15-441/641: Computer Networks
Domain Name System

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https://computer-networks.github.io/sp19/

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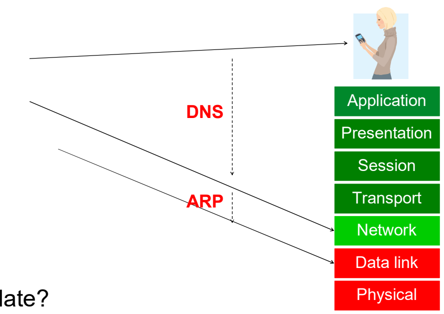
Too Much of a Good Thing?

- Hosts have a
  - host name
  - IP address
  - MAC address
- There is a reason ..
  - Remember?
- But how do we translate?



IP to MAC Address Translation

- How does one find the Ethernet address of a IP host?
- Address Resolution Protocol - ARP
  - Broadcast search for IP address
    - E.g., “who-has 128.2.184.45 tell 128.2.206.138” sent to Ethernet broadcast (all FF address)
  - Destination responds (only to requester using unicast) with appropriate 48-bit Ethernet address
    - E.g, “reply 128.2.184.45 is-at 0:d0:bc:f2:18:58” sent to 0:c0:4f:d:ed:c6

Caching ARP Entries

- Efficiency Concern
  - Would be very inefficient to use ARP request/reply every time need to send IP message to machine
- Each Host Maintains Cache of ARP Entries
  - Add entry to cache whenever you get ARP response
  - “Soft state”: set timeout of ~20 minutes

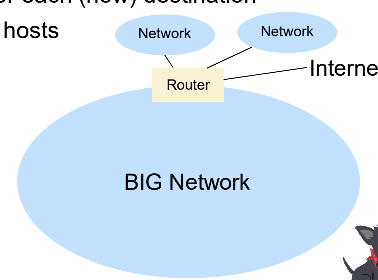
ARP Cache Example

- Show using command “arp -a”

```
Interface: 128.2.222.198 on Interface 0x1000003
  Internet Address      Physical Address      Type
128.2.20.218          00-b0-8e-83-df-50     dynamic
128.2.102.129         00-b0-8e-83-df-50     dynamic
128.2.194.66          00-02-b3-8a-35-bf     dynamic
128.2.198.34          00-06-5b-f3-5f-42     dynamic
128.2.203.3           00-90-27-3c-41-11     dynamic
128.2.203.61          08-00-20-a6-ba-2b     dynamic
128.2.205.192         00-60-08-1e-9b-fd     dynamic
128.2.206.125         00-d0-b7-c5-b3-f3     dynamic
128.2.206.139         00-a0-c9-98-2c-46     dynamic
128.2.222.180         08-00-20-a6-ba-c3     dynamic
128.2.242.182         08-00-20-a7-19-73     dynamic
128.2.254.36          00-b0-8e-83-df-50     dynamic
```

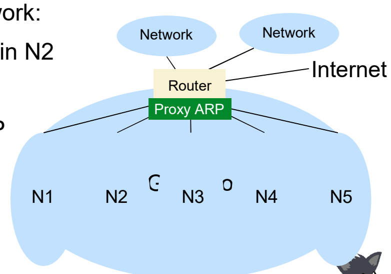

Challenge: Broadcast!

- Overhead scales (roughly) as N^2 for an N host network
  - N host does an ARP broadcast for each (new) destination
  - Each broadcast is delivered to N hosts
- Remember the solution?
- Subnetting!
  - Break up network into networks connected by router
- Not always a good idea
  - Extra complexity, management overhead, cost, …



Proxy ARP

- Limit the scope of ARP requests/responses inside an L2
- Proxy ARP makes it look like ne network:
  - Host1 in N1 sends ARP for host 2 in N2
  - Proxy ARP looks up MAC address
    - May require discovery using ARP
  - Responds to host 1’s request
    - Acts as proxy
  - Also forwards packets to host1
    - Acts as a switch



Host Names & Addresses

- Host addresses: *e.g., 169.229.131.109*
  - a number used by protocols
  - conforms to network structure (the “where”)
- Host names: *e.g., linux.andrew.cmu.edu*
  - mnemonic name usable by humans
  - conforms to organizational structure (the “who”)
- The Domain Name System (DNS) is how we map from one to the other
  - a directory service for hosts on the Internet

Why bother?

- Convenience
  - Easier to remember www.google.com than 74.125.239.49
- Provides a level of indirection!
  - Decoupled names from addresses
  - Many uses beyond just naming a specific host

DNS provides Indirection

- Addresses can change underneath
  - Move www.cnn.com to a new IP address
  - Humans/apps are unaffected
- Name could map to multiple IP addresses
  - Enables load-balancing
- Multiple names for the same address
  - E.g., many services (mail, www, ftp) on same machine
- Allowing "host" names to evolve into "service" names

DNS: Early days

- Mappings stored in a hosts.txt file (in /etc/hosts)
  - maintained by the Stanford Research Institute (SRI)
  - new versions periodically copied from SRI (via FTP)
- As the Internet grew this system broke down
  - SRI couldn't handle the load
  - conflicts in selecting names
  - hosts had inaccurate copies of hosts.txt
- The Domain Name System (DNS) was invented to fix this

Obvious Solutions (1)

Why not centralize DNS?

- Distant centralized database
  - Traffic volume
- Single point of failure
- Single point of update
- Single point of control
- Doesn't *scale!*

Goals?

- Scalable
  - many names
  - many updates
  - many users creating names
  - many users looking up names
- Highly available
- Correct
  - no naming conflicts (uniqueness)
  - consistency
- Lookups are fast

How?

- Partition the namespace – Hierarchy!
- Distribute administration of each partition
  - Autonomy to update my own (machines') names
    - Translation of cmu.edu names is done by CMU
  - Don't have to track everybody's updates
- Distribute name resolution for each partition

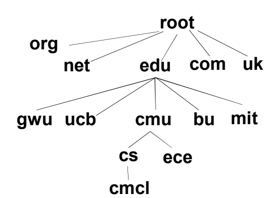
- *How should we partition things?*

Key idea: hierarchical distribution

Three intertwined hierarchies

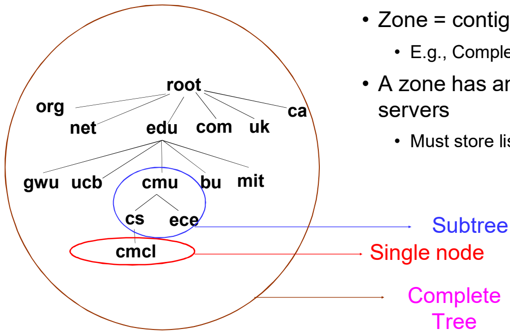
- Hierarchical namespace
  - As opposed to original flat namespace
- Hierarchically administered
  - As opposed to centralized administrator
- Hierarchy of servers
  - As opposed to centralized storage

DNS Design: Hierarchy Definitions



- Each node in hierarchy stores a list of names that end with same suffix
  - Suffix = path up tree
- E.g., given this tree, where would following be stored:
  - Fred.com
  - Fred.edu
  - Fred.cmu.edu
  - Fred.cmcl.cs.cmu.edu
  - Fred.cs.mit.edu

DNS Design: Zone Definitions



- Zone = contiguous section of name space
  - E.g., Complete tree, single node or subtree
- A zone has an associated set of name servers
  - Must store list of names and tree links

Server Hierarchy

- Top of hierarchy: Root servers
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, .uk, etc.
  - Managed professionally
- Bottom Level: Authoritative DNS servers
  - Actually store the name-to-address mapping
  - Maintained by the corresponding administrative authority

New TLDs started in 2012
… expect to see more
in the future.

Server Hierarchy

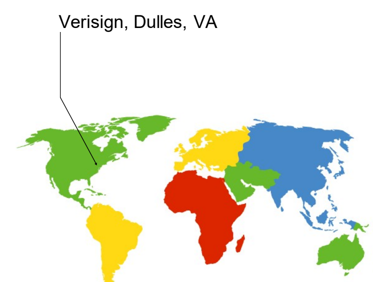
- Every server knows the address of the root name server
- Root servers know the address of all TLD servers
- …
- An authoritative DNS server stores name-to-address mappings ("resource records") for all DNS names in the domain that it has authority for

→ Each server stores a subset of the total DNS database

→ Each server can discover the server(s) responsible for any portion of the hierarchy

DNS Root

- Located in Virginia, USA



DNS Root Servers

- 13 root servers (labeled A-M; see http://www.root-servers.org/)

DNS Root Servers

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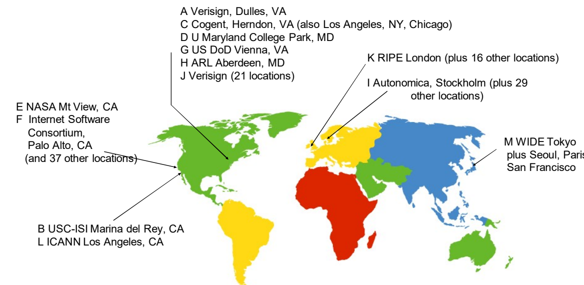
- Replicated via any-casting



Anycast in a nutshell

- Routing finds shortest paths to destination
- What happens if multiple machines advertise the same address?
- The network will deliver the packet to the closest machine with that address
- This is called “anycast”
  - Very robust
  - Requires no modification to routing algorithms

Programmer’s View of DNS

- Conceptually, programmers can view the DNS database as a collection of millions of *host entry structures*:

```
/* DNS host entry structure */
struct addrinfo {
  int    ai_family;     /* host address type (AF_INET) */
  size_t  ai_addrlen;    /* length of an address, in bytes */
  struct sockaddr *ai_addr;  /* address! */
  char   *ai_canonname;    /* official domain name of host */
  struct addrinfo *ai_next;  /* other entries for host */
};
```

- Functions for retrieving host entries from DNS:
  - `getaddrinfo`: query key is a DNS host name.
  - `getnameinfo`: query key is an IP address.

Properties of DNS Host Entries

- Different kinds of mappings are possible:
  - Simple case: 1-1 mapping between domain name and IP addr:
    - kittyhawk.cmcl.cs.cmu.edu maps to 128.2.194.242
  - Multiple domain names maps to the same IP address:
    - eecs.mit.edu and cs.mit.edu both map to 18.62.1.6
  - Single domain name maps to multiple IP addresses:
    - www.google.com maps to multiple IP addrs.
  - Some valid domain names don't map to any IP address:
    - for example: cmcl.cs.cmu.edu

DNS Records

RR format: **(class, name, value, type, ttl)**

- DB contains tuples called resource records (RRs)
  - Classes = Internet (IN), Chaosnet (CH), etc.
  - Each class defines value associated with type

FOR IN class:

- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is name of authoritative name server for this domain
- Type=CNAME
  - **name** is an alias name for some "canonical" (the real) name
  - **value** is canonical name
- Type=MX
  - **value** is hostname of mailserver associated with **name**

Inserting RRs into DNS

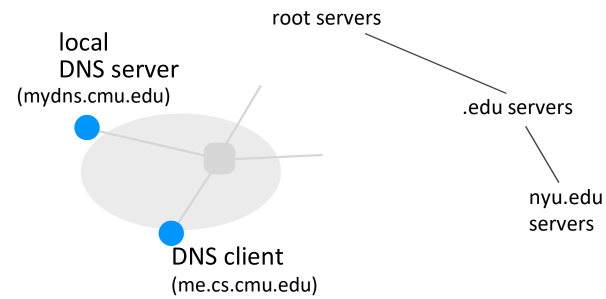
- Example: you just created company "FooBar"
- You get a block of IP addresses from your ISP
  - say 212.44.9.128/25
- Register foobar.com at registrar (e.g., NameCheap)
  - Provide registrar with names and IP addresses of your authoritative name server(s)
  - Registrar inserts RR pairs into the **.com** TLD server:
    - (**foobar.com**, **dns1.foobar.com**, **NS**)
    - (**dns1.foobar.com**, **212.44.9.129**, **A**)
- Store resource records in your server dns1.foobar.com
  - e.g., type A record for www.foobar.com
  - e.g., type MX record for foobar.com

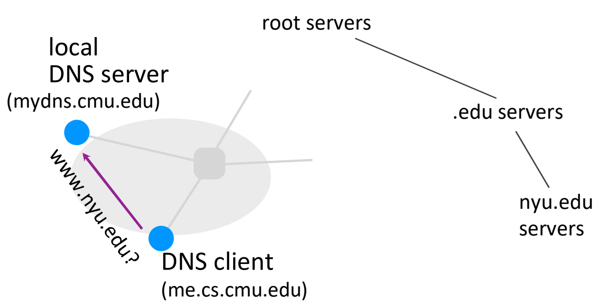
Using DNS (Client/App View)

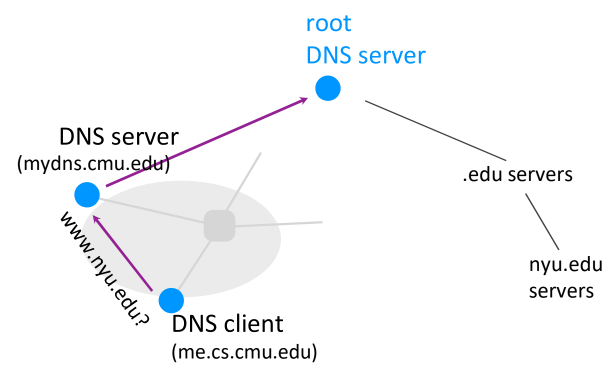
- Two components
  - Local DNS servers
  - Resolver software on hosts
- Each host has a resolver
  - Typically a library that applications can link to
- Client application
  - Obtain DNS name (e.g., from URL)
  - Triggers DNS request to its local DNS server

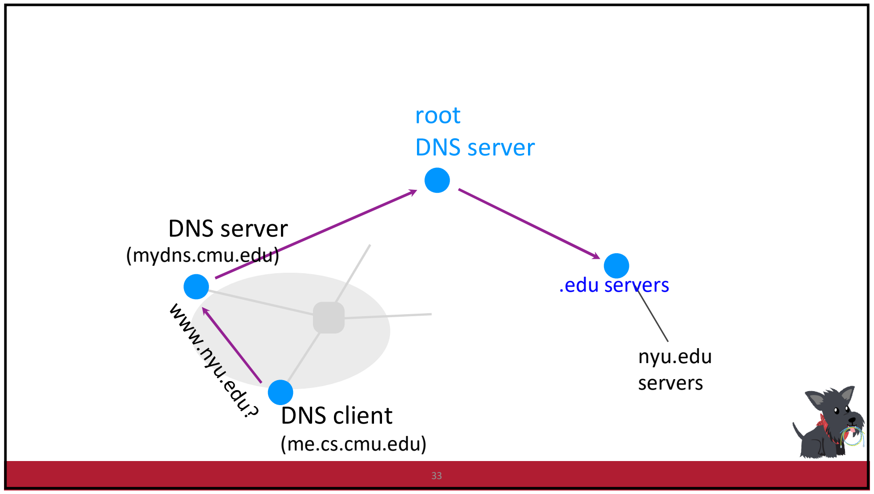
Servers/Resolvers

- Name servers: generally responsible for some zone
  - Answer queries about their zone
- Local DNS server ("default name server")
  - Answer queries about the local zone
  - Also do lookup of distant host names for local hosts
    - Can cache the response for other local hosts!
    - Clients configured with the default server's address or learn it via a host configuration protocol








root
DNS server
DNS server
(mydns.cmu.edu)
.edu servers
www.nyu.edu?
nyu.edu
servers
DNS client
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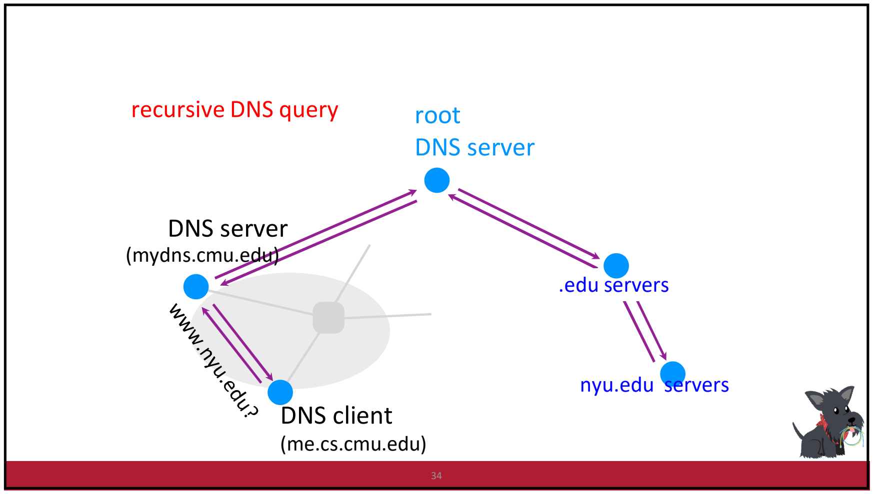
recursive DNS query
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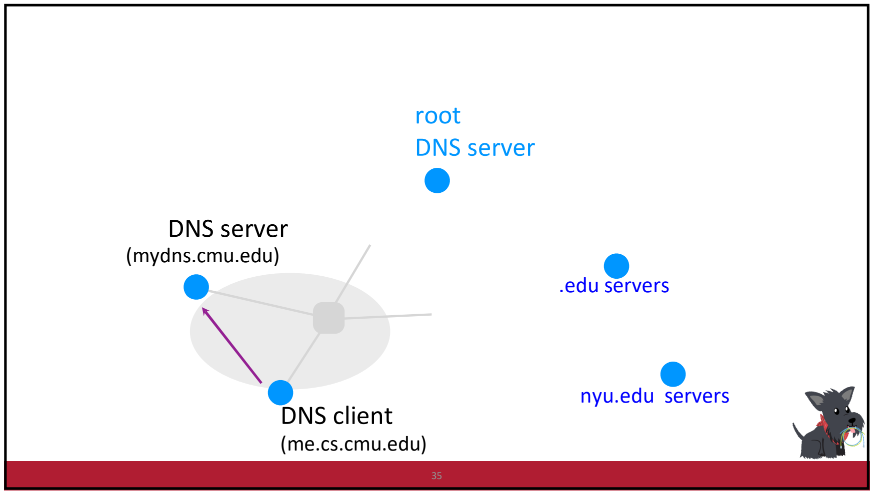
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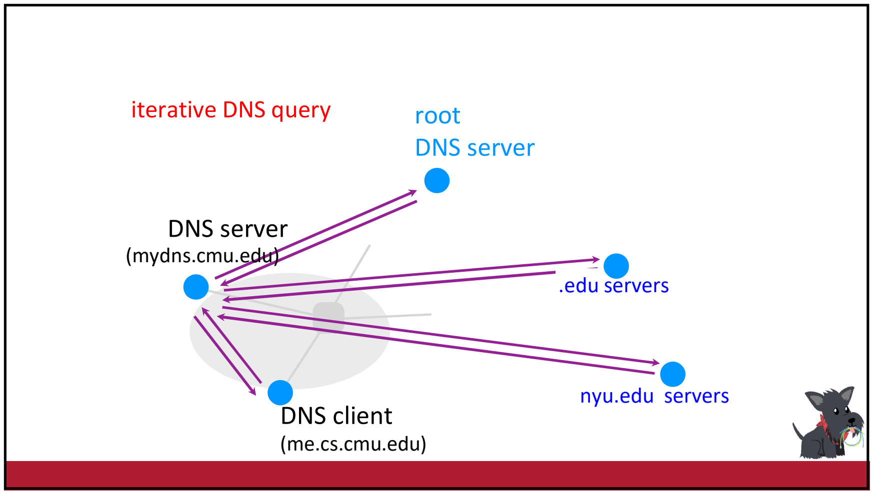
iterative DNS query
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Goals – how are we doing?

- Scalable
  - many names
  - many updates
  - many users creating names
  - many users looking up names
- Highly available

Per-domain availability

- DNS servers are replicated
  - Primary and secondary name servers required
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Try alternate servers on timeout
  - Exponential backoff when retrying same server

DNS Caching

- Caching of DNS responses at all levels
  - Reduces load at all levels
  - Reduces delay experienced by DNS client
- 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
- Why caching is effective
  - The top-level servers very rarely change
  - Popular sites visited often → local DNS server often has the information cached

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
- Negative caching is optional

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DNS Message Format

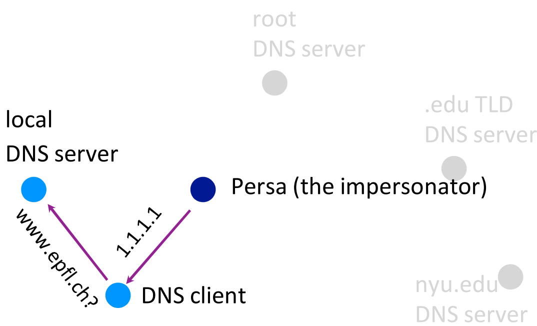
12 bytes	Identification	Flags
	No. of Questions	No. of Answer RRs
	No. of Authority RRs	No. of Additional RRs
Name, type fields for a query	Questions (variable number of answers)	
RRs in response to query	Answers (variable number of resource records)	
Records for authoritative servers	Authority (variable number of resource records)	
Additional "helpful info that may be used	Additional Info (variable number of resource records)	

DNS Header Fields

- Identification
  - Used to match up request/response
- Flags
  - 1-bit to mark query or response
  - 1-bit to mark authoritative or not
  - 1-bit to request recursive resolution
  - 1-bit to indicate support for recursive resolution

How can one attack DNS?

- Impersonate the local DNS server
  - give the wrong IP address to the DNS client



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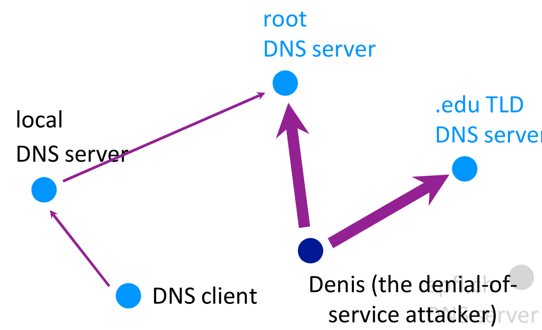
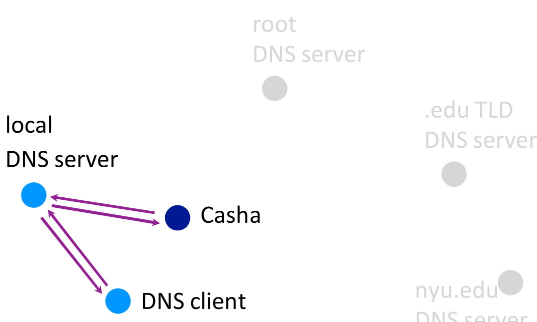


- Poison the cache of a DNS server
  - trick the server into caching the wrong IP address



How can one attack DNS?

- Impersonate the local DNS server
  - give the wrong IP address to the DNS client
- Denial-of-service the root or TLD servers
  - make them unavailable to the rest of the world
- Poison the cache of a DNS server
  - trick the server into caching the wrong IP address

Enter: DNSSEC

xtension to DNS to improve DNS security.

Enter DNSSEC

Extension to DNS to improve DNS security

- provides message authentication and integrity verification through cryptographic signatures
  - You know who provided the signature
  - No modifications between signing and validation
- It does not provide authorization
- It does not provide confidentiality
- It does not provide protection against DDOS

DNSSEC: Deployment Status

- 89% of top-level domains (TLDs) zones signed.
  - ~47% of country-code TLDs (ccTLDs) signed.
- Second-level domains (SLDs) vary widely:
  - Over 2.5 million .nl domains signed (~45%) (Netherlands). [1]
  - ~88% of measured zones in .gov are signed.
  - Over 50% of .cz (Czech Republic) domains signed.
  - ~24% of .br domains signed (Brazil). [2]
  - While only about 0.5% of zones in .com are signed, that percentage represents ~600,000 zones.

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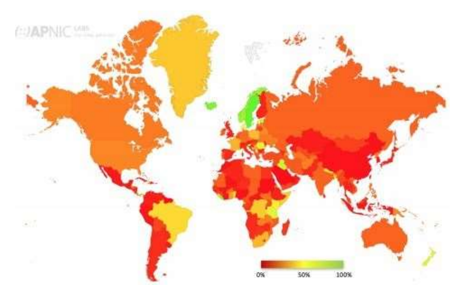

Important Properties of DNS

- Easy unique, human-readable naming
- Hierarchy helps with scalability
- Caching lends scalability, performance

- Not strongly consistent
- Trust model has some problems!