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

Regional Internet Registries (RIR)

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
Top Level Domains (TLDs)

ccTLD
Country-code domains
ISO 3166 codes
e.g., .us, .de, .ca, .es

IDN ccTLD
Internationalized
country-code domains
e.g.,.السعودية,.中國,.рф

gTLD
Generic top-level domains
e.g., .biz, .com, .edu,
.gov, .info, .net, .org,
.audio, .catering, .网络

There are currently 1,589 top-level domains (as of March 30, 2021)

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
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 $\rightarrow$ 128.6.4.24
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
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
### Key data that a DNS server maintains (partial list)

<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)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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

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**Most top-level DNS servers only support iterative queries**
DNS Resolvers: local name server

• **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

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

E.g., on Linux: resolver is configured via the `/etc/resolv.conf` file
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. \( \text{query(cs.rutgers.edu)} \rightarrow \text{any root name server} \)
   
   send query to f.root-servers.net: 192.5.5.241

2. Receive referral to a list of DNS servers for \text{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. \( \text{query(cs.rutgers.edu)} \rightarrow \text{edu name server} \)
   
   send query to d.edu-servers.net: 192.31.80.30

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

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

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