DNS

The not so basic basics of DNS…

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ANUIES
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Once upon a time…

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Names and Numbers

- Devices are identified over the Internet using IP addresses.
  - IPv4: 192.0.2.7
  - IPv6: 2001:db8::7
- Whie IP addresses are easy for machines to use, people prefer to use names.
- In the early days of the Internet, names were simple
  - No domain names yet
  - “Single-label names”, 24 characters maximum
  - Referred to as ***host names***

Name Resolution

- Mapping names to IP addresses (and IP addresses to names) is ***name resolution***
- Name resolution on the early Internet used a plain text ***file*** named HOSTS.TXT
  - Same function but slightly different format than the former */etc/hosts*
  - Centrally maintained by the NIC (Network Information Center) at the Stanford Research Institute (SRI)
  - Network administrators sent updates via email
- Ideally everyone had the latest version of the file
  - Released once per week
  - Downloadable via FTP

Problems with HOSTS.TXT

- Naming contention
  - Edits made by hand to a text file (no database)
  - No good method to prevent duplicates
- Synchronization
  - No one ever had the same version of the file
- Traffic and load
  - Significant bandwidth required then just to download the file
- **A centrally maintained host file just didn't scale**

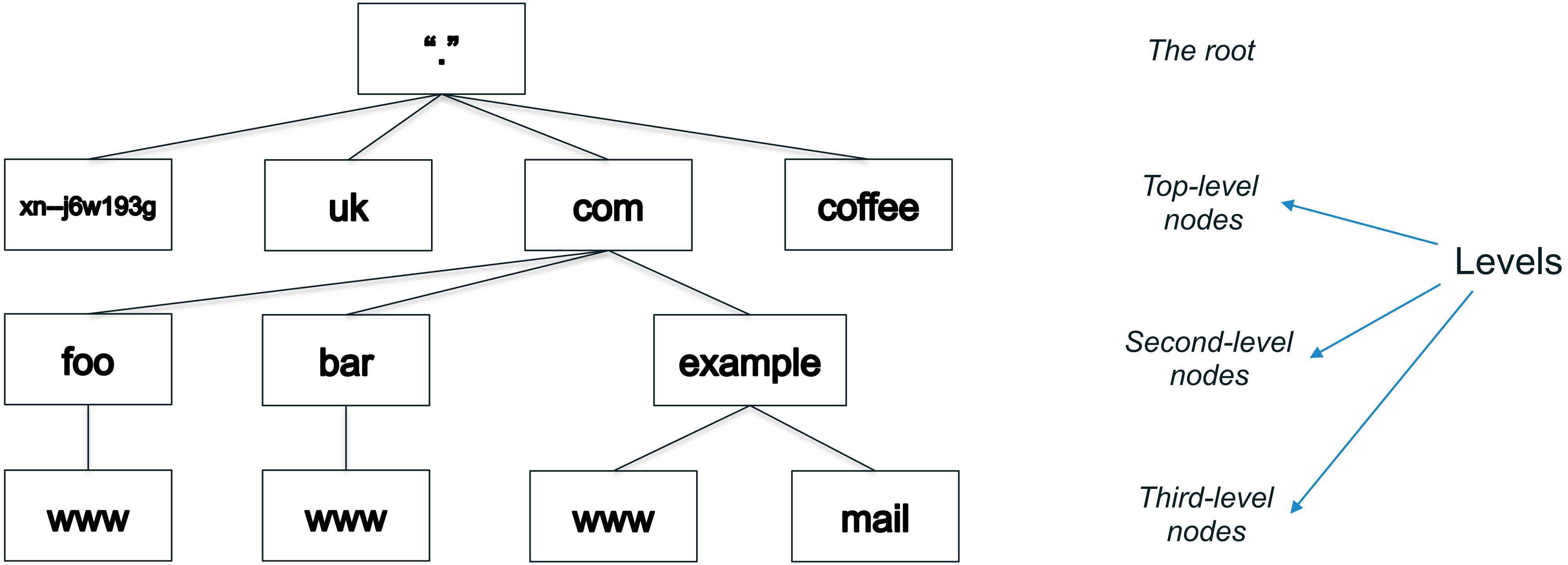
DNS to the Rescue

- Discussion started in the early 1980s on a replacement
- Goals:
  - Address HOST.TXT scaling issues
  - Simplify email routing
- Result was the ***Domain Name System***
- Requirements in multiple documents:
  - RFC 799, “Internet Name Domains”
  - RFC 819, “The Domain Naming Convention for Internet User Applications”

Rise of the DNS !

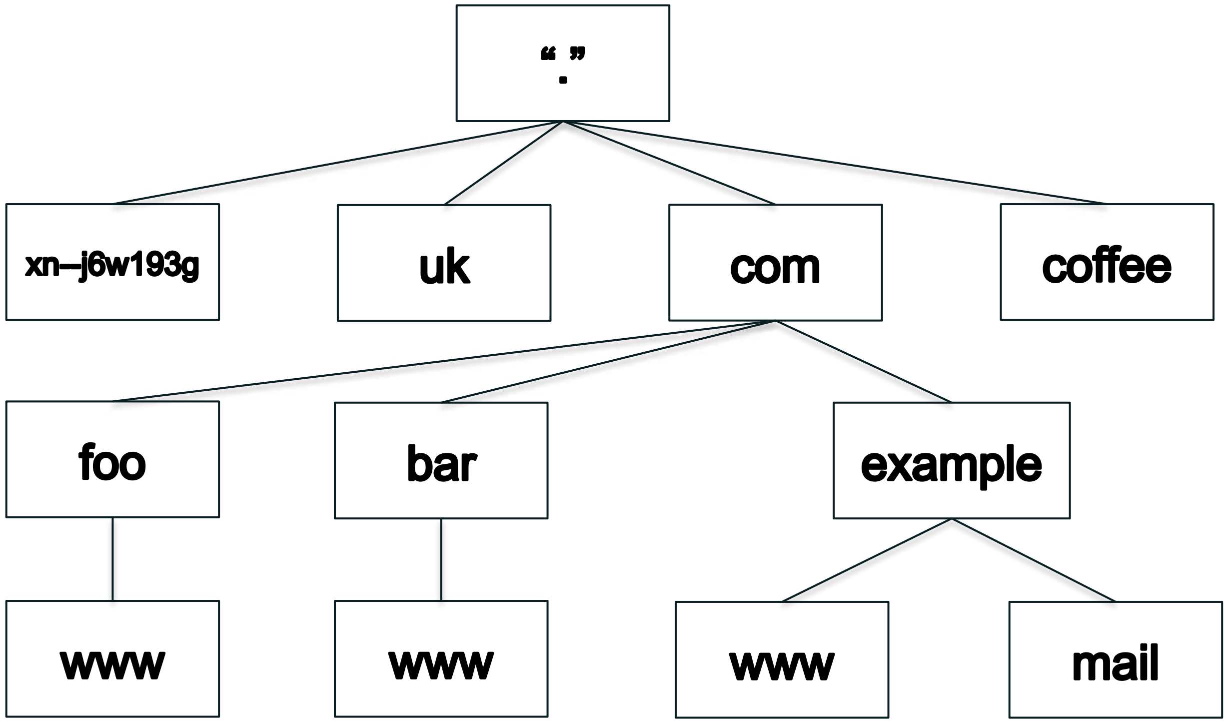
The Name Space

- DNS database structure is an inverted tree called the ***name space***
- Each node has a label
- The root node (and only the root node) has a null label



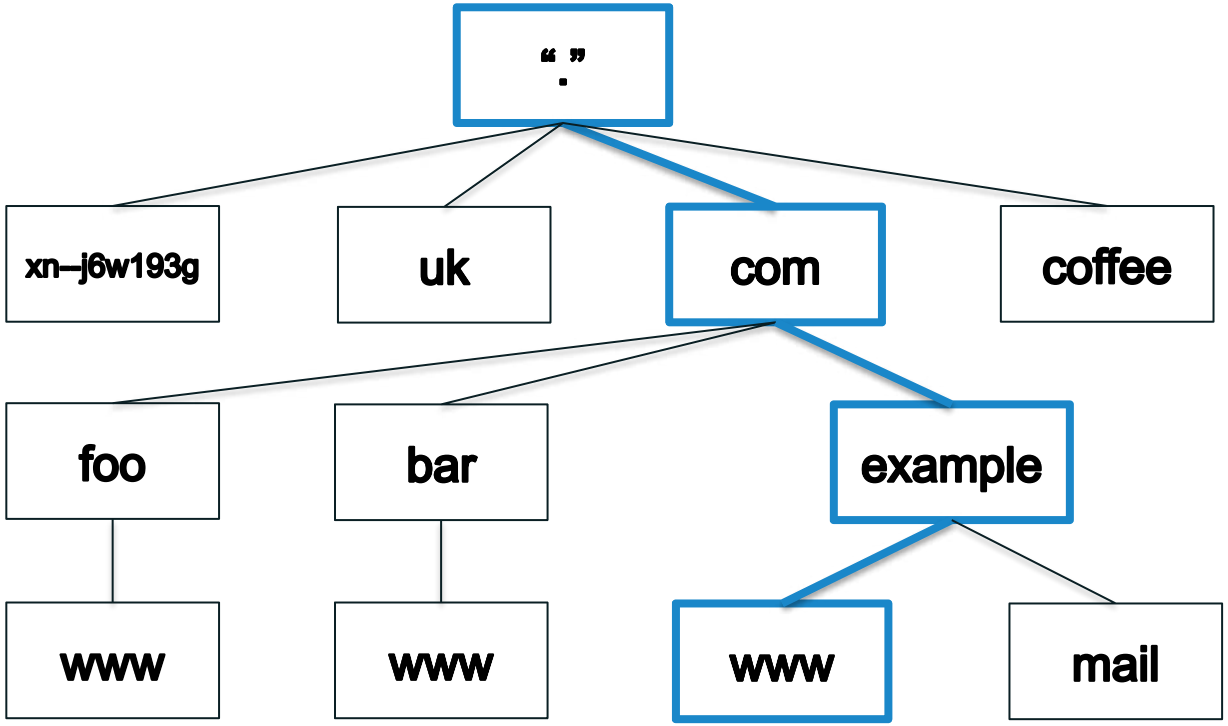
Label Syntax

- Legal characters for labels are "LDH" (letters, digits, hyphen)
- Maximum length 63 characters
- Comparisons of label names are not case sensitive



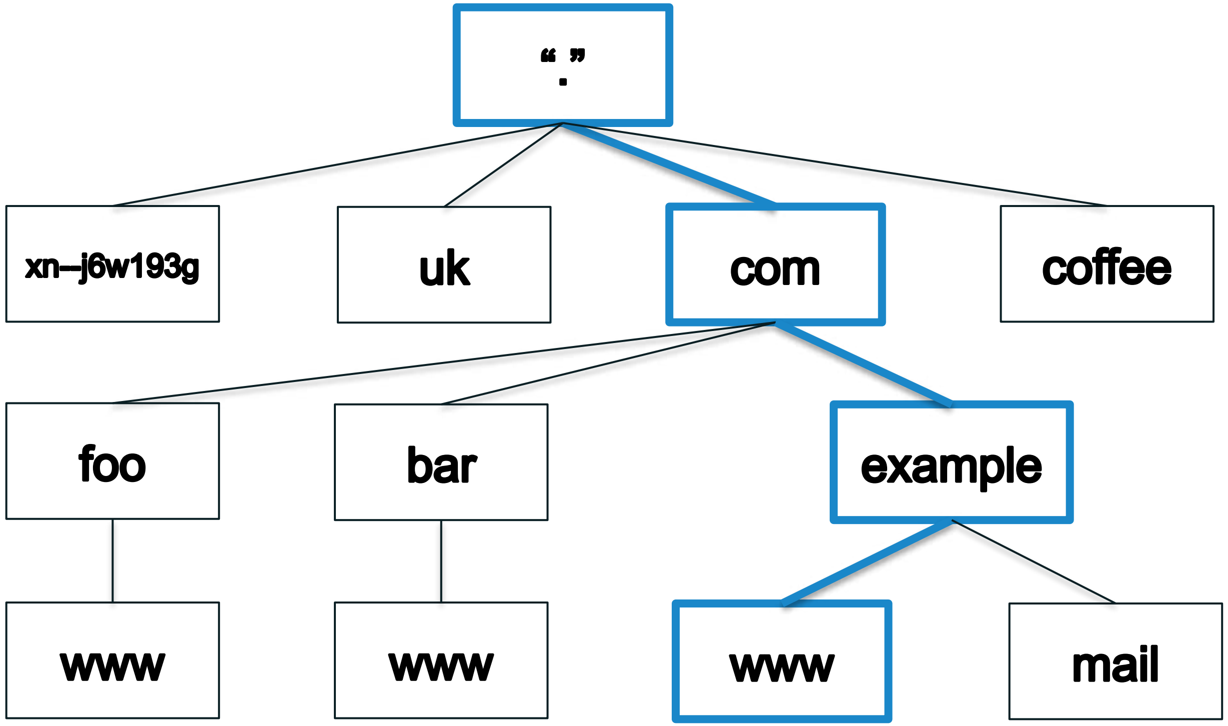
Domain Names

- Every node has a ***domain name***
- That ***domain name*** is built by sequencing node labels from one specified node up to the root, separated by dots
- Highlighted: *www.example.com.*



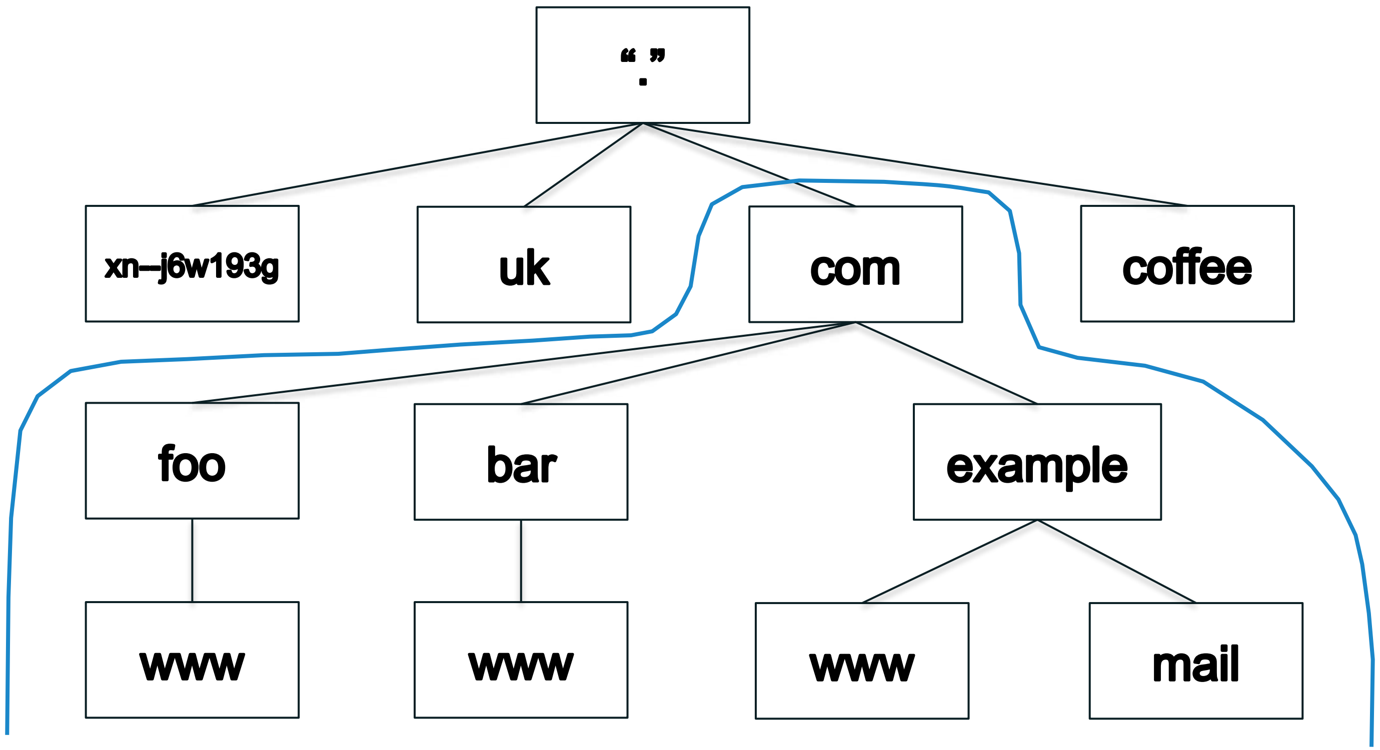
Fully Qualified Domain Names

- A ***fully qualified domain name (FQDN)*** unambiguously identifies a node
  - Not relative to any other domain name
- An FQDN ends in a dot
- Example FQDN: *www.example.com.*



Domains

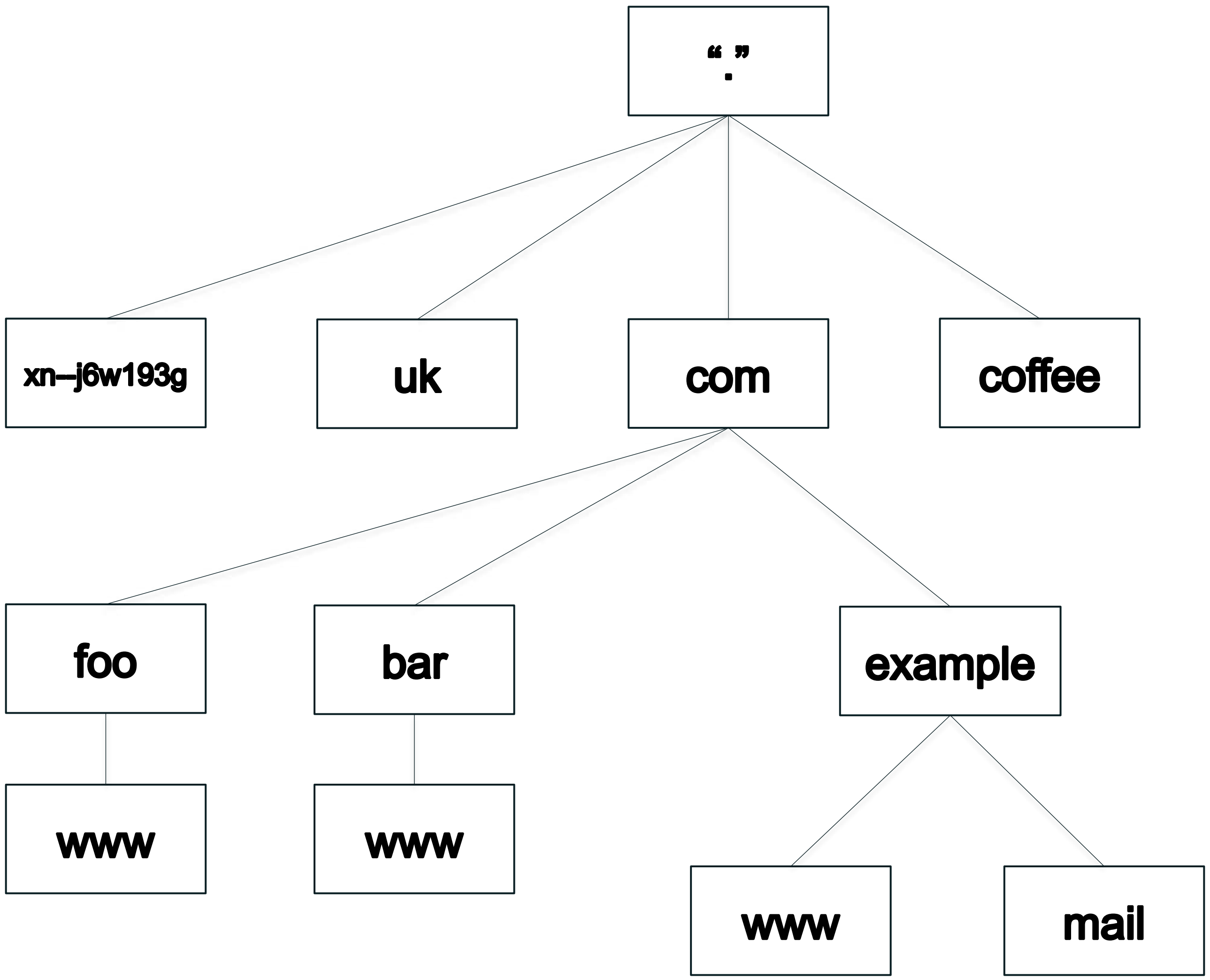
- A ***domain*** is a node and everything below it
- The top node of a domain is the ***apex*** of that domain
- Shown: the *com* domain



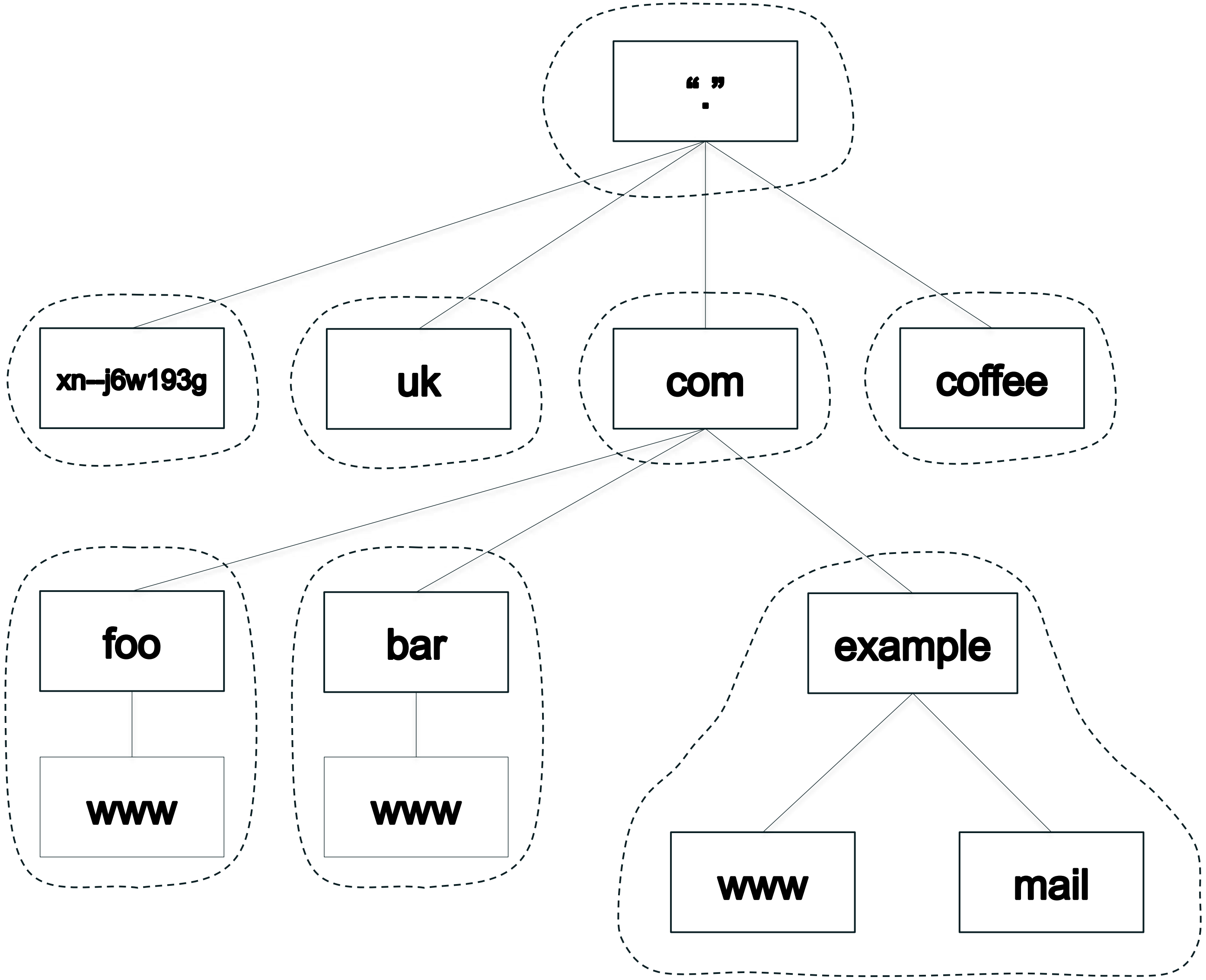
Zones

- The name space is divided up to allow distributed administration
- Administrative divisions are called ***zones***
- An administrator of any zone may delegate the administration of a subtree of its zone, thus creating a new zone
- ***Delegation*** creates zones
  - Delegating zone is the ***parent***
  - Created zone is the ***child***

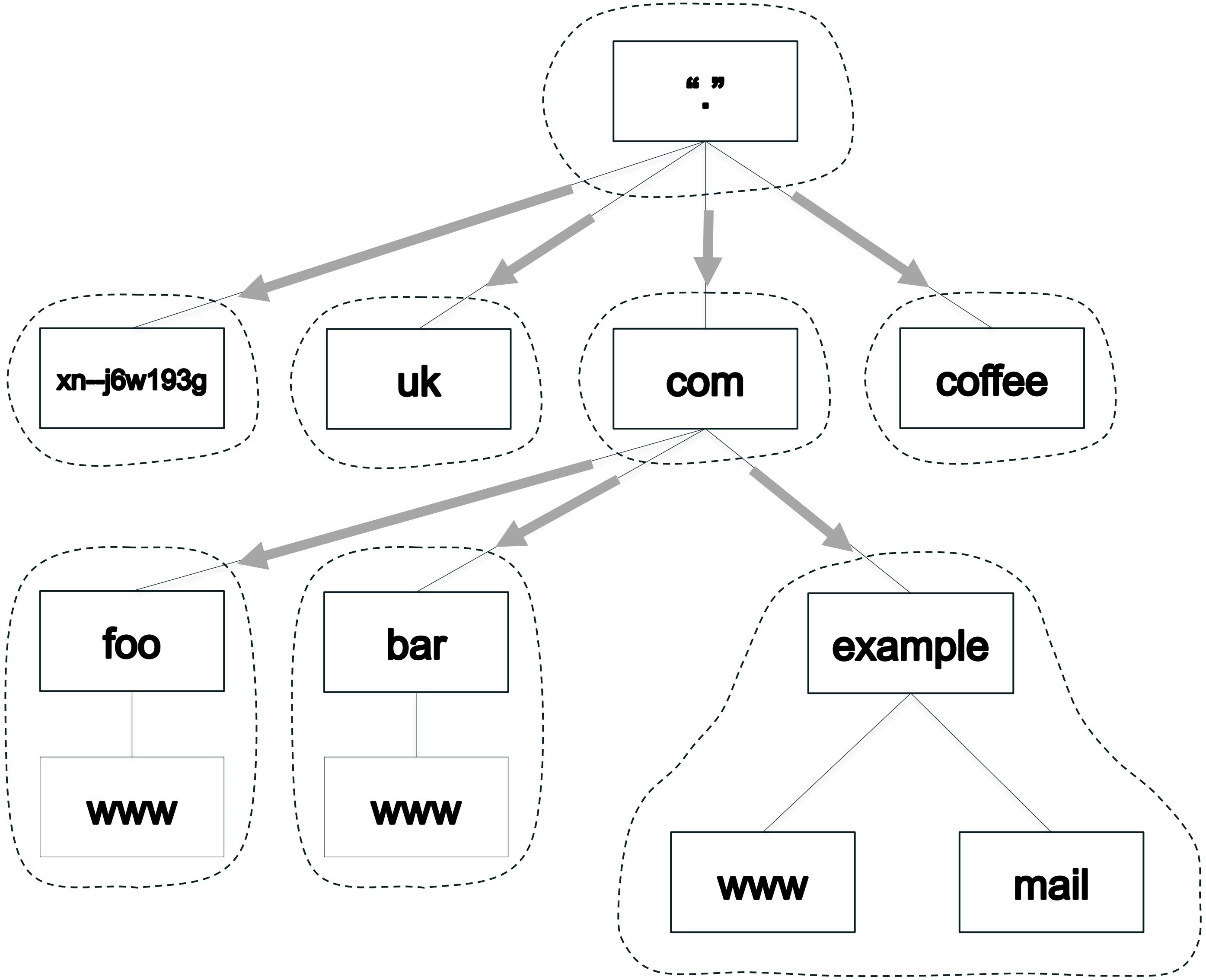
The Name Space



Zones are Administrative Boundaries



Delegation Creates Zones



DNS Database and Data

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DNS Data

- The DNS standard specifies the format of DNS data sent over the network
  - Informally called “wire format”
- The standard also specifies a text-based representation for DNS data called ***master file format,*** used for storing the data (much like tables in a database)
- A ***zone file*** contains all the data for a zone in master file format

DNS Resource Records

- Recall every node has a domain name
- A domain name can have different kinds of data associated with it
- That data is stored in ***resource records*** (this are the records in DNS database)
    - Sometimes abbreviated as ***RRs***
- Different record types for different kinds of data

Zone Files

- A zone consists of multiple resource records
- All the resource records for a zone are stored in a ***zone file***
- Every zone has (at least) one zone file
- Resource records from multiple zones are never mixed in the same file

Format of Resource Records

- Resource records have five fields:
  - ***Owner***: Domain name the resource record is associated with
  - ***Time to live (TTL)***: Time (in seconds) the record can be cached (will see later what caching is and how it works)
  - ***Class***: A mechanism for extensibility that is largely unused
  - ***Type***: The type of data the record stores
  - ***RDATA***: The data (of the type specified) that the record carries

Master File Format

- Resource record syntax in master file format:

```
[owner]    [TTL]    [class]    <type>    <RDATA>
```

- Fields in brackets are optional
  - Shortcuts to make typing zone files easier on humans
- Type and RDATA always appear

Common Resource Record Types

A	IPv4 address
AAAA	IPv6 address
NS	Name of an authoritative name server
SOA	“Start of authority”, appears at zone apex
CNAME	Name of an alias to another domain name
MX	Name of a “mail exchange server”
PTR	IP address encoded as a domain name (for reverse mapping)

Lots of Resource Records

- There are many other resource record types
- 87 types allocated
- IANA "DNS Resource Record (RR) TYPE Registry" under "Domain Name System (DNS) Parameters"
  - *http://www.iana.org/assignments/dns-parameters/dns-parameters.xhtml#dns-parameters-4*

IANA DNS Resource Record (RR) TYPE Registry

Domain Name System (DN...

www.iana.org/assignments/dns-parameters/dns-parameters.xhtml#dns-parameters-4

Resource Record (RR) TYPEs

Reference
[RFC6895][RFC1035]

Available Formats
CSV

Decimal	Hex	Registration Procedures	Note
0	0x0000	RRTYPE zero is used as a special indicator for the SIG RR [RFC2931], [RFC4034] and in other circumstances and must never be allocated for ordinary use.	
1-127	0x0000-0x007F	DNS RRTYPE Allocation Policy	data TYPEs
128-255	0x0080-0x00FF	DNS RRTYPE Allocation Policy	Q TYPEs, Meta TYPEs
256-61439	0x0100-0xEFFF	DNS RRTYPE Allocation Policy	data RRTYPEs
61440-65279	0xF000-0xFEFF	IETF Review	
65280-65534	0xFF00-0xFFFE	Reserved for Private Use	
65535	0xFFFF	Reserved (Standards Action)	

TYPE	Value	Meaning	Reference	Template	Registration Date
A	1	a host address	[RFC1035]		
NS	2	an authoritative name server	[RFC1035]		
MD	3	a mail destination (OBSOLETE - use MX)	[RFC1035]		
MF	4	a mail forwarder (OBSOLETE - use MX)	[RFC1035]		
CNAME	5	the canonical name for an alias	[RFC1035]		
SOA	6	marks the start of a zone of authority	[RFC1035]		

Address Records (A & AAAA)

- Most common use of DNS is mapping domain names to IP addresses
- Two most common types of resource records are:
  - Address (A) record stores mapping for a domain name to an IPv4 address

```
example.com.          A       192.0.2.7
```

  - “Quad A” (AAAA) record stores mapping for a domain name to an IPv6 address

```
example.com.          AAAA    2001:db8::7
```

Warehouse Analogy

- Most types are used by consumers of DNS
  - A, AAAA and almost everything else
- Some types are used mostly by DNS itself
  - NS, SOA
- DNS is like a warehouse
  - NS and SOA are the shelves you build…
  - ...so you can store stuff you care about (A, AAAA, etc.) in the warehouse

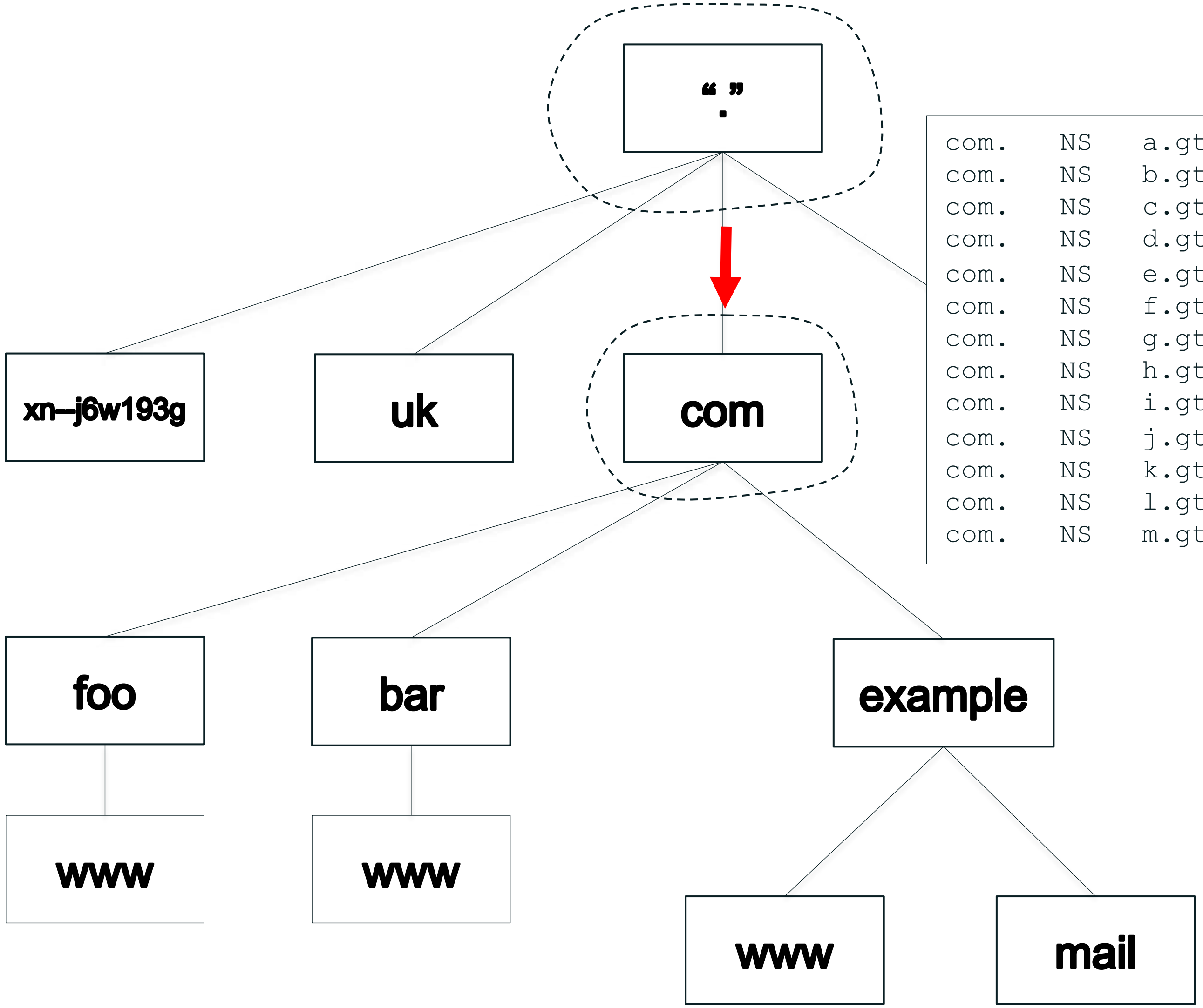
Name Server (NS)

- Specifies an authoritative name server for a zone
- The only record type to appear in two places
  - “Parent” and “child” zones

```
example.com.    NS    ns1.example.com.
example.com.    NS    ns2.example.com.
```

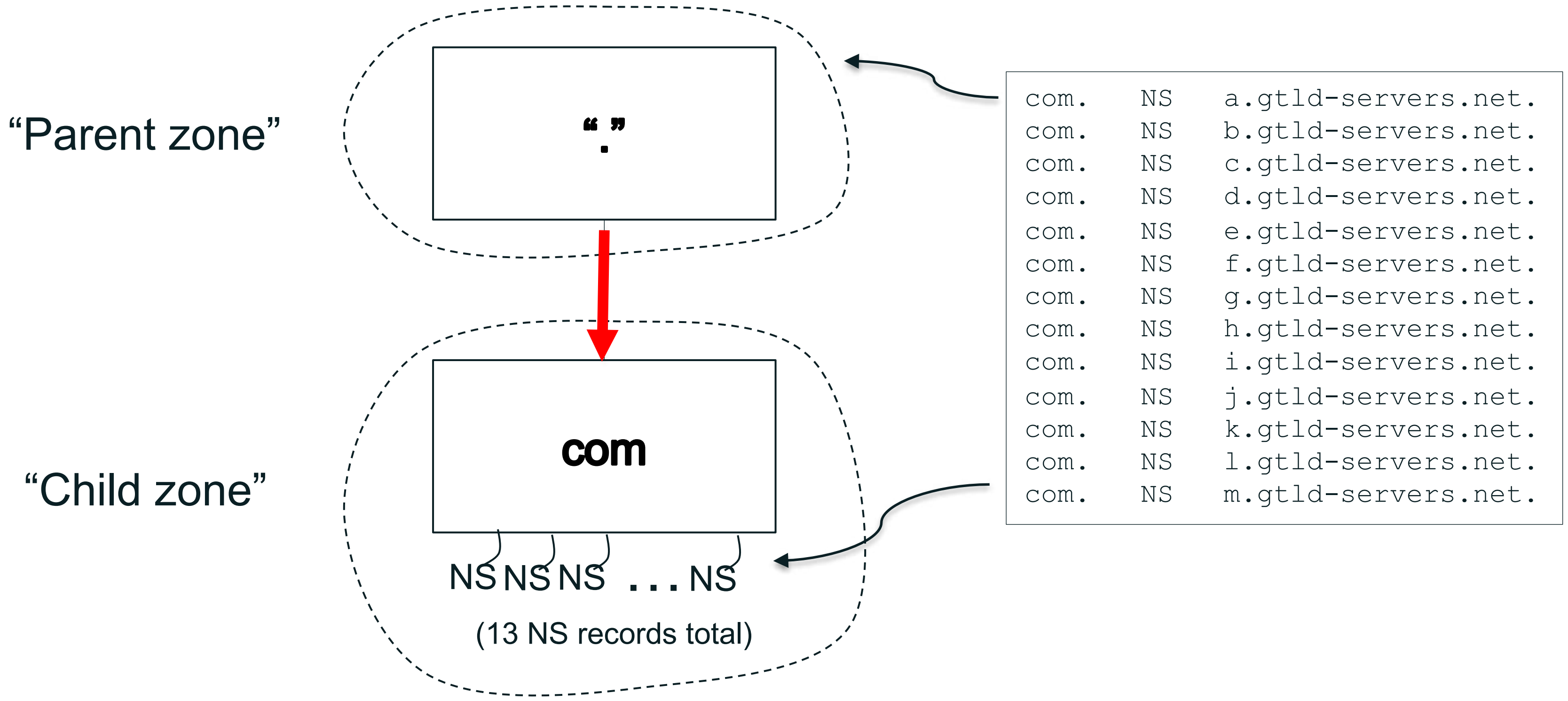
- Left hand side is the name of a *zone*
- Right hand side is the *name* of an authoritative name server for that *zone*
  - Not an IP address!

NS Records Mark Delegations



com.	NS	a.gtld-servers.net.
com.	NS	b.gtld-servers.net.
com.	NS	c.gtld-servers.net.
com.	NS	d.gtld-servers.net.
com.	NS	e.gtld-servers.net.
com.	NS	f.gtld-servers.net.
com.	NS	g.gtld-servers.net.
com.	NS	h.gtld-servers.net.
com.	NS	i.gtld-servers.net.
com.	NS	j.gtld-servers.net.
com.	NS	k.gtld-servers.net.
com.	NS	l.gtld-servers.net.
com.	NS	m.gtld-servers.net.

NS Records Appear in Two Places



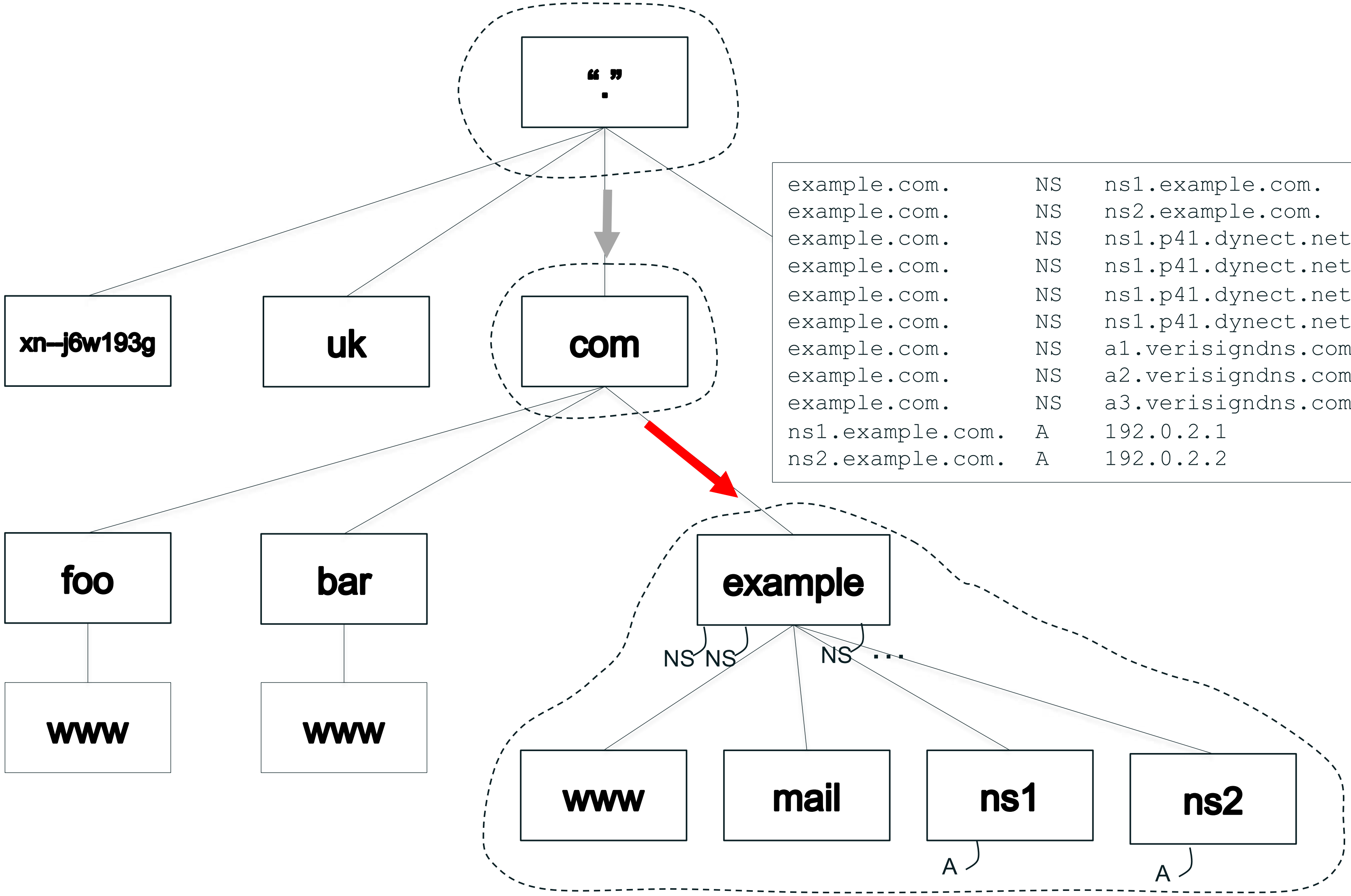
Glue Records

- A glue record is:
  - An A or AAAA record
  - Included in the parent zone as part of the delegation information
- Glue is needed to break a circular dependency
  - When the name of the name server ends in the name of the zone being delegated

```
example.com.   NS   ns1.example.com.
```

- Also for breaking for complicated dependencies not described here

More Delegation, Including Glue




```
example.com.       NS   ns1.example.com.
example.com.       NS   ns2.example.com.
example.com.       NS   ns1.p41.dynect.net.
example.com.       NS   ns1.p41.dynect.net.
example.com.       NS   ns1.p41.dynect.net.
example.com.       NS   ns1.p41.dynect.net.
example.com.       NS   a1.verisigndns.com.
example.com.       NS   a2.verisigndns.com.
example.com.       NS   a3.verisigndns.com.
ns1.example.com.   A    192.0.2.1
ns2.example.com.   A    192.0.2.2
```

Start of Authority (SOA)

- Contains administrative information about the zone.
- Every domain must have a Start of Authority record at the cutover point where the domain is delegated from its parent domain.
- SOA indicates that a name server is authoritative for a domain. If we do not receive a SOA RR in a query response from a server, that indicates the server is not authoritative for that domain.
- DNS name servers are normally set up in clusters (*master* and *secondaries*). The database for each cluster is synchronized through zone transfers. The data in a SOA record for a zone is used to control the zone transfer.

Start of Authority (SOA)

SOA records contain following fields:

- ***mname***: The primary name server for the domain, or the first name server in the name server list. For *example.com*, the primary might be *ns1.example.com*.
- ***rname***: The mailbox of the responsible party for the domain. For mailbox *john.doe@example.com* this field will be john\.doe.example.com.
- ***serial***: The version number of the original copy of a zone (preserved in zone transfers). If a secondary name server slaved to this one observes an increase in this number, the slave will assume that the zone has been updated, and it will initiate a zone transfer. Zone updates are denoted by the date and time stamp (e.g. if updated on 19 March 2020 at 15:55:00hs then the serial would be 20200316155500).

Start of Authority (SOA)

- ***refresh***: The number of seconds before a secondary should check for zone updates. Common practice is 24hs (a value of 86400).
- ***retry:*** The number of seconds before a failed refresh should be retried, normally set to less than *refresh*. Common practice is 2hs (a value of 7200).
- ***expire***: The upper limit in seconds before a secondary name servers should stop answering requests for the zone if the master does not respond. Common practice is 1000hs (a value of 360000).

Start of Authority (SOA)

- *minimum*: The TTL for negative caching purposes (for example, how long a resolver should consider a negative result for a subdomain to be valid before retrying).

```
example.com.      SOA   ns1.example.com. John\.doe.example.com. (
                         20200316155500 ; serial
                         86400          ; refresh (1 day)
                         7200           ; retry (2 hours)
                         3600000        ; expire (1000 hours)
                         172800 )       ; minimum (2 days)
```

CANNONICAL NAME (CNAME)

- The canonical name (CNAME) is normally used to alias one name to another (but do not confuse it with an ALIAS). In the case of CNAME there should be no other records on the same name.
- As an example suppose we want to have both *example.com* and *www.example.com* pointing at the same server *example.com*, the record should be:

```
www.example.com.   CNAME example.com.
```

- Note that a CNAME always points to a name (not an IP address).
- So somewhere else there should be a record like:

```
example.com.       A     192.0.2.7
```

CANNONICAL NAME (CNAME)

- Some restrictions:
  - CNAME records should not point directly to an IP address but always to another domain name.
  - CNAME records cannot co-exist with another record for the same name. It is not possible to have both a CNAME and TXT record for www.example.com.
  - A CNAME can point to another CNAME, although it is generally not recommended for performance reasons. The CNAME should point as closely as possible to the target name in order to avoid unnecessary performance overheads.
  - There is no direct correlation between a CNAME and an HTTP redirect. Configuring a CNAME does not automatically result in any HTTP redirect.

Mail Exchange (MX)

- The mail routing problem: where does mail for *user@example.com* should go?
- In the old days: look up the address of *example.com* and deliver via SMTP to that address
  - No flexibility: domain name in email address must be (also) a mail server
  - Not a problem in HOST.TXT days: email address meant *user@host*
  - But what if email address is a host not on the Internet?
    - E.g., UUCP
  - Or, you want the mail server on a different server than the server for that domain?
- DNS offered more flexibility
- MX (Mail Exchange) records de-couple the mail server from the email address

Mail Exchange (MX)

- Specifies a mail server and a preference for a mail destination

```
example.com.   MX   10 mail.example.com.
example.com.   MX   20 mail-backup.example.com.
```

- Owner name corresponds to the domain name in an email address, i.e., to the right of the “@”
- The number is a preference, lower is more desirable
- Rightmost field is the domain name of a mail server that accepts mail for the domain in the owner name

Reverse DNS entries (PTR)

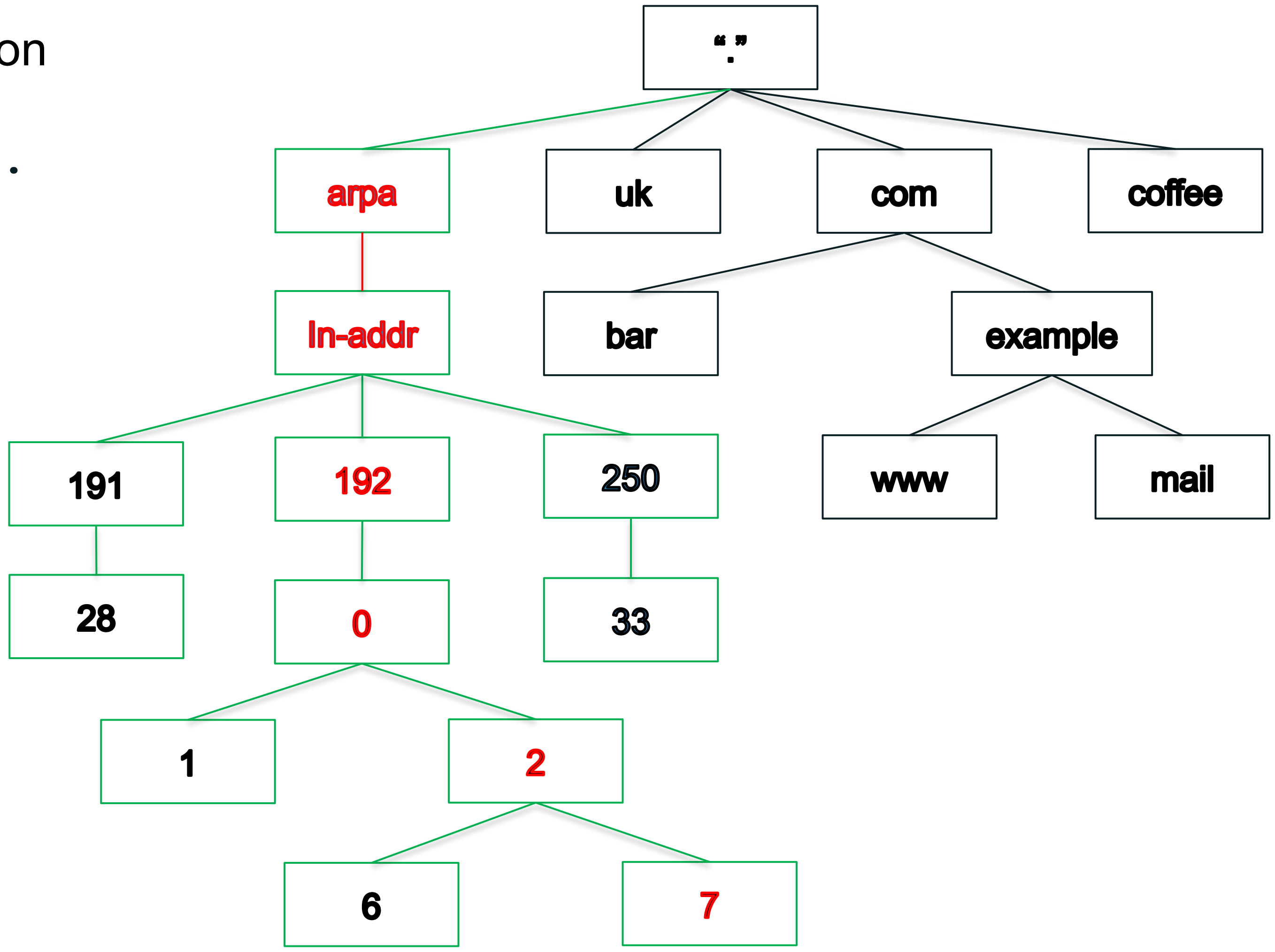
- The most common use of DNS is mapping domain names to IP addresses.
- DNS also maps IP addresses to domain names. This is called *reverse DNS* and it uses the PTR RR type.
- IPv4 reverse DNS is mapped via a special domain (subtree) called ***in-addr.arpa***.
- IPv6 reverse DNS is mapped via a special domain (subtree) called ***ip6.arpa***.
- To represent the IPv4 address *192.0.2.7* of *example.com* domain name, we reverse the IPv4 address and append the second level domain suffix ***in-addr.arpa.*** at the end, resulting in:

```
7.2.0.192.in-addr.arpa.
```

Reverse DNS entries (PTR)

- Subtree for previous reverse resolution

```
7.2.0.192.in-addr.arpa.
```



A Sample of More Resource Record Types

- **TXT**
  - Arbitrary text
- **URI**, **NAPTR**
  - Map domain names to URIs
- **TLSA**
  - Used by DANE to associate X.509 certificates with a domain name
- **CDS**, **CDNSKEY**, **CSYNC**
  - Child-parent synchronization
- **X25**, **ISDN**, **ATMA**
  - Addresses for non-IP networking protocols
- **LOC**, **GPOS**
  - Location information
- …and many more.

Sample Zone File: *example.com*

```
example.com.      SOA  ns1.example.com. hostmaster.example.com. (
                        20200316155500 ; serial
                        86400          ; refresh (1 hour)
                        7200           ; retry (2 hour)
                        2592000        ; expire (4 weeks 2 days)
                        172800 )       ; minimum (2 days)
example.com.      NS   ns1.example.com.
example.com.      NS   ns2.example.com.
example.com.      NS   ns1.p41.dynect.net.
example.com.      NS   ns1.p41.dynect.net.
example.com.      NS   ns1.p41.dynect.net.
example.com.      NS   ns1.p41.dynect.net.
example.com.      NS   a1.verisigndns.com.
example.com.      NS   a2.verisigndns.com.
example.com.      NS   a3.verisigndns.com.
example.com.      A    192.0.2.7
example.com.      AAAA 2001:db8::7
example.com.      MX   10 mail.example.com.
example.com.      MX   20 mail-backup.example.com.
www.example.com.  CNAME example.com.
ns1.example.com.  A    192.0.2.1
ns2.example.com.  A    192.0.2.2
```

Resolution Process

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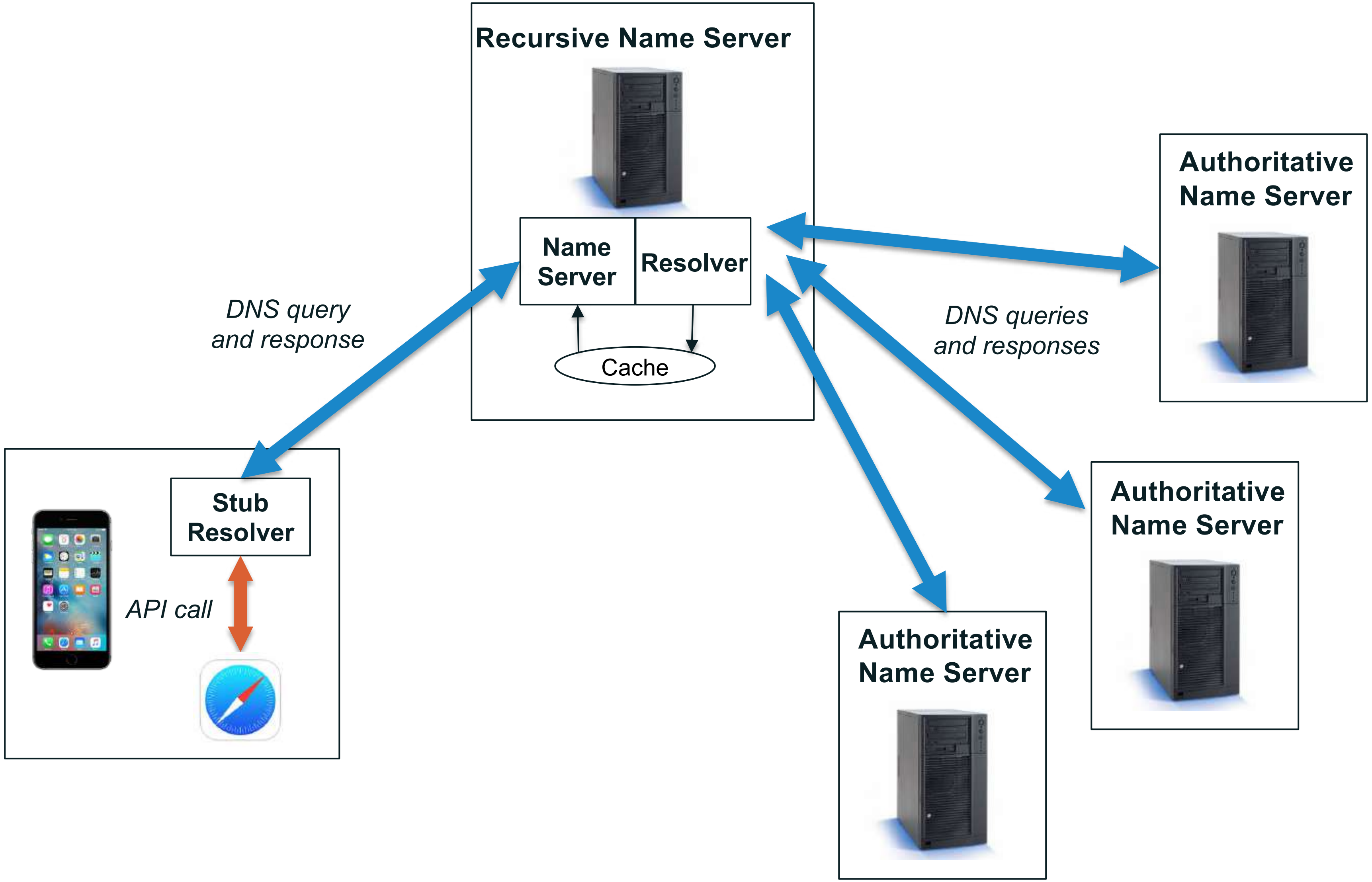
DNS in a nutshell

- DNS is a distributed database
  - Data is maintained locally but available globally
- ***Resolvers*** send queries
- ***Name servers*** answer queries
- Optimizations:
  - Caching to improve performance
  - Replication to provide redundancy and load distribution

DNS Components at a Glance



Name Servers and Zones

- Name servers answer queries
- A name server ***authoritative*** for a zone has complete knowledge of that zone
  - Can provide a definitive answer to queries about the zone
- Zones should have multiple authoritative servers
  - Provides redundancy
  - Spreads the query load

The Resolution Process

- Stub resolvers, recursive name servers and authoritative name servers cooperate to look up DNS data in the name space
- A DNS query always comprises three parameters:
  - Domain name, class, type
    - E.g., *www.example.com*, IN, A
- Two kinds of queries:
  - Stub resolvers send ***recursive*** queries
    - "I need the complete answer or an error."
  - Recursive name servers send ***non-recursive*** or ***iterative*** queries
    - "I can do some of the lookup work myself and will accept a ***referral***."

The Resolution Process

- The resolution process is the implementation of translating from an IP address to a domain name, or more general getting the answer for a specific query.

We will go though resolution process step by step…

The Resolution Process

But first…

- How do you start the resolution process if there is no local data (you are a resolver and you have just booted up)?
  - Empty cache, and/or
  - Not authoritative for any zones
- No choice but to start at the root zone
  - The ***root name servers*** are the servers authoritative for the root zone
- But how does a resolver find the NS, A, and AAAA records for the root name servers?
  - They must be configured (in fact, most of DNS software come preloaded with an up to date version of the file called ***hint file***)
  - No way to discover them
- The ***root hints file*** contains the names and IP addresses of the root name servers
  - https://www.iana.org/domains/root/files

List of Root Name Servers and Root Hints File

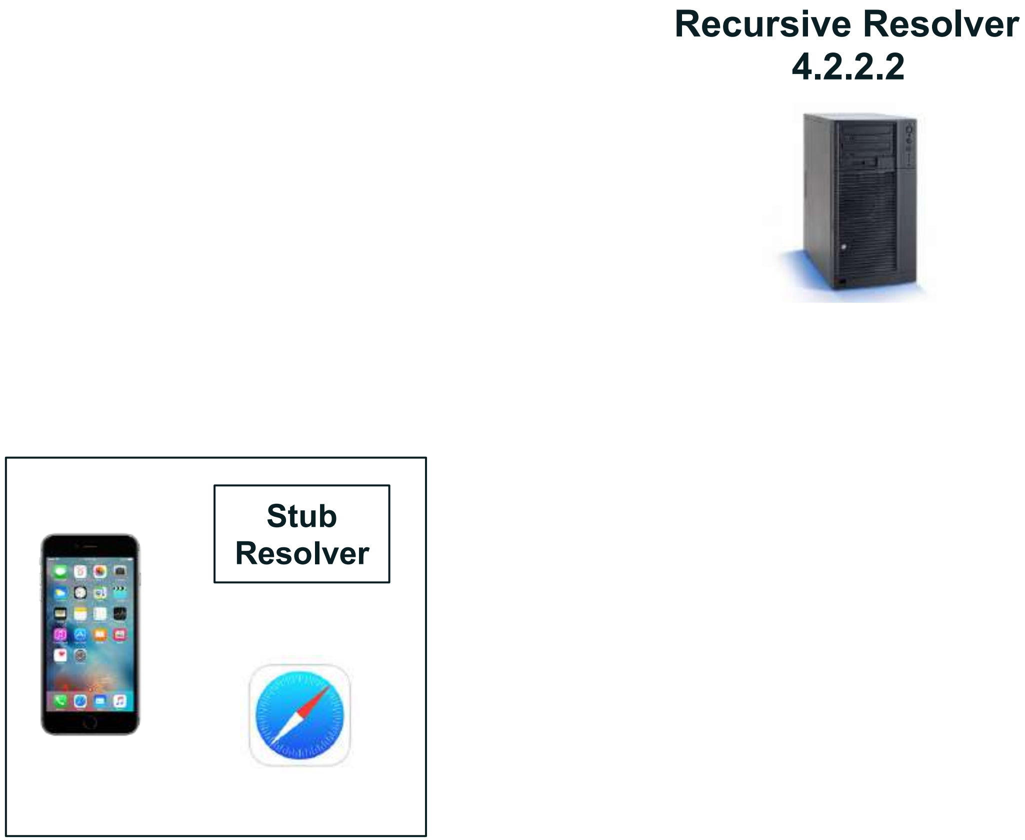
```
.                    NS      a.root-servers.net.
.                    NS      b.root-servers.net.
.                    NS      c.root-servers.net.
.                    NS      d.root-servers.net.
.                    NS      e.root-servers.net.
.                    NS      f.root-servers.net.
.                    NS      g.root-servers.net.
.                    NS      h.root-servers.net.
.                    NS      i.root-servers.net.
.                    NS      j.root-servers.net.
.                    NS      k.root-servers.net.
.                    NS      l.root-servers.net.
.                    NS      m.root-servers.net.
a.root-servers.net.  A       198.41.0.4
b.root-servers.net.  A       192.228.79.201
c.root-servers.net.  A       192.33.4.12
d.root-servers.net.  A       199.7.91.13
e.root-servers.net.  A       192.203.230.10
f.root-servers.net.  A       192.5.5.241
g.root-servers.net.  A       192.112.36.4
h.root-servers.net.  A       198.97.190.53
i.root-servers.net.  A       192.36.148.17
j.root-servers.net.  A       192.58.128.30
k.root-servers.net.  A       193.0.14.129
l.root-servers.net.  A       199.7.83.42
m.root-servers.net.  A       202.12.27.33
a.root-servers.net.  AAAA    2001:503:ba3e::2:30
b.root-servers.net.  AAAA    2001:500:84::b
c.root-servers.net.  AAAA    2001:500:2::c
d.root-servers.net.  AAAA    2001:500:2d::d
e.root-servers.net.  AAAA    2001:500:a8::e
f.root-servers.net.  AAAA    2001:500:2f::f
h.root-servers.net.  AAAA    2001:500:1::53
i.root-servers.net.  AAAA    2001:7fe::53
j.root-servers.net.  AAAA    2001:503:c27::2:30
k.root-servers.net.  AAAA    2001:7fd::1
l.root-servers.net.  AAAA    2001:500:9f::42
m.root-servers.net.  AAAA    2001:dc3::35
```

Understanding Caching

- When a recursive resolver boots up, it has no DNS data for specific domain names (except the root name servers, which are in its configuration files).
- Each time the recursive resolver learns the answer for a query, it *caches* the data to re-use for any future identical queries.
- It only caches the answer for a limited time: the TTL of the RR.
- When the TTL expires, the resolver clears that data from its cache. Any future query results in a fresh lookup.
- Caching speeds up the resolution process and lowers potential load throughout the DNS.

Resolution Process

The phone's stub resolver is configured to send queries to the recursive resolver with IP address 4.2.2.2



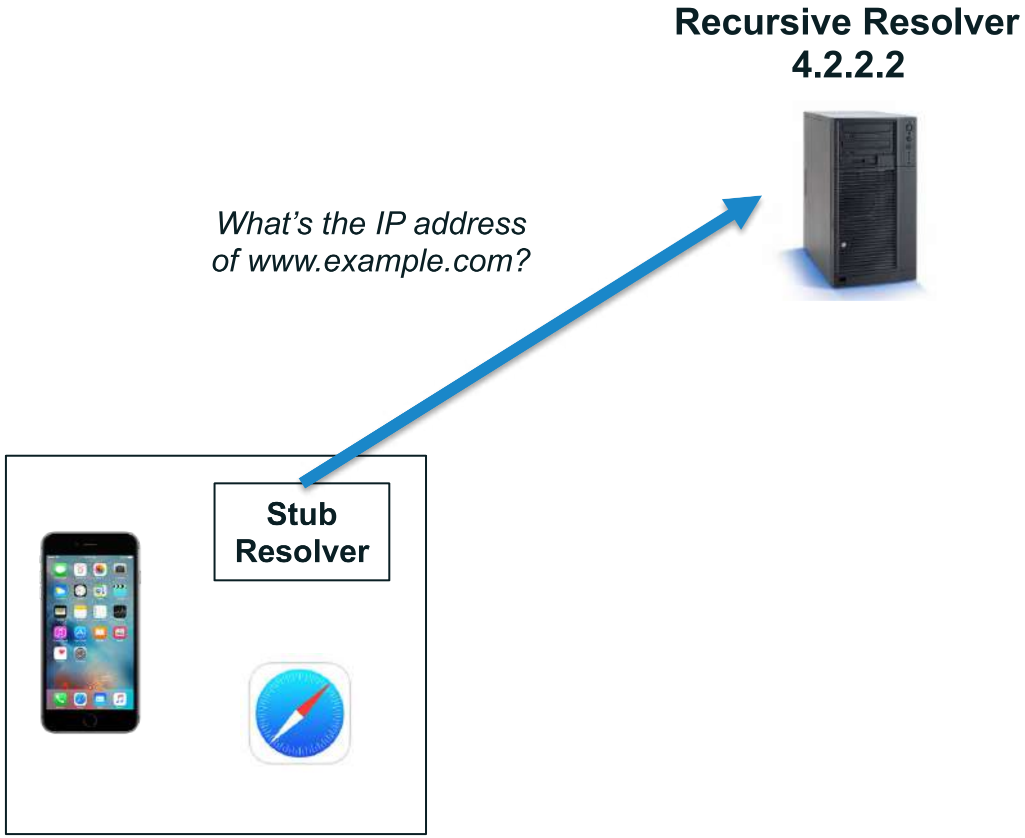
Resolution Process

A user types *www.example.com* into Safari, which then calls the stub resolver function to resolve the name

Recursive Resolver
4.2.2.2

Resolution Process

The phone's stub resolver sends a query for *www.example.com*, IN, A to 4.2.2.2

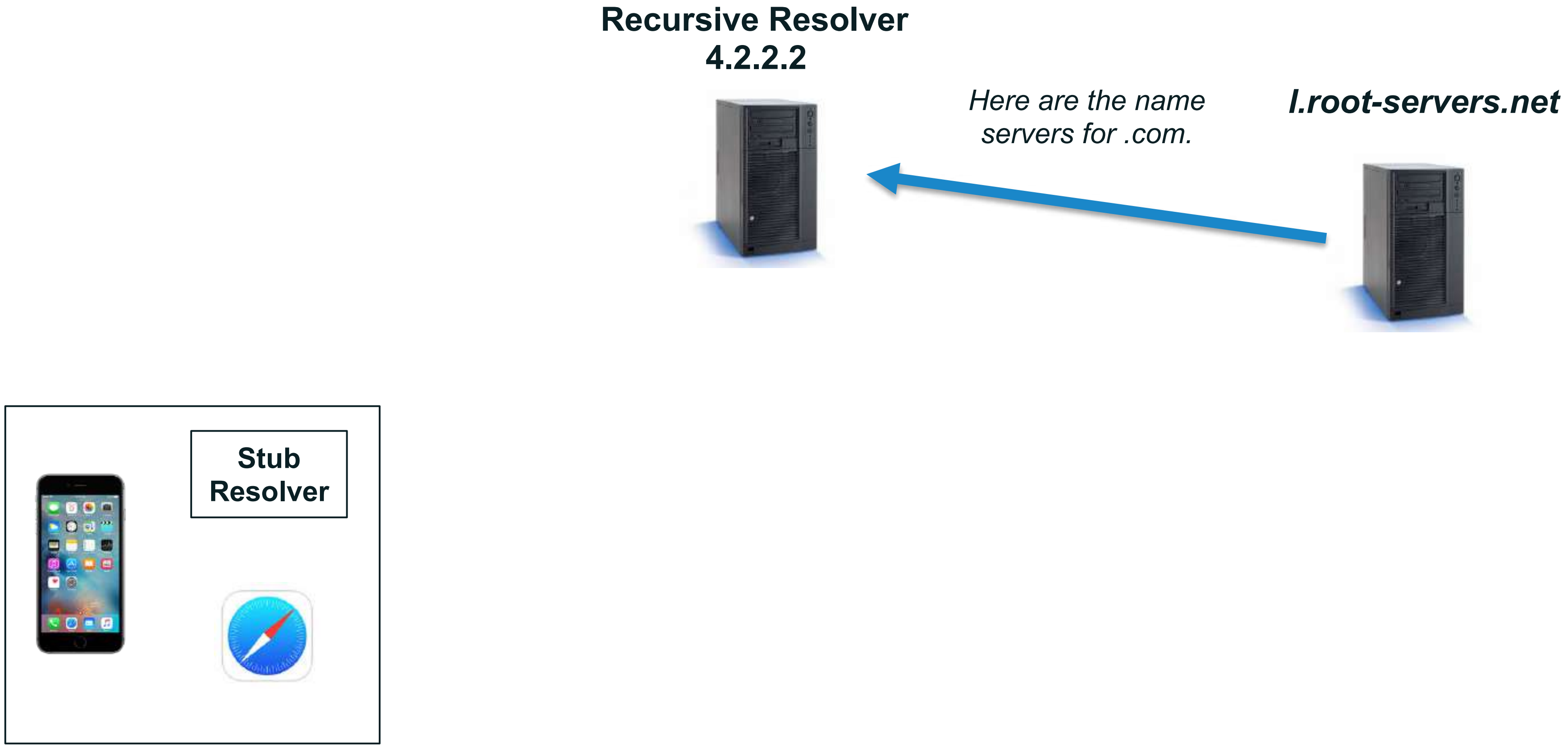


Resolution Process

Recursive resolver 4.2.2.2 has no data cached for *www.example.com*, so it queries a root server

Resolution Process

Root server returns a referral to *.com*

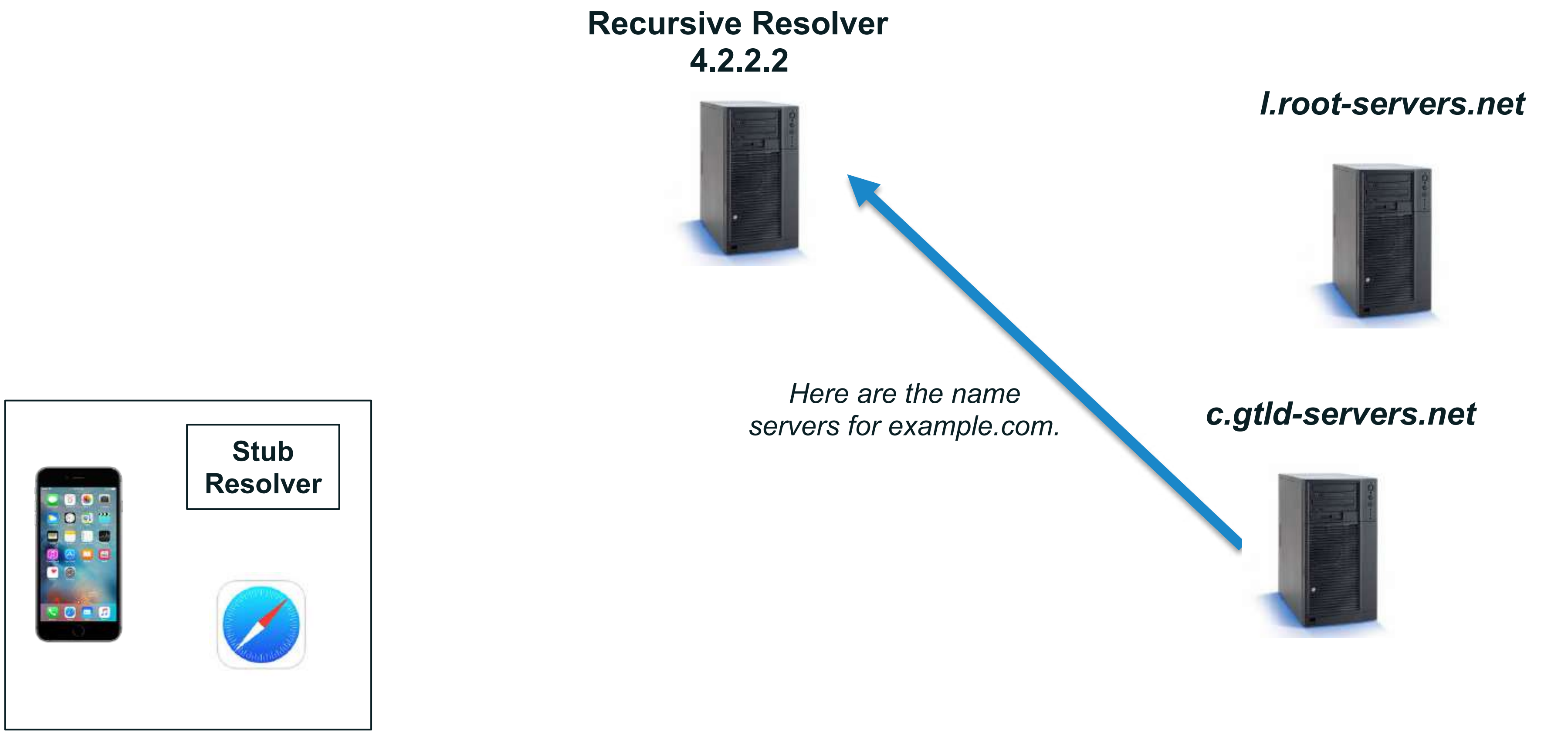


Resolution Process

Recursive resolver queries a *.com* server

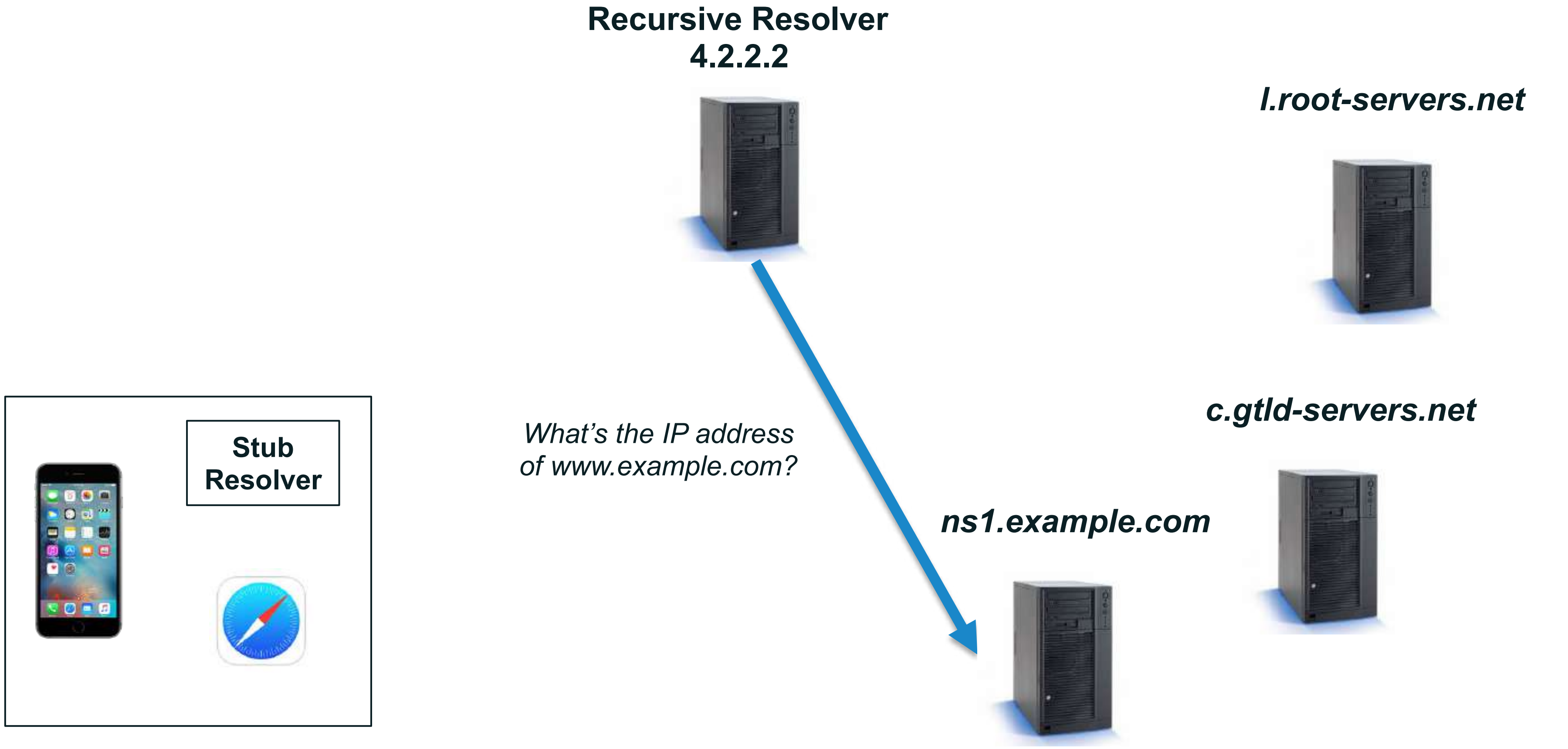
Resolution Process

.com server returns a referral to *example.com*



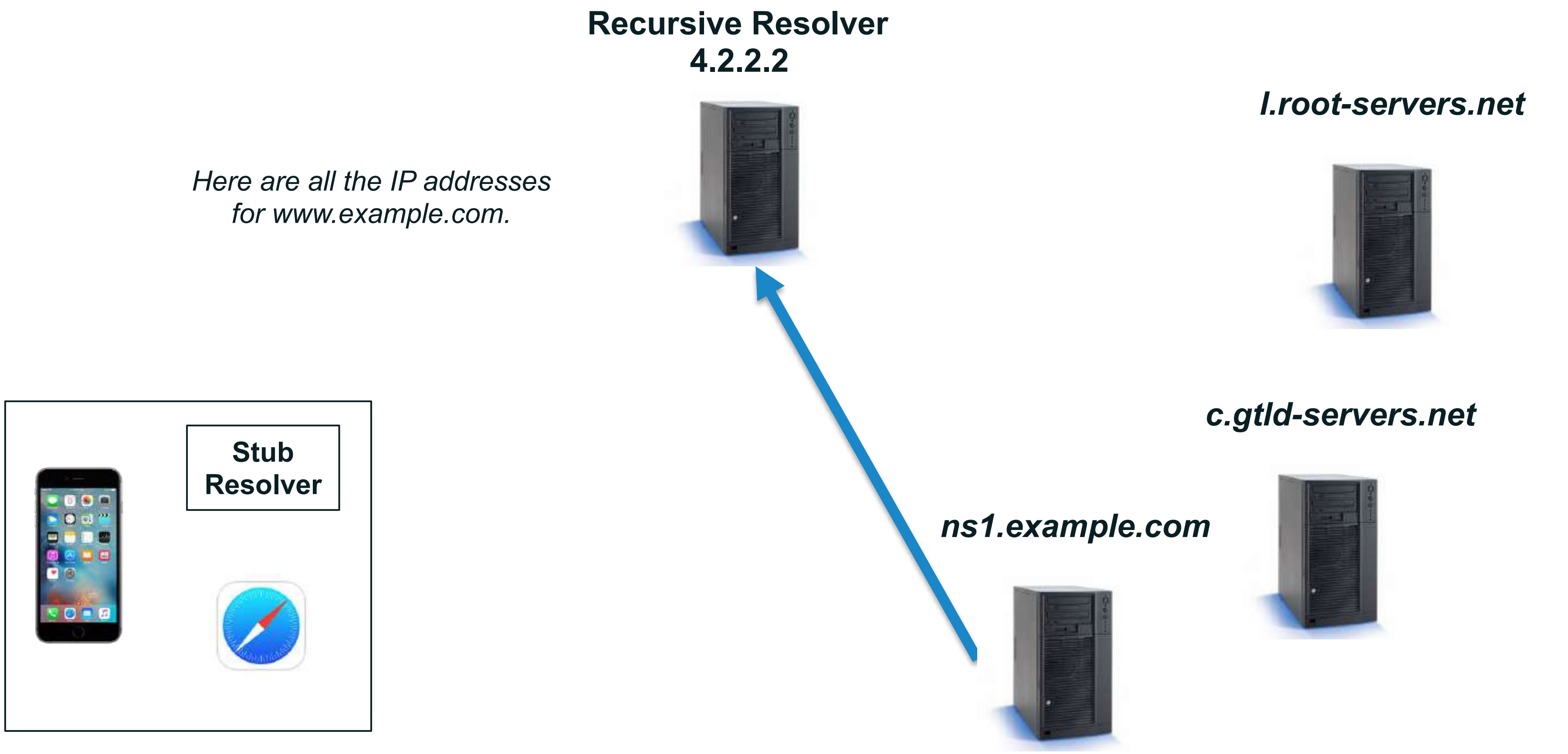
Resolution Process

Recursive resolver queries an *example.com* server



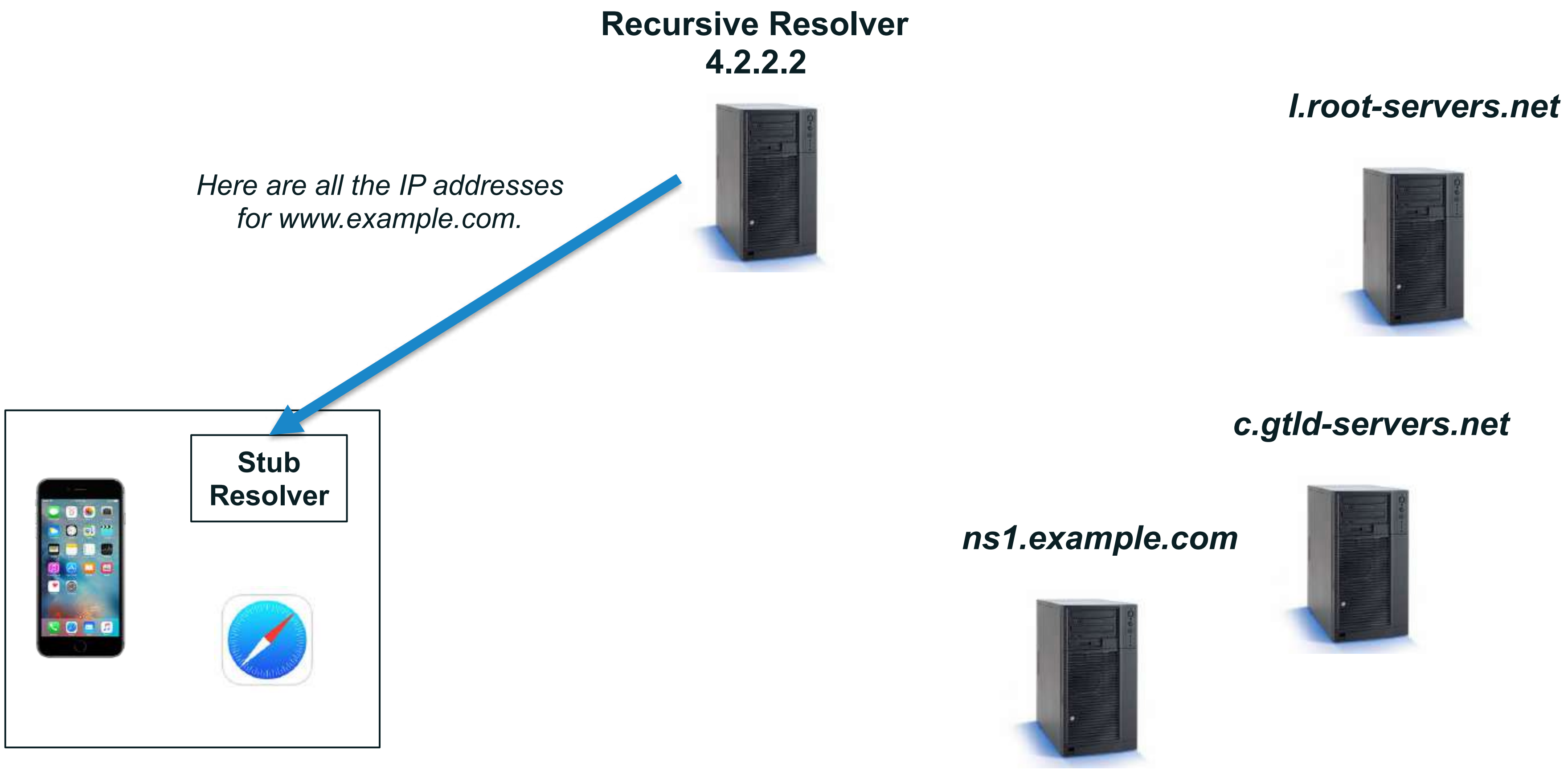
Resolution Process

example.com server returns the answer to the query because it is the authoritative for example.com



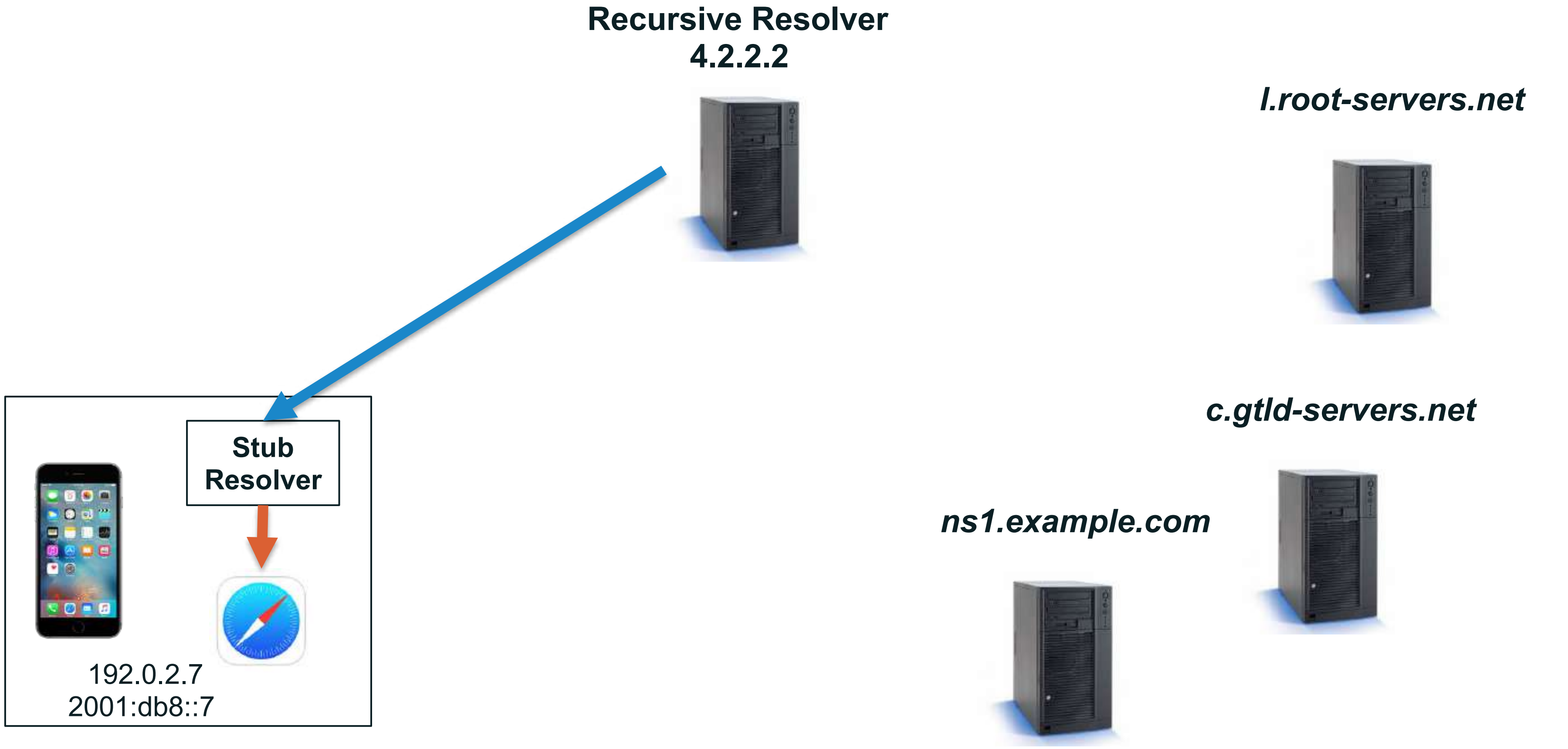
Resolution Process

Recursive resolver returns the answer to the query to the stub resolver



Resolution Process

Stub resolver returns the IP addresses to Safari



Resolution Process

- After the previous query, the recursive resolver at 4.2.2.2 now knows:
  - Names and IP addresses of the .com servers
  - Names and IP addresses of the example.com servers
  - IP addresses for www.example.com
- It caches all that data so that it can answer future queries quickly, without repeating the entire resolution process.

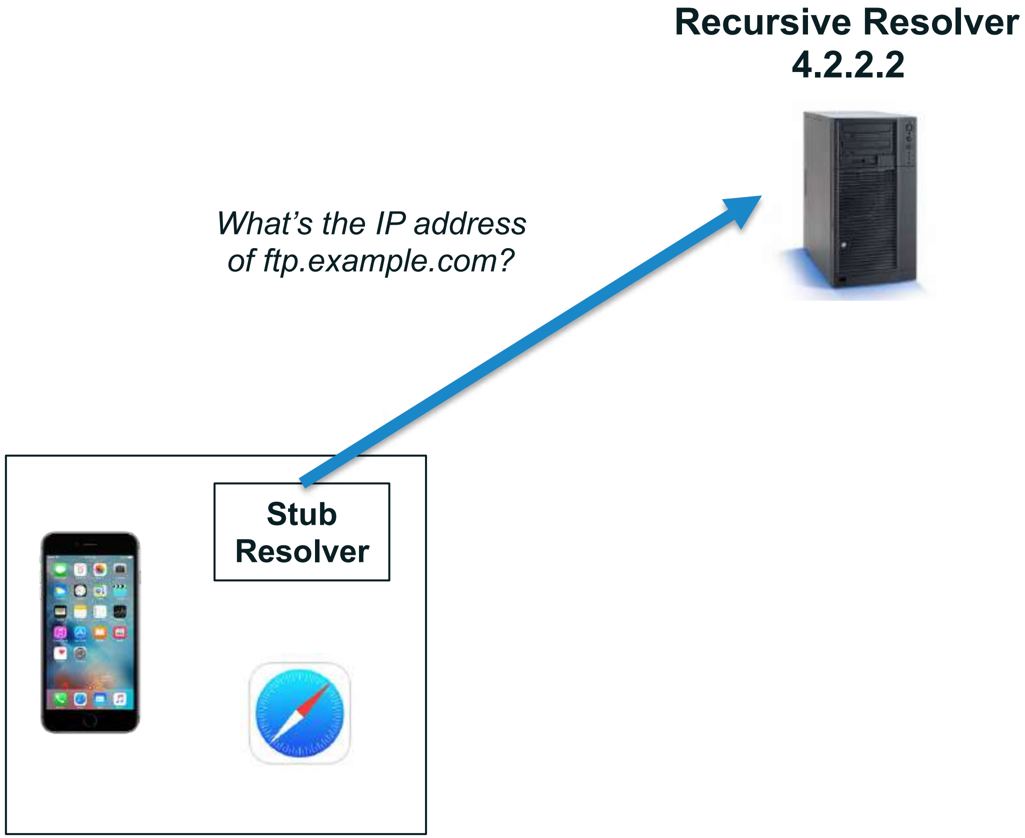
Let’s look at another query immediately following the first query . . .

Resolution Process

A user types *ftp.example.com* into Safari, and it calls the stub resolver function to resolve the name

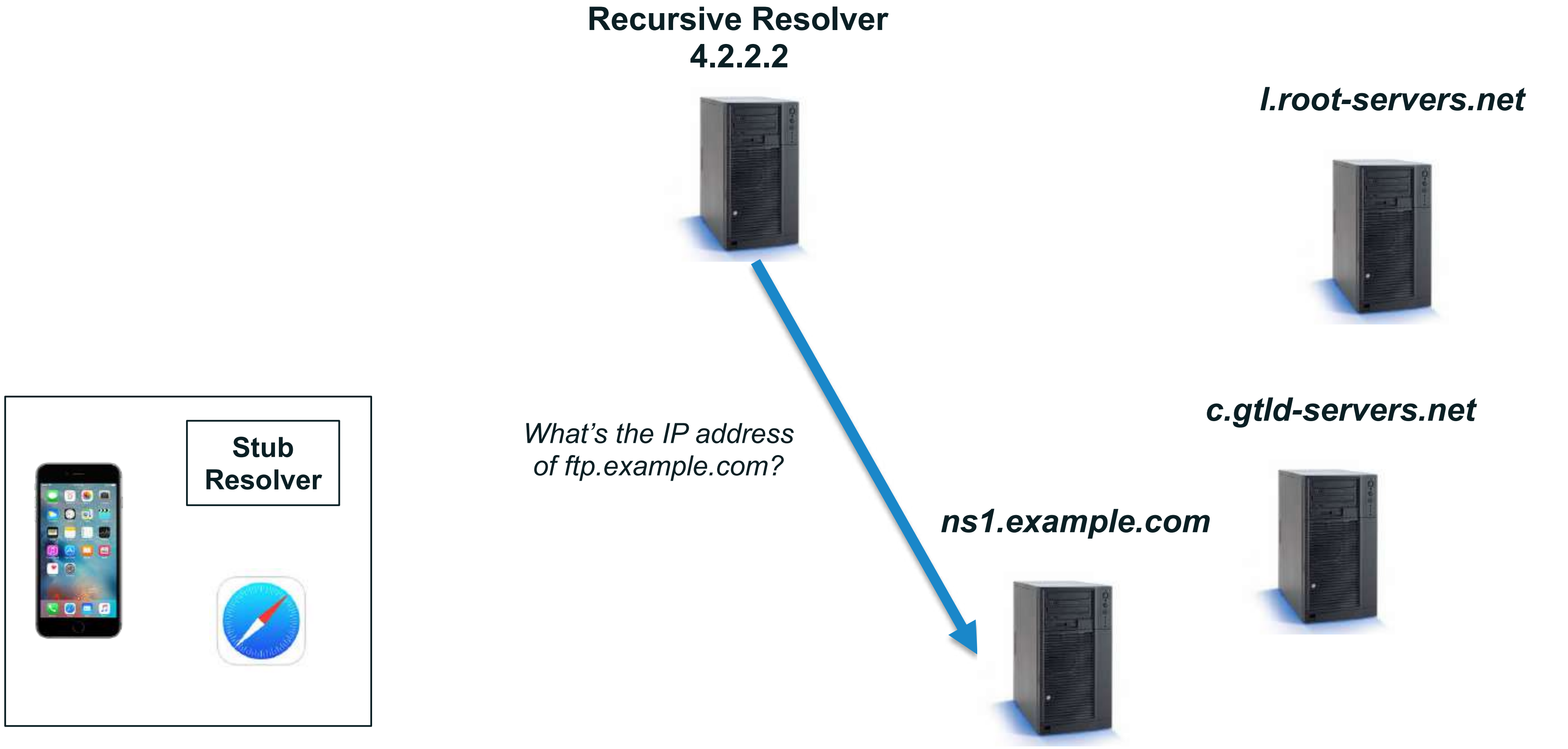
Resolution Process

The phone's stub resolver sends a query for *ftp.example.com*/IN/A to 4.2.2.2



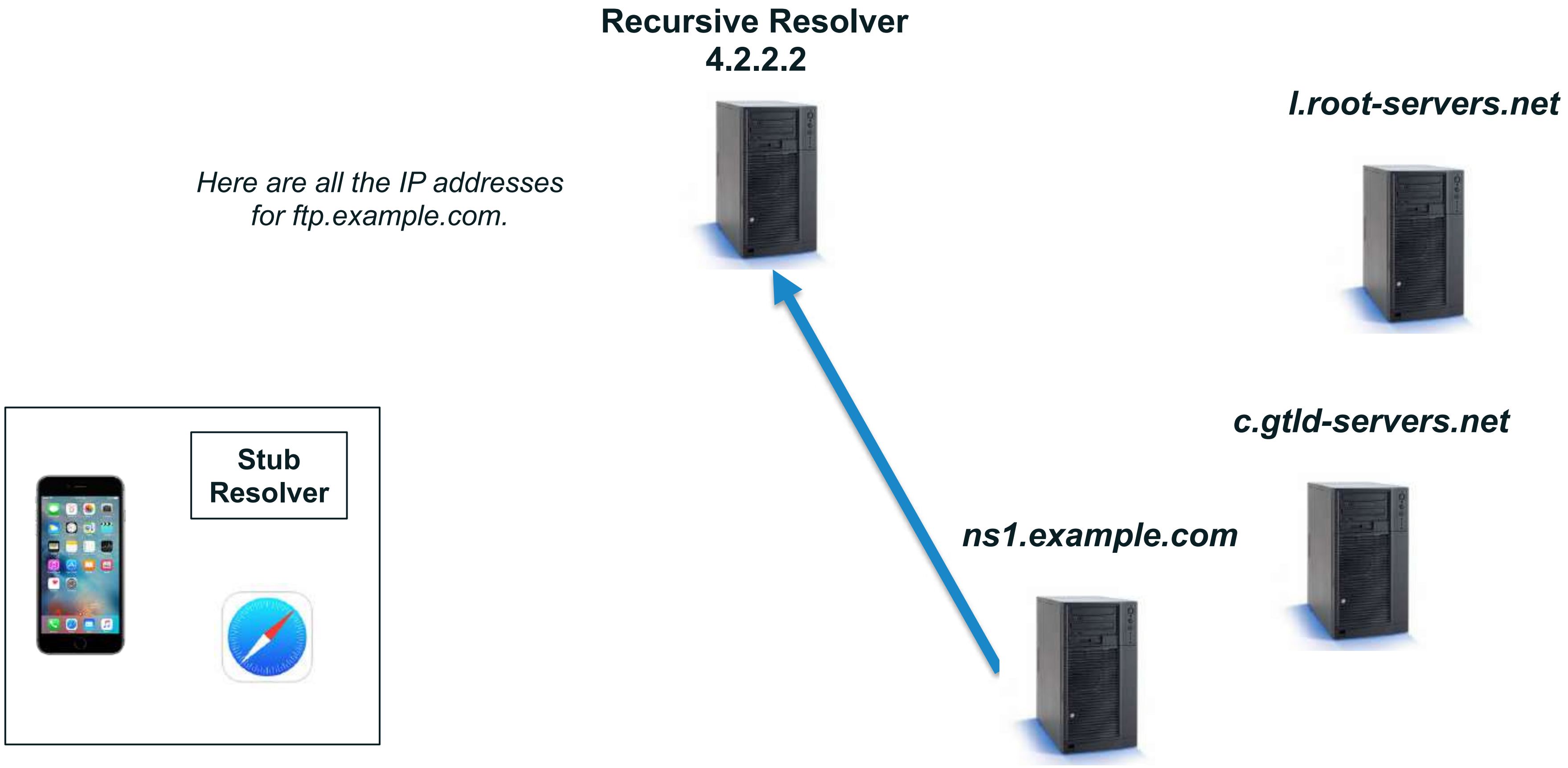
Resolution Process

Recursive resolver goes directly to example.com servers because it has that data in its cache



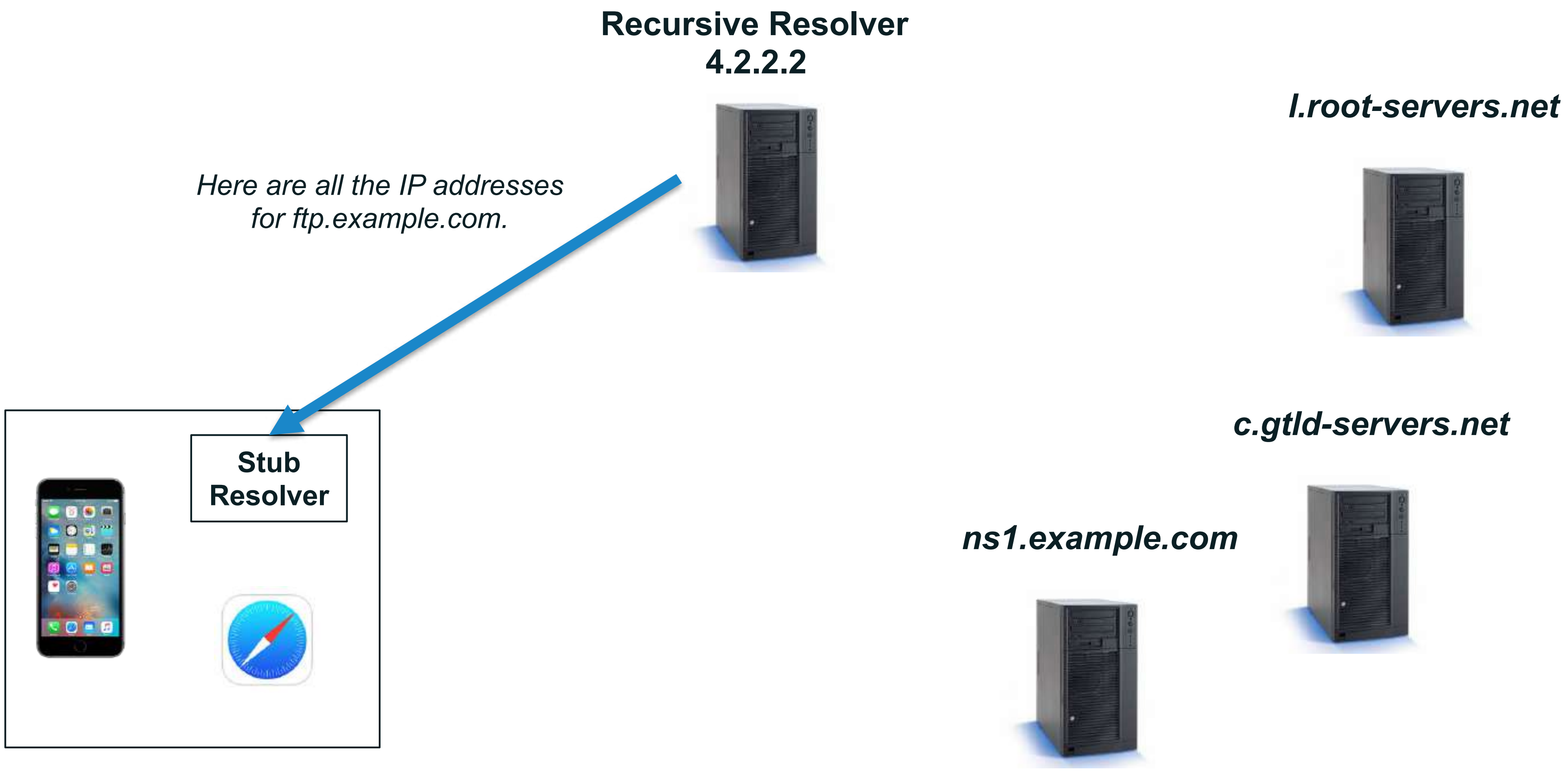
Resolution Process

example.com server returns the answer to the query



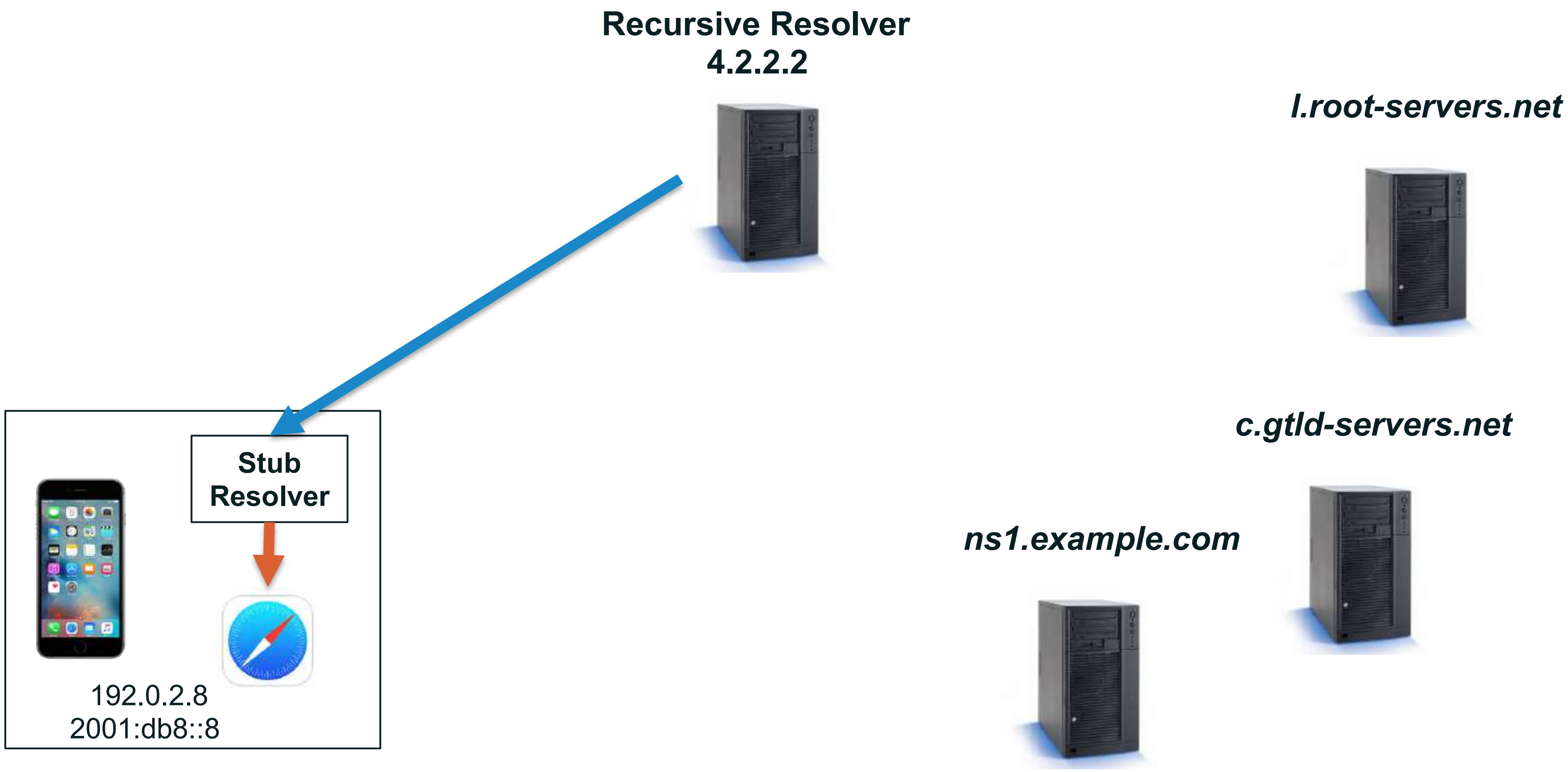
Resolution Process

Recursive resolver returns the answer to the query to the stub resolver



Resolution Process

Stub resolver returns the IP addresses to Safari



DNS Resilience #1

DNS Resilience #1

- Zones may and should have multiple authoritative servers
  - Provides redundancy
  - Spreads the query load

Authoritative Server Synchronization

- How do you keep a zone's data in sync across multiple authoritative servers?
- Fortunately, zone replication is built into the DNS protocol
- A zone's ***primary*** name server has the definitive zone data
  - Changes to the zone are made on the primary
- A zone's ***secondary*** or ***slave*** server retrieves the zone data from another authoritative server via a ***zone transfer***
  - The server it retrieves from is called the ***master server***
  - Master server is usually the primary but doesn't have to be
- Zone transfer is initiated by the secondary
  - Secondary polls the master periodically to check for changes
  - The master also notifies the primary of changes

Root Zone Administration Screenshot

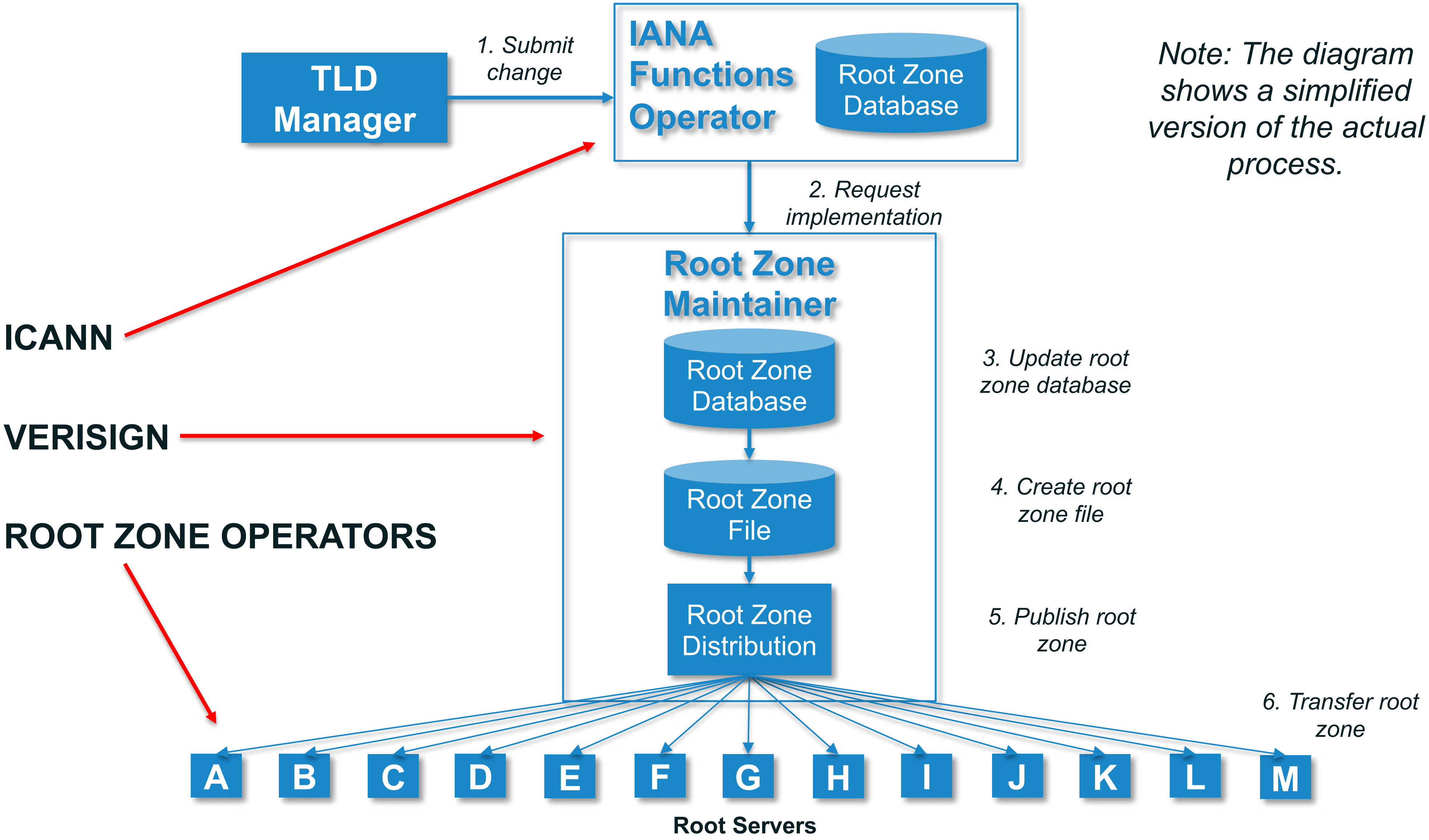
Root Zone Administration Screenshot

- Administration of the root zone is far from a trivial task
- Twelve organizations operate authoritative name servers for the root zone

The Root Servers Operators

- **A** Verisign
- **B** University of Southern California Information Sciences Institute
- **C** Cogent Communications, Inc.
- **D** University of Maryland
- **E** United States National Aeronautics and Space Administration (NASA) Ames Research Center
- **F** Information Systems Consortium (ISC)
- **G** United States Department of Defense (US DoD) Defense Information Systems Agency (DISA)
- **H** United States Army (Aberdeen Proving Ground)
- **I** Netnod Internet Exchange i Sverige
- **J** Verisign
- **K** Réseaux IP Européens Network Coordination Centre (RIPE NCC)
- **L** Internet Corporation For Assigned Names and Numbers (ICANN)
- **M** WIDE Project (Widely Integrated Distributed Environment)

Root Zone Change Process



Note: The diagram shows a simplified version of the actual process.

DNS Resilience #2

DNS Resilience #2 – (Root Server System's Resiliency)

- A root server operator may deploy copies of the root server it operates anywhere in the world using a technique called ***anycast***
  - Provides redundancy and resiliency to global DNS infrastructure
  - Spreads the load on its root server
- Each of those copies are called ***instances*** of the root server
- All instances should have identical DNS data to ensure they all give the same answers

The *root-servers.org* Web Site

As of 2020-04-28, the root server system consists of 1089 instances operated by the 12 independent root server operators.

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