Distributed Systems

16. Naming

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Fall 2016

Naming things

- Naming: map names to objects
  - Helps with using, sharing, and communicating information
- Examples
  - User names: *used for system login, email, chat*
  - Machine names: *used for ssh, email, web*
  - Files
  - Devices
  - Objects, functions, variables in programs
  - Network services

What’s a name?

Name: identifies what you want

Address: identifies where it is

Route: identifies how to get there

Binding: the association of a name with the object

– “choose a lower-level-implementation for a higher-level semantic construct”

RFC 1498: Inter-network Naming, addresses, routing

Pure & Impure Names

- Pure names – *identify*
  - The name contains no information aside from the name
  - It does not identify *where* the object can be found
  - Examples:
    - c8:2a:14:3f:92:d1 my computer's ethernet MAC address
    - paul.krzyzanowski my facebook name
    - 908-555-3836 phone # (this used to be an impure name)

Pure & Impure Names

- Impure names – *guide*
  - The name contains context information
  - Object is generally unmovable
  - Examples:
    - p@pk.org, pxk@cs.rutgers.edu
      - User names in different Internet domains: same person or not?
      - Context (domain name) is encoded into the name
    - /home/paul/bin/qsync
      - File pathname changes if we move the object

Uniqueness of names

- Easy on a small scale – problematic on a large scale
  - It can be difficult to make globally unique names

- Uniqueness for pure names
  - Designate a bit pattern or naming prefix that does not convey information
    - Ethernet MAC address: 3 bytes: organization, 3 bytes: controller
    - IP address: network & host (variable partition)

- Uniqueness for impure names
  - Use a hierarchy
  - Globally unique components (pure names)
    - Compound name: iterative list of pure names connected with separators
      - Domain name (www.cs.rutgers.edu)
      - URLs (http://pk.org/417/lectures/l-naming.html)
      - File pathnames (/usr/share/dict/words)

Terms: Naming convention = syntax

Naming system determines syntax for names

Naming convention can take any format

- Ideally one that will suit the application and user
  - E.g., human readable names for humans, binary identifiers for machines
- UNIX file names:
  - Parse components from left to right separated by /
    /home/paul/src/gps/gui.c
- Internet domain names:
  - Ordered right to left and delimited by .
    www.cs.rutgers.edu
- LDAP names
  - Attribute/value pairs ordered right to left, delimited by ,
    cn=Paul Krzyzanowski, o=Rutgers, c=US

Terms: Context

A particular set of *name* $\rightarrow$ *object* bindings

- Names are unique within the context
  - E.g., `/etc/postfix/main.cf` on a specific computer
- Each context has an associated naming convention
- A name is always interpreted relative to some context
  - E.g., directory /usr in a Linux file system on crapper.pk.org

Terms: Naming System

Connected set of contexts of the same type (same naming convention) along with a common set of operations

For example:

- System that implements DNS (Internet domain names)
- System that implements LDAP (directory of people)

Terms: Namespace = set of names

- A container for a set of names in the naming system

- A namespace has a scope
  - scope = region where the name exists & refers to the object
  - For example,
    - Names of all files in a directory
    - All domain names within rutgers.edu
    - E.g., Java package, local variables

- A namespace may be tree structured (hierarchical)
  - Fully-qualified or hierarchical names may be used to identify names outside the local namespace
  - Global namespace = root of the tree

Terms: Resolution

- Resolution = name lookup
  - Return the underlying representation of the name
  - Look up the **binding** of the name to its object
- For example,
  - www.rutgers.edu → 128.6.4.5
- Iterative resolution
  - Example: parse a pathname
- Recursive resolution
  - Example: parse a distribution list: each entity may be expanded

When do should you do a resolution?

Static binding
- Hard-coded

Early binding
- Look up binding before use
- Cache previously used binding

These can cause problems! (static and early binding)

Late binding
- Look up just before use

Name Service

The service that performs name resolution

Allows you to resolve names

- Looking up a *name* gives the corresponding *address* as a response

Can be implemented as

- Search through file
- Database query
- Client-server program (name server) – may be distributed
- …

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Directory Service

- Extension of name service:
  - Associates names with objects
  - Allows objects to have attributes
  - Can search based on attributes

- For example,
  - LDAP (Lightweight Directory Access Protocol)
  - Directory can be an object store:
    - E.g., look up printer object and send data stream to it

IP Domain Names

Human readable names

e.g., www.cs.rutgers.edu

Hierarchical naming scheme

- Top of hierarchy on the right
- No relation to IP address or network class

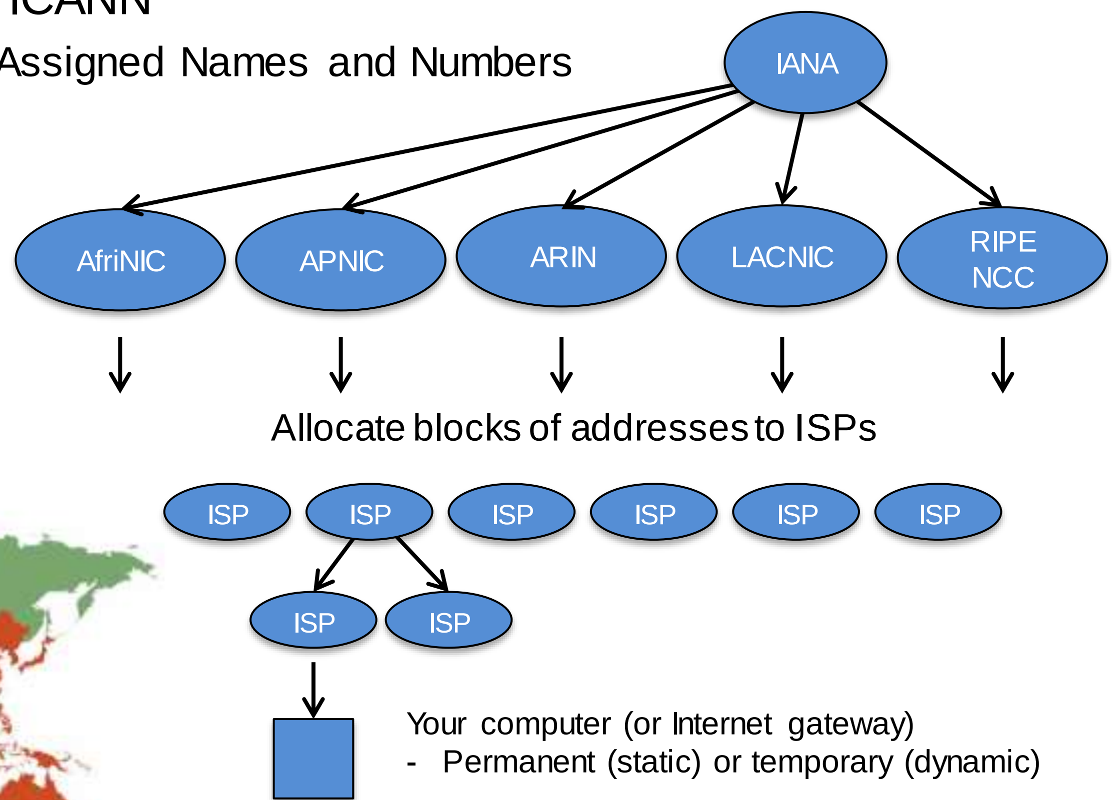
Case Study:
Internet Domain Name System (DNS)

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)



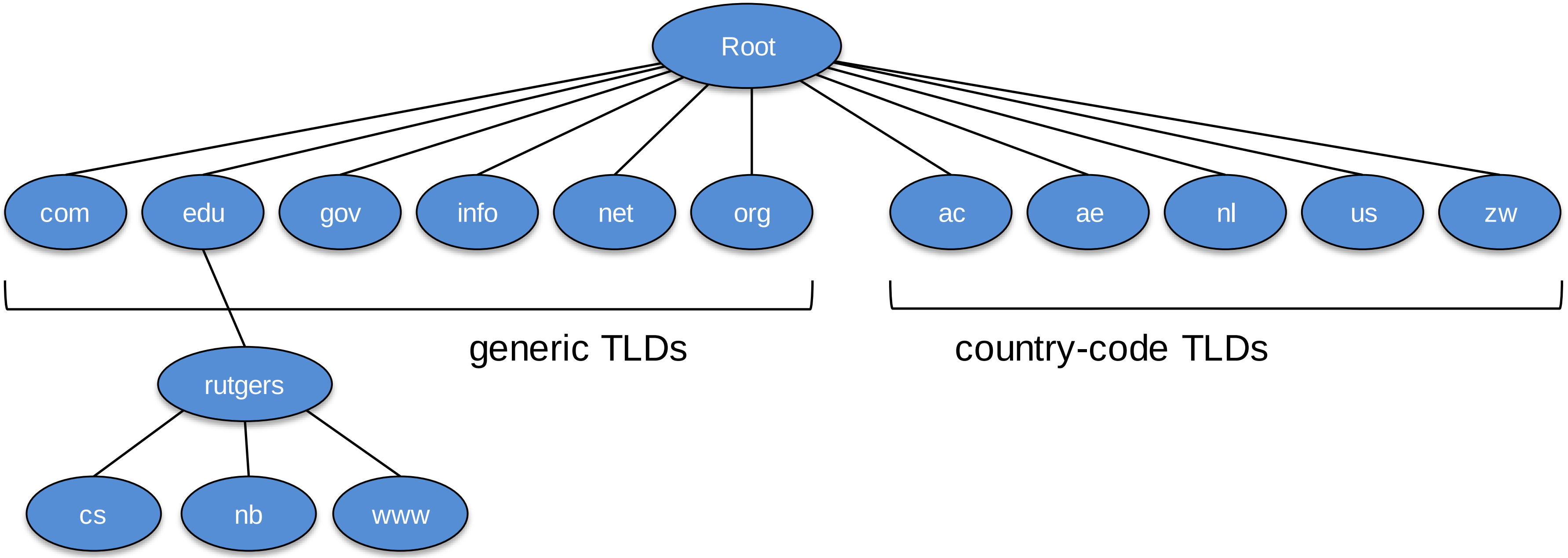
RIR Map

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 1,446 top-level domains (as of Oct 31, 2016)

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
  - 2,147 registars as of October 2016, including 701 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

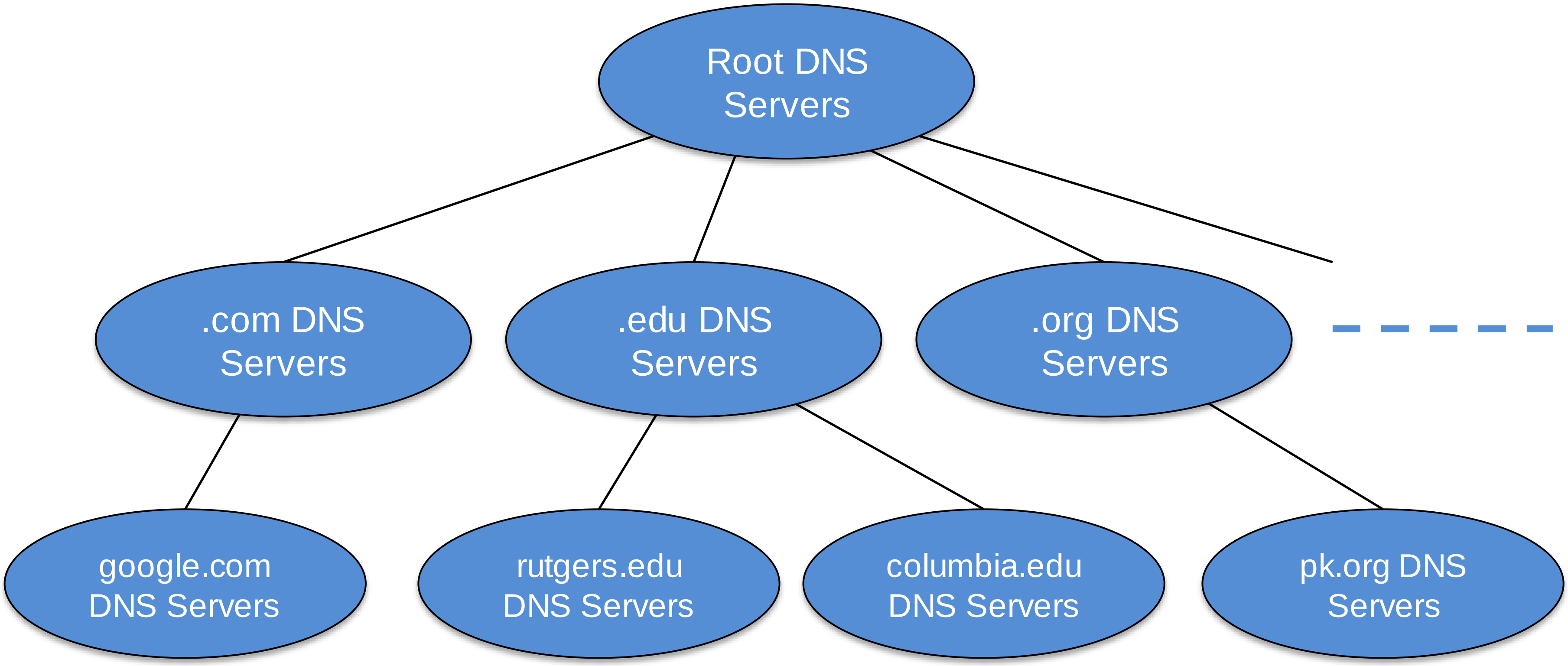
- **DNS** is an application-layer protocol
  - Name-address resolution is handled at the edge
  - The network core is unaware of host names … and does not care
  - There is no special relationship between names and addresses
    - Example: cs.poopybrain.com can resolve to cs.rutgers.edu

cs.poopybrain.com → cs.rutgers.edu

DNS provides

- Name to IP address translation
- Aliasing of names (called canonical names)
- Identification of name servers
- Mail server names
- 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

A DNS server returns answers to queries

Key data that a DNS server maintains (partial list)

Information	Abbreviation	Description
Host	A	Host address (name to address) Includes name, IP address, time-to-live (TTL)
Canonical name	CNAME	Name for an alias
Mail exchanger	MX	Host that handles email for the domain
Name server	NS	Identifies the name server for the zone: tell other servers that yours is the authority for info within the domain
Start of Zone Authority	SOA	Specifies authoritative server for the zone. Identifies the zone, time-to-live, and primary name server for the zone

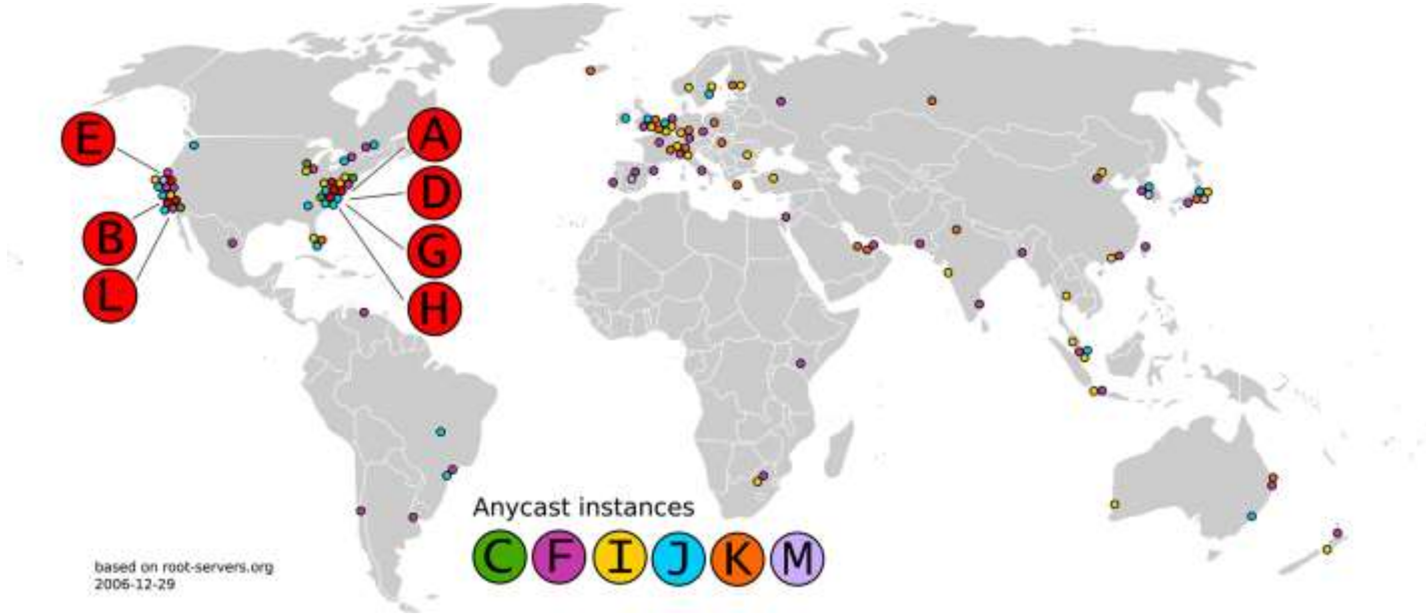
Finding your way

- 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

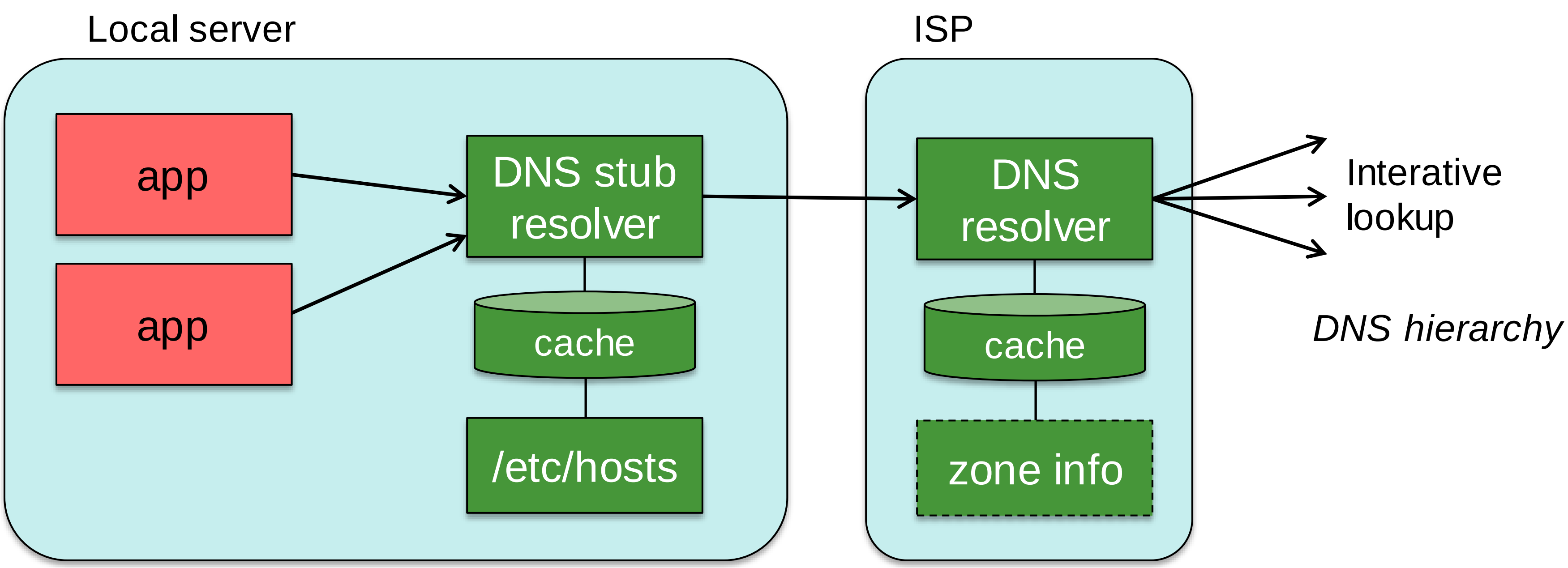
- Iterative (non-recursive) name resolution
  - DNS server will return a definitive answer or a **referral** to another DNS server
    - *referral* = reference to a DNS server for a lower level of the queried namespace
    - Server returns intermediate results to the client
    1. Send query to a root name server
    2. Send query to a 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!

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

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

External resolver
- DNS server that accepts recursion
- Running at ISP, 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

  } Name servers for .edu

- We know how to get to root name servers
    - Download http://www.internic.net/domain/named.root

Sample Query

Submit query to a local *DNS resolver:*

1. *query(cs.rutgers.edu)* → any root name server
   send query to c.root-servers.net: 192.33.4.12

2. Receive *referral* to a list of DNS servers for *edu*
   a.edu-servers.net: 192.5.6.30 g.edu-servers.net: 192.42.93.30

3. *query(cs.rutgers.edu)* → edu name server
   send query to g.edu-servers.net: 192.41.162.32

4. *Receive referral to rutgers.edu* name servers:
   - ns87.a0.incapsecuredns.net 192.230.121.86
   - ns8.a1.incapsecuredns.net.192.230.122.7
   - ns124.a2.incapsecuredns.net 192.230.123.123

5. query(cs.rutgers.edu) → rutgers name server
   send query to 192.230.122.7

6. The rutgers name server returns
   A: 128.6.4.2 *address*
   MX: dragon.rutgers.edu *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