

# CSCI-1680

## DNS

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- **We know how to open TCP connections to a server/port:**
  - E.g., 128.148.32.110, port 80



# Host names and IP Addresses

- **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

- **Host names**

- Mnemonics appreciated by humans
- Variable length, ASCII characters
- Provide little (if any) information about location\*
- Examples: [www.cs.brown.edu](http://www.cs.brown.edu), bbc.co.uk



# 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)



# Another Change in Layers...

- **Another mapping**
  - ARP: maps IP addresses to MAC addresses



# Scalable (Address $\leftrightarrow$ 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



320 --\*\*\*\*\*  
 10-Jun-82 17:48:41-PDT,114828;000000000000  
 Mail-from: ARPANET host SRI-NIC rcvd at 10-Jun-82 1747-PDT  
 Date: 10 Jun 1982 1742-PDT  
 From: Dyer  
 Subject: Hostname table, 10-June-82  
 To: dcacode252 at USC-ISI  
 cc: nic

ARPANET HOST NAMES AND LIAISON 10-Jun-82

HOST NAME	HOST ADDRESS	SPONSOR	LIAISON
ACC	10.2.0.54	VDH ARPA	Lockwood, Gregory (LOCKWOOD@BBNC) Associated Computer Consultants 414 East Cota Street Santa Barbara, California 93101 (805) 965-1023
			CPUtype: PDP-11/70(UNIX)
ACCAT-TIP	10.2.0.35	ARPA	McBride, William T. (MCBRIDE@USC-ISI) Naval Ocean Systems Center Code 8321 271 Catalina Boulevard San Diego, California 92152 (714) 225-2083 (AV) 933-2083
			CPUtype: H-316
AEROSPACE	10.2.0.65	AFSC	Nelson, Louis C. (LOU@AEROSPACE) Aerospace Corporation A2/1013 P.O. Box 92957 Los Angeles, California 90009 (213) 615-4424
			CPUtype: VAX-11/780(UNIX)
AFGL	10.1.0.66	AFSC	Cosentino, Antonio (COSENTINO@AFSC-HQ) Air Force Geophysics Laboratory SUNA Mail Stop 30 Hanscom Air Force Base, Massachusetts 01731 (617) 861-4161 (AV) 478-4161
			CPUtype: PDP-11/50(RSX11M) -> CDC-6600(NOS/BE)
AFGL-TAC	10.2.0.66	AFSC	Cosentino, Antonio (COSENTINO@AFSC-HQ) Air Force Geophysics Laboratory SUNA Mail Stop 30 Hanscom Air Force Base, Massachusetts 01731 (617) 861-4161 (AV) 478-4161

CPUtype: C/30



# 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 (security, 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

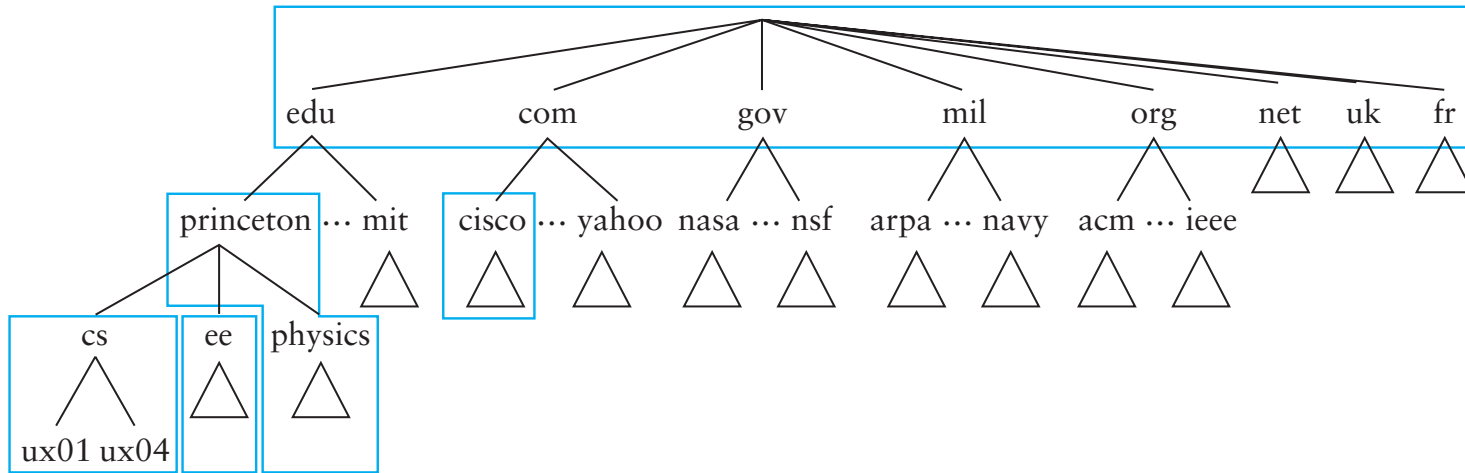


# DNS Measurements (Data from MIT, 2000)

- **What was being looked up?**
  - 60% A, 25% PTR, 5% MX, 6% ANY
- **Latency**
  - Median ~100ms (90<sup>th</sup> 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%**



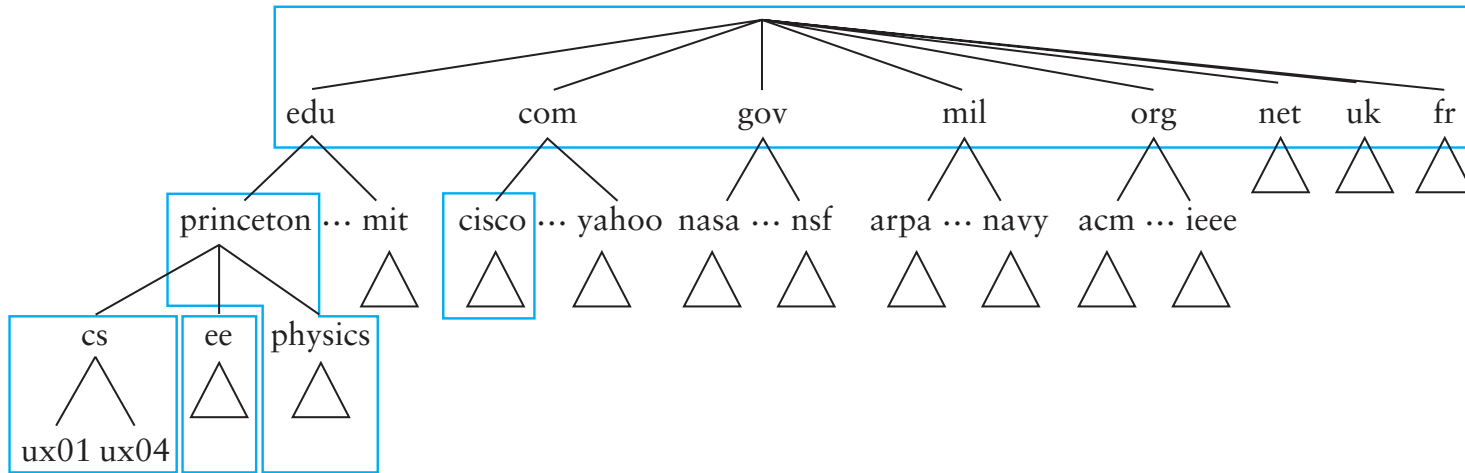
# Domain Name System (DNS)



- **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

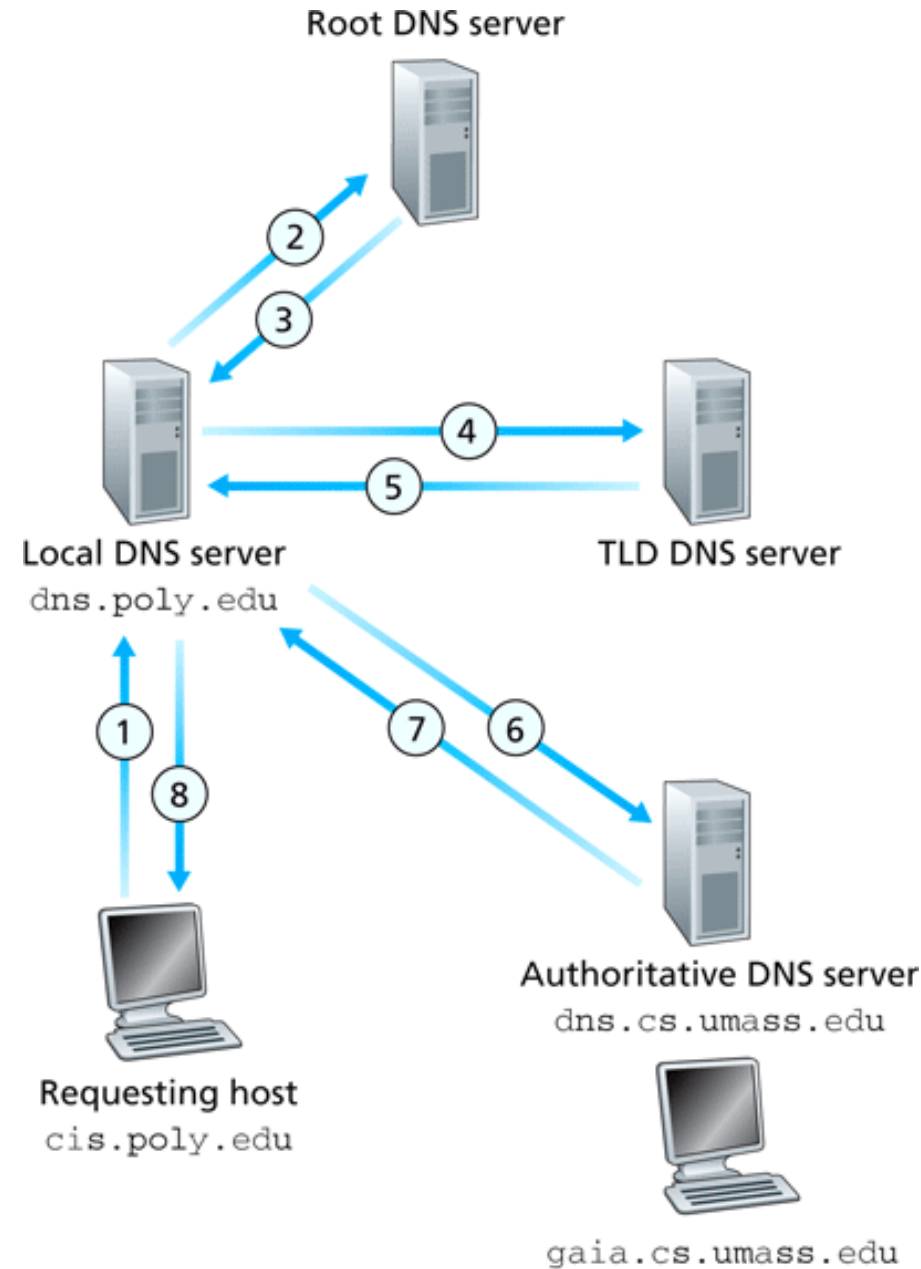


- **Hierarchy of DNS servers**
  - Root servers
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- **Performing the translation**
  - Local DNS servers
  - Resolver software



# Resolver operation

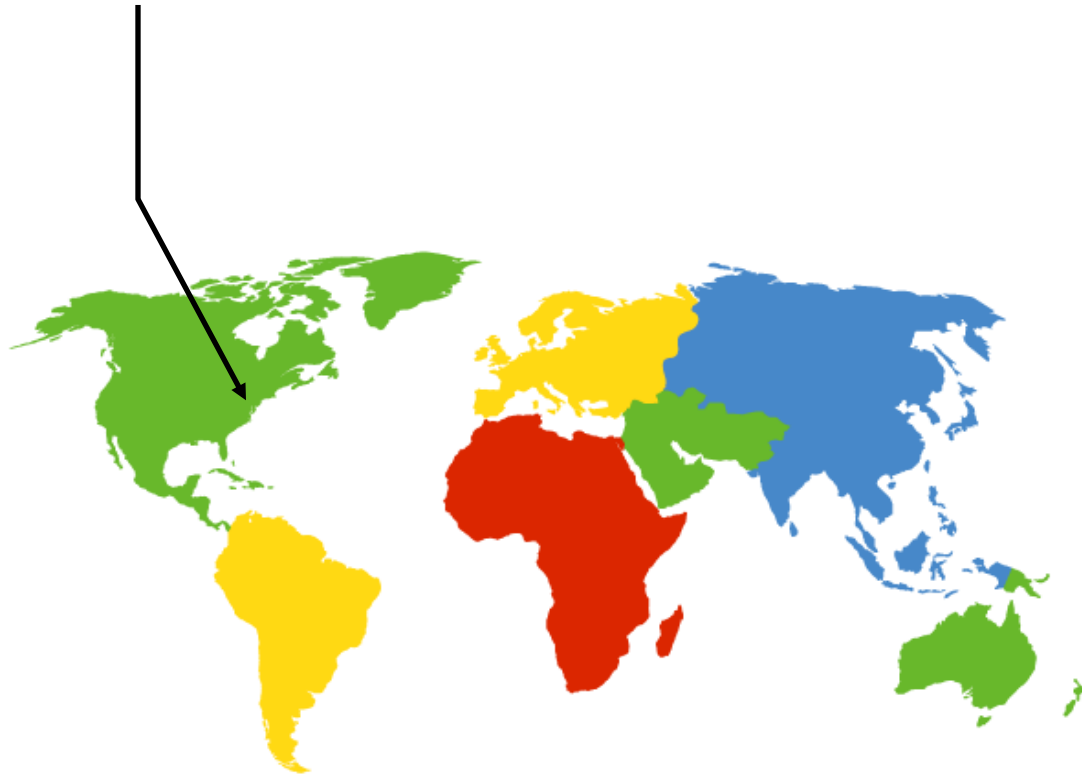
- Apps make **recursive** queries to local DNS server (1)
  - Ask server to get answer for you
- Server makes **iterative** queries to remote servers (2,4,6)
  - Ask servers who to ask next
  - Cache results aggressively



# DNS Root Server

- **Located in New York**
- **How do we make the root scale?**

Verisign, New York, NY



# DNS Root Servers

- **13 Root Servers ([www.root-servers.org](http://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****

A Verisign, New York, NY (also Frankfurt, HK, London, LA)  
C Cogent, Herndon, VA (also Los Angeles, NY, Chicago, Frankfurt and 3+)  
D U Maryland College Park, MD (also in 106 other locations)  
G US DoD Columbus, OH (+5)    K RIPE London (plus 41 other locations)  
H ARL Aberdeen, MD (also San Diego)  
J Verisign (118 locations)

E NASA Mt View, CA (+70)  
F Internet Software Consortium, Palo Alto, CA (and 57 other locations)

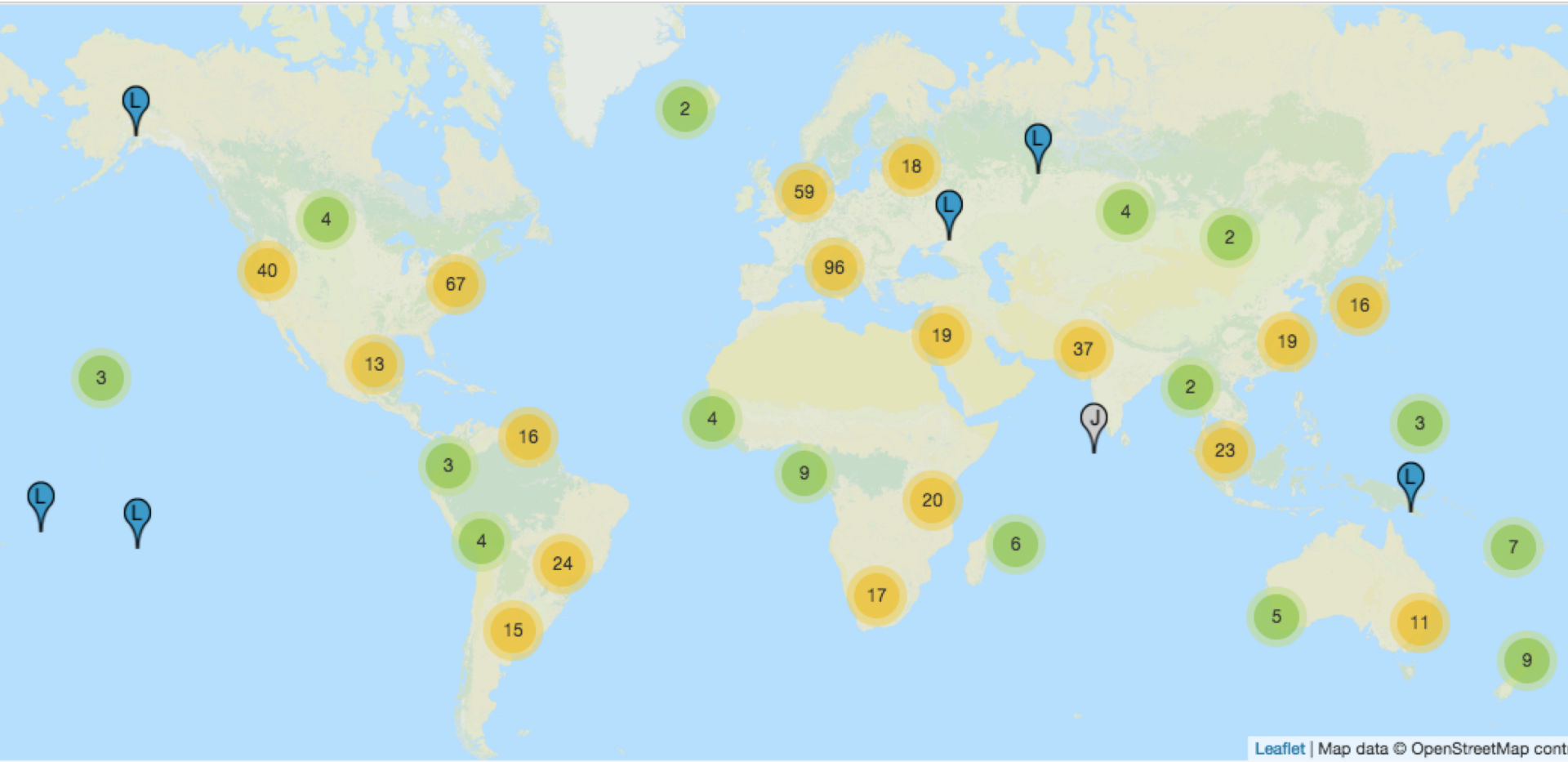
I Netnod, Stockholm (plus 49 other locations)

M WIDE Tokyo plus Seoul, Paris, San Francisco, Osaka

B USC-ISI Marina del Rey, CA  
L ICANN Los Angeles, CA (plus 157 other locations)



# DNS Root Servers



Leaflet | Map data © OpenStreetMap cont



From: [www.root-servers.org](http://www.root-servers.org), as of Nov 2016

# 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



# 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`
  - (BTW) Is the cost of these two queries the same?
- **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**



# Reverse Mapping

- **How do we get the other direction, IP address to name?**
- **Addresses have a natural hierarchy:**
  - 128.148.32.12
- **But, most significant element comes first**
- **Idea: reverse the numbers: 12.32.148.128 ...**
  - and look that up in DNS
- **Under what TLD?**
  - Convention: in-addr.arpa
  - Lookup 12.32.148.128.in-addr.arpa
  - in6.arpa for IPv6



# Example

```
dig . ns
```

```
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
```



# 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
- **Important RR types**
    - A – Internet Address (IPv4); AAAA – IPv6
    - 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



# Other uses of DNS

- **Local multicast DNS**
  - Used for service discovery
  - Made popular by Apple
  - This is how you learn of different Apple TVs in the building
- **Load balancing**
- **CDNs**



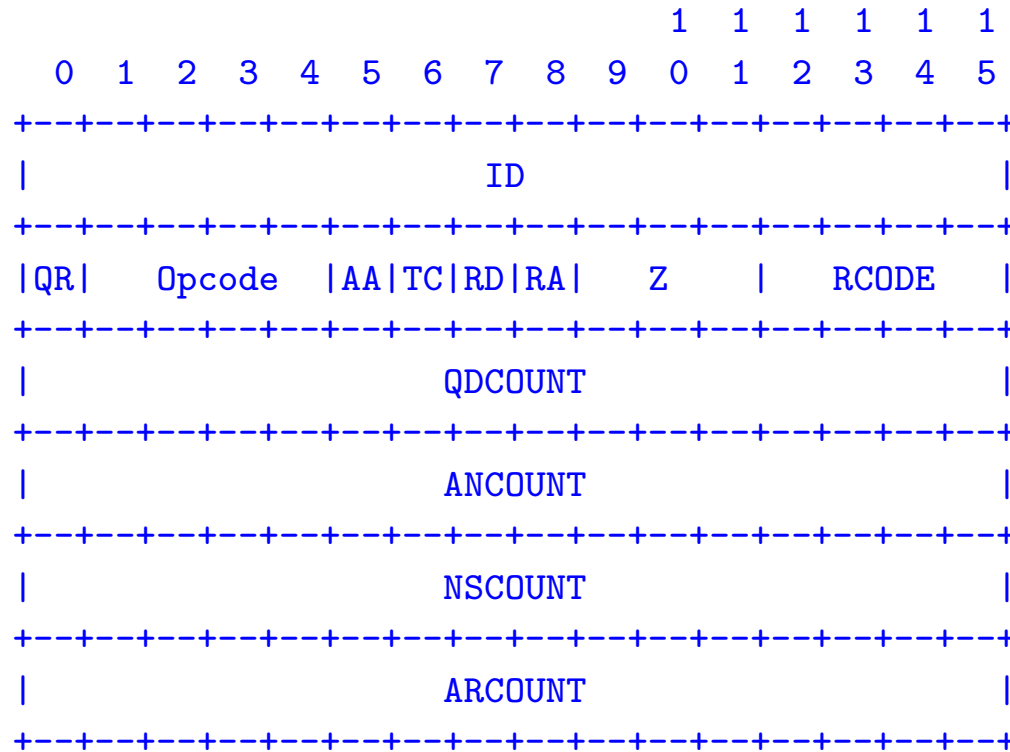
# Structure of a DNS Message

+-----+	
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



- **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, take first answer



# Inserting a Record in DNS

- **Your new startup helpme.com**
- **Get a block of addresses from ISP**
  - Say 212.44.9.0/24
- **Register helpme.com at namecheap.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 212.44.9.120
- **Configure your authoritative server (dns1.helpme.com)**
  - Type A record for www.helpme.com
  - Type MX record for helpme.com





# Inserting a Record in DNS, cont

- **Need to provide reverse PTR bindings**
  - E.g., 212.44.9.120 -> dns1.helpme.com
- **Configure your dns server to serve the 9.44.212.in-addr.arpa zone**
  - Need to add a record of this NS into the parent zone (44.212.in-addr.arpa)
- **Insert the bindings into the 9.44.212.in-addr.arpa zone**



# 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 for all sources
  - HTTPS can help
  - DNSSEC extension 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



# 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**



# Helpful ISPs

- Many ISPs hijack NXDOMAIN responses to “help” by offering search and advertisement related to the domain
- E.g., [www.bicycleisntadomain.com](http://www.bicycleisntadomain.com) doesn't (currently) exist
  - Could return a page with search and ads on bicycles (or domain registrations?)

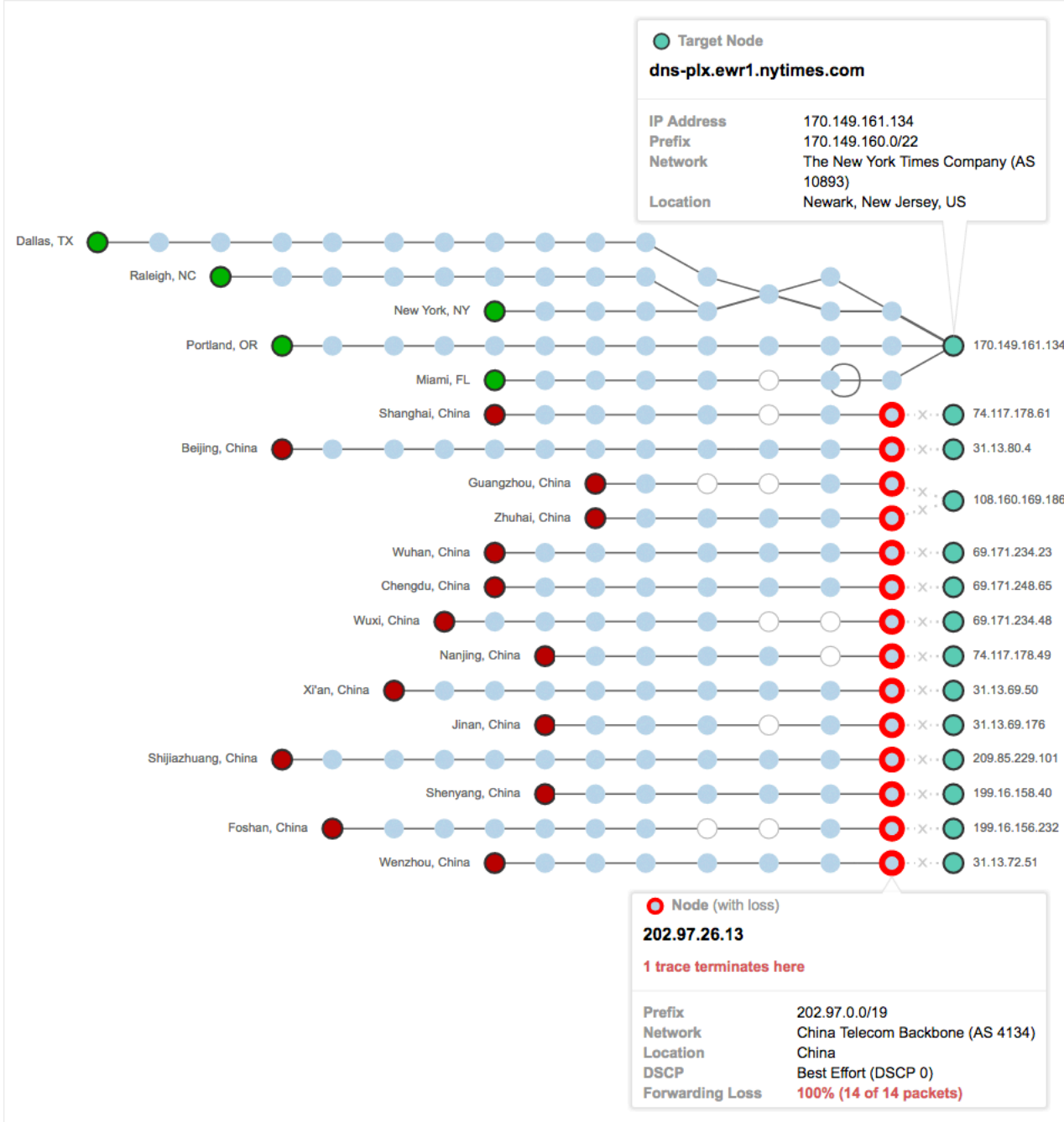


# Great Firewall of CIT

- **If attacker is on the path (say, it is the ISP, or a malicious version of TStaff):**
  - Can sniff all DNS queries
  - Send fake responses back first
  - Could do this selectively, to direct facebook.com to cs.brown.edu, for example...







# Great Firewall of China

- **Inject false responses to DNS queries *passing through* Chinese AS'es!**



# Solution: signatures

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



# Backup Slides

- **Good information, but not covered in class**



# 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!**



# SOPA - H. R. 3261

October 2011

- **“A BILL To promote prosperity, creativity, entrepreneurship, and innovation by combating the theft of U.S. property, and for other purposes”**

102.c.2

...

- **A service provider shall take technically feasible and reasonable measures designed to prevent access by its subscribers located within the United States to the foreign infringing site (or portion thereof) that is subject to the order, including measures designed to prevent the domain name of the foreign infringing site (or portion thereof) from resolving to that domain name’s Internet Protocol address.**

- **Would this work?**



# SOPA

- **Provider filtering would interact badly with DNSSEC**
- **Filtering would be easy to circumvent**
  - Circumvention could expose users to malicious DNS servers
- **Could cause collateral damage**
  - E.g., blog1.blogspot.com vs blog2.blogspot.com
- **The bill was withdrawn in 2012 after major online outcry, but highlights the importance of understanding technical underpinnings.**



See <http://www.circleid.com/pdf/PROTECT-IP-Technical-Whitepaper-Final.pdf> for details