The Domain Name System

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? (?-2019)

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History of DNS

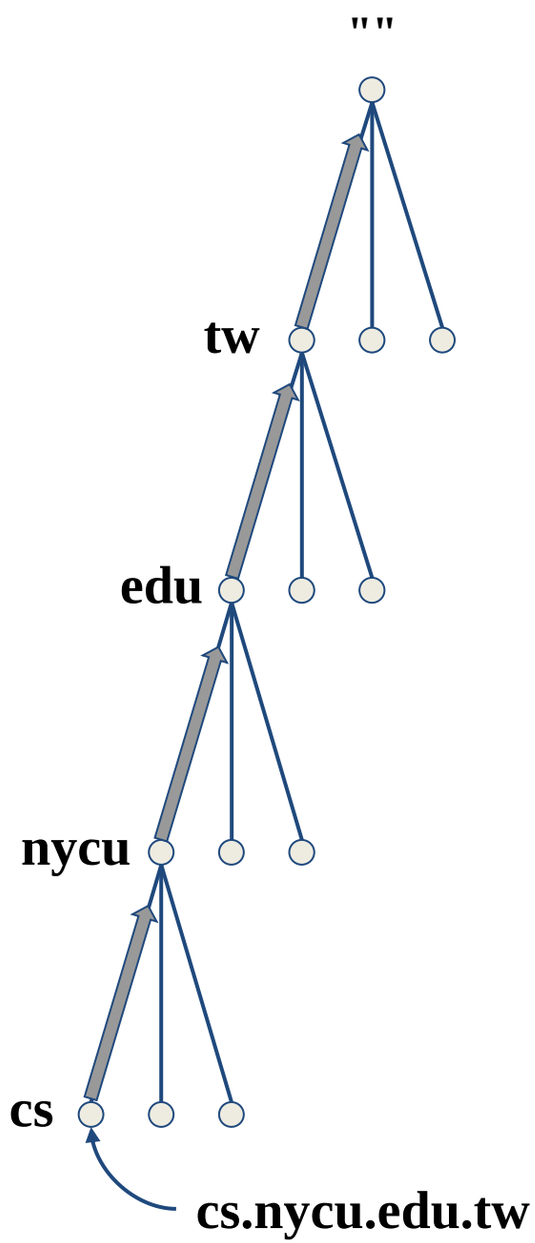
- What and Why is DNS?
  - IP is difficult to memorize, and IPv6 makes it worse
  - Domain Name ↔ IP Address(es)
- Before DNS
  - ARPANET
    - HOSTS.txt contains all the hosts' information (/etc/hosts)
    - Maintained by SRI's Network Information Center
      - Register → Distribute DB
  - Problems: Not scalable!
    - Traffic and Load
    - Name Collision
    - Consistency
- Domain Name System
  - Administration decentralization
  - Paul Mockapetris (University of Southern California)
    - RFC 882, 883 (1983) → 1034, 1035 (1987)

DNS Specification

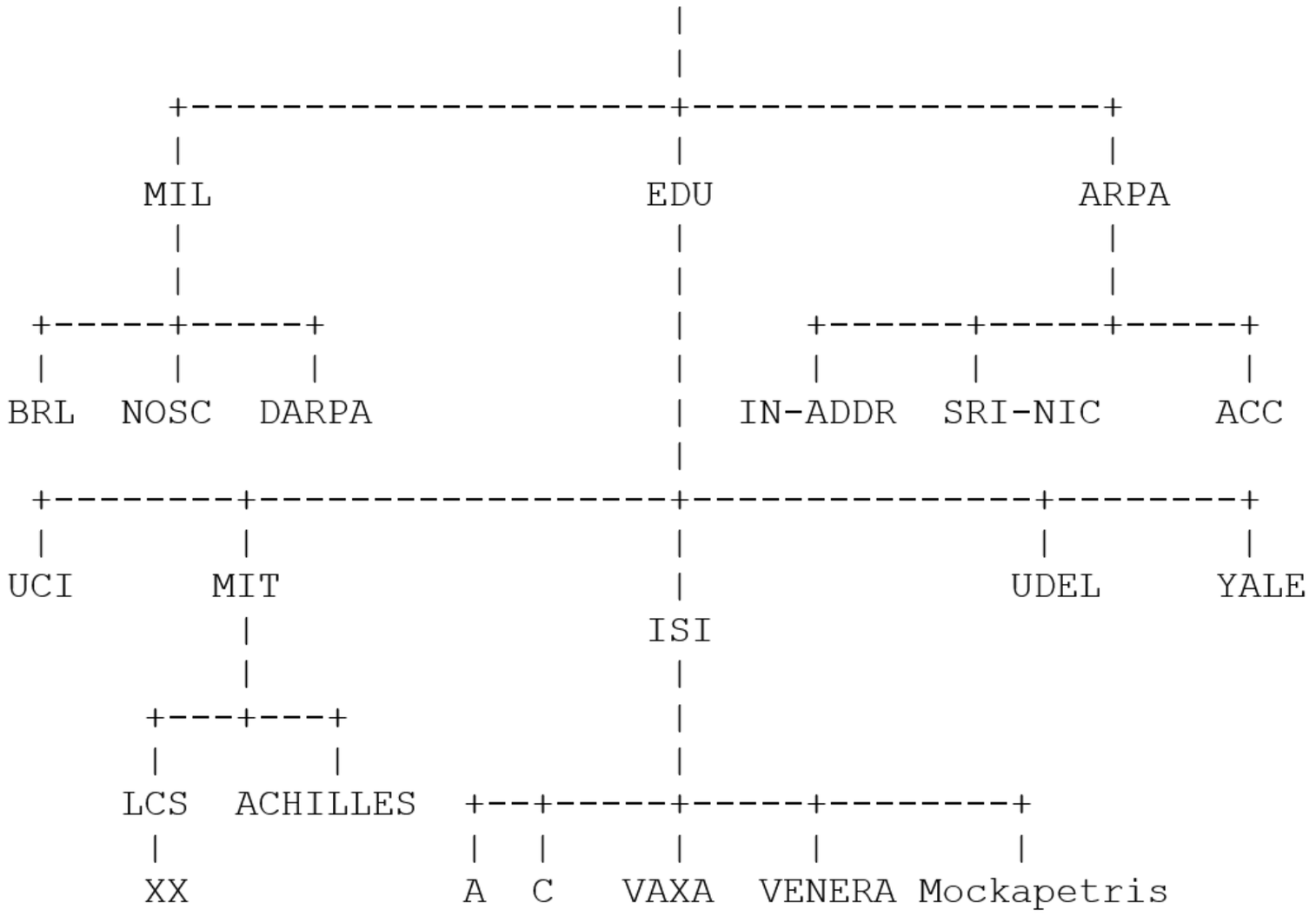
- Tree architecture – "**domain**" and "**subdomain**"
  - Divided into categories
  - Solves name collision
- Distributed database
  - Each site maintains a segment of the DB
  - Each site opens its information via network
- Client-Server architecture
  - Name servers provide information (Name Server)
  - Clients make queries to server (Resolver)

The DNS Namespace – (1)

- Domain name is
  - A inverted tree (Rooted tree)
    - Root with label '.'
    - Root with label '' (Null)
- Domain and subdomain
  - Each domain has a "domain name" to identify its position in database
    - domain: nycu.edu.tw
    - subdomain: cs.nycu.edu.tw



The DNS Namespace – (2)



https://tools.ietf.org/html/rfc1034#section-3.4

The DNS Namespace – (3)

- Domain level
  - Top-level / First level
    - Direct child of “root”
    - Maintained by ICANN (Internet Corporation for Assigned Names and Numbers)
  - Second-level
    - Child of a Top-level domain
- Domain name limitations (RFC1035: 2.3.4 “Size limits”)
  - Up to 63-octets in each label
  - Up to 255-octets in a full domain name
    - 253 visible characters and 2 length bytes
  - What is the real maximum length of a DNS name?
    - https://devblogs.microsoft.com/oldnewthing/20120412-00/?p=7873

The DNS Namespace – (4)

- gTLDs (generic Top-Level Domains)
- com: commercial organization, such as ibm.com
- edu: educational organization, such as purdue.edu
- gov: government organization, such as nasa.gov
- mil: military organization, such as navy.mil
- net: network infrastructure providing organization, such as hinet.net
- org: noncommercial organization, such as x.org
- int: International organization, such as nato.int

The DNS Namespace – (5)

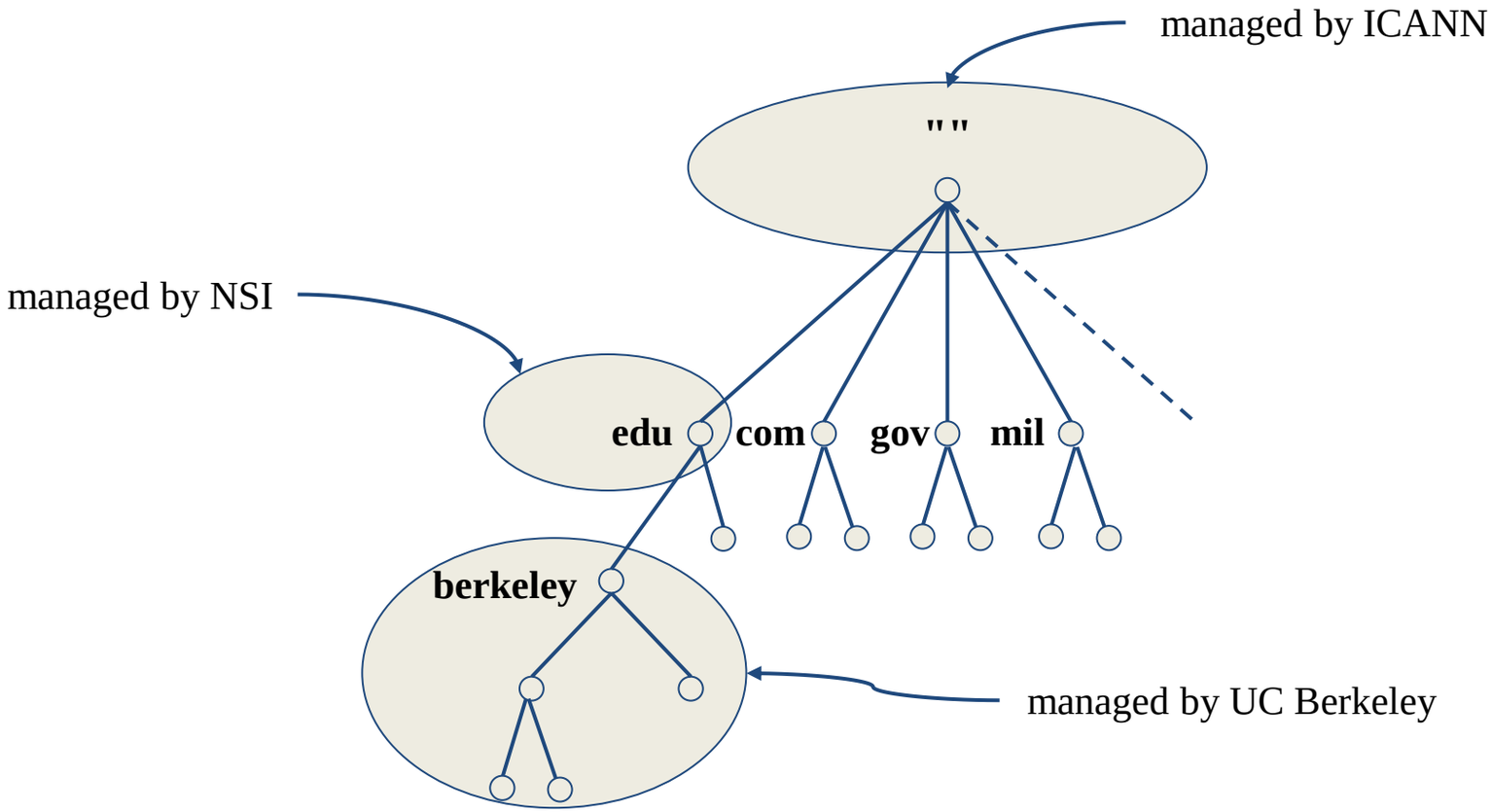
- New gTLDs launched in year 2000:
  - aero: for air-transport industry
  - biz: for business
  - coop: for cooperatives
  - info: for all uses
  - museum: for museum
  - name: for individuals
  - pro: for professionals
  - xxx: for adult entertainment industry (sTLD, s stands for sponsored)
    - On March 18st , 2011
- https://www.iana.org/domains/root/db

The DNS Namespace – (6)

- Other than US, ccTLD (country code TLD)
  - ISO 3166, but just based on
    - Taiwan => tw
    - Japan => jp
    - United States => us
    - United Kingdom => uk (ISO3166 is GB)
    - European Union => eu
  - Follow or not follow US-like scheme
    - US-like scheme example
      - edu.tw, com.tw, gov.tw
    - Other scheme
      - ac.jp, co.jp

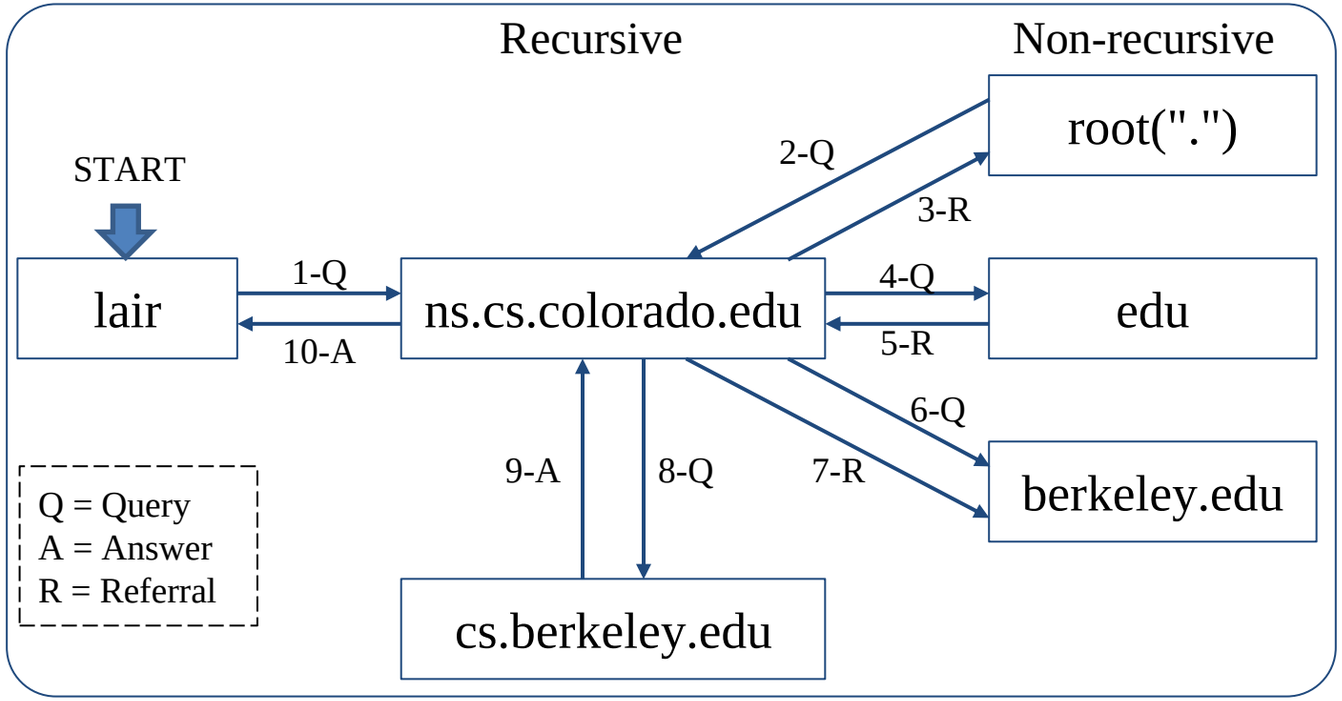
How DNS Works – DNS Delegation

- Administration delegation
  - Each domain can delegate responsibility to subdomain
    - Specify name servers of subdomain



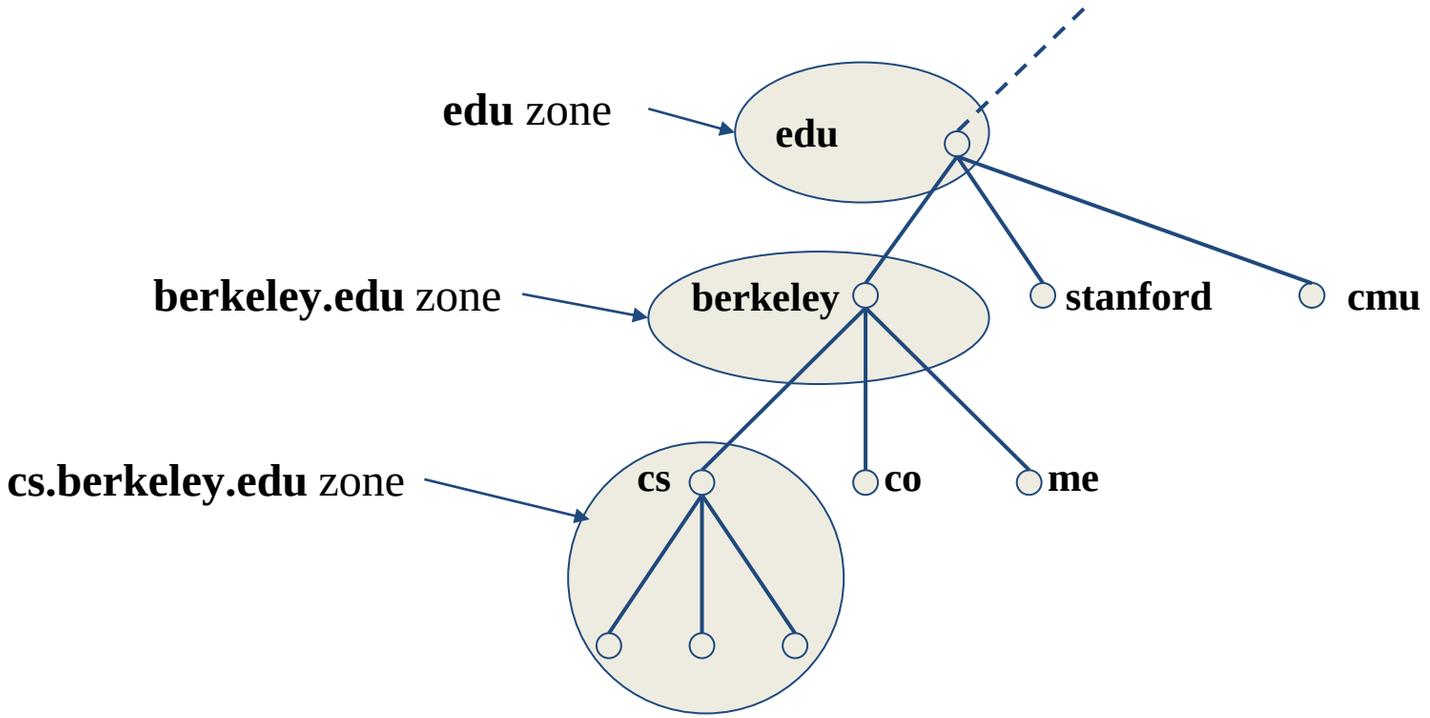
How DNS Works – DNS query process

- Recursive query process
  - Ex: query lair.cs.colorado.edu => vangogh.cs.berkeley.edu, name server "ns.cs.colorado.edu" has no cache data



DNS Delegation – Administered Zone

- Zone
  - Autonomously administered piece of namespace
    - Once the subdomain becomes a zone, it is independent to its parent
      - Even parent contains NS's A record



DNS Delegation – Administered Zone

- Two kinds of zone files
  - Forward Zone files
    - Hostname-to-Address mapping
    - Ex:
      - bsd1.cs.nctu.edu.tw. IN A 140.113.235.131
  - Reverse Zone files
    - Address-to-Hostname mapping
    - Ex:
      - 131.235.113.140.in-addr.arpa. IN PTR bsd1.cs.nctu.edu.tw.

The Name Server Taxonomy (1)

- Categories of name servers
  - Based on the source of name server's data
    - Authoritative: official representative of a zone (master/slave)
      - Master: get zone data from disk
      - Slave: copy zone data from master
    - Nonauthoritative: answer a query from cache
      - caching: caches data from previous queries
  - Based on the type of answers handed out
    - Recursive: do query for you until it return an answer or error
    - Nonrecursive: refer you to the authoritative server
  - Based on the query path
    - Forwarder: performs queries on behalf of many clients with large cache
    - Caching: performs queries as a recursive name server

The Name Server Taxonomy (2)

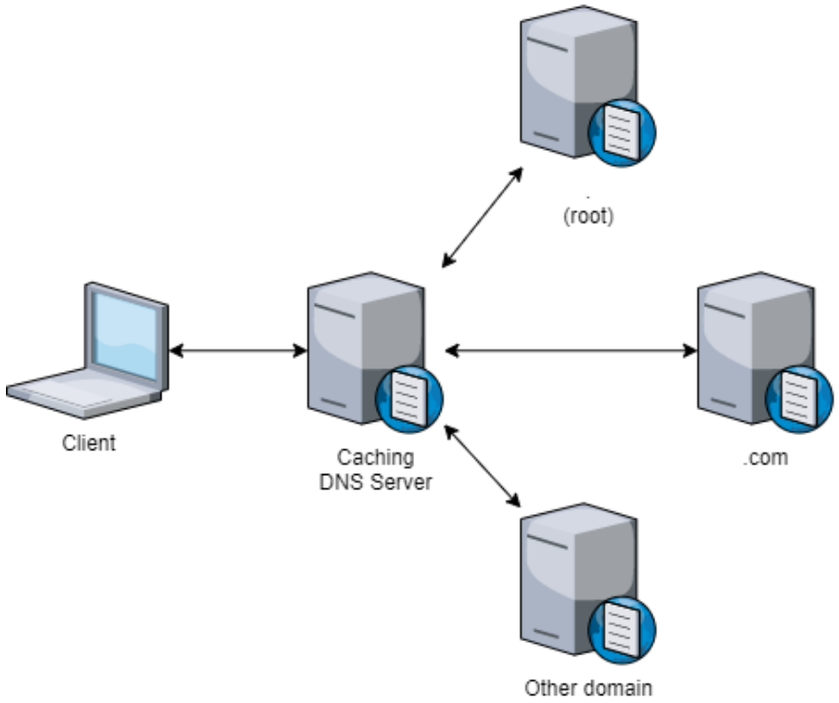
- Non-recursive referral
  - Hierarchical and longest known domain referral with cache data of other zone's name servers' addresses
  - Ex:
    - Query lair.cs.colorado.edu from a nonrecursive server
    - Whether cache has
      - IP of lair.cs.colorado.edu
      - Name servers of cs.colorado.edu
      - Name servers of colorado.edu
      - Name servers of edu
      - Name servers of root ("")
  - The resolver libraries do not understand referrals mostly. They expect the local name server to be recursive

The Name Server Taxonomy (3)

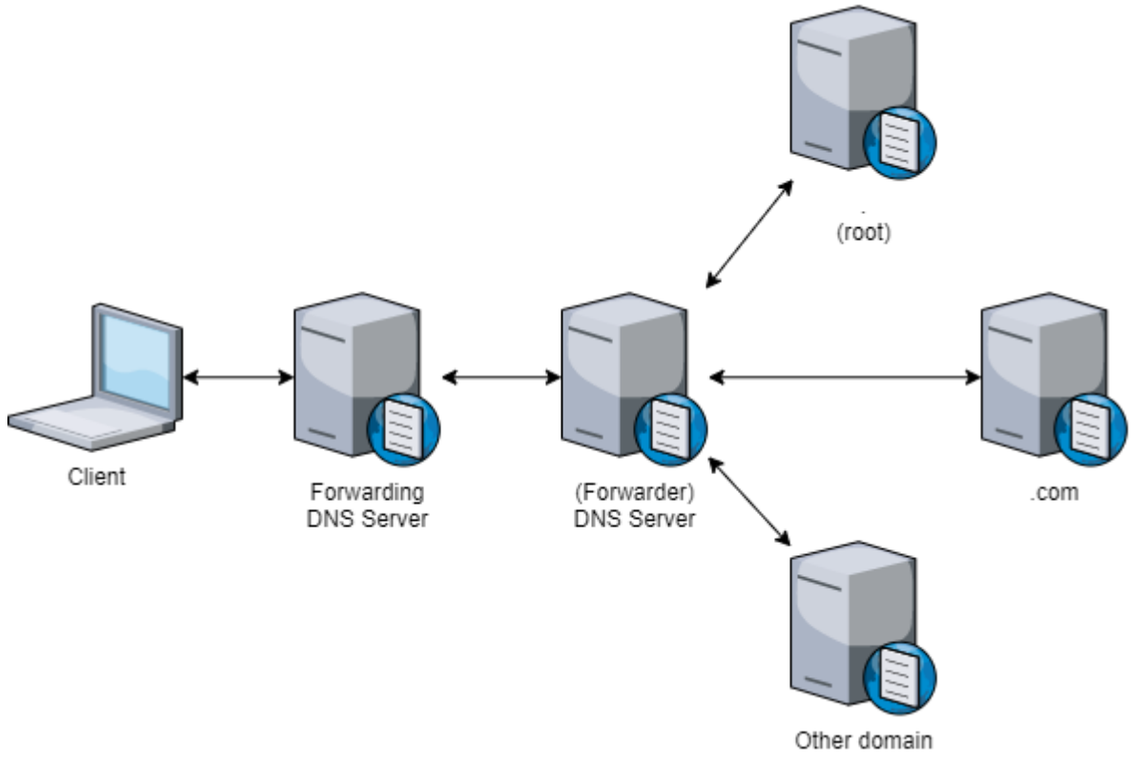
- Caching
  - Positive cache (Long TTL)
  - Negative cache (Short TTL)
    - No host or domain matches the name queried
    - The type of data requested does not exist for this host
    - The server to ask is not responding
    - The server is unreachable of network problem
- Negative cache
  - 60% DNS queries are failed
  - To reduce the load of root servers, the authoritative negative answers must be cached

The Name Server Taxonomy (4)

- Caching and forwarding DNS servers



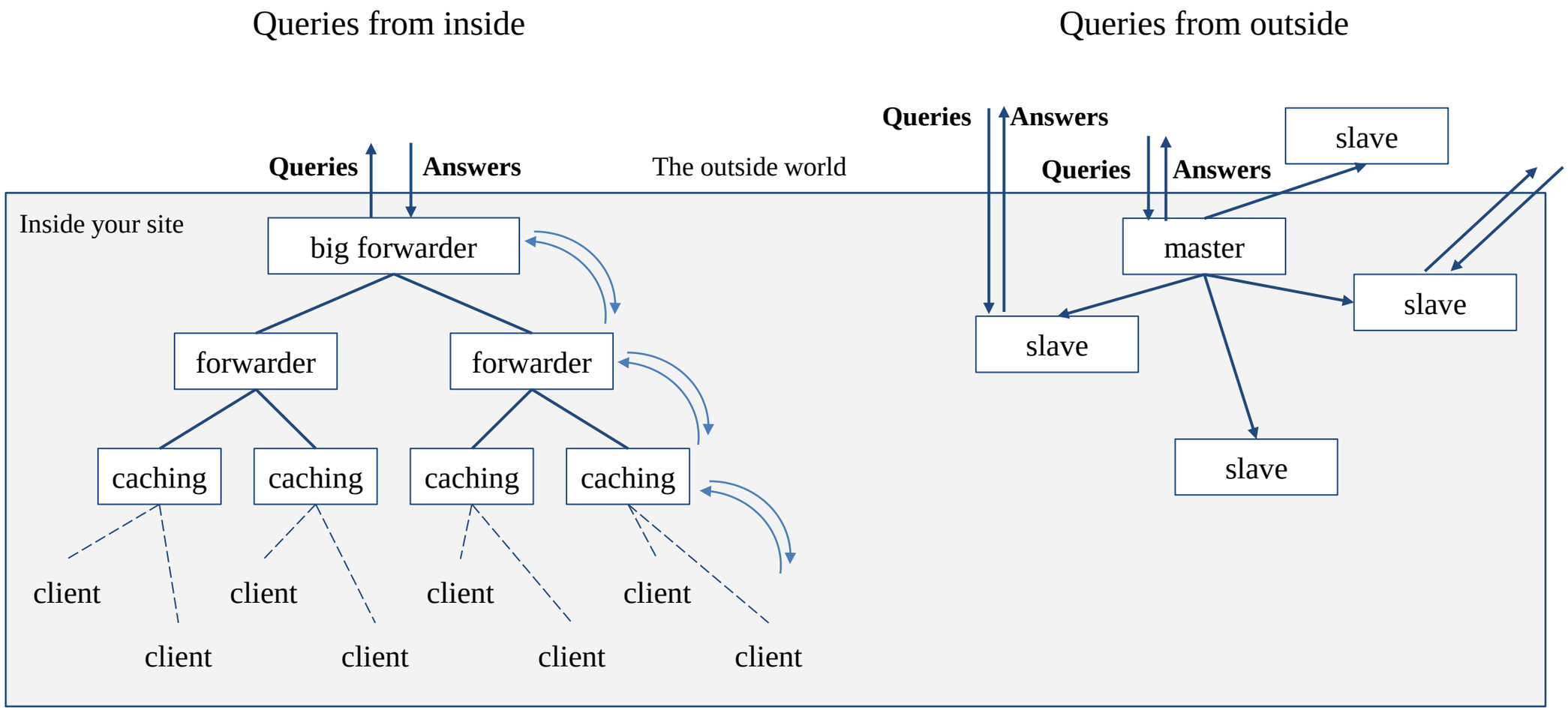
Caching



Forwarding

The Name Server Taxonomy (5)

- How to arrange your DNS servers?
  - Ex:



The Name Server Taxonomy (6)

- Root name servers
  - In named.root file of BIND
  - https://www.iana.org/domains/root/files

```
.                       3600000  IN  NS    A.ROOT-SERVERS.NET.
A.ROOT-SERVERS.NET.     3600000      A     198.41.0.4
A.ROOT-SERVERS.NET.     3600000      AAAA  2001:503:ba3e::2:30
.                       3600000      NS    B.ROOT-SERVERS.NET.
B.ROOT-SERVERS.NET.     3600000      A     199.9.14.201
B.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:200::b
.                       3600000      NS    C.ROOT-SERVERS.NET.
C.ROOT-SERVERS.NET.     3600000      A     192.33.4.12
C.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:2::c
.                       3600000      NS    D.ROOT-SERVERS.NET.
D.ROOT-SERVERS.NET.     3600000      A     199.7.91.13
D.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:2d::d
.                       3600000      NS    E.ROOT-SERVERS.NET.
E.ROOT-SERVERS.NET.     3600000      A     192.203.230.10
E.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:a8::e
.                       3600000      NS    F.ROOT-SERVERS.NET.
F.ROOT-SERVERS.NET.     3600000      A     192.5.5.241
F.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:2f::f
.                       3600000      NS    G.ROOT-SERVERS.NET.
G.ROOT-SERVERS.NET.     3600000      A     192.112.36.4
G.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:12::d0d
.                       3600000      NS    H.ROOT-SERVERS.NET.
H.ROOT-SERVERS.NET.     3600000      A     198.97.190.53
H.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:1::53
```

DNS Client Configurations

- /etc/resolv.conf
  - nameserver
  - domain
  - search
  - resolver(5), resolverconf(8)
- /etc/hosts
  - Format: **`IP FQDN Aliases`**
  - **`C:\Windows\system32\drivers\etc\hosts`**
  - hosts(5)
- /etc/nsswitch.conf
  - **`hosts: files (nis) (ldap) dns`**
  - nsswitch.conf(5)

DNS Client Commands – host

- **`$ host nasa.cs.nctu.edu.tw`**
  `nasa.cs.nctu.edu.tw has address 140.113.17.32`

- **`$ host 140.113.17.32`**
  `32.17.113.140.in-addr.arpa domain name`
  `pointer nasa.cs.nctu.edu.tw.`

DNS Client Commands – nslookup

- **$ nslookup nasa.cs.nctu.edu.tw**

```
Server:         140.113.235.1
Address:        140.113.235.1#53
Name:   nasa.cs.nctu.edu.tw
Address: 140.113.17.32
```

- **$ nslookup 140.113.17.225**

```
Server:         140.113.235.1
Address:        140.113.235.1#53
32.17.113.140.in-addr.arpa      name =
nasa.cs.nctu.edu.tw.
```

DNS Client Commands – dig (1)

- **$ dig nasa.cs.nctu.edu.tw**

```
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 47883
;; flags: qr aa rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;nasa.cs.nctu.edu.tw.            IN      A

;; ANSWER SECTION:
nasa.cs.nctu.edu.tw.    3600    IN      A       140.113.17.32


……
```

DNS Client Commands – dig (2)

- **$ dig -x 140.113.17.32**

```
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 5514
;; flags: qr aa rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;32.17.113.140.in-addr.arpa.    IN      PTR

;; ANSWER SECTION:
32.17.113.140.in-addr.arpa. 86400 IN    PTR     nasa.cs.nctu.edu.tw.

……
```

DNS Client Commands – drill

- **Drop-in replacement of dig in unbound**
- **$ drill -D www.cs.nctu.edu.tw**

```
;; ->>HEADER<<- opcode: QUERY, rcode: NOERROR, id: 36215
;; flags: qr rd ra ad ; QUERY: 1, ANSWER: 2, AUTHORITY: 0, ADDITIONAL: 0
;; QUESTION SECTION:
;; www.cs.nctu.edu.tw.  IN      A

;; ANSWER SECTION:
www.cs.nctu.edu.tw.     60      IN      A       140.113.235.48
www.cs.nctu.edu.tw.     60      IN      RRSIG   A 7 5 60 20220403192028
20220304183459 36008 cs.nctu.edu.tw.
vX731iLKKL5rhUhF2hre21laNy/6bQxst2k75o218h59j8xJ3kM9UqNm385tyTe2Rb223ScsR
SAOws4EMCs/CyVzFTfXe28wrA4jxVUCENpUByq7AInr3hrtUFdFdLRPwA16Vkzj950Yf+DtkC
rZzORGf12FxU48wsmYTAJswnM=

.....
```

DNS Security

- DNSSEC
  - Provide
    - Origin authentication of DNS data
    - Data integrity
    - Authenticated denial of existence
  - Not provide
    - Confidentiality
    - Availability
  - **$ dig +dnssec bsd1.cs.nctu.edu.tw**

```
;; ANSWER SECTION:
bsd1.cs.nctu.edu.tw.    3600    IN      A       140.113.235.131
bsd1.cs.nctu.edu.tw.    3600    IN      RRSIG   A 7 5 3600 …
```

RRSIG: Resource Record Signature

DNS Security (c.)

- DNS over TLS (DoT)
- DNS over HTTPS (DoH)
- DNS Amplification Attack
  - http://www.cc.ntu.edu.tw/chinese/epaper/0028/20140320_2808.html

DNS Server Software

- BIND https://www.isc.org/bind/
  - Complete DNS Server solution
- NSD https://www.nlnetlabs.nl/projects/nsd/about/
  - Authoritative DNS Server
    - No recursion, No caching
    - DNSSEC
- Unbound https://www.nlnetlabs.nl/projects/unbound/about/
  - Local resolver
    - Validating, Recursive, Caching
    - DoH, DoT
- https://en.wikipedia.org/wiki/Comparison_of_DNS_server_software

Misc.

- Internationalized Domain Name (IDN)
  - Punycode
    - A representation of Unicode with ASCII
    - .台灣 <-> .xn--kpry57d
    - https://en.wikipedia.org/wiki/Punycode
- Public & cloud services
  - Hurricane Electric Free DNS Hosting
    - https://dns.he.net/
  - AWS Route53
    - https://aws.amazon.com/route53/
- GeoDNS
  - Different DNS answers based on client's geographical location

Misc. (c.)

- DNS for fun
  - https://www.dns.toys/
- DNS Key Value Storage
  - https://dnskv.com/
- Tunnel
  - net/iodine
- Config
- FOSDEM 2023: Bizarre and Unusual Uses of DNS
  - Rule 53: If you can think of it, someone's done it in the DNS
  - https://fosdem.org/2023/schedule/event/dns_bizarre_and_unusual_uses_of_dns/