CSCI-1680
DNS

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Based partly on lecture notes by Rodrigo Fonseca, Scott Shenker and John Jannotti

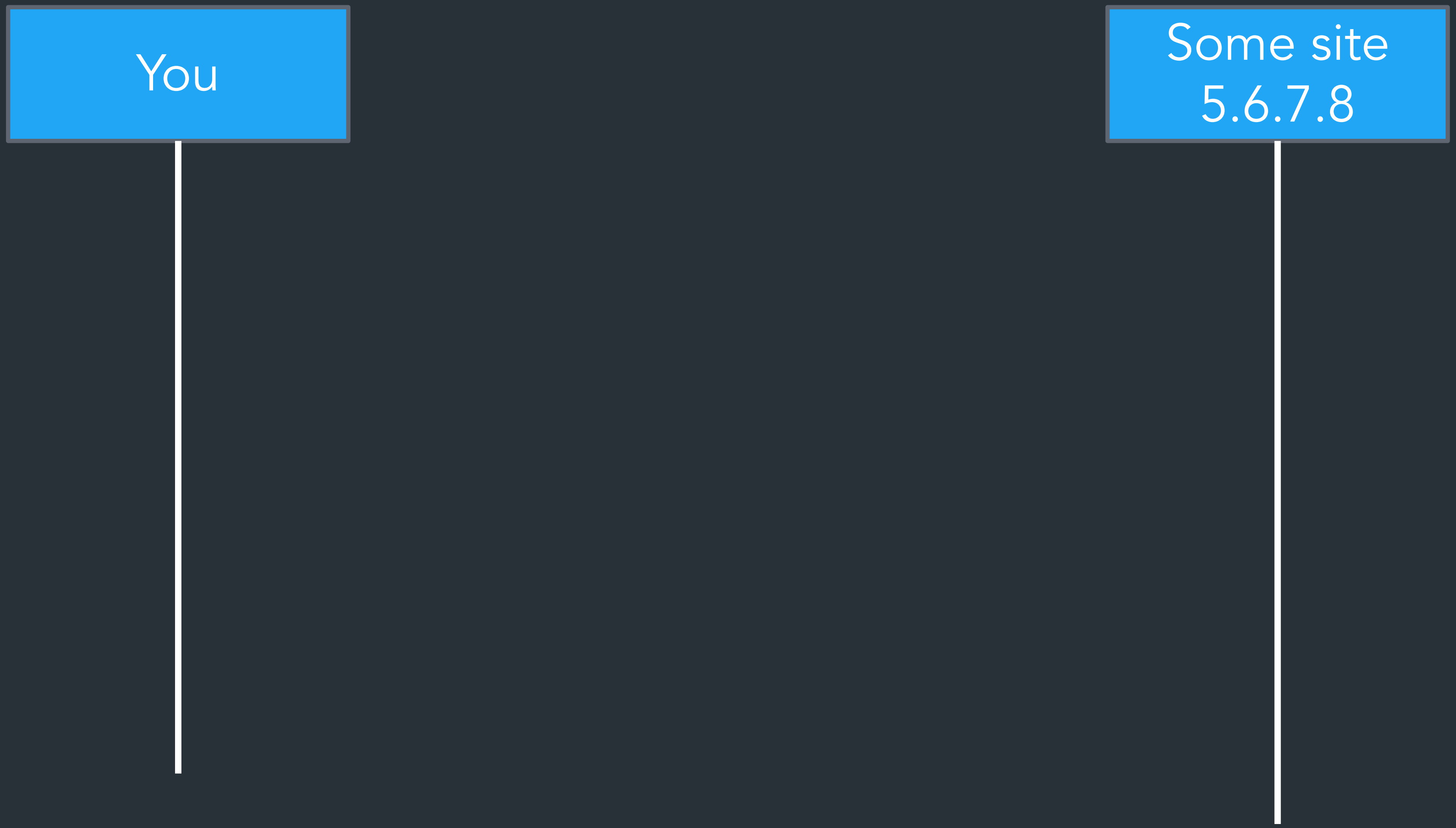
Administrivia

- TCP milestone II: sign up for a meeting this week (announcement soon)
- TCP gearup III: tentative, but probably this Thursday 5-7pm
- HW3: due tonight—it's short!

We're working through our grading backlog, should have progress soon

Connecting to a server: the story so far

POV: You want to connect to some website



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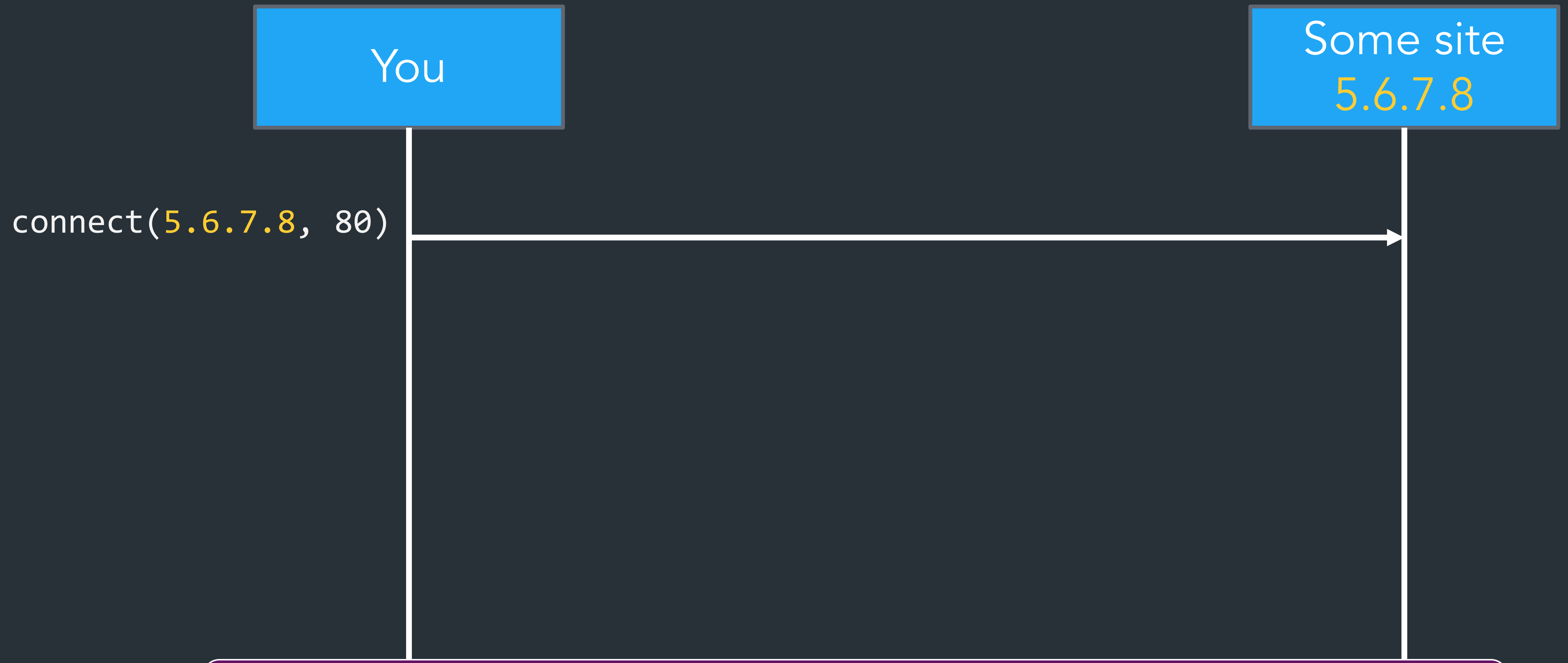
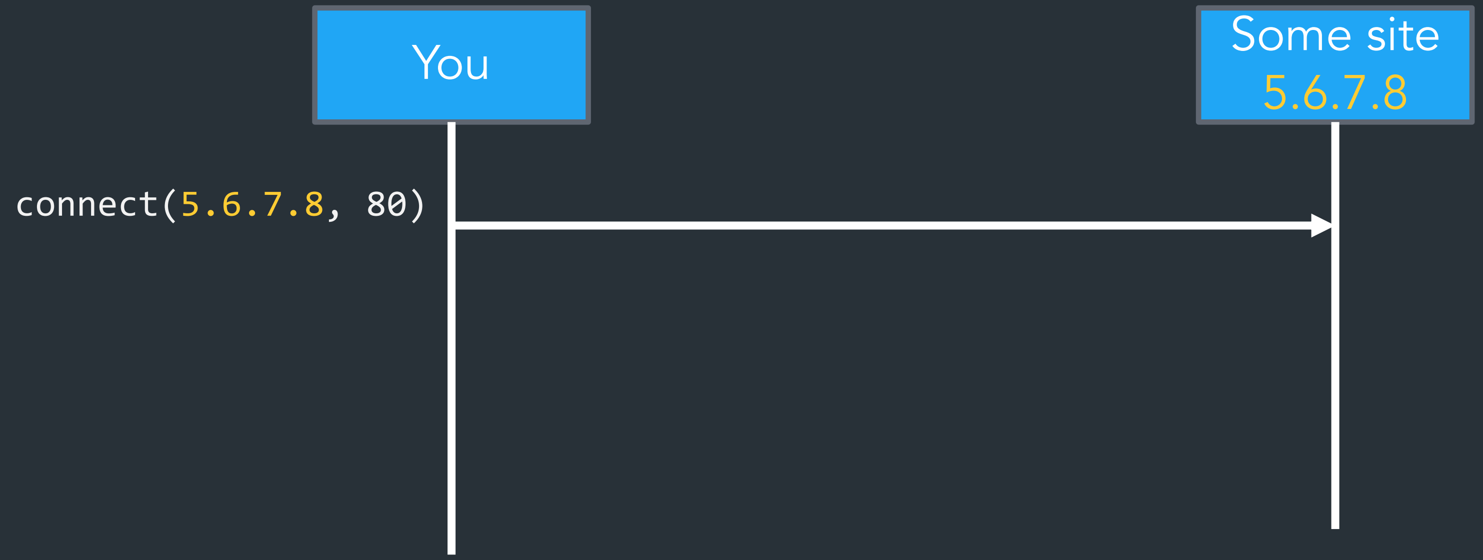


Is this how users interact with the network? No!

Why not? Why is this bad?



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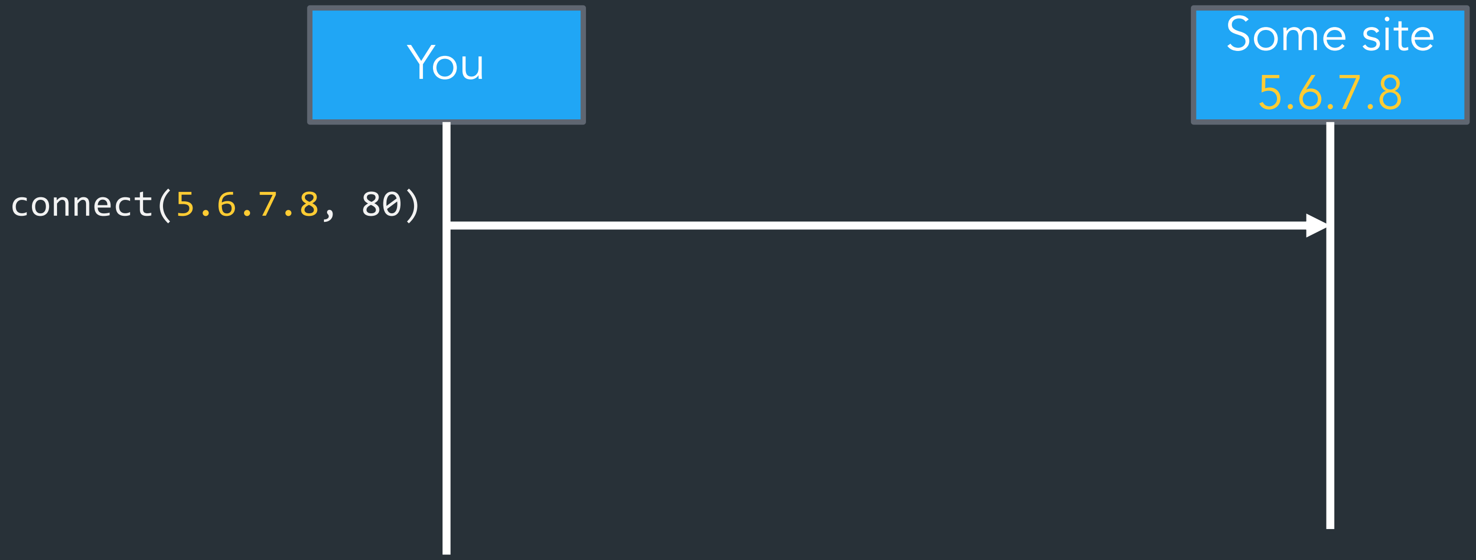

- Need to know IP addresses!
  - Users won’tk now
  - Hosts don’t know—can’t remember every single one!
- Some host ?= its IP address?   No!
  - A large website may be run by many servers
  - Devices may move between networks

What we have so far

IP addresses

- Used by routers to forward packets
- Fixed length, binary numbers
- Assigned based on where host is on the network
- Usually refers to one host

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Examples

- 5.6.7.8
- 212.58.224.138
- 2620:6e:6000:900:c1d:c9f7:8a1c:2f48

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Human readable: ❌
Scalable for distributed services: ❌

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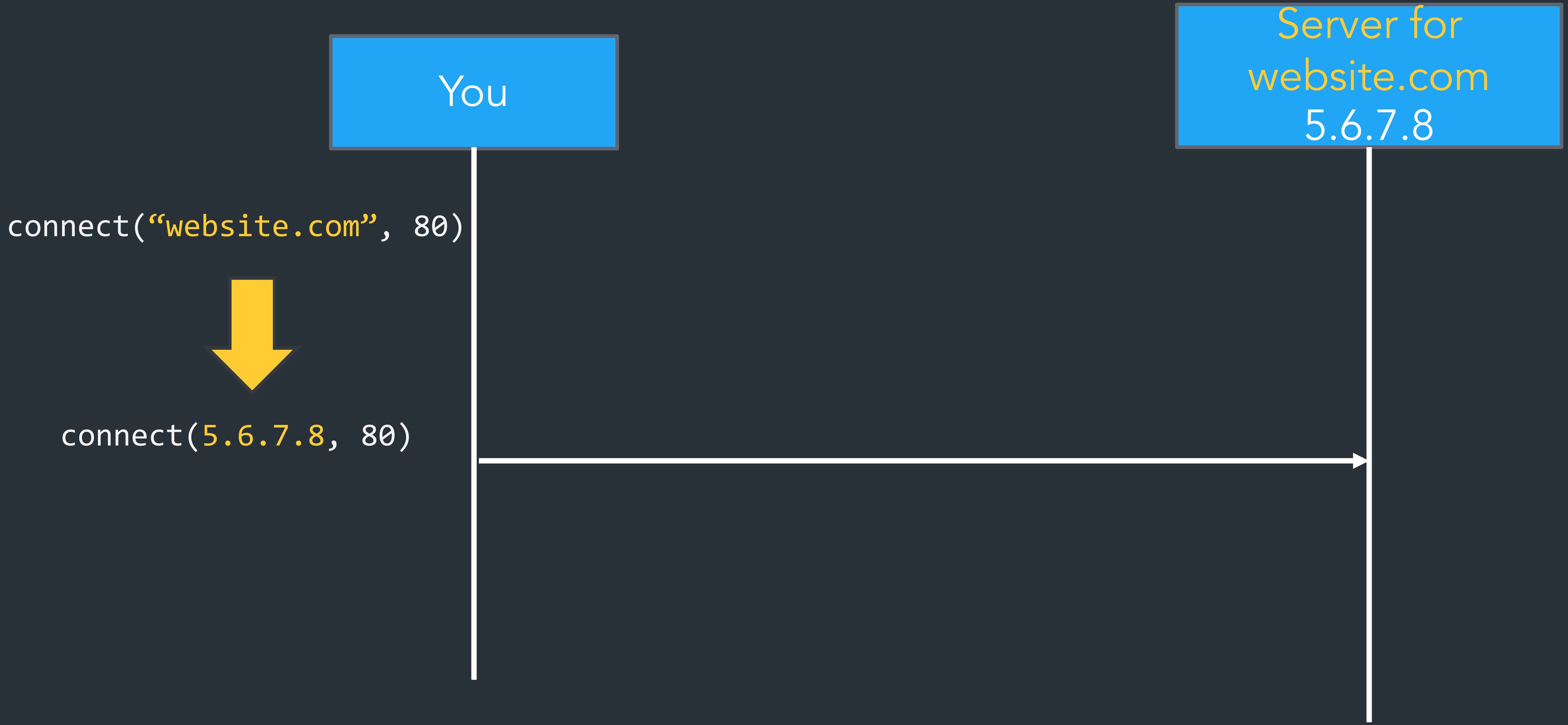
=> Need a new abstraction for "stuff" we are trying to access

What we want: a new abstraction for names



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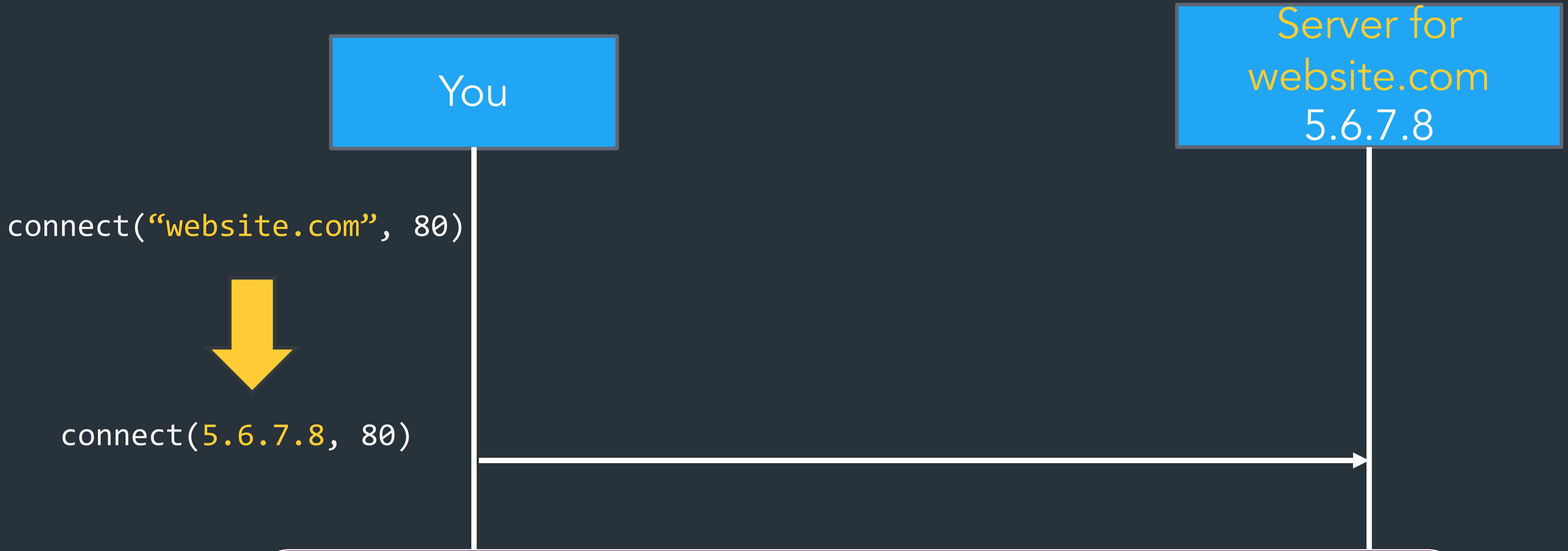

Want: names
- Human-readable
- Variable length
- Don’t need to care about where destination is/what server it is
  => Can refer to a service, not just a host

What does this mean?

`cs.brown.edu => 128.148.32.110`

Why?

- Names are easier to remember
- Addresses can change underneath

- Useful Multiplexing/sharing

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```
cs.brown.edu => 128.148.32.110
```

Why?

- Names are easier to remember
- Addresses can change underneath
  - e.g, renumbering when changing providers
- Useful Multiplexing/sharing
  - One name -> multiple addresses
  - Multiple names -> one address

Another Change in Layers…

- Remember ARP
  - ARP: maps IP addresses to MAC addresses

The original way: one file: `hosts.txt`

- Flat namespace
- Central administrator kept master copy (for the Internet)
- To add a host, emailed admin
- Downloaded file regularly

```
320 -- ************************
10-Jun-82 17:48:41-PDT,114828;000000000000
Mail-from: ARPANET host SRI-NIC rcvd at 10-Jun-82 1747-PDT
Date: 10 Jun 1982 1742-PDT
From: Dyer
Subject: Hostname table, 10-June-82
To:   dcacode252 at USC-ISI
cc:   nic

      ARPANET HOST NAMES AND LIAISON                  10-Jun-82

HOST NAME    HOST ADDRESS     SPONSOR        LIAISON

ACC             10.2.0.54   VDH  ARPA   Lockwood, Gregory (LOCKWOOD@BBNC)
                                         Associated Computer Consultants
                                         414 East Cota Street
                                         Santa Barbara, California 93101
                                         (805) 965-1023
   CPUtype: PDP-11/70(UNIX)
ACCAT-TIP       10.2.0.35        ARPA   McBride, William T.
                                         (MCBRIDE@USC-ISIC)
                                         Naval Ocean Systems Center
                                         Code 8321
                                         271 Catalina Boulevard
                                         San Diego, California 92152
                                         (714) 225-2083 (AV) 933-2083
   CPUtype: H-316
AEROSPACE       10.2.0.65        AFSC   Nelson, Louis C. (LOU@AEROSPACE)
                                         Aerospace Corporation
                                         A2/1013
                                         P.O. Box 92957
                                         Los Angeles, California 90009
                                         (213) 615-4424
   CPUtype: VAX-11/780(UNIX)
AFGL            10.1.0.66        AFSC   Cosentino, Antonio
                                         (COSENTINO@AFSC-HQ)
                                         Air Force Geophysics Laboratory
                                         SUNA
                                         Mail Stop 30
                                         Hanscom Air Force Base,
                                          Massachusetts 01731
                                         (617) 861-4161 (AV) 478-4161
   CPUtype: PDP-11/50(RSX11M) -> CDC-6600(NOS/BE)
AFGL-TAC        10.2.0.66        AFSC   Cosentino, Antonio
                                         (COSENTINO@AFSC-HQ)
                                         Air Force Geophysics Laboratory
                                         SUNA
                                         Mail Stop 30
                                         Hanscom Air Force Base,
                                          Massachusetts 01731
                                         (617) 861-4161 (AV) 478-4161
   CPUtype: C/30
```

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Does it scale?

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Does it scale?

Lol no.

Scalable (Address <-> Name) Mappings

Original way: one file: `hosts.txt`

- Flat namespace
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- To add a host, emailed admin
- Downloaded file regularly

Is this feasible today? Lol no.

Domain Name System (DNS)

- Originally proposed by RFC882, RFC883 (1983)

- Distributed protocol to translate hostnames -> IP addresses
  - Human-readable names
  - Delegated control
  - Load-balancing/content delivery
  - So much more…

=> Distributed key-value store, before it was cool…

Goals for DNS

- Scalability
- Distributed Control
- Fault Tolerance

Goals for DNS

- Scalability
  - Must handle a huge number of records
    - With some software synthesizing names on the fly
  - Must sustain update and lookup load
- Distributed Control
  - Let people control their own names
- Fault Tolerance
  - Minimize lookup failures in face of other network problems

The good news

Compared to other distributed systems, some properties that make these goals easier to achieve…

1. Read-mostly database

   Lookups MUCH more frequent than updates
2. Loose consistency

   When adding a machine, not end of the world if it takes minutes or hours to propagate

Can use lots and lots of caching

- Once you’ve lookup up a hostname, remember
- Don’t have to look again in the near future

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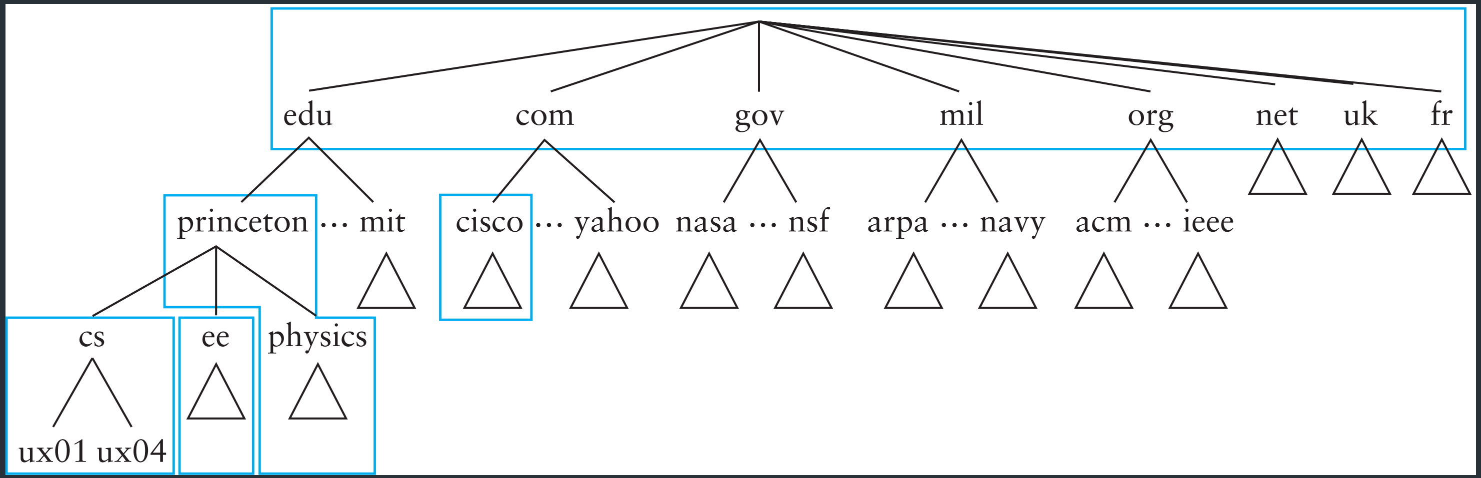
How it works

Hierarchical namespace broken into *zones*

```
cslab1a.cs.brown.edu
```

How it works

- Hierarchical namespace broken into *zones*
  - root (.), edu., brown.edu., cs.brown.edu.,
  - Zones separately administered => delegation
  - Parent zone tells you how to find servers for subdomains
- Each zone served from multiple replicated servers
- Lots and lots of caching



Types of DNS servers

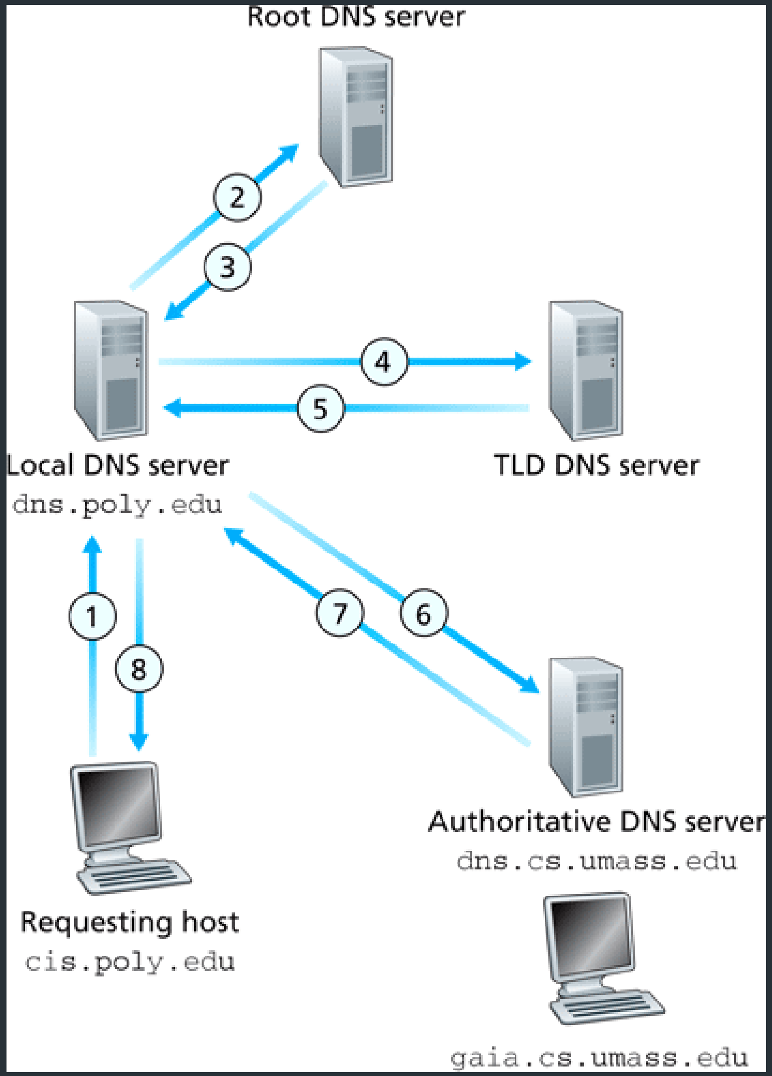
“Types” of DNS servers

- Top Level Domain (TLD) servers
  - Generic domains (e.g., com, org, edu)
  - Country domains (e.g., uk, br, tv, in, ly)
  - Special domains (e.g., arpa)
  - Corporate domains (…)
- Authoritative DNS servers
  - Provides public records for hosts at an organization
  - Can be maintained locally or by a service provider
- Recursive resolvers
  - Big public servers, or local to a network
  - Lots of caching

How a resolver works

Resolver operation

- Apps make recursive queries to local DNS server (1)
  - Ask server to get answer for you
- Server makes iterative queries to remote servers (2,4,6)
  - Ask servers who to ask next
  - Cache results aggressively

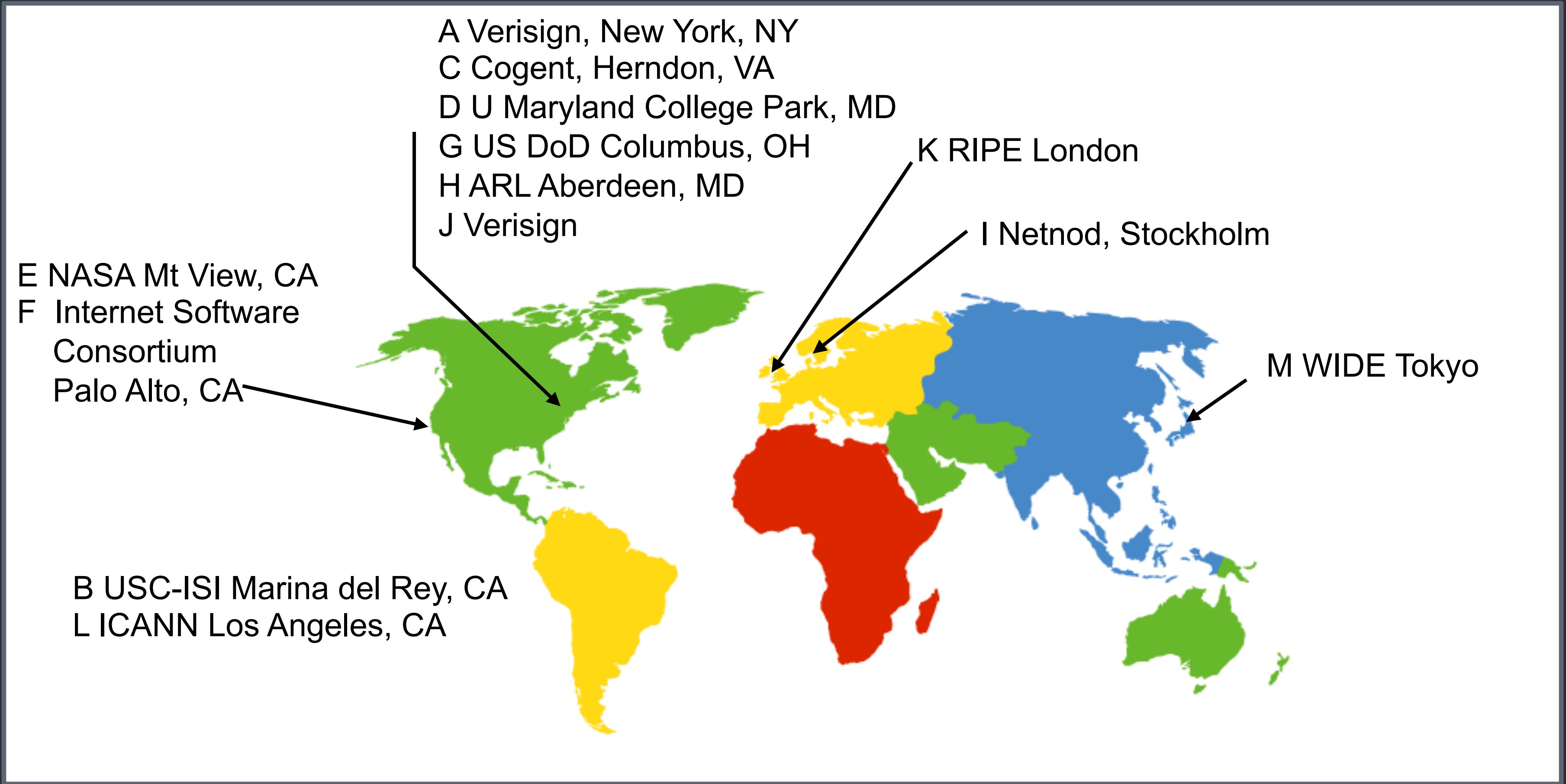


Where is the root server?

- Located in New York
- How do we make the root scale?

DNS Root Servers

- 13 Root Servers (www.root-servers.org)
  - Labeled A through M (e.g, A.ROOT-SERVERS.NET)
- Does this scale?



DNS Root Servers

- 13 Root Servers (www.root-servers.org)
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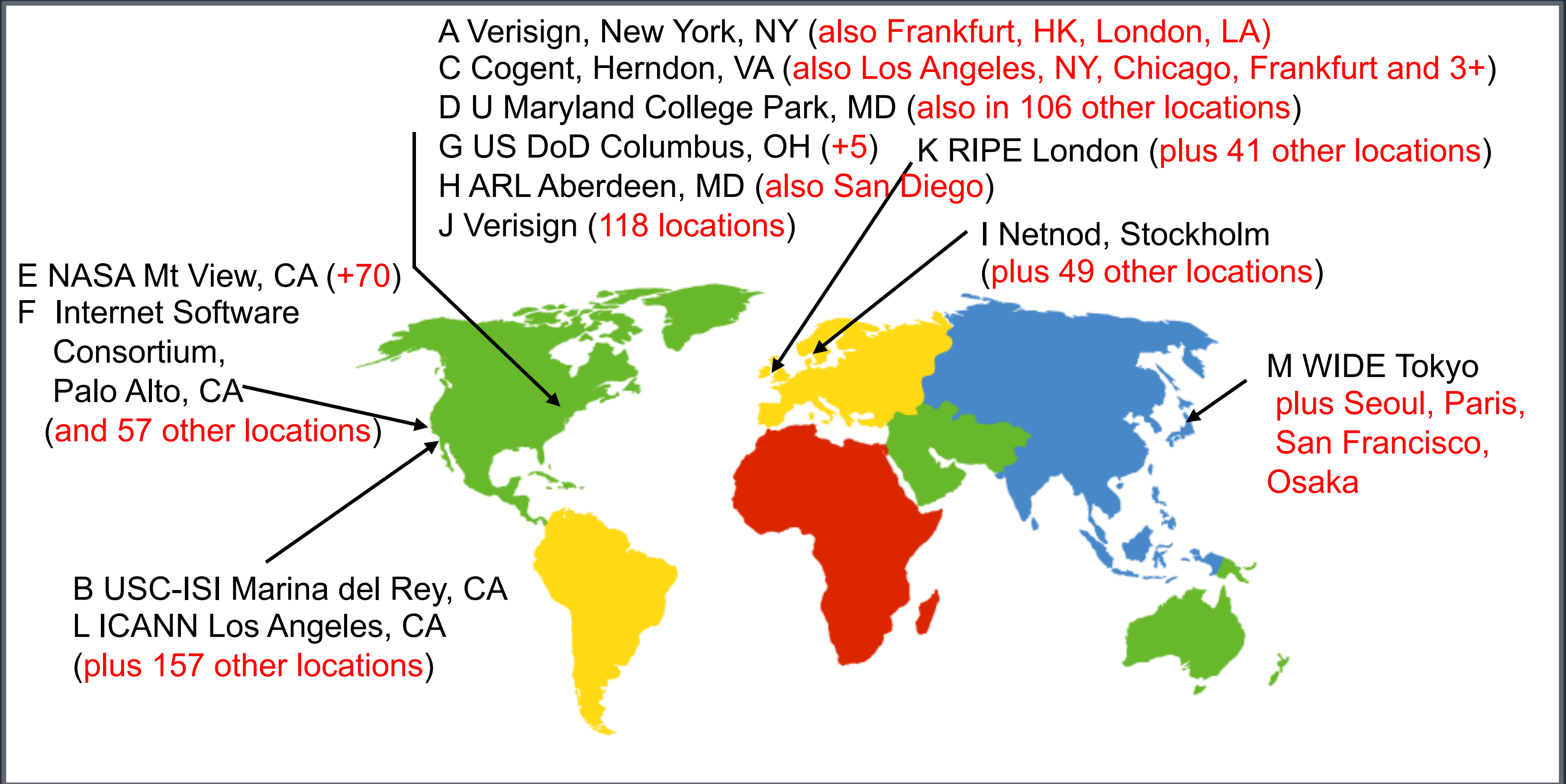
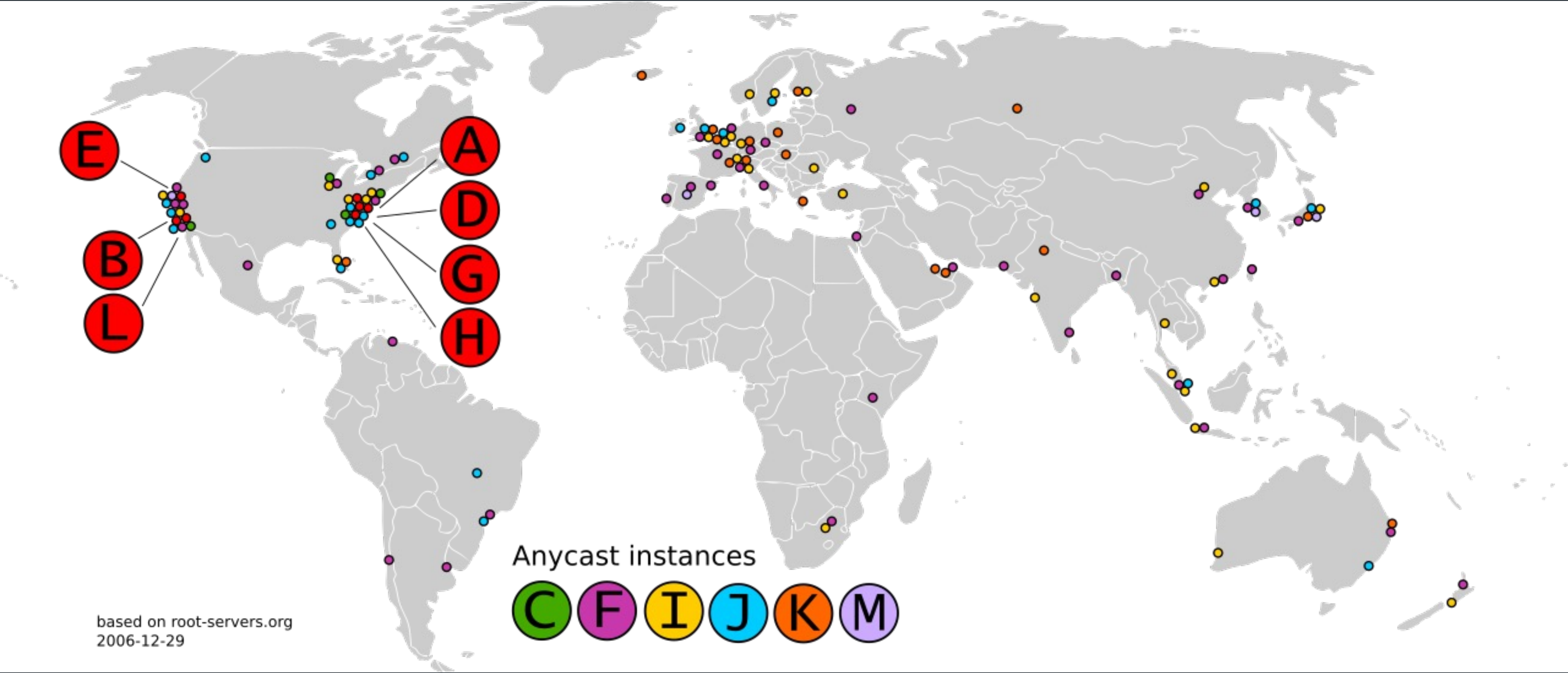
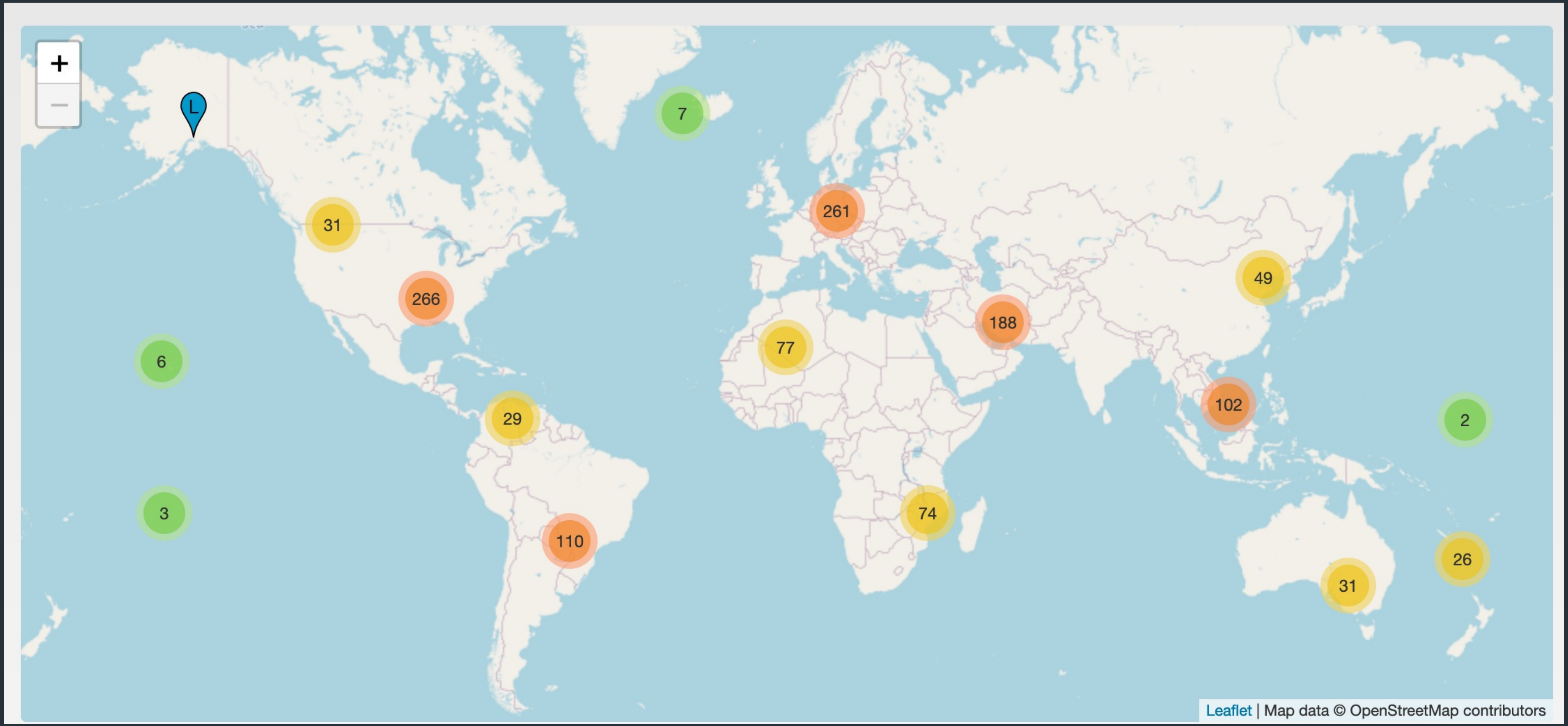
- Remember anycast?




E
B
L
A
D
G
H
Anycast instances
C
F
I
J
K
M
based on root-servers.org
2006-12-29

DNS Root Servers: Today



From: www.root-servers.org

DNS Caching

- Recursive queries are expensive
- Caching greatly reduces overhead
  - Top level servers very rarely change
  - Popular sites visited often
  - Local DNS server caches information from many users
- How long do you store a cached response?
  - Original server tells you: TTL entry
  - Server deletes entry after TTL expires

Reverse DNS

How do we get the other direction, IP address to name?

- Addresses have a natural hierarchy:
  - 128.148.32.12
- Idea: reverse the numbers: 12.32.148.128 …
  - and look that up in DNS
- Under what TLD?
  - Convention: in-addr.arpa
  - Lookup 12.32.148.128.in-addr.arpa
  - in6.arpa for IPv6

DNS Protocol

- TCP/UDP port 53
- Most traffic uses UDP
  - Lightweight protocol has 512 byte message limit
  - Retry using TCP if UDP fails (e.g., reply truncated)
- Bit in query determines if query is recursive

DNS Example

```
$ dig cs.brown.edu @10.1.1.10
; <<>> DiG 9.10.6 <<>> cs.brown.edu @10.1.1.10
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 8536
;; flags: qr aa rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 1


;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 1220
;; QUESTION SECTION:
;cs.brown.edu. IN A


;; ANSWER SECTION:
cs.brown.edu.            1800      IN      A        128.148.32.12


;; Query time: 69 msec
;; SERVER: 10.1.1.10#53(10.1.1.10)
;; WHEN: Tue Apr 19 09:03:39 EDT 2022
;; MSG SIZE  rcvd: 57
```

When server doesn't know all info…

```
% dig +norec cs.brown.edu @j.root-servers.net

; <<>> DiG 9.10.6 <<>> +norec cs.brown.edu @j.root-servers.net
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 61618
;; flags: qr; QUERY: 1, ANSWER: 0, AUTHORITY: 13, ADDITIONAL: 27

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 1232
;; QUESTION SECTION:
;cs.brown.edu. IN A

;; AUTHORITY SECTION:
edu. 172800 IN NS a.edu-servers.net.
edu. 172800 IN NS b.edu-servers.net.
edu. 172800 IN NS l.edu-servers.net.
edu. 172800 IN NS m.edu-servers.net.

;; ADDITIONAL SECTION:
a.edu-servers.net. 172800 IN A 192.5.6.30
b.edu-servers.net. 172800 IN A 192.33.14.30
c.edu-servers.net. 172800 IN A 192.26.92.30
d.edu-servers.net. 172800 IN A 192.31.80.30
e.edu-servers.net. 172800 IN A 192.12.94.30
```

Example

```
dig . ns

dig +norec www.cs.brown.edu @a.root-servers.net

dig +norec www.cs.brown.edu @a.edu-servers.net

dig +norec www.cs.brown.edu @bru-ns1.brown.edu

    www.cs.brown.edu.   86400 IN    A     128.148.32.110
```

Resource Records

All DNS info represented as resource records (RR)

name [ttl] [class] type rdata

- name: domain name
- TTL: time to live in seconds
- class: for extensibility, normally IN (1) "Internet"
- type: type of the record
- rdata: resource data dependent on the type

- Example RRs

```
www.cs.brown.edu.    86400  IN    A     128.148.32.110
cs.brown.edu.        86400  IN    NS    dns.cs.brown.edu.
cs.brown.edu.        86400  IN    NS    ns1.ucsb.edu.
```

DNS record types

RR Type	Purpose	Example
A	IPv4 Address	`128.148.56.2`
AAAA	IPv6 Address	`2001:470:8956:20::1`

CNAME	Specifies an alias
	("Canonical name")
		`systems.cs.brown.edu. 86400 IN`
		`CNAME systems-v3.cs.brown.edu.`
		`systems-v3.cs.brown.edu. 86400 IN A 128.148.36.51`

MX	Mail servers	`MX <priority> <ip>` `eg. MX 10 1.2.3.4`
SOA	Start of authority	Information about who owns a zone
PTR	Reverse IP lookup	`7.34.148.128.in-addr.arpa. 86400 IN` `PTR quanto.cs.brown.edu.`
SRV	How to reach specific services (eg. host, port)	`_minecraft._tcp.example.net 3600` `SRV <priority> <weight> <port> <server IP>`

More: https://en.wikipedia.org/wiki/List_of_DNS_record_types

Inserting a Record in DNS

Your new startup helpme.com

Some important details

- How do local servers find root servers?
  - DNS lookup on a.root-servers.net ?
  - Servers configured with *root cache* file
  - Contains root name servers and their addresses

```
.                        3600000  IN  NS    A.ROOT-SERVERS.NET.
A.ROOT-SERVERS.NET.      3600000      A     198.41.0.4
...
```

- How do you get addresses of other name servers?
  - To obtain the address of www.cs.brown.edu, ask a.edu-servers.net, says a.root-servers.net
  - How do you find a.edu-servers.net?
  - Glue records: A records in parent zone

Other uses of DNS

- Local multicast DNS
  - Used for service discovery
  - Made popular by Apple
  - This is how you learn of different Apple TVs in the building
- Load balancing
- CDNs (more on this later)

Reliability

- Answers may contain several alternate servers
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Use same identifier for all queries
  - Don't care which server responds, take first answer

Inserting a Record in DNS

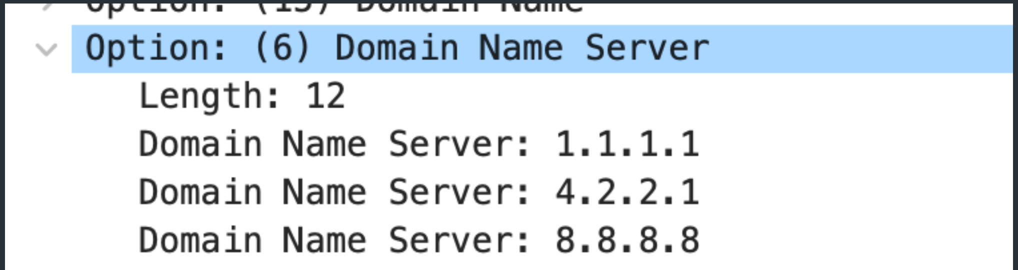
- Your new startup helpme.com
- Get a block of addresses from ISP
  - Say 212.44.9.0/24
- Register helpme.com at namecheap.com (for ex.)
  - Provide name and address of your authoritative name server (primary and secondary)
  - Registrar inserts RR pair into the **.com** TLD server:
    - helpme.com NS dns1.helpme.com
    - dns1.helpme.com A 212.44.9.120
- Configure your authoritative server (dns1.helpme.com)
  - Type A record for www.helpme.com
  - Type MX record for helpme.com

Inserting a Record in DNS, cont

- Need to provide reverse PTR bindings
  - E.g., 212.44.9.120 -> dns1.helpme.com
- Configure your dns server to serve the 9.44.212.in-addr.arpa zone
  - Need to add a record of this NS into the parent zone (44.212.in-addr.arpa)
- Insert the bindings into the 9.44.212.in-addr.arpa zone

DNS Security

- You go to starbucks, how does your browser find www.google.com?
  - Ask local name server, obtained from DHCP



- Can you trust this DNS server?

Great Firewall of CIT

If attacker is on the path (say, it is the ISP, or a malicious version of TStaff), what could they do?

- Can sniff all DNS queries
- Send fake responses back first
- Could do this selectively, to direct facebook.com to cs.brown.edu, for example…

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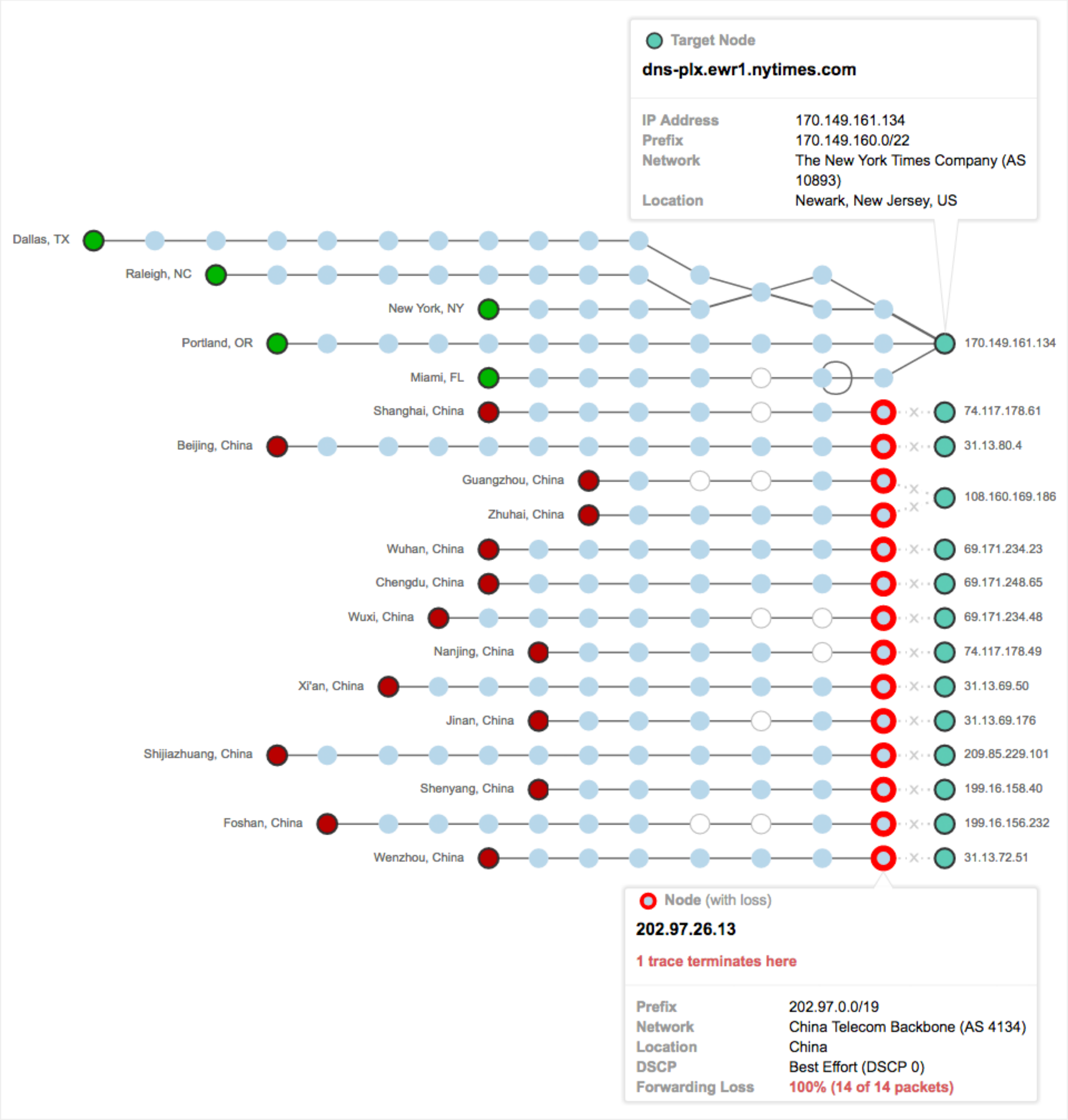

https://blog.thousandeyes.com/monitoring-dns-in-china/

Public DNS

Public DNS resolvers provided by cloud companies and ISPs

- 8.8.8.8 (Google)
- 1.1.1.1 (Cloudflare)
- … and others

Why do this?


DNS: 8.8.8.8 kuşun Ötsün !
Alternatif: 8.8.4.4
@KADIKOYBASKA

"Helpful" ISPs

- Many ISPs hijack NXDOMAIN responses to "help" by offering search and advertisement related to the domain
- E.g., www.bicycleisntadomain.com doesn't (currently) exist
  - Could return a page with search and ads on bicycles (or domain registrations?)

What can be done?

Some defenses against DNS spoofing/hijacking

What can be done?

Some defenses against DNS spoofing/hijacking

- DNSSEC: protocol to sign/verify hierarchy of DNS lookups
  - Expensive to deploy, hierarchy must support at all levels
  - APNIC DNSSEC monitor: https://stats.labs.apnic.net/dnssec
  - https://www.internetsociety.org/resources/deploy360/2012/nist-ipv6-and-dnssec-statistics-6/

- Tunneling DNS: client uses DNS via more secure protocol
  - DNS over HTTPS
  - DNS over TLS

More on DNS

Structure of a DNS Message

- Same format for queries and replies
  - Query has 0 RRs in Answer/Authority/Additional
  - Reply includes question, plus has RRs
- Authority allows for delegation
- Additional for glue, other RRs client might need

```
+---------------------+
|        Header       |
+---------------------+
|       Question      | the question for the name server
+---------------------+
|        Answer       | RRs answering the question
+---------------------+
|      Authority      | RRs pointing toward an authority
+---------------------+
|      Additional     | RRs holding additional information
+---------------------+
```

Header format

- Id: match response to query; QR: 0 query/1 response
- RCODE: error code.
- AA: authoritative answer, TC: truncated,
- RD: recursion desired, RA: recursion avai

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

Other RR Types

- CNAME (canonical name): specifies an alias

```
www.google.com.              446199  IN      CNAME   www.l.google.com.
www.l.google.com.    300     IN      A       72.14.204.147
```

- MX record: specifies servers to handle mail for a domain (the part after the @ in email addr)
  - Different for historical reasons
- SOA (start of authority)
  - Information about a DNS zone and the server responsible for the zone
- PTR (reverse lookup)

```
7.34.148.128.in-addr.arpa. 86400 IN   PTR     quanto.cs.brown.edu.
```