DNS: Domain Name System

EE 122: Intro to Communication Networks

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http://inst.eecs.berkeley.edu/~ee122/

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Host Names vs. IP addresses

- Host names
  - Mnemonic name appreciated by humans
  - Variable length, full alphabet of characters
  - Provide little (if any) information about 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
  - www.cnn.com vs. 64.236.16.20 *(but not tiny urls)*
- Addresses can change underneath
  - Move www.cnn.com to 4.125.91.21
  - E.g., renumbering when changing providers
- Name could map to multiple IP addresses
  - www.cnn.com 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 ↔ Address) Mappings

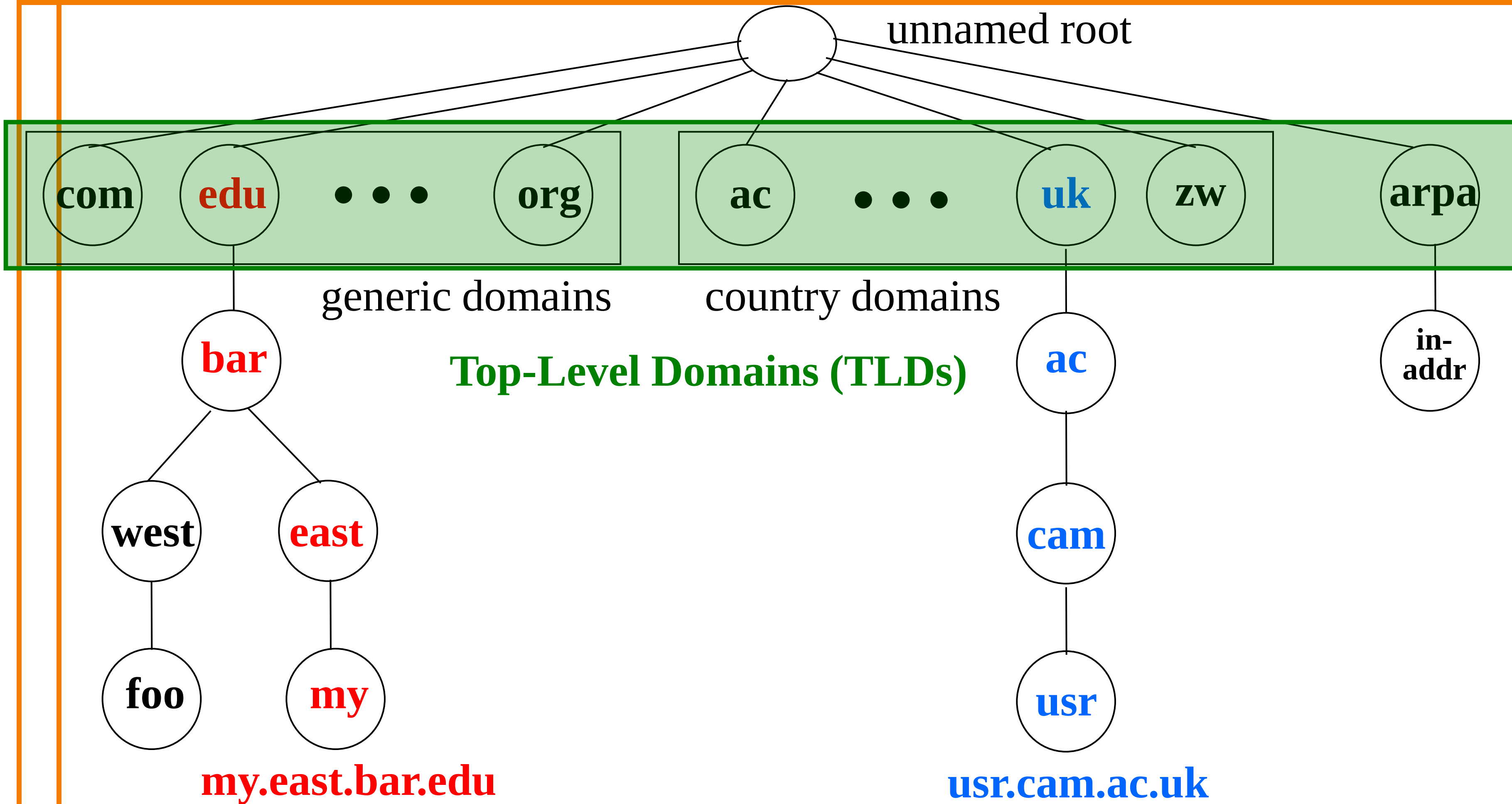
- Originally: per-host file
  - Flat namespace
  - **`/etc/hosts`**
  - SRI (Menlo Park) kept master copy
  - Downloaded regularly
- Single server doesn’t scale
  - Traffic implosion (lookups & updates)
  - Single point of failure
  - Amazing politics

Needed a distributed, hierarchical collection of servers

Domain Name System (DNS)

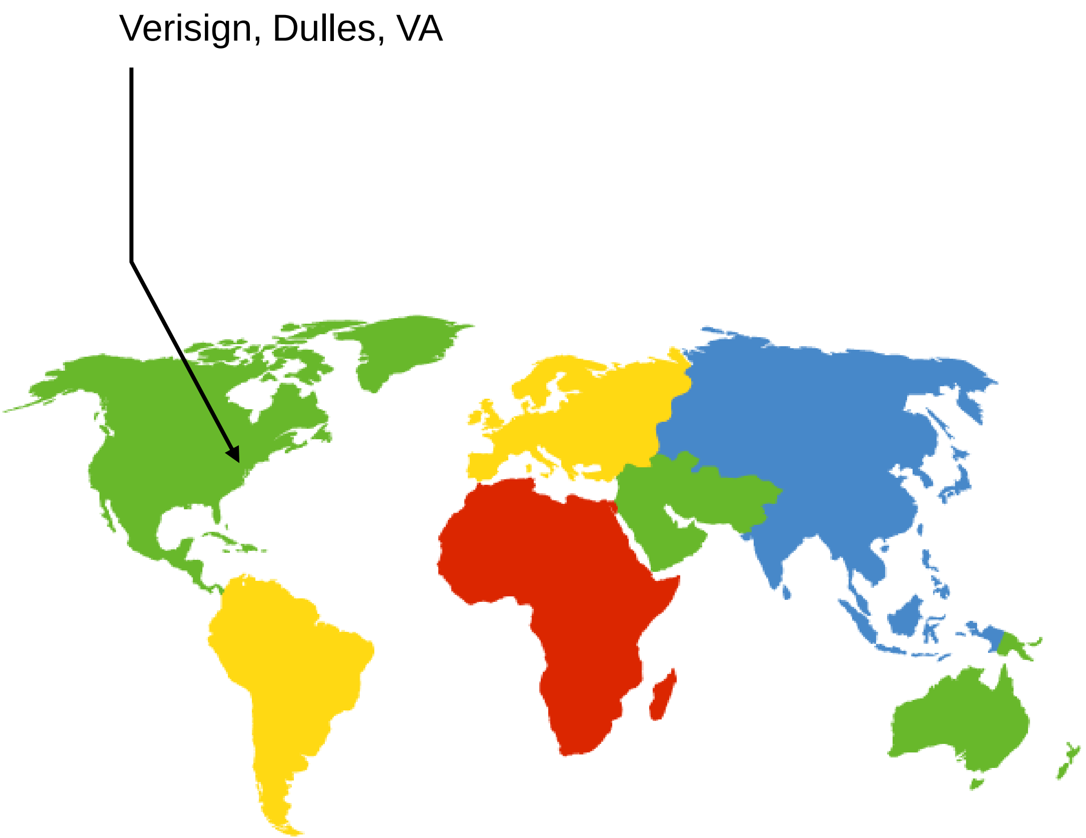
- Properties of DNS
  - Hierarchical name space divided into zones
  - Zones distributed over collection of DNS servers
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - Authoritative DNS servers
- Performing the translations
  - Local DNS servers
  - Resolver software

Distributed Hierarchical Database



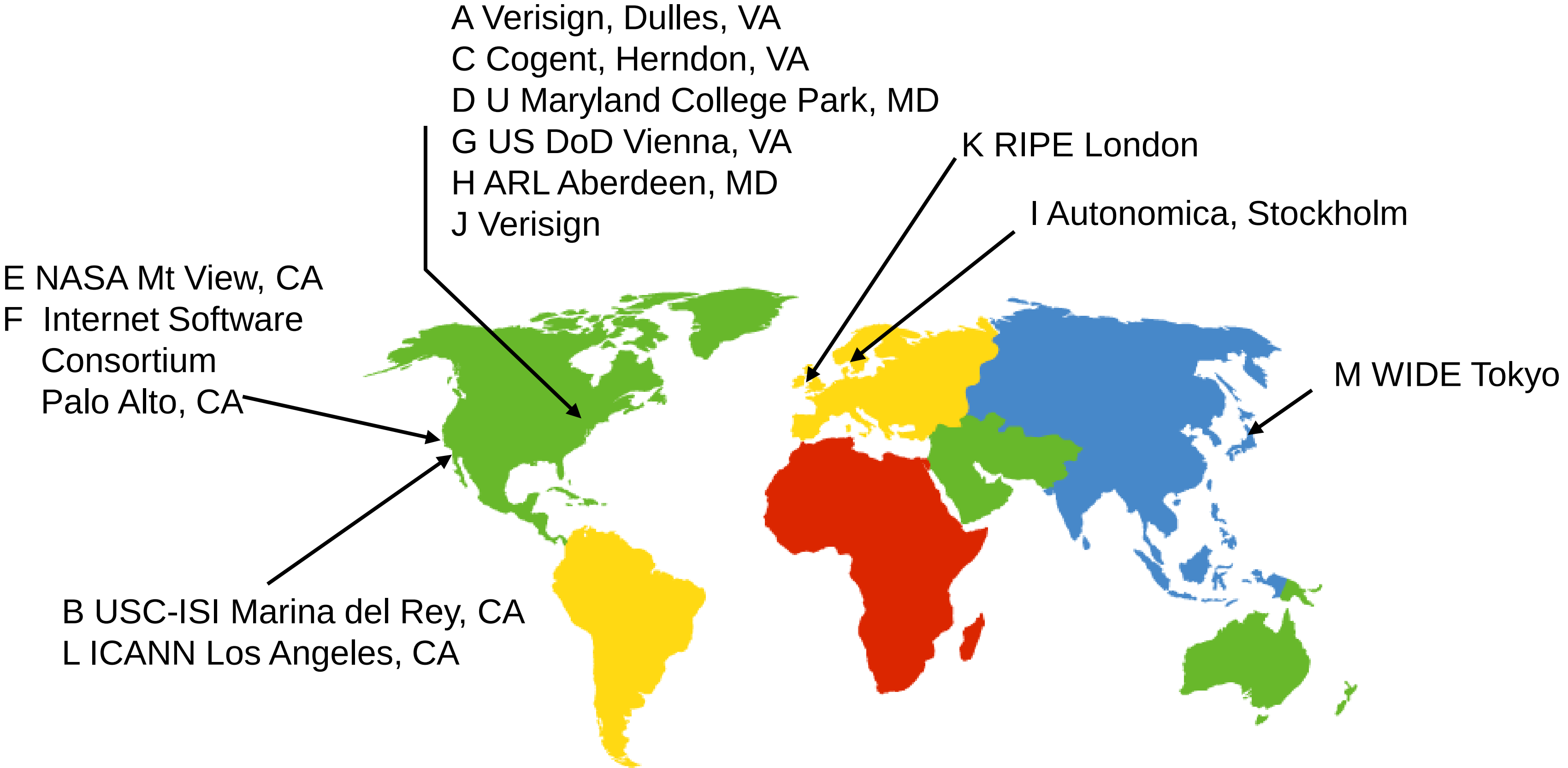
DNS Root

- 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?



DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- Replication via any-casting (localized routing for addresses)

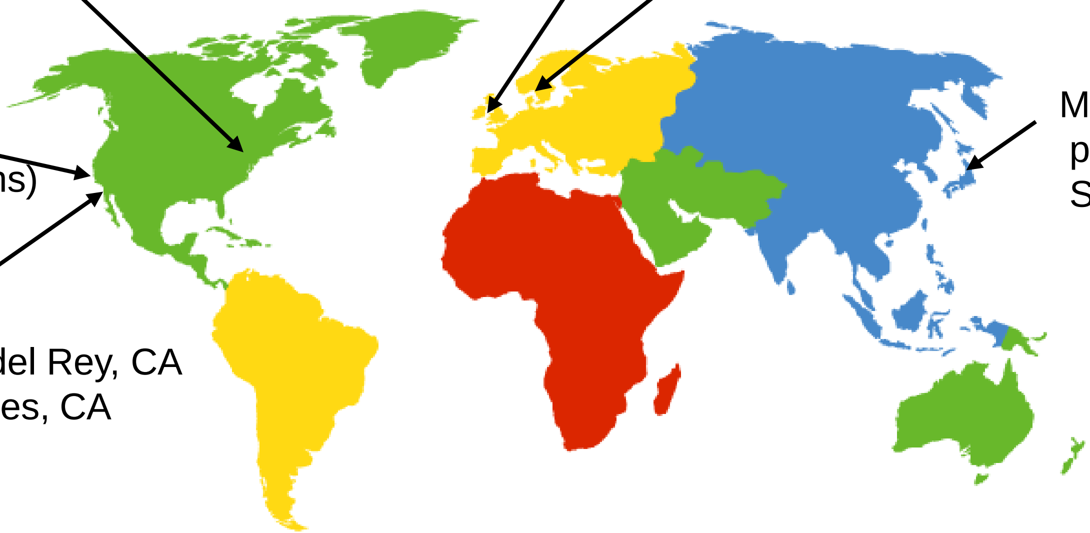
A Verisign, Dulles, VA
C Cogent, Herndon, VA (also Los Angeles, NY, Chicago)
D U Maryland College Park, MD
G US DoD Vienna, VA
H ARL Aberdeen, MD
J Verisign (21 locations)

K RIPE London (plus 16 other locations)

I Autonomica, Stockholm
(plus 29 other locations)

E NASA Mt View, CA
F Internet Software Consortium, Palo Alto, CA
(and 37 other locations)

M WIDE Tokyo
plus Seoul, Paris, San Francisco



B USC-ISI Marina del Rey, CA
L ICANN Los Angeles, CA

TLD and Authoritative DNS Servers

- Top-level domain (TLD) servers
  - Generic domains (e.g., com, org, edu)
  - Country domains (e.g., uk, fr, cn, jp)
  - Special domains (e.g., arpa)
  - Typically managed professionally
    - Network Solutions maintains servers for "**com**"
    - Educause maintains servers for "**edu**"
- Authoritative DNS servers
  - Provide public records for hosts at an organization
  - For the organization's servers (e.g., Web and mail)
  - Can be maintained locally or by a service provider

Question

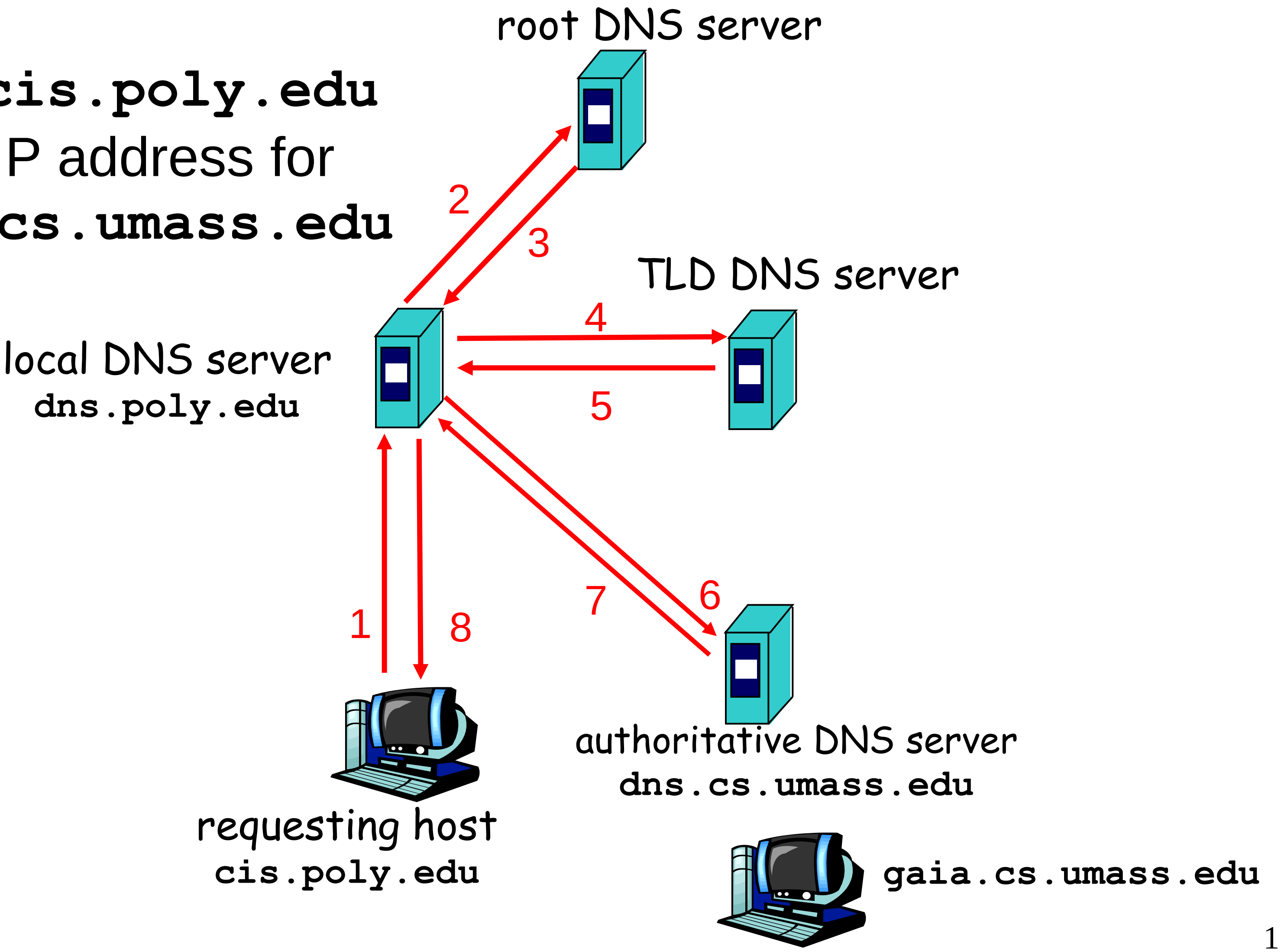
- Could we replace DNS with a Google-like infrastructure?

Using 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 *gethostbyname()* to trigger resolver code
- Server application
  - Extract client IP address from socket
  - Optional *gethostbyaddr()* to translate into name

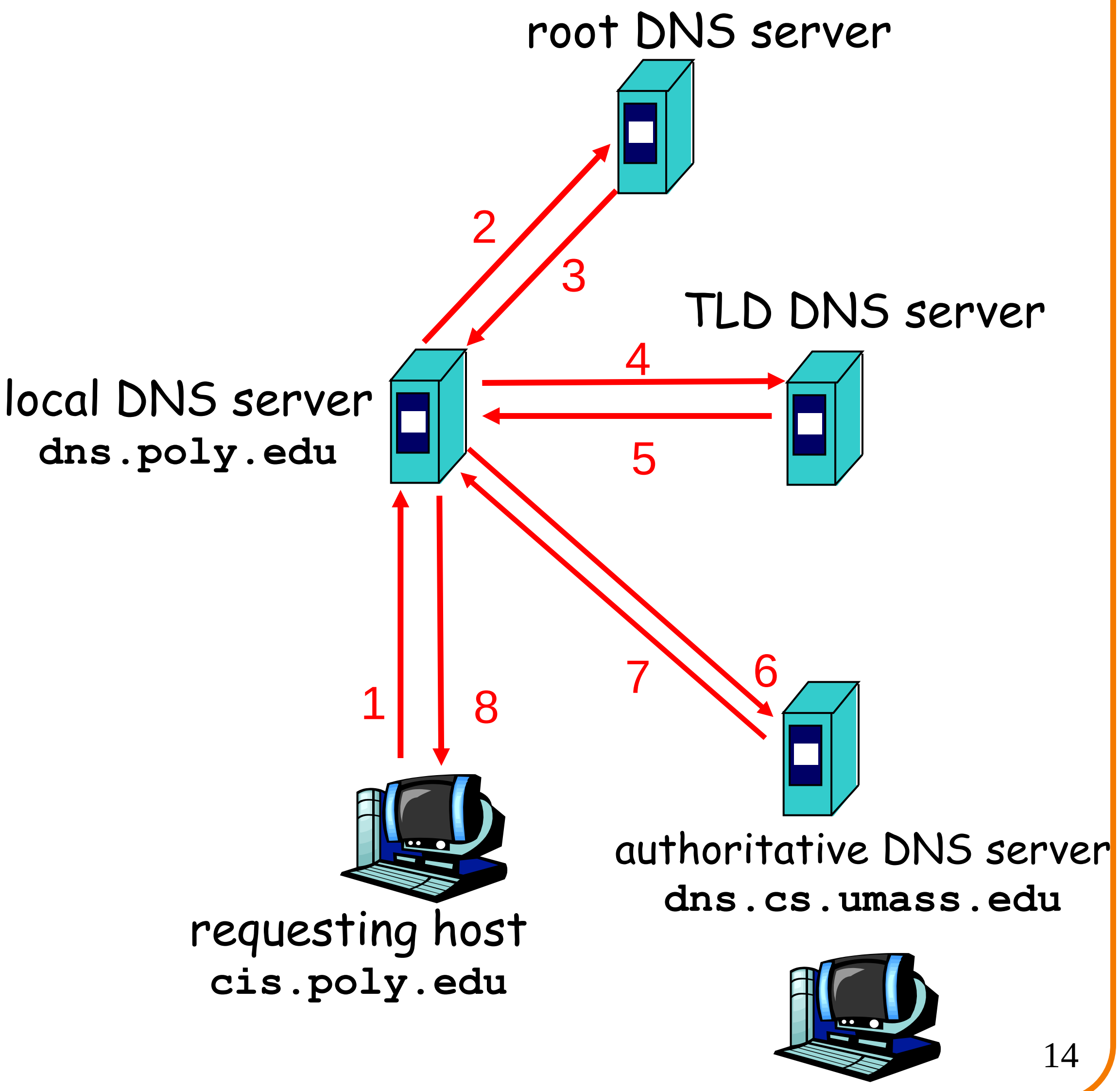
Example

Host at **`cis.poly.edu`** wants IP address for **`gaia.cs.umass.edu`**



Recursive vs. Iterative Queries

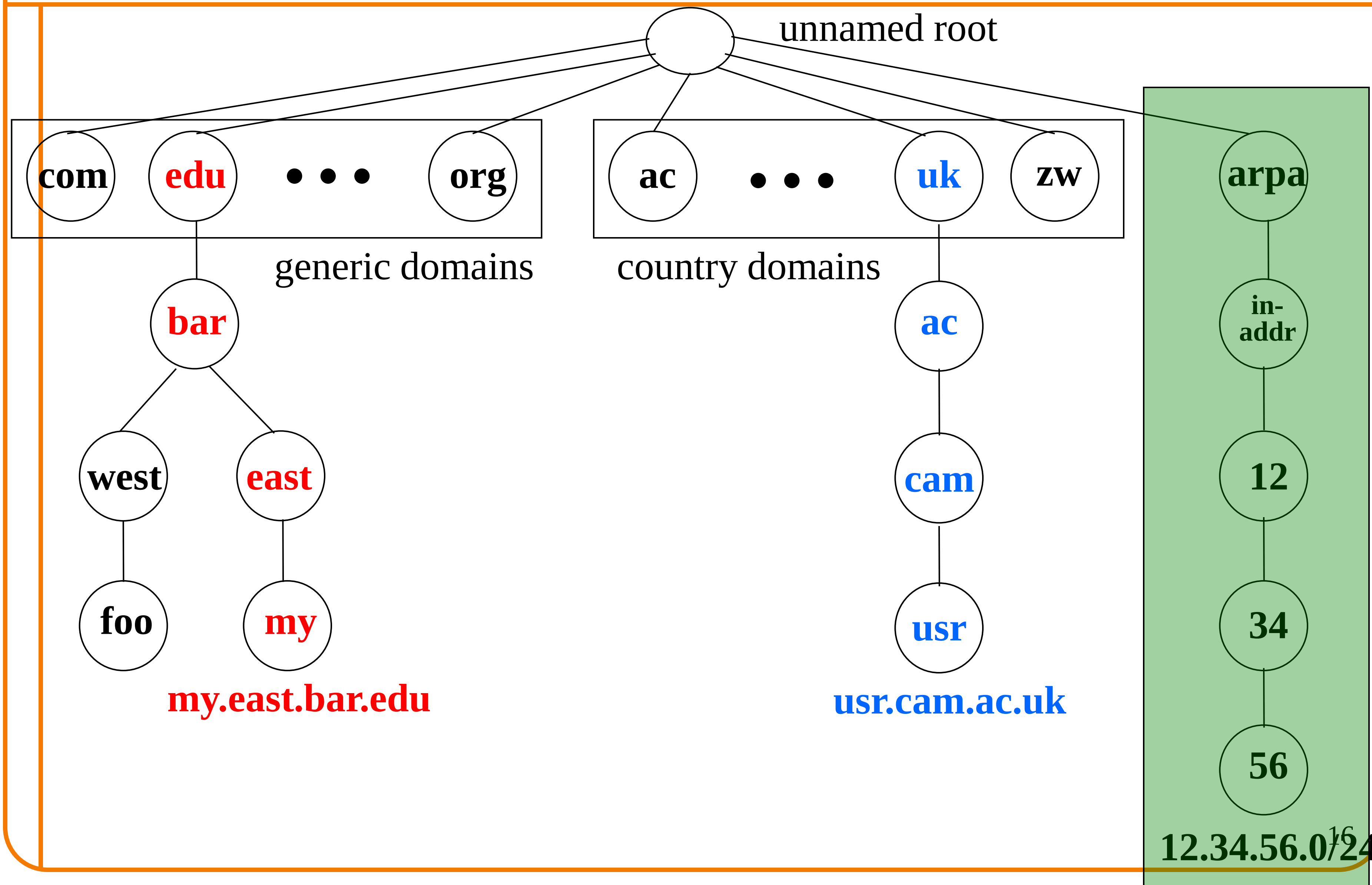
- Recursive query
  - Ask server to get answer for you
  - E.g., request 1 and response 8
- Iterative query
  - Ask server who to ask next
  - E.g., all other request-response pairs



Reverse Mapping (Address → Host)

- How do we go the other direction, from an IP address to the corresponding hostname?
- Addresses already have natural "quad" hierarchy:
  - 12.34.56.78
- But: quad notation has most-sig. hierarchy element on left, while www.cnn.com has it on the right
- Idea: reverse the quads = 78.56.34.12 …
  - … and look that up in the DNS
- Under what TLD?
  - Convention: **in-addr.arpa**
  - So lookup is for **`78.56.34.12.in-addr.arpa`**

Distributed Hierarchical Database



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
- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a "time to live" (TTL) field
  - Server deletes cached entry after TTL expires

Negative Caching

- Remember things that don't work
  - Misspellings like *www.cnn.comm* and *www.cnnn.com*
  - These can take a long time to fail the first time
  - Good to remember that they don't work
  - … so the failure takes less time the next time around
- But: negative caching is optional
  - And not widely implemented

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

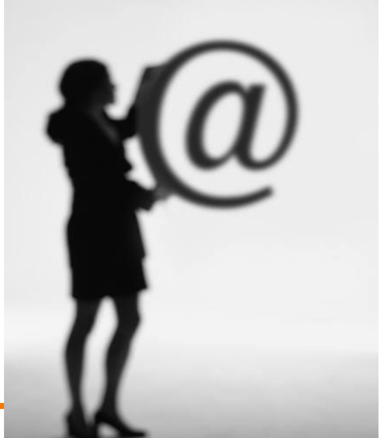
16 bits	***16 bits***
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

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*, con't

- In addition, need to provide reverse PTR bindings
  - E.g., **212.44.9.129** → **dns1.foobar.com**

- Normally, these would 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
  - And 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 90^{th} 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?
- Degrees of freedom:

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

- 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, hopefully: 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, con't

- 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, con't

- Suppose Bad Guy is at Starbuck's and they can sniff (or even guess) the identification field the local server will use in its next request:

16 bits	*16 bits*
Identification	**Flags**

- 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 Starbuck 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 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