CS 253: Web Security

DNS, HTTP, Cookies

Admin

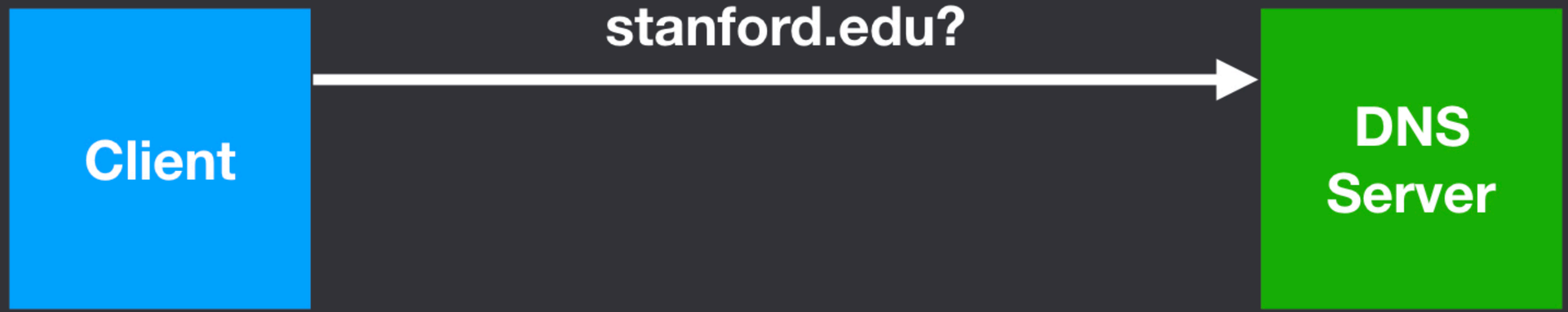
- Assignment 0 is out!
- Dropping one assignment, for total of 5 assignments
- Office hours this week
  - Feross: Today, 3-5pm, Gates 323
  - Esther: Friday, 1-3pm, Huang Basement

What happens when you type a URL and press enter?

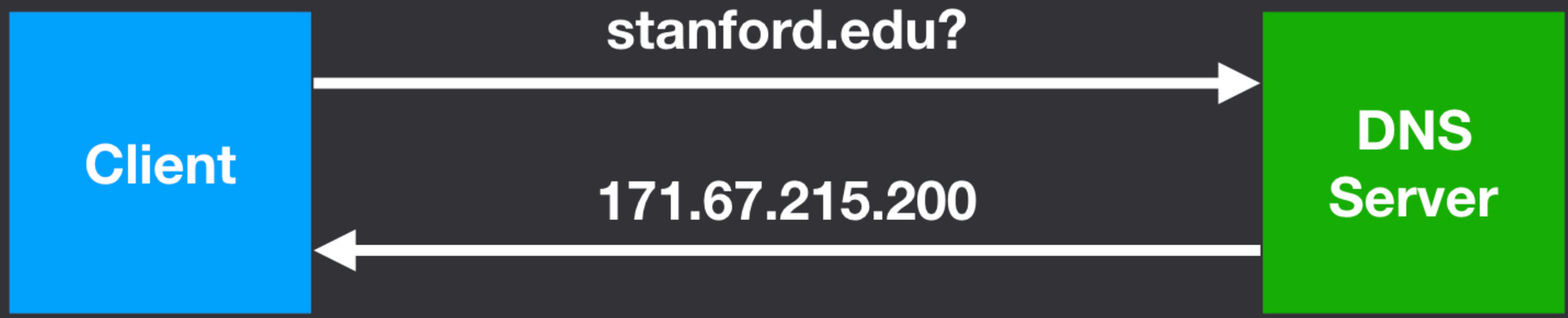
Domain Name System (DNS)

DNS

DNS



DNS



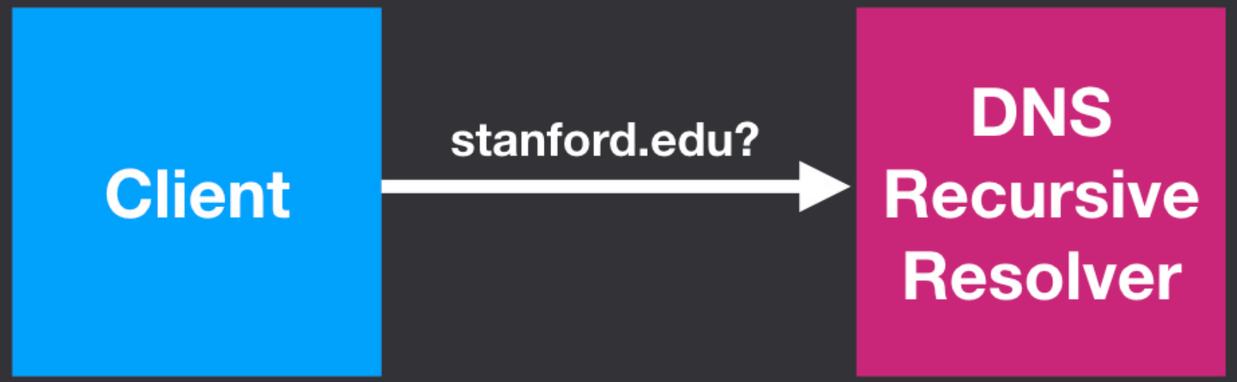
How does the "DNS server" work?

DNS

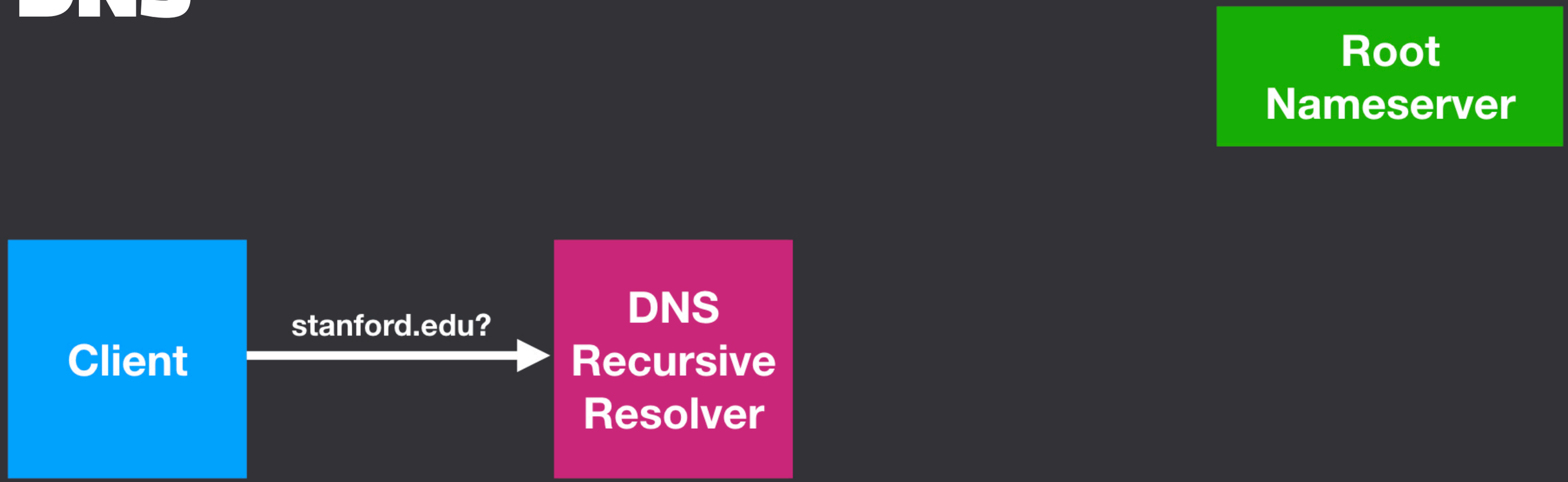
Client

DNS Recursive Resolver

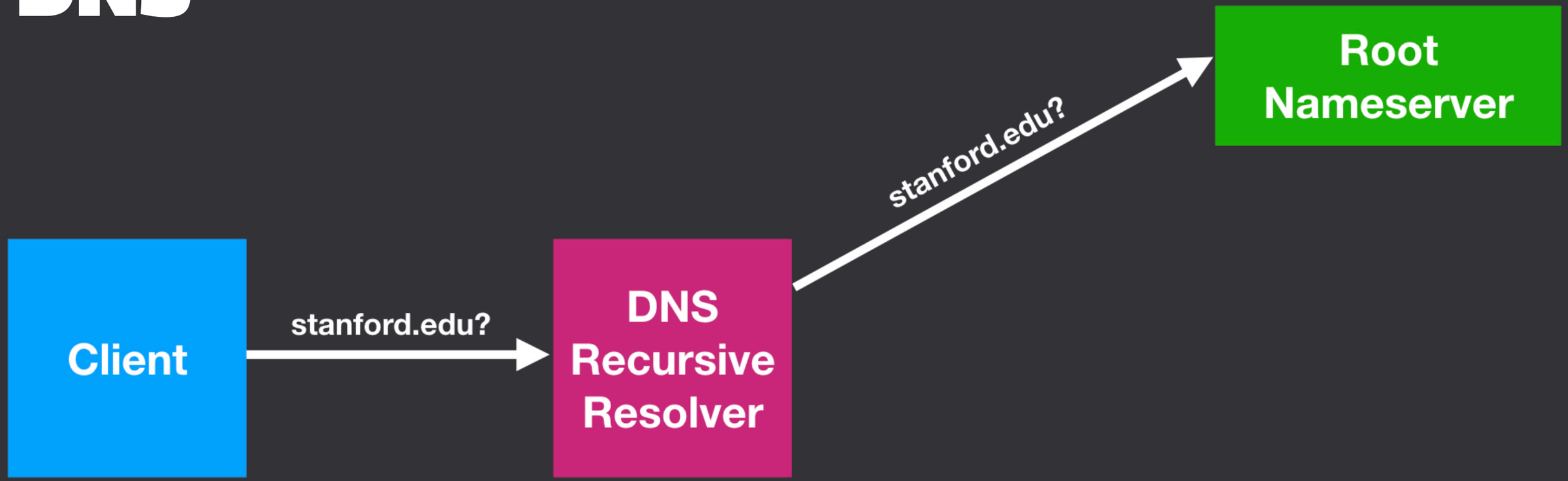
DNS



DNS


Root
Nameserver
Client
stanford.edu?
DNS
Recursive
Resolver

DNS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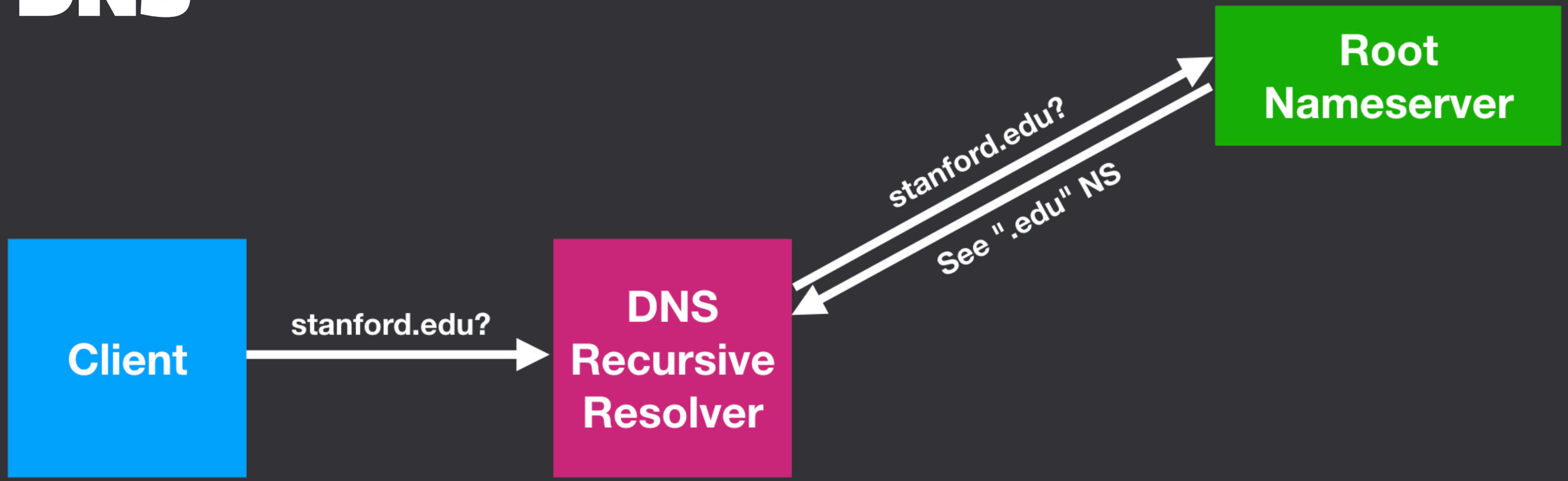
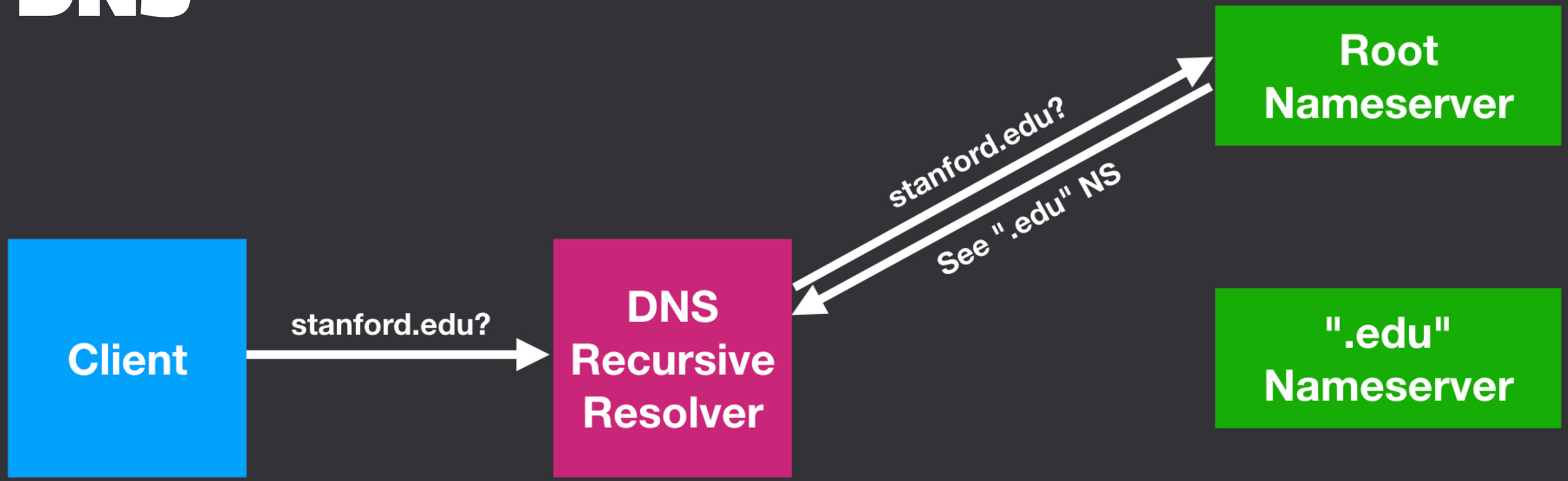
DNS


Root Nameserver
stanford.edu?
See ".edu" NS
Client
stanford.edu?
DNS Recursive Resolver

DNS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Recursive
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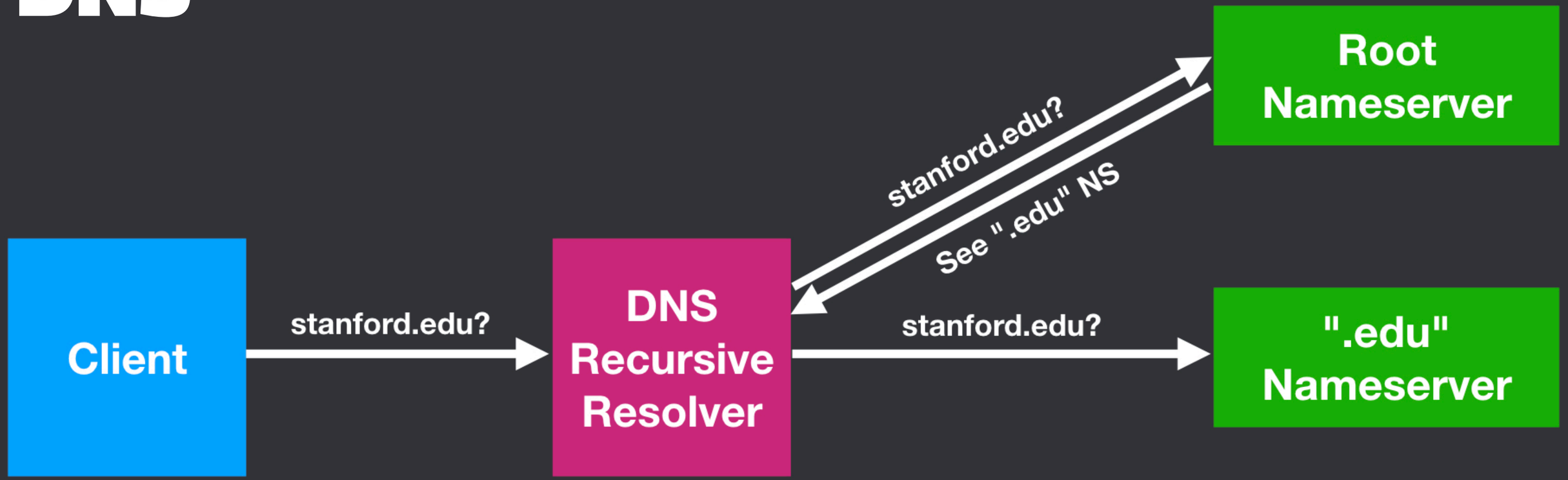
".edu"
Nameserver

DNS


Root
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See ".edu" NS
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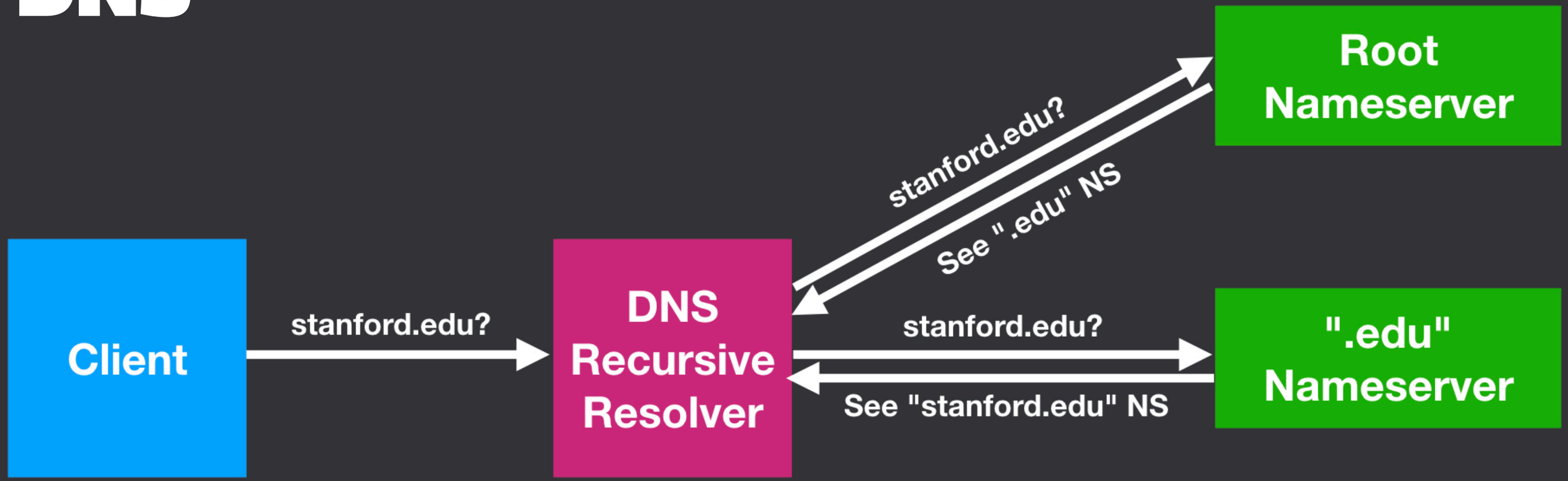
DNS
Recursive
Resolver
stanford.edu?
".edu"
Nameserver

DNS


Root Nameserver
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DNS Recursive Resolver
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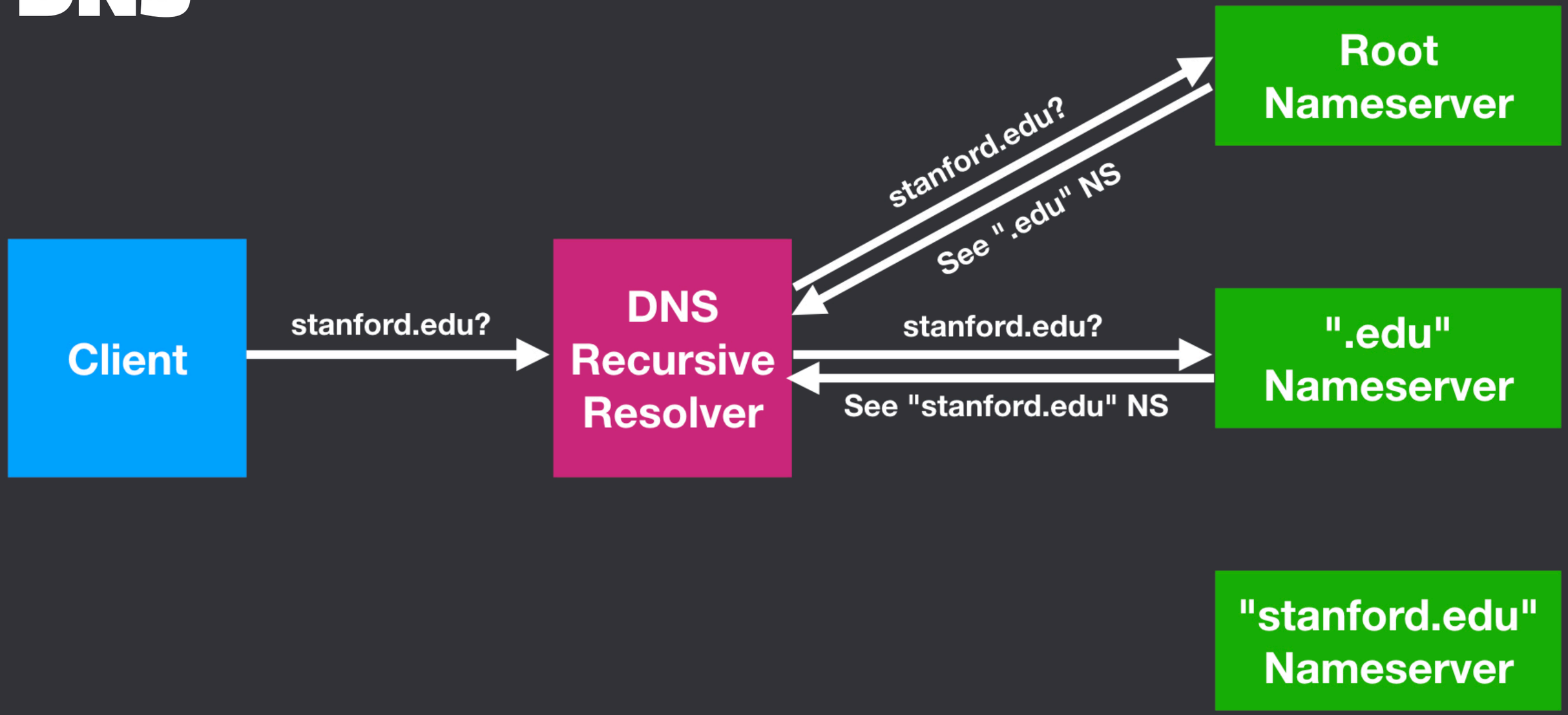
".edu" Nameserver
See "stanford.edu" NS

DNS


Root Nameserver
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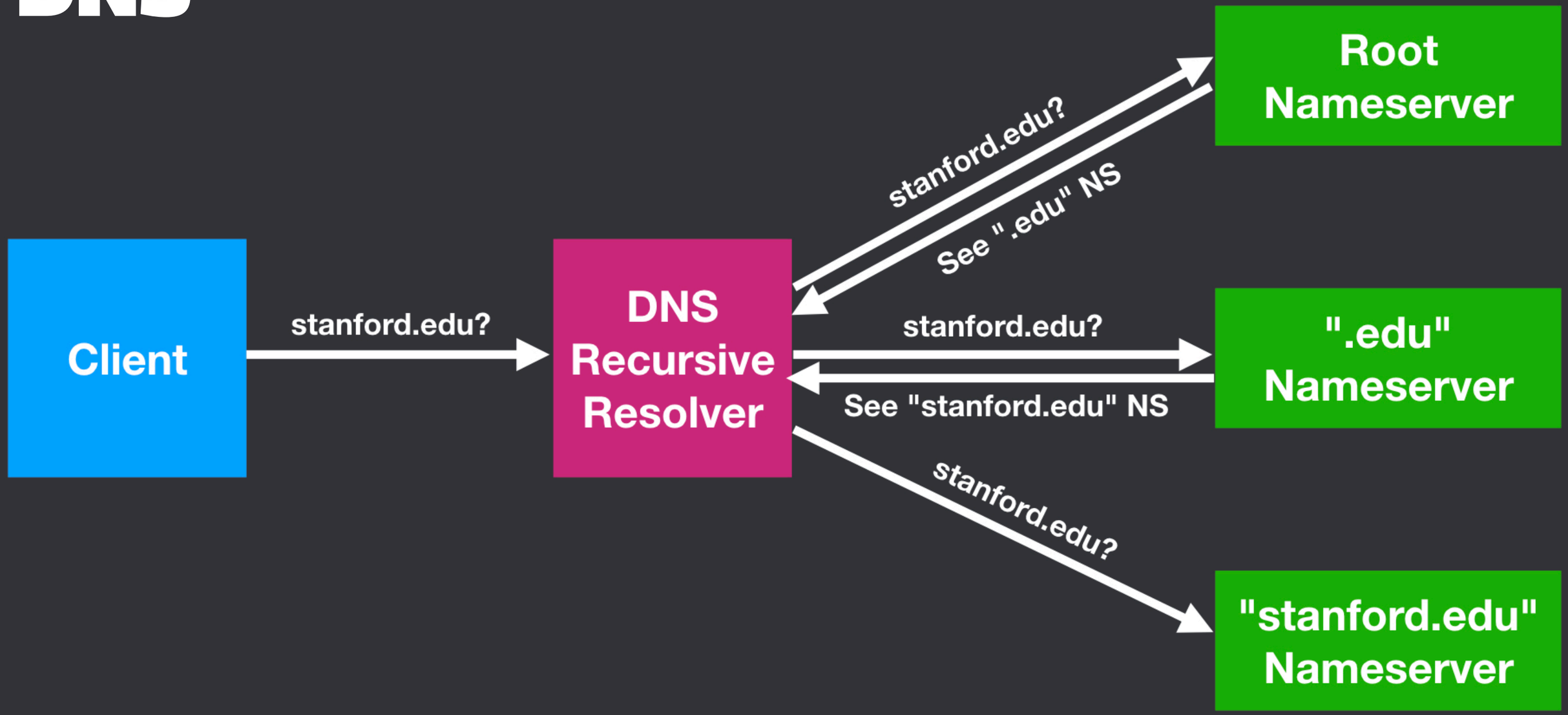
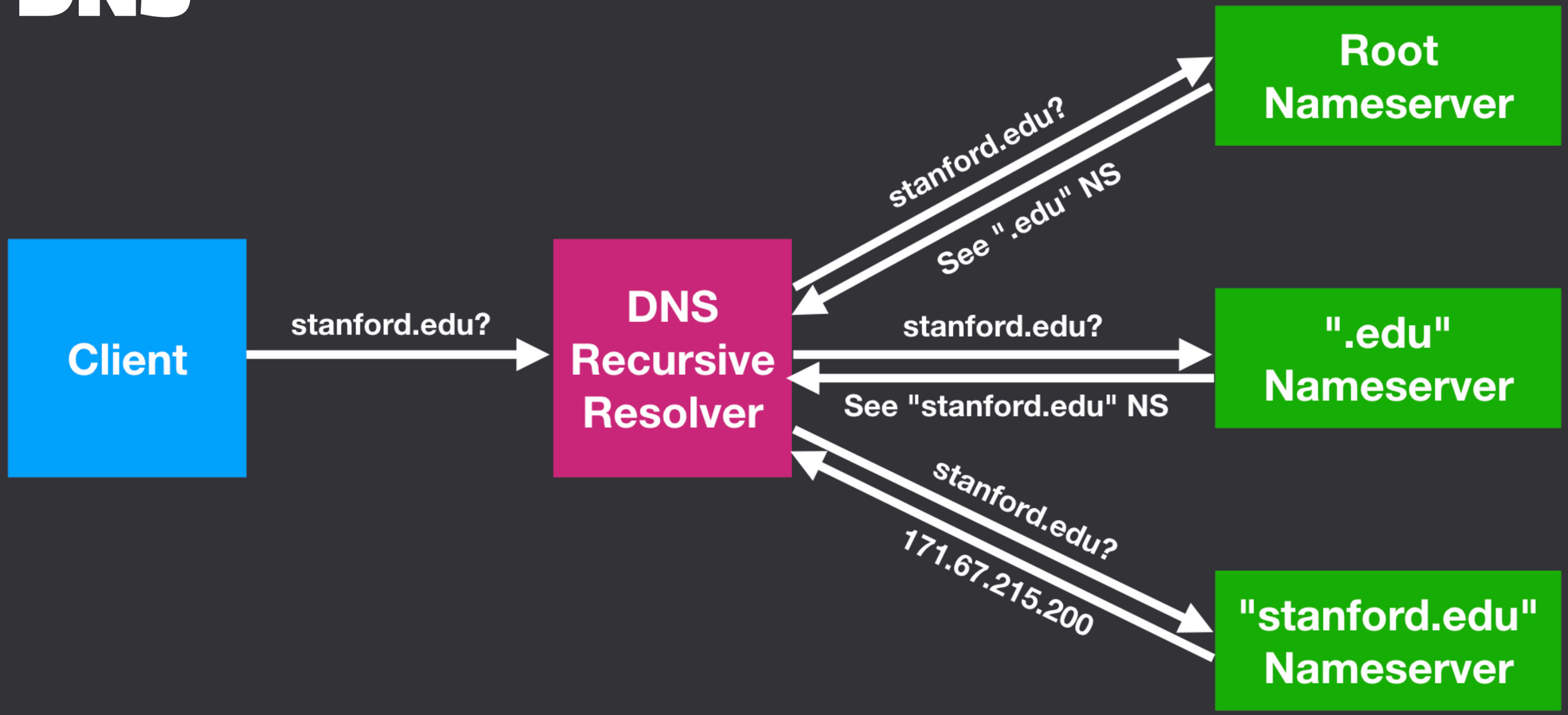
See ".edu" NS
Client
stanford.edu?
DNS Recursive Resolver
stanford.edu?
".edu" Nameserver
See "stanford.edu" NS
"stanford.edu" Nameserver

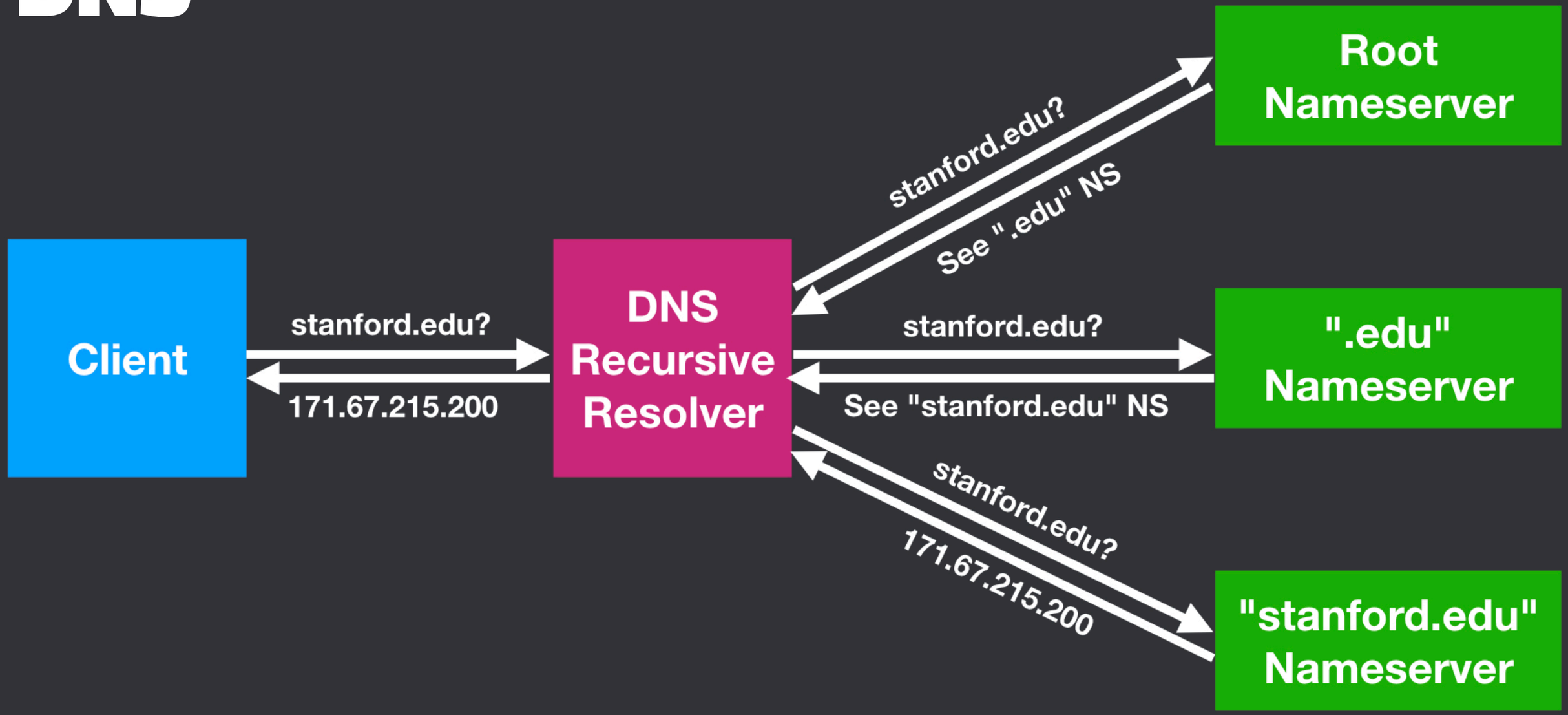
DNS


Root Nameserver
stanford.edu?
See ".edu" NS
Client
stanford.edu?
DNS Recursive Resolver
stanford.edu?
".edu" Nameserver
See "stanford.edu" NS
stanford.edu?
"stanford.edu" Nameserver

DNS


Root Nameserver
stanford.edu?
See ".edu" NS
Client
stanford.edu?
DNS Recursive Resolver
stanford.edu?
".edu" Nameserver
See "stanford.edu" NS
stanford.edu?
171.67.215.200
"stanford.edu" Nameserver

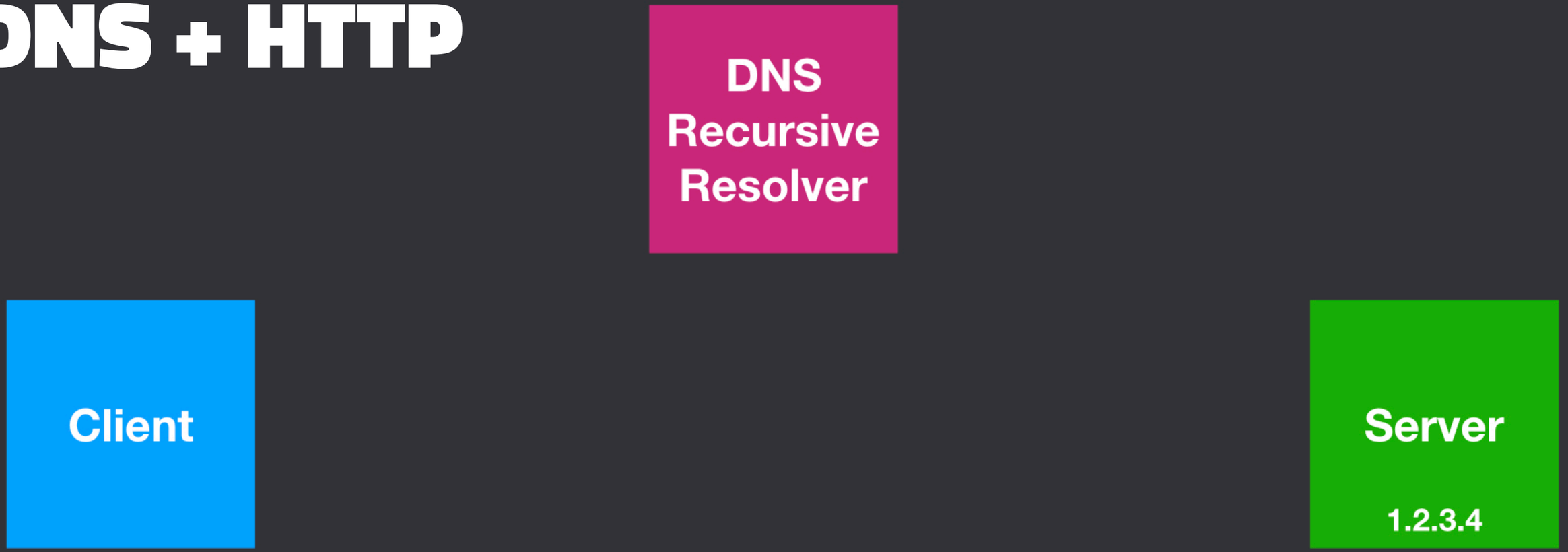
DNS


Root Nameserver
stanford.edu?
See ".edu" NS
Client
stanford.edu?
171.67.215.200
DNS Recursive Resolver
stanford.edu?
See "stanford.edu" NS
".edu" Nameserver
stanford.edu?
171.67.215.200
"stanford.edu" Nameserver

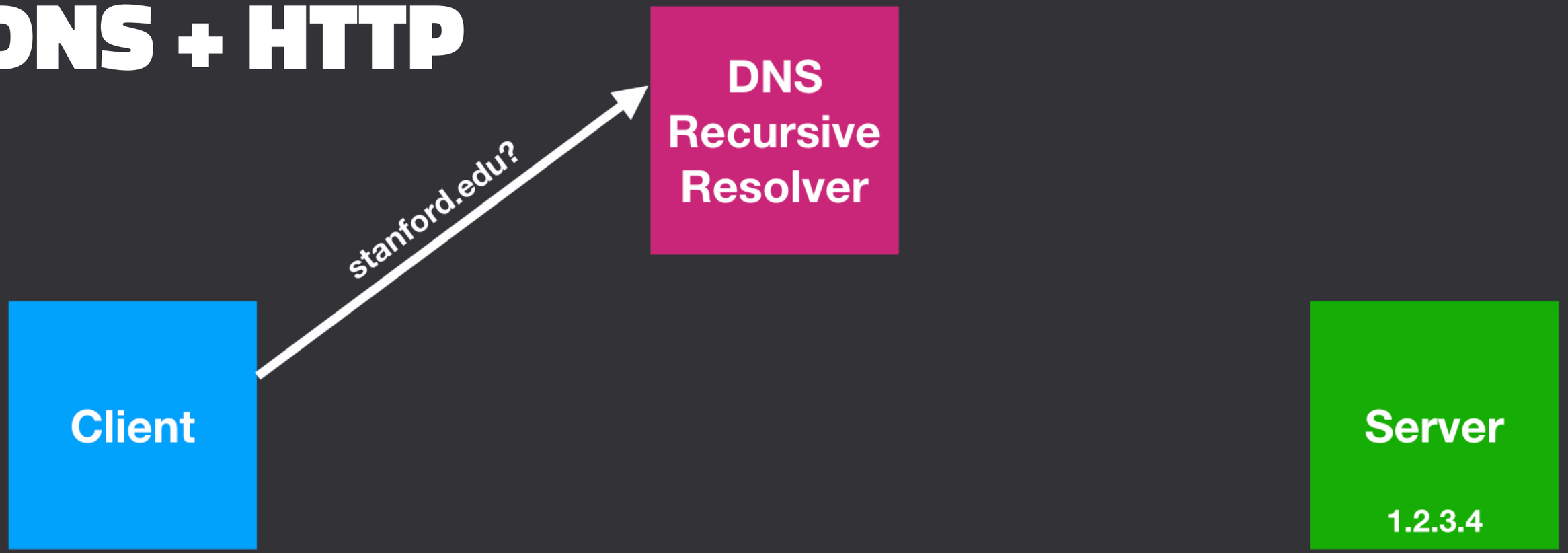
What happens when you type a URL and press enter?

1. **Client** asks **DNS Recursive Resolver** to lookup a hostname (**`stanford.edu`**).
2. **DNS Recursive Resolver** sends DNS query to **Root Nameserver**
   - **Root Nameserver** responds with IP address of **TLD Nameserver** (".edu" Nameserver)
3. **DNS Recursive Resolver** sends DNS query to **TLD Nameserver**
   - **TLD Nameserver** responds with IP address of **Domain Nameserver** ("stanford.edu" Nameserver)
4. **DNS Recursive Resolver** sends DNS query to **Domain Nameserver**
   - **Domain Nameserver** is authoritative, so replies with server IP address.
5. **DNS Recursive Resolver** finally responds to **Client**, sending server IP address (171.67.215.200)

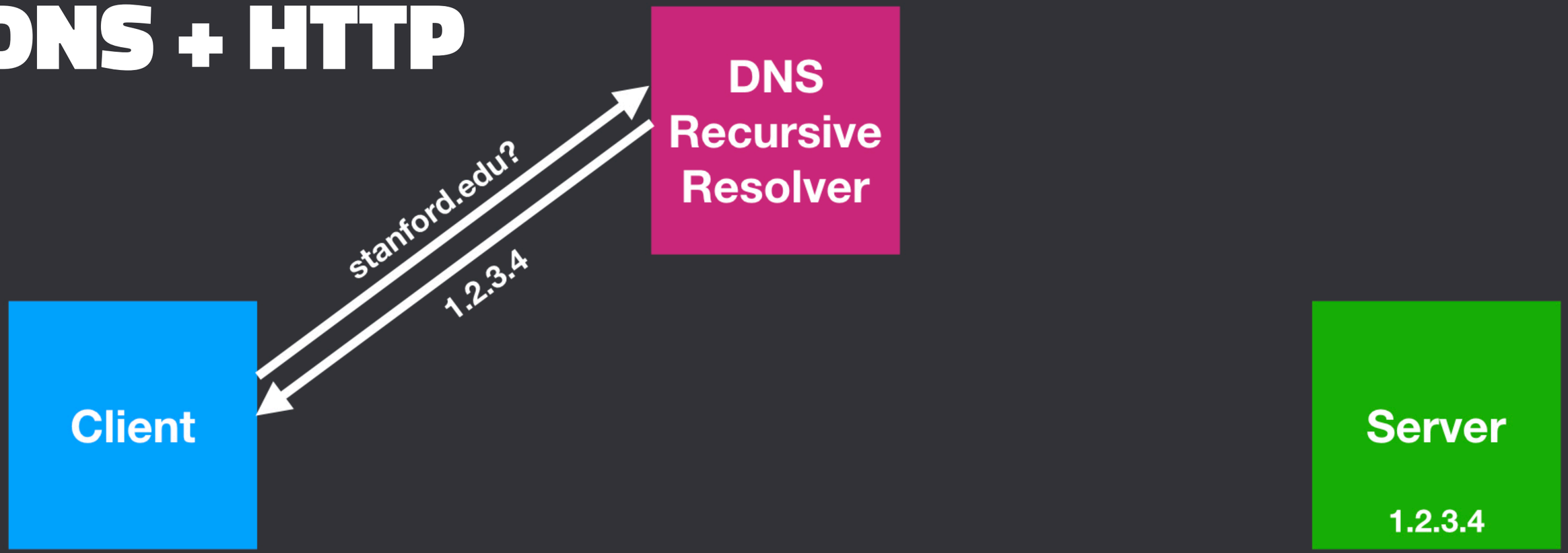
DNS + HTTP



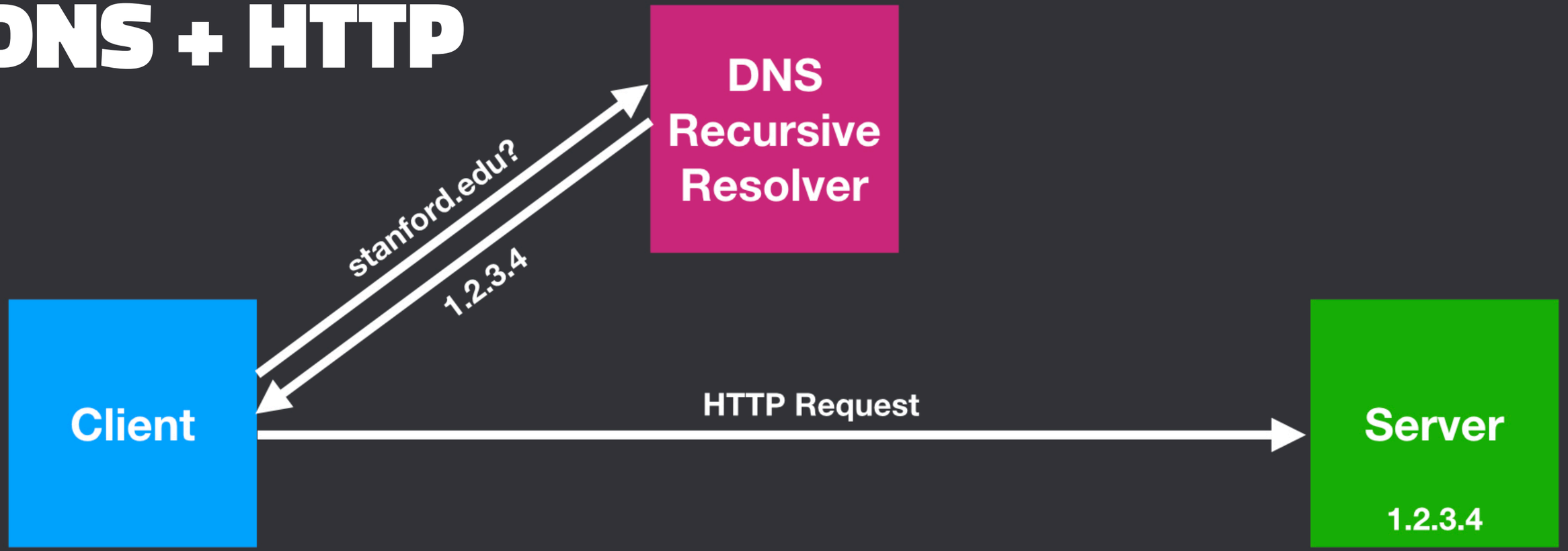
DNS + HTTP



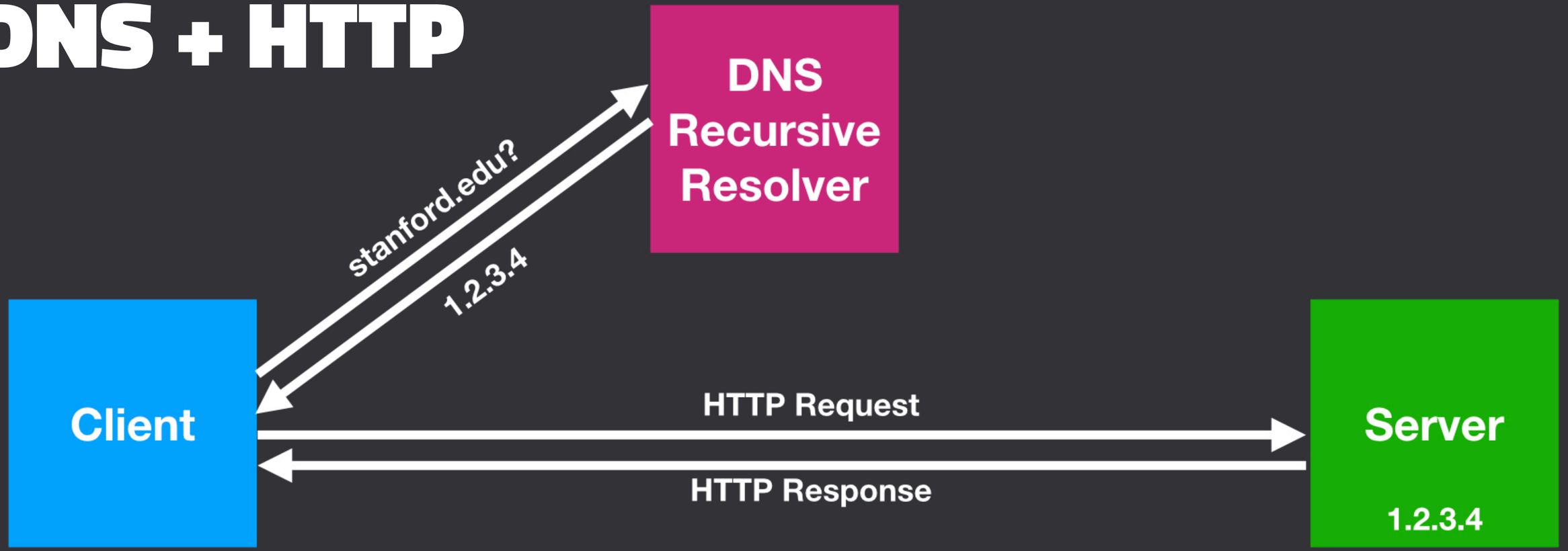
DNS + HTTP


DNS
Recursive
Resolver
stanford.edu?
1.2.3.4
Client
Server
1.2.3.4

DNS + HTTP


DNS
Recursive
Resolver
stanford.edu?
1.2.3.4
Client
HTTP Request
Server
1.2.3.4

DNS + HTTP


DNS
Recursive
Resolver
stanford.edu?
1.2.3.4
Client
HTTP Request
HTTP Response
Server
1.2.3.4

Attacks on DNS

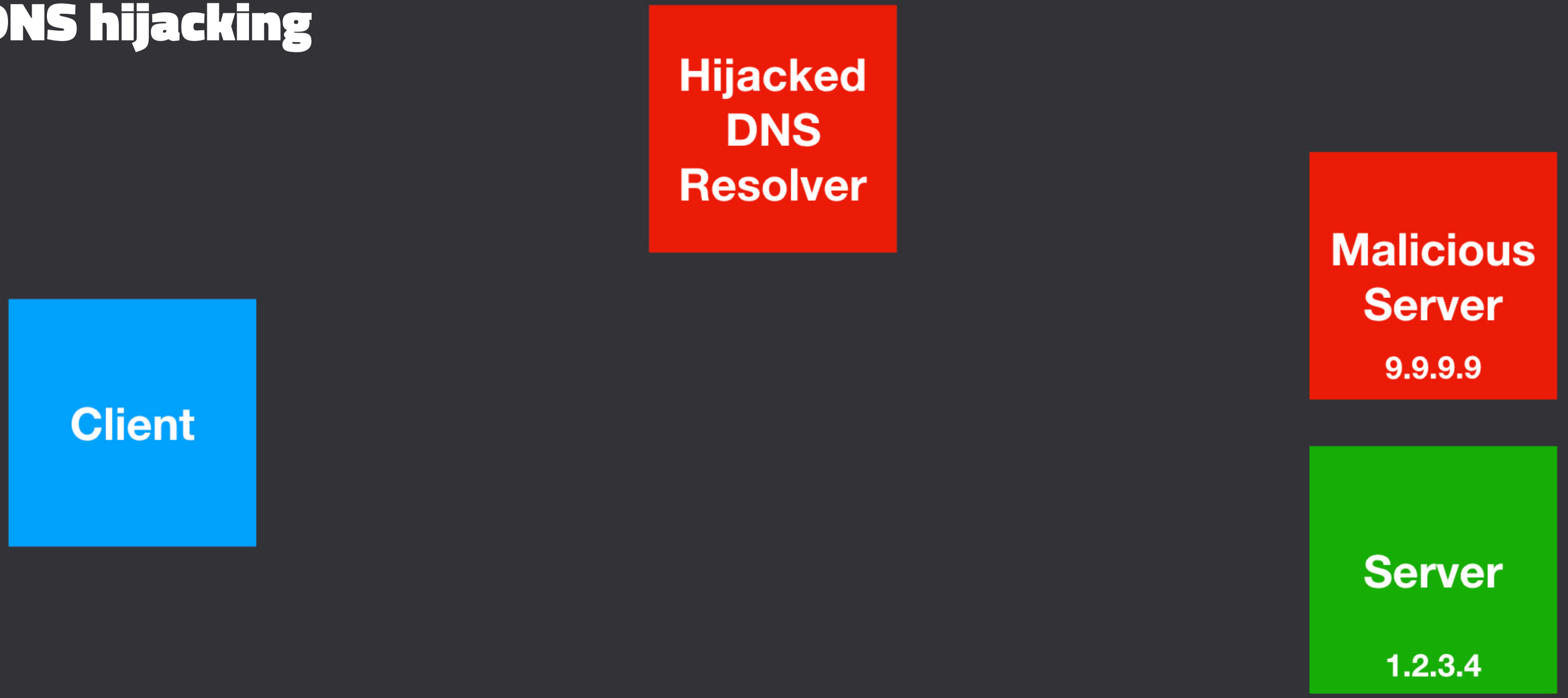
DNS hijacking

- Attacker changes DNS records of target to point to own IP address
- All site visitors are directed to attacker's web server
- Motivation
  - Phishing
  - Revenue through ads, cryptocurrency mining, etc.
- How do they do it?

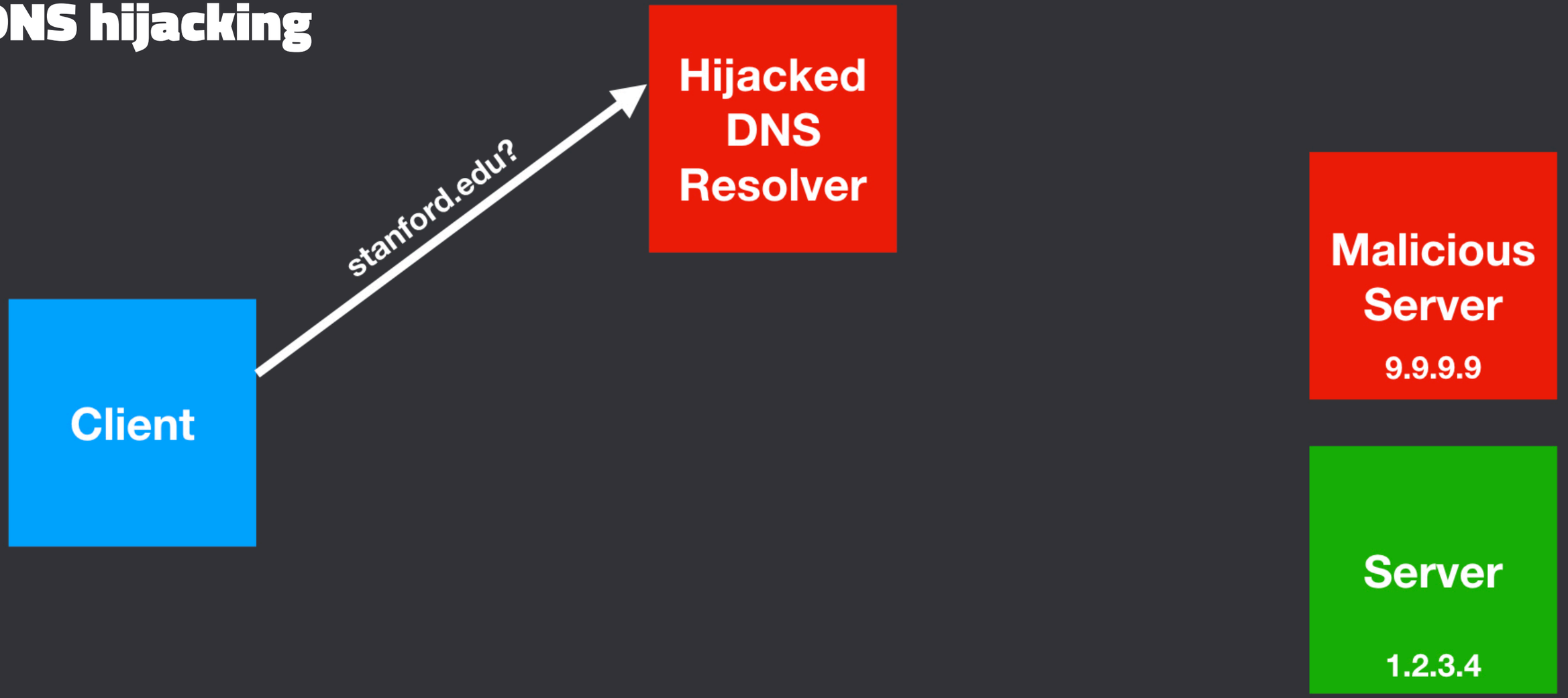
DNS hijacking vectors

- Malware changes user's local DNS settings
- Hacked recursive DNS resolver
- Hacked router
- Hacked DNS nameserver
- Compromised user account at DNS provider

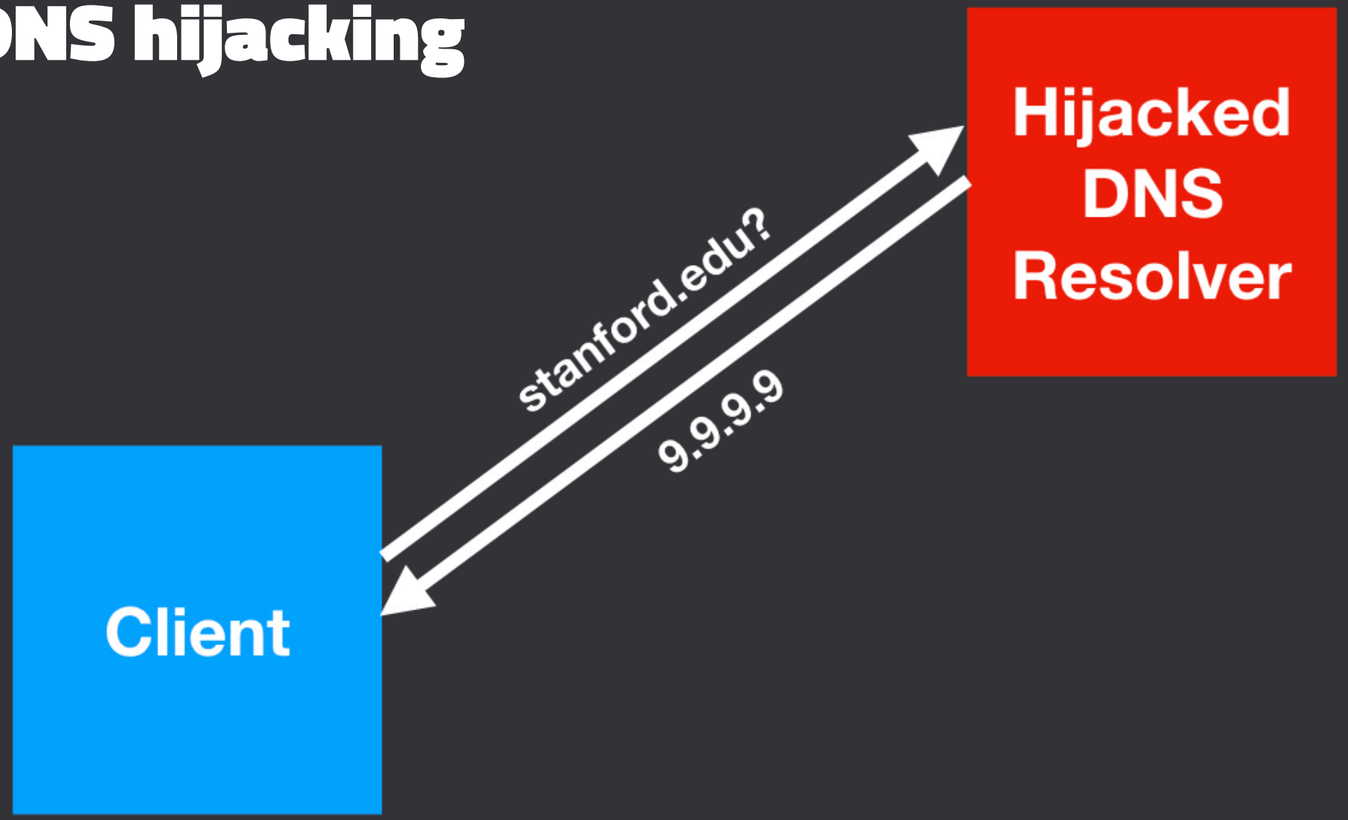
DNS hijacking



DNS hijacking



DNS hijacking



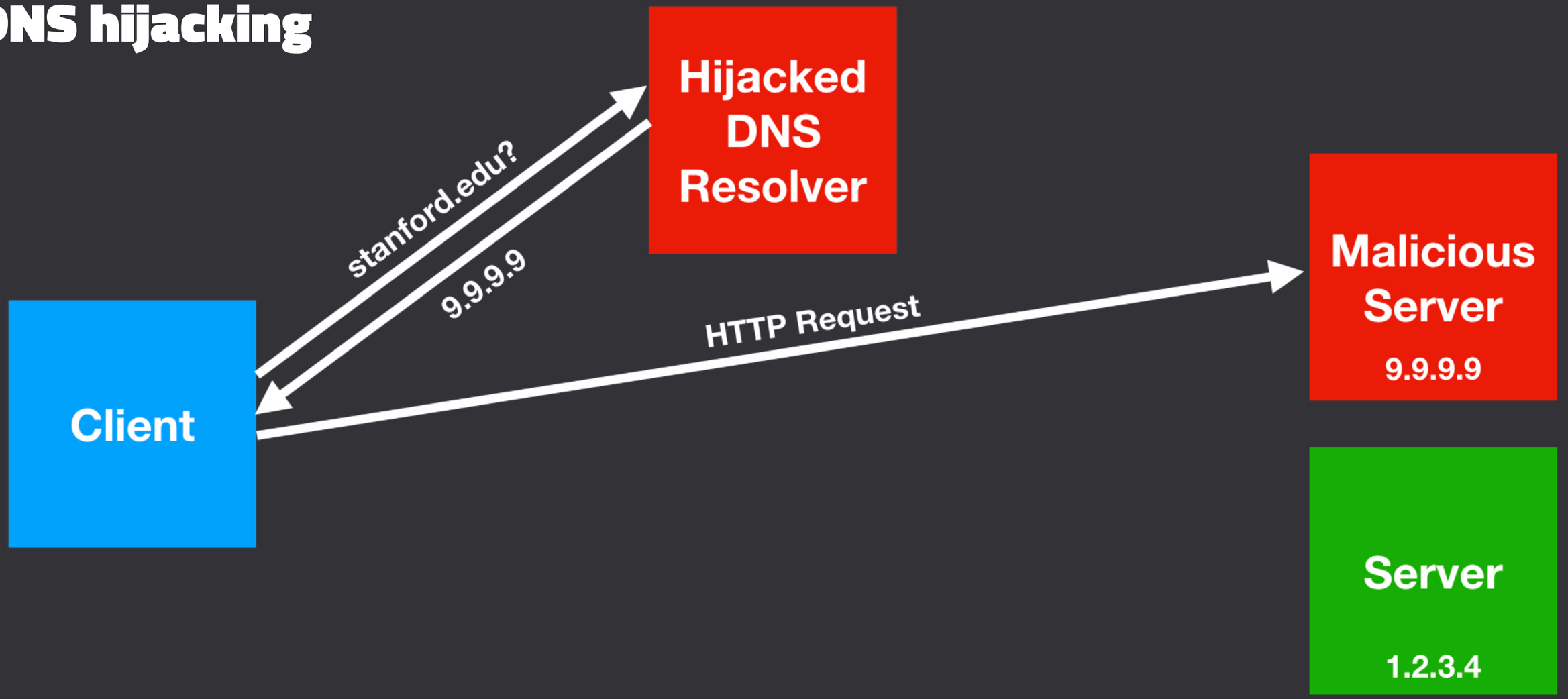
Malicious Server

9.9.9.9

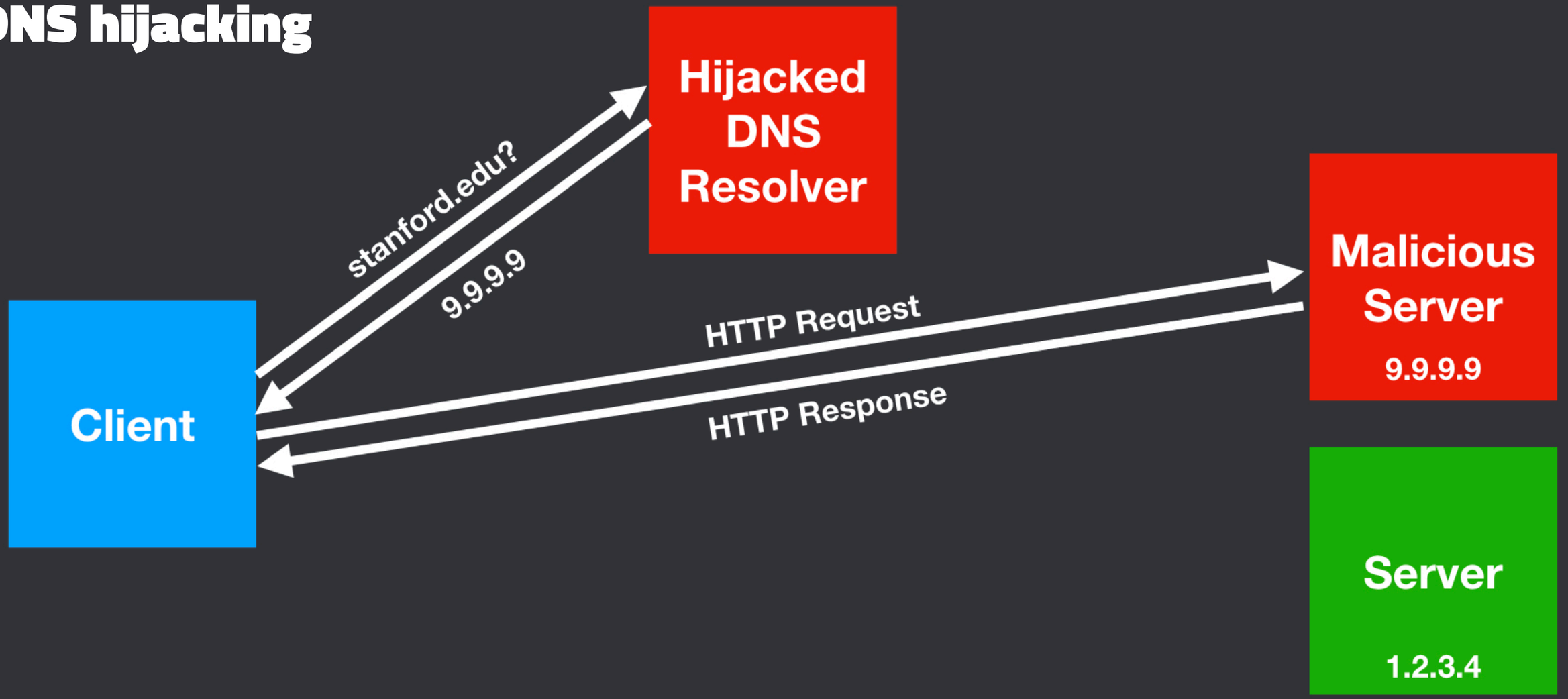
Server

1.2.3.4

DNS hijacking



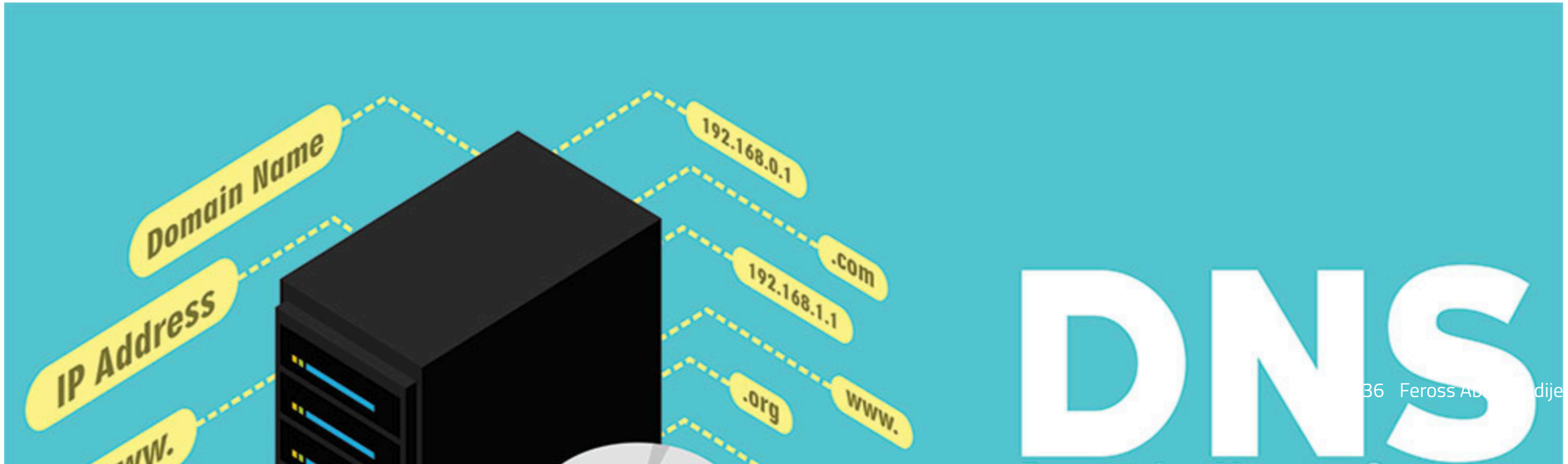
DNS hijacking



University Security

86% of Education Industry Experienced DNS Attack in Past Year

The education industry also has the lowest adoption of network security policy management automation at only 8%, according to a new report.



T · ·Mobile·

Search

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DNS privacy

- Queries are in plaintext
- ISPs have been known to sell this data
- **Pro tip:** Consider switching your DNS settings to Cloudflare (`1.1.1.1`) or another provider with a good privacy policy

FIREFOX

What's next in making Encrypted DNS-over-HTTPS the Default

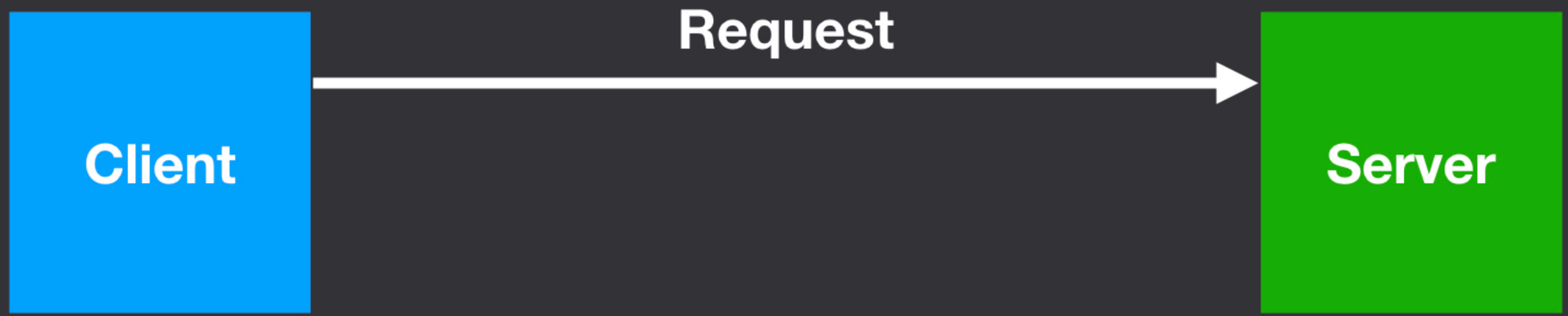
Selena Deckelmann | September 6, 2019

In 2017, Mozilla began working on the DNS-over-HTTPS (DoH) protocol, and since June 2018 we've been running experiments in

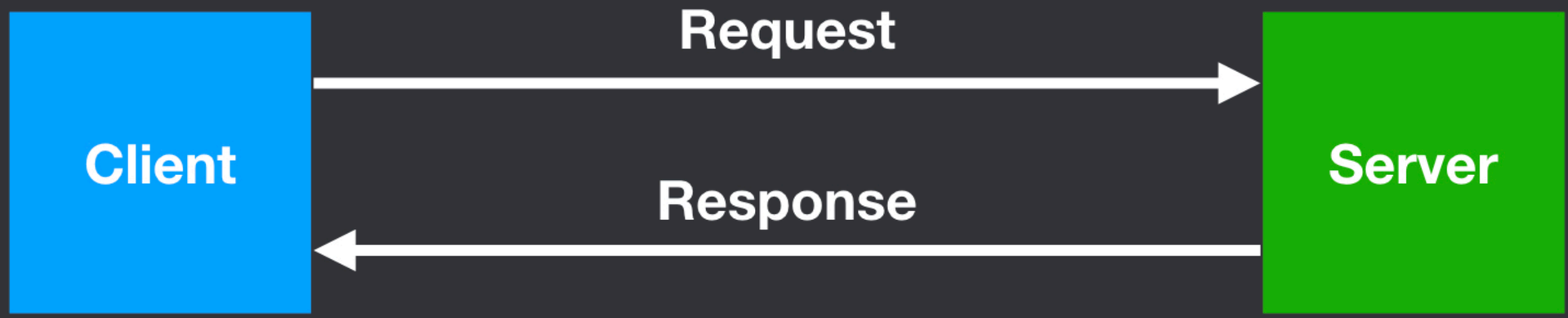
What happens when you type a URL and press enter?

HTTP

HTTP



HTTP



Demo: Make an HTTP request

Demo: Make an HTTP request

```
curl https://twitter.com

curl https://twitter.com > twitter.html
open twitter.html
```

HTTP request

```
GET / HTTP/1.1
Host: twitter.com
User-Agent: Mozilla/5.0 ...
```


GET / HTTP/1.1
Method
Path
Protocol Version

HTTP response

```
HTTP/1.1 200 OK
Content-Length: 9001
Content-Type: text/html; charset=UTF-8
Date: Tue, 24 Sep 2019 20:30:00 GMT

<!DOCTYPE html ...
```

```
HTTP/1.1 200 OK
```

Protocol Version

Status Code

Status Message

HTTP

- **Client-server model** - Client asks server for resource, server replies
- **Simple** - Human-readable text protocol
- **Extensible** - Just add HTTP headers
- **Stateless** - Two requests have no relation to each other
- **Transport protocol agnostic** - Only requirement is reliability

HTTP is stateless?

- Obviously, we interact with "stateful" servers all the time
- "Stateless" means the HTTP protocol itself does not store state
- If state is desired, is implemented as a layer on top of HTTP

HTTP Status Codes

- **1xx** - Informational ("Hold on")
- **2xx** - Success ("Here you go")
- **3xx** - Redirection ("Go away")
- **4xx** - Client error ("You messed up")
- **5xx** - Server error ("I messed up")

HTTP Success Codes

- **200 OK** - Request succeeded
- **206 Partial Content** - Request for specific byte range succeeded

HTTP Redirection Codes

- **301 Moved Permanently** - Resource has a new permanent URL
- **302 Found** - Resource temporarily resides at a different URL
- **304 Not Modified** - Resource has not been modified since last cached

HTTP Client Error Codes

- **400 Bad Request** - Malformed request
- **401 Unauthorized** - Resource is protected, need to authorize
- **403 Forbidden** - Resource is protected, denying access
- **404 Not Found** - Ya'll know this one

HTTP Server Error Codes

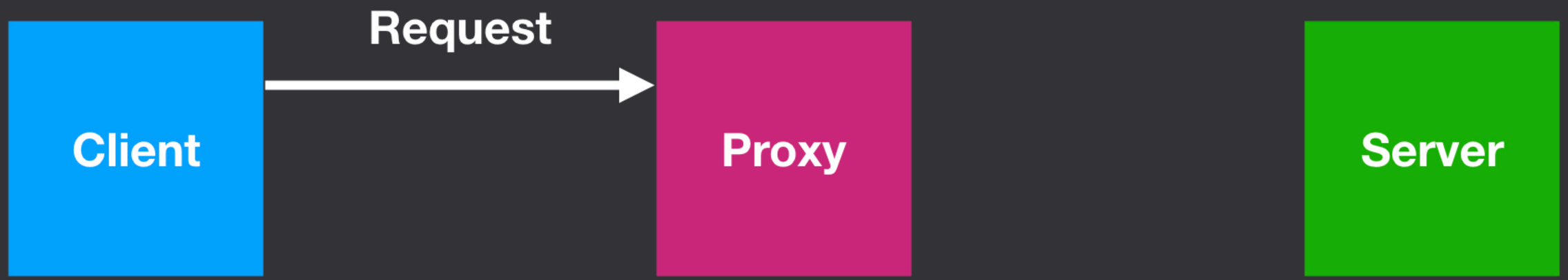
- **500 Internal Server Error** – Generic server error
- **502 Bad Gateway** - Server is a proxy; backend server is unreachable
- **503 Service Unavailable** - Server is overloaded or down for maintenance
- **504 Gateway Timeout** - Server is a proxy; backend server responded too slowly

HTTP proxy servers

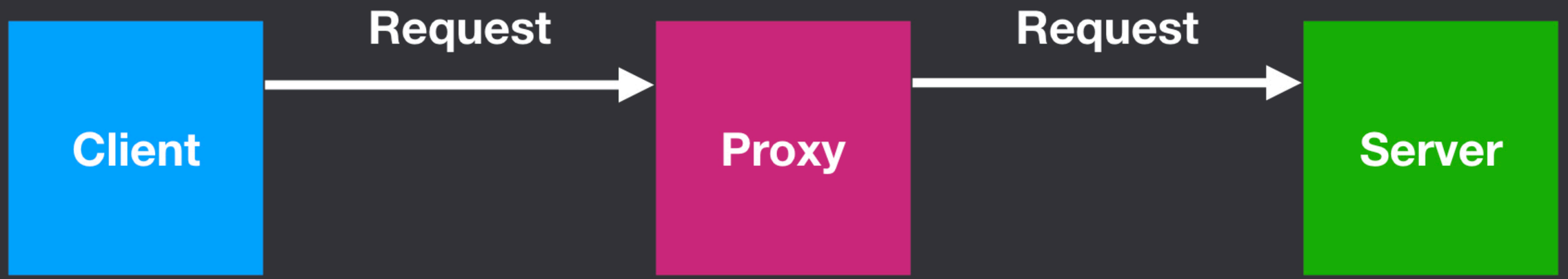
- Can cache content
- Can block content (e.g. malware, adult content)
- Can modify content
- Can sit in front of many servers ("reverse proxy")

HTTP with a proxy server

HTTP with a proxy server



HTTP with a proxy server



HTTP with a proxy server

HTTP with a proxy server

HTTP request

```
GET / HTTP/1.1
Host: example.com
User-Agent: Mozilla/5.0 ...
```

```
Host: example.com
```

Header Name

Header Value

HTTP headers

- Let the client and the server pass additional information with an HTTP request or response
- Essentially a map of key-value pairs
- Allow experimental extensions to HTTP without requiring protocol changes

Useful HTTP request headers

- **`Host`** - The domain name of the server (e.g. **`example.com`**)
- **`User-Agent`** - The name of your browser and operating system
- **`Referer`** - The webpage which led you to this page (misspelled)
- **`Cookie`** - The cookie server gave you earlier; keeps you logged in
- **`Range`** - Specifies a subset of bytes to fetch

Useful HTTP request headers

- **`Cache-Control`** - Specifies if you want a cached response or not
- **`If-Modified-Since`** - Only send resource if it changed recently
- **`Connection`** - Control TCP socket (e.g. **`keep-alive`** or **`close`**)
- **`Accept`** - Which type of content we want (e.g. **`text/html`**)
- **`Accept-Encoding`** - Encoding algorithms we understand (e.g. **`gzip`**)
- **`Accept-Language`** - What language we want (e.g. **`es`**)

Demo: Make an HTTP request with headers

Demo: Make an HTTP request with headers

```
curl https://twitter.com --header "Accept-Language: es" --silent | grep JavaScript

curl https://twitter.com --header "Accept-Language: ar" --silent | grep JavaScript
```

HTTP response

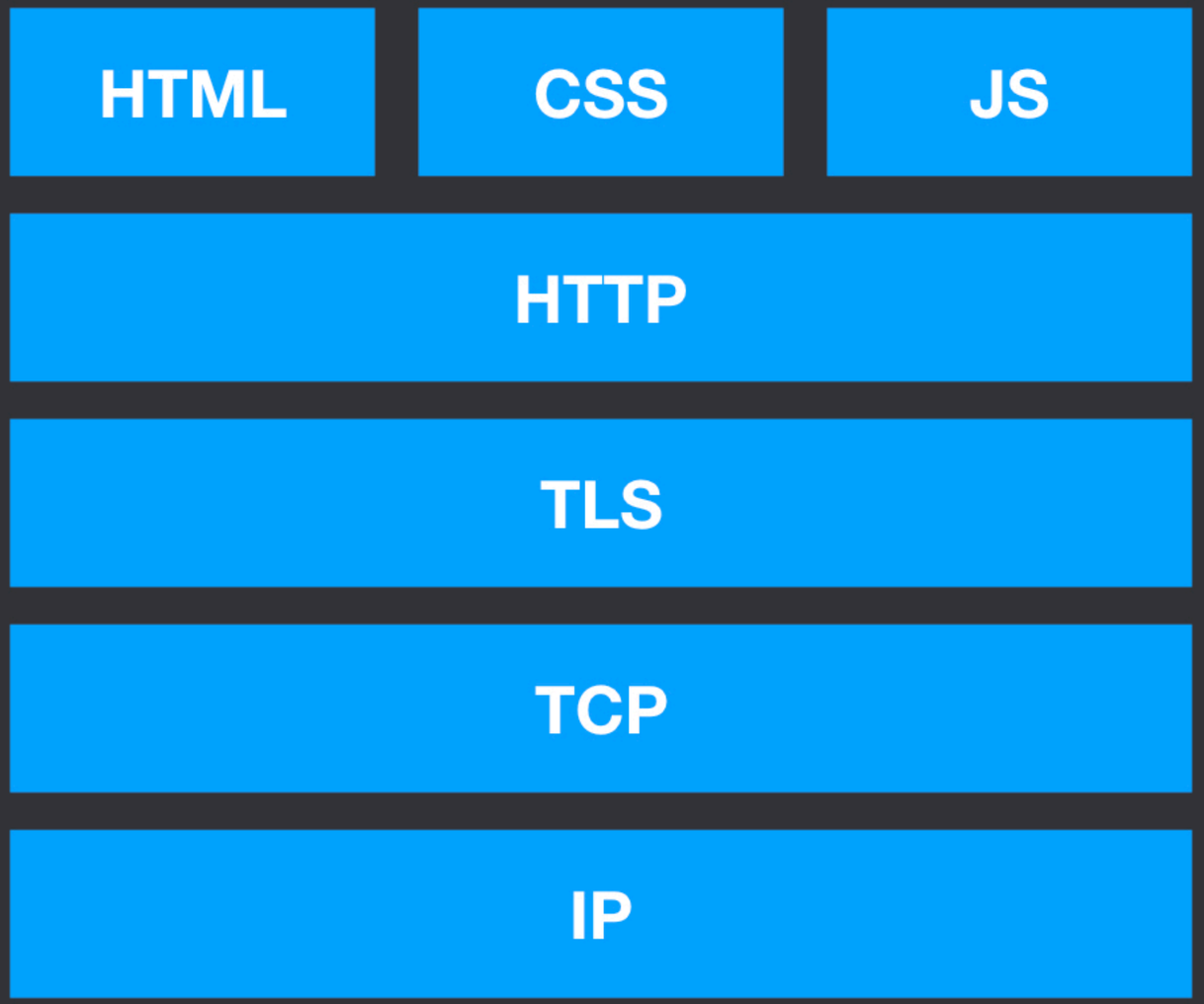
```
HTTP/1.1 200 OK
Content-Length: 9001
Content-Type: text/html; charset=UTF-8
Date: Tue, 24 Sep 2019 20:30:00 GMT

<!DOCTYPE html ...
```

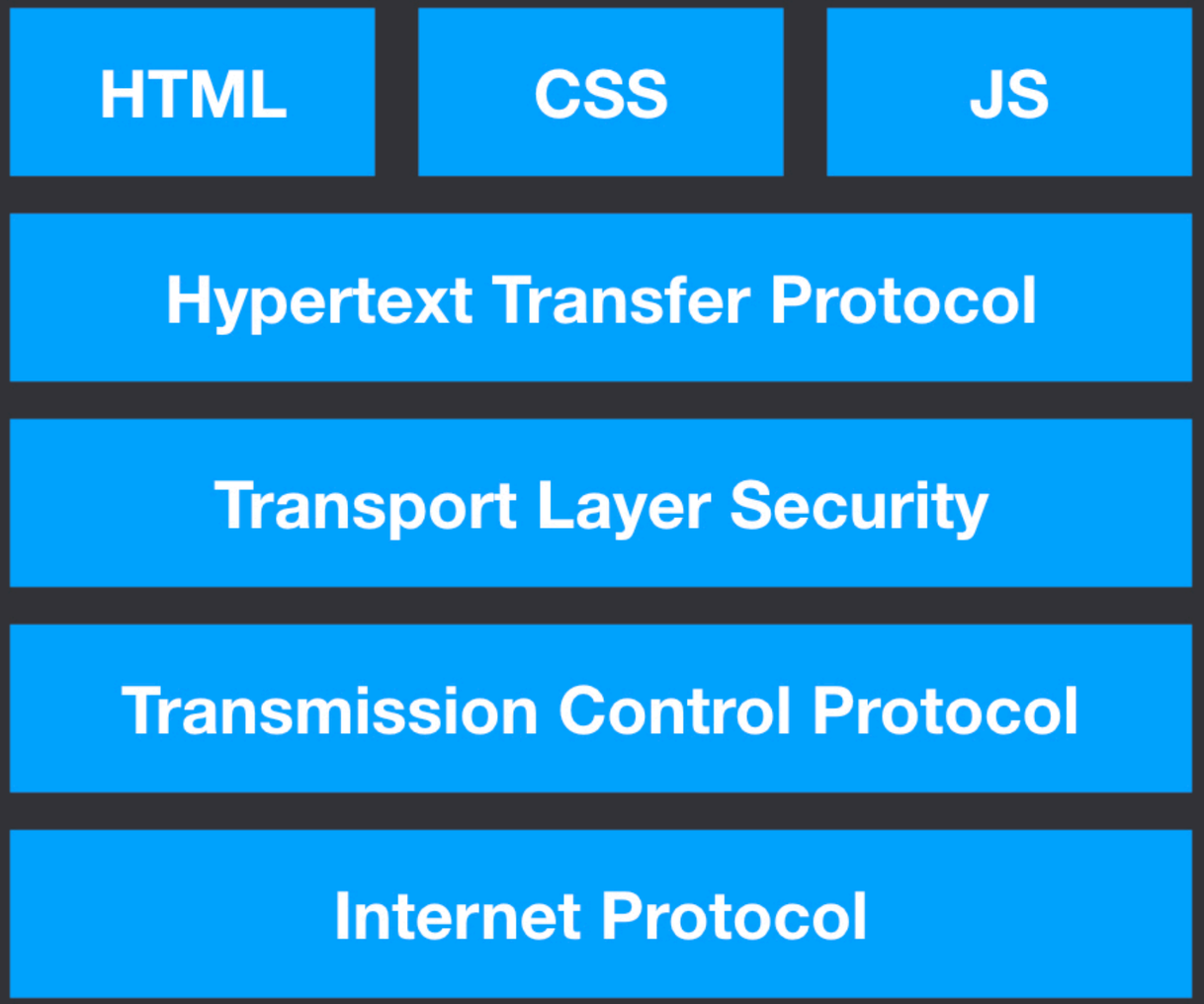
Useful HTTP response headers

- **`Date`** - When response was sent
- **`Last-Modified`** - When content was last modified
- **`Cache-Control`** - Specifies whether to cache response or not
- **`Expires`** - Discard response from cache after this date
- **`Vary`** - List of headers which affect response; used by cache
- **`Set-Cookie`** - Set a cookie on the client

Useful HTTP response headers

- **`Location`** - URL to redirect the client to (used with 3xx responses)
- **`Connection`** - Control TCP socket (e.g. **`keep-alive`** or **`close`**)
- **`Content-Type`** - Type of content in response (e.g. **`text/html`**)
- **`Content-Encoding`** - Encoding of the response (e.g. **`gzip`**)
- **`Content-Language`** - Language of the response (e.g. **`ar`**)
- **`Content-Length`** - Length of the response in bytes


HTML
CSS
JS
HTTP
TLS
TCP
IP


HTML
CSS
JS
Hypertext Transfer Protocol
Transport Layer Security
Transmission Control Protocol
Internet Protocol

Demo: Implement an HTTP client

- Not magic!
- Steps:
  - Open a TCP socket
  - Send HTTP request text over the socket
  - Read the HTTP response text from the socket

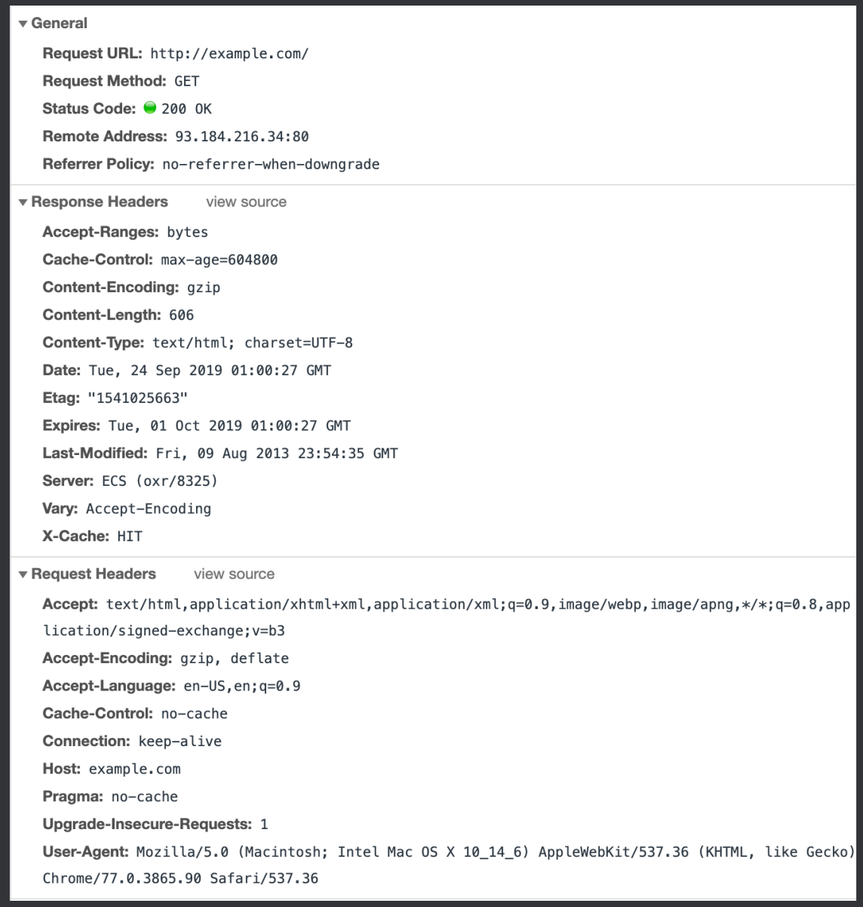
Implement an HTTP client

```
const net = require('net')

const socket = net.createConnection({
  host: 'example.com',
  port: 80
})

const request = `
GET / HTTP/1.1
Host: example.com

`.slice(1)

socket.write(request)
socket.pipe(process.stdout)
```

Implement an HTTP client (take 2)

```
const dns = require('dns')
const net = require('net')

dns.lookup('example.com', (err, address) => {
  if (err) throw err

  const socket = net.createConnection({
    host: address,
    port: 80
  })

  const request = `
GET / HTTP/1.1
Host: example.com

`.slice(1)

  socket.write(request)
  socket.pipe(process.stdout)
})
```

Demo: Chrome DevTools



What happens when you type a URL and press enter?

1. Perform a **DNS lookup** on the hostname (**`example.com`**) to get an IP address (**`1.2.3.4`**)
2. Open a **TCP socket** to **`1.2.3.4`** on port **`80`** (the HTTP port)
3. Send an **HTTP request** that includes the desired path (**`/`**)
4. Read the **HTTP response** from the socket
5. Display the response to the user

Missing some steps!

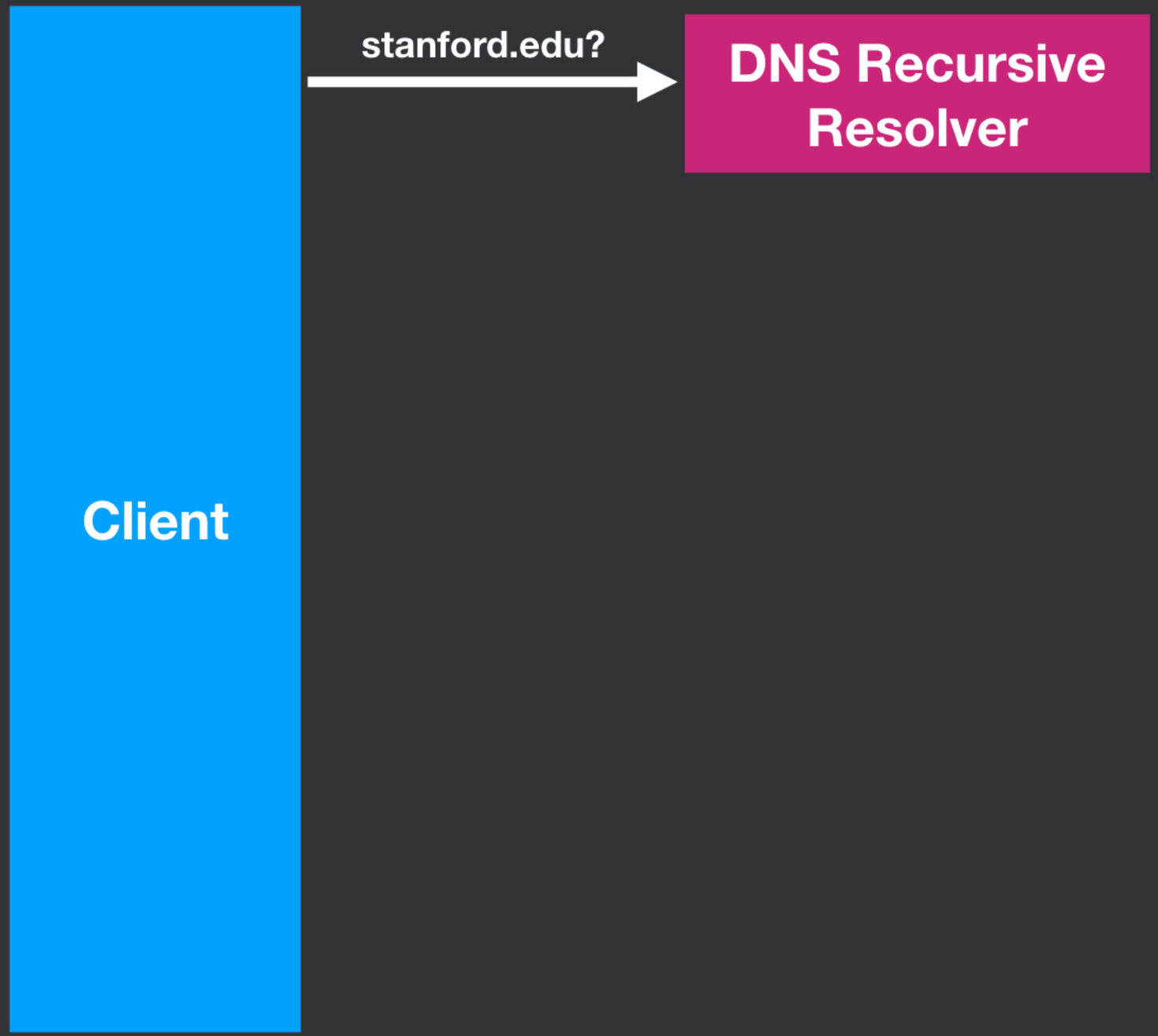
- HTML subresources!

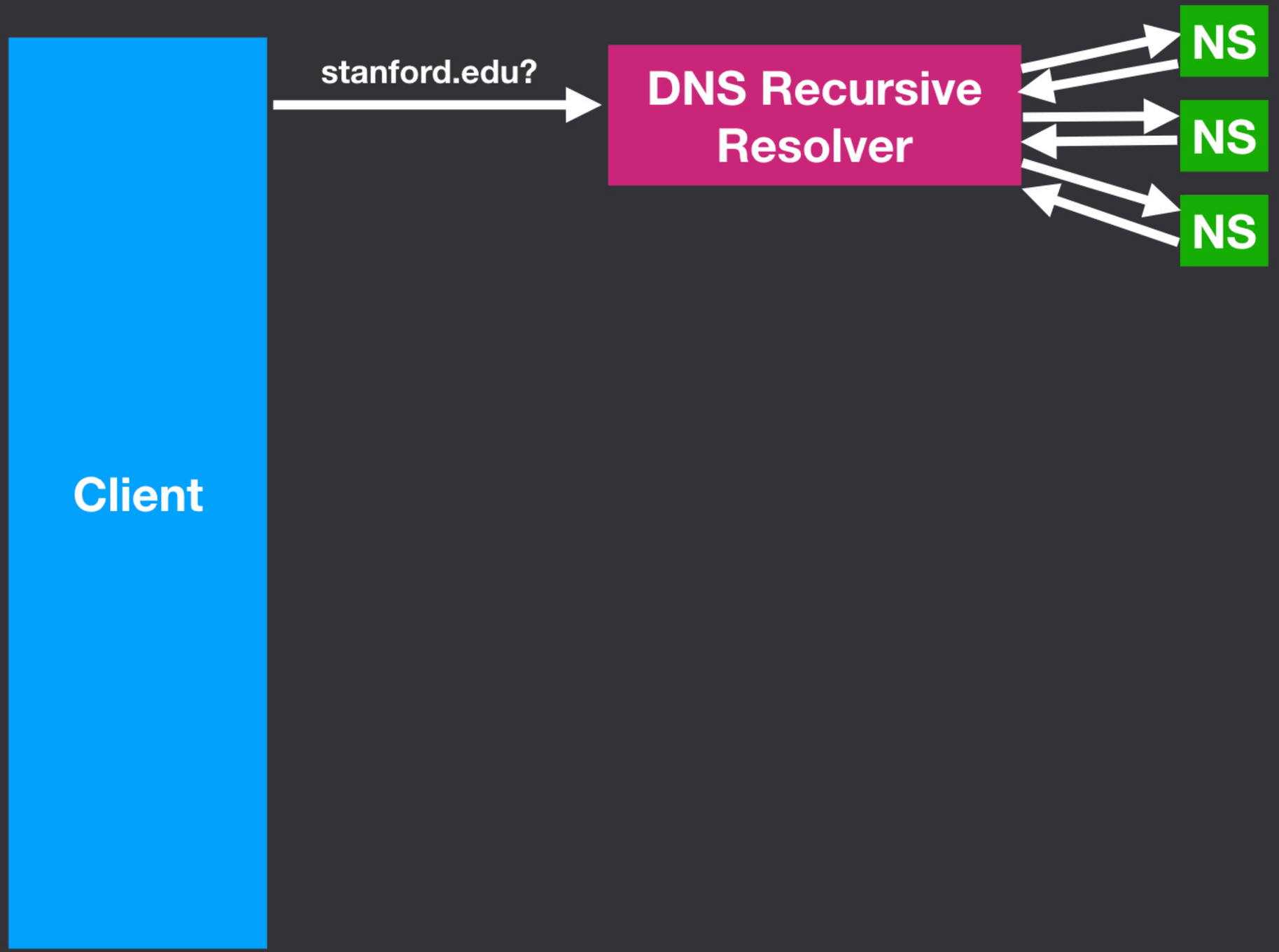
What happens when you type a URL and press enter?

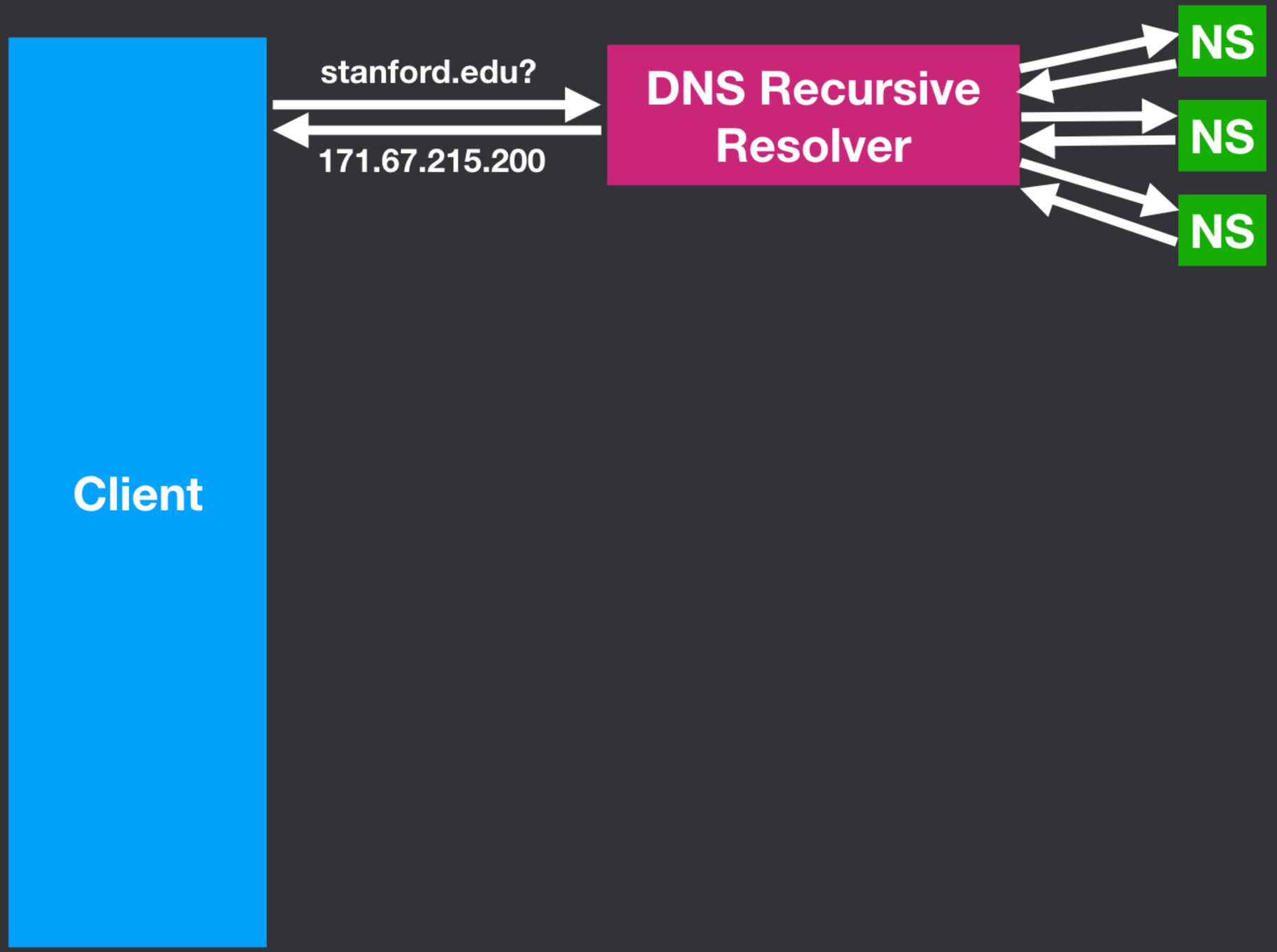
1. Perform a **DNS lookup** on the hostname (**`example.com`**) to get an IP address (**`1.2.3.4`**)
2. Open a **TCP socket** to **`1.2.3.4`** on port **`80`** (the HTTP port)
3. Send an **HTTP request** that includes the desired path (**`/`**)
4. Read the **HTTP response** from the socket
5. Parse the HTML into the DOM
6. Render the page based on the DOM
7. Repeat until all external resources are loaded:
   - If there are pending external resources, make HTTP requests for these (run steps 1-4)
   - Render the resources into the page

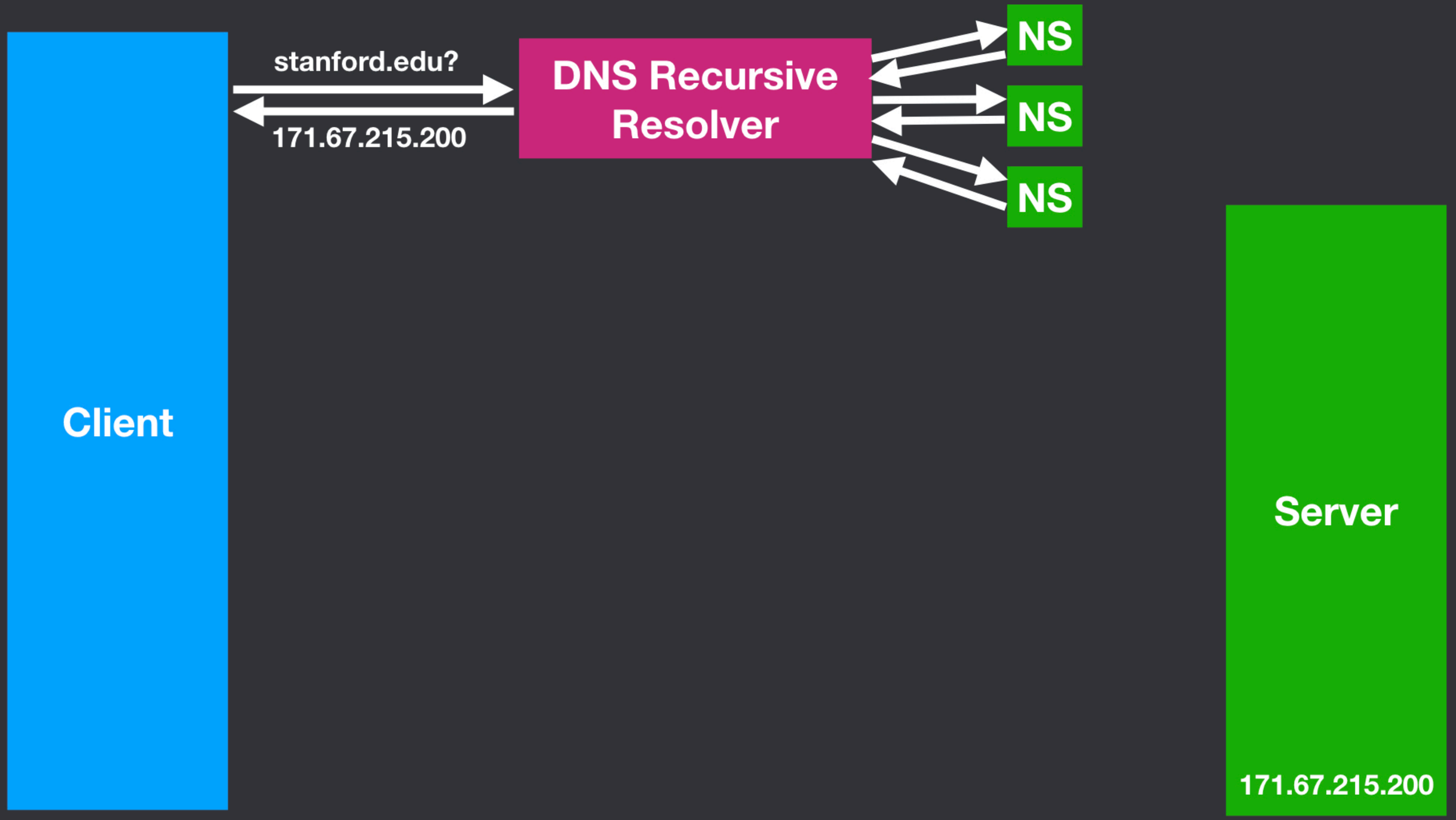
Client

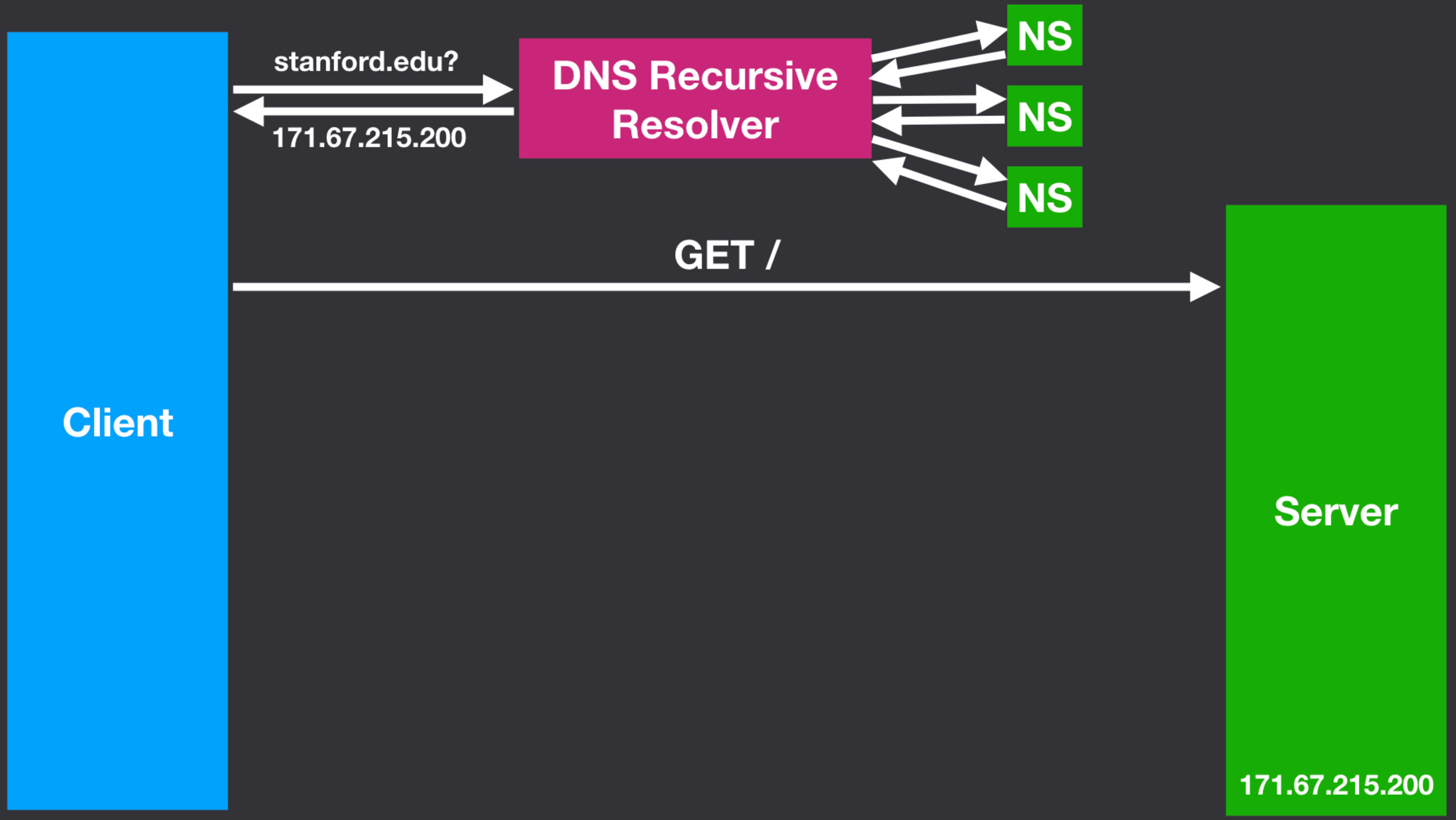
DNS Recursive Resolver


stanford.edu?
DNS Recursive Resolver
Client

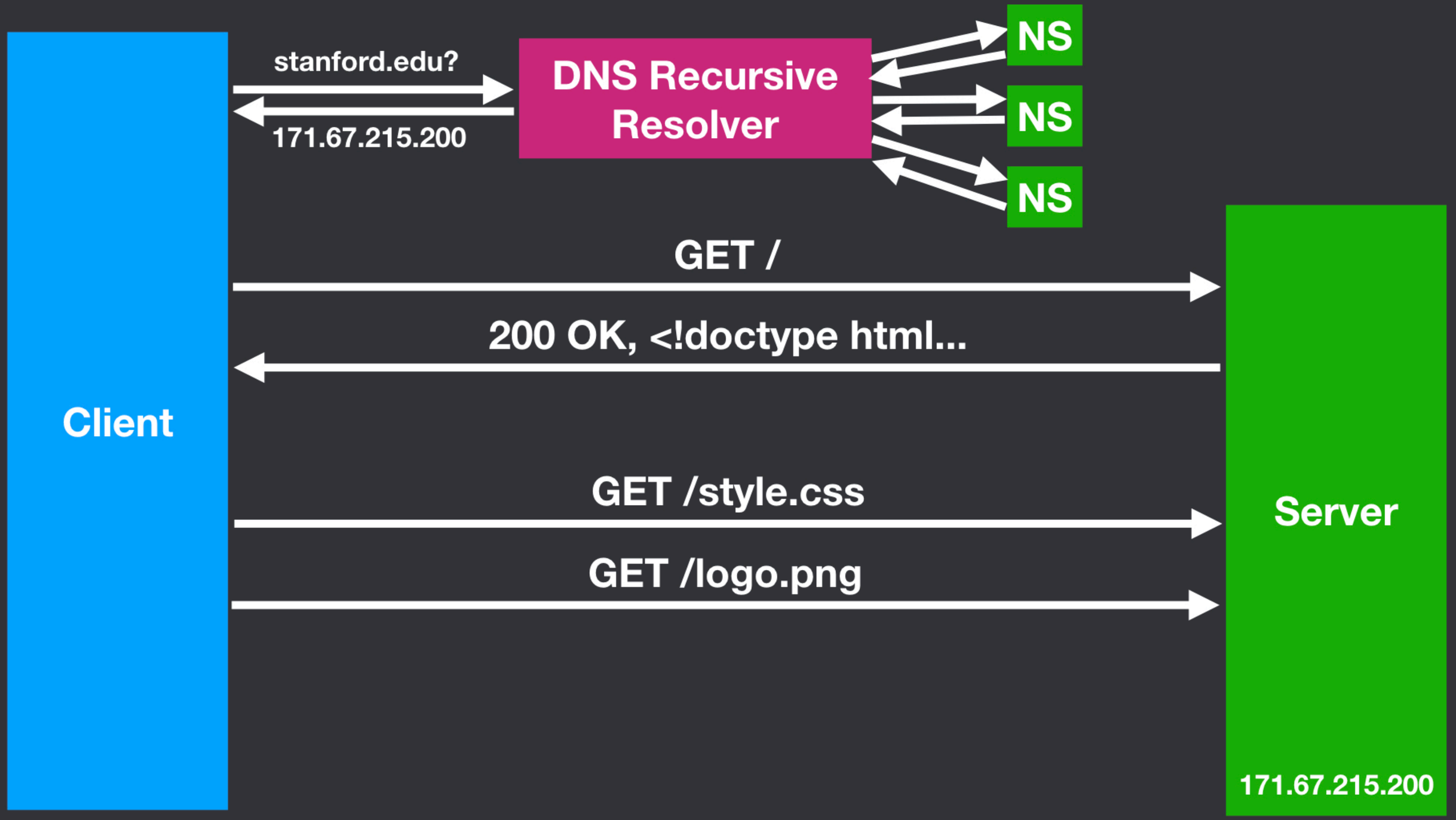

Client
stanford.edu?
DNS Recursive Resolver
NS
NS
NS

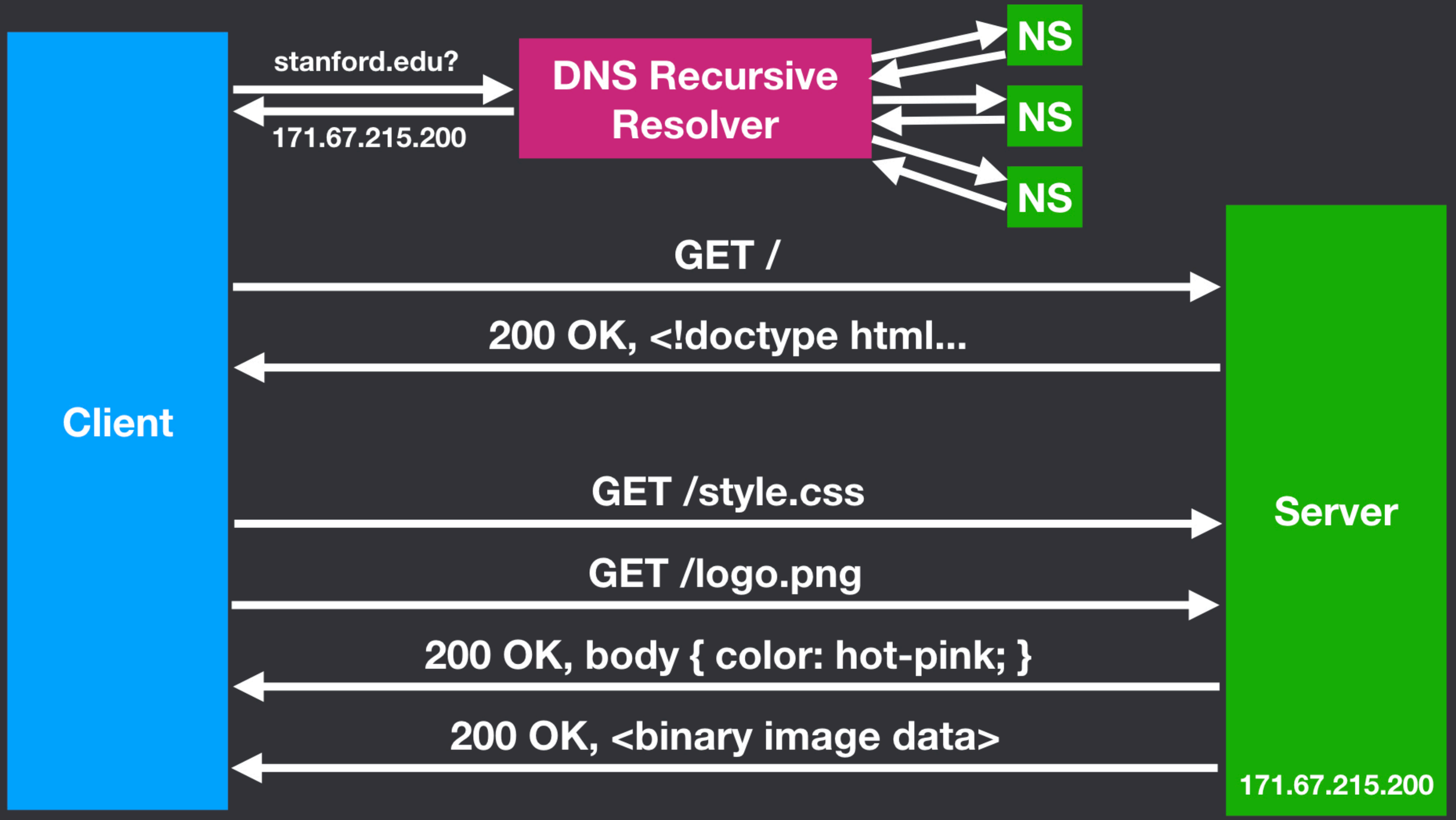

Client
stanford.edu?
171.67.215.200
DNS Recursive Resolver
NS
NS
NS


Client
stanford.edu?
171.67.215.200
DNS Recursive Resolver
NS
NS
NS
Server
171.67.215.200


stanford.edu?
171.67.215.200
DNS Recursive Resolver
NS
NS
NS
GET /
Client
Server
171.67.215.200


stanford.edu?
171.67.215.200
DNS Recursive Resolver
NS
NS
NS
GET /
200 OK, <!doctype html...
Client
Server
171.67.215.200


Client
stanford.edu?
171.67.215.200
DNS Recursive Resolver
NS
NS
NS
GET /
200 OK, <!doctype html...
GET /style.css
GET /logo.png
Server
171.67.215.200


stanford.edu?
171.67.215.200
DNS Recursive Resolver
NS
NS
NS
Client
GET /
200 OK, <!doctype html...
GET /style.css
GET /logo.png
200 OK, body { color: hot-pink; }
200 OK, <binary image data>
Server
171.67.215.200

Cookies

Server sets a cookie on the client

```
Set-Cookie: theme=dark;
```

Header Name

Cookie Name

Cookie Name

Client sends cookie to the server

```
Cookie: theme=dark;
```

Header Name

Cookie Name

Cookie Name

Demos: Cookies

Demo: Insecure Login 1

```
<!doctype html>
<html lang='en'>
  <head>
    <meta charset='utf-8' />
    <title>My Cool Site</title>
  </head>
  <body>
    <form method='POST' action='/login'>
      Username:
      <input name='username' />
      Password:
      <input name='password' type='password' />
      <input type='submit' value='Login' />
    </form>
  </body>
</html>
```

Demo: Insecure Login 1

```
const express = require('express')
const cookieParser = require('cookie-parser')
const { createReadStream } = require('fs')
const bodyParser = require('body-parser')

const app = express()
app.use(cookieParser())
app.use(bodyParser.urlencoded({ extended: false }))

// Routes go here!

app.listen(4000)
```

Demo: Insecure Login 1

```
const USERS = { alice: 'password', bob: '50505' }
const BALANCES = { alice: 500, bob: 100 }

app.get('/', (req, res) => {
  const username = req.cookies.username
  if (username) {
    res.send(`Hi ${username}. Your balance is $${BALANCES[username]}.`)
  } else {
    createReadStream('index.html').pipe(res)
  }
})

app.post('/login', (req, res) => {
  const username = req.body.username
  const password = USERS[username]
  if (password === req.body.password) {
    res.cookie('username', username)
    res.redirect('/')
  } else {
    res.send('fail!')
  }
})
```

END