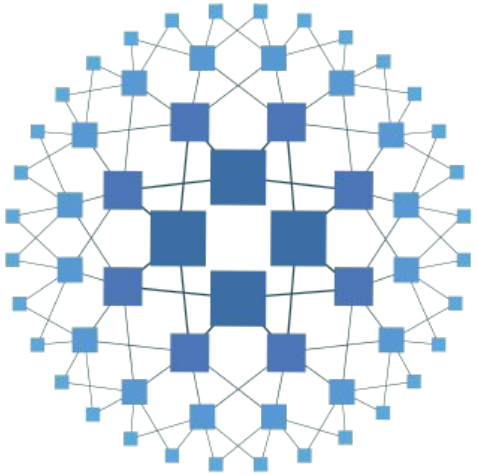
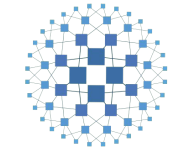
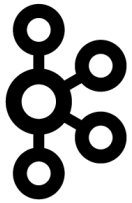


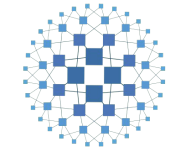
Scaling WebSockets

With HAProxy, Pub - Sub and Distributed Caches



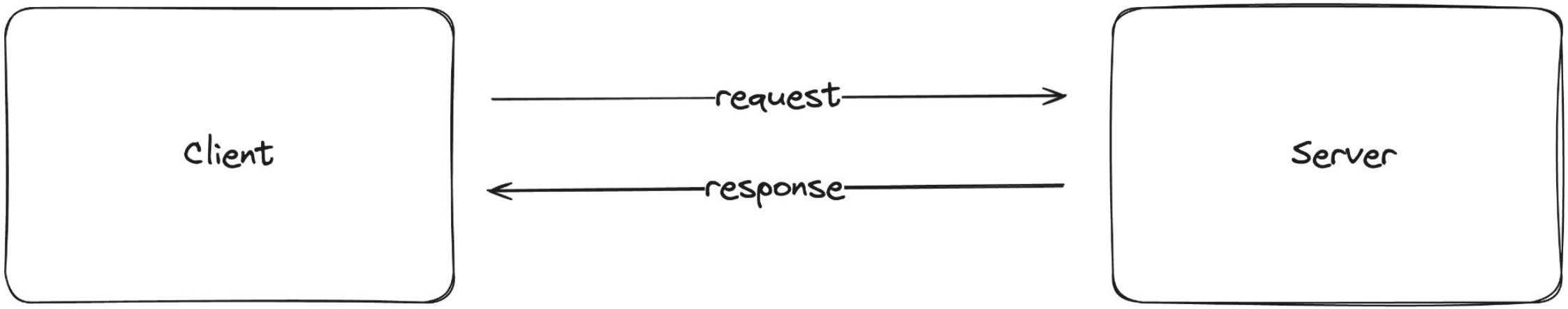
Introduction





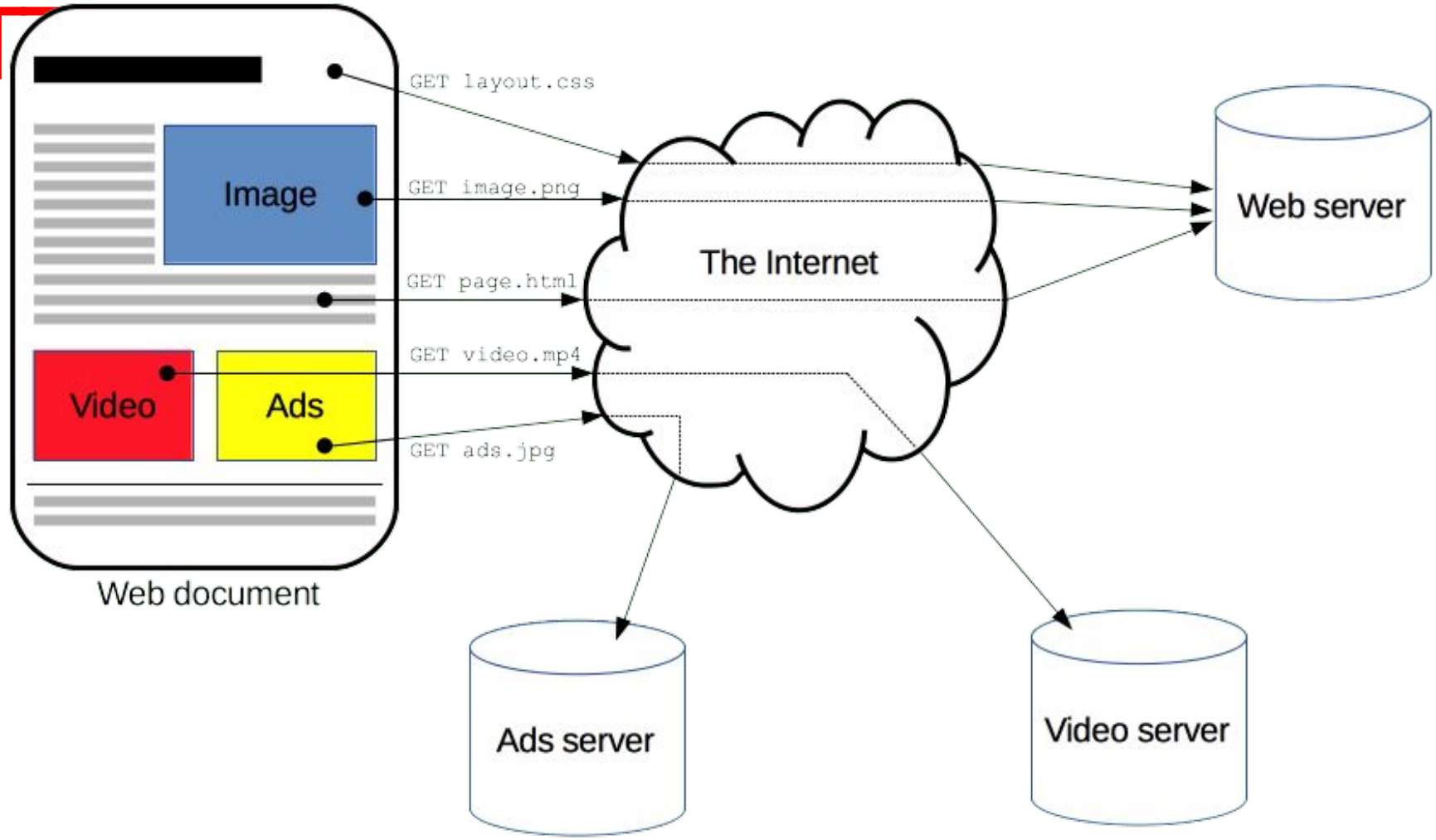
Exchanging information over the WWW

Client - Server architecture

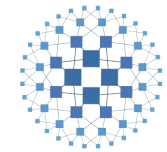


https://developer.mozilla.org/en-US/docs/Web/HTTP/Overview

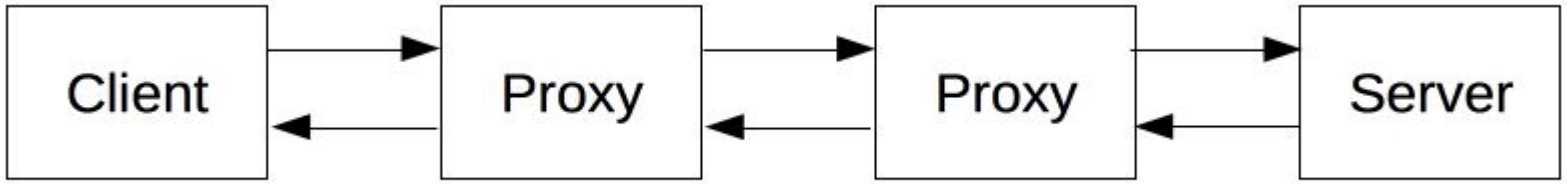
Communication happens over HT



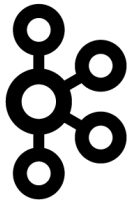
https://developer.mozilla.org/en-US/docs/Web/HTTP/Overview

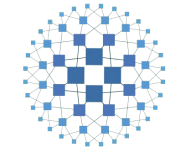


Hypertext Transfer Protocol



- *It is a stateless protocol*
- *Uses TCP as the transport layer protocol*

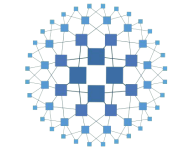




HTTP Protocol

TCP Connection Establishment in HTTP

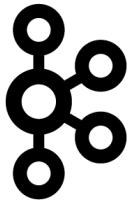
- Before HTTP communication begins, a TCP connection must be established, requiring several round-trips
- HTTP/1.0 defaults to opening separate TCP connections for each request/response pair, which can be inefficient

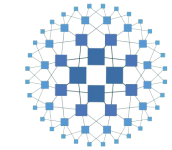


HTTP Protocol

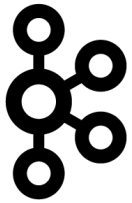
Improvements in HTTP/1.1

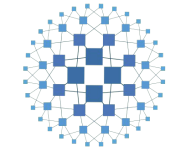
- HTTP/1.1 introduced pipelining and persistent connections to optimize TCP usage, although pipelining proved challenging

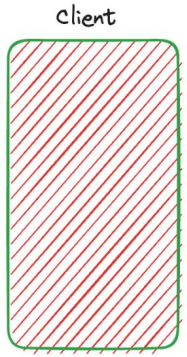


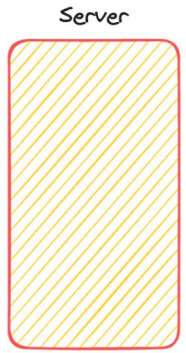


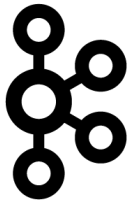
Demonstration

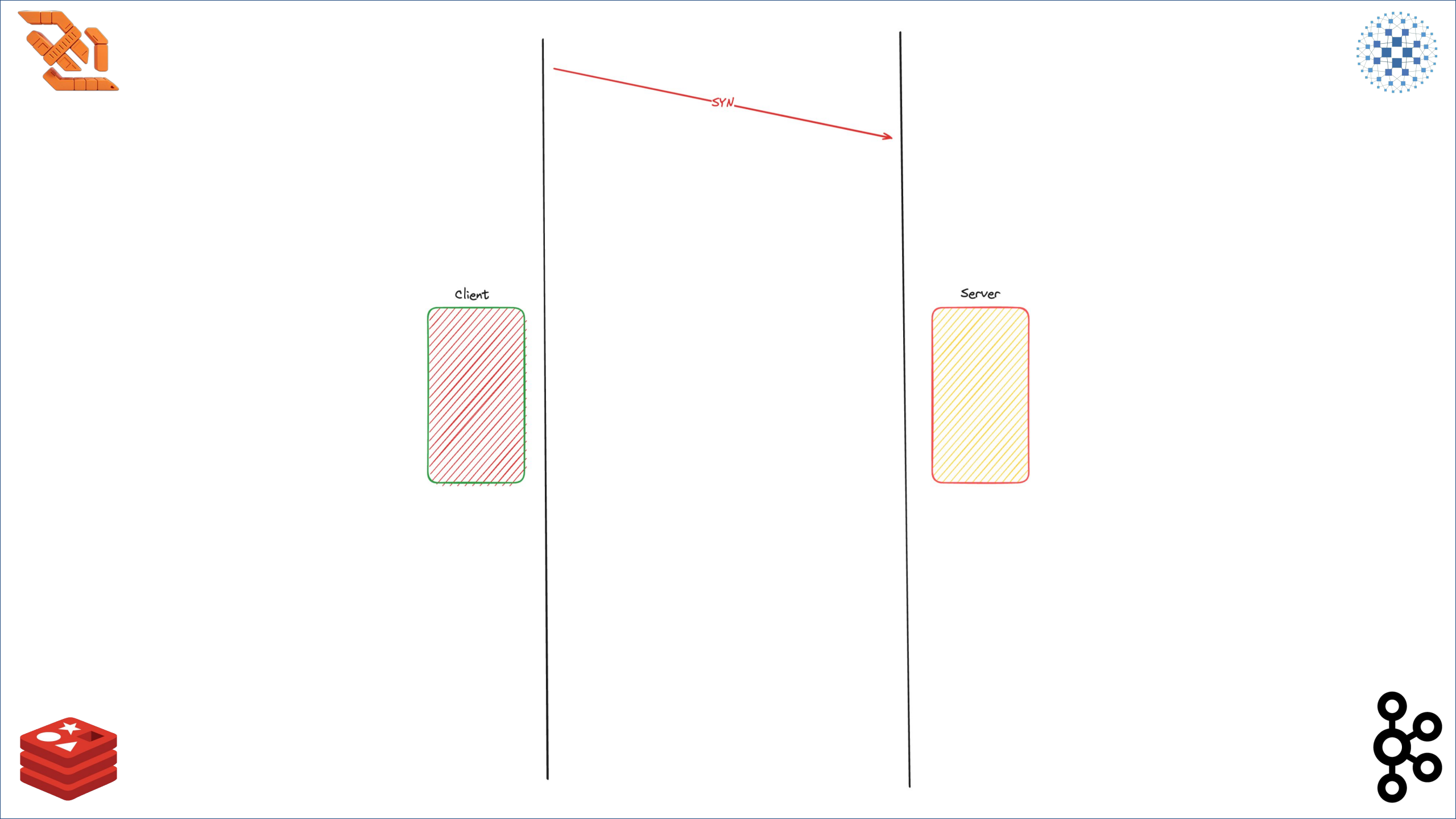


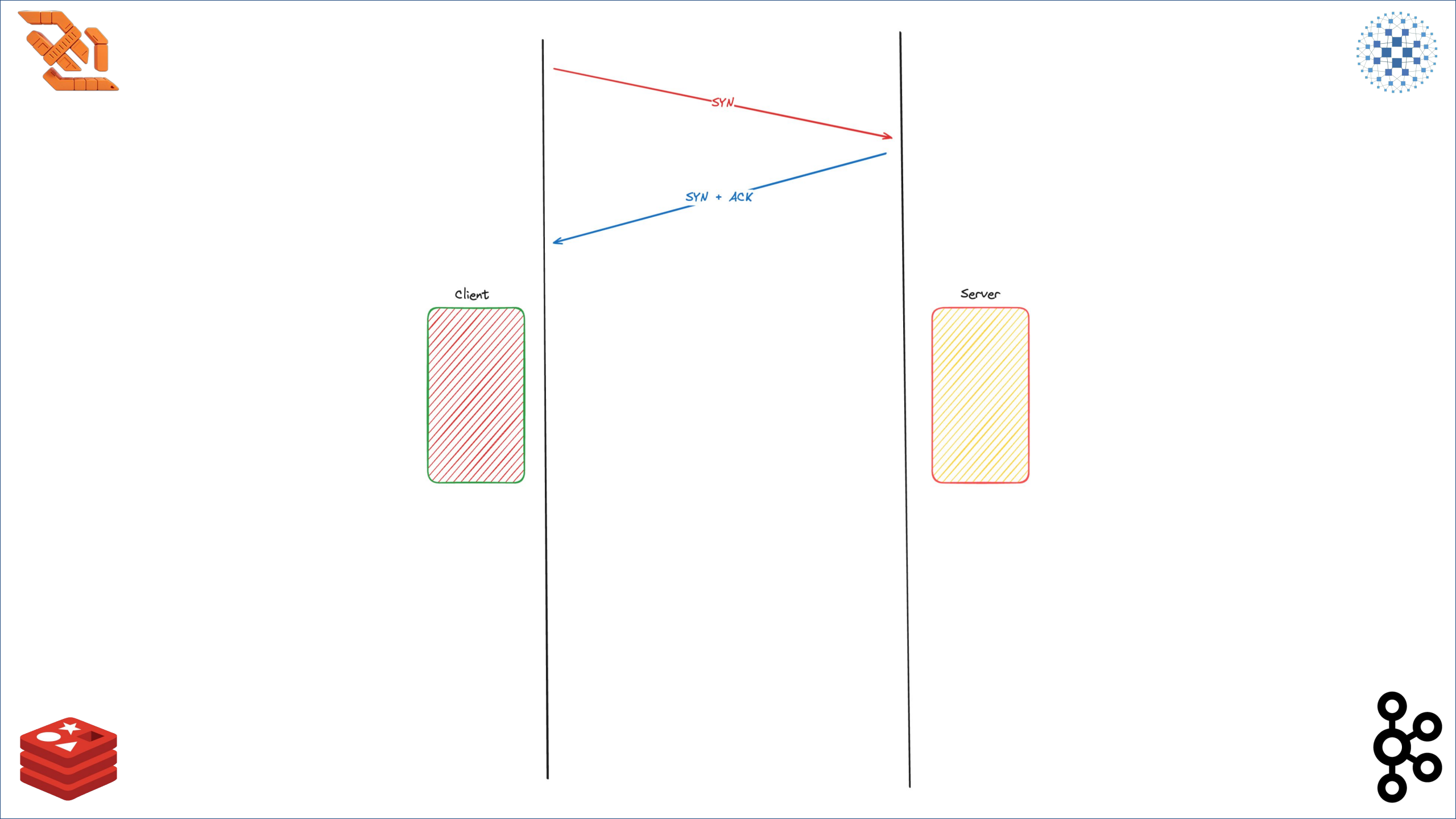


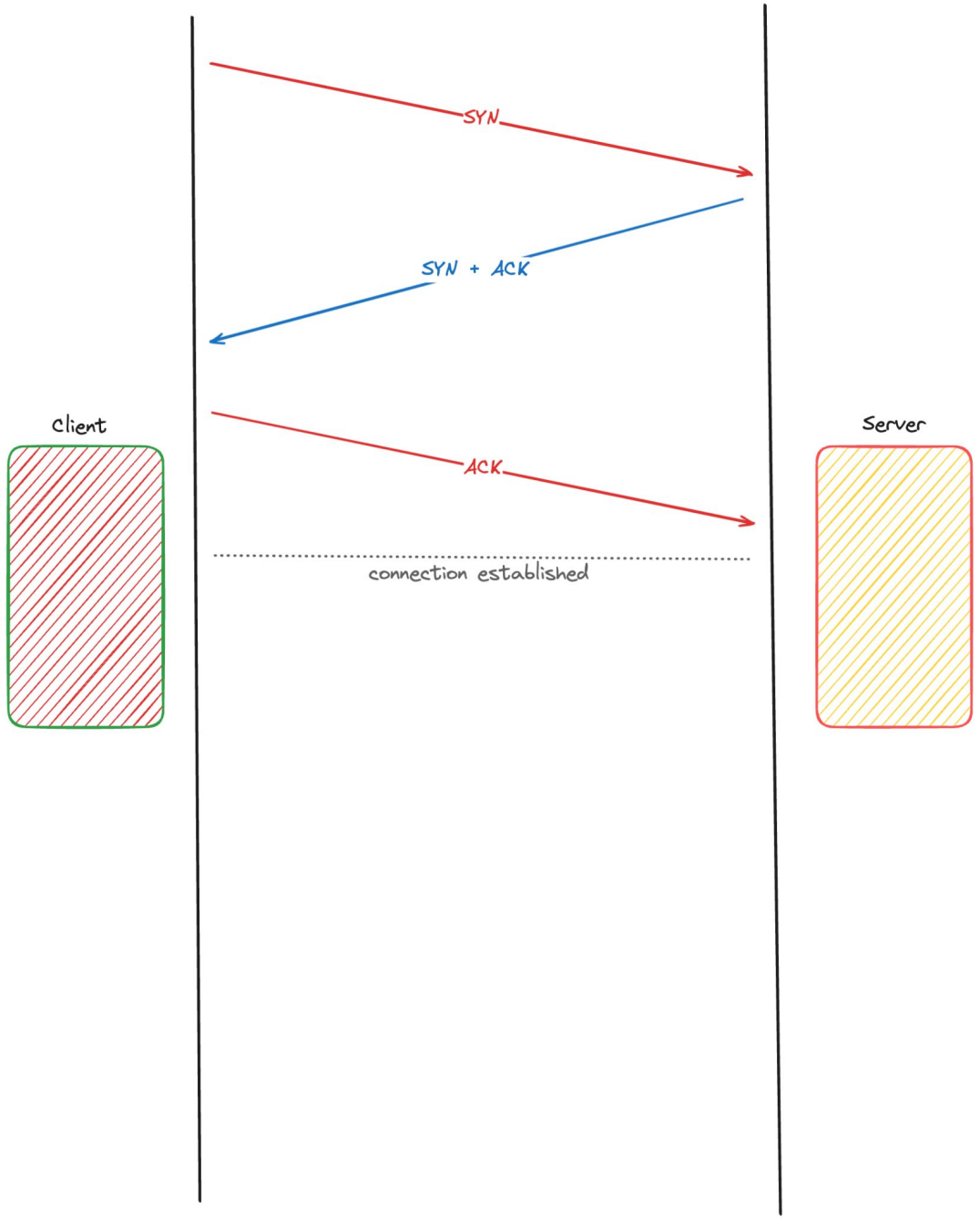

Client

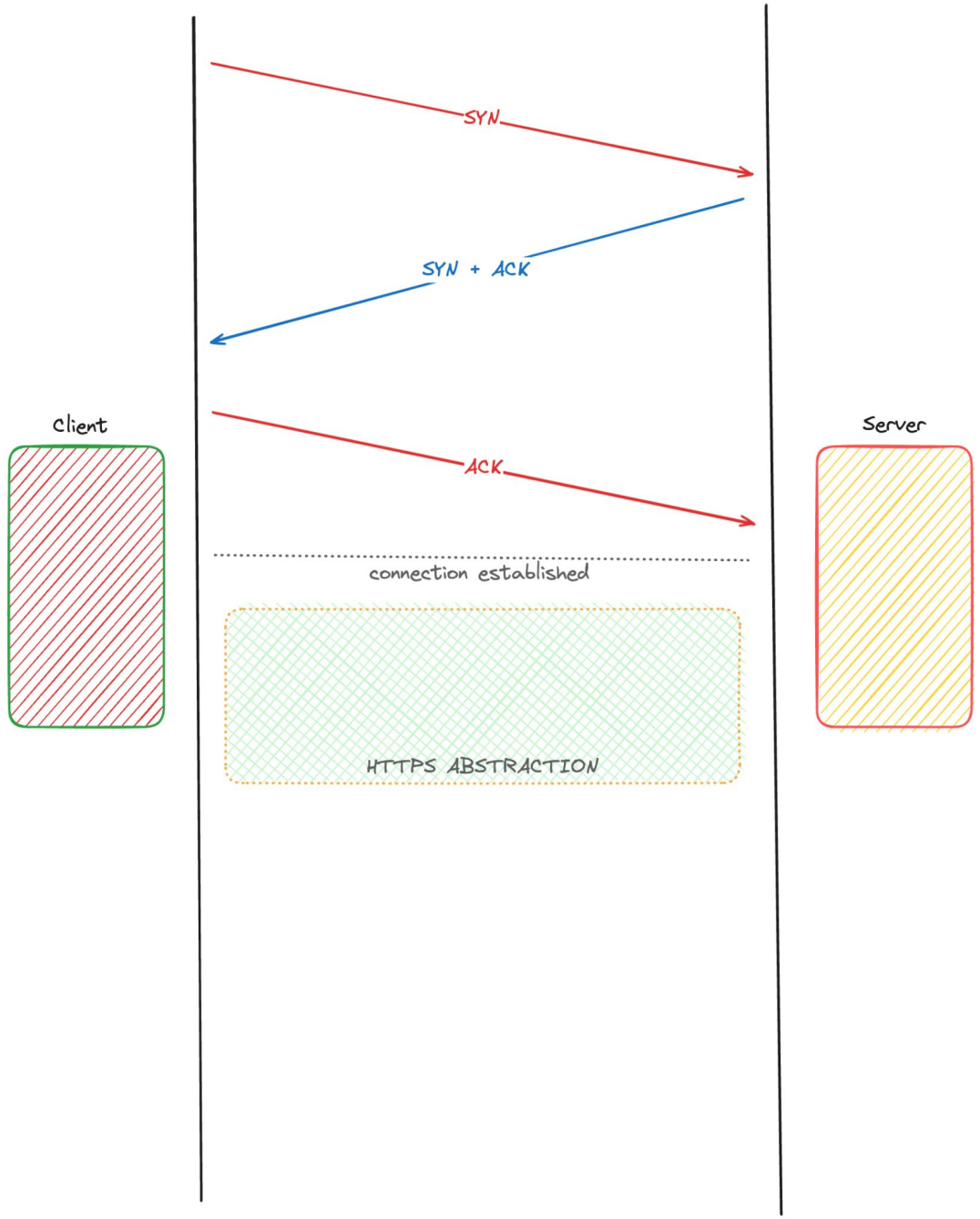

Server

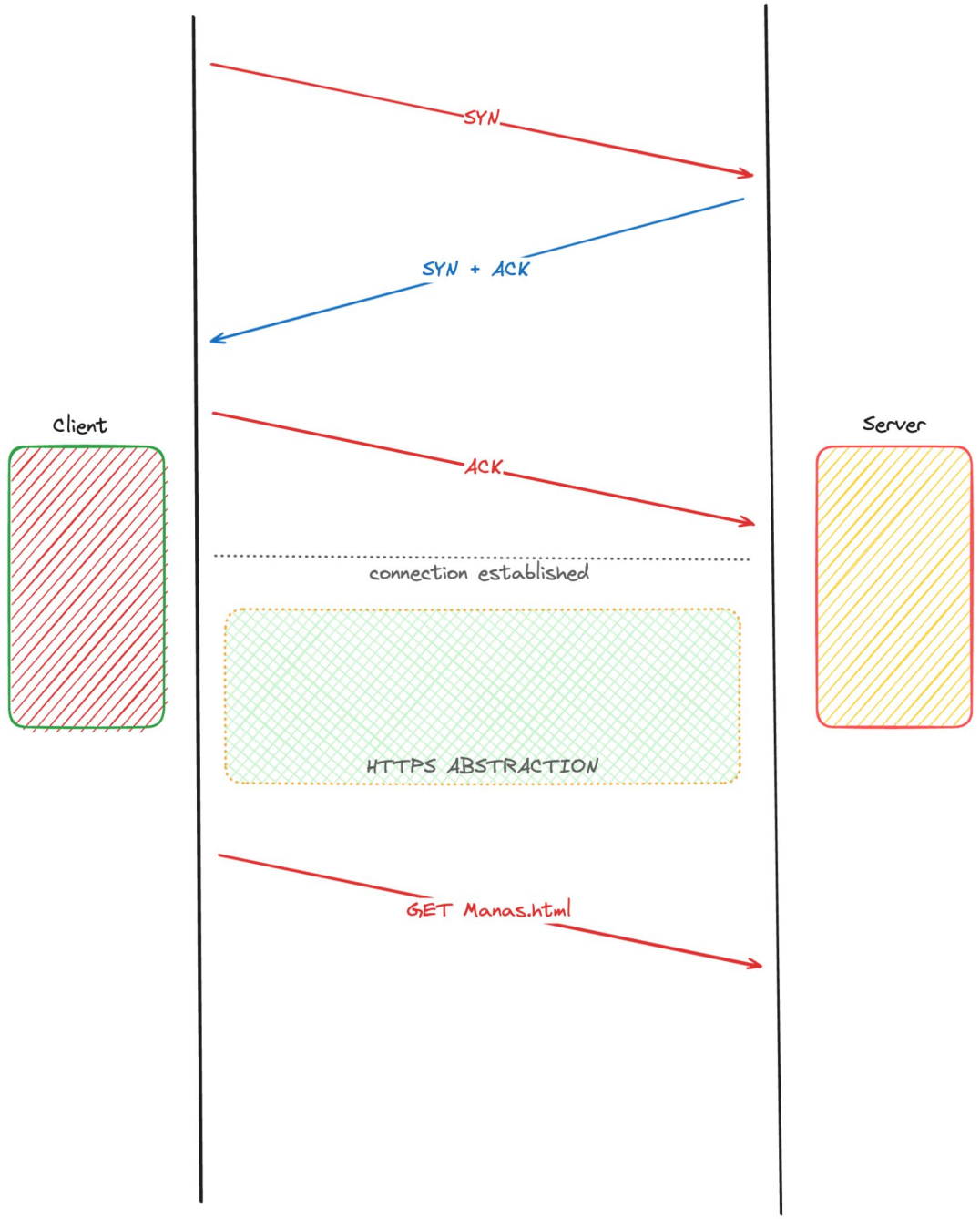


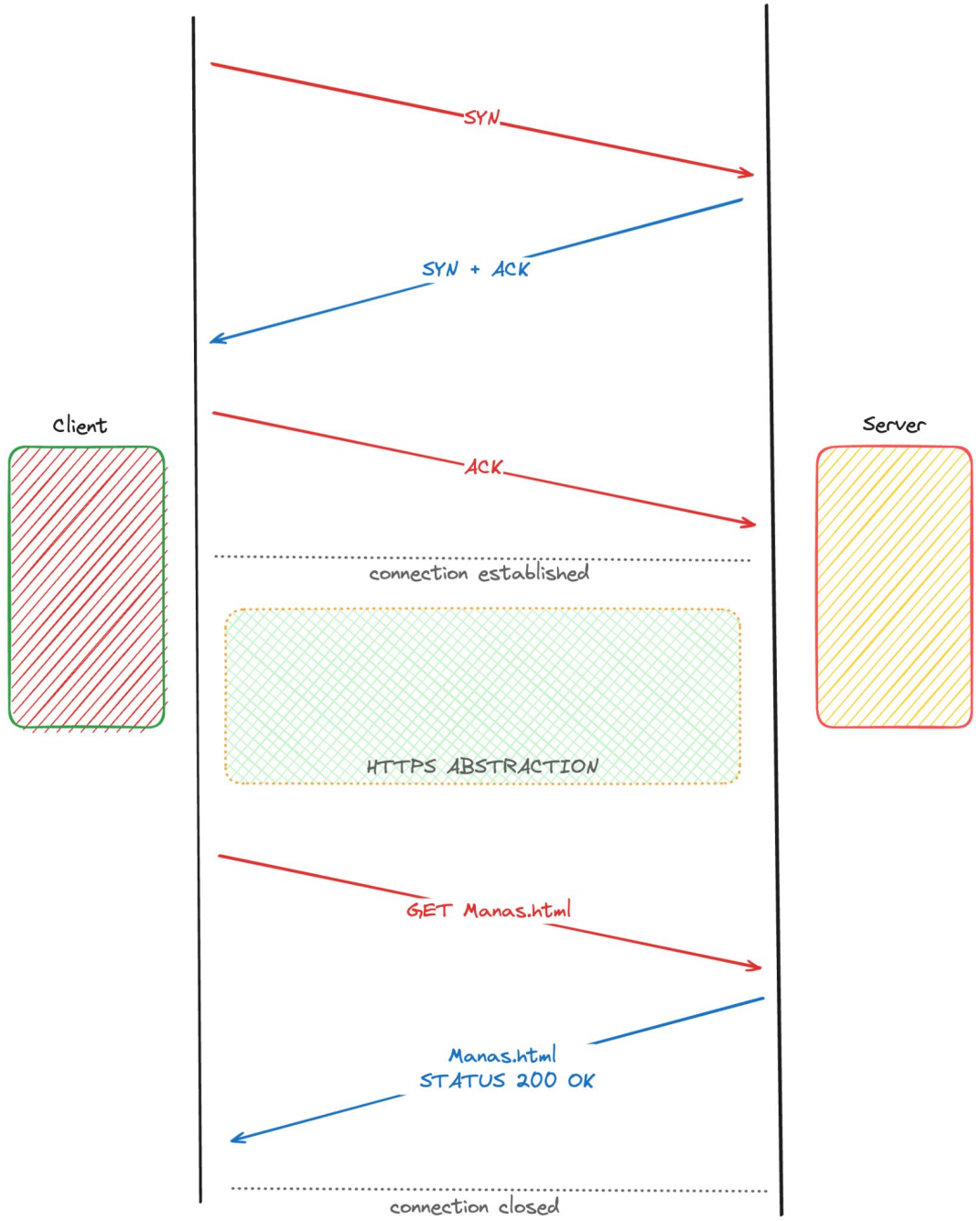

SYN
Client
Server


SYN
SYN + ACK
Client
Server

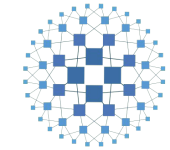

SYN
SYN + ACK
Client
Server
ACK
connection established


SYN
SYN + ACK
ACK
Client
Server
connection established
HTTPS ABSTRACTION

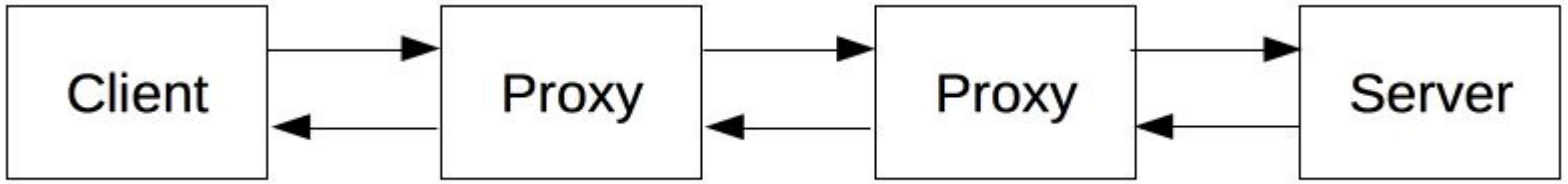

SYN
SYN + ACK
Client
Server
ACK
connection established
HTTPS ABSTRACTION
GET Manas.html


SYN
SYN + ACK
Client
Server
ACK
connection established
HTTPS ABSTRACTION
GET Manas.html
Manas.html
STATUS 200 OK
connection closed

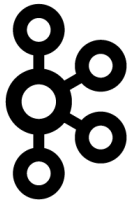
https://developer.mozilla.org/en-US/docs/Web/HTTP/Overview

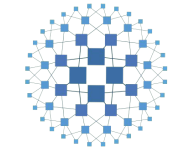


Hypertext Transfer Protocol



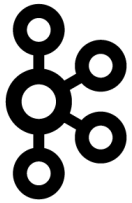
- *The browser is always the entity initiating the request. It is never the server that sends a response automatically*
- *The connection is cut-off after a request-response pair*

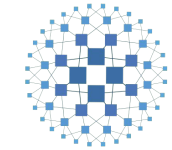




How to achieve a stateful connection ?

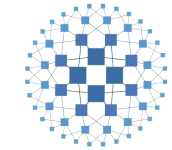
WebSocket Protocol





Why WebSocket Protocol ?

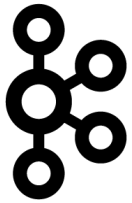
- *Full-duplex, bi-directional communication*
- *Persistent Stateful Connection*
- *Server can send resources even without client initiating a request*

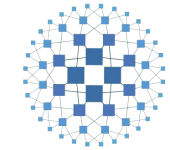


WebSocket Protocol

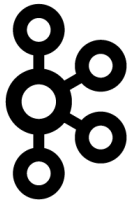
Initial GET request over a HTTP /1.1 with an upgrade flag

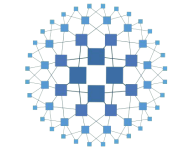
```
GET /chat HTTP/1.1
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
Origin: http://example.com
Sec-WebSocket-Protocol: chat, superchat
Sec-WebSocket-Version: 13
```



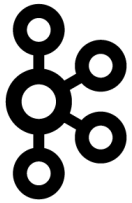


WebSocket Protocol

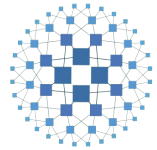




Proof of Work

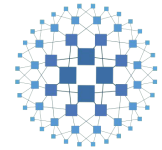


https://github.com/akarmanya/wscale

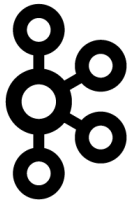


```ts
// WebSocketServer.ts

import { WebSocketServer, WebSocket } from 'ws'
import express from 'express'

function onSocketPreError(e: Error) {
  console.log(e)
}

function onSocketPostError(e: Error) {
  console.log(e)
}

const app = express()
const PORT: string | number = process.env.PORT || 8080

const httpServer = app.listen(PORT, () => {
  console.log(`HTTP Server is running on PORT ${PORT}`)
})

const wss = new WebSocketServer({ noServer: true })
```

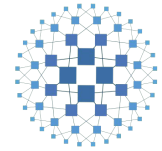
https://github.com/akarmanya/wscale



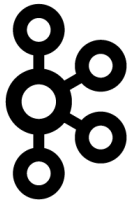
```
// WebSocketServer.ts

httpServer.on('upgrade', (req, socket, head) => {
  socket.on('error', onSocketPreError)

  wss.handleUpgrade(req, socket, head, (ws) => {
    socket.removeListener('error', onSocketPreError)
    wss.emit('connection', ws, req)
  })
})
```

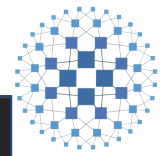


https://github.com/akarmanya/wscale



```ts
// WebSocketServer.ts

wss.on('connection', function connection(ws: WebSocket, req) {
  console.log(
    `HTTP Server upgraded to WSS Server and is running on PORT ${PORT}`
  )

  ws.on('error', onSocketPostError)

  ws.on('message', function message(data: any, isBinary: boolean) {
    try {
      wss.clients.forEach(function each(client) {
        if (client.readyState === WebSocket.OPEN) {
          client.send(data, { binary: isBinary })
        }
      })
    } catch (error) {
      console.error(error)
    }
  })

  ws.on('close', () => {
    console.log('Connection closed from ws server')
  })
})
```



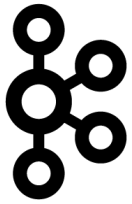


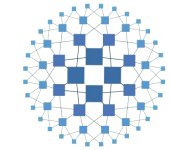
Wi-Fi: en0

(ip.addr eq 192.168.254.10 and ip.addr eq 192.168.254.81) and (tcp.port eq 8080)

No.	Time	Source	Destination	Protocol	Length	Info
737…	361.019315	192.168.254.10	192.168.254.81	TCP	78	49911 → 8080 [SYN] Seq=0 Win=65535 Len=0 MSS=1460 WS=64 TSval=269310857 TSecr=0 SACK_PERM=1
737…	361.022139	192.168.254.81	192.168.254.10	TCP	74	8080 → 49911 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK_PERM=1 TSval=4120177935 TSecr
737…	361.022260	192.168.254.10	192.168.254.81	TCP	66	49911 → 8080 [ACK] Seq=1 Ack=1 Win=131712 Len=0 TSval=269310859 TSecr=4120177935
737…	361.022588	192.168.254.10	192.168.254.81	HTTP	590	GET / HTTP/1.1
737…	361.025558	192.168.254.81	192.168.254.10	TCP	66	8080 → 49911 [ACK] Seq=1 Ack=525 Win=30080 Len=0 TSval=4120177939 TSecr=269310859
737…	361.585718	192.168.254.81	192.168.254.10	HTTP	209	HTTP/1.1 101 Switching Protocols
737…	361.585822	192.168.254.10	192.168.254.81	TCP	66	49911 → 8080 [ACK] Seq=525 Ack=144 Win=131584 Len=0 TSval=269311417 TSecr=4120178364
738…	381.479311	192.168.254.81	192.168.254.10	WebSocket	68	WebSocket Ping [FIN]
738…	381.479396	192.168.254.10	192.168.254.81	TCP	66	49911 → 8080 [ACK] Seq=525 Ack=146 Win=131584 Len=0 TSval=269331255 TSecr=4120198393
738…	381.479532	192.168.254.10	192.168.254.81	WebSocket	72	WebSocket Pong [FIN] [MASKED]
738…	381.482689	192.168.254.81	192.168.254.10	TCP	66	8080 → 49911 [ACK] Seq=146 Ack=531 Win=30080 Len=0 TSval=4120198396 TSecr=269331255
738…	391.720247	192.168.254.10	192.168.254.81	WebSocket	75	WebSocket Text [FIN] [MASKED]
738…	391.723511	192.168.254.81	192.168.254.10	TCP	66	8080 → 49911 [ACK] Seq=146 Ack=540 Win=30080 Len=0 TSval=4120208638 TSecr=269341461
738…	391.777315	192.168.254.81	192.168.254.10	WebSocket	89	WebSocket Text [FIN]
738…	391.777398	192.168.254.10	192.168.254.81	TCP	66	49911 → 8080 [ACK] Seq=540 Ack=169 Win=131584 Len=0 TSval=269341517 TSecr=4120208691
738…	405.199381	192.168.254.10	192.168.254.81	WebSocket	72	WebSocket Connection Close [FIN] [MASKED]
738…	405.203350	192.168.254.81	192.168.254.10	TCP	66	8080 → 49911 [ACK] Seq=169 Ack=546 Win=30080 Len=0 TSval=4120222118 TSecr=269354904
738…	405.222155	192.168.254.81	192.168.254.10	WebSocket	70	WebSocket Connection Close [FIN]
738…	405.222218	192.168.254.10	192.168.254.81	TCP	66	49911 → 8080 [ACK] Seq=546 Ack=173 Win=131584 Len=0 TSval=269354926 TSecr=4120222137

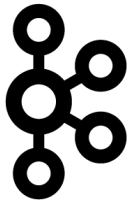
```
▶ Frame 73729: 78 bytes on wire (624 bits), 78 bytes captured (624 bits) on interface en0, id 0
▶ Ethernet II, Src: Apple_7f:c0:07 (ac:bc:32:7f:c0:07), Dst: Raspberr_02:cb:df (b8:27:eb:02:cb:df)
▶ Internet Protocol Version 4, Src: 192.168.254.10, Dst: 192.168.254.81
▼ Transmission Control Protocol, Src Port: 49911, Dst Port: 8080, Seq: 0, Len: 0
    Source Port: 49911
    Destination Port: 8080
    [Stream index: 27]
    [TCP Segment Len: 0]
    Sequence number: 0    (relative sequence number)
    Sequence number (raw): 2402399483
    [Next sequence number: 1    (relative sequence number)]
    Acknowledgment number: 0
    Acknowledgment number (raw): 0
    1011 .... = Header Length: 44 bytes (11)
  ▼ Flags: 0x002 (SYN)
      000. .... .... = Reserved: Not set
      ...0 .... .... = Nonce: Not set
      .... 0... .... = Congestion Window Reduced (CWR): Not set
      .... .0.. .... = ECN-Echo: Not set
```

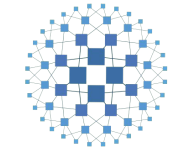




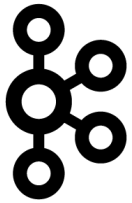
Why WebSockets are difficult to *scale*

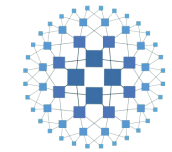
- *HTTP works on a duplex communication model*
- *The client initiates a request to the server for a resource*
- *The server responds back with a response*
- *Once the client receives the response, the connection is closed*





Demonstration





http server 1

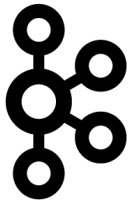
Load Balancer

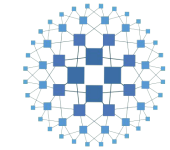
client

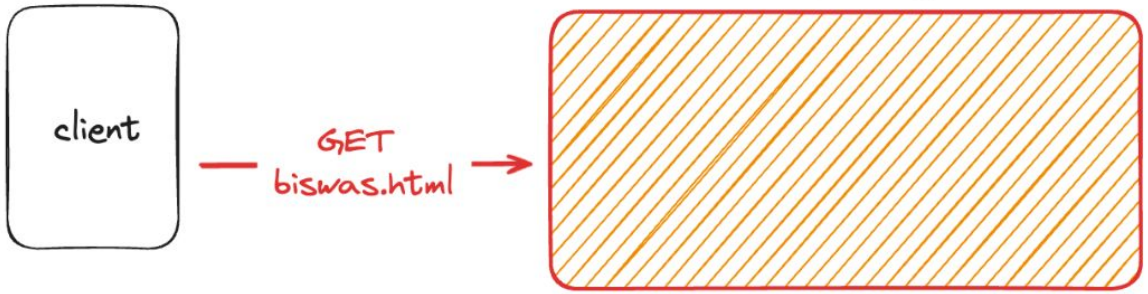
http server 2

Database

http server 3



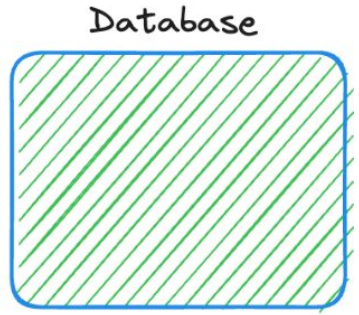


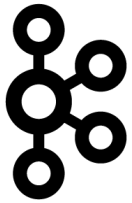

client
GET
biswas.html
Load Balancer

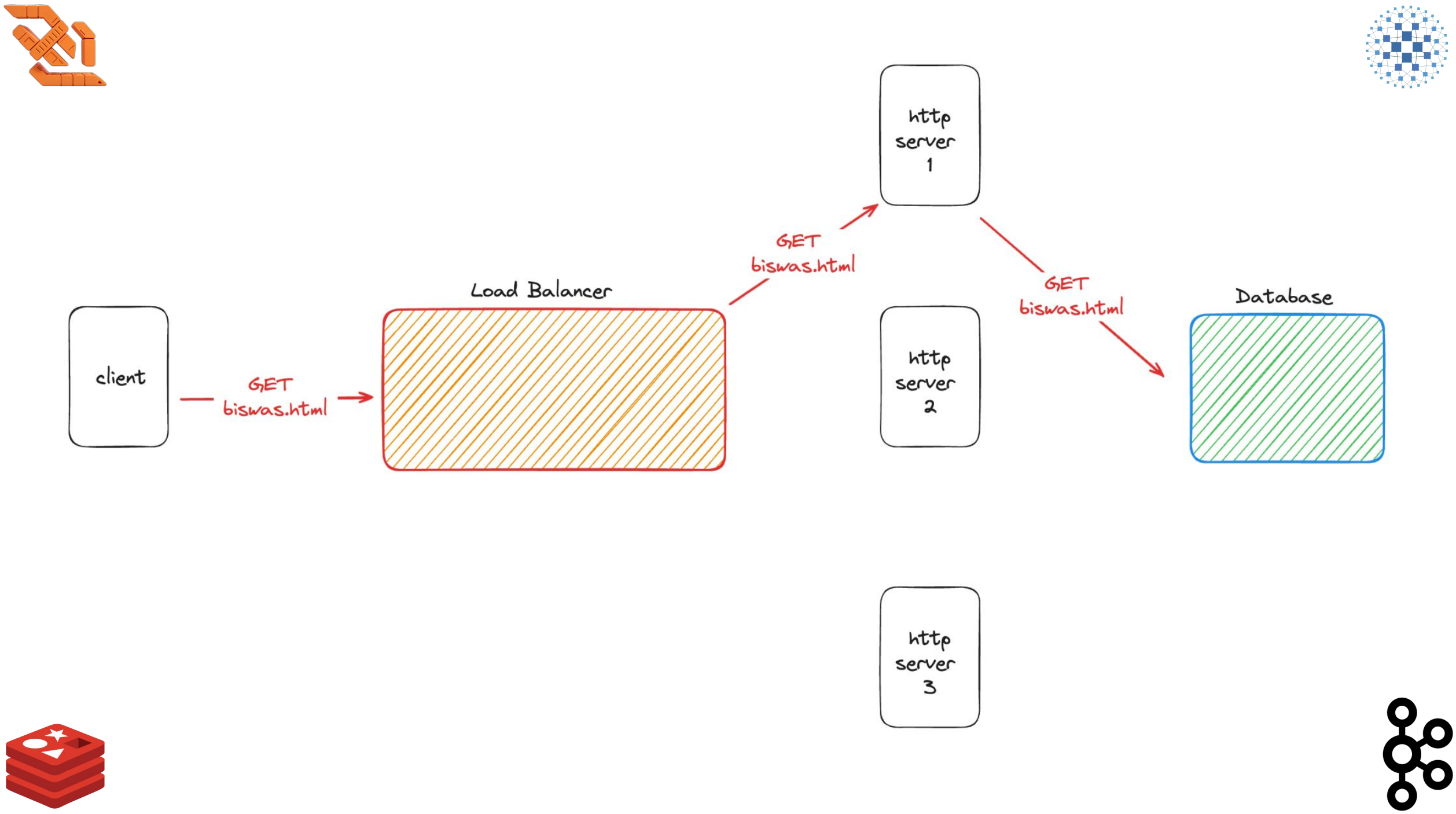

http
server
1

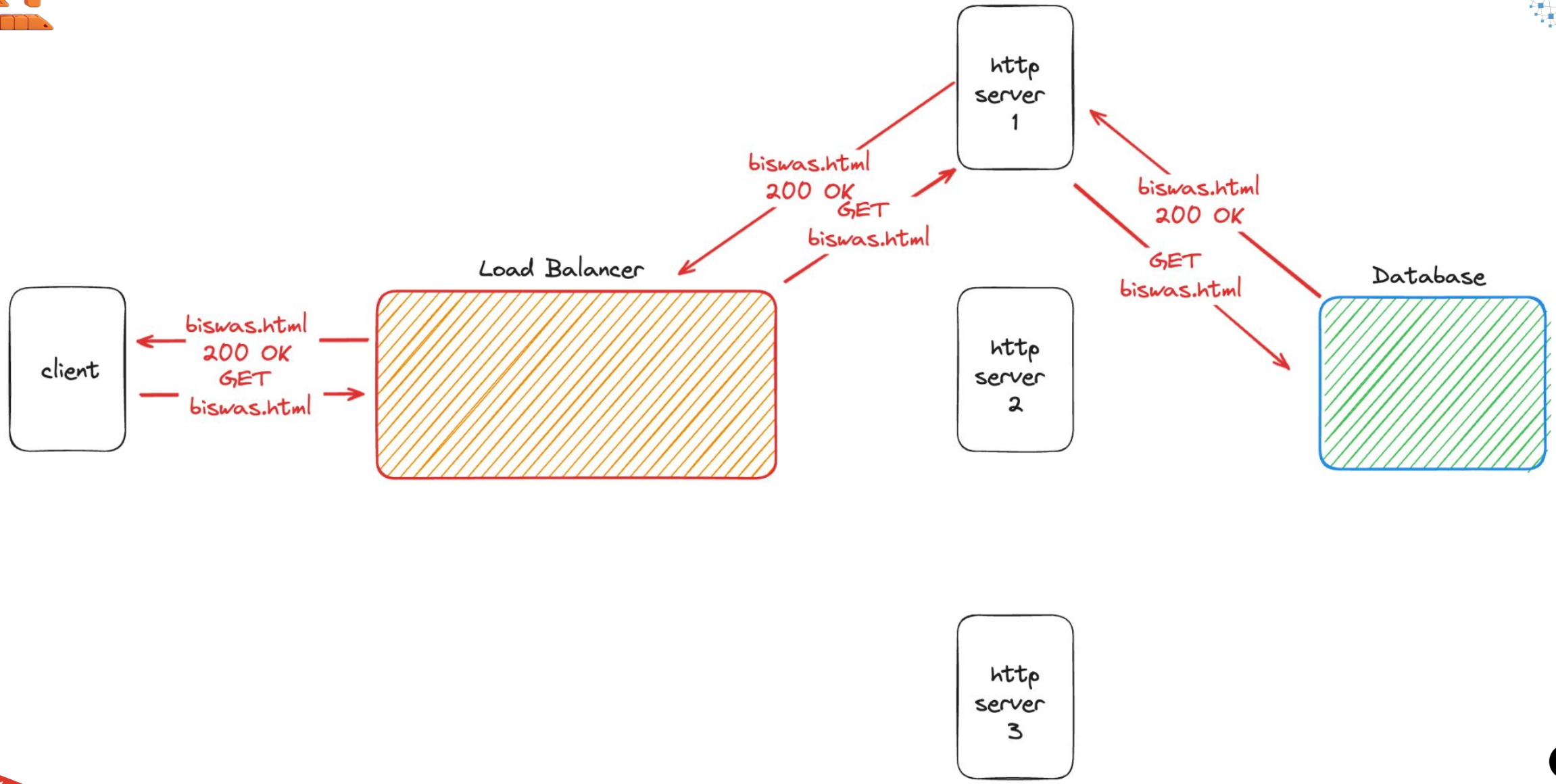

http
server
2

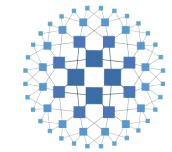

http
server
3


Database




client
GET
biswas.html
Load Balancer
GET
biswas.html
http
server
1
http
server
2
http
server
3
GET
biswas.html
Database


http server 1
biswas.html 200 OK
GET biswas.html
biswas.html 200 OK
GET biswas.html
Load Balancer
client
biswas.html 200 OK
GET biswas.html
http server 2
Database
http server 3



http server 1

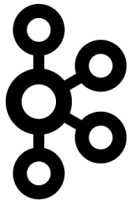
Load Balancer

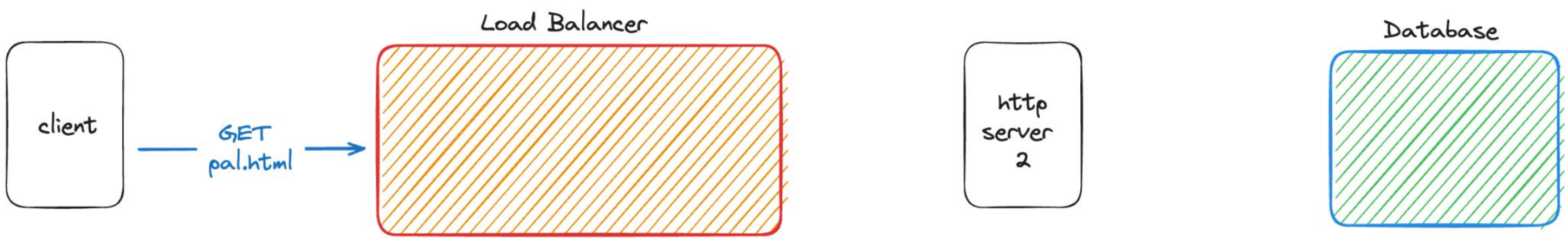
client

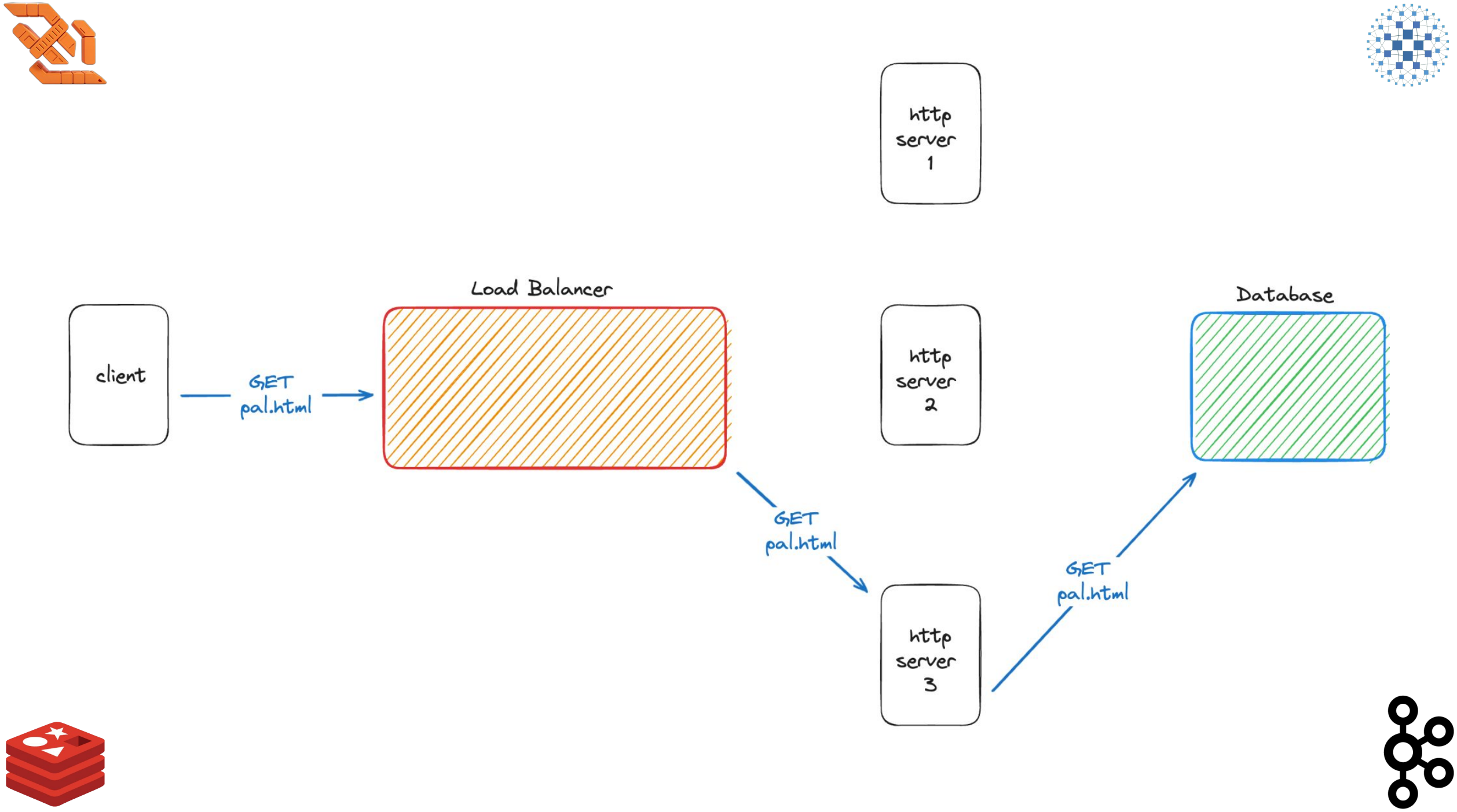
http server 2

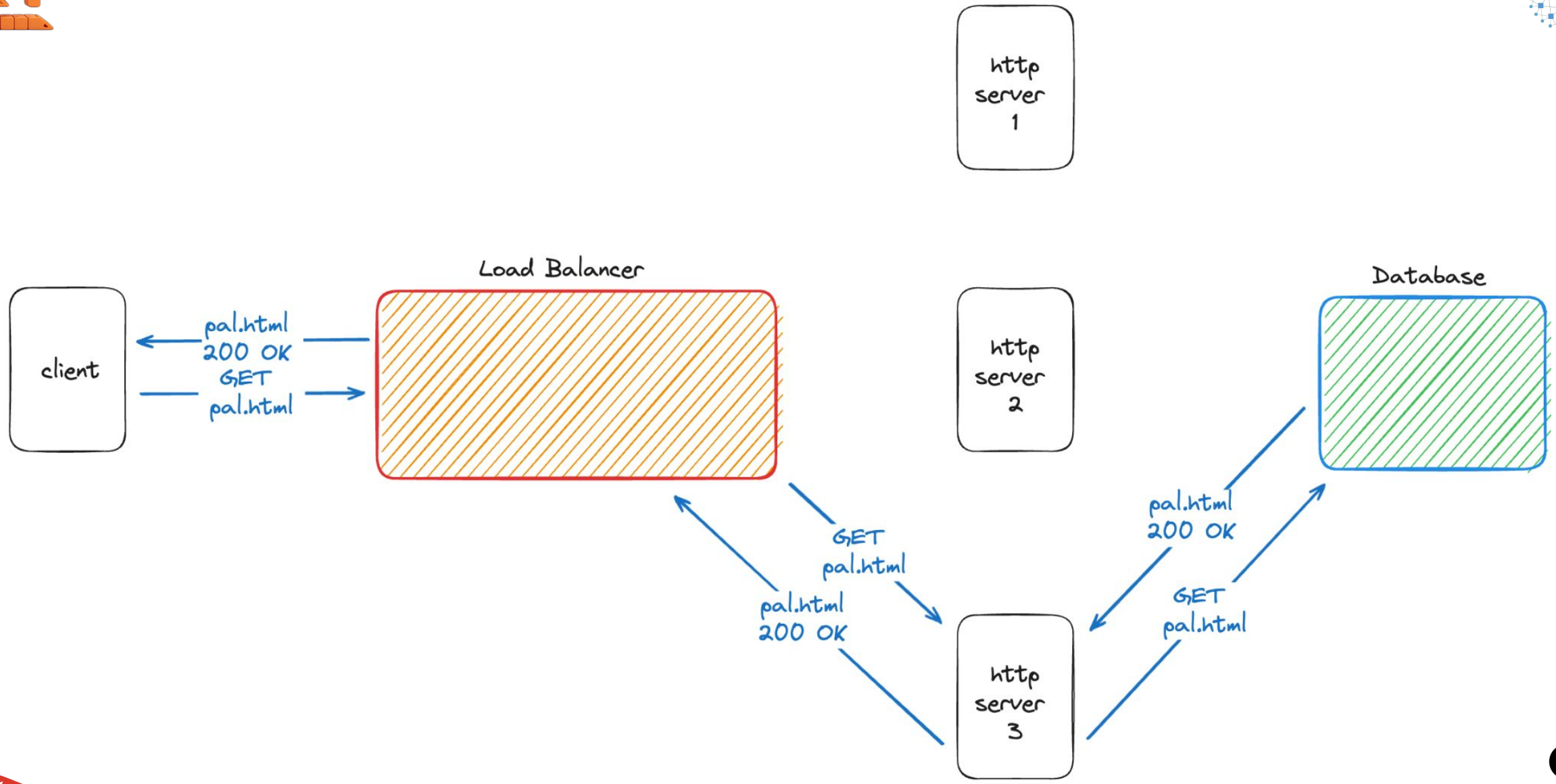
Database

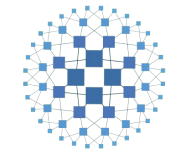
http server 3




http server 1
Load Balancer
client
GET pal.html
http server 2
Database
http server 3


http server 1
Load Balancer
client
GET pal.html
http server 2
Database
GET pal.html
GET pal.html
http server 3


http server 1
Load Balancer
Database
client
pal.html
200 OK
GET
pal.html
http server 2
GET
pal.html
pal.html
200 OK
pal.html
200 OK
GET
pal.html
http server 3



http server 1

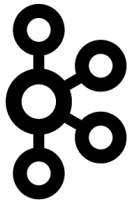
Load Balancer

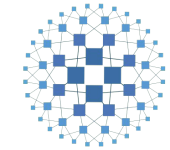
client

http server 2

Database

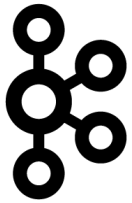
http server 3

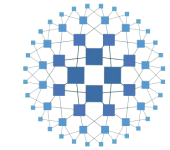




Why WebSockets are difficult to *scale*

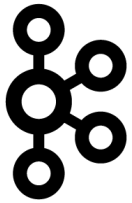
- *Hence, one client can request to multiple HTTP servers and the client state need not be stored*
- *Millions of clients can be served independently across multiple HTTP servers*
- *Therefore, HTTP servers are horizontally scalable*

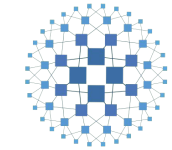




Why WebSockets are difficult to *scale*

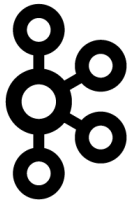
- *However, in case of WebSocket connection, one client is binded to a single WebSocket server*
- *Loss of connection implies loss of state*
- *Therefore, one client ideally binds to one WebSocket server and scaling horizontally cannot replicate states across the servers*





How to achieve a *synchronised* stateful connection ?

Load Balancer
Publisher - Subscriber



The Architecture

client 1

client 2

client 3

HAProxy acts as a reverse proxy load balancer that supports ws:// distributing the incoming load across multiple WebSocket servers that can be independently scaled horizontally

HAProxy

ws 1

ws 2

ws 3

Redis acts as a Publisher - Subscriber service. Each WebSocket sever subscribe to a common channel. Any new updates by a publisher is fired to all the subscribers

Redis

The Architecture

client 1

client 2

client 3

HAProxy acts as a reverse proxy load balancer that supports ws:// distributing the incoming load across multiple WebSocket servers that can be independently scaled horizontally

HAProxy

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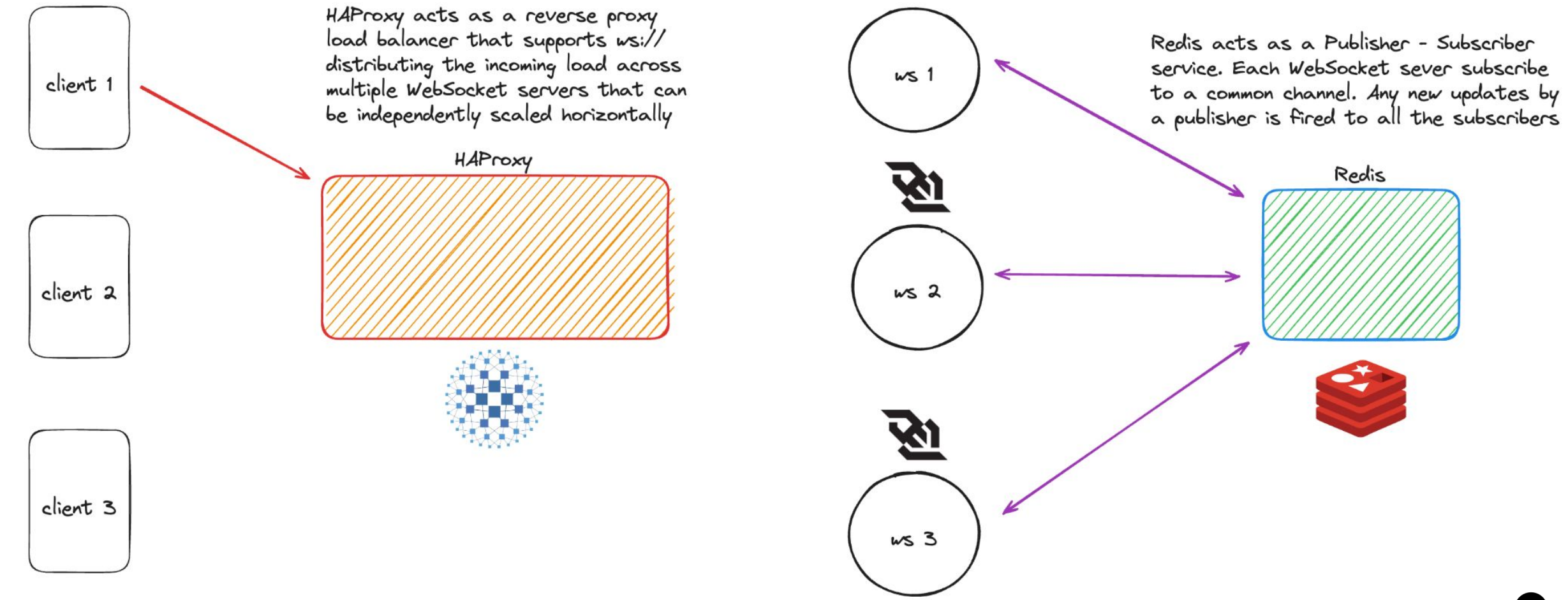
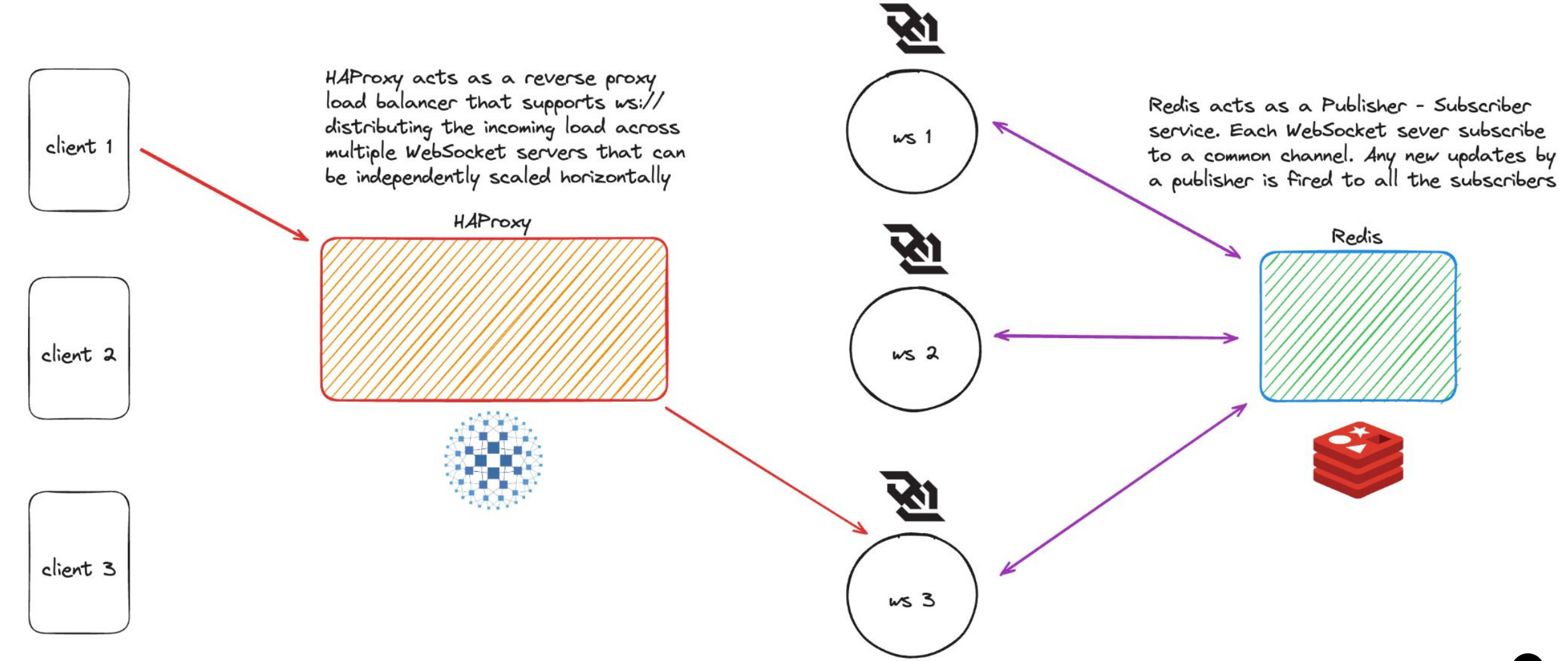
Redis acts as a Publisher - Subscriber service. Each WebSocket sever subscribe to a common channel. Any new updates by a publisher is fired to all the subscribers

Redis

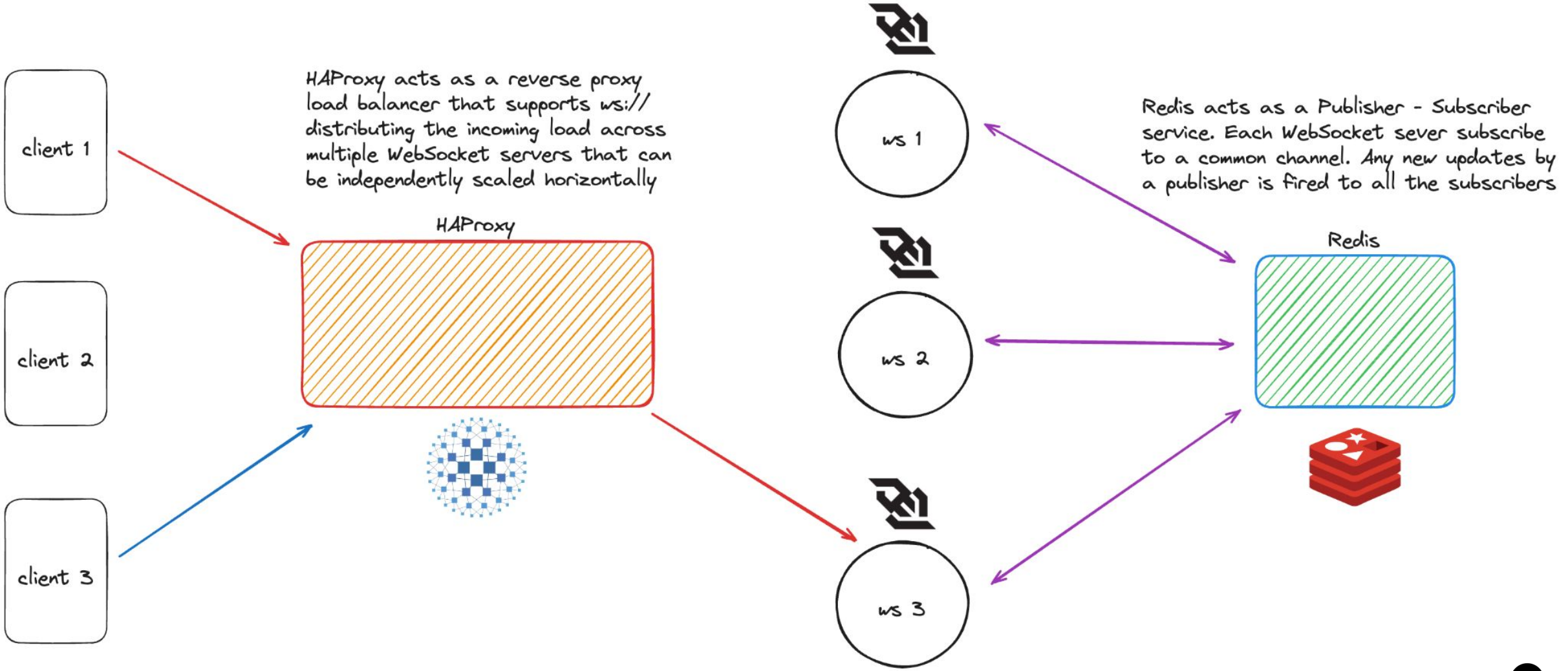
The Architecture



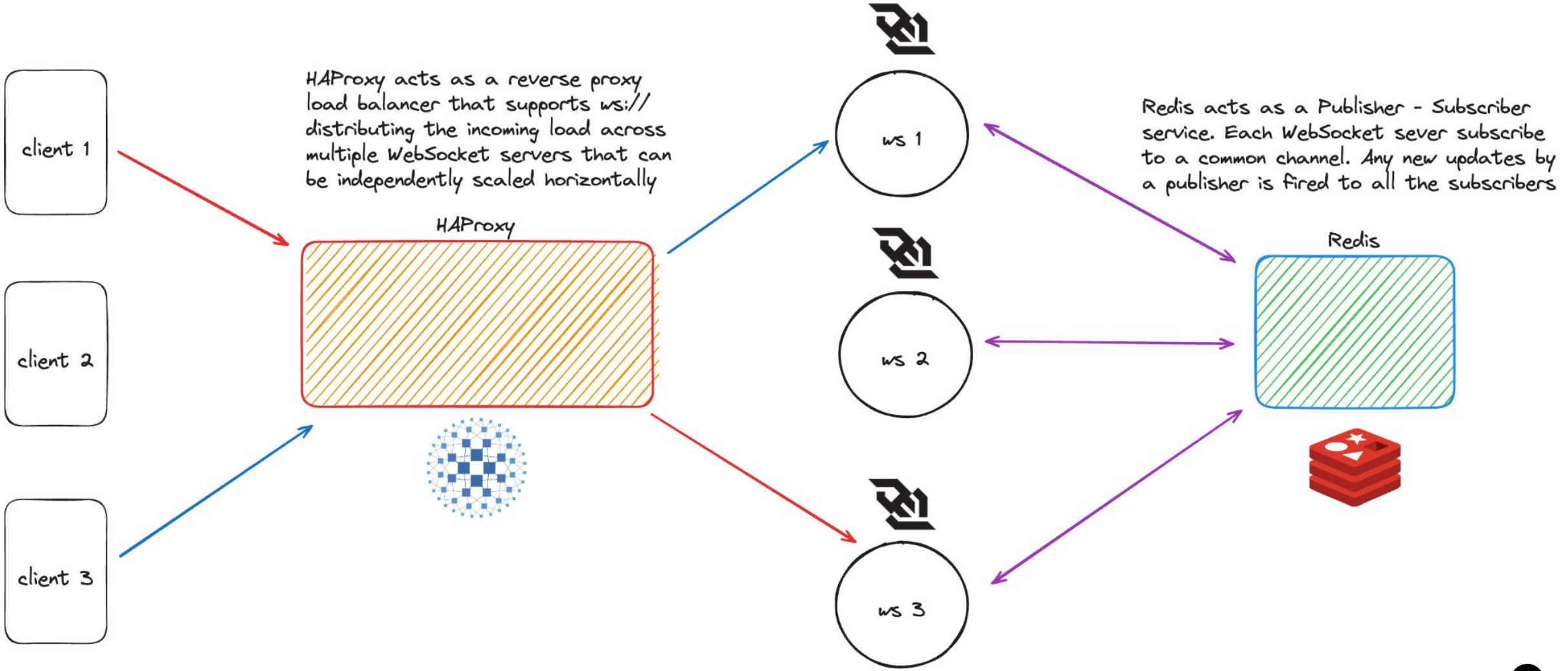
The Architecture



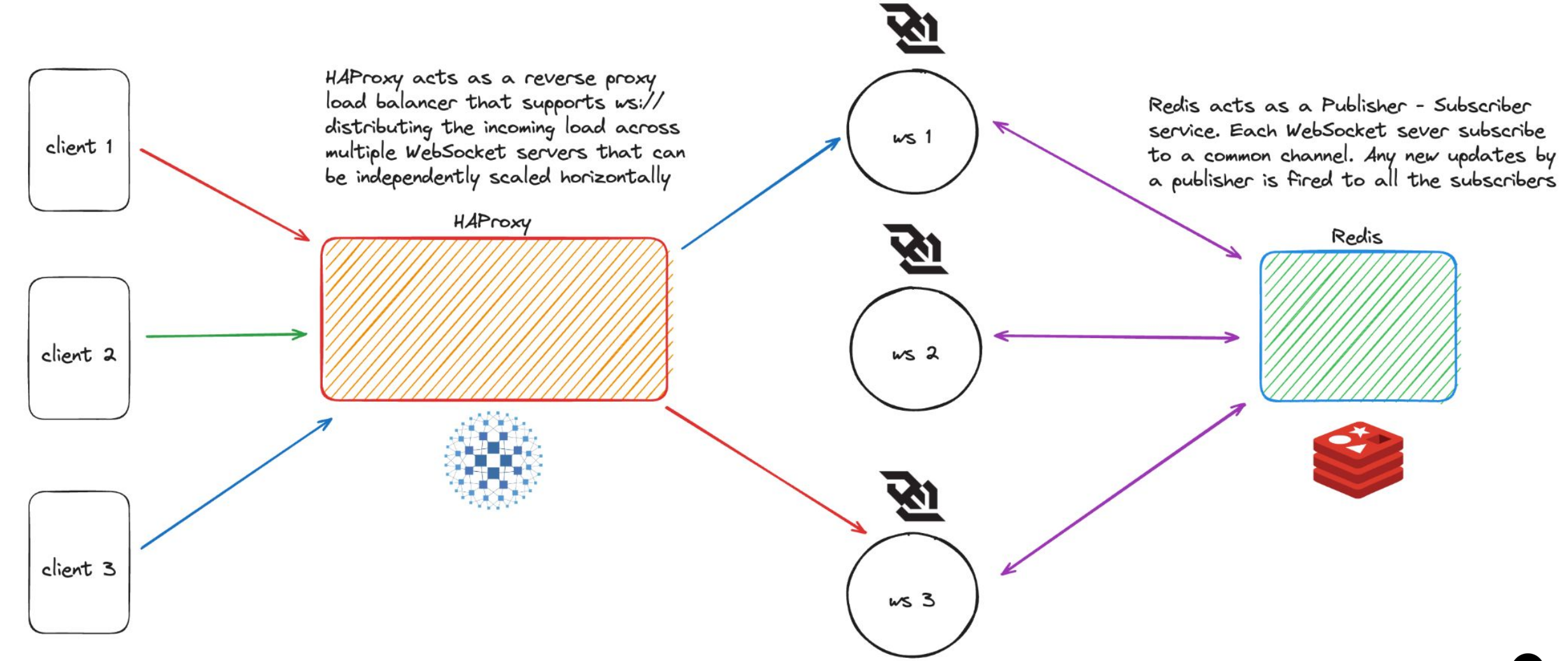
The Architecture



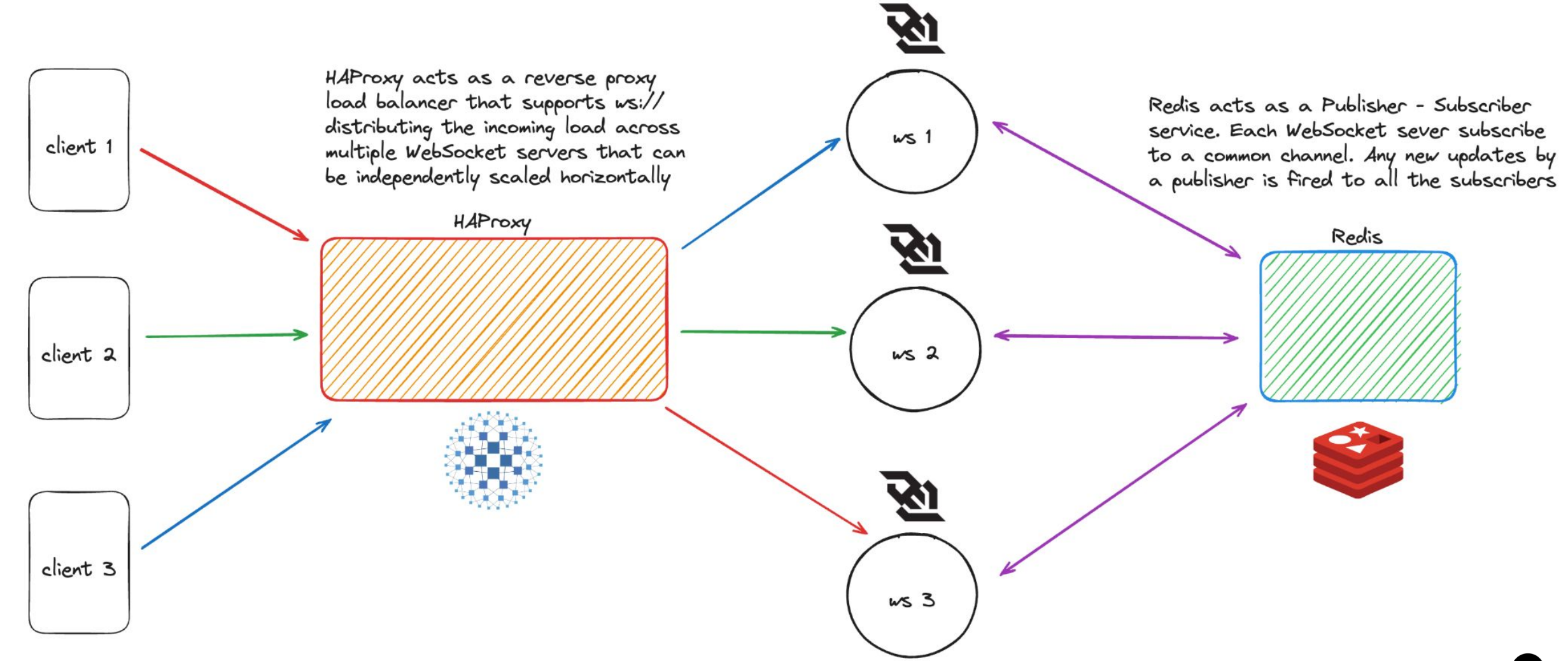
The Architecture



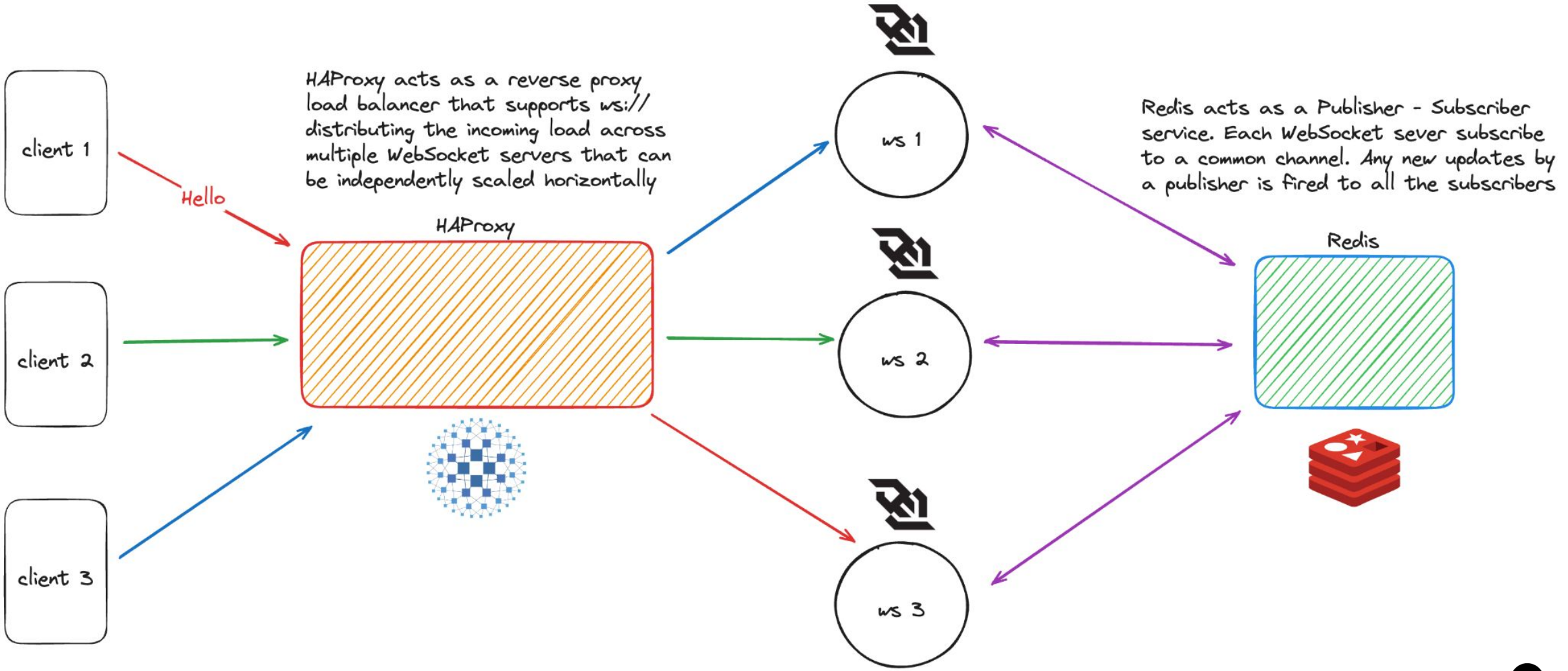
The Architecture



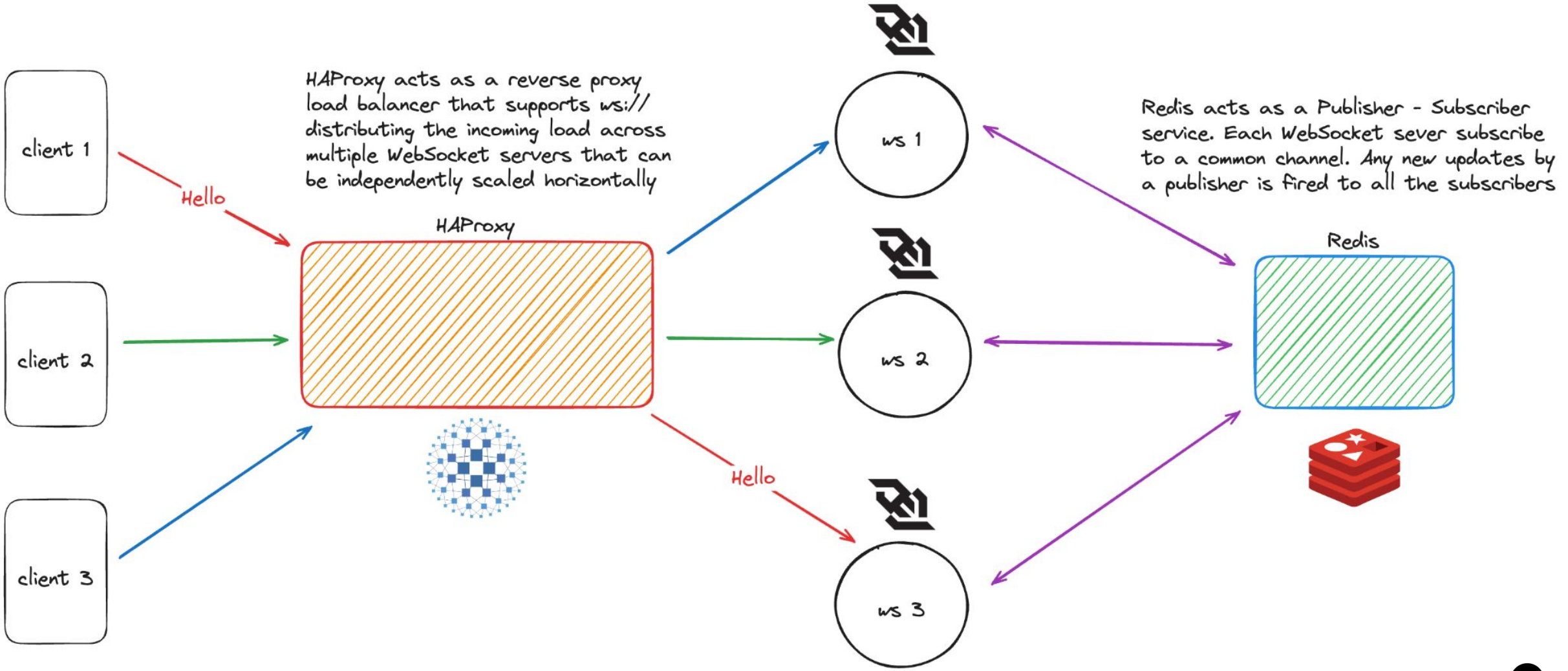
The Architecture



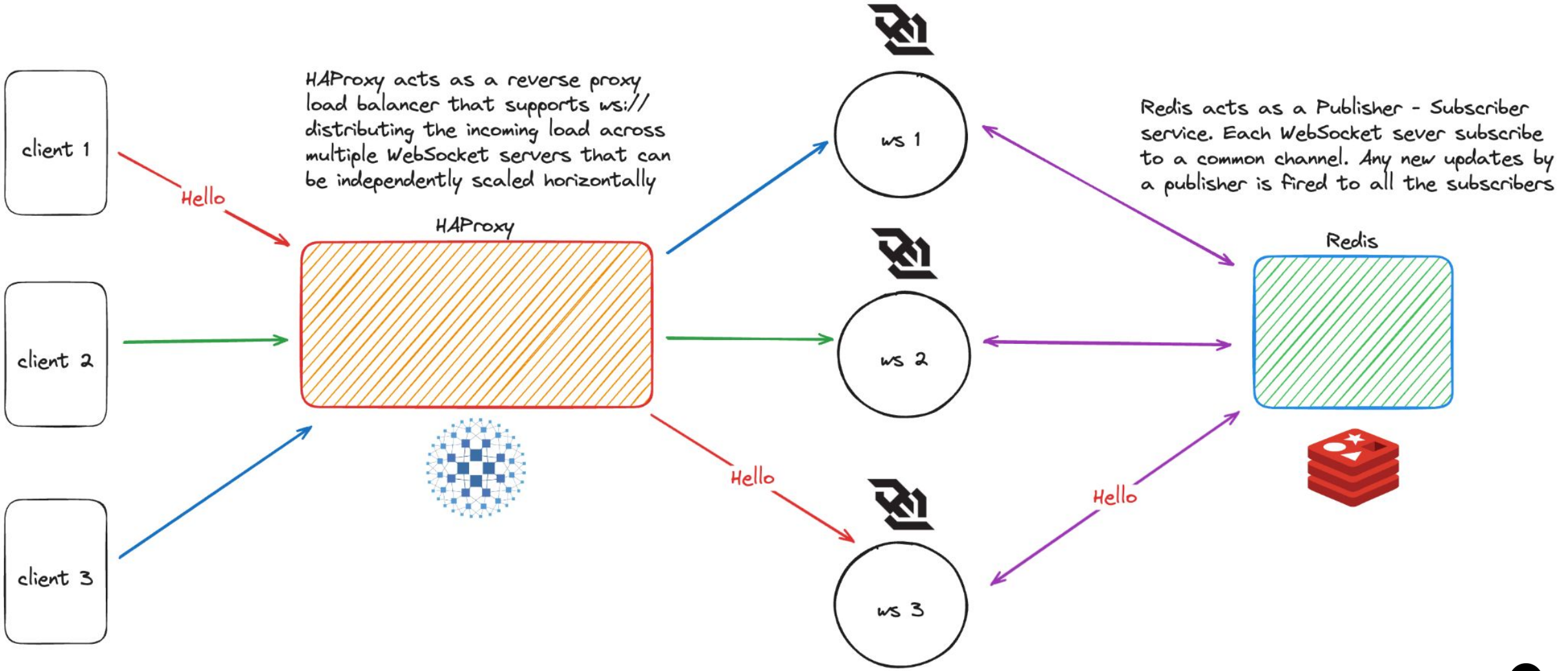
The Architecture



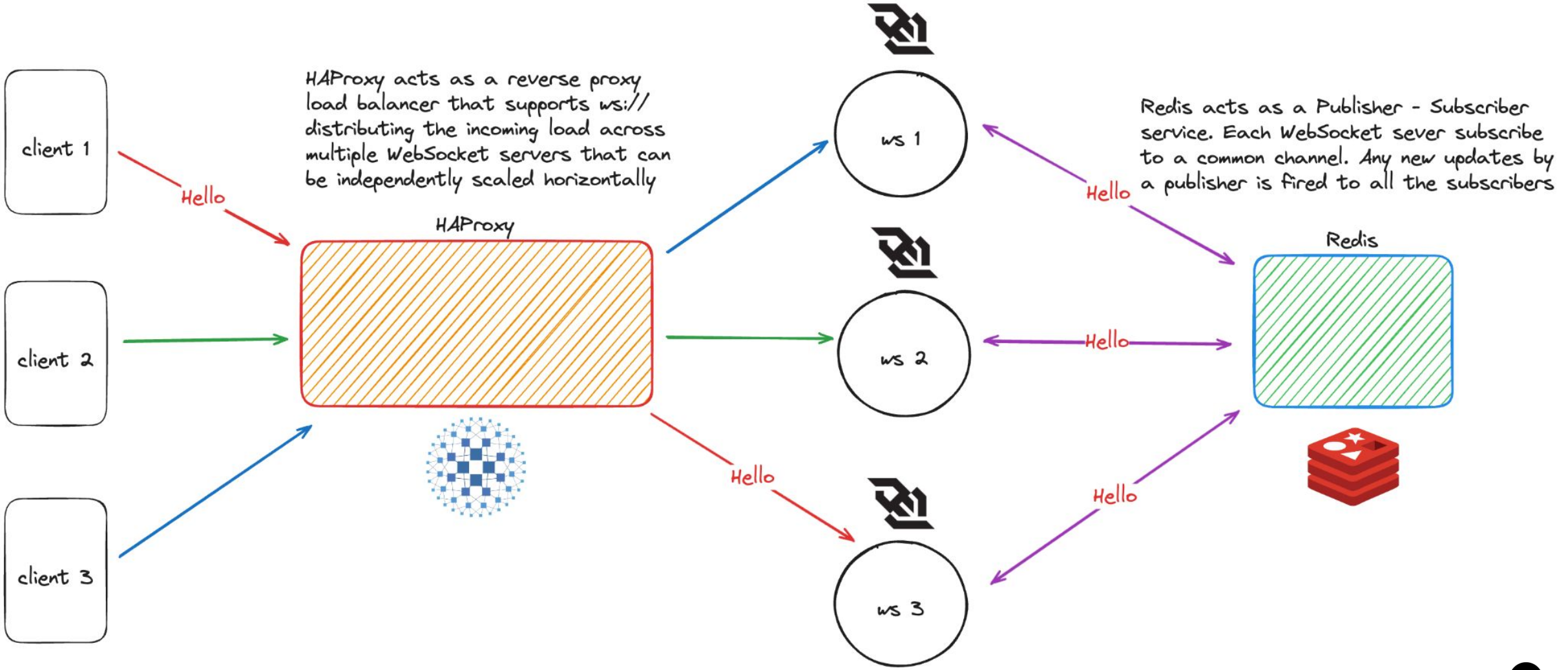
The Architecture



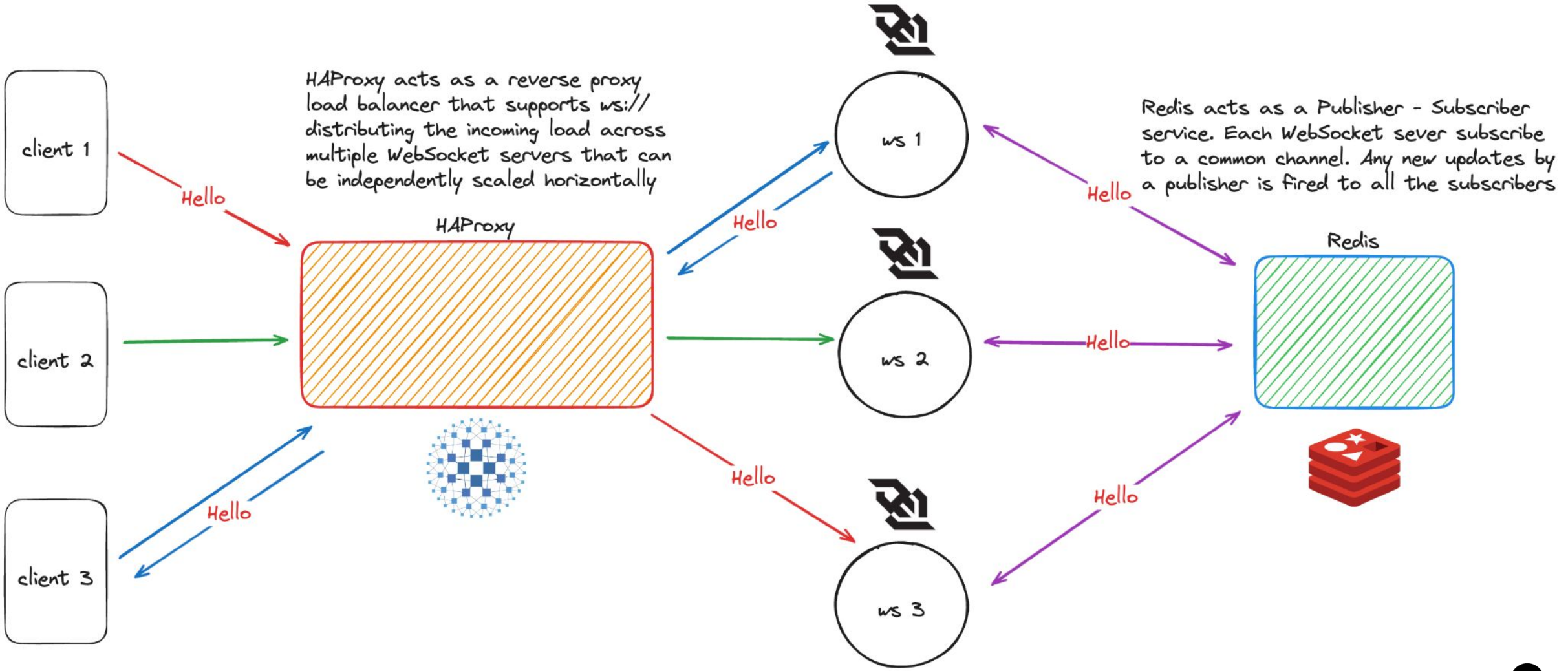
The Architecture



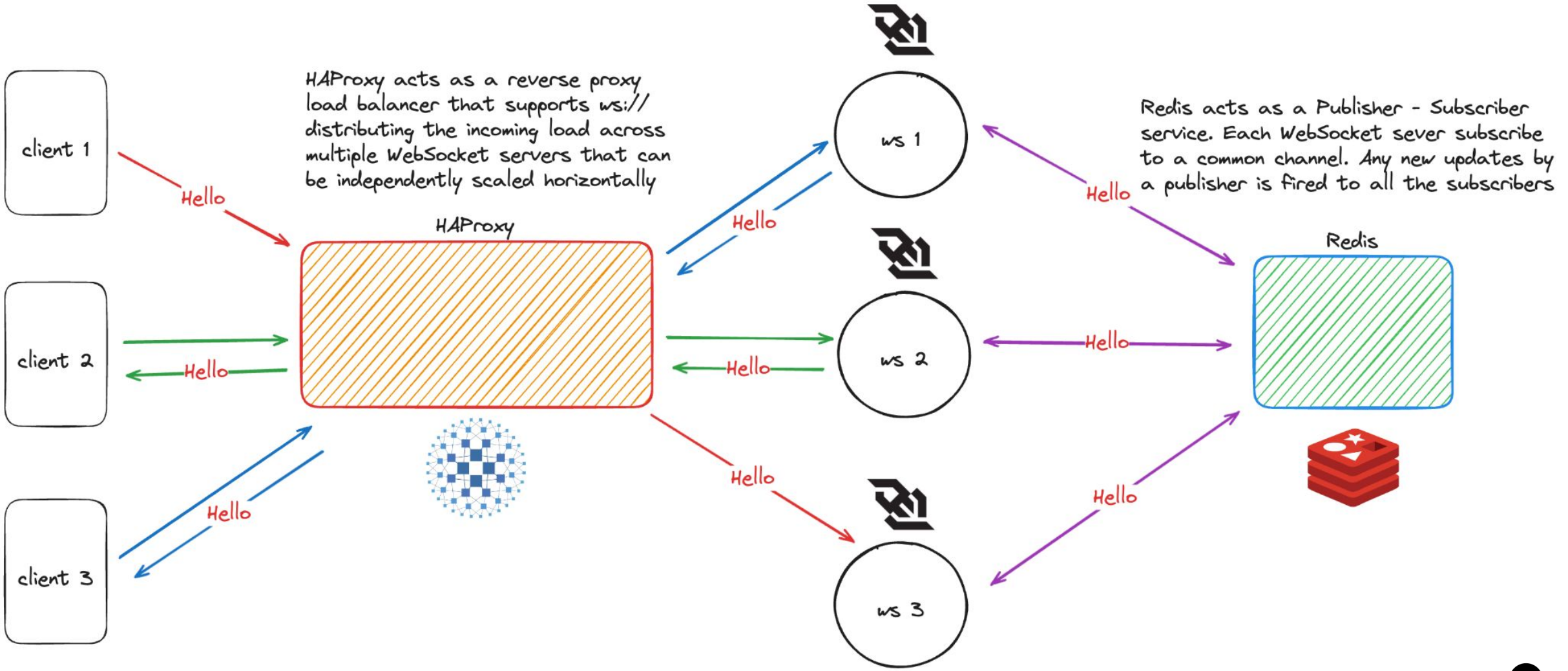
The Architecture



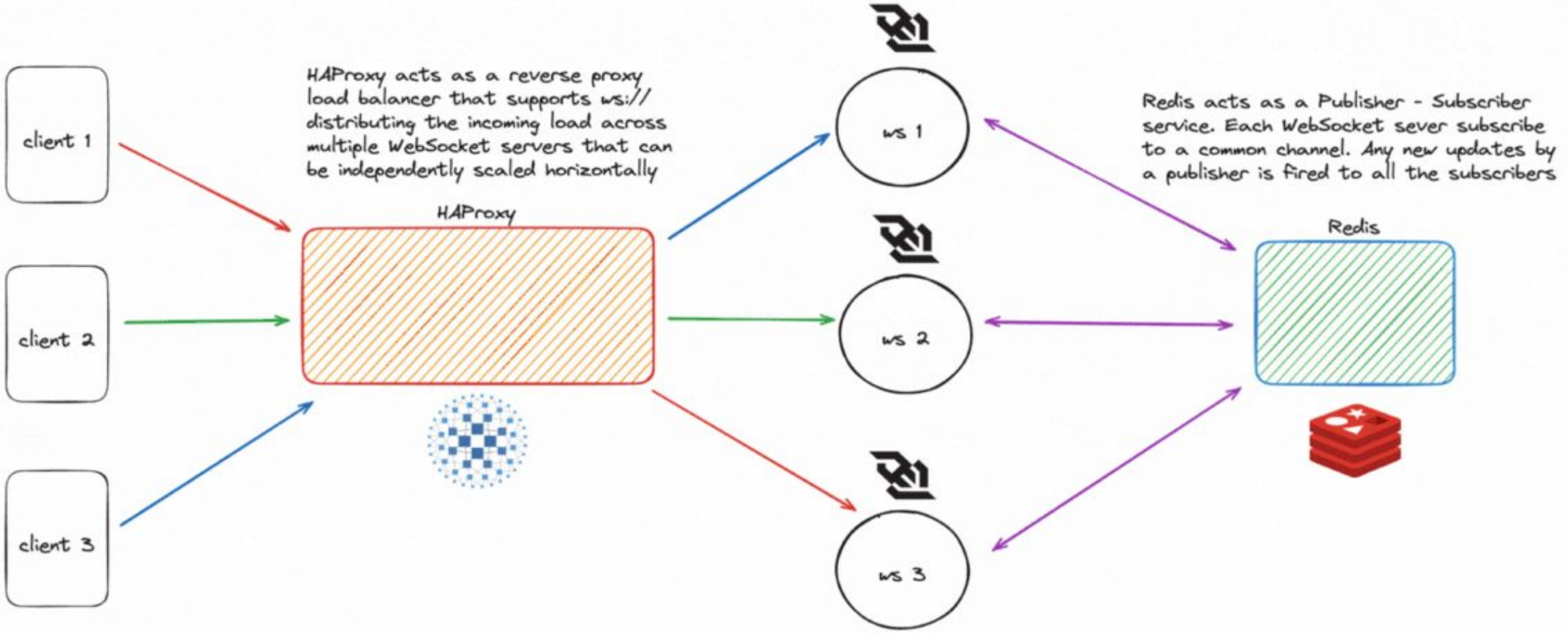
The Architecture



The Architecture



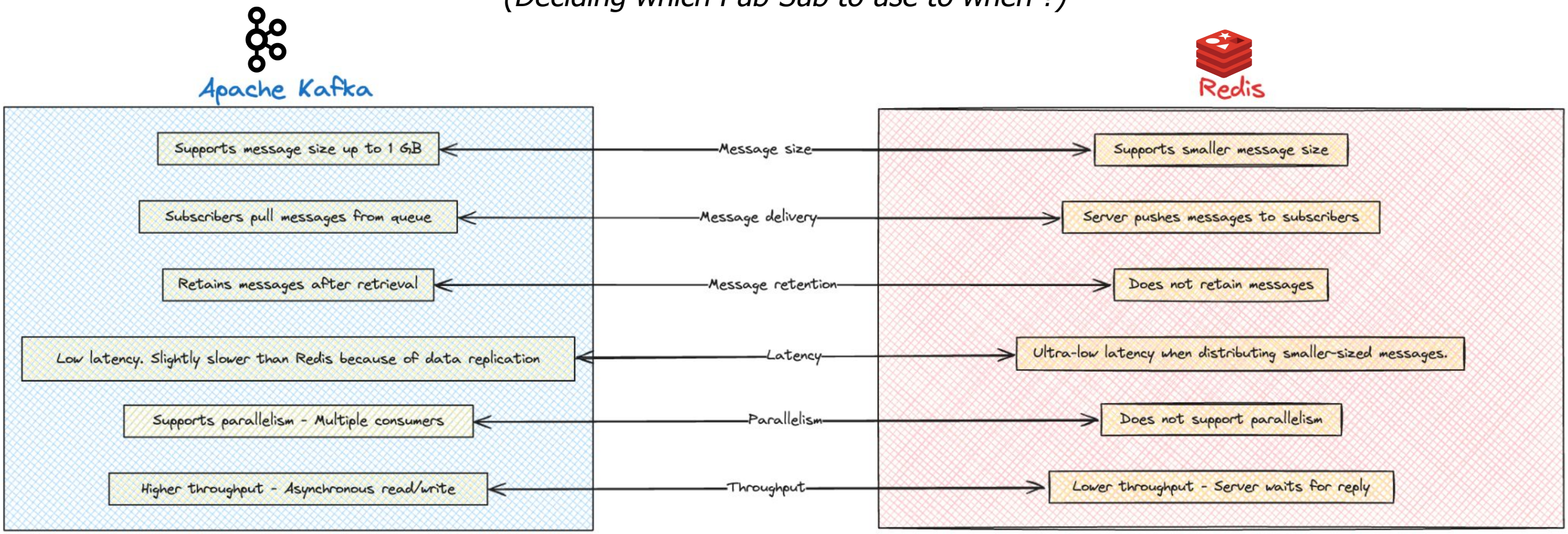
The Architecture



https://aws.amazon.com/compare/the-difference-between-kafka-and-redis/

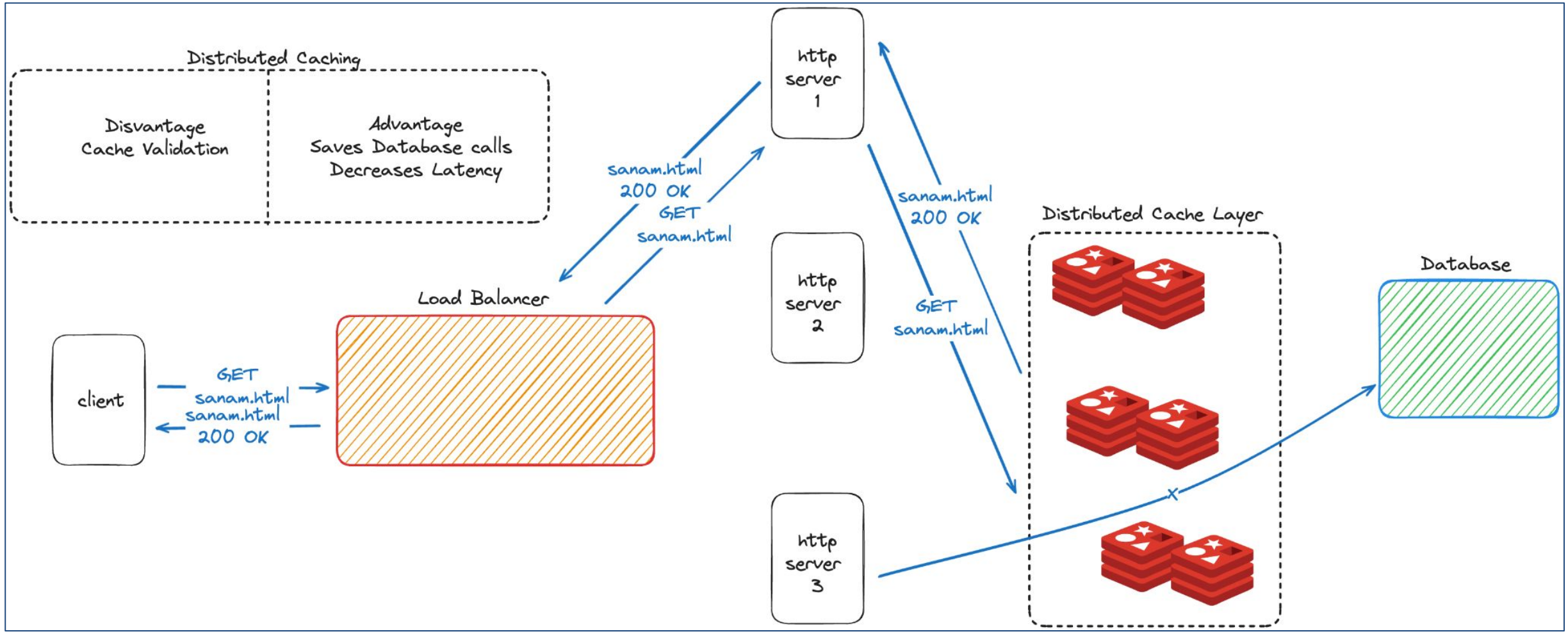
Redis v/s Kafka

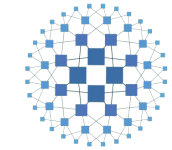
(Deciding which Pub-Sub to use to when ?)



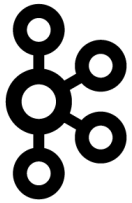
https://redis.io/glossary/distributed-caching/

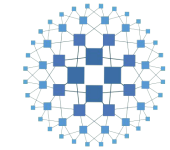
Distributed Caching





Conclusion



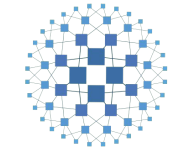


Conclusions

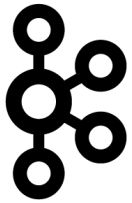
- A single WebSocket connection is blocking in nature and highly resource intensive

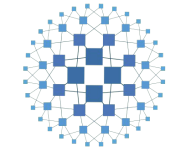
- WebSocket cannot be scaled vertically due to hardware limitations

- Horizontal scaling is only possible across multiple WebSockets if the incoming load can be balanced to multiple servers using a *Reverse Proxy* and all of them maintain a common state through a *Pub-Sub* mechanism



Limitation



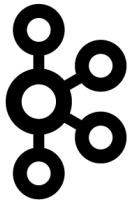


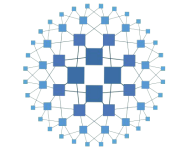
Limitations

- Maintaining a common state across all the WebSockets is hard to implement

- In case of frequent state updates and concurrent access to shared resources may lead to race conditions

- Employing synchronization mechanisms such as mutexes, semaphores, or atomic operations to coordinate access to shared resources need to be employed when dealing with distributed systems leading to higher latency





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- https://datatracker.ietf.org/doc/html/rfc6455
- https://www.haproxy.org
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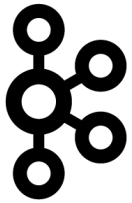

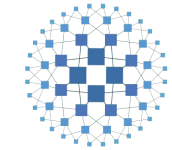

Thank you

https://github.com/akarmanya/wscale

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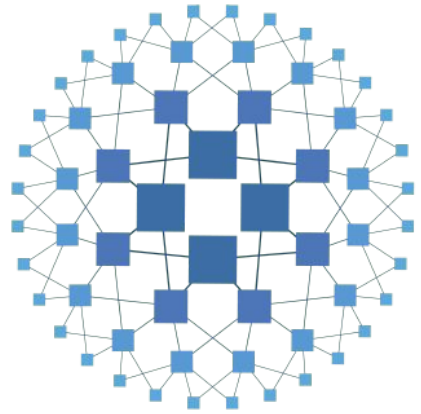

Questions ?