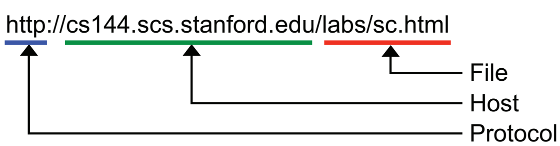
## Administrivia

- **Midterm exam Thursday**
  - 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

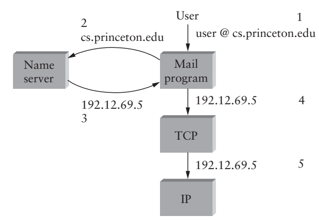
## Outline

- **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 (sometimes TCP)
- **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)

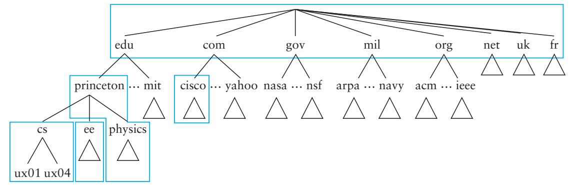
## Goals of DNS

- **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

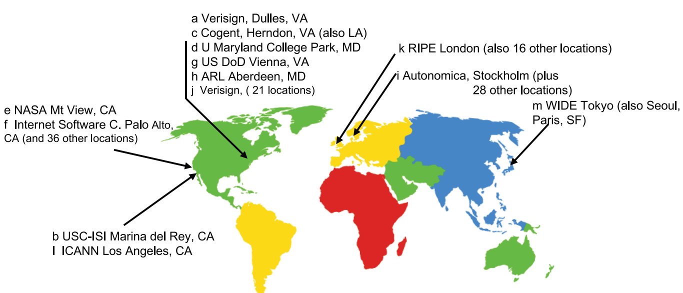
- **Properties that make DNS goals easier to achieve:**
  1. **Read-only or read-mostly database**
     - People typically look up hostnames much more often than they are updated
  2. **Loose consistency**
     - When adding a machine, may be okay if info takes minutes or hours to propagate
- **These 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)



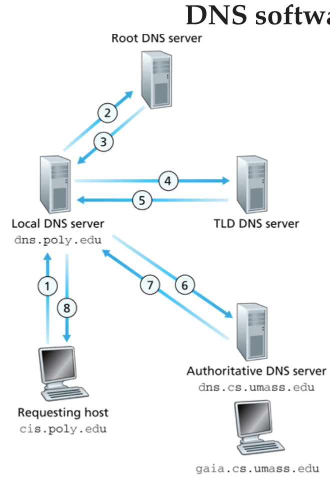

- **Break namespace into a bunch of zones**
  - `.` ("root"), `edu.`, `stanford.edu.`, `cs.stanford.edu.`, ...
  - Zones separately administered $\Longrightarrow$ delegation
  - Parent zones tell you how to find servers for dubdomains.
- **Each zone served from several replicated servers**

## 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.    1800 IN A   171.67.216.14
stanford.edu.    1800 IN A   171.67.216.16
stanford.edu.  172800 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.edu-servers.net
dig +norec www.scs.stanford.edu @argus.stanford.edu
dig +norec www.scs.stanford.edu @ns1.fs.net
```

- **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**
- **OPCODE - 0=standard query**
- **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 (zero-length) 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 unilaterally change SOA
  - To speed propagation, primary can also notify secondary of change, providing a hint to refresh sooner [RFC 1996]

## Other Records

- **Start of Authority (SOA) record**
  - States administrative information for a zone
  - `dig stanford.edu soa`
  - 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
  - `dig scs.stanford.edu mx`

## 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`
  - `sing.stanford.edu` → `171.67.76.65`
  - `65.76.67.171.in-addr.arpa` → `sing.stanford.edu`

## 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
  - Acronym now re-purposed [RFC 3172]: *Address and Routing Parameter Area*

## 2-minute stretch

## 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., `_sip` for SIP (VOIP) protocol
  - _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**

## TXT records

- **Can place arbitrary text in DNS**
  ***name* [TTL] [IN] TXT "*text*" . . .**
  - *text* – whatever you want it to mean
- **Great for prototyping new services**
  - Don't need to change DNS infrastructure
- **Example:** `dig gmail.com txt`
  - What's this? SPF = "sender policy framework" (previously known as "sender permitted from")
  - Much spam is forged email
  - SPF specifies IP addresses allowed to send mail from `@gmail.com`
  - Can have incremental deployment
  - Only mail servers must change, DNS can stay the same
  - Now SPF standardized (sort of), has RR type 99 [RFC 4408]

## Editorial

- **SPF is based on envelope sender address**
  - Nice because available earlier in SMTP protocol
  - So some users can reject forged mail while some accept
- **Microsoft proposed competing standard, *Sender ID* [RFC 4406]**
  - Instead of simple language, used XML monstrosity
  - Instead of envelope sender, extract address from message
- **No agreement between camps, couldn't standardize**
  - Compromise: kill XML, but use address in message
  - But Microsoft patented extracting address from message!

## SPF vs. Sender ID (continued)

- **Compromise 2: Have two competing standards**
  - After a few years, see which standard more widely used
- **Use different formats for SPF vs. Sender ID**
  - Start SPF records with string `"v=spf1 "`
  - Start Sender ID records with string `"spf2.0/pra "`
- **SPF had a head start—lots of sites had adopted it**
- **Dirty trick appeared in final draft of Sender ID**
  - If no `spf2.0/pra` record present, but see `v=spf1`, treat `v=spf1` as if it were a sender ID record
  - Causes sender ID machines to reject mail from SPF sites (E.g., if you use SPF and post to mailing list, some recipients will reject)
  - Thwarts idea of independent experiment

## 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:**

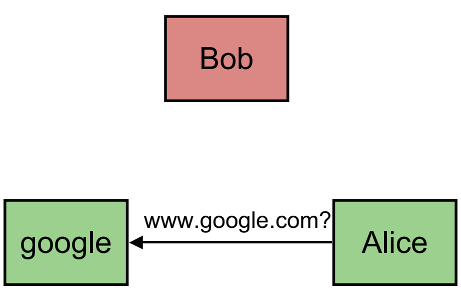
  Despite the best efforts of the security community, the details of a critical internet vulnerability discovered by Dan Kaminsky about six months ago have leaked.

- **One of the basic problems: DNS caching**
  - If you can poison the cache, the damage stays
  - Who knows how far it spreads. . .

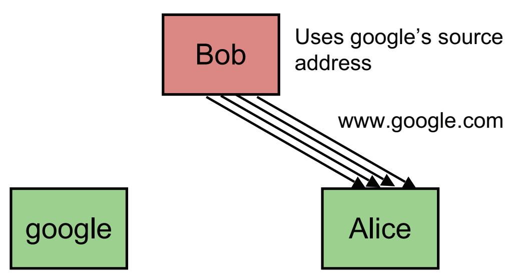
## DNS exploit example

- **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




## Exploit Example



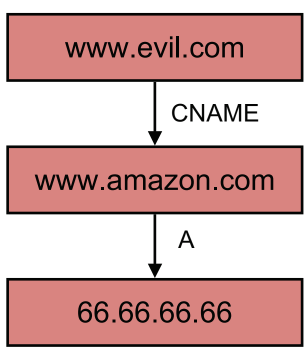
## Countermeasures

- **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.amazon.com`
  - Provides A record for `www.amazon.com`

## Exploit Example



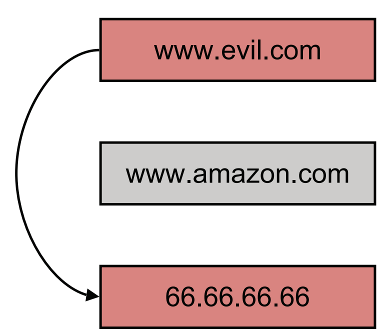

## It gets worse

- **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

## 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?
- DNSSEC extensions may finally be deployed soon [RFC 4033]

## 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