TCP milestone II: sign up for a meeting soon (by Monday at latest—don’t stress about having it all done)

TCP gearup III: tonight (11/9), 5-7pm

HW4: TBA, but due after TCP
The story so far

POV: You want to connect to some website

connect(example.com, 80)
The story so far

POV: You want to connect to some website

You → DNS resolver
connect(example.com, 80)

DNS resolver → example.com 5.6.7.8
A example.com?

5.6.7.8
The story so far

POV: You want to connect to some website

connect(example.com, 80)

You → DNS resolver → example.com DNS server → example.com 5.6.7.8

A example.com?

5.6.7.8 → 5.6.7.8
Warmup

Q: If the randomsite.com’s DNS server goes down, can another DNS server still resolve randomsite.com?

- Hopefully a backup authoritative server (SHOULD have at least 2)
- Would fail unless result is cached
How it scales: caching

DNS Resolvers cache responses to avoid doing recursive/iterative queries
• Many messages => extra computation, extra latency

```
$ dig cs.brown.edu @10.1.1.10
;; ANSWER SECTION:
cs.brown.edu. 1800 IN A 128.148.32.12
```

TTL (in seconds)
How it scales: caching

DNS Resolvers cache responses to avoid doing recursive/iterative queries
- Many messages => extra computation, extra latency

How long to cache?
- Every record has a TTL (in seconds), delete when it expires

$ dig cs.brown.edu @10.1.1.10
;; ANSWER SECTION:
cs.brown.edu. 1800 IN A 128.148.32.12
$ 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
dig: DNS lookup utility

Usage: dig +option -option DOMAIN @nameserver

where:
+short: Don't print lots of stuff
+norec: No recursion
+nodnssec: Disable DNSSEC

-x: Do reverse DNS

DOMAIN: Domain to lookup (or IP if -x)

@nameserver: Nameserver to query
Today

How does this work in practice? What can go wrong?

connect(example.com, 80)

A example.com?

5.6.7.8
How it scales: caching

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• Many messages => extra computation, extra latency

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=> Every record has a TTL (in seconds), delete when it expires

$ dig cs.brown.edu @10.1.1.10
;; ANSWER SECTION:
cs.brown.edu. 1800 IN A 128.148.32.12
Related: redundant services via DNS

Can return multiple answers for one record

=> If a client can’t connect to first result, can try next one

$ dig nytimes.com

;; ANSWER SECTION:
nytimes.com. 111 IN A 151.101.65.164
nytimes.com. 111 IN A 151.101.1.164
nytimes.com. 111 IN A 151.101.129.164
nytimes.com. 111 IN A 151.101.193.164

;; Query time: 40 msec
;; SERVER: 10.1.1.10#53(10.1.1.10)
;; WHEN: Thu Nov 09 08:42:41 EST 2023
;; MSG SIZE  rcvd: 104

DNS server usually shuffles answers on each response—why?
Facebook DNS outage (2021)

BGP configuration bug: Facebook withdraws all routes for its DNS servers to the Internet

=> Facebook DNS unreachable—not even Facebook could access their systems!

Traffic graph
Many writeups here
user@host$ dig @1.1.1.1 facebook.com # CloudFlare
  ;>HEADER<<- opcode: QUERY, status: SERVFAIL, id: 5153
;facebook.com.
IN A
user@host$ dig @8.8.8.8 facebook.com # Google Public DNS
  ;>HEADER<<- opcode: QUERY, status: SERVFAIL, id: 43224
;facebook.com.
IN A
user@host$ dig @208.67.222.222 facebook.com # OpenDNS
  ;>HEADER<<- opcode: QUERY, status: SERVFAIL, id: 7643
;facebook.com.
IN A
user@host$ dig @176.103.130.130 facebook.com # AdGuard
  ;>HEADER<<- opcode: QUERY, status: SERVFAIL, id: 5434
;facebook.com.
IN A
## DNS record types

<table>
<thead>
<tr>
<th>RR Type</th>
<th>Purpose</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IPv4 Address</td>
<td>128.148.56.2</td>
</tr>
<tr>
<td>AAAA</td>
<td>IPv6 Address</td>
<td>2001:470:8956:20::1</td>
</tr>
<tr>
<td>CNAME</td>
<td>Specifies an alias</td>
<td>systems.cs.brown.edu. 86400 IN CNAME systems-v3.cs.brown.edu. 86400 IN A 128.148.36.51</td>
</tr>
<tr>
<td>NS</td>
<td>DNS servers for a domain</td>
<td>cs.brown.edu. 86400 IN NS br1.brown.edu</td>
</tr>
<tr>
<td>MX</td>
<td>Mail servers</td>
<td>MX 10 1.2.3.4</td>
</tr>
<tr>
<td>SOA</td>
<td>Start of authority</td>
<td>Information about who owns a zone</td>
</tr>
<tr>
<td>PTR</td>
<td>Reverse IP lookup</td>
<td>7.34.148.128.in-addr.arpa. 86400 IN PTR quanto.cs.brown.edu.</td>
</tr>
<tr>
<td>SRV</td>
<td>How to reach specific services (eg. host, port)</td>
<td>_minecraft._tcp.example.net 3600 SRV &lt;priority&gt; &lt;weight&gt; &lt;port&gt; &lt;server IP&gt;</td>
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Reverse DNS

What if we want to map IP address => domain name?
Reverse DNS

What if we want to map IP address => domain name?

Leverages hierarchy in IP addresses, but in reverse

=> How? reverse the numbers: 12.32.148.128, then look that up

12.32.148.128.in-addr.arpa

TRIES TO INDICATE WHO OWN
owns an IP

NOT A 1-TO-1 MAPPING.
What happens when you register a new domain?
What happens when you buy a domain?

You get control of yoursite.com
Need an authoritative DNS server for yoursite.com

Two choices:
1. (Most common) Can have external company manage DNS servers for you (Google DNS, amazon route53, name.com, godaddy)
2. Alternatively, you can run the authoritative server yourself

When you buy yoursite.com, an entry gets added to .com that says, “Nameservers for yoursite.com are …”

After this, you can configure actual records for your domain, eg.
  yoursite.com => 1.2.3.4
  something.yoursite.com => x.x.x.x

...
Registering a new domain

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
Registering a new domain

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.)
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    • 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 Resolution:
What can go wrong?
You 

connect(example.com, 80)

DNS resolver

A example.com?

5.6.7.8

example.com

5.6.7.8

QUERY

RESP

-DUNP UDP (PORT 53)
DNS Protocol

- TCP/UDP port 53
- Most traffic uses UDP
  - Lightweight protocol has 512 byte message limit
  - Can run over TCP (more on this later)
- A few options to request recursive queries, ...
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?

  ![Option: (6) Domain Name Server]
  
  | Length: 12 | Domain Name Server: 1.1.1.1 |
  | Domain Name Server: 4.2.2.1 |
  | Domain Name Server: 8.8.8.8 |

  OFTEN LOCAL TO NETWORK YOU ARE ON (NOT HERE)
In standard form, a DNS resolver can:
- Lie
- Drop your query
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?
You

Local DNS

Public DNS

example.com 5.6.7.8

You ask for example.com's IP address. Your local DNS server looks up the IP address for you. However, it receives a fake answer from a public DNS server, which is part of a cache poisoning attack. The IP address returned is 1.2.3.4 instead of the correct one. This fake IP address is then cached in your system, leading to incorrect network responses.
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…

CACHE POISONING

COULD DROP/BLOCK QUERIES.
DNS Hijacking w/ IP Filtering

Client

Facebook

125.3.4.5

MALICIOUS ROUTER (or DNS SERVER)

RESERVED IP IT KNOWS IS BLOCKED BY ITS ROUTERS.
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?

⇒ Served by Anycast
   - Low latency.
Changing DNS servers in response to blocking of Twitter in Turkey (2014)

Writeup, with more links: https://www.thousandeyes.com/blog/internet-censorship-around-the-world
“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?)

```
NXDOMAIN
\~
ONE.COM
ISP SEARCH SITE
```
"CAPTIVE PORTAL" : How coffee shops and similar hijack connections (starting w/ DNS)

You

Wi-Fi

\[=\]

Coffee Pot

\[=\]

Captive Portal

\[\text{Not captive}\]

\[?\]
What can be done?

Some defenses against DNS spoofing/hijacking

$ \Rightarrow \text{NO AUTHENTICATION/VERIFICATION OF DNS RECORDS BY DEFAULT.} $
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

• 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 available
Other RR Types

- **CNAME (canonical name):** specifies an alias
  
  - 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.
Example

dig . ns

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

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

dig +nored 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.
% 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

When server doesn’t know all info...
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