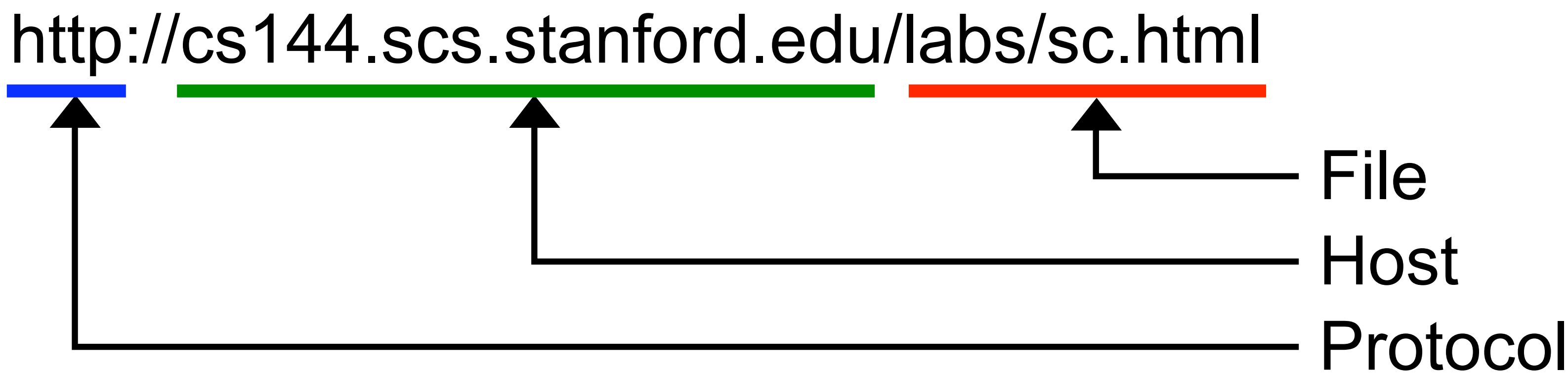
Administrivia

- **Lab 2 due right now**
  - Free extension to midnight for being here
  - Put `/* Attended-Lecture */` at top of `reliable.c`
- **Midterm exam one week from today**
  - Open Book, Open notes, no electronic devices allowed
  - Feel free to print out and bring lecture slides
- **SCPD students:**
  - Email `cs144-staff@scs.stanford.edu` with your exam monitor information
  - Please ensure the email subject is "`exam monitor`"
- **Any other students with special exam needs**
  - Please email `cs144-staff` to make arrangements

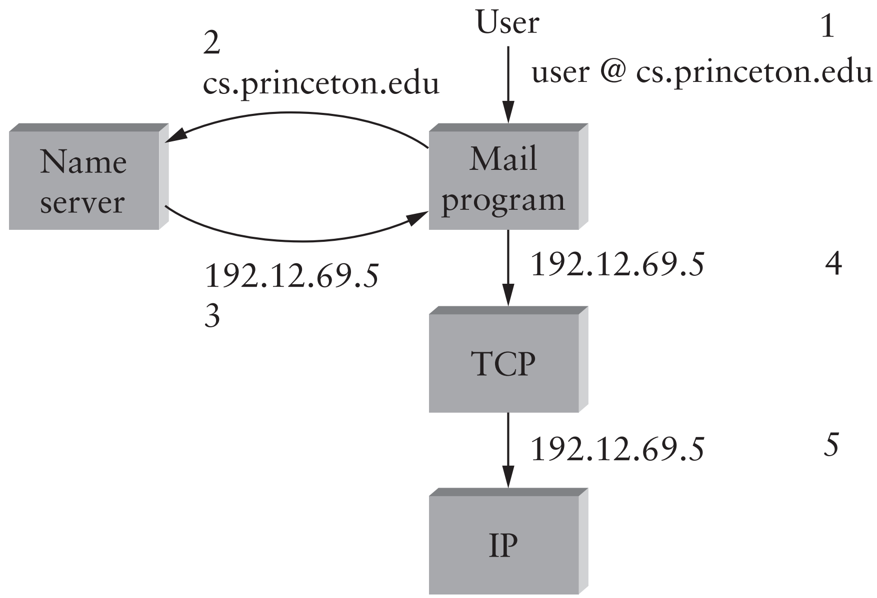
Outline

- DNS architecture
- DNS protocol and resource records (RRs)
- Record types: A, NS, glue, MX, SOA, CNAME
- Reverse lookup
- Load balancing
- DNS security

Parsing a URL



Motivation



- **Users can't remember IP addresses**
  - Need to map symbolic names (`www.stanford.edu`) →IP addr
- **Implemented by library functions & servers**
  - `getaddrinfo ()` talks to server over UDP
- **Actually, more generally, need to map symbolic names to values**

`hosts.txt` system

- **Originally, hosts were listed in a file,** `hosts.txt`
  - Email global network administrator when you add a host
  - Administrator mails out new `hosts.txt` file every few days
- **Would be completely impractical today**
  - `hosts.txt` today would be huge (gigabytes)
  - What if two people wanted to add same name?
  - Who is authorized to change address of a name?
  - People need to change name mappings more often than every few days (e.g., Dynamic IP addresses)

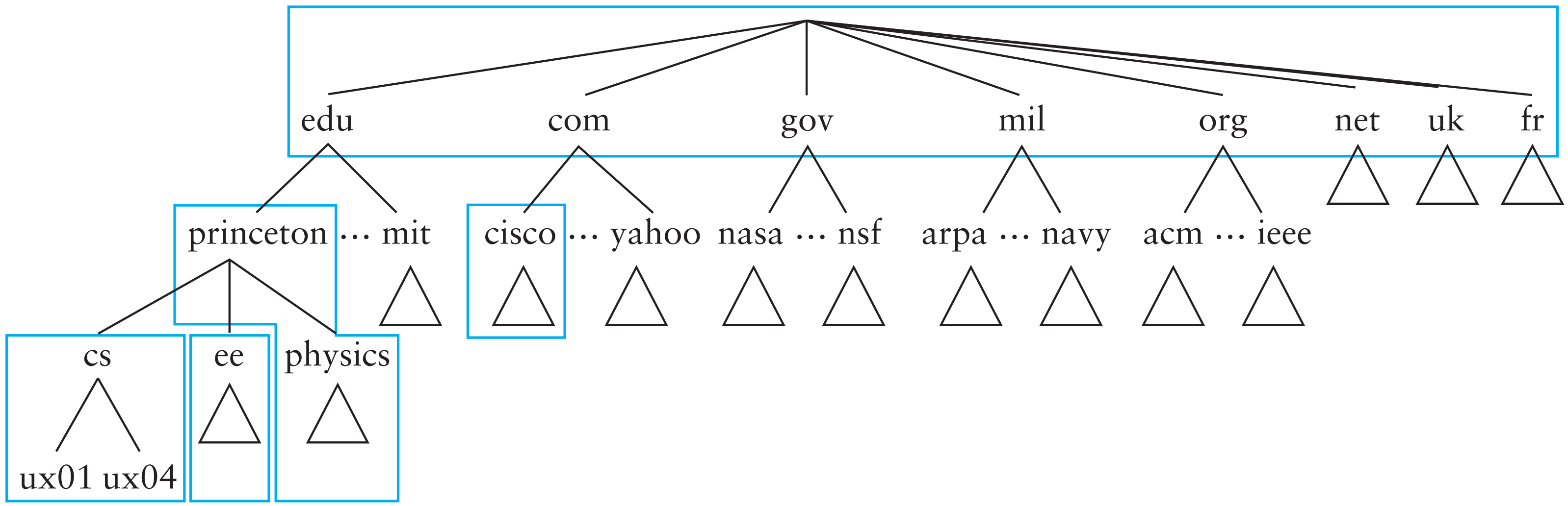
Goals of DNS

- **Scalability**
  - Must handle huge number of records
  - Potentially *exponential* in name size—because custom software may synthesize names on-the-fly
- **Distributed control**
  - Let people control their own names
- **Fault-tolerance**
  - Old software assumed `hosts.txt` always there
  - Bad potential failure modes when name lookups fail
  - Minimize lookup failures in the face of other network problems

The good news

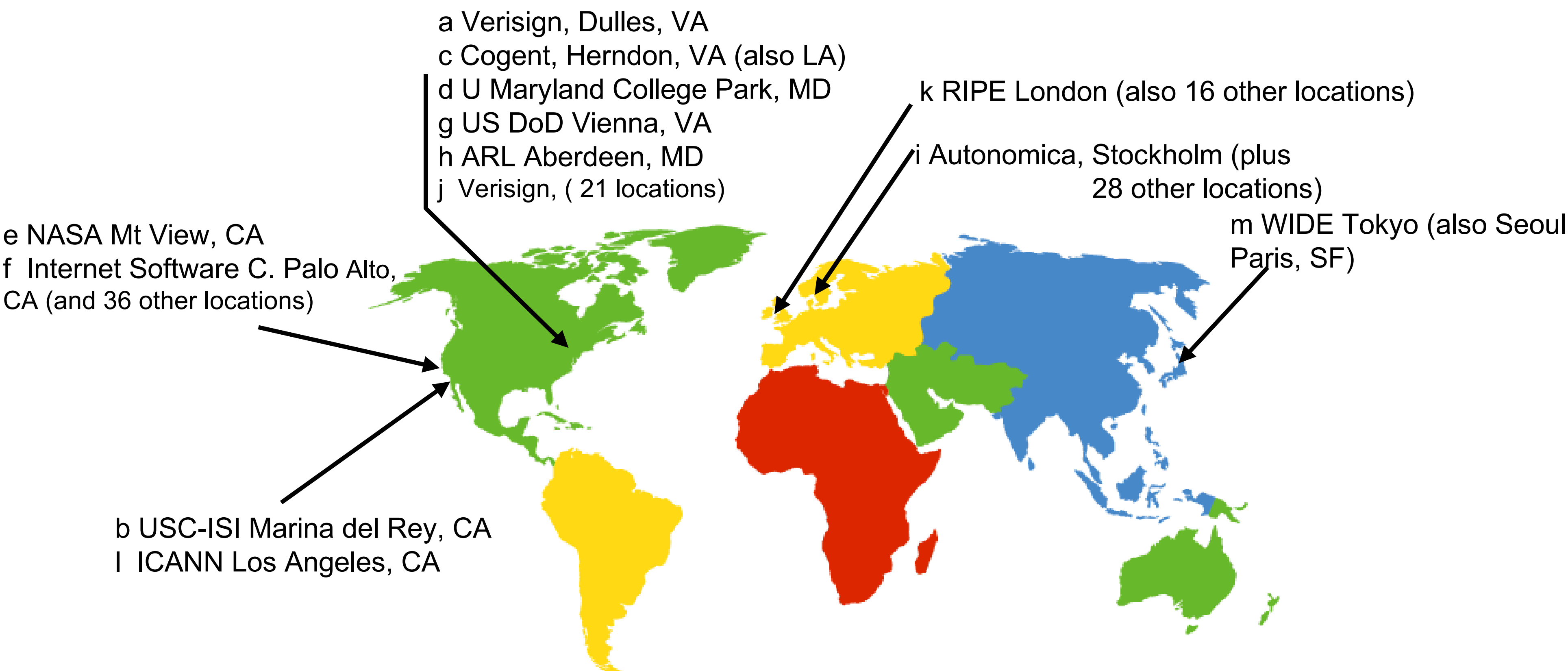
- **Properties that make DNS goals easier to achieve:**
  1. **Read-only or read-mostly database**
     - People typically look up hostnames much more often than they are updated
  2. **Loose consistency**
     - When adding a machine, may be okay if info takes minutes or hours to propagate
- **These suggest approach w. aggressive caching**
  - Once you have looked up hostname, remember result
  - Don't need to look it up again in near future

Domain Name System (DNS)



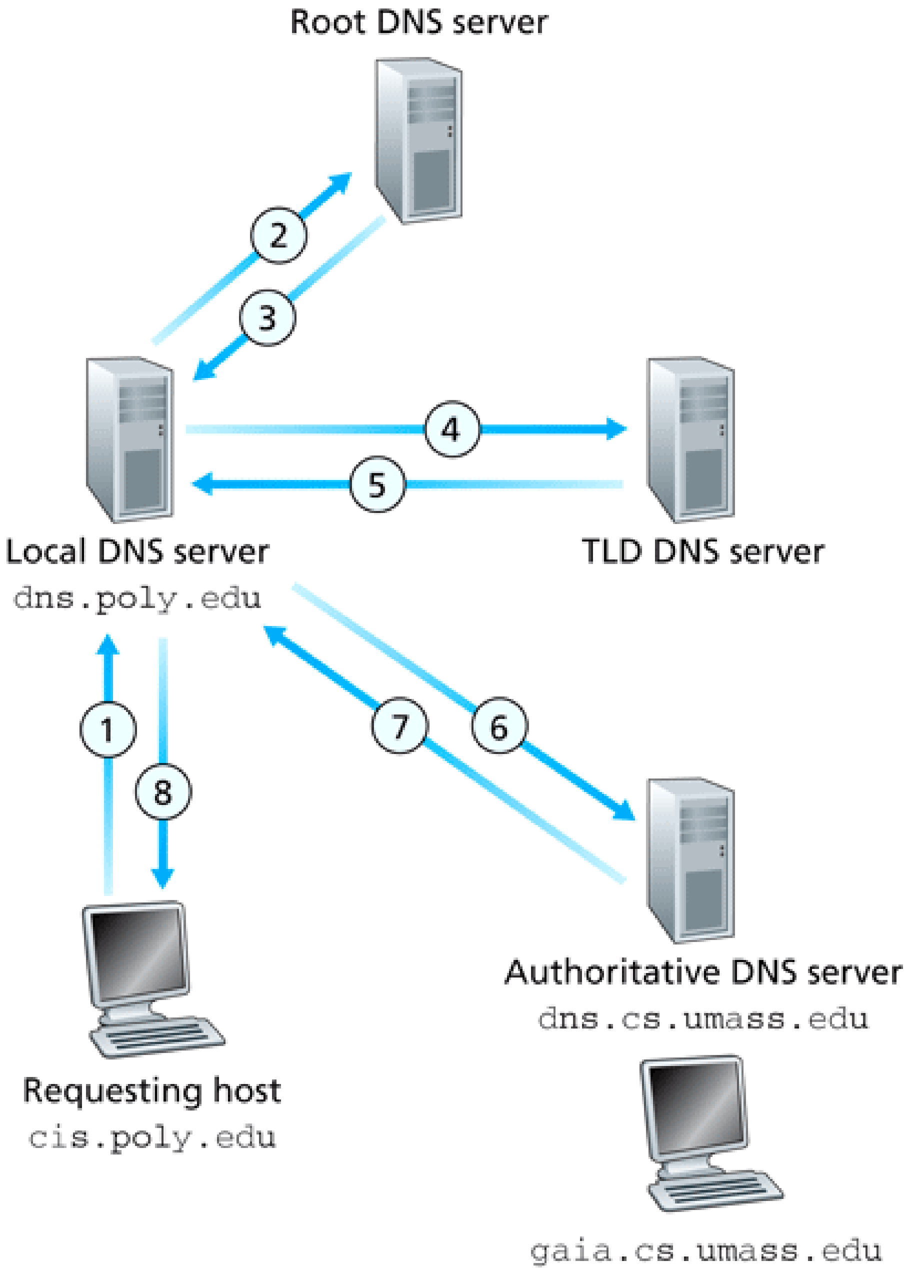
- **Break namespace into a bunch of zones**
  - `.` ("root"), `edu.`, `stanford.edu.`, `cs.stanford.edu.`, `...`
  - Zones separately administered $\Longrightarrow$ delegation
  - Parent zones tell you how to find servers for dubdomains.
- **Each zone served from several replicated servers**

Root servers



- **Root (and TLD) servers must be widely replicated**
  - For some, use various tricks like IP anycast

DNS software architecture



- **Two types of query**
  - Recursive
  - Non-Recursive
- **Apps make recursive queries to local DNS server (1)**
- **Local server queries remote servers non-recursively (2, 4, 6)**
  - Aggressively caches result
  - E.g., only contact root on first query ending `.umass.edu`

DNS protocol

- **TCP/UDP port 53**
- **Most traffic uses UDP**
  - Lightweight protocol has 512 byte UDP message limit
  - retry w. TCP if UDP fails (e.g., reply truncated)
- **TCP requires message boundaries**
  - Prefix all messages w. 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 (e.g., `www.stanford.edu.`)
  - TTL – time to live in seconds
  - *class* – for extensibility, usually IN (1) "Internet"
  - *type* – type of the record
  - *rdata* – resource data dependent on the *type*

- **Two important DNS RR types:**
  - A – Internet address (IPv4)
  - NS – name server

- **Example resource records (`dig stanford.edu`):**

```
stanford.edu.    3600  IN A   171.67.216.4
stanford.edu.    3600  IN A   171.67.216.7
stanford.edu.    6171  IN NS  Argus.stanford.edu.
...
```

Some implementation details

- **How does local name server know root servers?**
  - Need to configure name server with *root cache* file
  - Contains root name servers and their addresses

```
.                     3600000  NS   A.ROOT-SERVERS.NET.
A.ROOT-SERVERS.NET.   3600000  A    198.41.0.4
.                     3600000  NS   B.ROOT-SERVERS.NET.
B.ROOT-SERVERS.NET.   3600000  A    128.9.0.107
...
```

- **How do you get addresses of other name servers**
  - To lookup names ending `.stanford.edu.`, ask `Argus.stanford.edu.`
  - Chicken and egg problem:
    How to get `Argus.stanford.edu.`'s address?
  - Solution: glue records – A records in parent zone
  - Name servers for `edu.` have A record of `Argus.stanford.edu.`

Glue Record Example

- **Look up** `www.scs.stanford.edu` **assuming no cache**

```
dig +norec www.scs.stanford.edu @a.root-servers.net
dig +norec www.scs.stanford.edu @a.gtld-servers.net
dig +norec www.scs.stanford.edu @argus.stanford.edu
dig +norec www.scs.stanford.edu @mission.scs.stanford.edu
```

- **Get intermediary results for** `.edu`**,** `stanford.edu`**,** `scs.stanford.edu`**, and** `www.scs.stanford.edu`

- **Where are the glue records?**

Structure of a DNS message [RFC 1035]

```
+---------------------+
|        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 message format for queries and replies**
  - Query has zero RRs in Answer/Authority/Additional sections
  - Reply includes question, plus has RRs
- **Authority allows for delegation**
- **Additional for glue + other RRs client might need**

Header format

```
                                1  1  1  1  1  1
  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      ID                       |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|QR|   Opcode  |AA|TC|RD|RA|   Z    |   RCODE   |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    QDCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ANCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    NSCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ARCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

- **QR** – 0=query, 1=response
- **RCODE** – error code
- **AA**=authoritative answer, **TC**=truncated, **RD**=recursion desired, **RA**=recursion available

Encoding of RRs

```
                                1  1  1  1  1  1
  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                                               |
/                                               /
/                      NAME                     /
|                                               |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      TYPE                     |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                     CLASS                     |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      TTL                      |
|                                               |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                   RDLENGTH                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--|
/                     RDATA                     /
/                                               /
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

Encoding of domain names

- **A DNS name consists of a series of labels**
  - `www.stanford.edu.` has 3 labels: `www`, `stanford`, and `edu`
  - Labels can contain letters, digits, and "`-`", but should not start or end with "`-`"
  - Maximum length 63 characters
  - Encoded as length byte followed by label
  - Last label always empty label
- **Names are case insensitive**
  - But server must preserve case of question in replies
  - Example: request `www.sTANford.EDu`, look at authority

Name compression

```
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
| 1  1|                OFFSET                   |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

- **Observation: many common suffixes in DNS messages**
  - Particularly because of case preservation rule
- **Allow pointer labels to re-use suffixes**
  - Recal label starts with length byte (0-63)
  - If value $\geq$ 0xc0 (192), subtract 0xc000 from first *two* bytes, and treat as pointer into message

Secondary servers

- **Availability requires geographically disperate replicas**
  - E.g., I ask MIT to serve `scs.stanford.edu`
- **Typical setup: One master many slave servers**
- **How often to sync up servers? Trade-off**
  - All the time $\Longrightarrow$ high overhead
  - Rarely $\Longrightarrow$ stale data
- **Put trade-off under domain owner's control**
  - Fields in SOA record control secondary's behavior
  - Primary can change SOA without asking human operator of secondary
  - Primary can also give secondary a hint to check freshness

Other Records

- **Start of Authority (SOA) record**
  - States administrative information for a zone
  - `dig stanford.edu soa`
  - `dig sing.stanford.edu ns`
  - Tells you how long you can cache negative results
- **Mail Exchange (MX) record**
  - For historical reasons, mail does not have to use A records directly
  - Example: ping `scs.stanford.edu`
  - No such host, but you can still mail CS144 staff there

CNAME records

- **CNAME record specifies an alias:**

  name* [TTL] [IN] CNAME *canonical-name

  - As if any RR's associated w. *canonical-name* also for *name*
  - Can look up with `AI_CANONNAME` flag to `getaddrinfo`

- **Examples, to save typing:**

```
wb.scs.stanford.edu.   CNAME  williamsburg-bridge.scs.stanford.edu.
mb.scs.stanford.edu.   CNAME  manhattan-bridge.scs.stanford.edu.
```

- **CNAME precludes any other RRs for name**
  - E.g., might want: `david.com CNAME david.stanford.edu`
  - Illegal, because `david.com` would need NS records

- **Note answer section can have CNAME for query name + other RR(s) for *canonical-name***
  - But don't point MXes to CNAMEs, as no A recs in additional section (try `bad-mx.scs.stanford.edu.`)

Reverse Lookups

- **Remember traceroute…**
- **Traceroute can learn names of hosts through** ***reverse lookup***
- **128.30.2.121 → 121.2.30.128.in-addr.arpa**
- **PTR record points to canonical name**
- **Example: tinyos.stanford.edu → sing.stanford.edu → 65.76.67.171.in-addr.arpa ptr**

Mapping addresses to names

- **PTR records specify names**

  ***name* [TTL] [IN] PTR "*ptrdname*"**

  - *name* – somehow encode address…how?
  - *ptrdname* – domain name for this address

- **IPv4 addrs stored under `in-addr.arpa` domain**
  - Reverse name, append `in-addr.arpa`
  - To look up 171.66.3.9 → `9.3.66.171.in-addr.arpa.`
  - Why reversed? Delegation!

- **IPv6 under `ip6.arpa`**
  - Historical note: ARPA funded original Internet

Using DNS for load-balancing

- **Can have multiple RR of most types for one name**
  - Required for NS records (for availability)
  - Useful for A records
  - (Not legal for CNAME records)
- **Servers rotate order in which records returned**
  - `getaddrinfo` returns a linked list of `addrinfo` structures
  - Most apps just use first address returned
  - Even if your name server caches results, clients will be spread amonst servers
- **Example:** `dig cnn.com` **multiple times**

SRV records

- **Service location records**
  _service._proto.name* [...] SRV *prio weight port target
  - _service – E.g., `_sfs` for NYU's SFS file system
  - _proto – `_tcp` or `_udp`
  - name – domain name record applies to
  - prio – as with MX records, lower # → higher priority
  - weight – within priority, affects randomization of order
  - port – TCP or UDP port number (particularly useful for SIP)
  - target – Server name, for which client needs A record
- **Like a generalization of MX records for arbitrary services**

DNS redirection for content distribution

- **Play with akamai and** `www.microsoft.com`

Classless `in-addr` delegation

- **How to delegate on non-byte boundary?**
- **Solution: Use CNAME records**
  - So-called *classless* in-addr delegation
- **Example:**

```
1.3.66.171.in-addr.arpa. CNAME 1.ptr.your-domain.com.
2.3.66.171.in-addr.arpa. CNAME 2.ptr.your-domain.com.
3.3.66.171.in-addr.arpa. CNAME 3.ptr.your-domain.com.
```

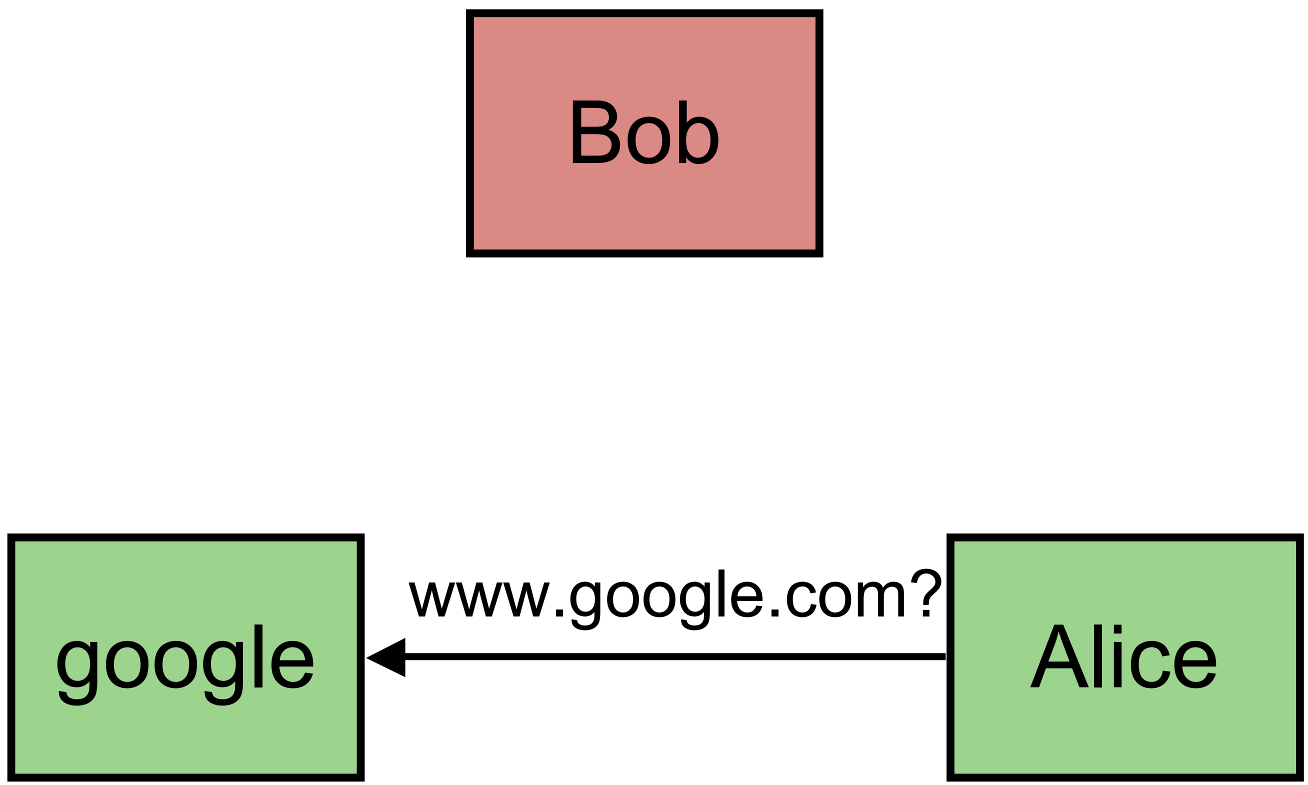
DNS exploits

- **July 29, 2008, Bruce Scnheier: “Despite the best efforts of the security community, the details of a critical internet vulnerability discovered by Dan Kaminsky about six months ago have leaked.”**
- **One of the basic problems: DNS caching**
  - If you can poison the cache, the damage stays
  - Who knows how far it spreads…

DNS exploit example

- **Alice wants to look up** `www.google.com`
- **Bob the attacker knows**
- **Bob knows source address/port, destination address/port**
- **Bob generates a spoof response:** `www.google.com` **is** `www.evil.com`
- **Challenge: Bob has to guess Query ID**
- **If Bob guesses, RR can stay in Alice's cache a long time**

Exploit Example



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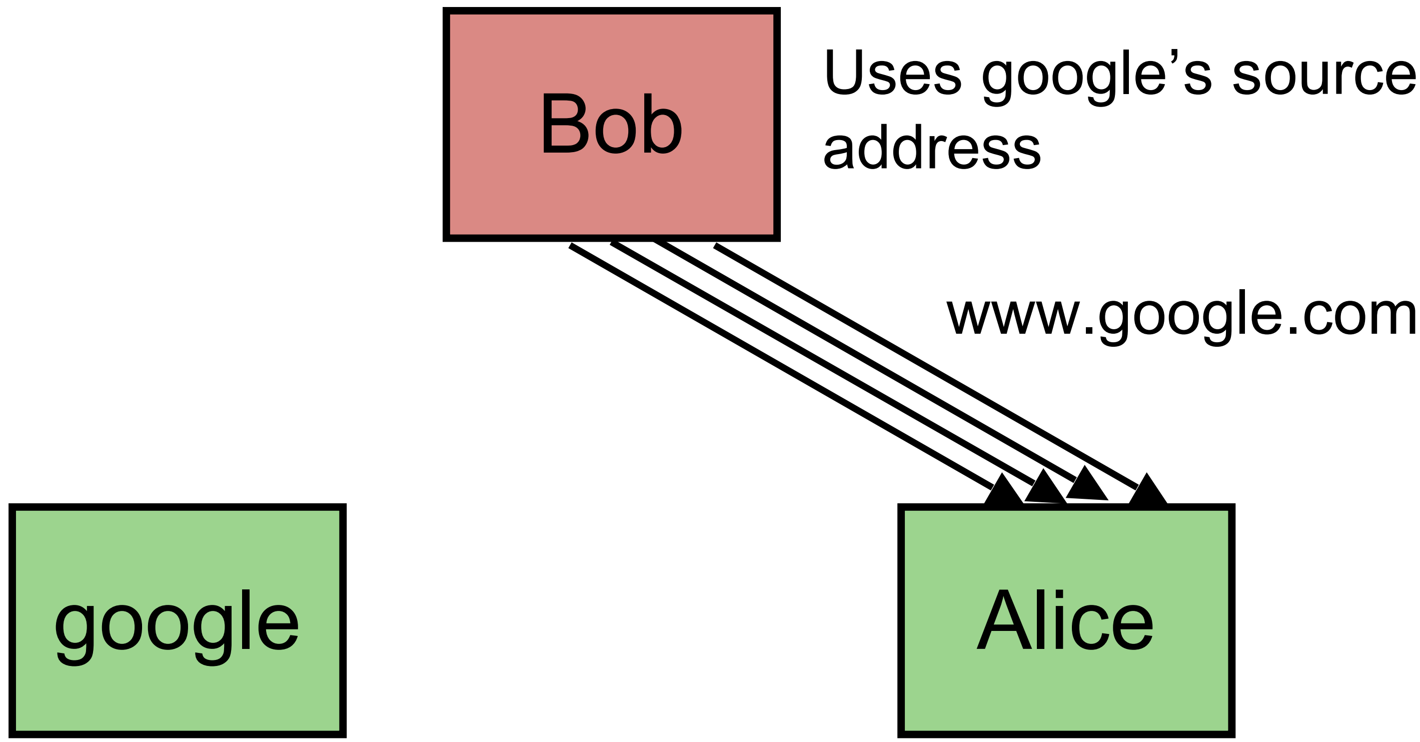


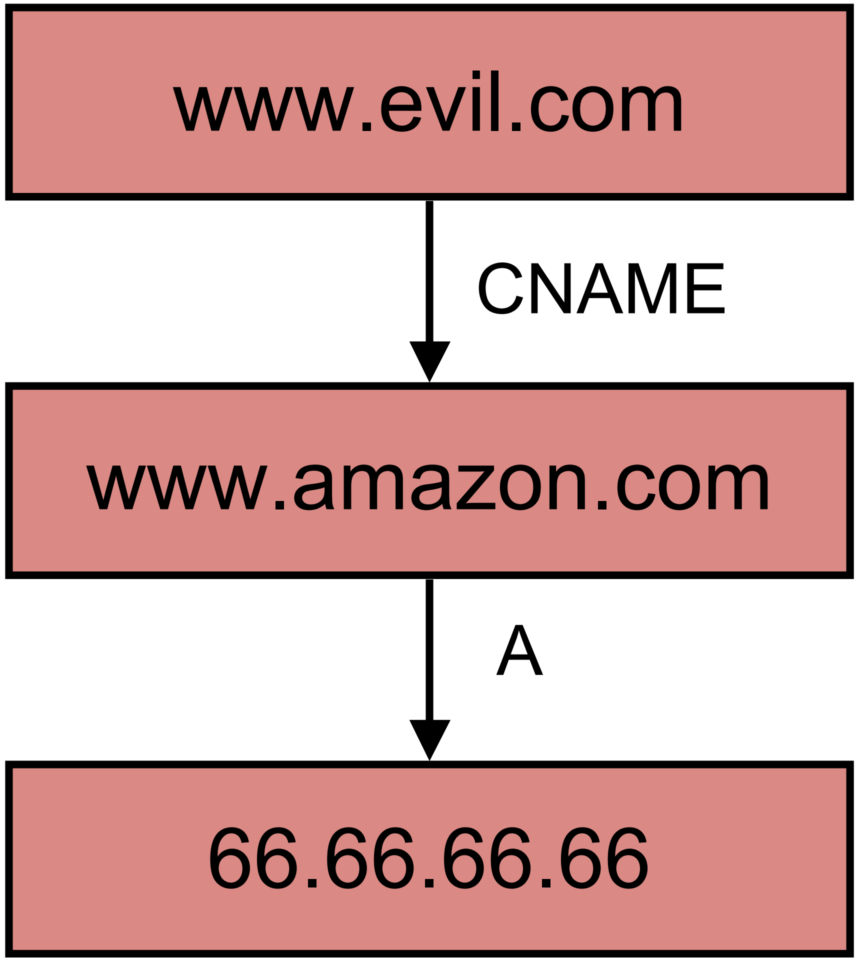
Countermeasures

- Choose good QIDs (used to be incremented, now randomly generated), 16 bits
- Randomize source port, 16 bits
- Some protection, but only makes it take longer, networks are faster each day

Another exploit

- **DNS clients used to trust all responses**
- **Problem: glue records and helpful A records**
  - Ask NS of `evil.com` for `www.evil.com`
  - Says `www.evil.com` is a CNAME for `www.google.com`
  - Provides A record for `www.google.com`

Exploit Example



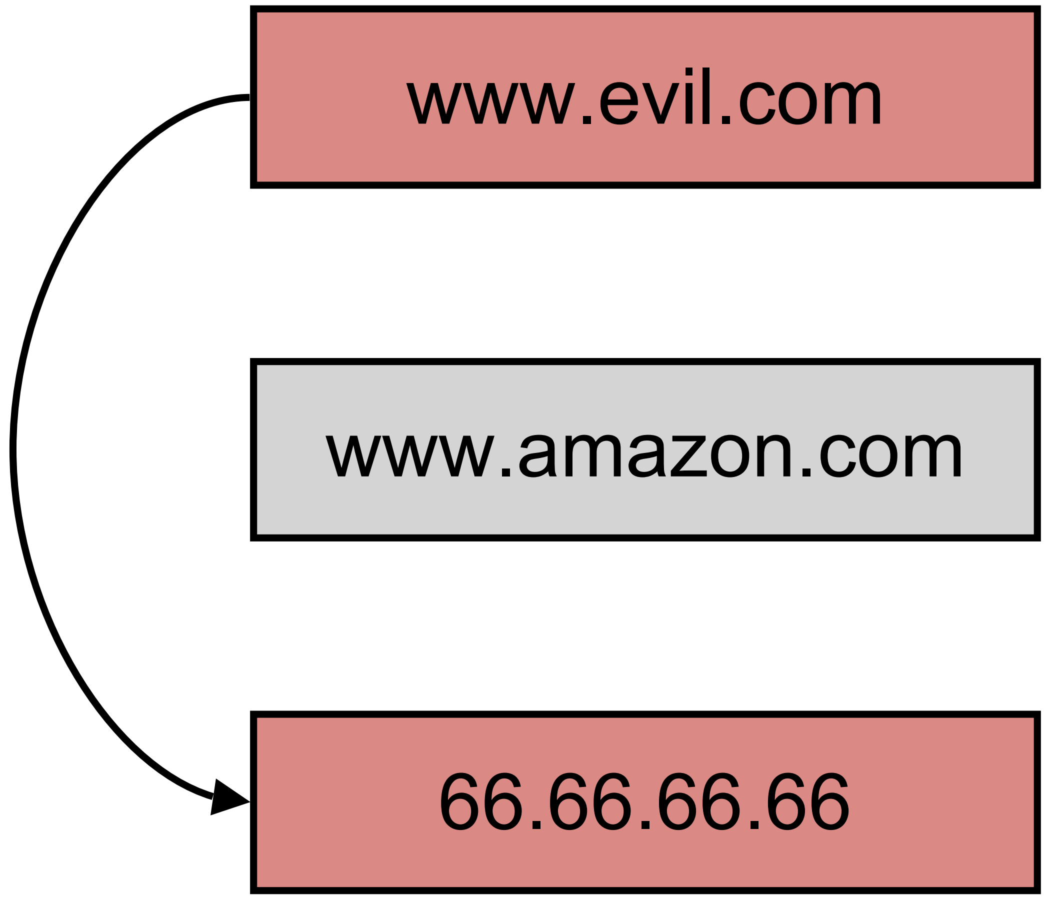
It gets worse

- **Glue records can overwrite standard A records**
- **Even if you have a good A record for** `www.amazon.com`**, it's overwritten**
- **E.g., Server wants name of my IP address**
  - Looks up `66.66.66.66.in-addr.arpa`
- **I say nameserver for** `66.66.66.66.in-addr.arpa` **is** `www.amazon.com`
  - Include glue A record for `www.amazon.com` in my reply

Solution 1

- **Only use glue records for duration of query**
  - Cache only end-to-end traversal of pointers, not intermediate steps
- **In CNAME example `www.evil.com` will point to evil server**
  - `www.amazon.com` will not point to evil server
- **In `in-addr.arpa` example, can lie about hostname**
  - But I can lie anyway
  - Have to check reverse lookup result by doing forward lookup

Example



Solution 2: bailiwick checking

- **Only pay attention to answers for the domain you've asked**
- **Response from `evil.com` can't tell you the A record for `google.com`**
- **Ask `google.com` for `www.google.com`**
- **Opponent can still race, but at least it's not deterministic**

Recent Kaminsky exploit

- Make winning the race easier
- Brute force attack
- Force Alice to look up `AAAA.google.com`, `AAAB.google.com`, etc.
- Forge CNAME responses for each lookup, inserting A record for `www.google.com`
- Circumvents bailiwick checking

Solution: signatures

- Signature: cryptographic way to prove a party is who they say they are (more later in quarter)
- Requires a chain of trust
- Whom do you trust to sign DNS?

DNS Overview

- Distributed system for mapping names to values (e.g., IP addresses)
- Read-dominated workload allows caching
- Name structure allows distribution, independent administration
- Caching means bad data can stay a long time
- Standard protocol does not authenticate response is from server: DNSSec does