DNS Deep Dive

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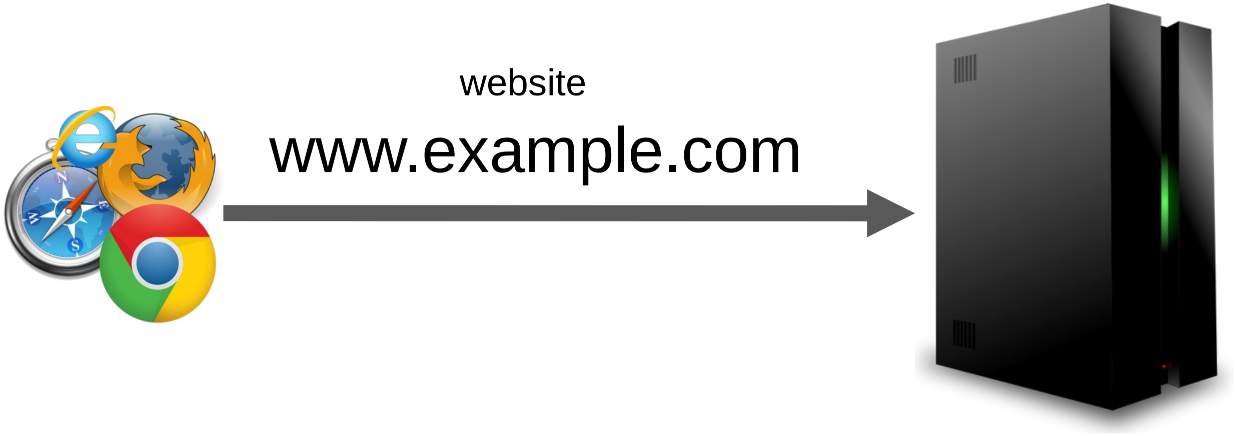
Overview

- Beyond the DNS basics
    - The underlying DNS distributed database model
    - DNS tree navigation basics
    - DNS Packet Evolution -- Some of the sharp / unusual edges of the protocol
    - Resource Record Types
- Resilience of the system
- DNS Software and APIs
- To be continued at IETF109?

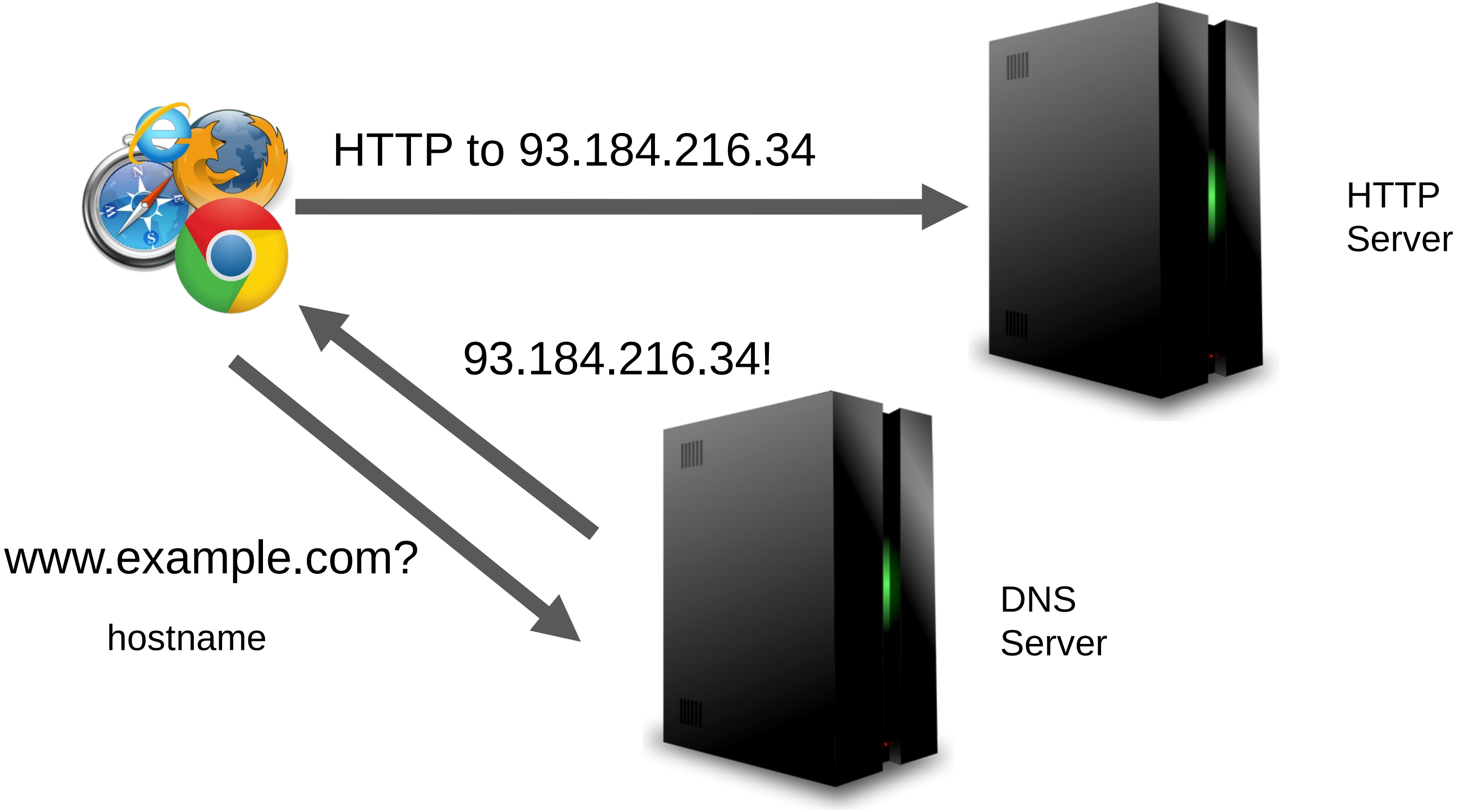
DNS as the novice Internet user sees it



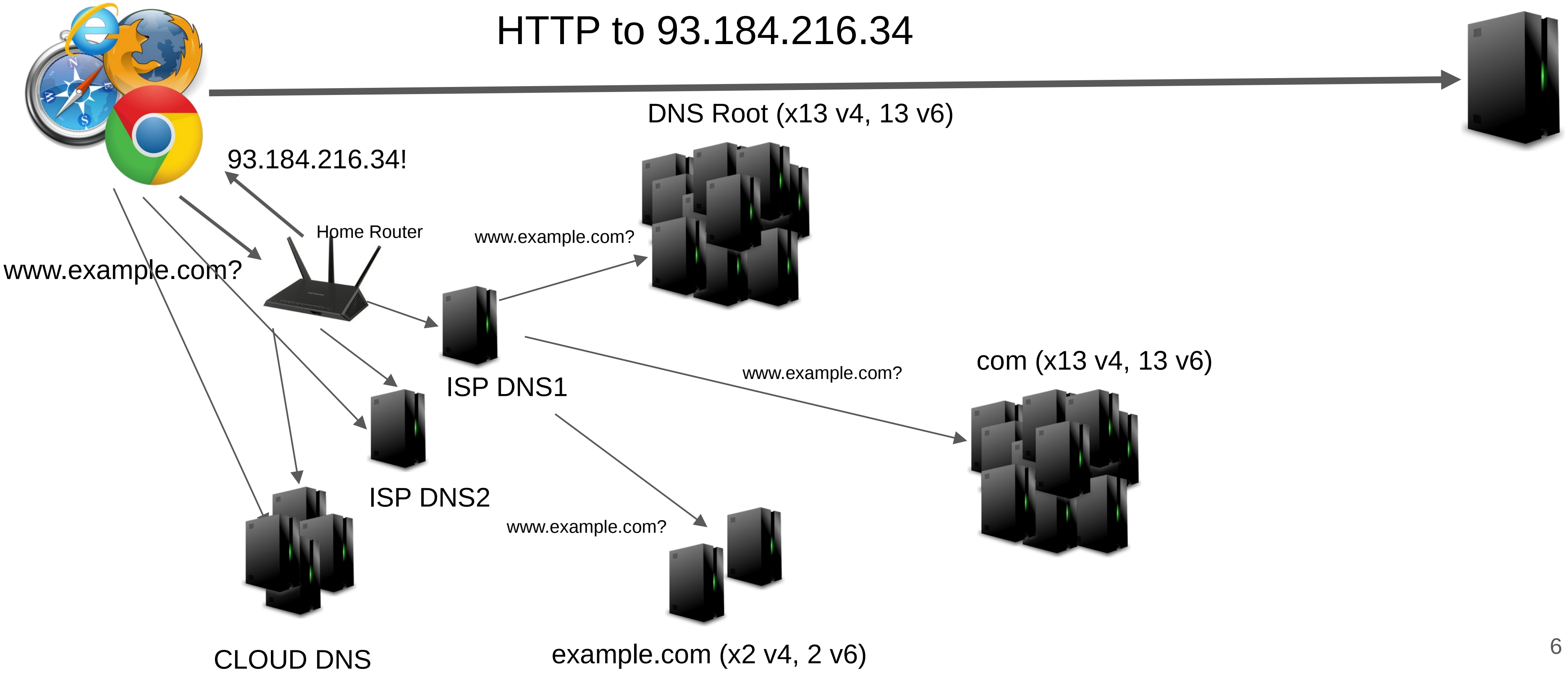
website

www.example.com

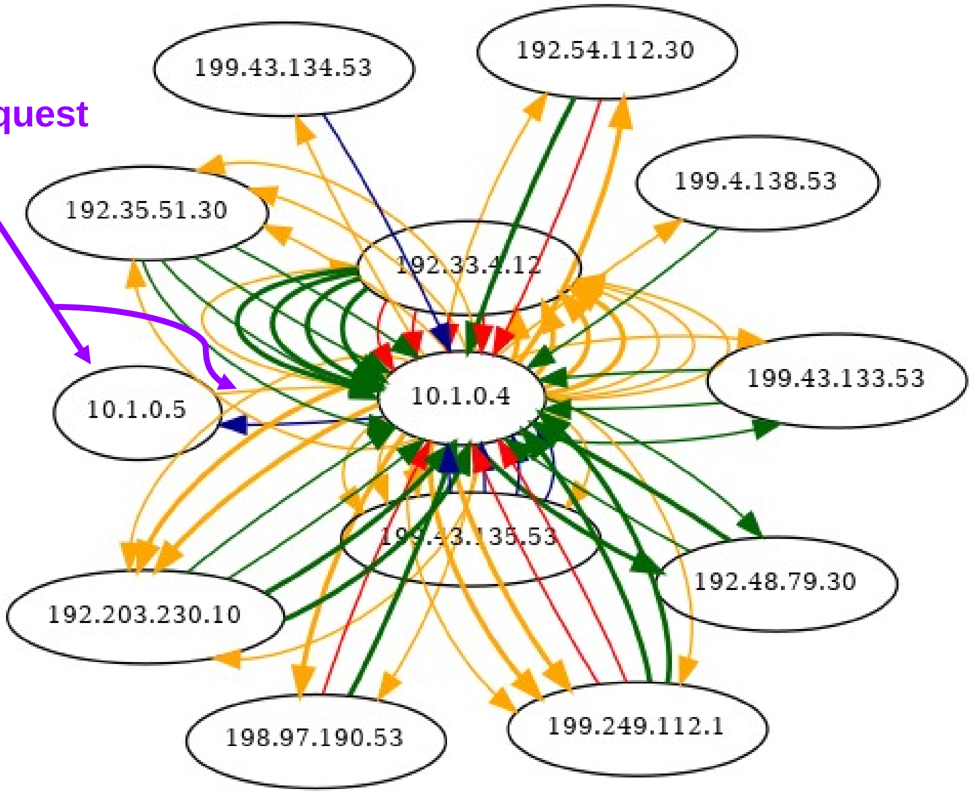
DNS as the Techy Internet user sees it



DNS is Much Much More Complex



The example.com web page



You make a single request

- Each line is a DNS request
- The center node is an ISP resolver

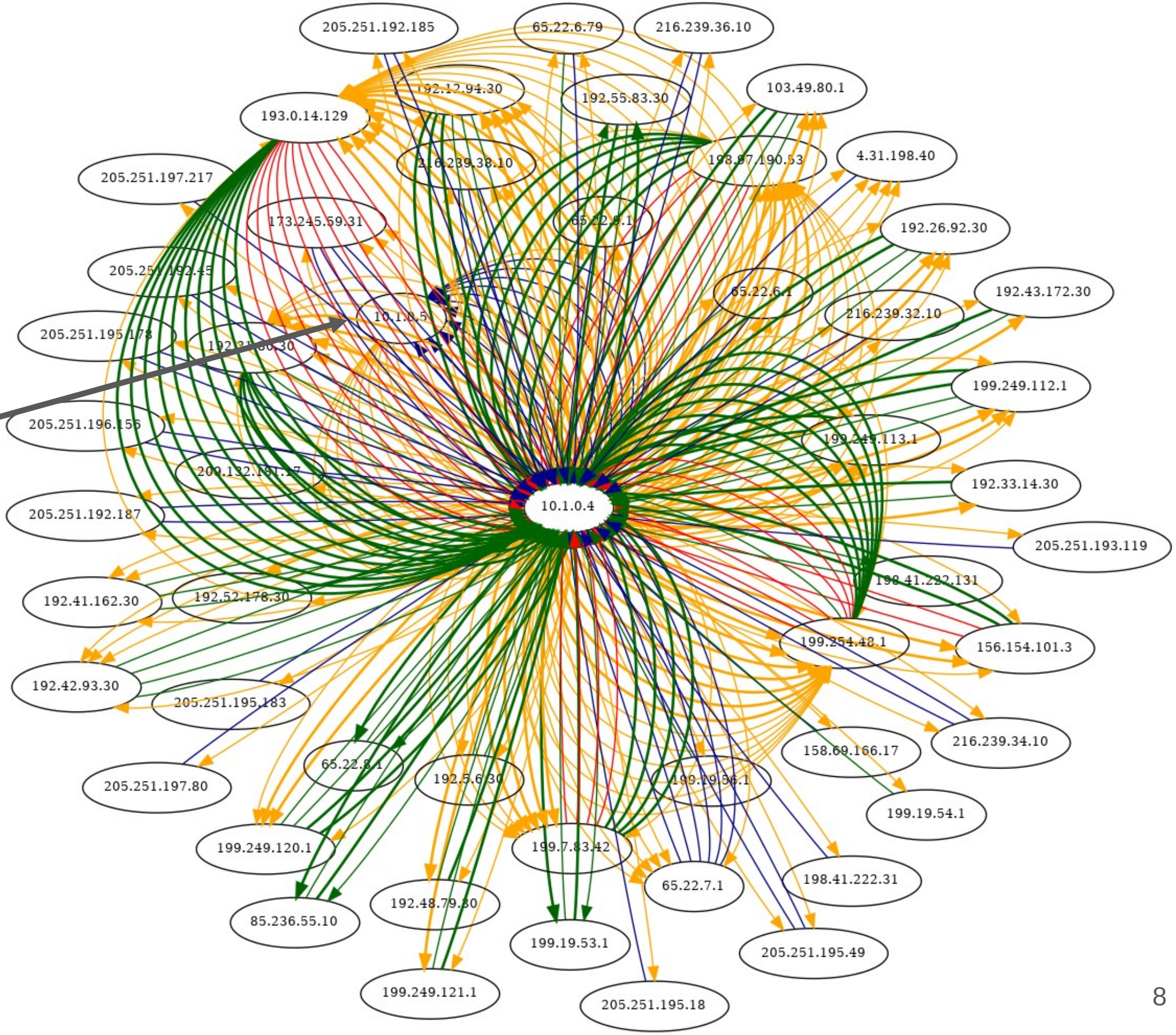
Query

Authoratative/DNSSEC

Truncated

Response

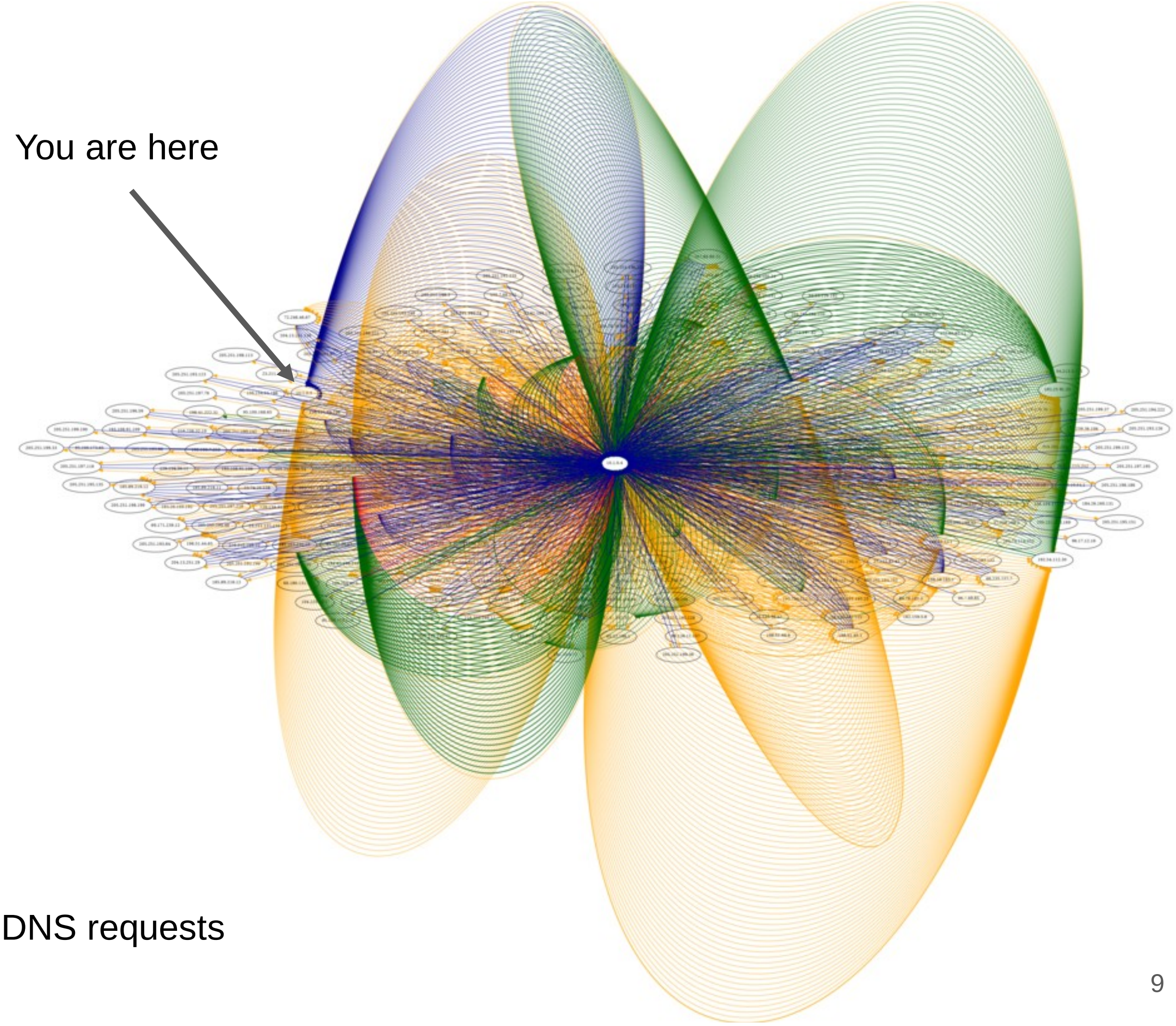
ietf.org web page (without caching)



You are here

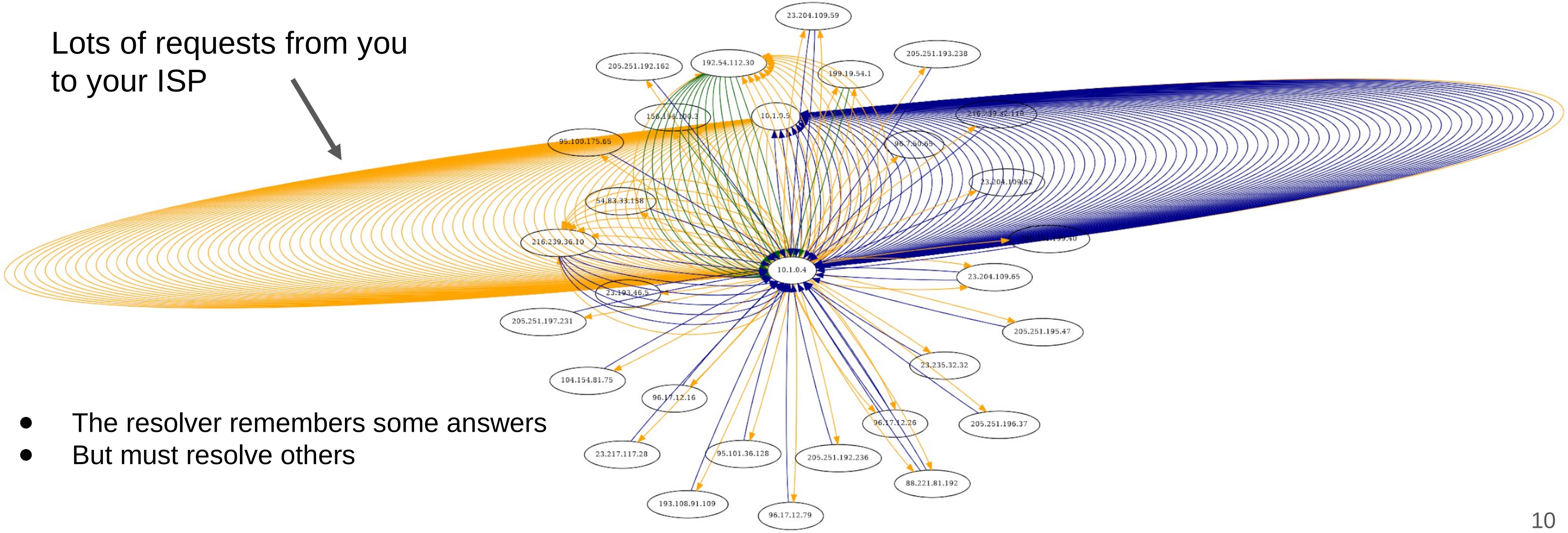
webmd.com
(without caching)

You are here



TL;DR: Web pages generate many DNS requests

Webmd.com - after DNS caching



Lots of requests from you to your ISP

- The resolver remembers some answers
- But must resolve others

The Underlying Distributed Model of the DNS

DNS was created as a replacement for /etc/hosts

Distributed system to replace static information

Back in **my day:**

```
    127.0.0.1      localhost localhost.localdomain
    ::1            localhost localhost.localdomain
    93.184.216.34  www.example.com
```

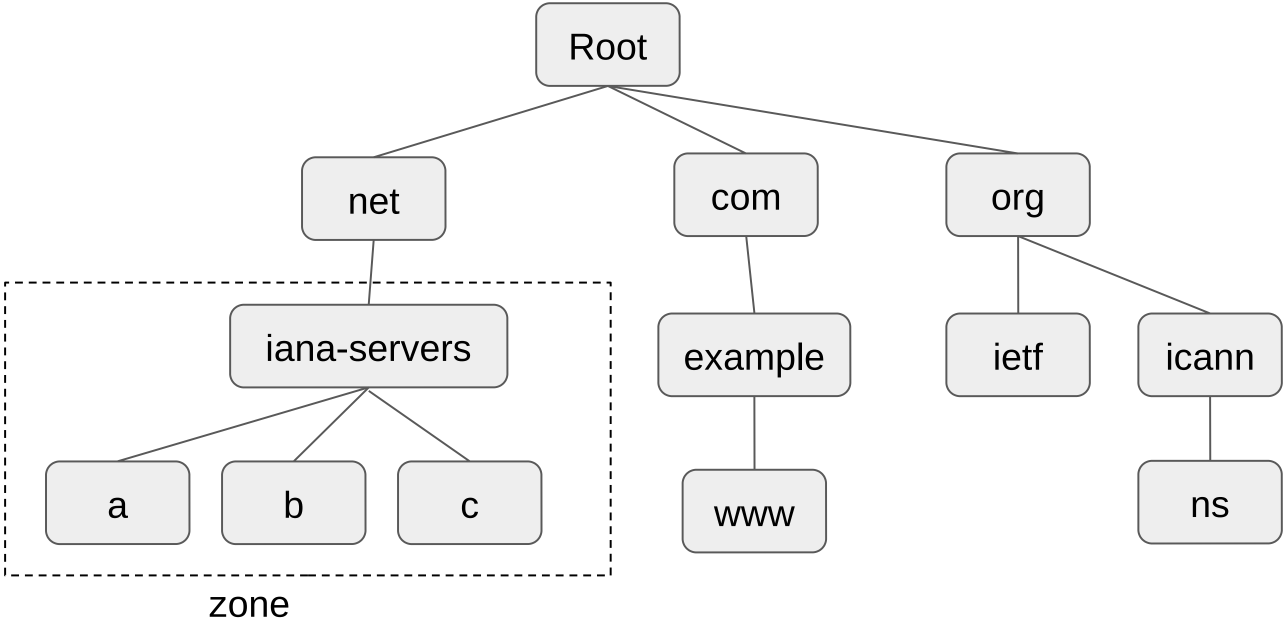
is all we needed.

The DNS 'tree' RFC103{4,5}

The Root (aka ".")

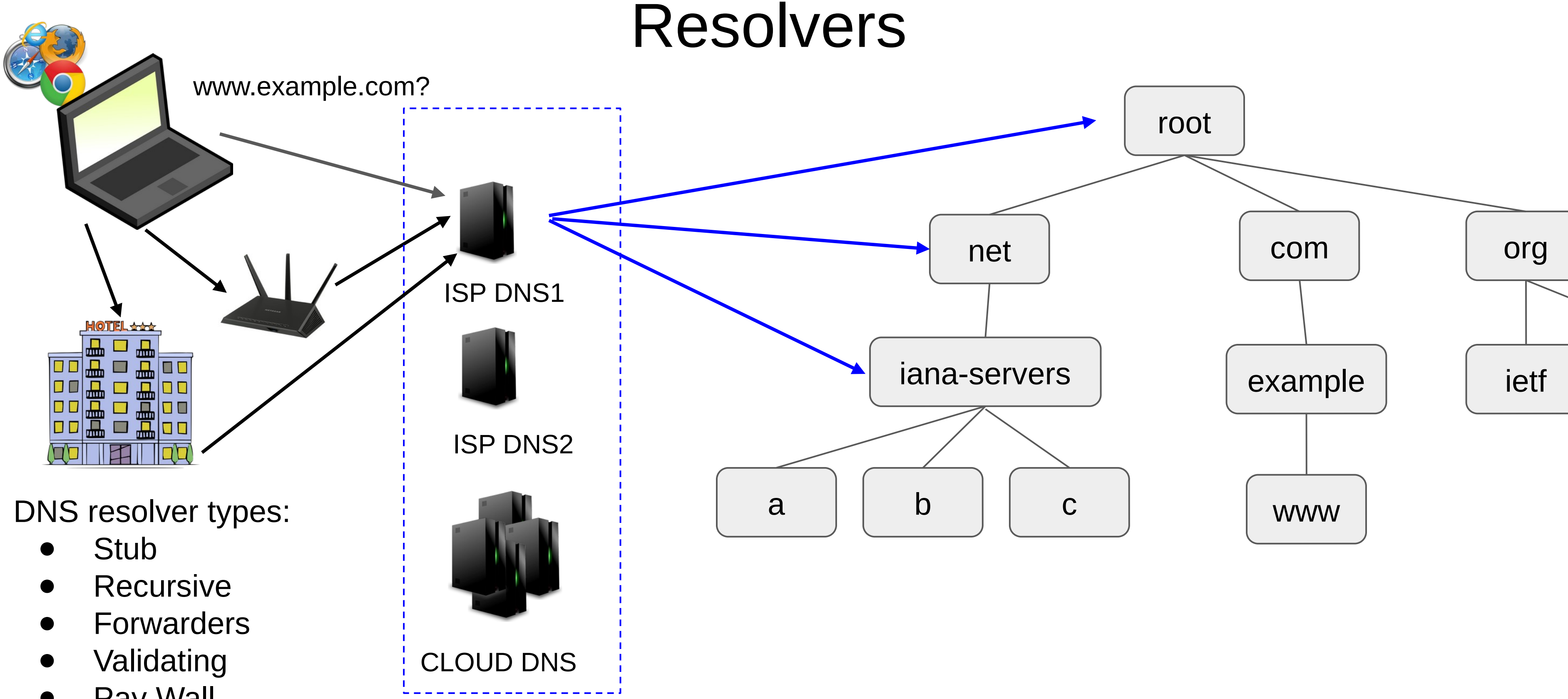
Top Level Domains (TLDs)

Second Level Domains (SLDs)



IMPORTANT: name server records in .net (13), .com (13), and .org (6) are not shown in these slides

Resolvers



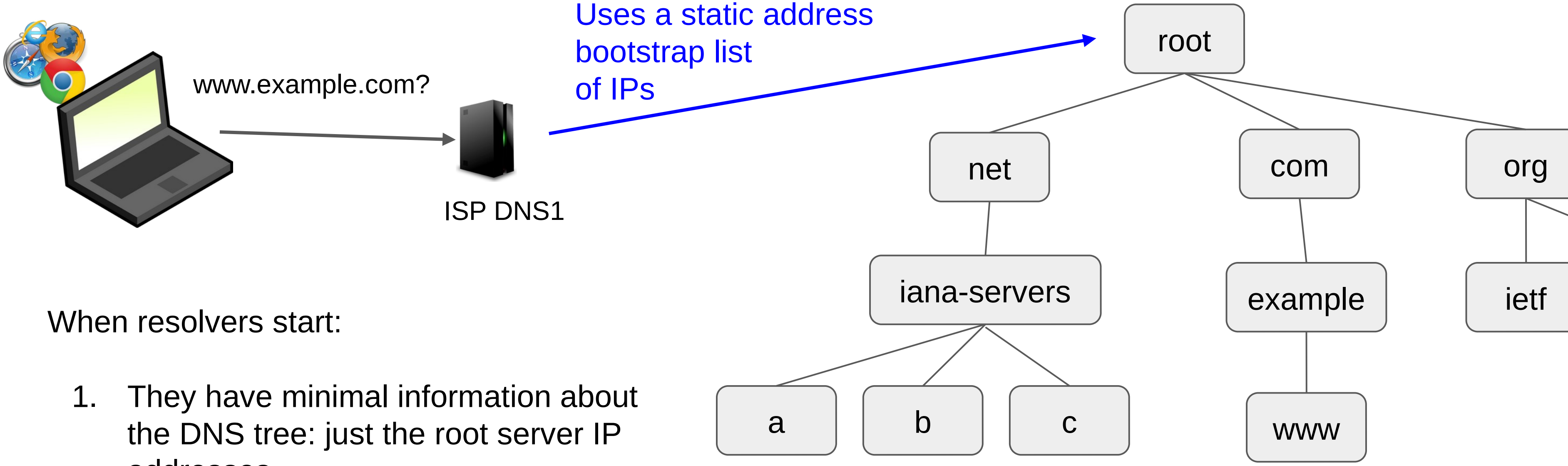
DNS resolver types:

- Stub
- Recursive
- Forwarders
- Validating
- Pay Wall

(to be described later)

Resolvers query the tree to find your answer

Priming Queries -- Bootstrapping Resolvers



Uses a static address bootstrap list of IPs

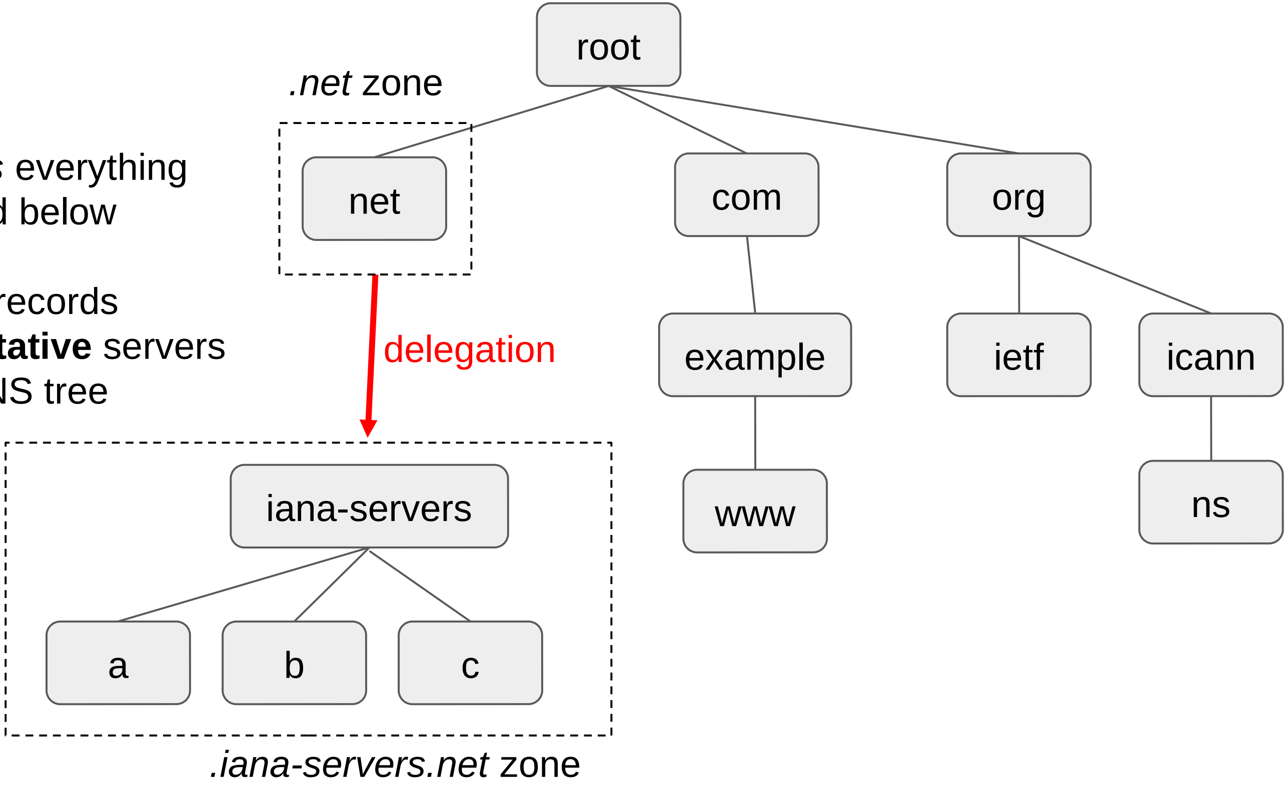
When resolvers start:

1. They have minimal information about the DNS tree: just the root server IP addresses.
2. The first thing they do is query them to ensure their hard-coded list is still correct

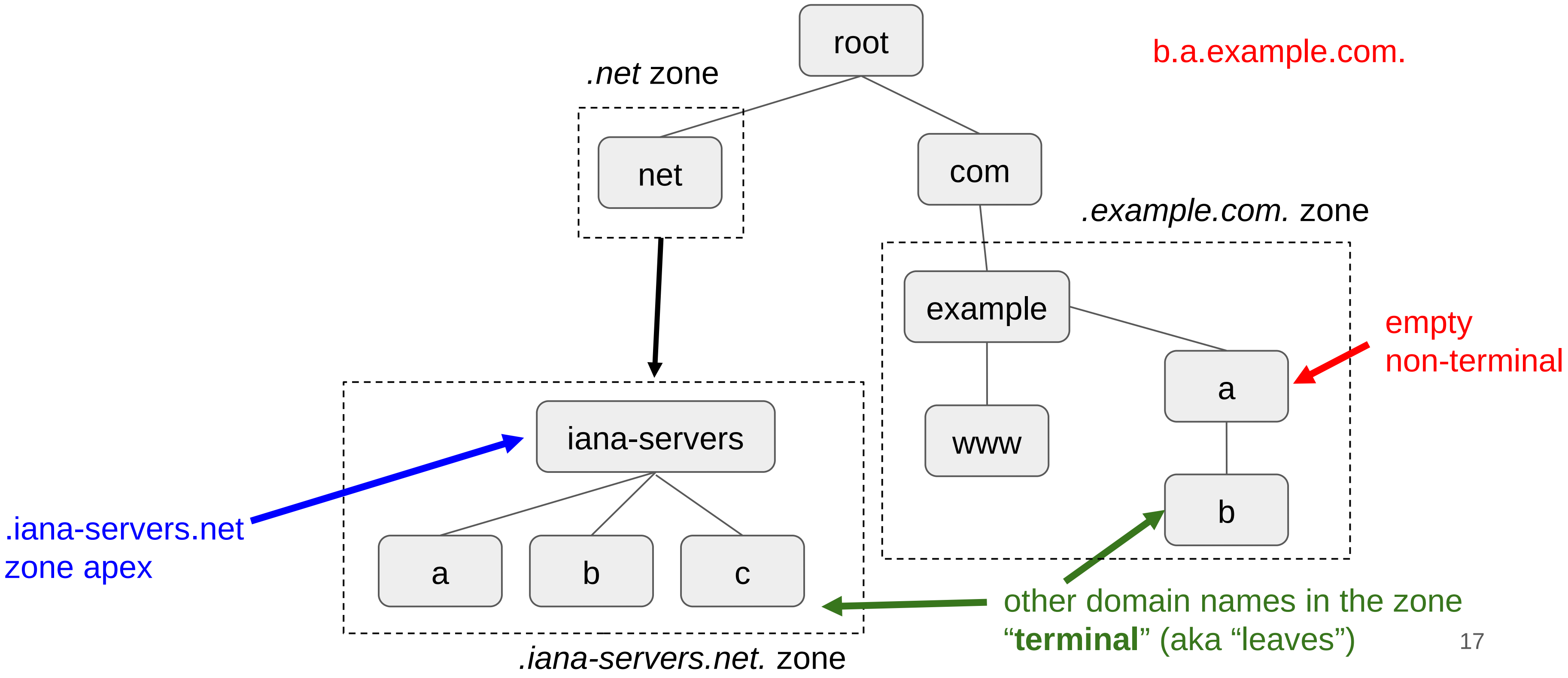
This is called a “priming query”

The DNS is a **distributed** protocol via **delegations**

The **.net** zone *delegates* everything in **.iana-servers.net** and below to **.iana-servers.net** using *nameserver (**NS**)* records that point to the **authoritative** servers for that portion of the DNS tree



Some DNS Terminology



b.a.example.com.

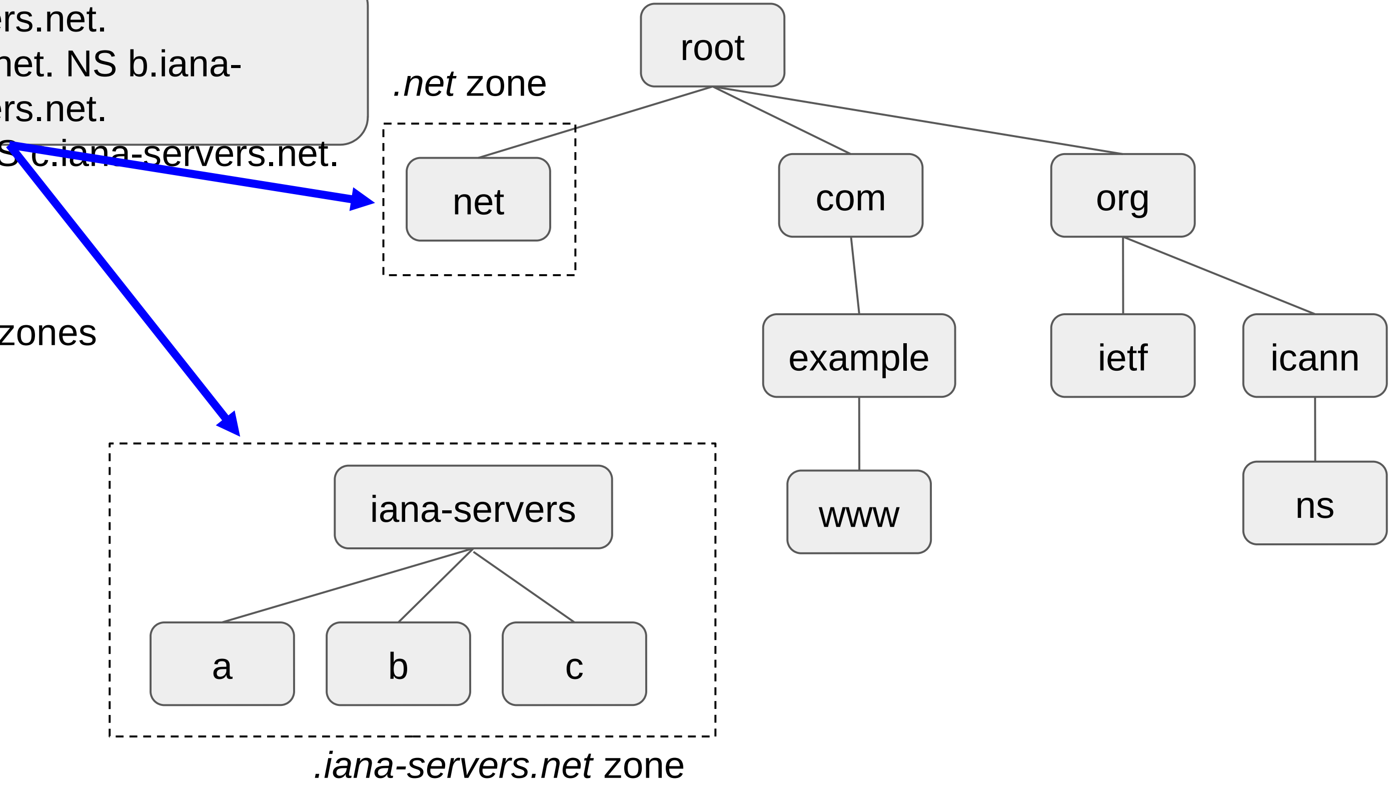
empty
non-terminal

.iana-servers.net
zone apex

other domain names in the zone
"**terminal**" (aka "leaves")

Duplicate records needed in parent/child zones

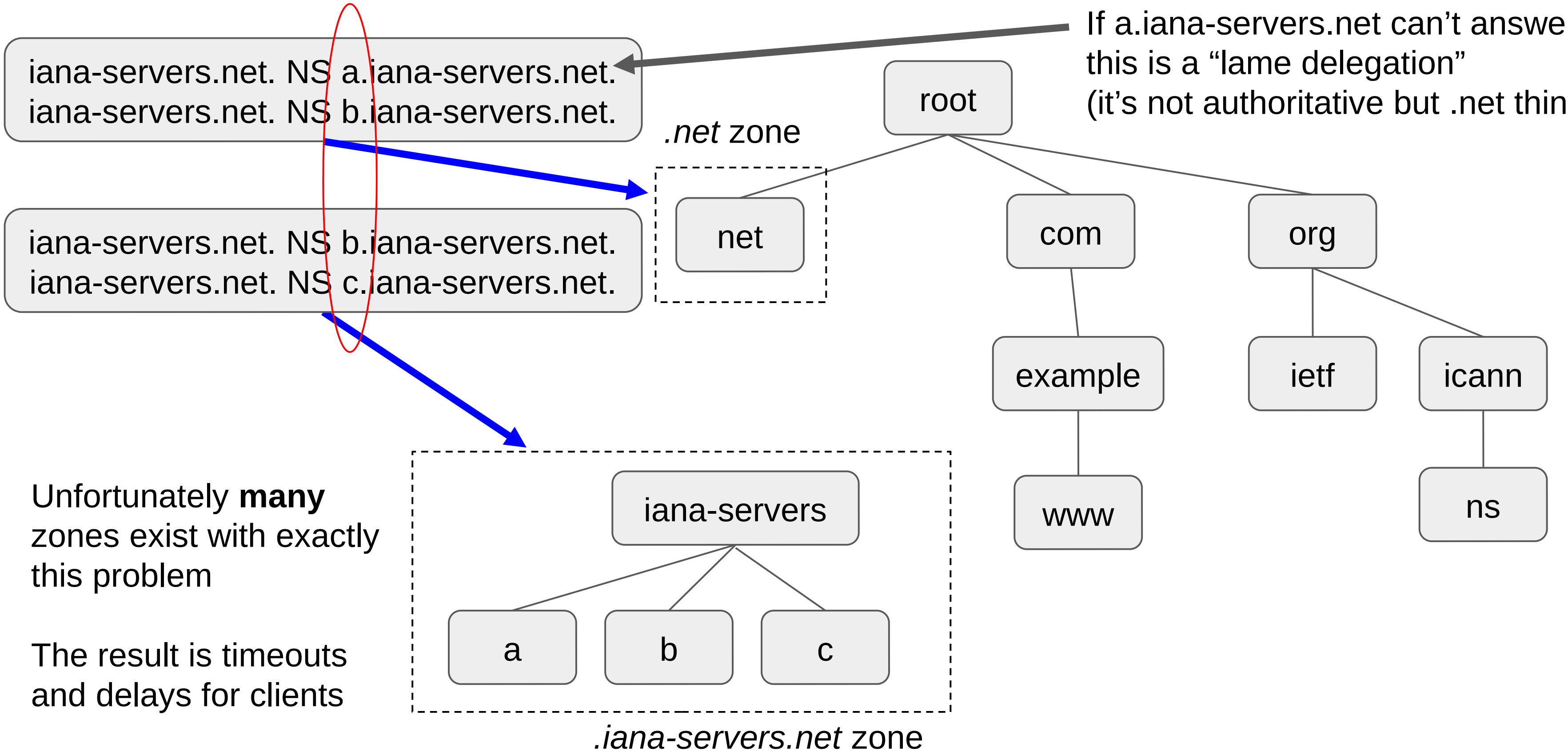
iana-servers.net. NS a.iana-servers.net.
iana-servers.net. NS b.iana-servers.net.
iana-servers.net. NS c.iana-servers.net.



Should be in both zones

The child is the authoritative source!

Does this work? -- Yes but actually not well



iana-servers.net. NS a.iana-servers.net.
iana-servers.net. NS b.iana-servers.net.

iana-servers.net. NS b.iana-servers.net.
iana-servers.net. NS c.iana-servers.net.

If a.iana-servers.net can’t answer,
this is a “lame delegation”
(it’s not authoritative but .net thinks it is)

Unfortunately **many** zones exist with exactly this problem

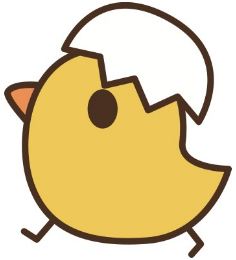
The result is timeouts and delays for clients

Trees that refer to the Forest

- Let’s query ***.com***’s servers about **example.com**:

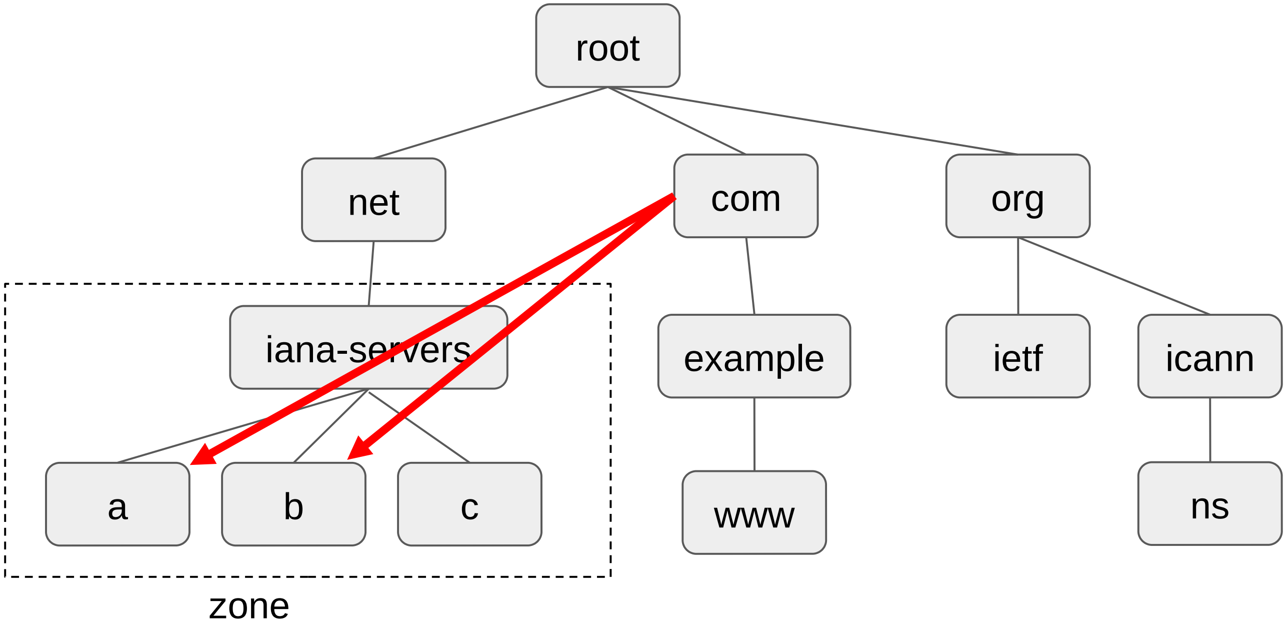
```
# dig @a.gtld-servers.net. www.example.com A
;; AUTHORITY SECTION:
example.com.     172800 IN  NS  a.iana-servers.net.
example.com.     172800 IN  NS  b.iana-servers.net.
```

2 day TTL



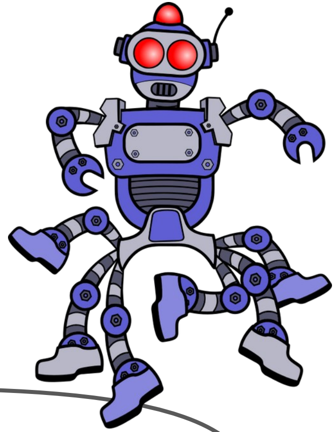
- The answer: *.com* doesn’t know where *www.example.com* is
- But it does know where to send you next: **to IANA-SERVERS.NET**
- ***But where is IANA-SERVERS.NET???***
  - *(here we go again)*

Finding Authoritative Servers -- Pictorially



If you **ask *.com*** where ***www.example.com*** is, they tell you to go ask a **completely different part of the tree**

Tricky Tree Grafting -- AKA, what is glue?



```
# dig @c.gtld-servers.net. iana-servers.net ns    (asking .net)
;; ANSWER SECTION:
iana-servers.net.     956  IN   NS   a.iana-servers.net.
iana-servers.net.     956  IN   NS   ns.icann.org.
iana-servers.net.     956  IN   NS   c.iana-servers.net.
iana-servers.net.     956  IN   NS   b.iana-servers.net.
```

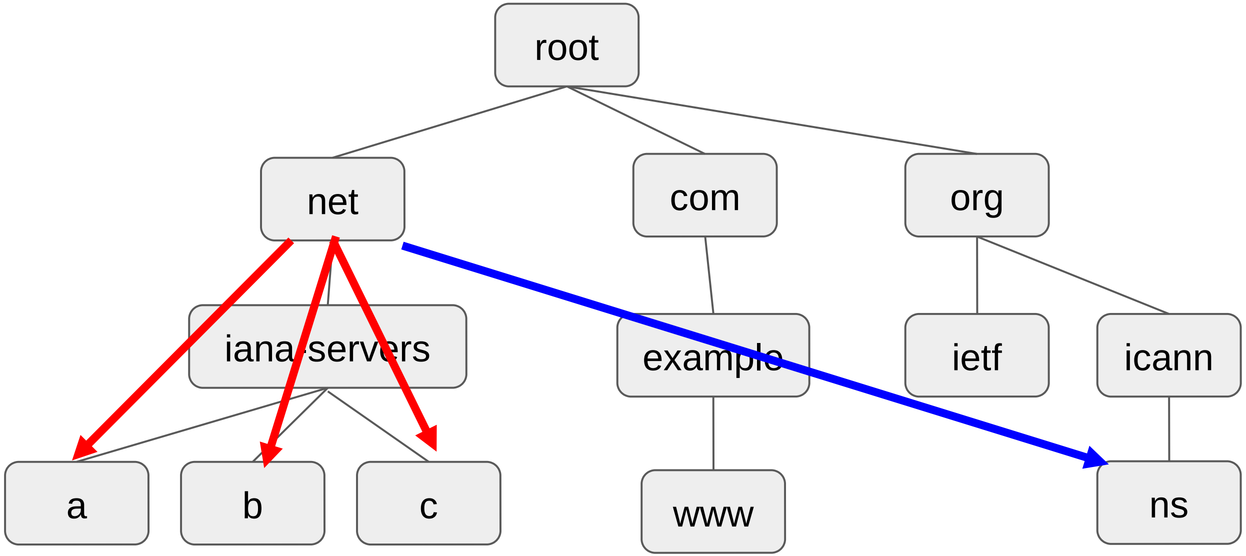
Glue!

How do I talk to *a.iana-servers.net* if it's *inside iana-servers.net itself??*

```
;; ADDITIONAL SECTION:
a.iana-servers.net.   956  IN   AAAA    2001:500:8f::53
b.iana-servers.net.   956  IN   AAAA    2001:500:8d::53
...
```

(note the random ordering of the answer section)

Including Glue



- ***.net's** nameservers* knows where **the authoratatative source for iana-servers.net is**
- "In-balliwick" name servers are within the zone itself
  - But {a,b,c}.iana-servers.net Must have glue records!
- "Out-of-balliwick" servers are external
  - *ns.icann.org* is out-of-balliwick for *iana-servers.net*

DNS Packet Evolution

```
                                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                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

```
                                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                     /
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

DNS - A very very simple protocol

- DNS packets ship resource records around
- All ***Resource Records*** are composed of a triplet
  - A Query Name   “www.example.com”   (aka a “domain name”)
  - A Query Type   AAAA = IPv6 address
  - A Query Class   IN = Internet   *(aka, almost the only value used)*
- Resource Record Sets
  - ALL matching combinations are an atomic unit
  - You can’t ask for “just 2”
  - They are **not ordered**
- Response Records also contain
  - A *“Time To Live”*
  - Response Data

DNS Packet Components

- Header
  - Transaction ID
  - Flags
  - Number of records in each section
- DNS Resource Record Sections
  - Question
  - Answer
  - Authoritative
  - Additional

Why are multiple questions a problem?

- Do you wait for all authoritative answers?
- What if one authoritative answer has an error and another doesn't?
- What if there are two different errors?
- ...

RFC1035:
[This] section contains QDCOUNT (usually 1) entries

DNS Packet Sections

- Question
  - Where the (single) question goes
  - Repeated in a response
- Answer
  - The answer to the question
- Authoritative
  - What DNS server is the “true” source for the answers
- Additional
  - Anything else you might want to know
    - But shouldn’t trust!
  - E.G., Glue

What happens when DNS things go wrong?

The DNS packet headers contain an “response code” (RCODE) field, yay!

```
                                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   |
```

Drat, it’s only **4 bits…** There are way more than 16 problems

Let’s get creative about the RCODE problem

What if….

Now bear with me….

What if….

We stuck the extra bits somewhere else?

And thus, the “**OPT**” (pseudo-) resource record was created

EDNS0’s “OPT” record -- more bits! RFC2671

- An **“extend” pseudo resource** record to add to the **additional section**
- DNS servers only respond with one if the **client indicates support**
- **Required** to support some protocol modifications (e.g. DNSSEC)
- Reuses the Resource Record byte format, but **changes many fields**
- **Features:**
  - Total RCODE size becomes 4 + 8 = 12 bits
  - Supports additional protocol flags
  - Adds application level max message size / PMTU type discovery
  - Adds support for additional DNS extensions
- Used for other extensions:
  - Client Subnet in DNS Queries (RFC7871)
  - Extended errors (RFC-TBD)
  - ...

OPT Resource Record Field Reusage

RR Field	New Meaning
NAME	Must be empty
TYPE	OPT(41) (16 bits)
CLASS	UDP Payload Size (16 bits) -- max response accepted
TTL (32 bits)	Extended RCODE (8 bits), version (8 bits = 0) and Flags (16 bits)
RDLEN	Data length (same)
RDATA	Atribute (16-bit)/value (variable length) pairs

Truncation

What happens when a response is too big?

- Greater than the client said it could handle in the OPT/UDP Payload Size

A few things:

- The Truncation bit (TC) is set
- Resource records are removed from the response to make it fit. Maybe.
    - Some try to remove unimportant items (the additional section goes first)
    - Some servers drop everything and just expect clients to use TCP
    - Response Rate Limiting (RRL) -- a DDoS defense -- triggers the TC bit due to query frequency
- Clients need to come back over TCP to get the full answer
    - Sometimes clients come back and sometimes they don’t if they got the answer they wanted

Ok, but what if you need MOAR errors, text, etc...

What if….

Now bear with me….

What if….

We stuck the extra bits somewhere else?

A soon to be RFC: extended errors!Another OPT

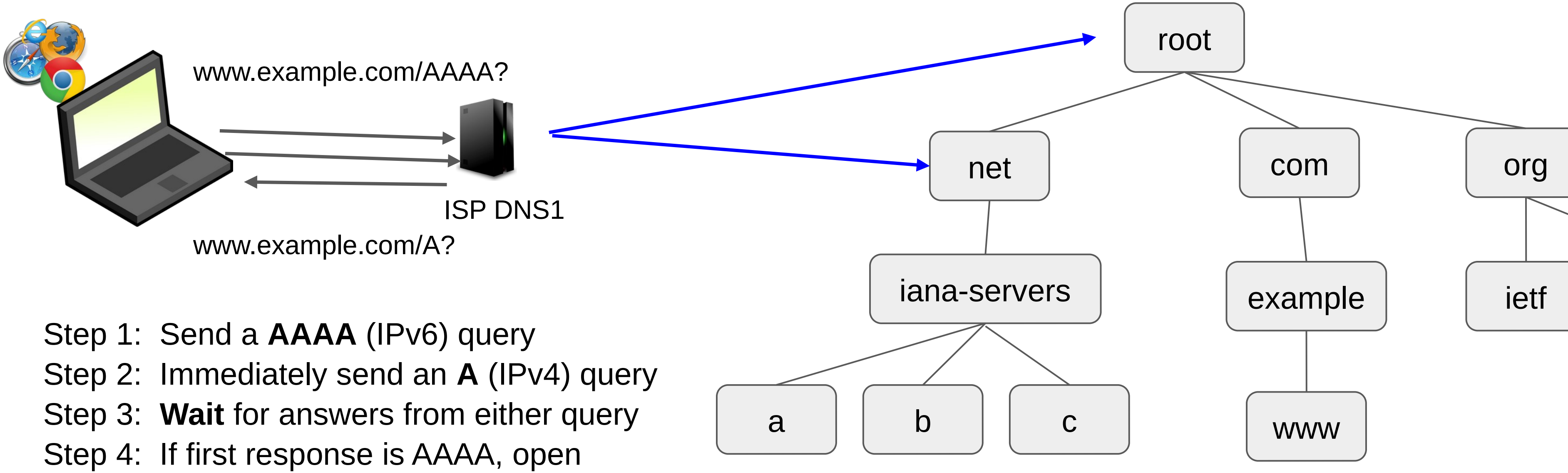
(it’s errors all the way down)

DNS Resource Record Types

Resource Record Types

Type	Content
A	IPv4 Address
AAAA	IPv6 Address
SOA	Zone information at the APEX
TXT	Free-form text blob

IPv4/IPv6 Deployment: Happy Eyeballs (RFC8305)



www.example.com/AAAA?

ISP DNS1

www.example.com/A?

root

net

com

org

iana-servers

example

ietf

a

b

c

www

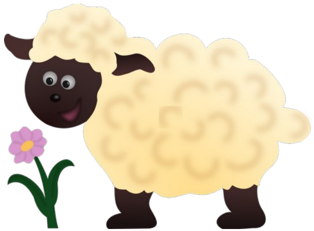
Step 1: Send a **AAAA** (IPv6) query

Step 2: Immediately send an **A** (IPv4) query

Step 3: **Wait** for answers from either query

Step 4: If first response is AAAA, open connection. If first response is A, wait a bit (50ms) for a AAAA and then give up and open an IPv4 connection with sadness.

Step 5: **Profit** from your dual-stack deployment!



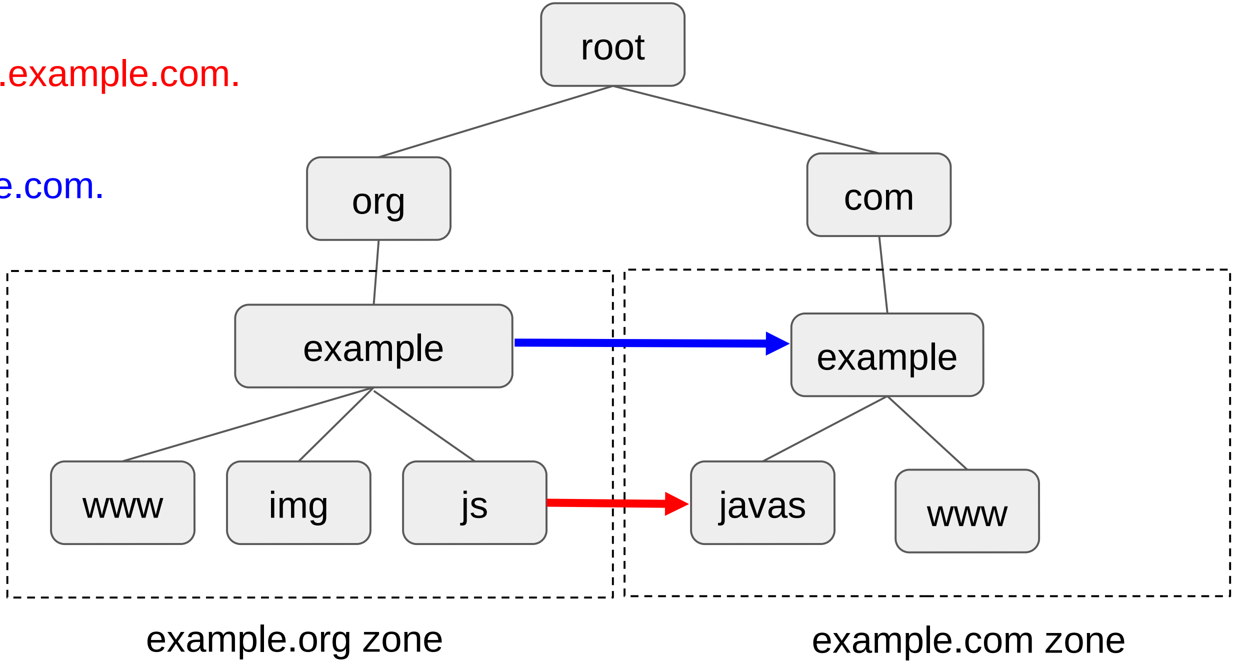
CNAMEs and DNAMEs

js.example.org. 3600 IN CNAME javas.example.com.
CNAMEs cannot occur at the apex

example.org. 3600 IN DNAME example.com.

CNAMEs are aliases for other tree elements (can be in the same zone or in another)

DNAMEs are aliases for zones themselves

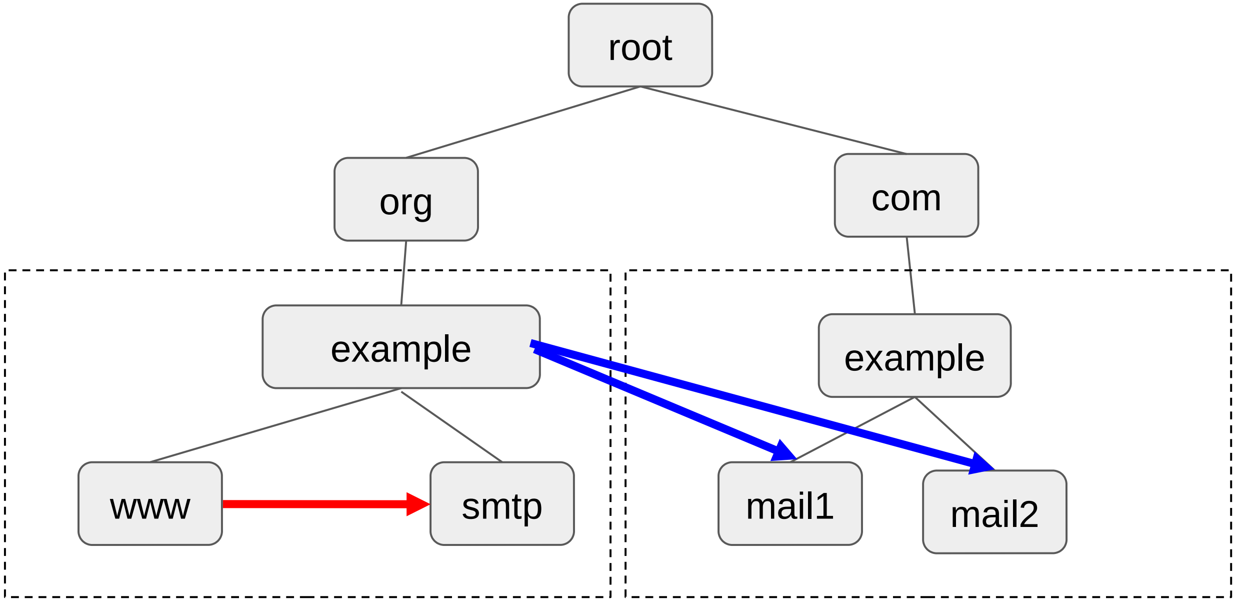


IMPORTANT: CNAMEs MUST exist alone at a name (minus DNSSEC entries)
IMPORTANT: CNAMEs point to ALL records at the other name (A, AAAA, NS, MX, etc)

MX Records

Mail Exchange (MX) records

- Where should e-mail for a domain-name be sent?
- Prioritized contact list



```
www.example.org.     3600 IN AAAA    2606:2800:220:1:248:1893:25c8:1946
www.example.org.     3600 IN MX      5 smtp.example.org.

example.org.         3600 IN AAAA          93.184.216.34
example.org.         3600 IN MX            10 mail1.example.com.
example.org.         3600 IN MX            20 mail2.example.com.
```

Outsourcing mail service is very common

Wildcards (RFC4592)

- Generating responses for missing data
  - Left most label must be a "*" (and only a "*")
  - Matches any label that doesn't already exist
    - Including sub-labels under it
  - Causes a nameserver to **synthesize and answer**
  - **Please read RFC4592**! Good examples therein.
- Example records:

```
*.example.com.      3600 IN MX  10 mail.example.com
host1.example.com.  3600 IN A   192.0.2.1
```

- Reponses:

```
host1.example.com/MX    MATCHES
host2.example.com/MX    MATCHES
host1.example.com/A     DOESN'T MATCH (returns 192.0.2.1)
host2.example.com/A     DOESN'T MATCH (returns NXDOMAIN)
```

Underbar labels: “_foo” (RFC855{2,3})

- For a long time people kept putting TXT records at the APEX
  - SPF
  - DKIM
  - DOMAINKEY
  - DNS ownership verification (google, facebook, docusign, …)
  - …
- The “right” solution was to use a new RRTYPE rather than TXT
  - But this was slower to deploy
- The new solution: use TXT and RRTYPE records at “_” prefixes
  - _spf.example.com. IN TXT - The right “new” for SPF
  - _domainkey.example.com. IN TXT - DKIM key publishing
  - _25._tcp.mail.example.com. IN TLSA - DANE for secured SMTP (RFC7672)
  - _imaps._tcp.example.com. IN SRV - Service host discovery

Summary: DNS is a global distributed identifier DB

Yes, but how does this all scale so well?

I have no idea

Let’s ask Geoff

Extended Errors RFC -- in the RFC editor’s queue

- **SERVFAIL** error is the standard “I couldn’t” response
  - Operators are clueless as to why
  - e.g. most types of DNSSEC validation failures triggers this
- Extended error **adds context** for SERVFAIL (and others)
- With **optional text** providing greater debugging detail