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 $\leftrightarrow$ Address) Mappings

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

Scalable (Name $\leftrightarrow$ 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)

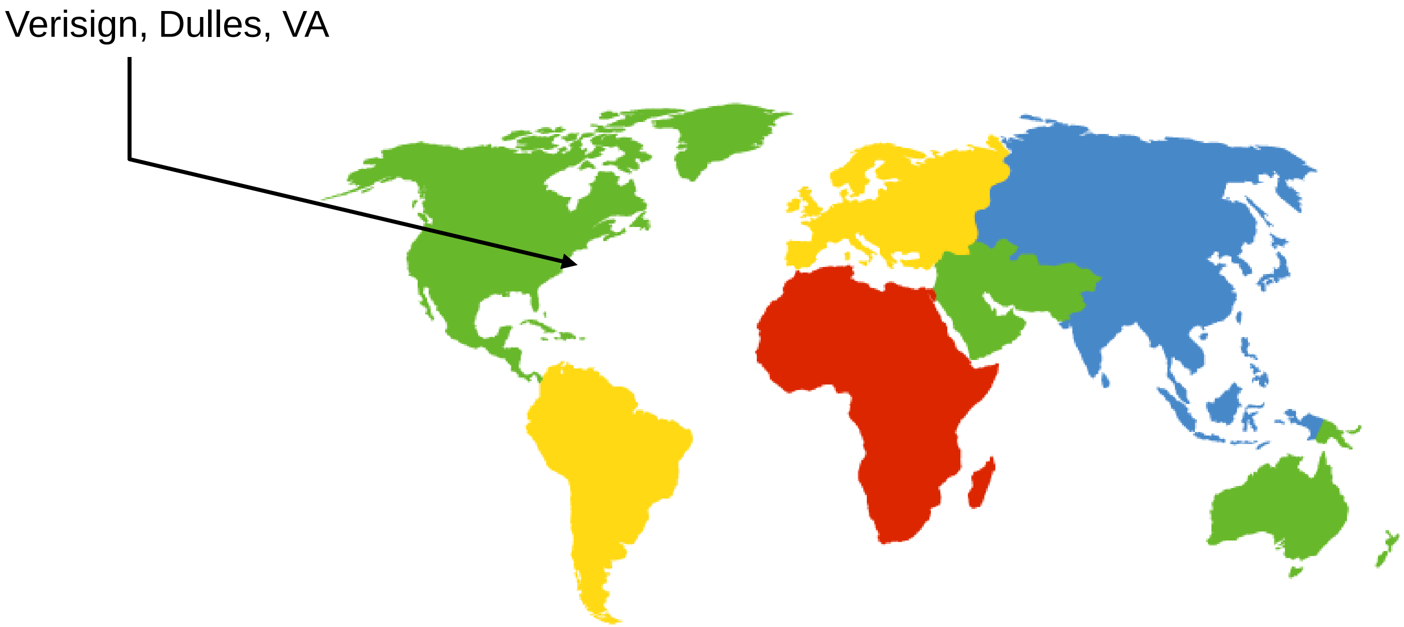
- Large scale dynamic, distributed application
  - Replaced Network Information Center (NIC)
- RFC 1034 and 1035
- Name space
  - Set of possible names
- Bindings
  - Maps internet domain names into IP addresses
- Name server
  - Resolution mechanism

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

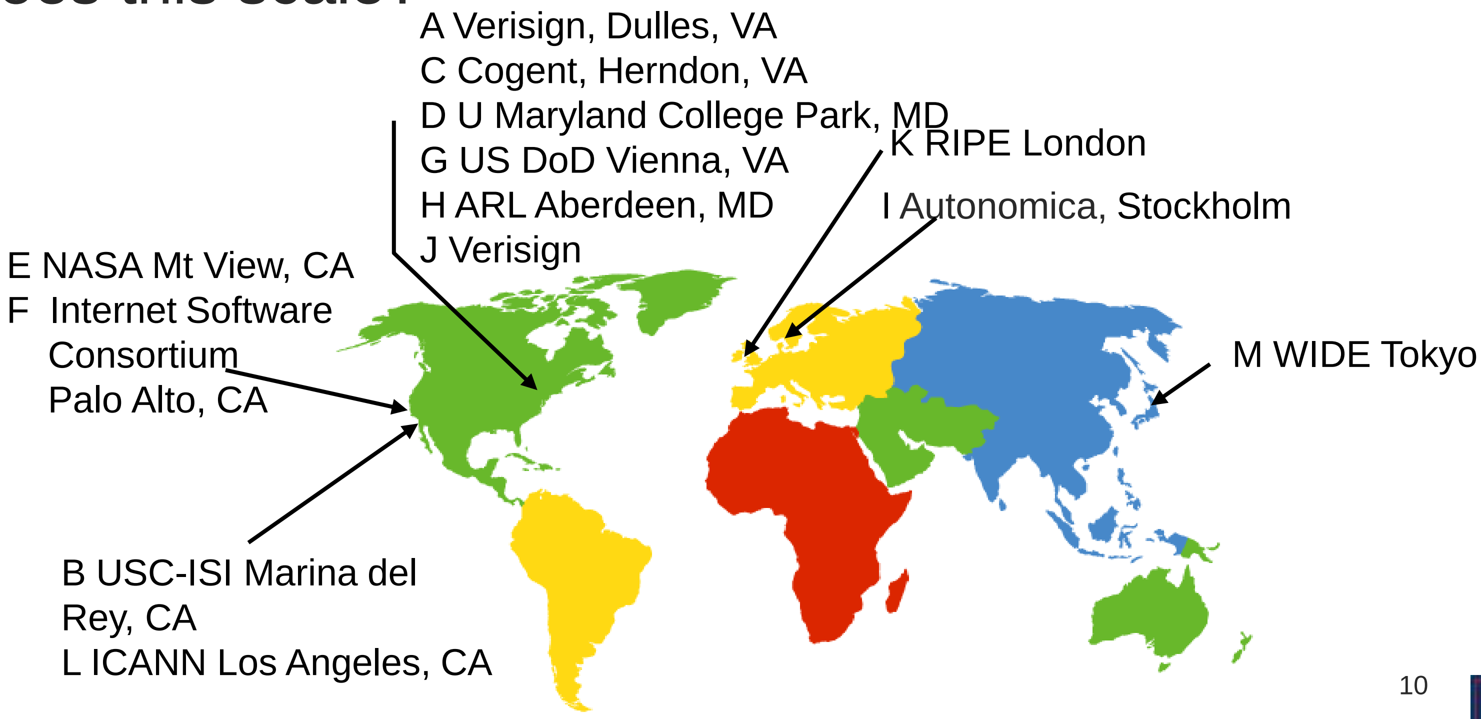
DNS Root

- 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?



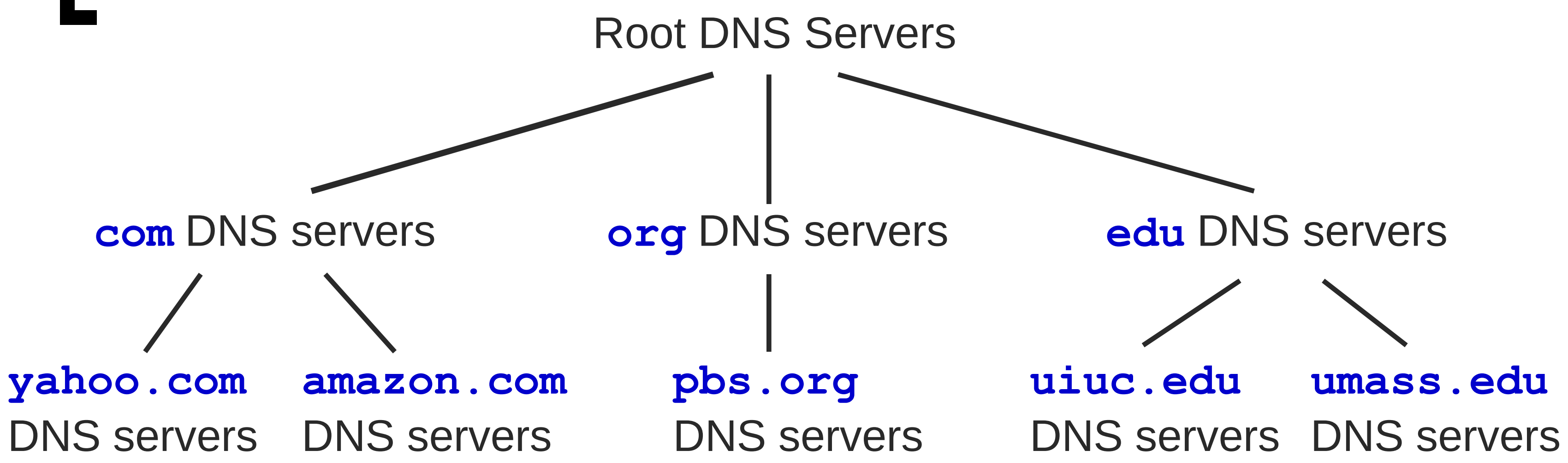
TLD and Authoritative Servers

- 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

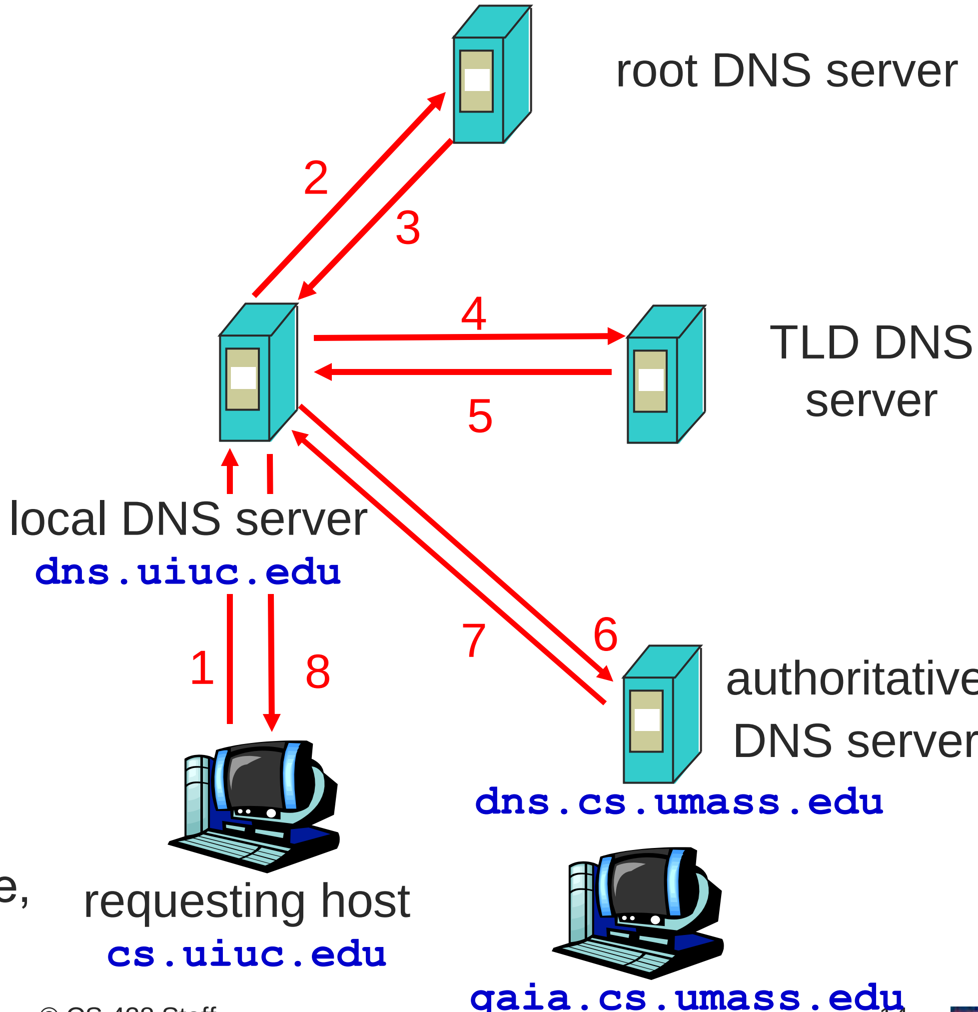
Distributed, Hierarchical Database



- 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`**

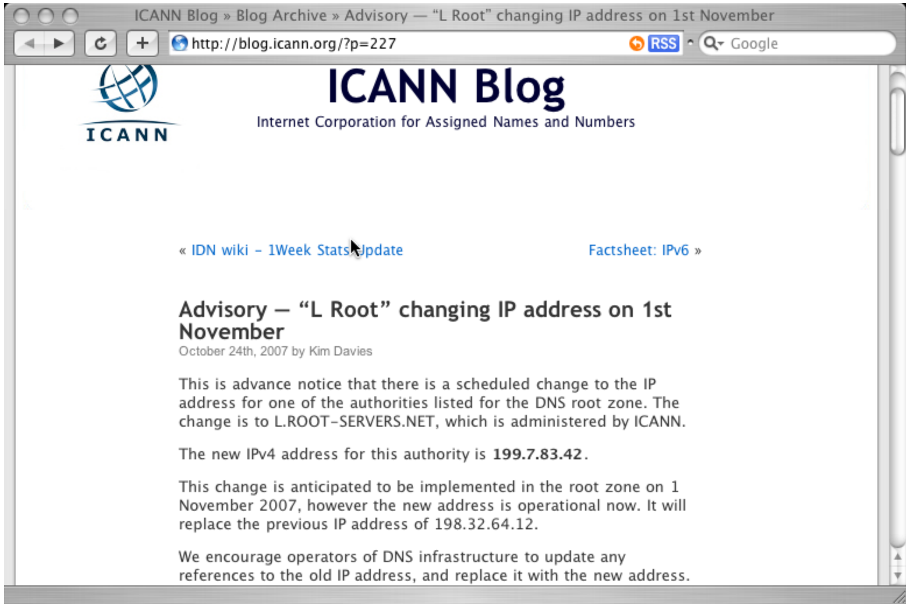
DNS – Name Server

- 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?



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 $\rightarrow$ 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