Where we are in the course ...

Part 1: Overview & Principles

Part 2: Applications

Part 3: Transport

Part 4: Algorithms
Computer networks

Part 2: Applications

#1  DNS: How do we name and discover services?

#2  The Web: How do you see weather.com?

#3  Video: How does video streaming work?
Computer networks

Part 2: Applications

#1  DNS: How do we name and discover services?

#2  The Web: How do you see weather.com?

#3  Video: How does video streaming work?
What purpose does “Domain Name Service” serve?

The Internet has one global system for

- **addressing hosts** IP
  by design

- **naming hosts** Domain names
  by accident, an afterthought

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**DNS**
A nice, funny primer on the DNS
via Philipp Jost on Slack

[https://howdns.works]
Using Internet services can be divided into four logical steps

step 1  A person has name of entity she wants to access  www.ethz.ch

step 2  She invokes an application to perform the task  Chrome

step 3  The application invokes DNS to resolve the name into an IP address  129.132.19.216

step 4  The application invokes transport protocol to establish an app-to-app connection
The DNS system is a distributed database which enables resolving a name to an IP address.

![Diagram]

- DNS
- Name: www.ethz.ch
- IP Address: 129.132.19.216
In practice, names can be mapped to more than one IP

- www.ethz.ch: 129.132.19.216
- www.cloudflare.com: 198.41.214.162, 198.41.215.162 (load-balancing)
In practice, IPs can be mapped by more than one name

```
www.ethz.ch  129.132.19.216
www.example.com  93.184.216.34  (reuse your machine)
www.example.net  93.184.216.34
```

“dig X” for X = {stackoverflow.com, superuser.com, serverfault.com}
How does one resolve a name into an address?

<table>
<thead>
<tr>
<th>HOSTNAME</th>
<th>HOST ADDR</th>
<th>LIAISON</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFWL-TIP</td>
<td>176 D Hyde (505)247-1711 x3803</td>
<td></td>
<td>TIP, Up 3-74</td>
</tr>
<tr>
<td>ALOHA-TIP</td>
<td>164 R Binder (808)948-7066</td>
<td></td>
<td>TIP</td>
</tr>
<tr>
<td>AMES-1L</td>
<td>208 J Hart (415)965-5935</td>
<td></td>
<td>USER, up 12-73</td>
</tr>
<tr>
<td>AMES-67</td>
<td>16 W.Hathaway (415)965-6033</td>
<td></td>
<td>SERVER</td>
</tr>
<tr>
<td>AMES-TIP</td>
<td>141 W.Hathaway (415)965-6033</td>
<td></td>
<td>TIP</td>
</tr>
<tr>
<td>ANL</td>
<td>7 L Amiot (312)739-7711 x6530</td>
<td></td>
<td>SERVER, up 2-74</td>
</tr>
<tr>
<td>ARPA-DMS</td>
<td>28 S Crocker (202)694-5037</td>
<td></td>
<td>USER, Agency use only</td>
</tr>
<tr>
<td>ARPA-TIP</td>
<td>156 S Crocker (202)694-5037</td>
<td></td>
<td>TIP</td>
</tr>
<tr>
<td>BBN-11L</td>
<td>5 R Thomas (617)491-1850 x483</td>
<td></td>
<td>Peripheral processor for #69, up 12-73</td>
</tr>
</tbody>
</table>
How does one resolve a name into an address?

The first one is from 1974. After a lot of fruitless searching, I remembered that back then we simply xeroxed the hosts.txt file and put it into the Arpanet Directory, so I copied that. The second copy is from 1982, shortly before we cut over to the domain naming system. It is quite long, so we split it into three parts which I am sending as three emails so as not to gronk anyone's mail system.

How does one resolve a name into an IP?

Initially, all name to address mappings were in a file called hosts.txt in /etc/hosts updated by download from authoritative list.

Problem: scalability in terms of query load & speed, management, consistency, availability.
When you need... more flexibility, 

you add... a layer of indirection

When you need... more scalability, 

you add... a hierarchical structure

gethostbyname()
To scale,
DNS uses three intertwined hierarchies

- naming structure
- addresses are hierarchical
  https://www.inf.ethz.ch/de/departement/

- management
  hierarchy of authority over names

- infrastructure
  hierarchy of DNS servers
naming structure

addresses are hierarchical

https://www.inf.ethz.ch/de/departement/
Top Level Domain (TLDs) sit at the top

Many new ones being added — see [https://www.iana.org/domains/root/db](https://www.iana.org/domains/root/db)
Domains are subtrees

+ many more
A name, e.g. inf.ethz.ch, represents a leaf-to-root path in the hierarchy.
management hierarchy of authority over names
The DNS system is
hierarchically administered
managed by IANA (*)

root

com org net edu gov mil be ch de fr

epfl ethz nzz

www inf ee

(*) see http://www.iana.org/domains/root/db
managed by The Swiss Education & Research Network (*)

(*) see https://www.switch.ch/about/id/
managed by

ETH Zürich
Informatikdienste ICT-Networks
Hierarchical administration means that name collision is trivially avoided.
infrastructure hierarchy of DNS servers
The DNS infrastructure is hierarchically organized
13 root servers (managed professionally)
serve as root (*)

(*) see http://www.root-servers.org/
<table>
<thead>
<tr>
<th></th>
<th>root-servers.net</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td></td>
<td>VeriSign, Inc.</td>
</tr>
<tr>
<td>b.</td>
<td></td>
<td>University of Southern California</td>
</tr>
<tr>
<td>c.</td>
<td></td>
<td>Cogent Communications</td>
</tr>
<tr>
<td>d.</td>
<td></td>
<td>University of Maryland</td>
</tr>
<tr>
<td>e.</td>
<td></td>
<td>NASA</td>
</tr>
<tr>
<td>f.</td>
<td></td>
<td>Internet Systems Consortium</td>
</tr>
<tr>
<td>g.</td>
<td></td>
<td>US Department of Defense</td>
</tr>
<tr>
<td>h.</td>
<td></td>
<td>US Army</td>
</tr>
<tr>
<td>i.</td>
<td></td>
<td>Netnod</td>
</tr>
<tr>
<td>j.</td>
<td></td>
<td>VeriSign, Inc.</td>
</tr>
<tr>
<td>k.</td>
<td></td>
<td>RIPE NCC</td>
</tr>
<tr>
<td>l.</td>
<td></td>
<td>ICANN</td>
</tr>
<tr>
<td>m.</td>
<td></td>
<td>WIDE Project</td>
</tr>
</tbody>
</table>
Instances of the k-root server (*) are hosted in more than 40 locations worldwide

(*) see k.root-servers.org
Two of these locations are in Switzerland:
in Zürich and in Geneva
To scale root servers, operators rely on **BGP anycast**

**Intuition**

Routing finds shortest-paths

If several locations announce the same prefix, then routing will deliver the packets to the “closest” location

This enables seamless replication of resources
IP traffic
129.132.14.129

Deutsche Telekom

IP traffic
129.132.14.129

ETH

swisscom

skynet
All locations announce 193.0.14.0/23 in BGP, with 193.0.14.129 being the IP of the server.
Each instance receives up to 70k queries per second
summing up to more than 4 billions queries per day
Do you see any problems in performing load-balancing this way?
TLDs server are also managed professionally by private or non-profit organization.
The bottom (and bulk) of the hierarchy is managed by Internet Service Provider or locally.
Every server knows the address of the root servers (*)
required for bootstrapping the systems

(*) see https://www.internic.net/domain/named.root
Each root server knows the address of all TLD servers

```
$ dig @a.root-servers.net ch.

ch.           172800 IN  NS  a.nic.ch.
ch.           172800 IN  NS  b.nic.ch.
ch.           172800 IN  NS  c.nic.ch.
ch.           172800 IN  NS  d.nic.ch.
ch.           172800 IN  NS  e.nic.ch.
ch.           172800 IN  NS  f.nic.ch.
ch.           172800 IN  NS  h.nic.ch.
```
From there on,
each server knows the address of all children
Any .ch DNS server knows all the addresses of all sub-domains.
To scale, DNS adopt three intertwined hierarchies

<table>
<thead>
<tr>
<th>naming structure</th>
<th>addressing are hierarchical</th>
</tr>
</thead>
<tbody>
<tr>
<td>management</td>
<td>hierarchy of authority</td>
</tr>
<tr>
<td>infrastructure</td>
<td>hierarchy of DNS servers</td>
</tr>
</tbody>
</table>
To ensure availability, each domain must have at least a primary and secondary DNS server

Ensure name service availability as long as one of the servers is up

DNS queries can be load-balanced across the replicas

On timeout, clients use alternate servers exponential backoff when trying the same server
Overall, the DNS system is highly scalable, available, and extensible.

**scalable**
- #names, #updates, #lookups, #users,
- but also in terms of administration

**available**
- domains replicate independently of each other

**extensible**
- any level (including the TLDs)
- can be modified independently
You’ve founded next-startup.ch and want to host it yourself, how do you insert it into the DNS?

You register next-startup.ch at a registrar X

e.g. Swisscom or GoDaddy

Provide X with the name and IP of your DNS servers

e.g., [ns1.next-startup.ch, 129.132.19.253]

You set-up a DNS server @129.132.19.253

define A records for www, MX records for next-startup.ch…
Using DNS relies on two components

- Resolver software
  - trigger resolution process
  - send request to local DNS server

- Local DNS server
  - usually, near the endhosts
  - configured statically (resolv.conf)
  - or dynamically (DHCP)

gethostbyname()
DNS queries and replies use UDP (port 53),
reliability is implemented by repeating requests
A DNS server stores Resource Records composed of a (name, value, type, TTL)
<table>
<thead>
<tr>
<th>Records</th>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>hostname</td>
<td>IP address</td>
</tr>
<tr>
<td>NS</td>
<td>domain</td>
<td>DNS server name</td>
</tr>
<tr>
<td>MX</td>
<td>domain</td>
<td>Mail server name</td>
</tr>
<tr>
<td>CNAME</td>
<td>alias</td>
<td>canonical name</td>
</tr>
<tr>
<td>PTR</td>
<td>IP address</td>
<td>corresponding hostname</td>
</tr>
</tbody>
</table>
DNS resolution can either be recursive or iterative
When performing a recursive query, the client offloads the task of resolving to the server
local DNS server
(dns1.ethz.ch)

root servers

.edu servers

www.nyu.edu?

DNS client
(me.inf.ethz.ch)

nyu.edu servers
DNS server

.root
dns1.ethz.ch

local DNS server

www.nyu.edu?

DNS client
(me.inf.ethz.ch)

.edu servers

.nyu.edu servers
DNS client (me.inf.ethz.ch)

local DNS server (dns1.ethz.ch)

root DNS server

.edu servers

nyu.edu servers

www.nyu.edu?
www.nyu.edu?

DNS client
(me.inf.ethz.ch)

local DNS server
(dns1.ethz.ch)

root DNS server

.edu servers

nyu.edu servers
When performing a iterative query, the server only returns the address of the next server to query
Where is .edu?

Where is www.nyu.edu?

Where is nyu.edu?

DNS server

root DNS server

.local DNS server

Where is .edu?

Where is nyu.edu?

Where is www.nyu.edu?

dns client (me.inf.ethz.ch)

.edu servers

nyu.edu servers
This is not exactly fast…
To reduce resolution times, DNS relies on caching

DNS servers cache responses to former queries and your client and the applications (!)

Authoritative servers associate a lifetime to each record Time-To-Live (TTL)

DNS records can only be cached for TTL seconds after which they must be cleared
As top-level servers rarely change & popular websites are visited often, caching is very effective (*)

Top 10% of names account for 70% of lookups

9% of lookups are unique

Limit cache hit rate to 91%

Practical cache hit rates ~75%

A significant outage of DNS could make the Internet unusable

[DownDetector (CC BY-SA 4.0), via Wikimedia]
A significant outage of DNS could make the Internet unusable
One occurred on Oct. 21, 2016!

100,000 malicious hosts estimated to be involved

Home routers, cameras, baby monitors …

(Unverified) 1.2 Tbps reported traffic volume

Readings for this lecture

Kurose-Ross (KR) sections

1.4 Delay, loss, and throughput in packet switched networks
1.7 (optional) History of computer networking and the Internet
2.4 DNS — The Internet’s directory service