pages/listing-2012-02-25-en

- **Domain name registrar:** this is the company you use to register
  - Company that lets you register a domain name
  - Registrars update the registry database at the NIC
Shared registration

• Multiple domain **registrars** provide domain **registration services**
  – 2,437 registrars as of March 2021, including 1202 unique DropCatch.com registrars

• The registrar you choose becomes the **designated registrar** for your domain
  – Maximum period of registration for a domain name = 10 years

• The **registry operator** keeps the **central registry database** for the top-level domain

• Only the designated registrar can change information about domain names
  – A domain name owner may invoke a domain transfer process

Example
• *Namecheap* is the designated registrar for **poopybrain.com**
• *VeriSign, Inc.* is the registry operator for the .com **gTLD**

See https://www.icann.org/registrar-reports/accredited-list.html for the latest list of registrars
The problem

Every device connected to the internet has a unique Internet Protocol (IP) address

How do you resolve user-friendly machine names to IP addresses?

www.cs.rutgers.edu → 128.6.4.24
Original solution

Through the 1980s

- Search `/etc/hosts` file for machine name (see RFC 606)
- File periodically downloaded from Network Information Center (NIC) at the Stanford Research Institute (SRI)
- This was not sustainable with millions of hosts on the Internet
  - A lot of data
  - A lot of churn in the data
    - new hosts added, deleted, addresses changed
  - Maintenance
  - Traffic volume

*Solution doesn’t scale!*
DNS: Domain Name System

• Distributed database: a hierarchy of name servers

• **DNS** is an application-layer protocol
  – Name-address resolution is handled at the edge
  – The network core is unaware of host names … and does not care
  – There is no special relationship between names and addresses
  • Example: cs.poopybrain.com can resolve to cs.rutgers.edu

  cs.poopybrain.com → cs.rutgers.edu
DNS servers provide...

- Name to IP address translation
- Aliasing of names (called **canonical** names)
- Identification of name servers
- Names of mail servers

**Load distribution:**
- Multiple name servers may handle a query for a domain
- Caching – store past look-ups
- Ability to provide a set of IP addresses for a name
DNS is a distributed, hierarchical database

A collection of DNS servers

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Authoritative DNS server

• An **authoritative name server** is responsible for answering queries about its zone
  – Provides *real* answers vs. *cached* answers
  – Configured by the administrator

• **Zone** = group of machines under a node in the tree
  E.g., rutgers.edu
<table>
<thead>
<tr>
<th>Information</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host</td>
<td>A</td>
<td>Host address (name to address) Includes name, IP address, time-to-live (TTL)</td>
</tr>
<tr>
<td>Canonical name</td>
<td>CNAME</td>
<td>Name for an alias</td>
</tr>
<tr>
<td>Mail exchanger</td>
<td>MX</td>
<td>Host that handles email for the domain</td>
</tr>
<tr>
<td>Name server</td>
<td>NS</td>
<td>Identifies the name server for the zone: tell other servers that yours is the authority for info within the domain</td>
</tr>
<tr>
<td>Start of Zone Authority</td>
<td>SOA</td>
<td>Specifies authoritative server for the zone. Identifies the zone, time-to-live, and primary name server for the zone</td>
</tr>
</tbody>
</table>
Finding your way

• How do you find the DNS Server for rutgers.edu?
  – That’s what the domain registry keeps track of
  – When you register a domain,
    • You supply the addresses of at least two DNS servers that can answer queries for your zone
    • You give this to the domain registrar, who updates the database at the domain registry

• So how do you find the right DNS server?
  – Start at the root
Root name servers

- The **root name server** answers can return a list of authoritative name servers for top-level domains

- 13 root name servers
  - A.ROOT-SERVERS.NET, B.ROOT-SERVERS.NET, ...
  - Each has redundancy (via *anycast* routing or load balancing)
    - Each server is really a set of machines

Download the latest list at http://www.internic.net/domain/named.root
DNS Queries

• Iterative (non-recursive) name resolution
  – DNS server will return a definitive answer or a referral to another DNS server
    • referral = reference to a DNS server for a lower level of the queried namespace
    • Server returns intermediate results to the client
  1. Send query to a root name server
  2. Send query to an edu name server
  3. Send query to a rutgers name server
  – Advantage: stateless

• Recursive DNS name resolution
  – Name server will take on the responsibility of fully resolving the name
    • May query multiple other DNS servers on your behalf
    – DNS server cannot refer the client to a different server
  – Disadvantage: name server has more work; has to keep track of state
  – Advantages: Caching opportunities, less work for the client!

Quiz answer:
With iterative resolution in DNS…
… a DNS server returns a referral or the requested information

Most top-level DNS servers only support iterative queries
DNS Resolver = client side of DNS
- Not really a part of the DNS hierarchy
- Acts as an intermediary between programs that need to resolve names and the name servers
- A resolver is responsible for performing the full resolution of the query

Where are the resolvers?
- Each local system has one: that’s what applications contact
  - Local cache; may be a process or a library
  - On Linux & Windows, these are limited DNS servers (called stub resolvers)
    - Usually not capable of handling referrals and expect to talk with a name server that can handle recursion (full resolution)
- ISPs (and organizations) run them on behalf of their customers
  - Including a bunch of free ones (OpenDNS, Google Public DNS)

Resolvers cache past lookups – they are not responsible for zones
DNS Resolvers in action

Local stub resolver:
- check local cache
- check local hosts file
- send request to external resolver

E.g., on Linux: resolver is configured via the /etc/resolv.conf file

External resolver
- DNS server that accepts recursion
- Running at ISP, Cloudflare, Google Public DNS, OpenDNS, etc.
Sample query

• Rutgers registered rutgers.edu with the .edu domain
  – educause.net is the domain registry for the .edu gTLD
  – Registration includes defining the name servers for .rutgers.edu
    • ns124.a2.incapsecuredns.net: 192.230.123.124
    • ns8.a1.incapsecuredns.net: 192.230.122.8
    • ns87.a0.incapsecuredns.net: 192.230.121.87

• EDUCAUSE registered its name servers with root name servers
  • ns1.twtelecom.net
  • ns1.educause.edu
  • ns1.twtelecom.net

• We know how to get to root name servers
  • Download http://www.internic.net/domain/named.root
Submit query to a local DNS resolver:

1. \textit{query(cs.rutgers.edu)} \rightarrow \text{any root name server} \\
   send query to f.root-servers.net: 192.5.5.241

2. Receive \textit{referral} to a list of DNS servers for \textit{edu} \\
   a.edu-servers.net: 192.5.6.30 \hspace{1cm} \ldots \hspace{1cm} d.edu-servers.net: 192.31.80.30 \hspace{1cm} \ldots

3. \textit{query(cs.rutgers.edu)} \rightarrow \text{edu name server} \\
   send query to d.edu-servers.net: 192.31.80.30

4. \textit{Receive referral to rutgers.edu} name servers: \\
   - dns2.rutgers.edu. \hspace{1cm} 192.230.121.86 \\
   - ns1.rutgers.edu. \hspace{1cm} 192.230.122.7 \\
   - ru-ufl.rutgers.edu. \hspace{1cm} 192.230.123.123 \\
   - ns6.dnsmadeeasy.com. \hspace{1cm} 208.80.124.13

5. \textit{query(cs.rutgers.edu)} \rightarrow \text{rutgers name server} \\
   send query to 208.80.124.13

6. The rutgers name server returns \\
   A: 128.6.48.178 \hspace{1cm} \textit{address} \\
   MX: cs-rutgers-edu.mail.protection.outlook.com. \hspace{1cm} \textit{domain name for email}
Caching

- Starting every query at the root would place a huge load on root name servers

- A name server can **cache** results of previous queries
  - Save query results for a *time-to-live* amount of time
  - The time-to-live value is specified in the domain name record by an authoritative name server
The End