Privacy in the Domain Name System (DNS):

DNS Privacy in Practice

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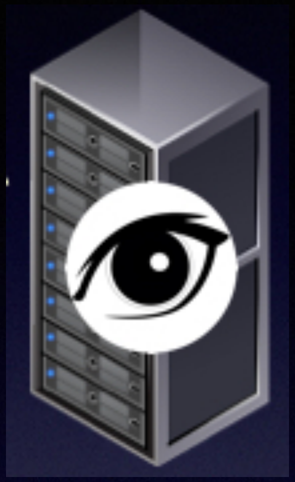
Overview

- First - lets look at your DNS queries!
- Desktop DoT stub resolvers (client) (Stubby)
- Set up your own DoT recursive (Unbound) - decrypt DoT
- DoH - Clients & Browsers (Firefox) - decrypt DoH
- Mobile Apps
- DNS Libraries (getdns)
- Routers

Firefox DoH Decryption is easier….

dnsprivacy.org



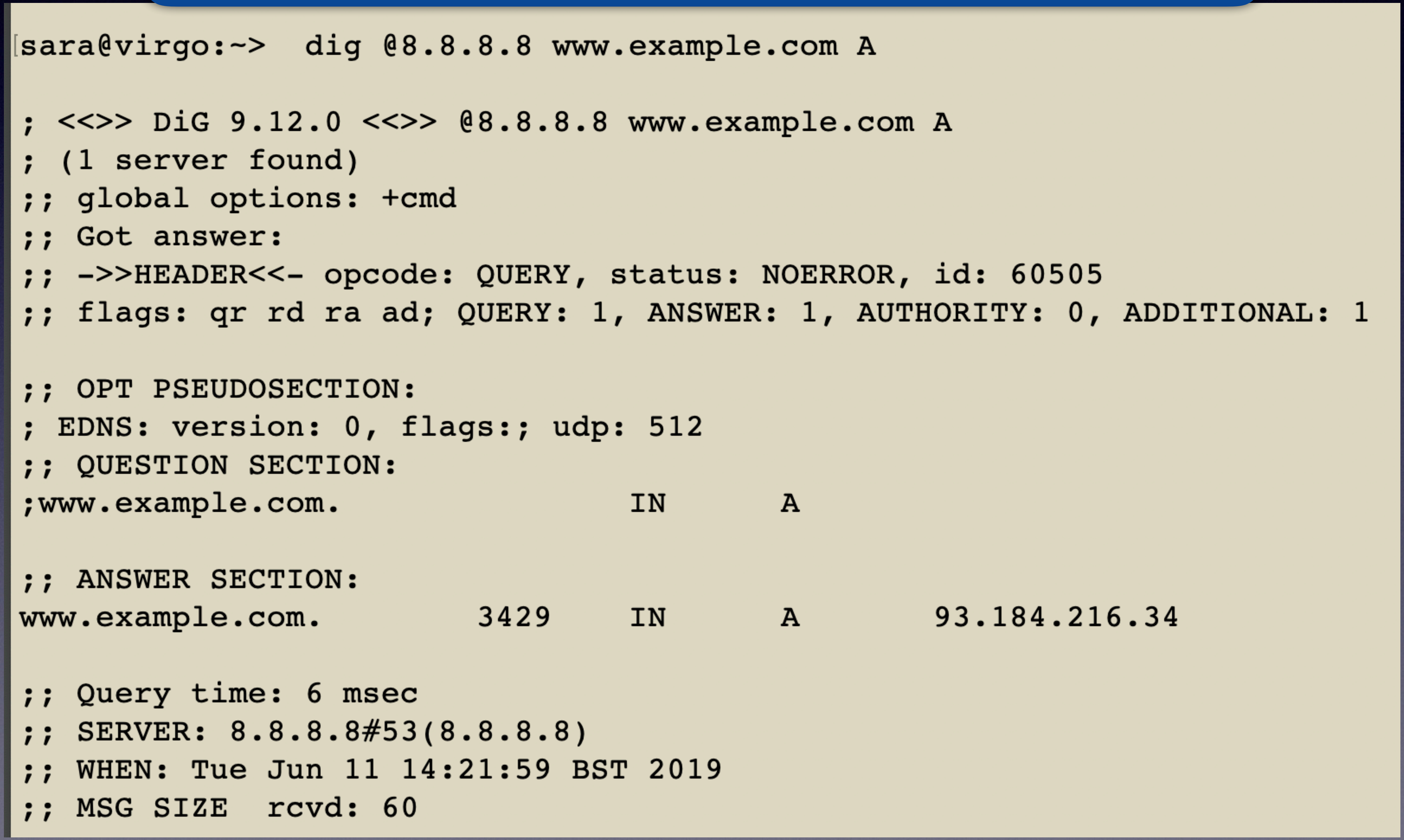
- DNS Privacy Clients
- DNS Privacy Servers setup guides
- DNS Privacy Test and Public resolvers
- DNS Privacy Monitoring
- DNS Privacy Current work

Reference material here for most setups and recursive resolvers

DNS Basics

DNS Basics - A UDP query

‘dig’ is available on most *nix systems (or ‘drill’)



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;; global options: +cmd
;; Got answer:
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; EDNS: version: 0, flags:; udp: 512
;; QUESTION SECTION:
;www.example.com.               IN      A

;; ANSWER SECTION:
www.example.com.        3429    IN      A       93.184.216.34

;; Query time: 6 msec
;; SERVER: 8.8.8.8#53(8.8.8.8)
;; WHEN: Tue Jun 11 14:21:59 BST 2019
;; MSG SIZE  rcvd: 60
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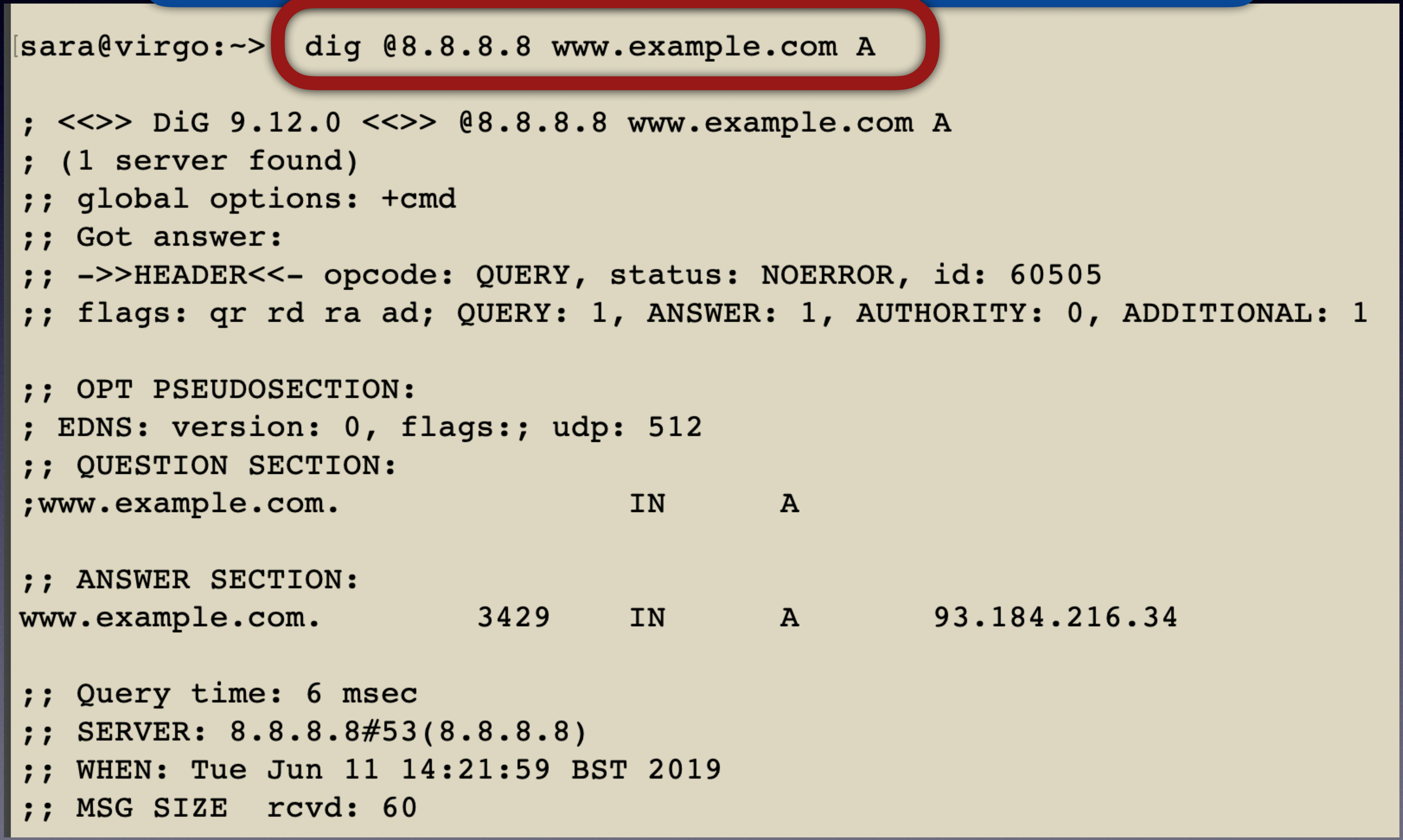

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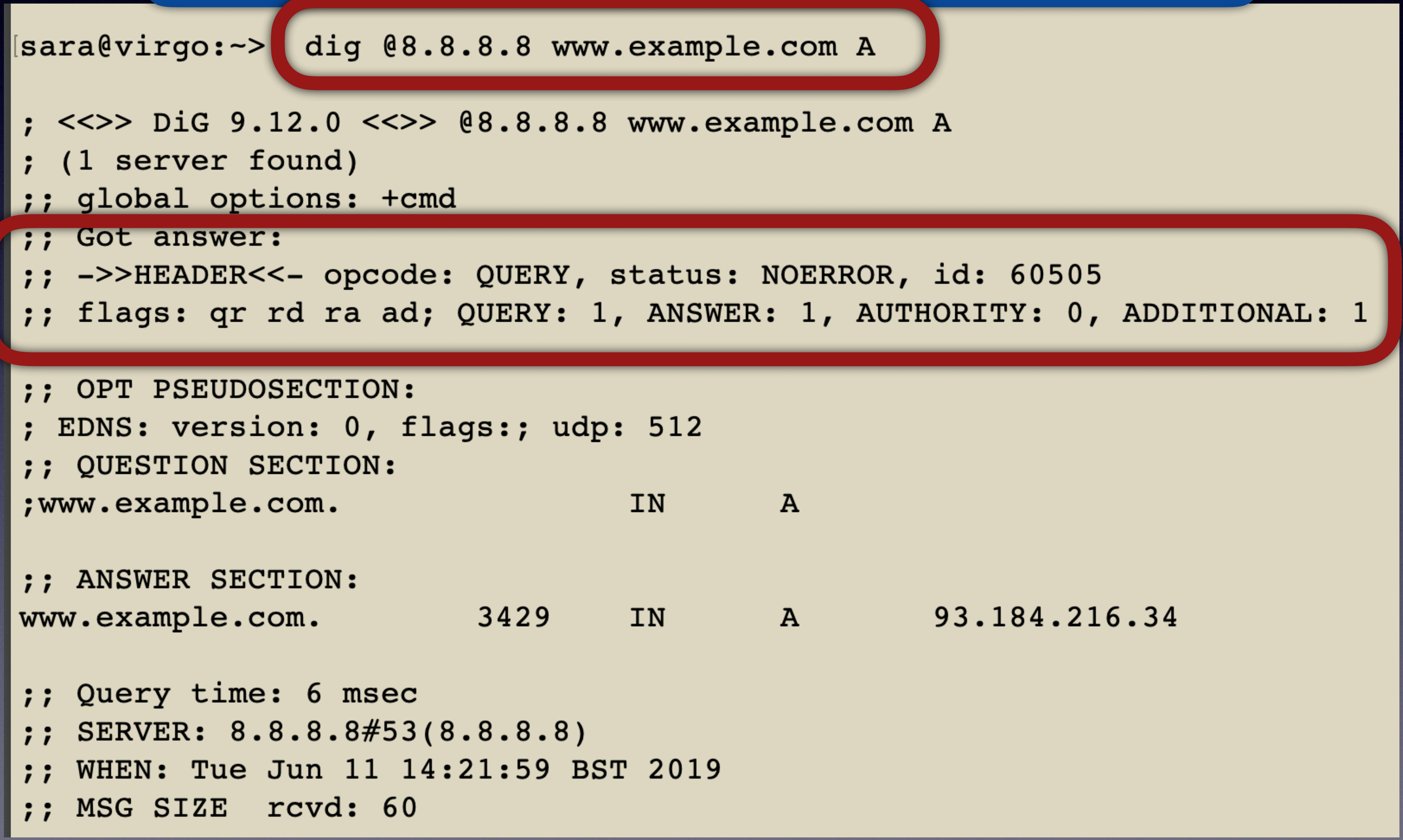

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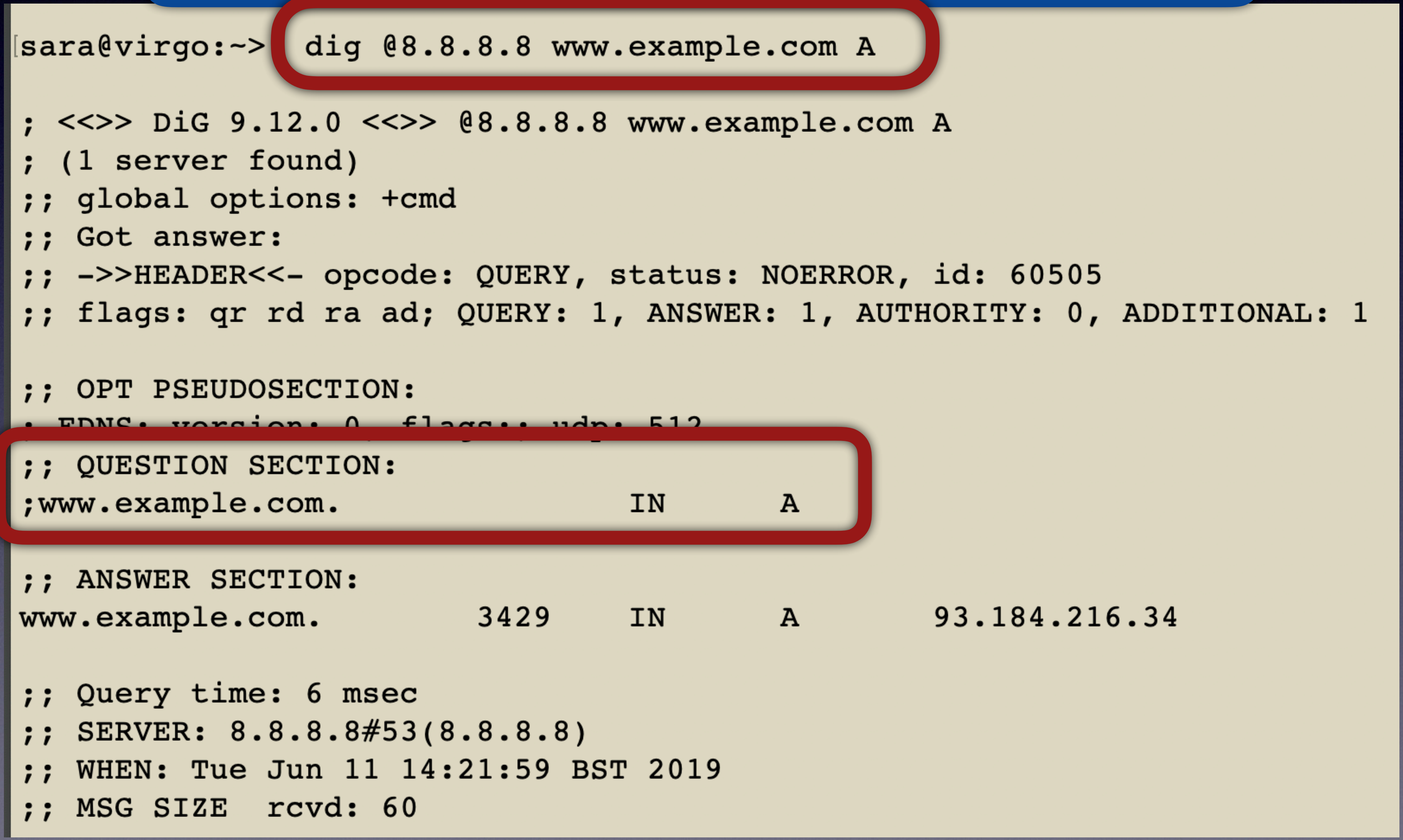

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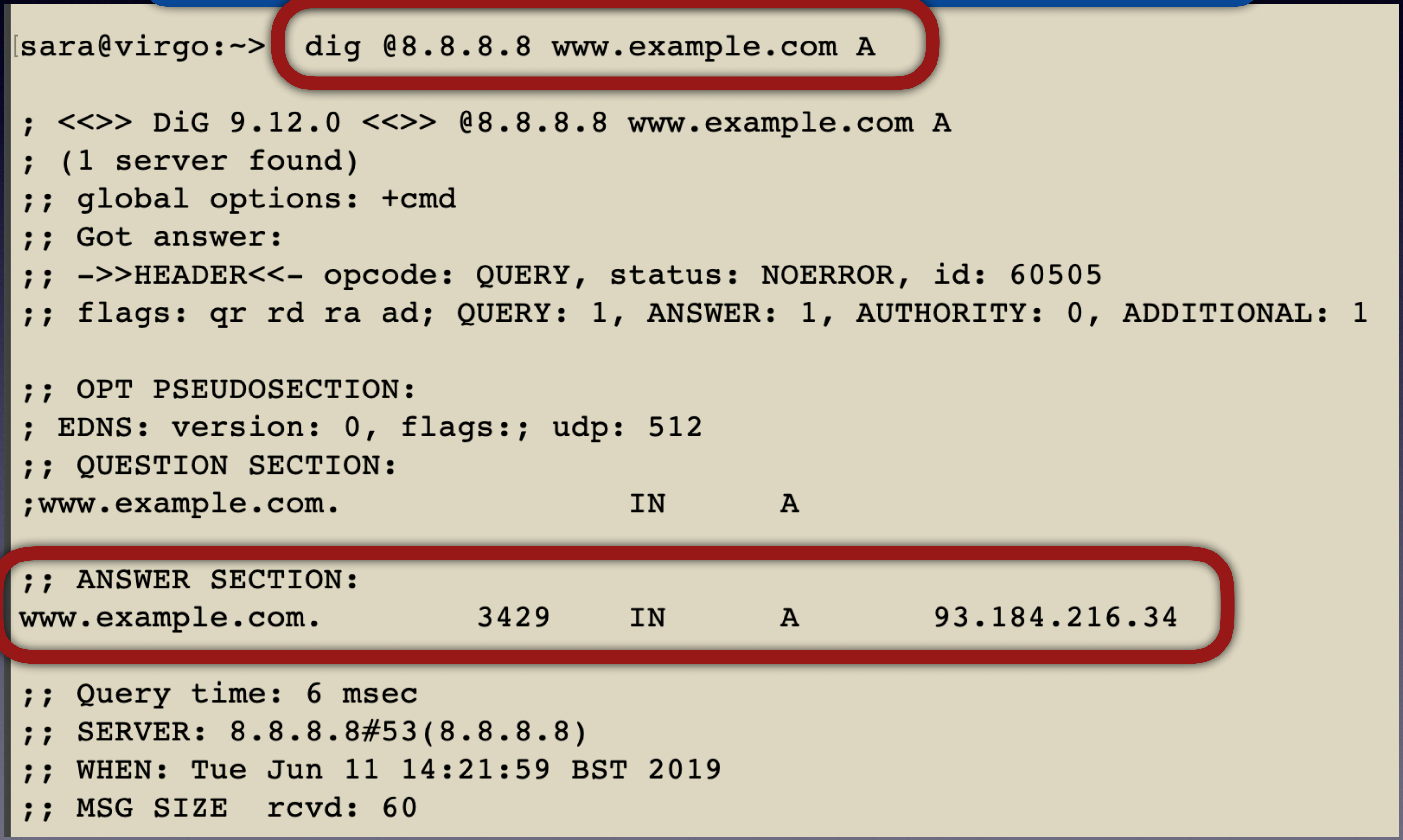

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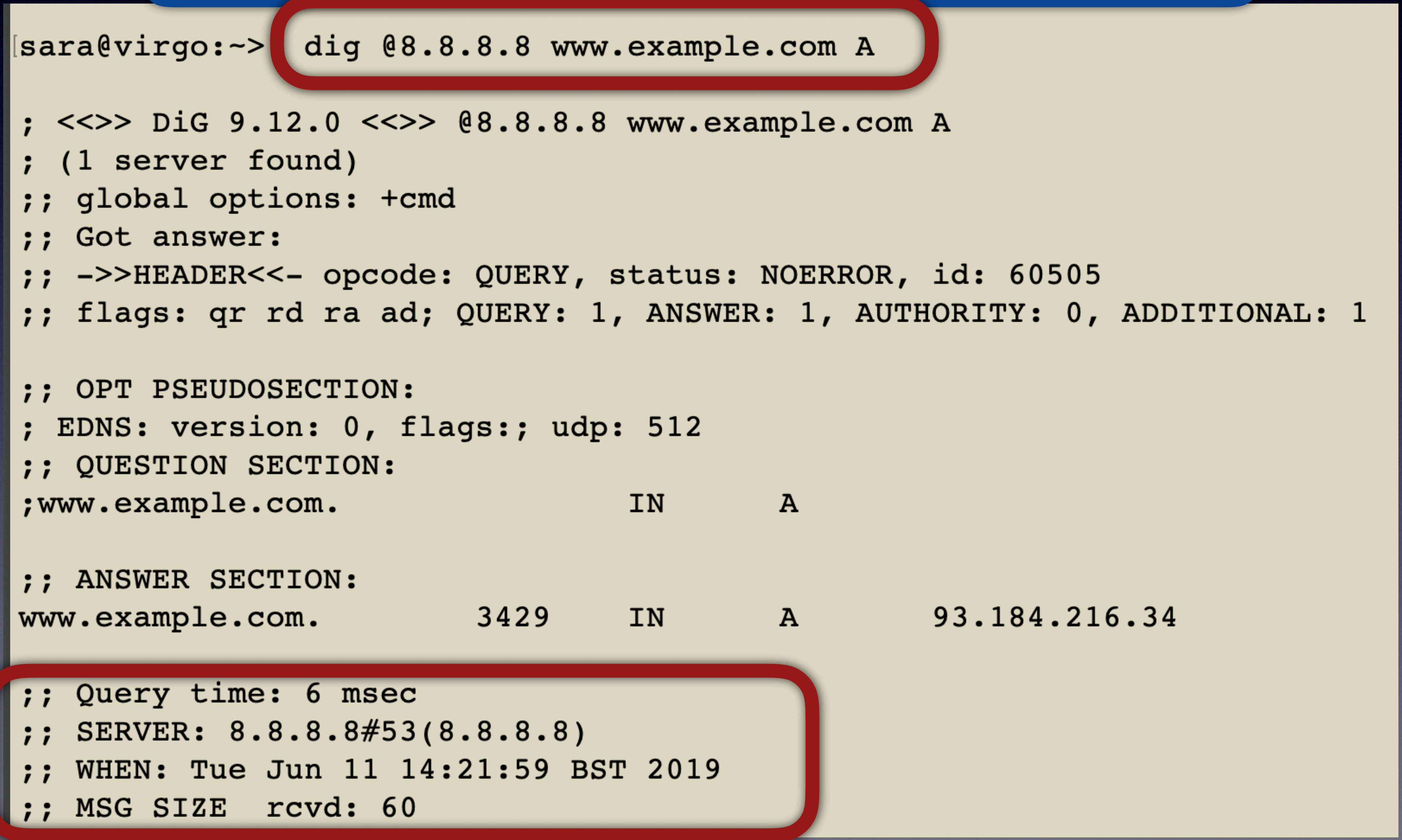

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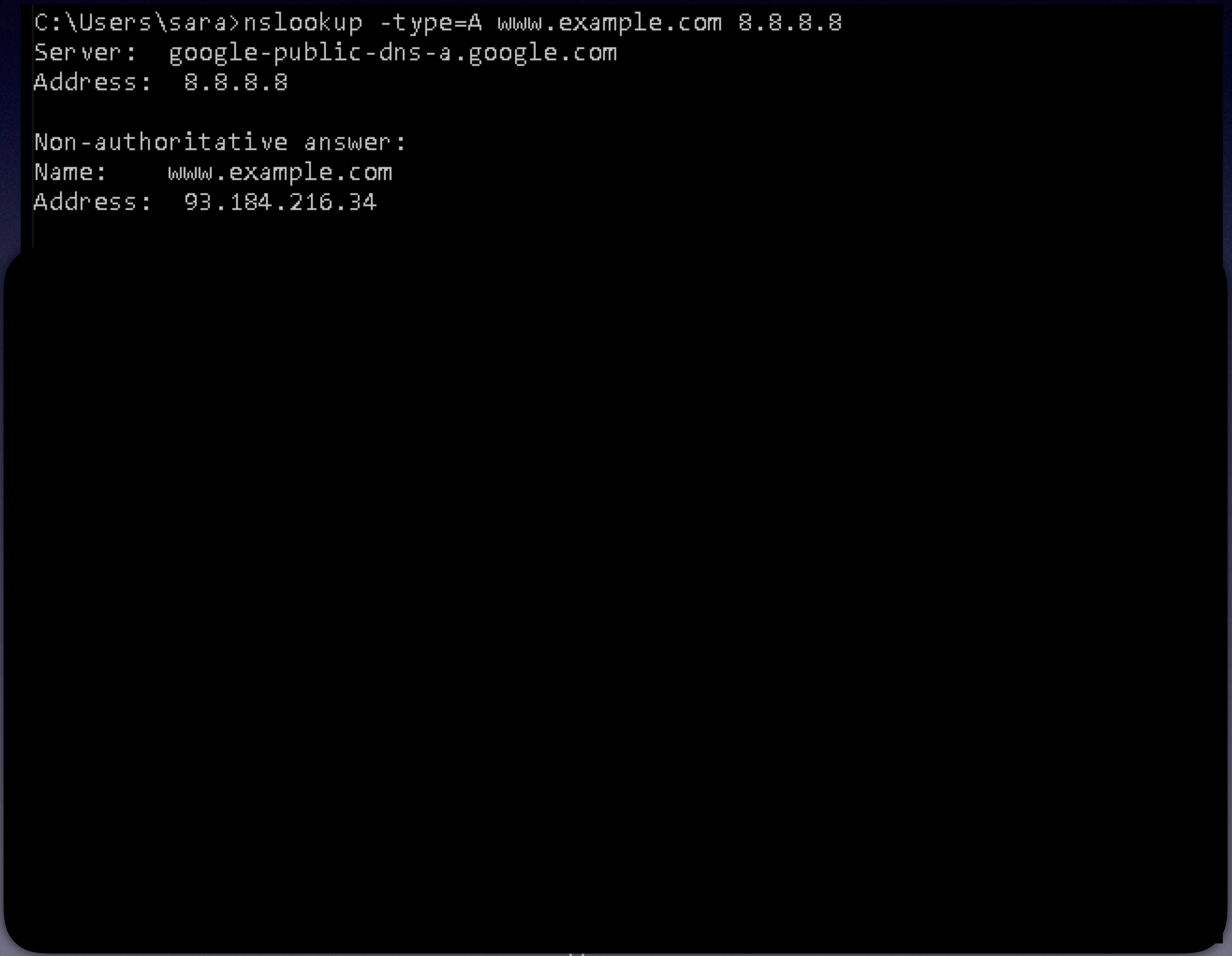
DNS Basics - A UDP query

‘nslookup’ is available on Windows

order is important!



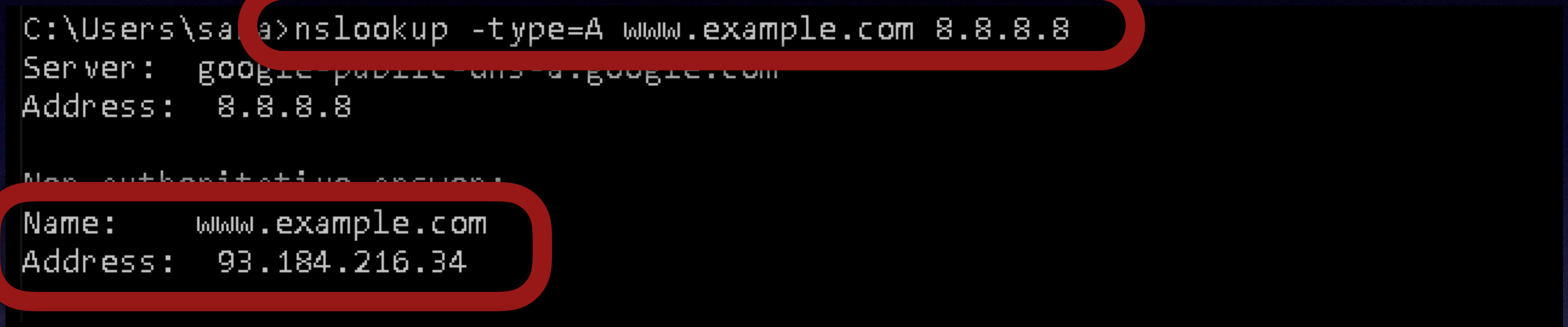
```
C:\Users\sara>nslookup -type=A www.example.com 8.8.8.8
Server:  google-public-dns-a.google.com
Address:  8.8.8.8

Non-authoritative answer:
Name:    www.example.com
Address:  93.184.216.34
```

DNS Basics - A UDP query

'nslookup' is available on Windows

order is important!



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[redacted]

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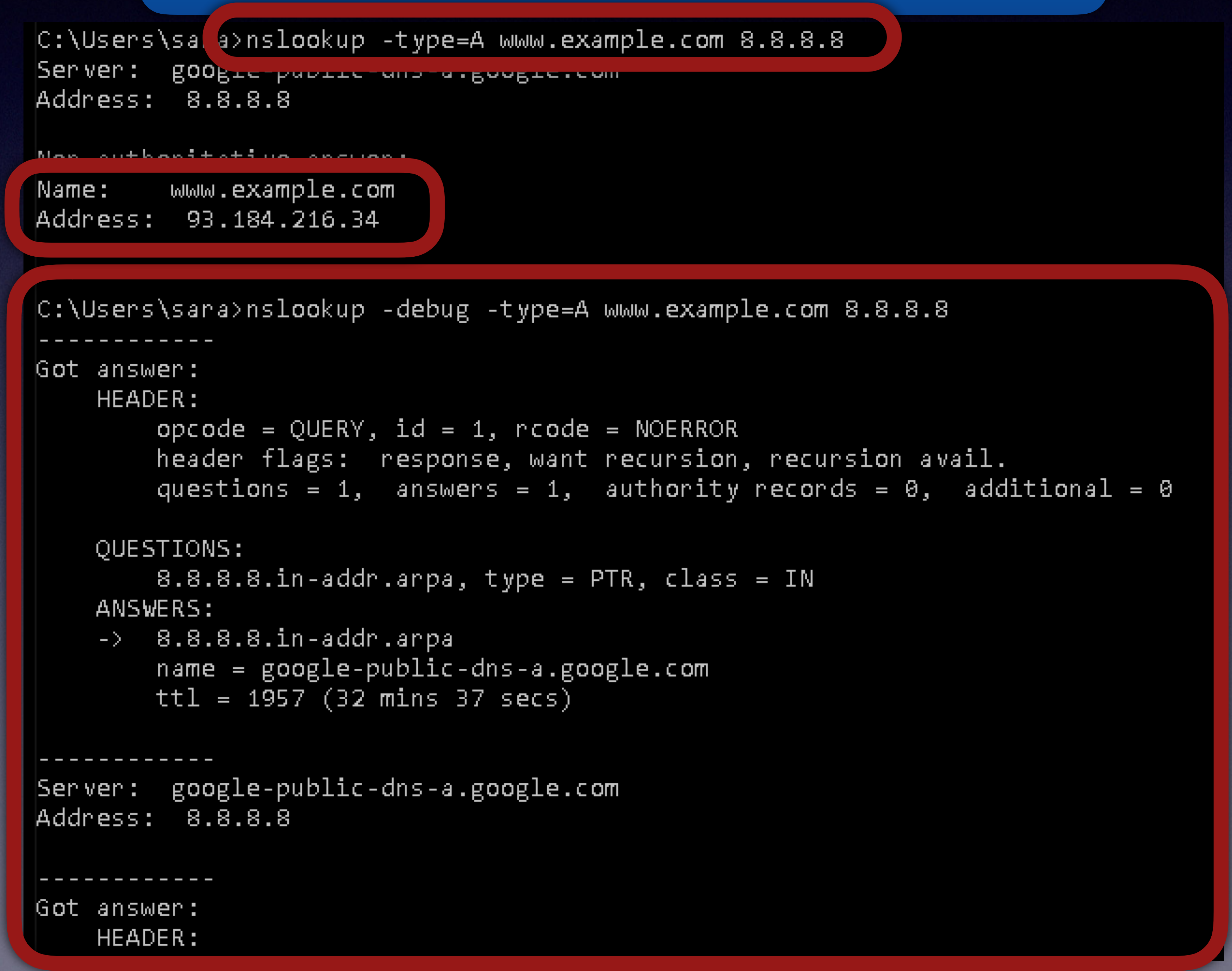

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Server:  google-public-dns-a.google.com
Address:  8.8.8.8

Non-authoritative answer:
Name:    www.example.com
Address:  93.184.216.34
```

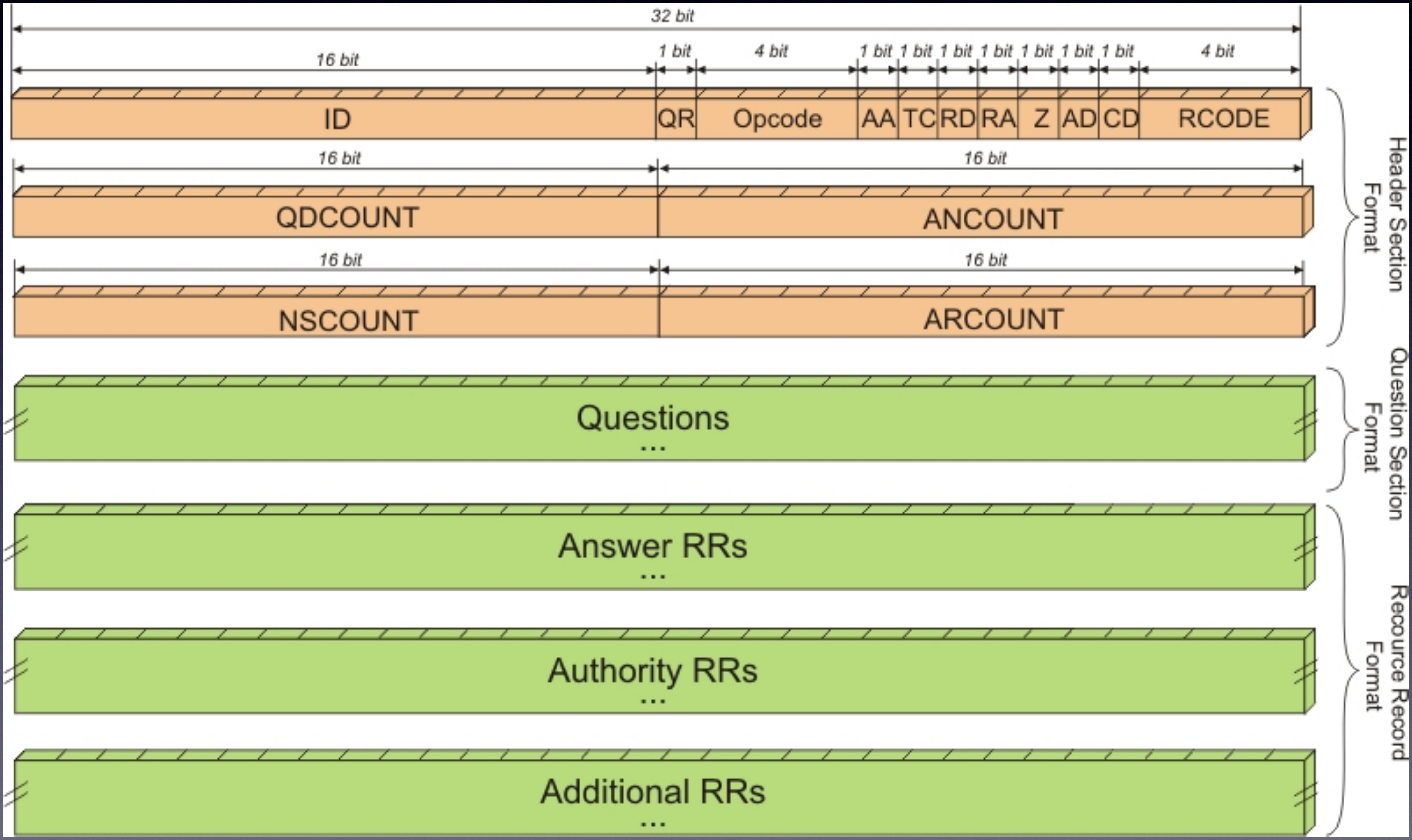
```
C:\Users\sara>nslookup -debug -type=A www.example.com 8.8.8.8
------------
Got answer:
    HEADER:
        opcode = QUERY, id = 1, rcode = NOERROR
        header flags:  response, want recursion, recursion avail.
        questions = 1,  answers = 1,  authority records = 0,  additional = 0

    QUESTIONS:
        8.8.8.8.in-addr.arpa, type = PTR, class = IN
    ANSWERS:
    ->  8.8.8.8.in-addr.arpa
        name = google-public-dns-a.google.com
        ttl = 1957 (32 mins 37 secs)

------------
Server:  google-public-dns-a.google.com
Address:  8.8.8.8

------------
Got answer:
    HEADER:
```

DNS Packet structure



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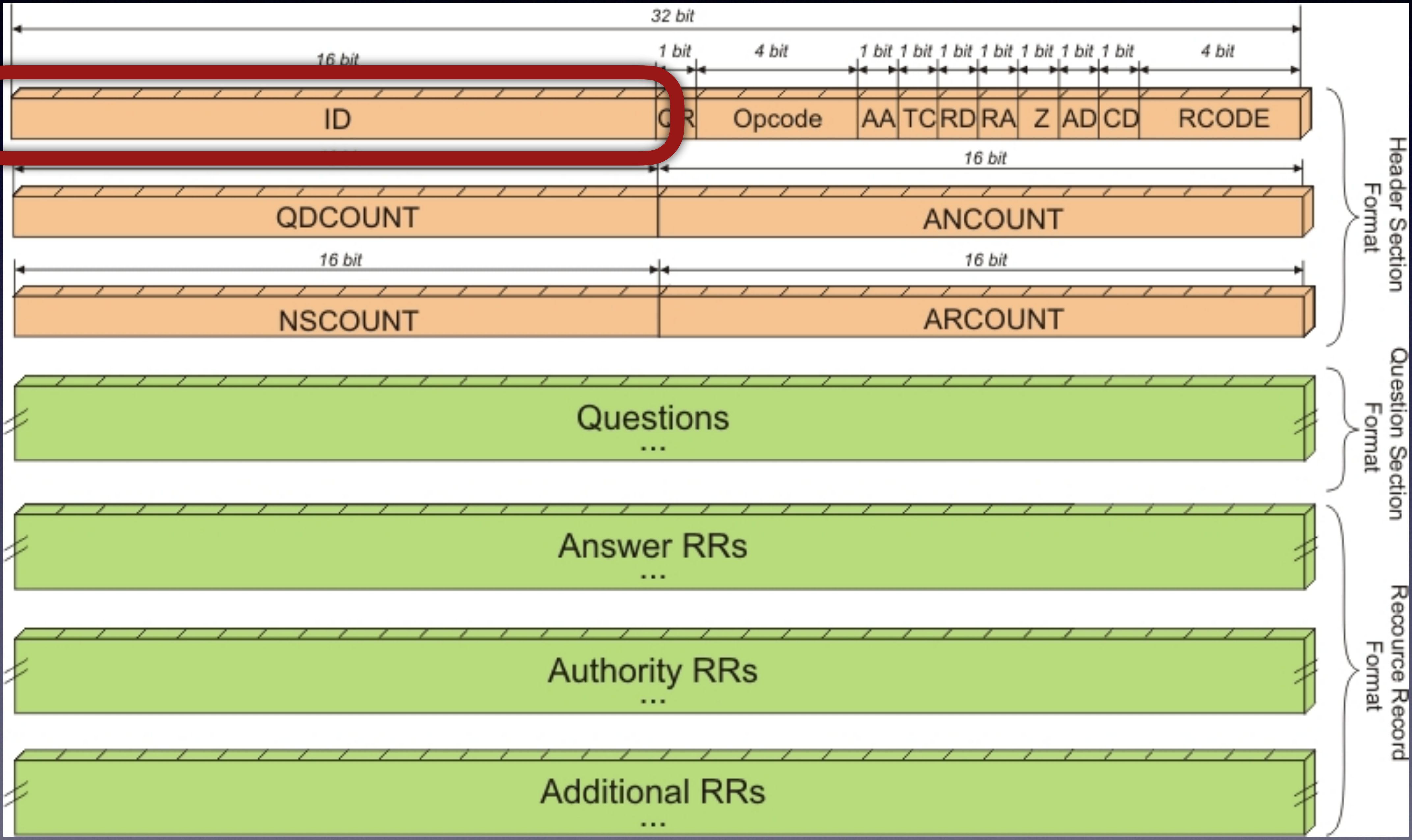

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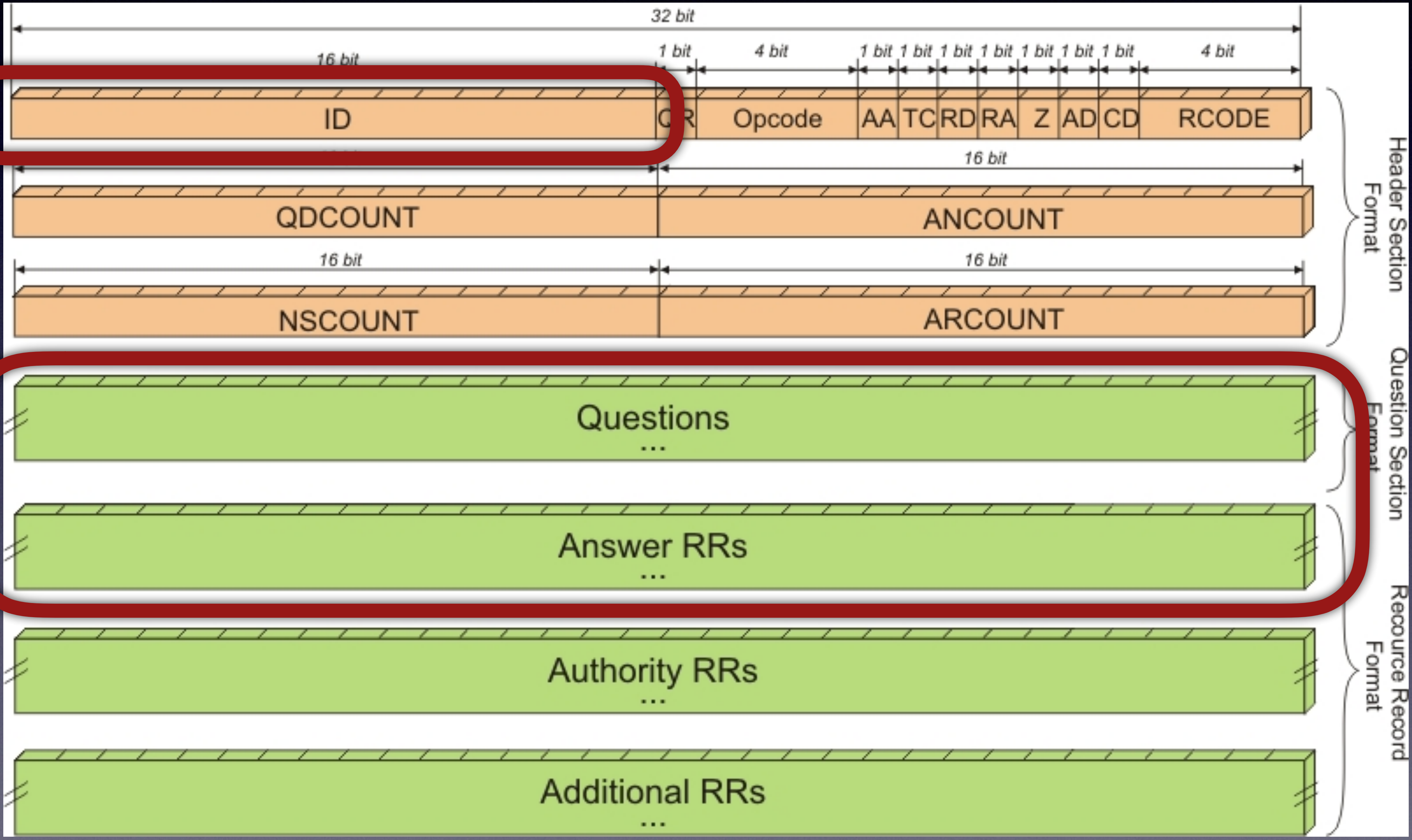

Exercise - use dig

- Do a dig for a domain name and also try these options

  ```
  dig @8.8.8.8 www.example.com A
  ```

  - +short (just IP)
  - +qr (also print query)
  - +trace (trace delegations from the root - shows auth servers)
  - +tcp (but alas, ‘dig’ doesn’t do TLS, more on that later)

Exercise - look at your DNS Settings

- Do ‘dig’ again, without the @8.8.8.8 - what IP was used?
- Look at system settings via a GUI or command line
  - Note there are usually multiple settings from command line
- See next slides for OS specifics
  - *nix systems
  - Windows

Finding your DNS settings - *nix

- **macOS GUI**:
  - Settings->Network->Advanced->DNS

- **Command line:** (Most *nix distros don't directly use /etc/resolv.conf now)
  - systemd-resolved.service: `` `resolvectl status` `` (Global)
  - for macOS run `‘scutil —-dns`` ` and look at 'lan'

- Flush the cache:
  - macOS 10.14: `‘sudo killall -HUP mDNSResponder`` `
  - systemd: `` `sudo systemd-resolve --flush-caches` ``

Finding your DNS settings - Windows

- Open the Control Panel
- Choose 'Network and Internet'
- Choose 'View network status and tasks' under 'Network and Sharing Center'
- Choose 'Change adapter settings' from the left hand menu
- Then choose your interface - most likely either 'Wi-fi'
- In the dialog that appears, click on the 'Properties' button at the bottom
- Double click on 'Internet Protocol Version 4 (TCP/IPv4)' at the bottom
- Repeat for 'Internet Protocol Version 6 (TCP/IPv6)'

- Flush DNS cache: from a terminal run `ipconfig /flushdns`

Exercise - DNS traffic inspection

Need Wirshark 3.0.2

- Install Wireshark (GUI) or tcpdump (command line)
- Close all your apps
- Flush the local DNS cache (see previous slides)

- Start a capture with WS:
  - Choose the Wifi (or Ethernet) interface
  - Add a capture filter of 'port 53'
  - Hit the Blue fin
  - Add a filter of 'ip.addr == 8.8.8.8'
- `tcpdump -i eth0 host 8.8.8.8 and port 5 -n <-v> <-X>`

- Do a few 'dig's to 8.8.8.8 and look at the packets
(capture bytes for later on!)

Exercise - DNS traffic inspection

- Close all your apps
- Flush the local DNS cache (see previous slides)
- Then open one by one to see the DNS queries….
- Change your DNS setting and send all your queries to Google/Cloudfare/Quad9 (if you dare!)

What DNS reveals

- Mail clients - email hosting (server name!), which client
- Chat services - jabber server and Slack channels
- Calendars - where hosted
- Apps - often check for updates when opened
- Browsers - which client, which plugins. Open tabs, most visited, favourites, …. Then your browsing…

DoT on the Desktop

kdig & getdns_query

- ‘kdig’ comes as part of the ‘knot’ package (no Windows package)
    - syntax is exactly like ‘dig’ but…
    - +tls
- getdns_query - comes as part of the Stubby packages,
    - syntax is similar to dig, but different and output format is very different!

Lets do DoT on the desktop!

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Software	See DNS Privacy Clients for details
Stubby	• Specifically designed as a privacy stub • Best for upstream performance (pipelines queries) + privacy features (but no cache yet)
Unbound	• Can use as a caching forwarder • But uses a new connection for each query (poor performance) • Can also configure stub zones
BIND	• Does not do DoT natively, but can be set up with a TLS proxy to forward queries over TLS
Knot resolver	• Similar to Unbound but less well known
systemd	• Native support but very 'systemd'-like….(only Opportunistic)

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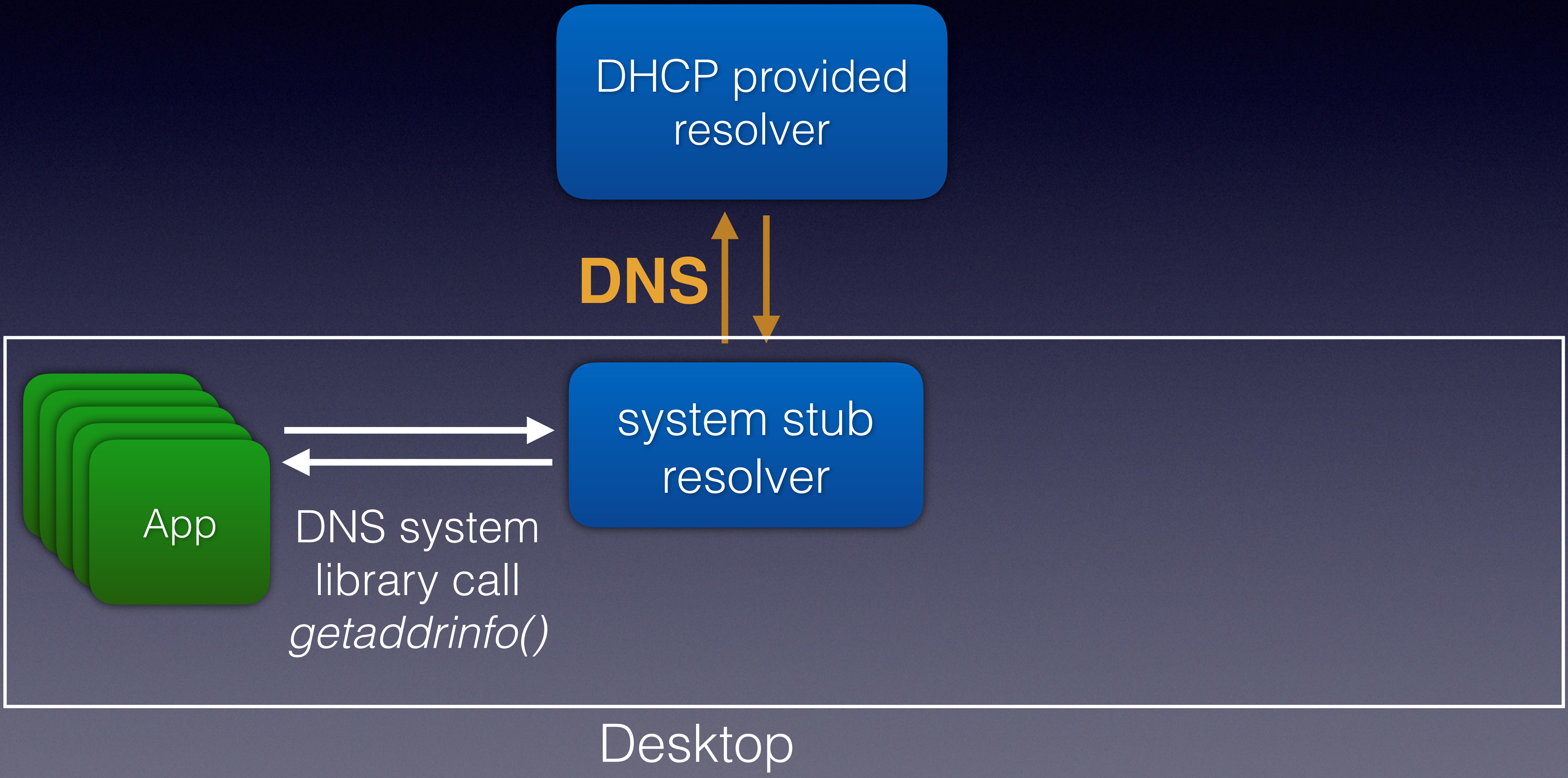
How does Stubby work?



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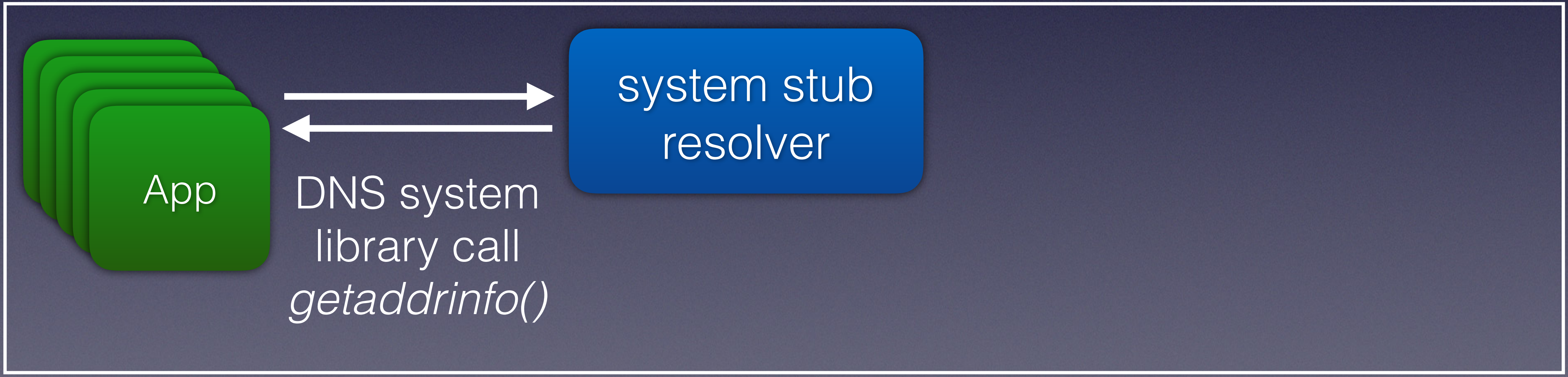

Desktop

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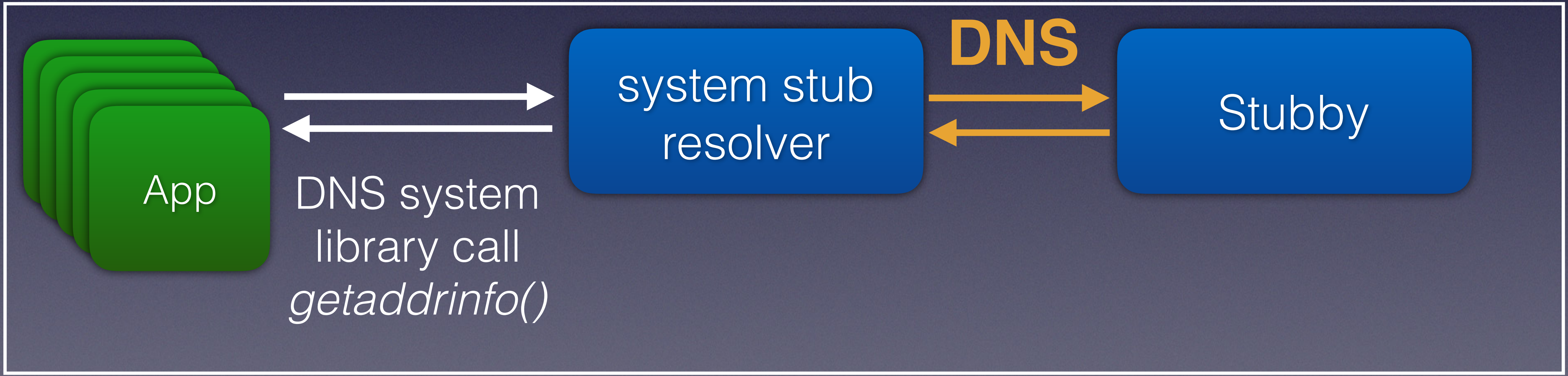

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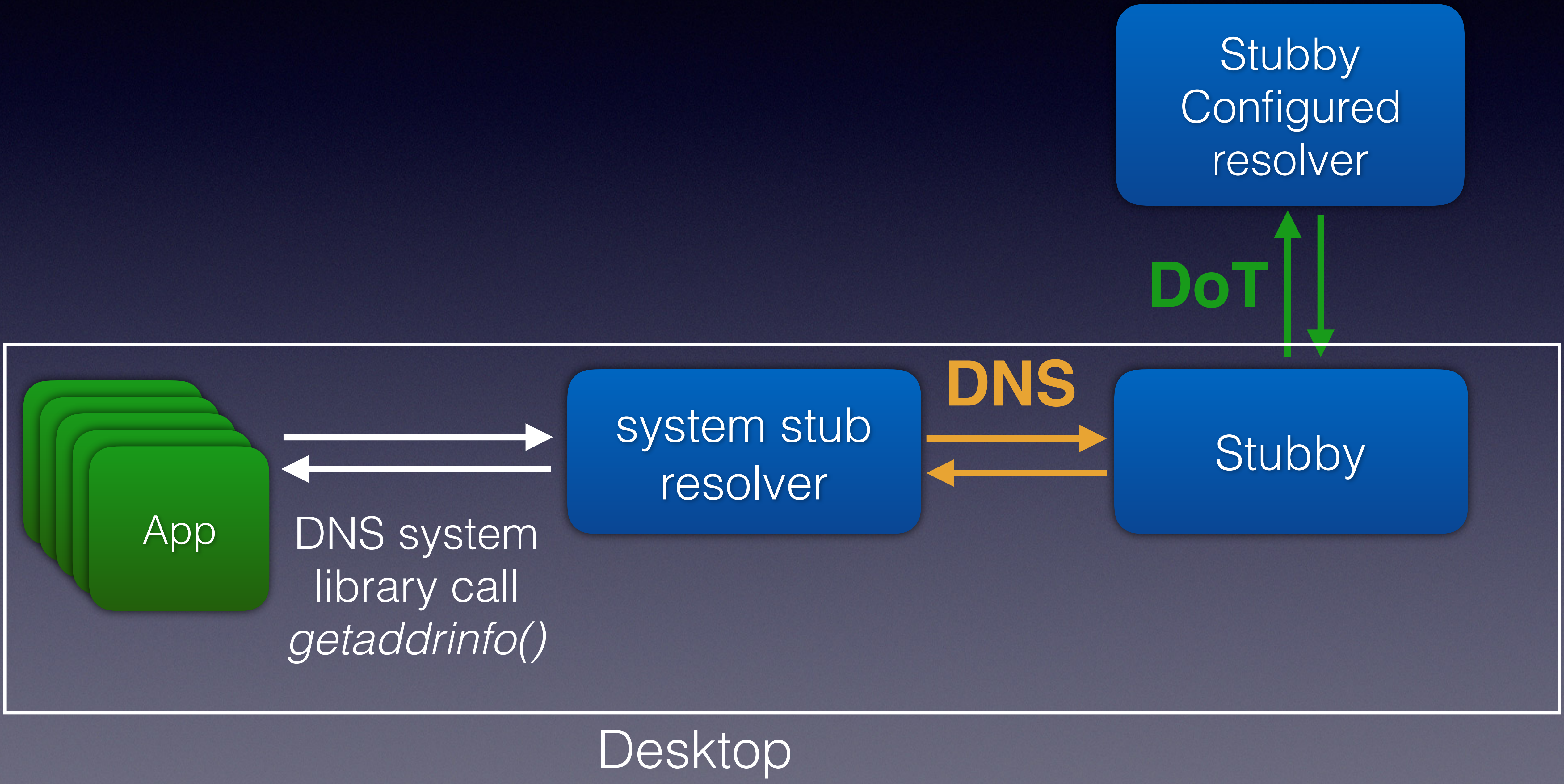
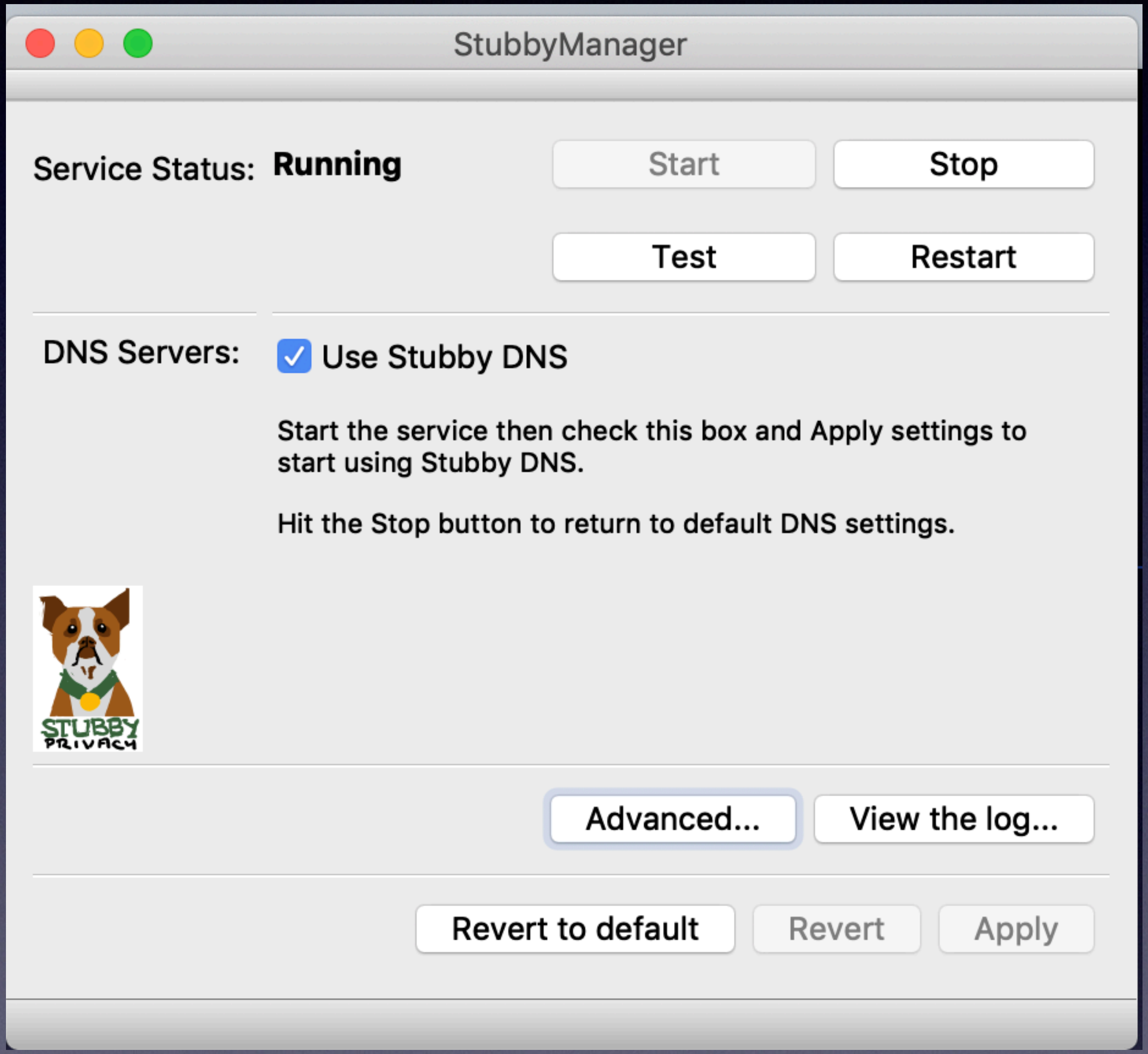


Stubby - Installing

- Stubby Homepage - built on the getdns library
- Stubby Installation Guide
  - Linux distros
    - Packages (NOTE: debian package version is wrong!)
    - Build from source
  - macOS
    - Homebrew
    - Prototype StubbyManager GUI for macOS
  - Windows
    - Windows installer (MSI, zip)
    - Chocolatey package

Install Stubby!

Stubby GUI



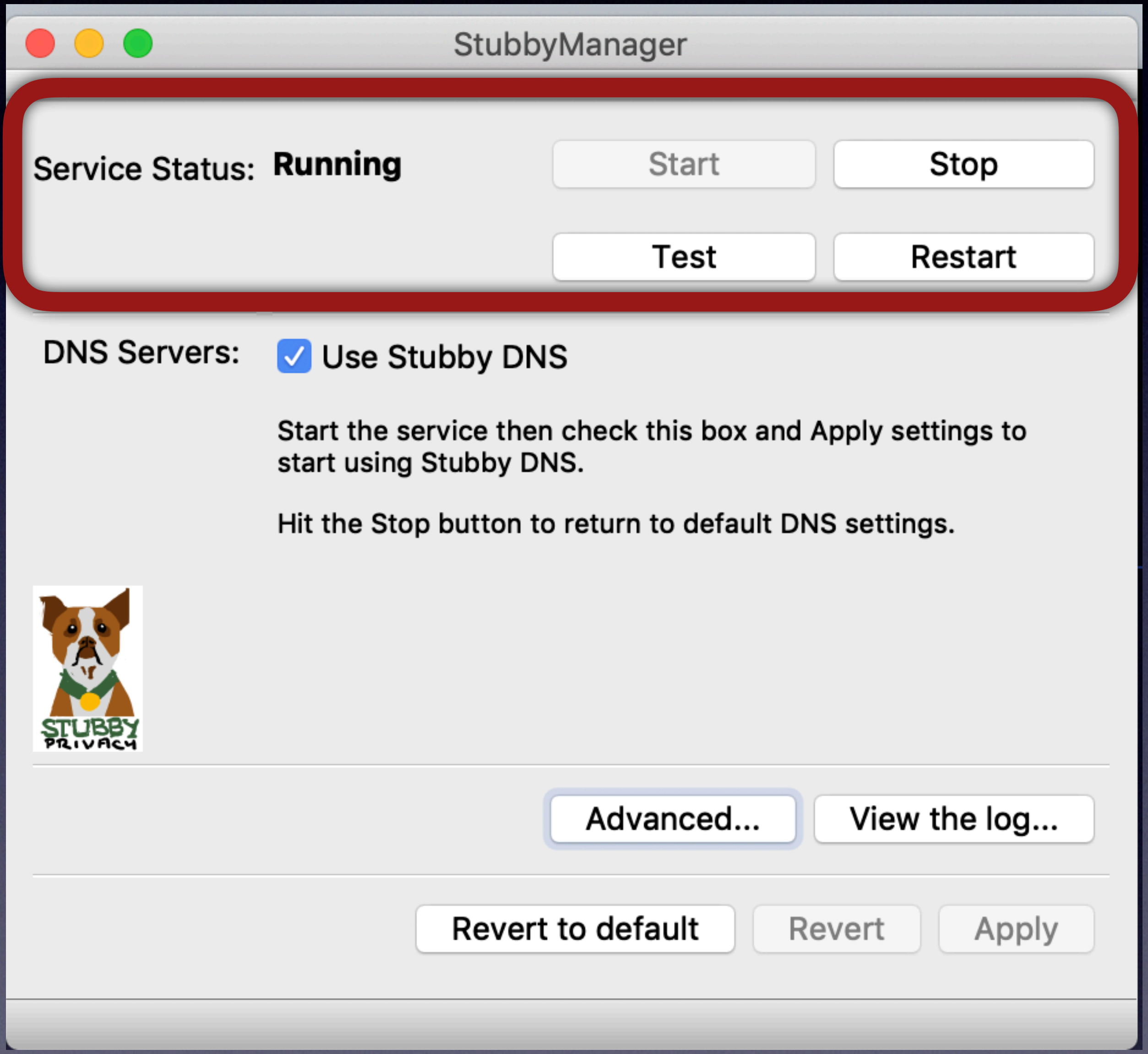
Service Status: **Running**

DNS Servers: ☑ Use Stubby DNS

Start the service then check this box and Apply settings to start using Stubby DNS.

Hit the Stop button to return to default DNS settings.

Stubby GUI



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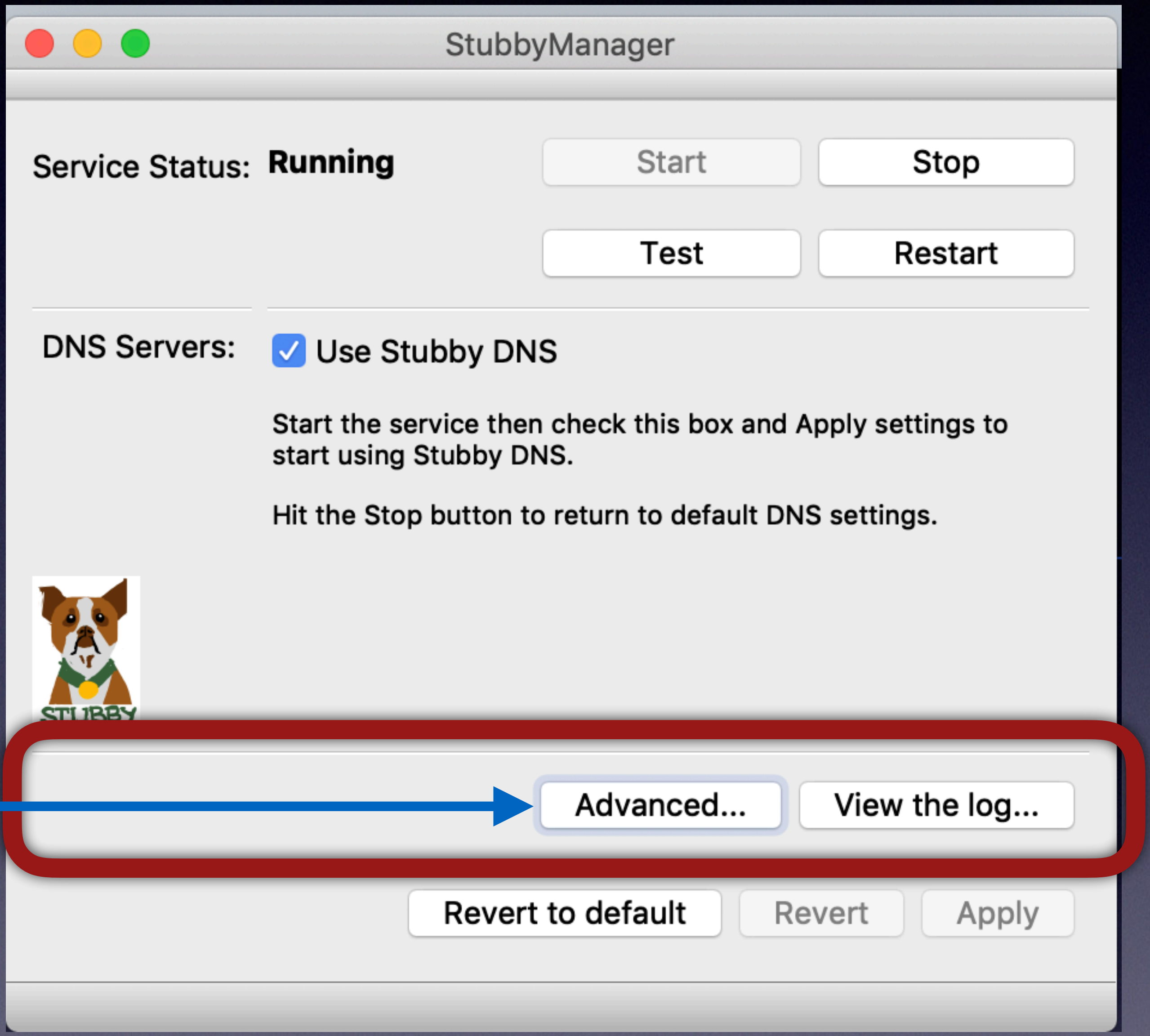

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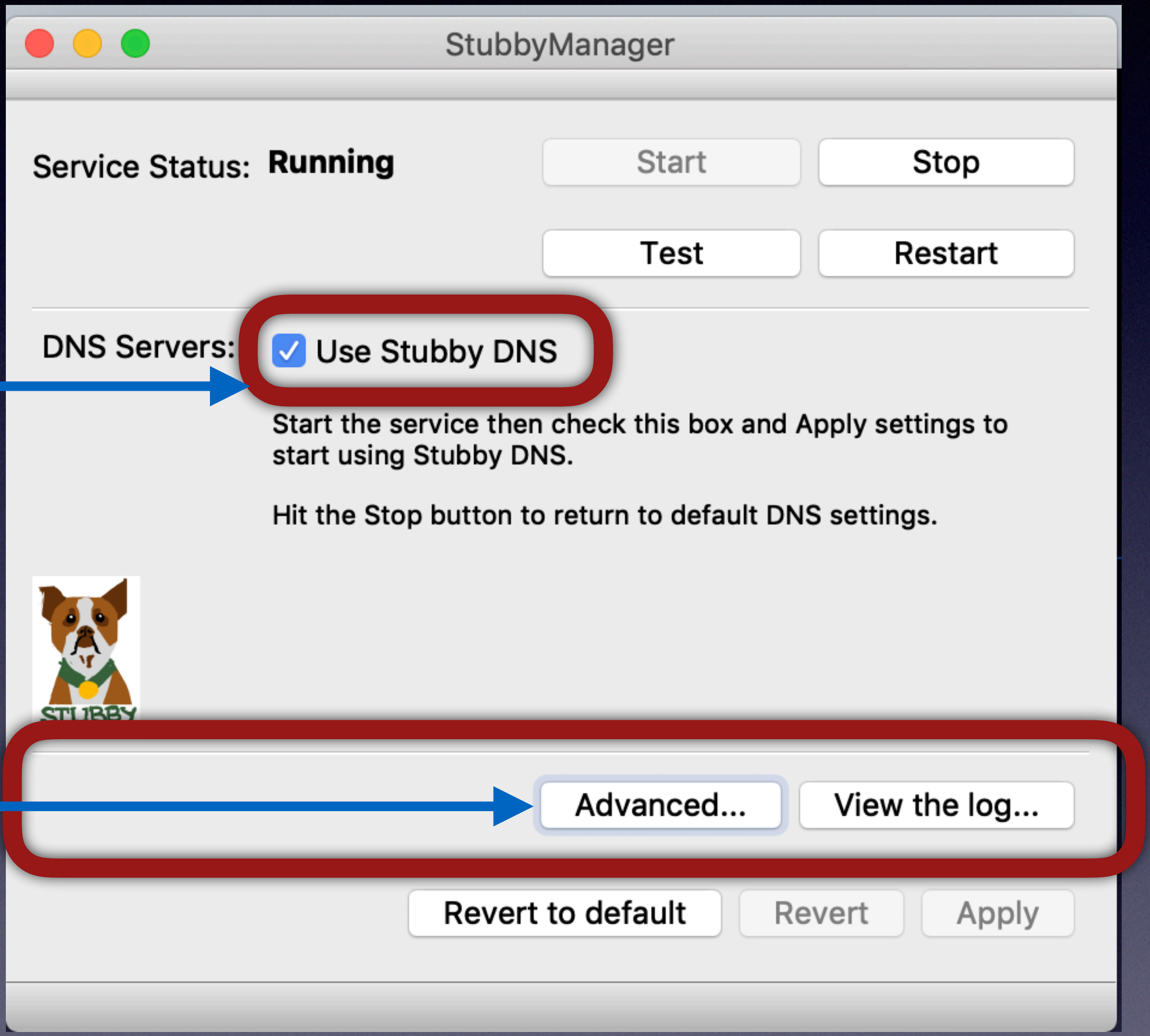
Edit the config file

Stubby GUI



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Update system resolver

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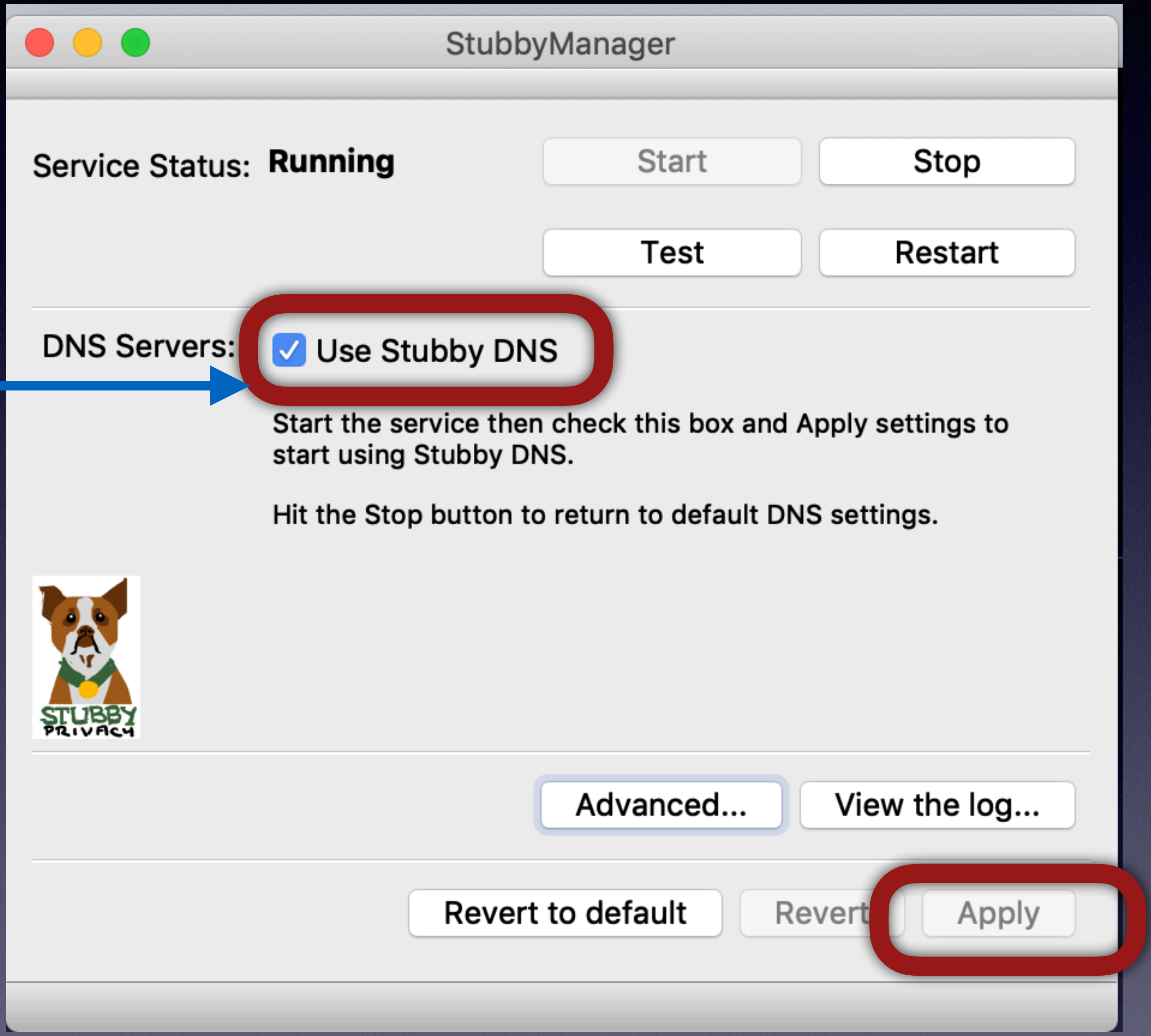
Stubby GUI

Update system resolver


StubbyManager

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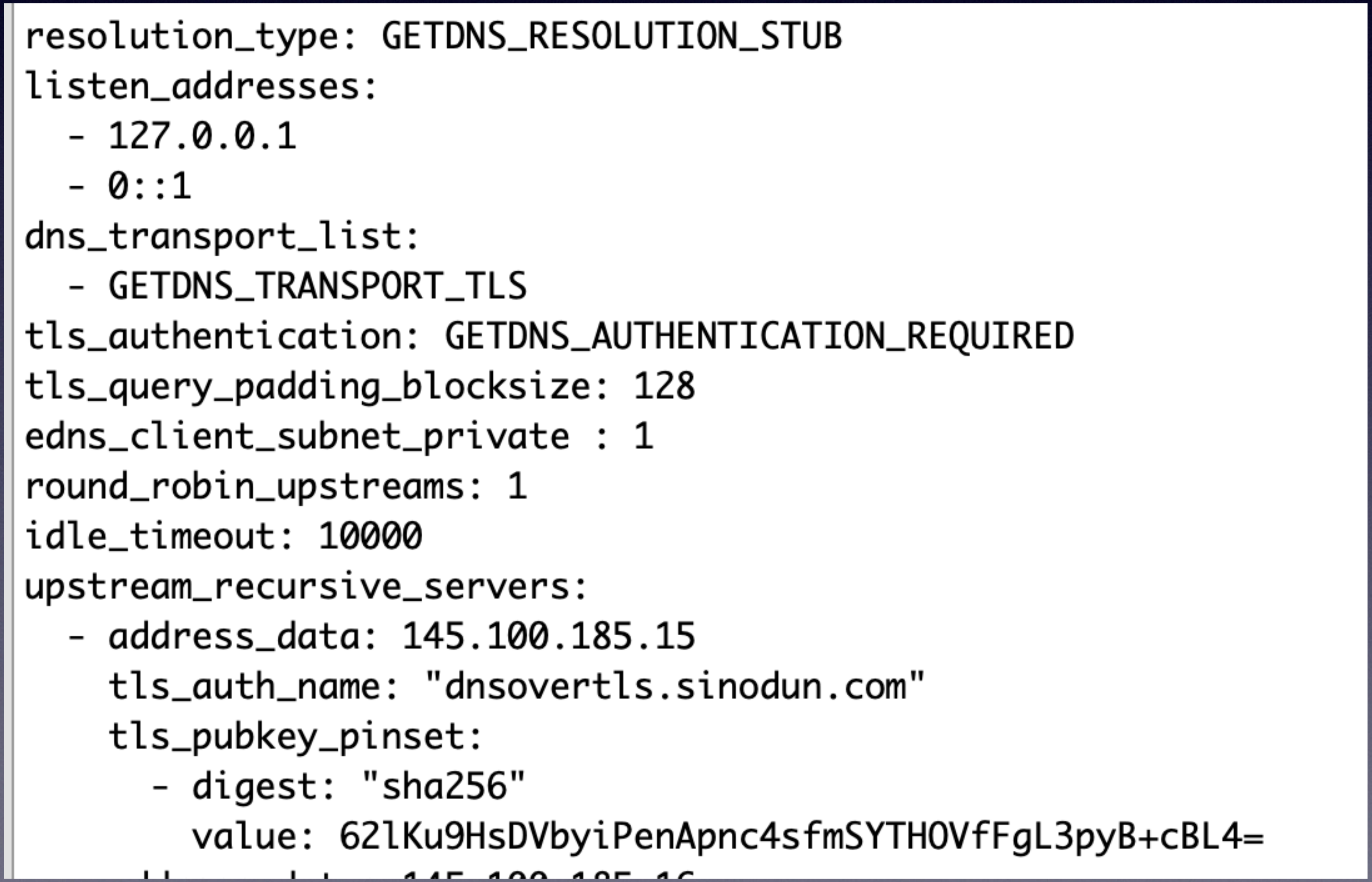
Stubby - Configuring

- Stubby has a stubby.yml config file - defaults:



```
resolution_type: GETDNS_RESOLUTION_STUB
listen_addresses:
  - 127.0.0.1
  - 0::1
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
tls_authentication: GETDNS_AUTHENTICATION_REQUIRED
tls_query_padding_blocksize: 128
edns_client_subnet_private : 1
round_robin_upstreams: 1
idle_timeout: 10000
upstream_recursive_servers:
  - address_data: 145.100.185.15
    tls_auth_name: "dnsovertls.sinodun.com"
    tls_pubkey_pinset:
      - digest: "sha256"
        value: 62lKu9HsDVbyiPenApnc4sfmSYTHOVfFgL3pyB+cBL4=
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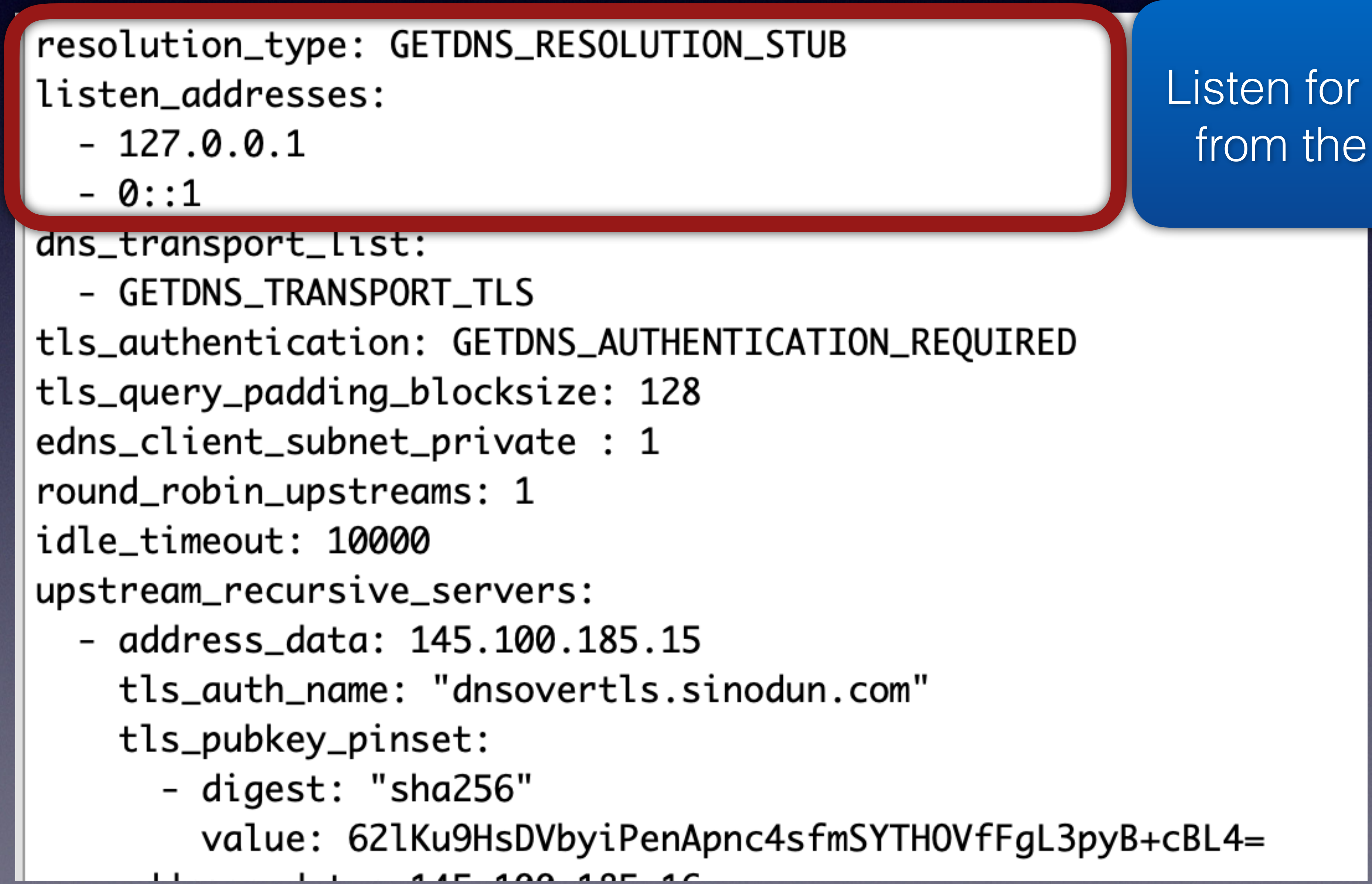

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Listen for queries coming from the local machine

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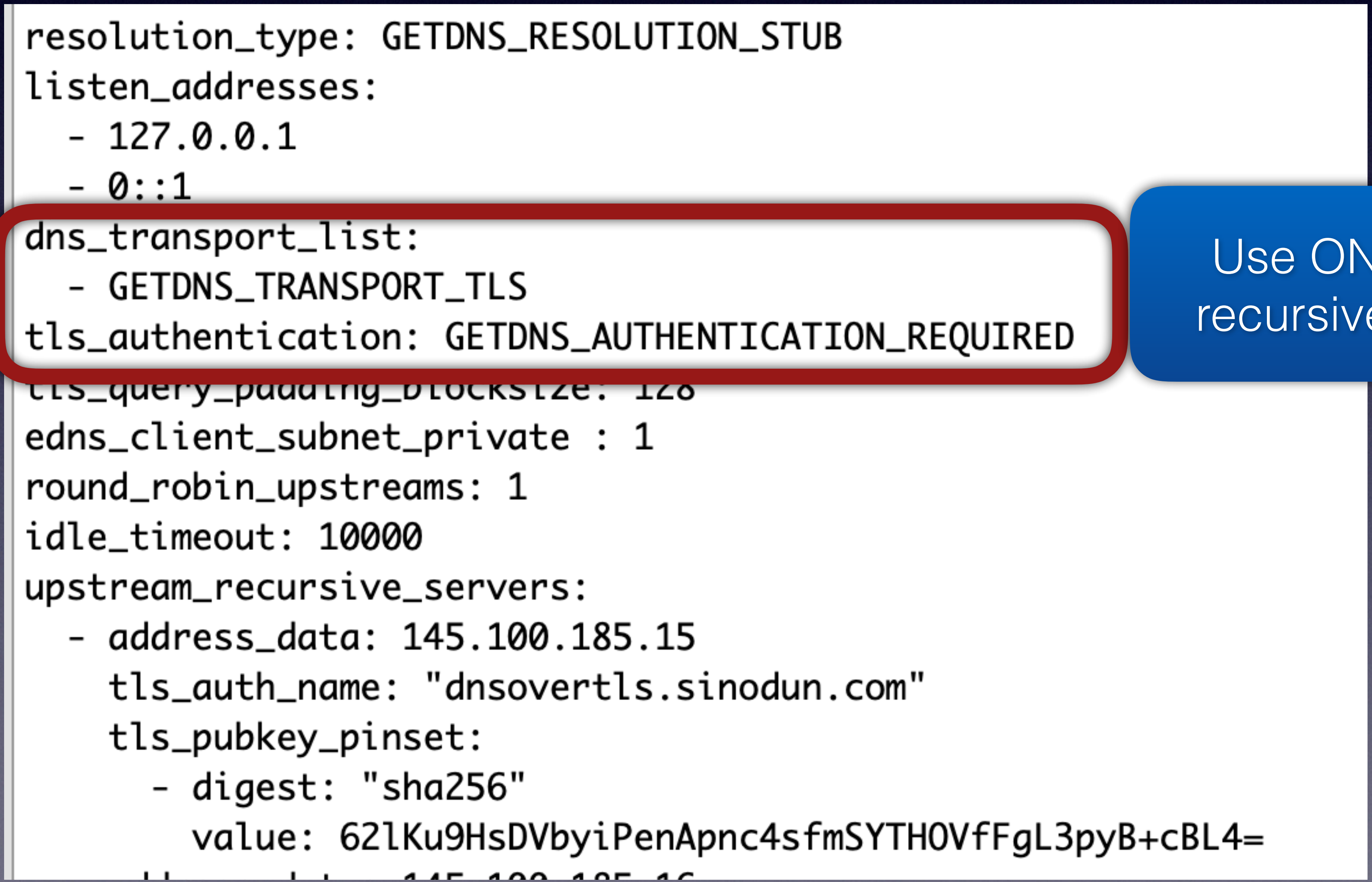

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  - address_data: 145.100.185.16
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Use ONLY TLS to the recursive, require auth

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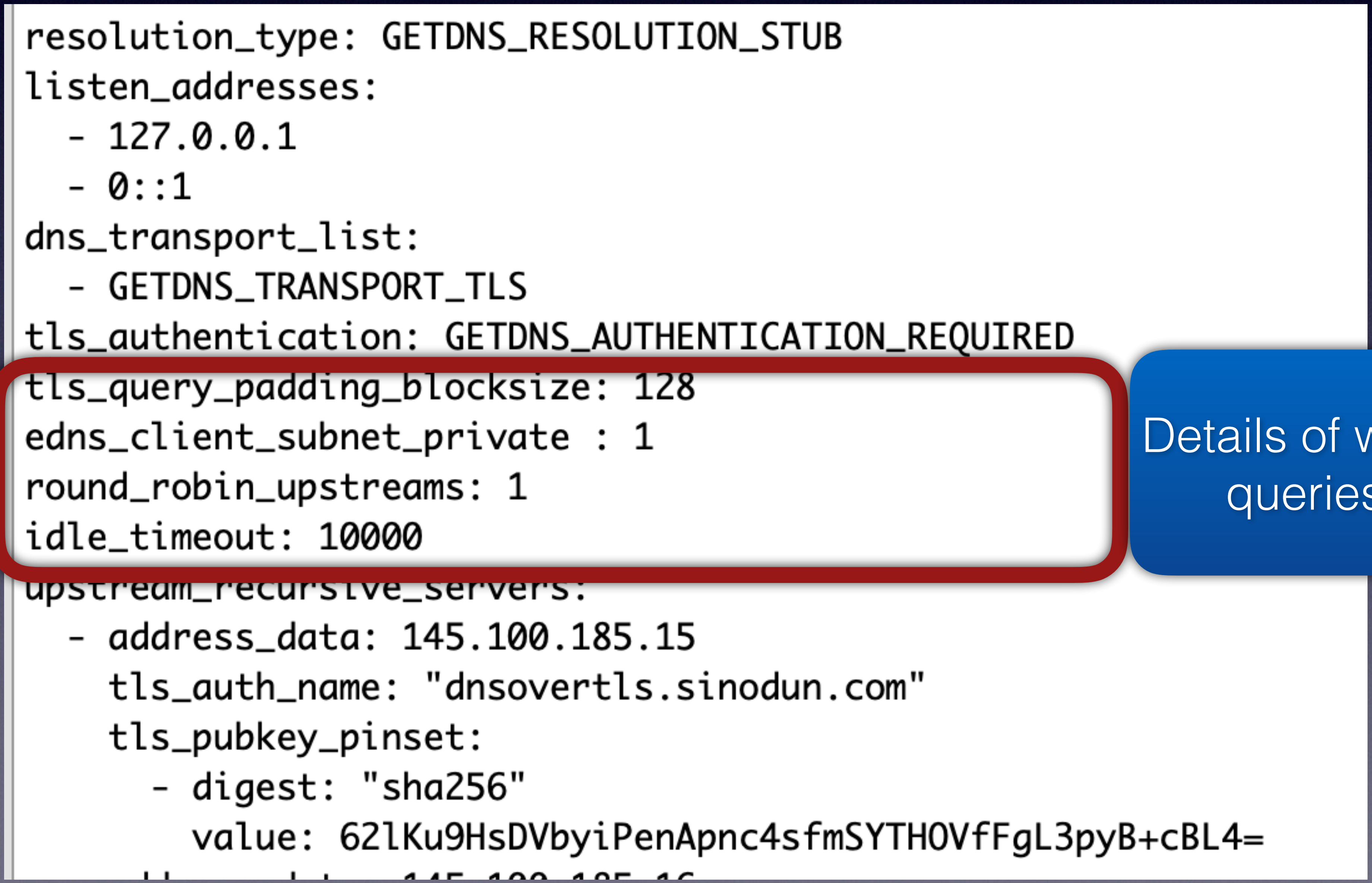

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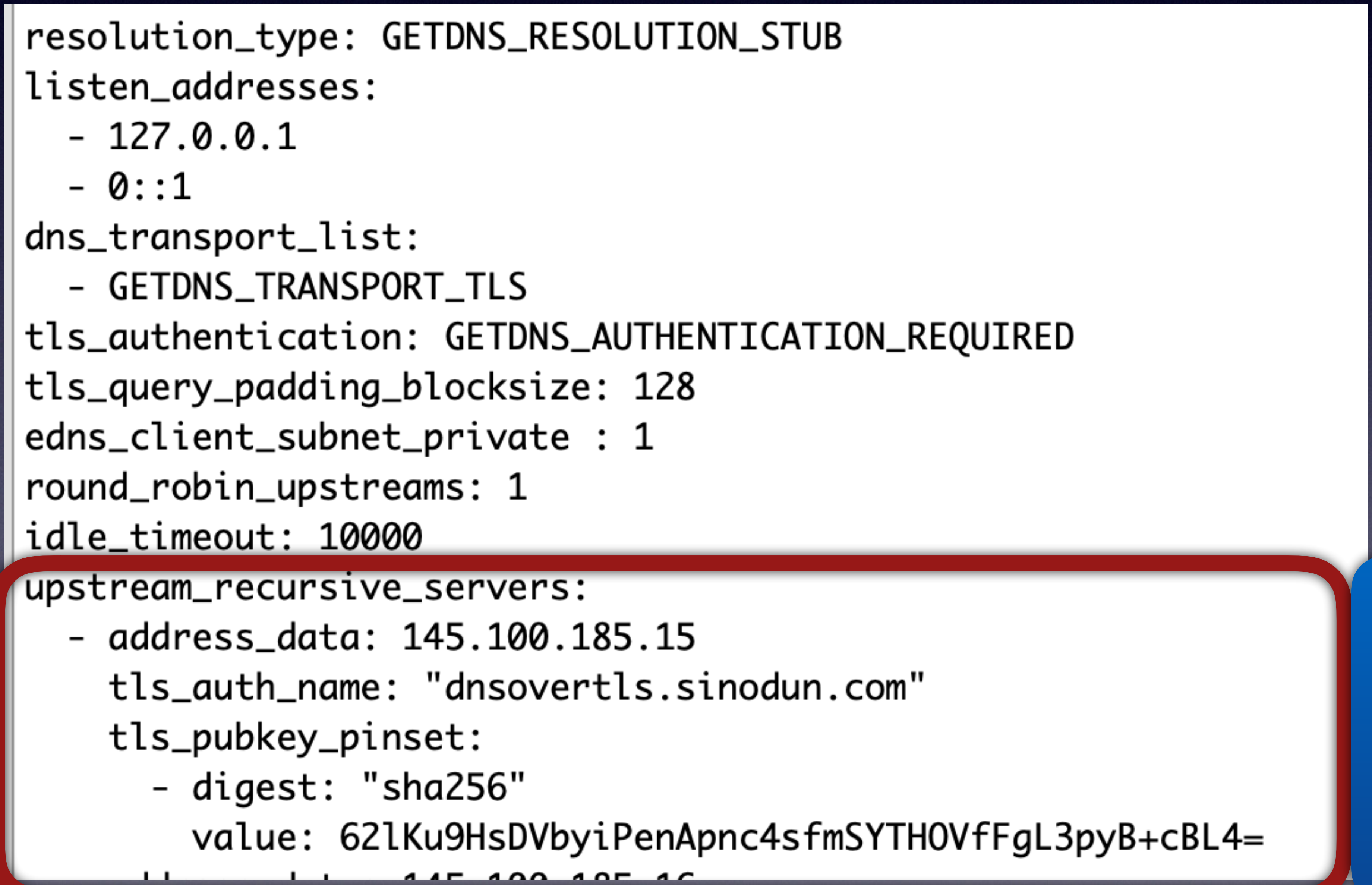
Details of what/how to send queries to recursive

Stubby - Configuring

- Stubby has a stubby.yml config file - defaults:



```
resolution_type: GETDNS_RESOLUTION_STUB
listen_addresses:
  - 127.0.0.1
  - 0::1
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
tls_authentication: GETDNS_AUTHENTICATION_REQUIRED
tls_query_padding_blocksize: 128
edns_client_subnet_private : 1
round_robin_upstreams: 1
idle_timeout: 10000
upstream_recursive_servers:
  - address_data: 145.100.185.15
    tls_auth_name: "dnsovertls.sinodun.com"
    tls_pubkey_pinset:
      - digest: "sha256"
        value: 62lKu9HsDVbyiPenApnc4sfmSYTHOVfFgL3pyB+cBL4=
```

Which recursive + auth details (default is Stubby servers)

Stubby - Run it

- Run from the command line to start e.g.

```
sudo <path_to_exe>stubby -l <-C stubby.conf>
```

- Look at log - reports config

- Test Stubby. Open a new terminal and do a query directly to Stubby

```
dig @127.0.0.1 www.example.com
```

Run Stubby!

Stubby - Use for all DNS

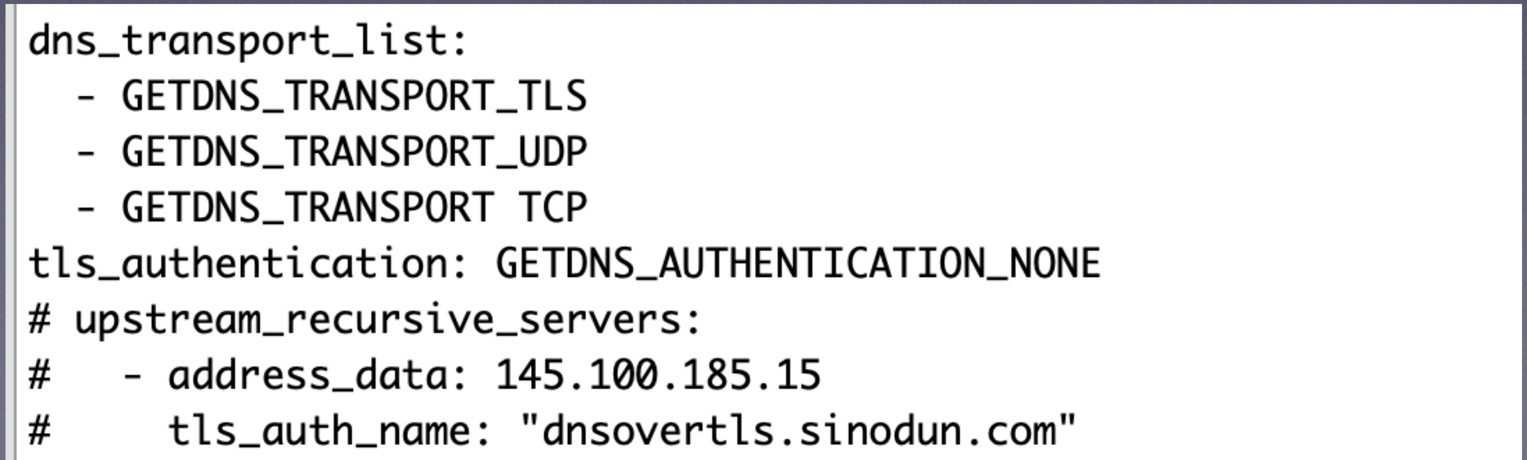
- Need to update your system resolver settings (and hit ‘Apply’): [systemd probably edit /etc/systemd/resolved.conf but…]
    - 127.0.0.1
    - 0::1
- Stubby log: lots of TLS connections (or a few long-lived)
- Look in Wireshark
    - No queries on port 53
    - The switch to port 853 - your queries are hidden in TLS sessions (note Wireshark doesn’t recognise DoT)!

How to decrypt TLS traffic?

- Client session keys - need a way to export them from the client (works for all TLS versions/cipher suites)
  - Stubby/Unbound do not support this yet
  - (Later we will see that Firefox does)
- Server private RSA keys - need access to private keys, normally only admins have this
  - Does not work with PFS ciphers (TLS 1.3, some TLS 1.2)
  - We can set up our own server to access the keys but have to restrict server to ‘weak’ ciphers

Stubby - other options

- Depending on your OS, you can configure Stubby to run as a service
  - Note you might have issues as you change network or hit a captive portal….
- Probably have getdns_query installed ('dig' like but with DoT)
  - `getdns_query @8.8.8.8~dns.google www.example.com -Lm +return_call_reporting`
- If you want to do Opportunistic DoT to the local resolver, reset your system resolvers and update 3 items in your config:



```
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
  - GETDNS_TRANSPORT_UDP
  - GETDNS_TRANSPORT TCP
tls_authentication: GETDNS_AUTHENTICATION_NONE
# upstream_recursive_servers:
#   - address_data: 145.100.185.15
#     tls_auth_name: "dnsovertls.sinodun.com"
```

Stubby - as a Sophisticated Service

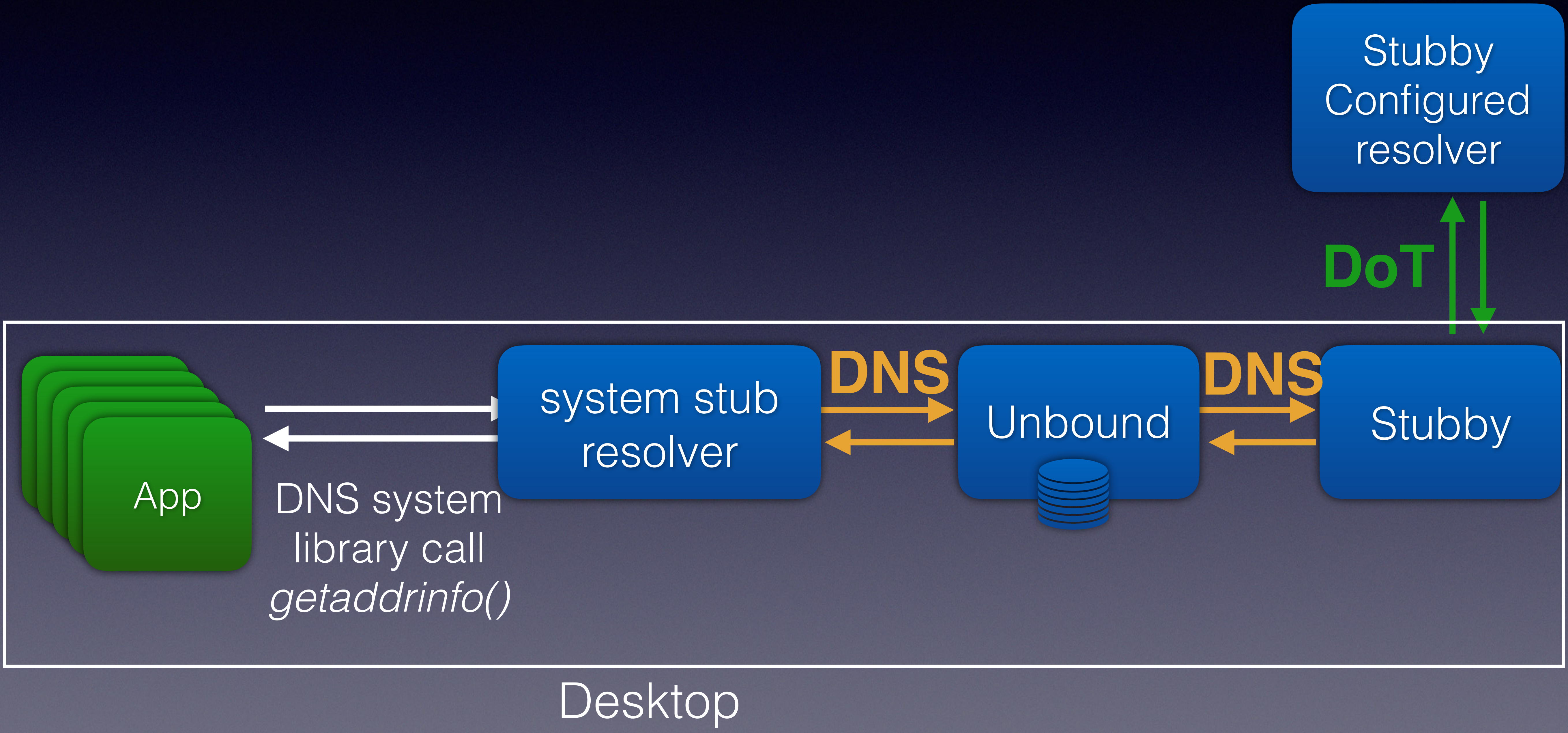
- Ideally - you could configure which networks you 'trust' and which you don't and use different configurations
- REALLY need a nice GUI with visual indicators to help users understand the state (GUI icon in menu: Bold=Strict)
- BUT - think about the usability here. 'Usable Security'
    - Green lock in HTTPS is per website (still confusing)
    - DNS is per network… and users don't understand DNS!

Unbound as a DoT stub

Unbound as a DoT stub

- Actually a recursive resolver but can be configured to cache locally and just forward all queries to another recursive resolver.
- Download from: https://nlnetlabs.nl/projects/unbound/download/
  - Packages, homebrew, Windows installers
- Example config here: Unbound config and in git repo
  - Must specify path to CA bundle to do authentication (Windows requires `tls-win-cert:` instead). May need to change user…
  - Can set up stub-zones for local queries
- To run in foreground: `sudo unbound -c <conf_file> -d <-vvvv>`
  - Unbound uses a new TCP connection for _every_ query (inefficient)

Bonus points: Unbound+Stubby


Stubby Configured resolver
DoT
App
DNS system library call *getaddrinfo()*
system stub resolver
DNS
Unbound
DNS
Stubby
Desktop

Running a DoT recursive resolver

Running a DoT Recursive

- Overview is here: [Running a DNS Privacy Resolver]
- Several open source DNS implementations do DoT natively (some do DoH too)
- Big differences to ‘normal DNS resolver’
  - Need to have a valid certificate for name (LE is good option)
  - Need a bit more configuration
  - Need to think about data handling (Best practices)

Unbound as a recursive DoT resolver

- Download from: https://nlnetlabs.nl/projects/unbound/download/
  - Packages, homebrew, Windows installers
- Full example config is here: Unbound server config
  - Next slide (and git repo) has suggested config for this lab
- Need to create a self-signed certificate using openssl & update paths in config file (need openssl 1.1.1):

```
>openssl req -x509 -newkey rsa:4096 -keyout key.pem -out cert.pem -days 7
>openssl rsa -in key.pem -out key_rsa.pem
```

- Sample cert and key files are in the git repo

unbound_rec.conf

```
server:
  directory: "/etc/unbound"
  username: unbound
  chroot: "/etc/unbound"
  logfile: "" # logging will be to stdout.
  pidfile: "/etc/unbound/unbound.pid"
  # verbosity: 1 # uncomment and increase to get more logging.
  # listen on localhost on port 853, answer queries from the local subnet.
  interface: 127.0.0.1@853
  interface: 0::1@853

  tls-service-key: “<path>/key_rsa.pem”
  tls-service-pem: “<path>/cert.pem"
  tls-port: 853
  incoming-num-tcp: 100 # Number of simultaneous incoming TCP connections

  # Listen on UDP but still issues queries upstream over UDP.
  # Only available in 1.6.7 and later
  udp-upstream-without-downstream: yes
  qname-minimisation: yes # Enable QNAME minimisation

  # Force a weak cipher suite to allow decryption
  # NEVER USE IN PRODUCTION!!!
  tls-ciphers: "RSA"
```

Unbound as a recursive DoT resolver

- To run in foreground: `sudo unbound -c <conf_file> -d  <-v>`
- Now lets point Stubby at this recursive resolver

```
tls_authentication: GETDNS_AUTHENTICATION_NONE
upstream_recursive_servers:
 - address_data: 127.0.0.1
```

- Or use ‘kdig’ or ‘getdns_query’ to do individual queries
- Look in Wireshark again on the ‘loopback’ interface with capture filter 'port 853’ to see the traffic from Stubby to Unbound
- Look on port 53 to see the traffic from Unbound out the authoritative servers

Decrypt local DoT traffic

- In Wireshark go to Preferences
- Expand ‘Protocols’ and select the word ‘Protocol’
- Start typing ‘TLS’ - this will jump you to the TLS settings
- Click on the Edit button next ‘RSA keys list’
- Add an entry for 127.0.0.1, 853, tls, <path the ‘key_rsa.pem’ file>
- Then hit OK twice to save the settings

Decrypt local DoT traffic

- Now look at the TLS -> Server Hello in Wireshark and you will see a Cipher containing RSA
- Select a packet now marked as ‘Unknown Ignored Packet’ - Wireshark doesn’t support DoT directly
- Click on the ‘Encrypted Application Data’, then at the very bottom select the pane marked ‘Decrypted TLS bytes’ - you should see what looks like a domain name!

DoH on the Desktop

DoH for Desktop

- Clients:
  - Cloudflare have release two tools to provide DOH clients, see Cloudflared
  - Frank Denis has a dnscrypt-proxy (client proxy) that supports DoH.
- ‘dig’ like tool for DoH:
  - Curl also supports DoH https://github.com/curl/doh

```
./doh www.example.com https://cloudflare-dns.com/dns-query
```

DoH in Browsers

Browsers

- Desktop:
  - Firefox (DoH)
  - [Chrome (DoH)]
  - Yandex (DNSCrypt)
- Mobile browser:
  - Bromite - based on Chrome (DoH)
  - Tenta for Android (DoT)

Browsers

- Desktop:
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Firefox

- Download the latest Firefox Nightly (or Firefox)

Need Latest Firefox Nightly to decrypt DoH

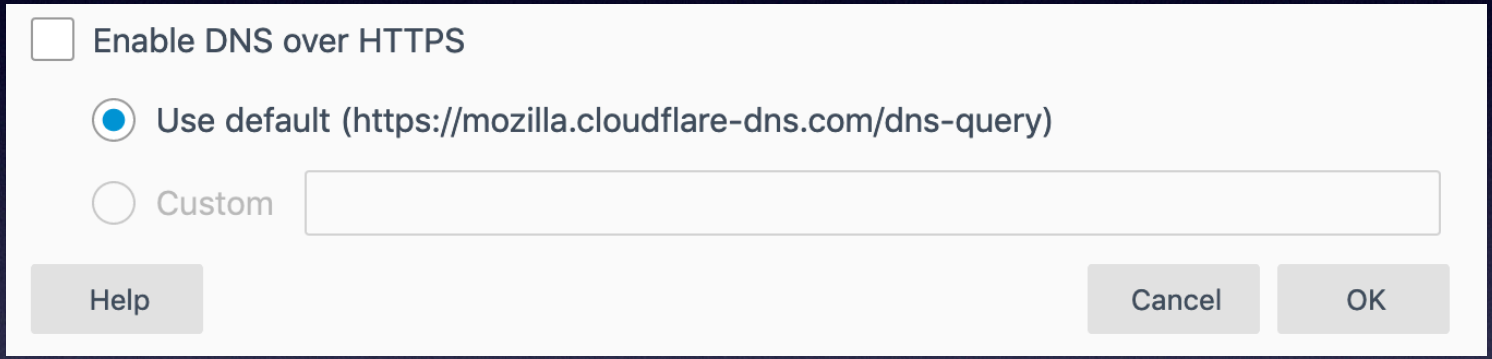
- Close your other apps.

- See DNS activity via `about:networking` tab
    - Select 'DNS Lookup' to do individual queries (use refresh)
    - Select 'DNS' to see queries (Note TRR=False)

- 2 levels of config
    - 'Easy' via a Preferences GUI option
    - Low-level via `about:config`

Firefox - DoH in the GUI

- Firefox->Preferences. Scroll to bottom 'Network Settings' click on 'Settings'
- Scroll the bottom to find the DoH checkbox



☐ Enable DNS over HTTPS

[✓ Use default (https://mozilla.cloudflare-dns.com/dns-query)]

Custom

- Check the box and open a tab, look again at about:networking
- Look in Wireshark again… Nothing on port 53 or 853.
  Look on port 443 - can you tell the DNS from the HTTP?
  Note: all DoH goes to Cloudflare, use a filter expression to see only DoH:

```
host cloudflare-dns.com
```

```
ip.addr == 108.61.201.119 or ip.addr == 104.16.248.249 or ipv6.addr ==
2606:4700::6810:f9f9 or ipv6 == 2606:4700::6810:f8f9
```

Firefox - DoH in the GUI

- Easy right? And you don't need to be an Admin on the machine…
  - And remember - in the next release this may be on by default!
  - Too easy? Use it without knowing (back to Informed Consent)
- Extreme scenarios
  - Great to avoid DNS snooping and interference in untrusted network
  - But so easy a child in a house where parental controls are enabled can do it with no-one knowing
- But all your other DNS queries are still clear text….

Firefox - DoH via config

- Use the about:config tab and in the search box type ‘trr’
- Will see a variety of settings…
    - ‘trr.mode’ = 2. This will fall back to cleartext DNS via the system resolver if it can’t talk to the DoH resolver (like Op DoT)
    - ‘trr.mode’ = 3 fails instead (like Strict DoT)
- Go back to your DoH setting and ‘mis-type’ the URI and apply
    - Now all the traffic has TRR=false
    - Did you get a warning?

GUIs for DNS settings are hard….

Decrypt DoH traffic

- Great SharkFest presentation on this
- For long captures start Wireshark with capture filter
  `` `port 443 and host cloudflare-dns.com` ``
- Close then re-start Firefox Nightly set up to export session keys:
  - Linux/macOS - close Firefox and relaunch from command line:
    ```
    SSLKEYLOGFILE="$PWD/keys.txt" <path>/firefox -no-remote -profile /tmp/ff
    ```
  - Firefox on Windows, create start-fx.cmd file, without quotes in the set line:
    ```
    set SSLKEYLOGFILE=C:\Users\User\Desktop\keys.txt
    start firefox
    ```

Decrypt DoH traffic

- In Wireshark go to Preferences
- Expand ‘Protocols’ and select the word ‘Protocol’
- Start typing ‘TLS’ - this will jump you to the TLS settings
- (Pre)-Master-Secret log filename - click browse and select the file exported by Firefox. Click OK
- Hey presto! Wireshark decodes packets as DoH.

DoH

- HTTP request to https://dnsserver.example.net/dns-query
- Query can use POST or GET:

```
:method = GET
:scheme = https
:authority = dnsserver.example.net
:path = /dns-query?
dns=AAABAAABAAAAAAAAA3d3dwdleGFtcGxlA2NvbQAAAQAB
accept = application/dns-message
```

Query

```
:status = 200
content-type = application/dns-messag
content-length = 61
cache-control = max-age=3709
<61 bytes represented by the following hex encoding>
00 00 81 80 00 01 00 01  00 00 00 00 03 77 77 77
```

Response

DoT/DoH for your mobile phone

Mobile DNS encryption

Mobile OS	Options
Android	**Android supports DNS-over-TLS in Android Pie** Opportunistic by default to system resolver, also user override. Talk by the Android developers: Video, Slides
	• App called 'Intra' which can be used to send all queries from the device over DoH to a user configured resolver • Cloudflare has an App: 1.1.1.1 • Quad 9 has an App: Quad9 Connect • Other apps are available….
iOS	• Cloudflare has an App: 1.1.1.1 • Other apps are available….
	Work started on a Stubby app but stalled

Mobile traffic inspection is not straightforward…

Mobile DNS encryption

Mobile OS	Options
Android	**Android supports DNS-over-TLS in Android Pie** Opportunistic by default to system resolver, also user override. Talk by the Android developers: Video, Slides
	• App called 'Intra' which can be used to send all queries from the device over DoH to a user configured resolver • Cloudflare has an App: 1.1.1.1 • Quad 9 has an App: Quad9 Connect • Other apps are available….
iOS	• Cloudflare has an App: 1.1.1.1 • Other apps are available….
	Work started on a Stubby app but stalled

Both do DoT and DoH but only to one resolver

Mobile traffic inspection is not straightforward…

DNS Privacy Libraries

DNS Privacy libraries

Language	Library
C (Nodejs, python)	getdns
Go	GoDNS
Rust	trust-dns

getdns

- getdns Modern, asynchronous DNS library with DNSSEC and DoT
  - Specifically designed to be used by developers
  - Implements new DNS features quickly (experimental)
  - Significantly more useful than libc DNS functions
- Written in C but has Python and nodejs bindings
  - Quick start guide to C library
  - Deeper tutorial: Slides, Video
- Comes with a 'dig' like tool: getdns_query

```
getdns_query @8.8.8.8~dns.google www.example.com -Lm
+return_call_reporting
```

Routers

- DNS-over-TLS forwarding on a Turris router
- OpenWRT (LEDE)
- Asuswrt-Merlin