Weaponizing Middleboxes for TCP Reflected Amplification

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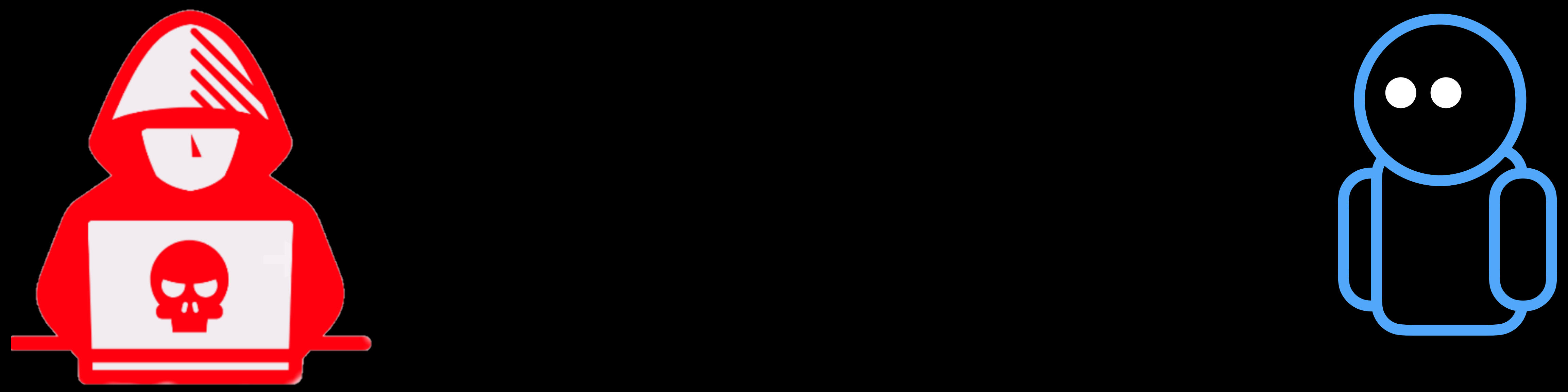
Denial of Service attacks



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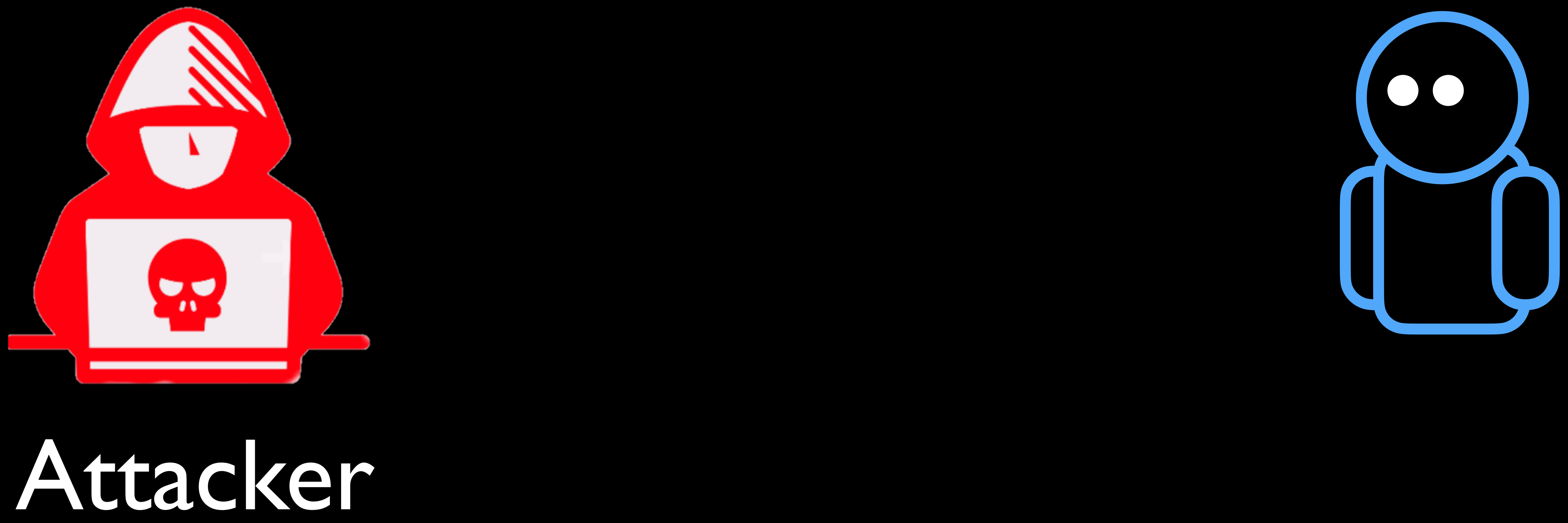
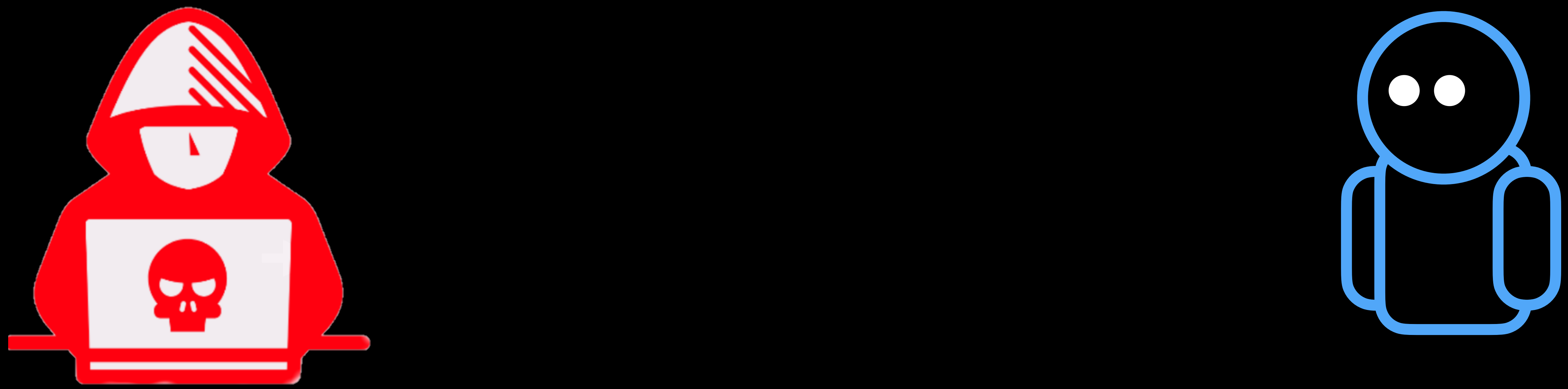


Attacker

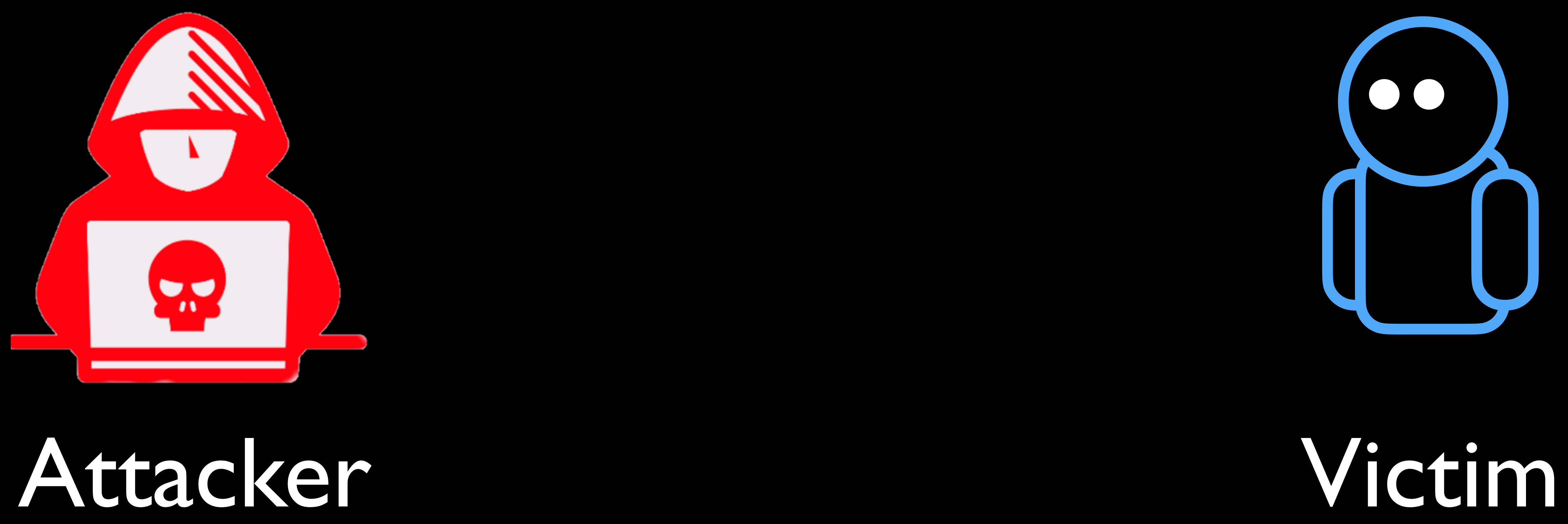
Denial of Service attacks



Attacker

Victim

Denial of Service attacks



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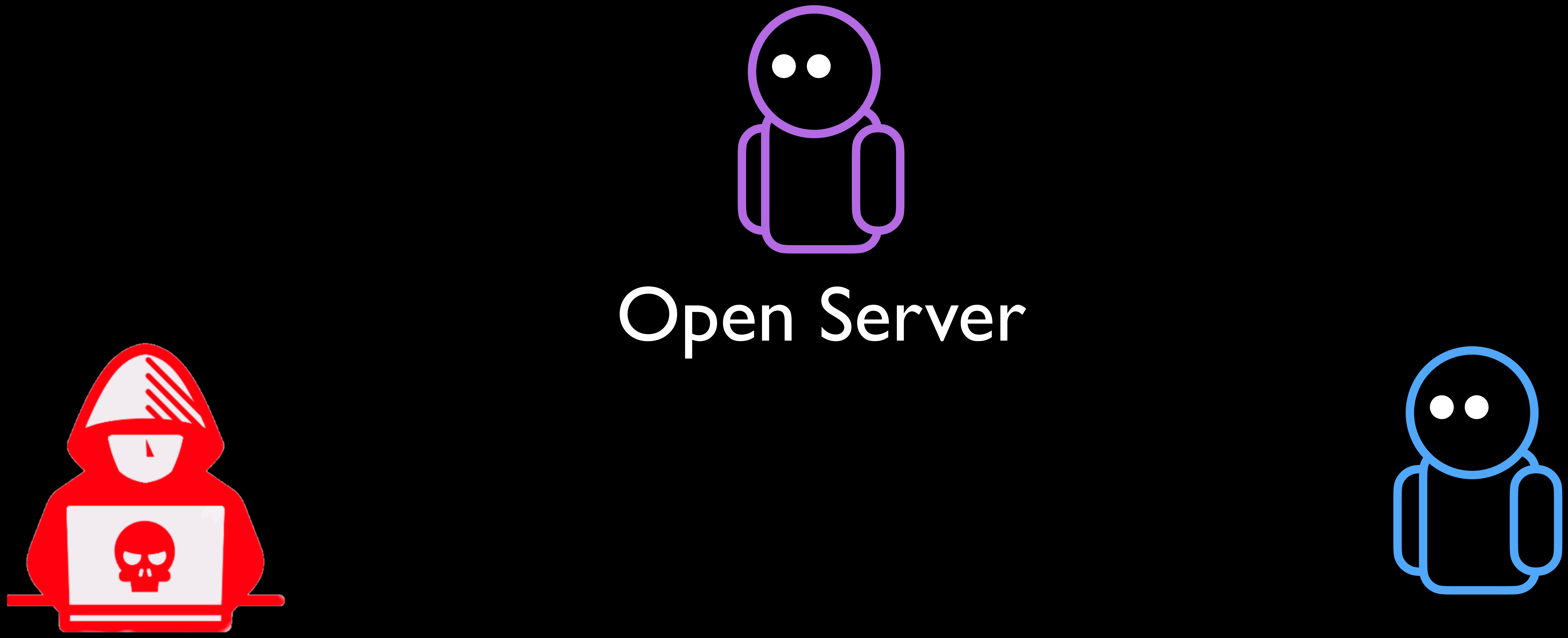
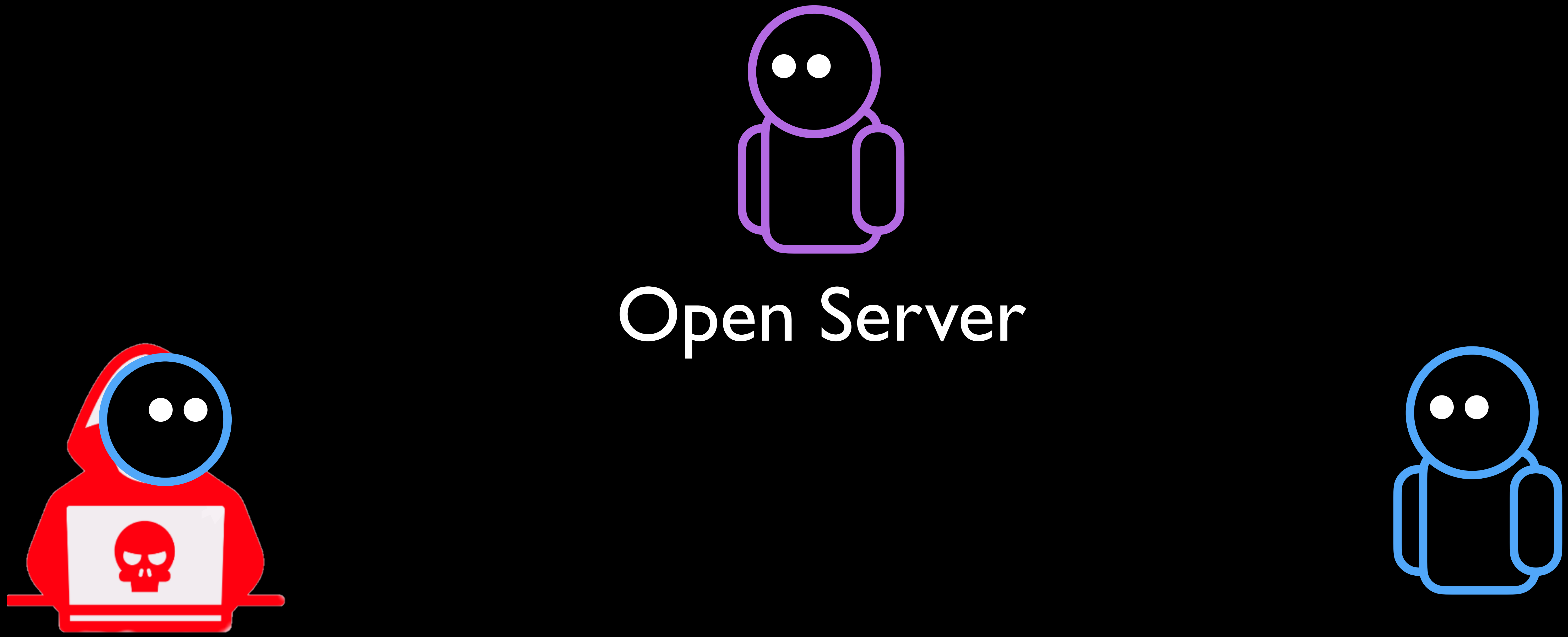
Reflected amplification attacks



Open Server

Reflected amplification attacks



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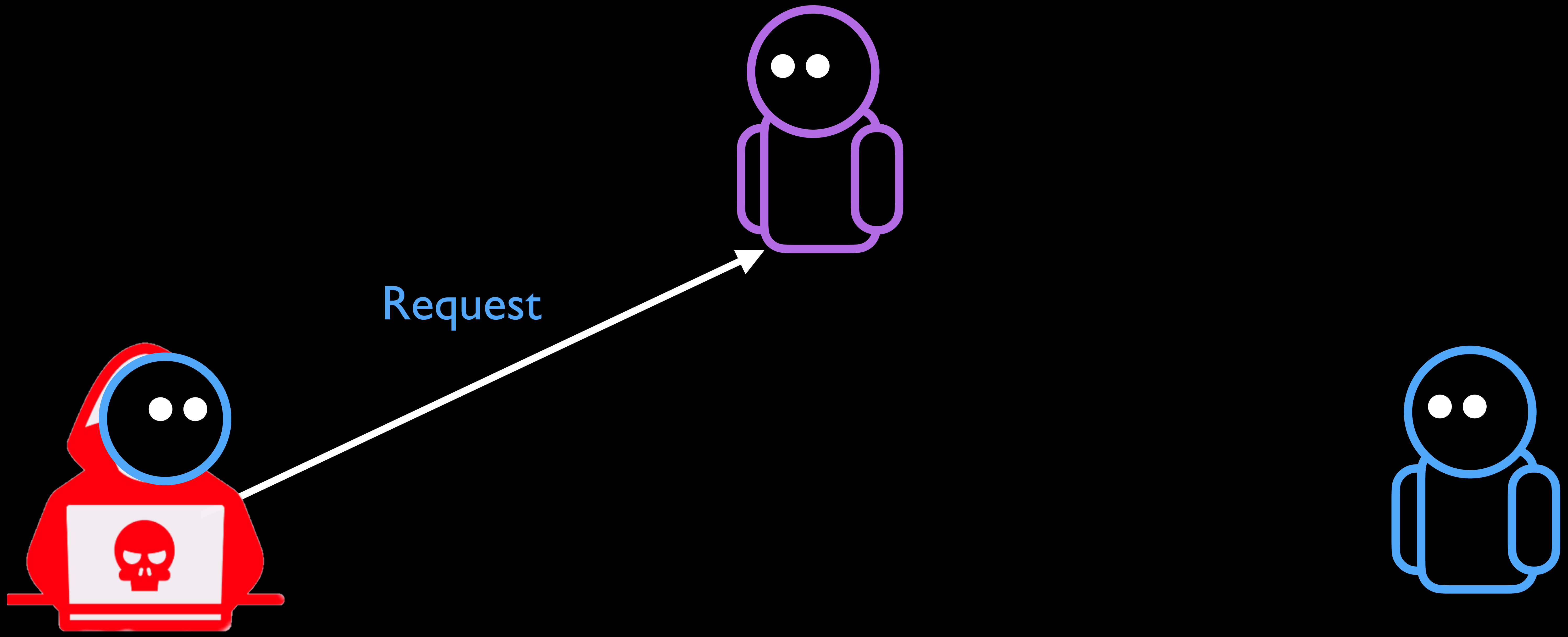

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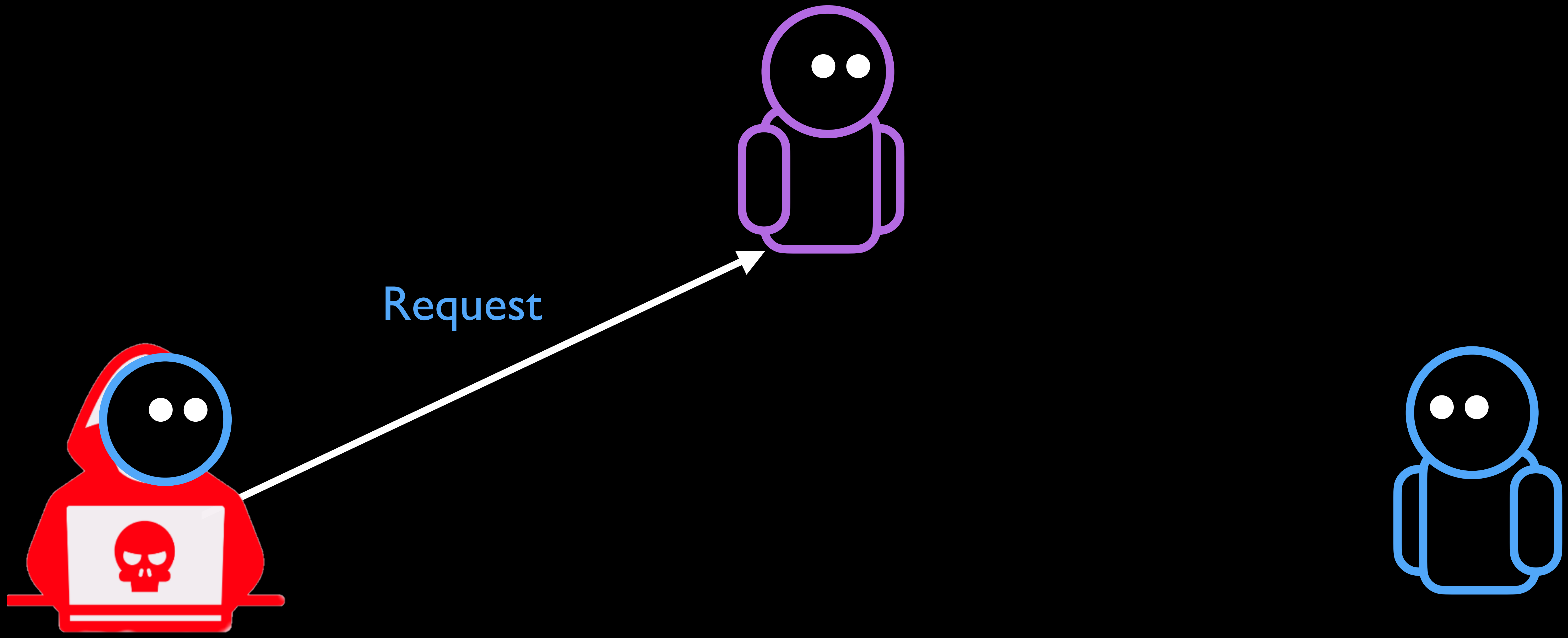

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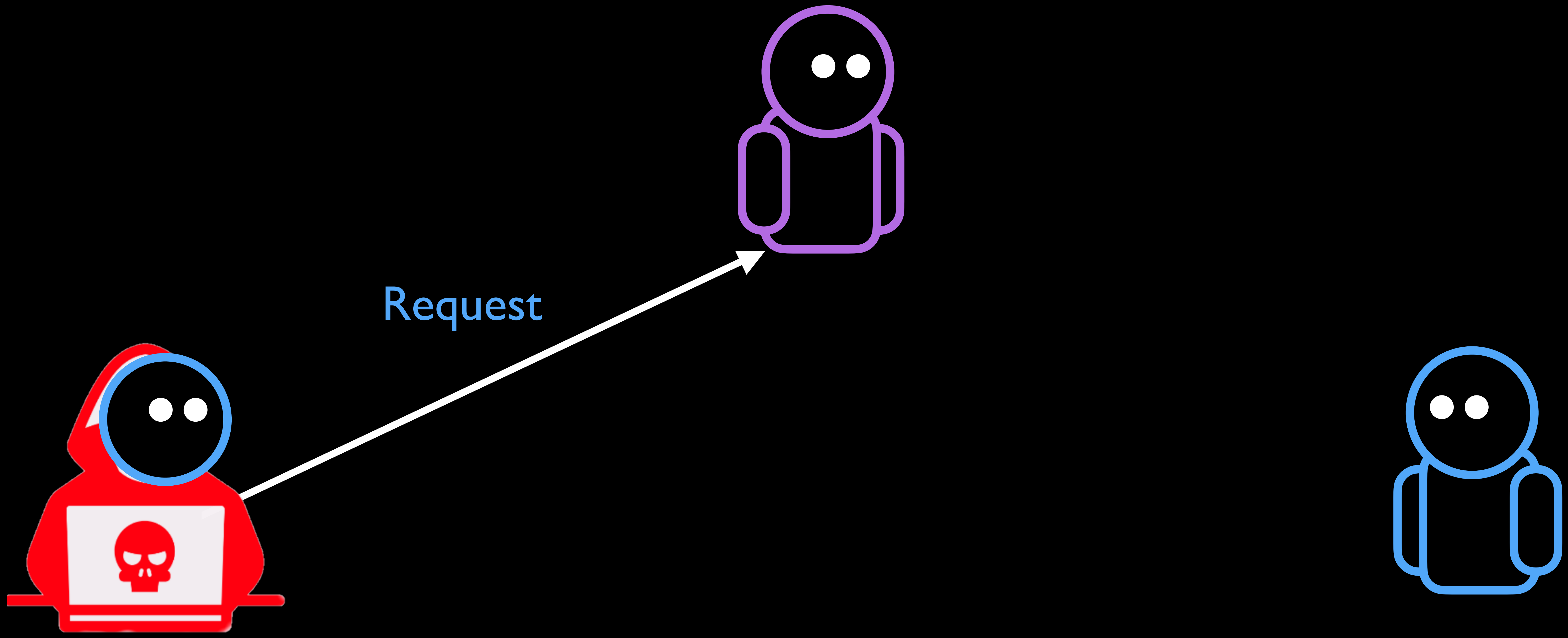

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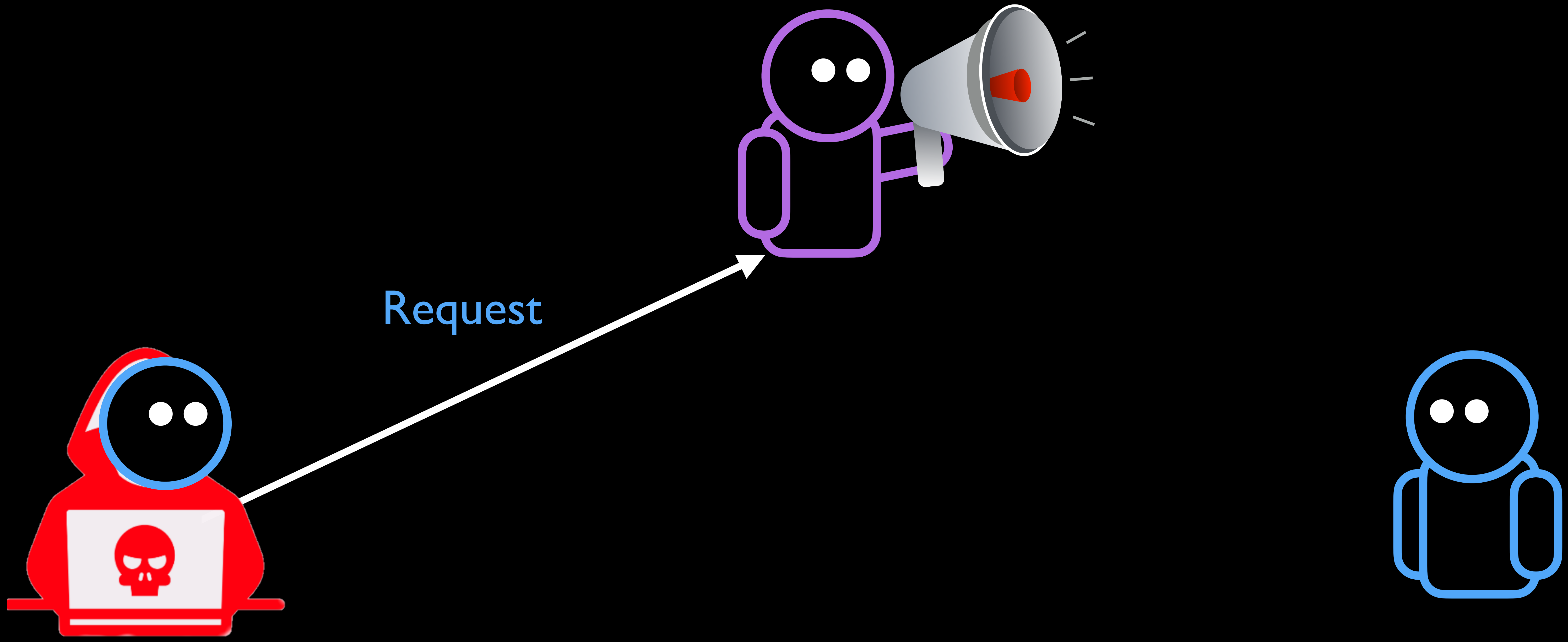

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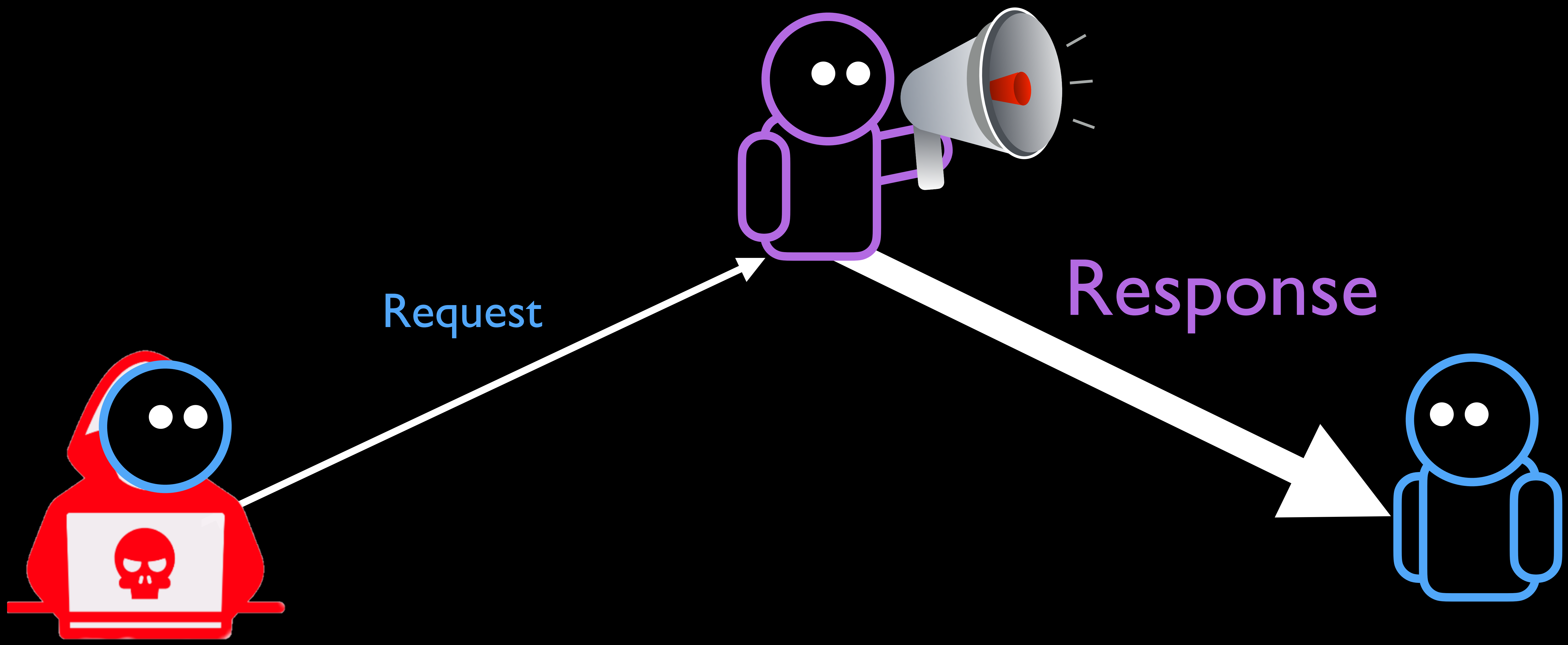

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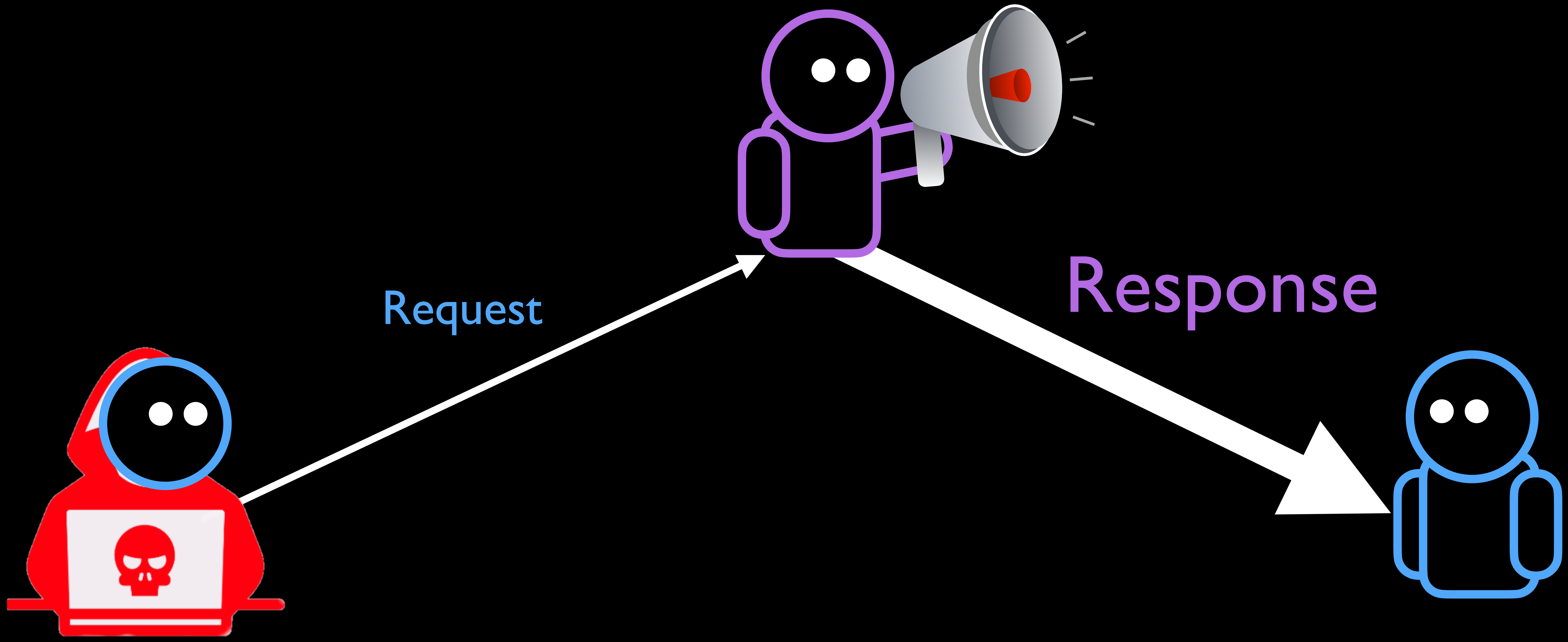

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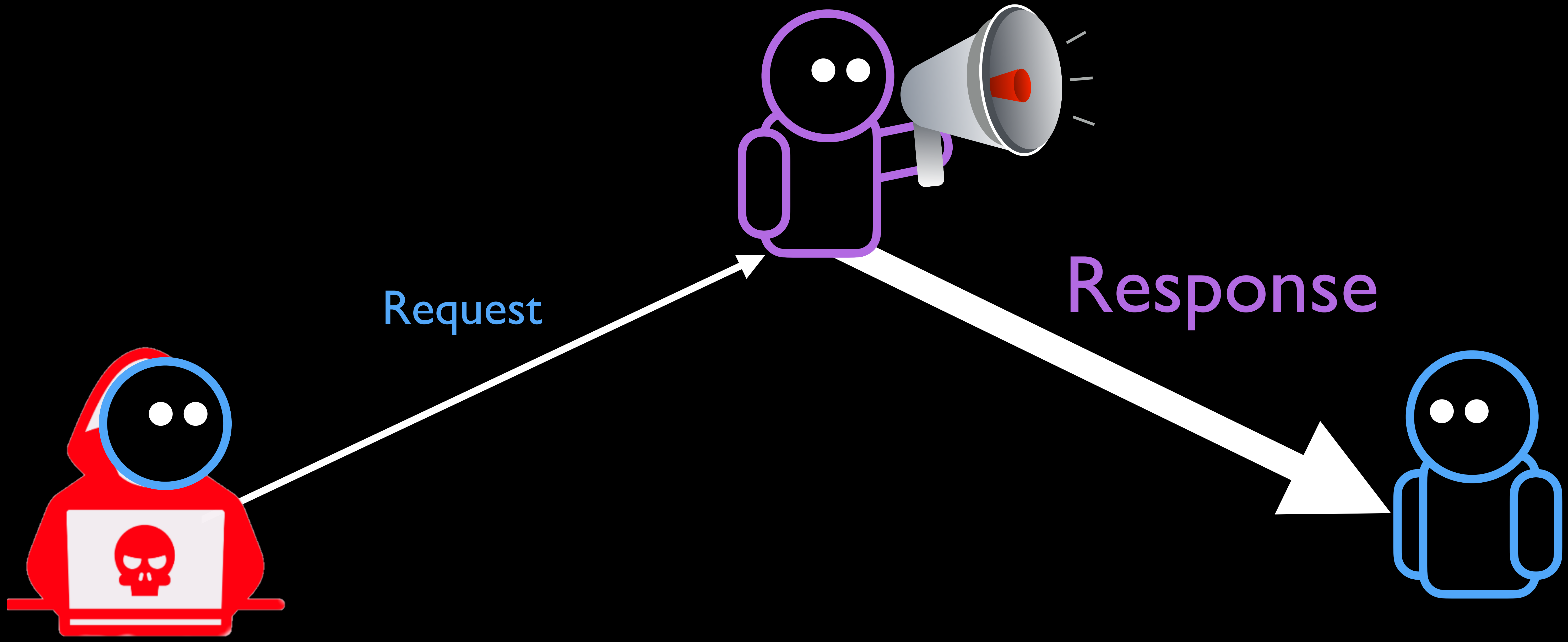

$$\text{Amplification factor} = \frac{|\text{Response}|}{|\text{Request}|}$$

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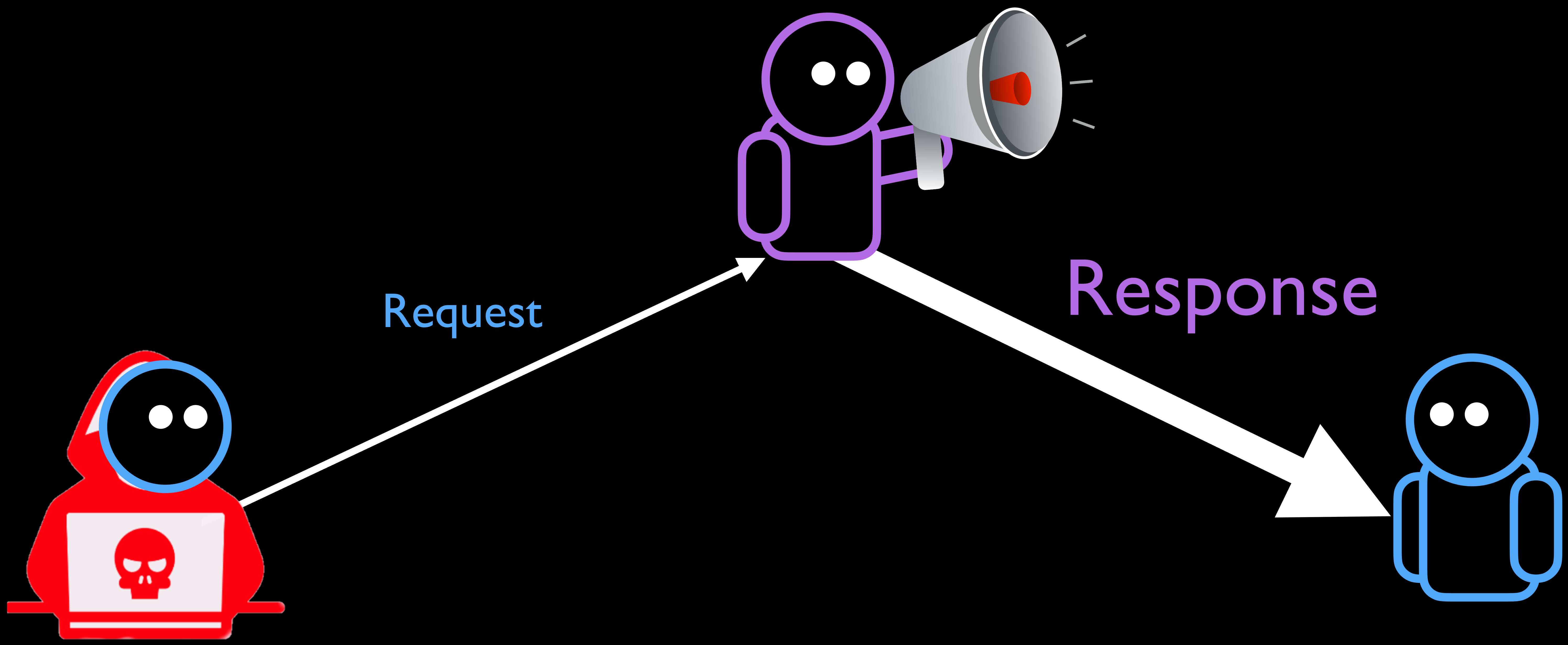

$$\text{Amplification factor} = \frac{|\text{Response}|}{|\text{Request}|}$$

54x	DNS
556.9x	NTP
51,000x	memcached

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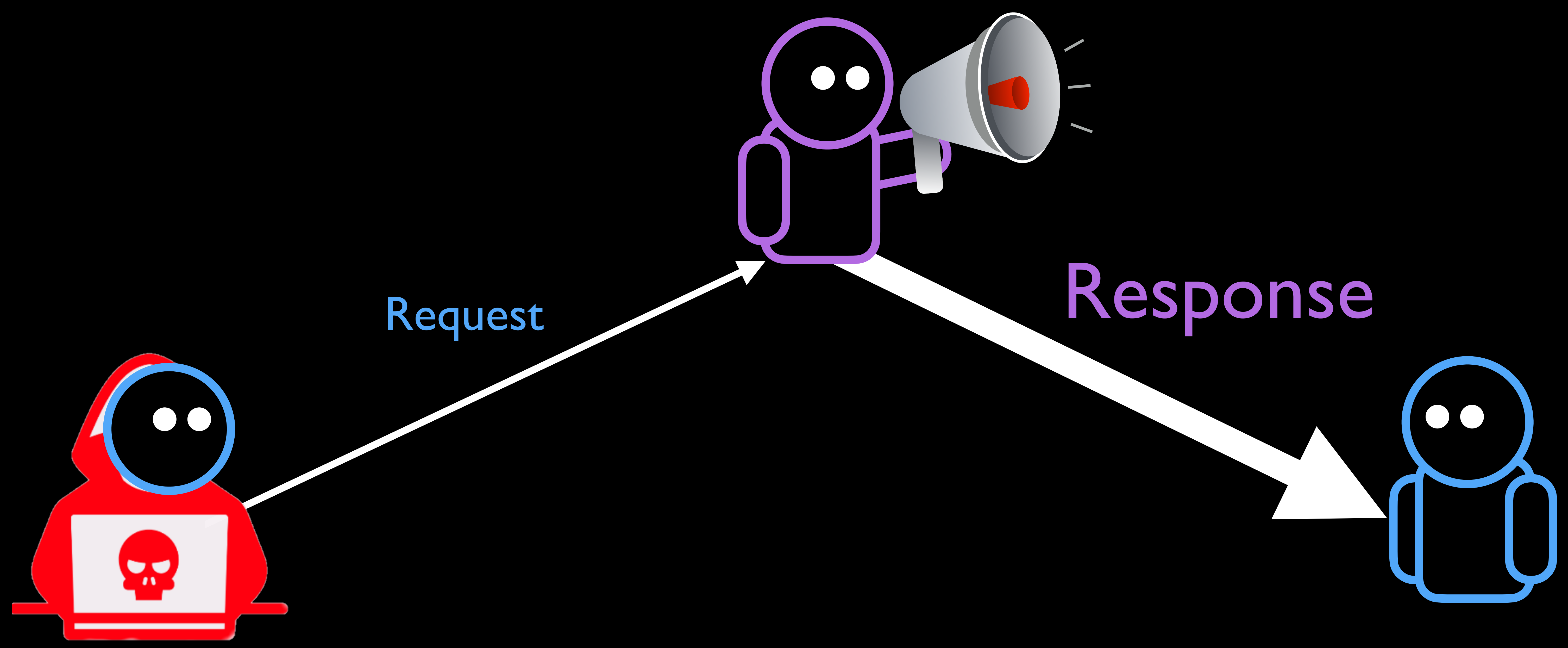

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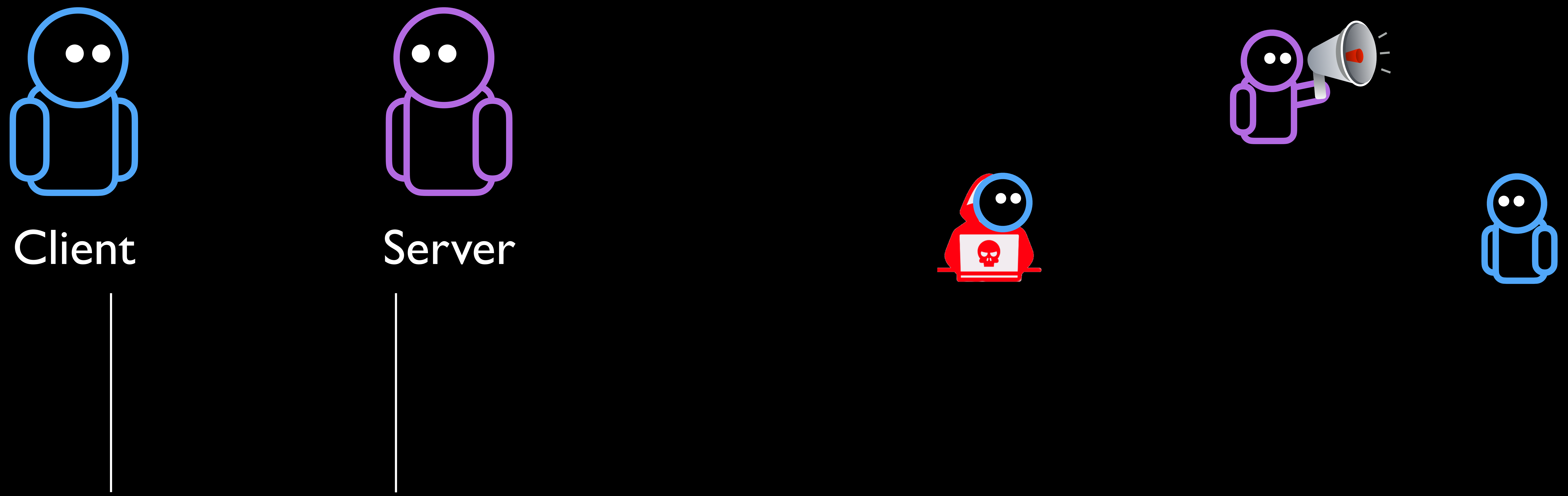
51,000x	memcached

Almost all prior reflected amplification attacks use UDP

Reflected amplification attacks

UDP is connection-less



Client

Server

Reflected amplification attacks

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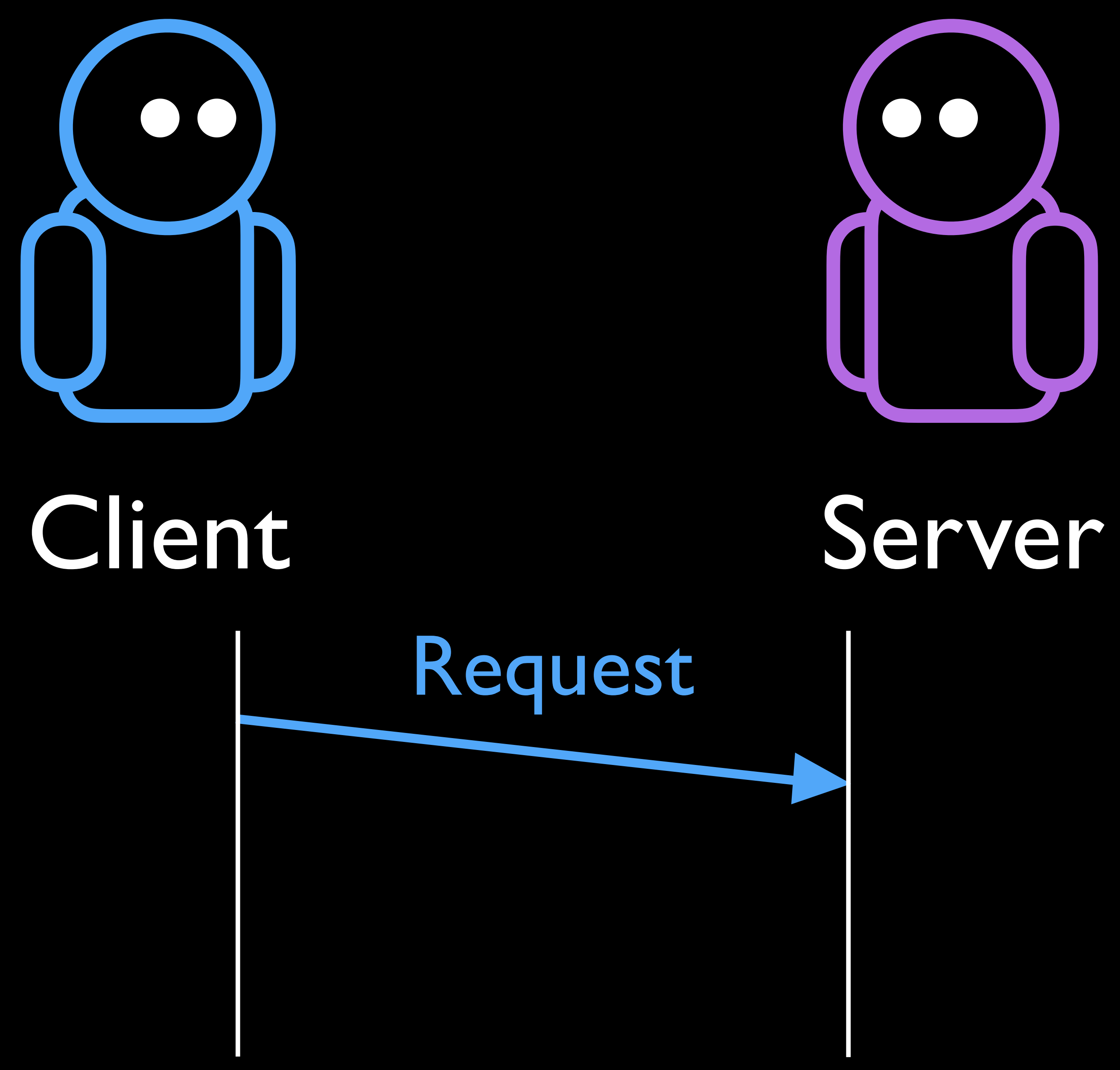

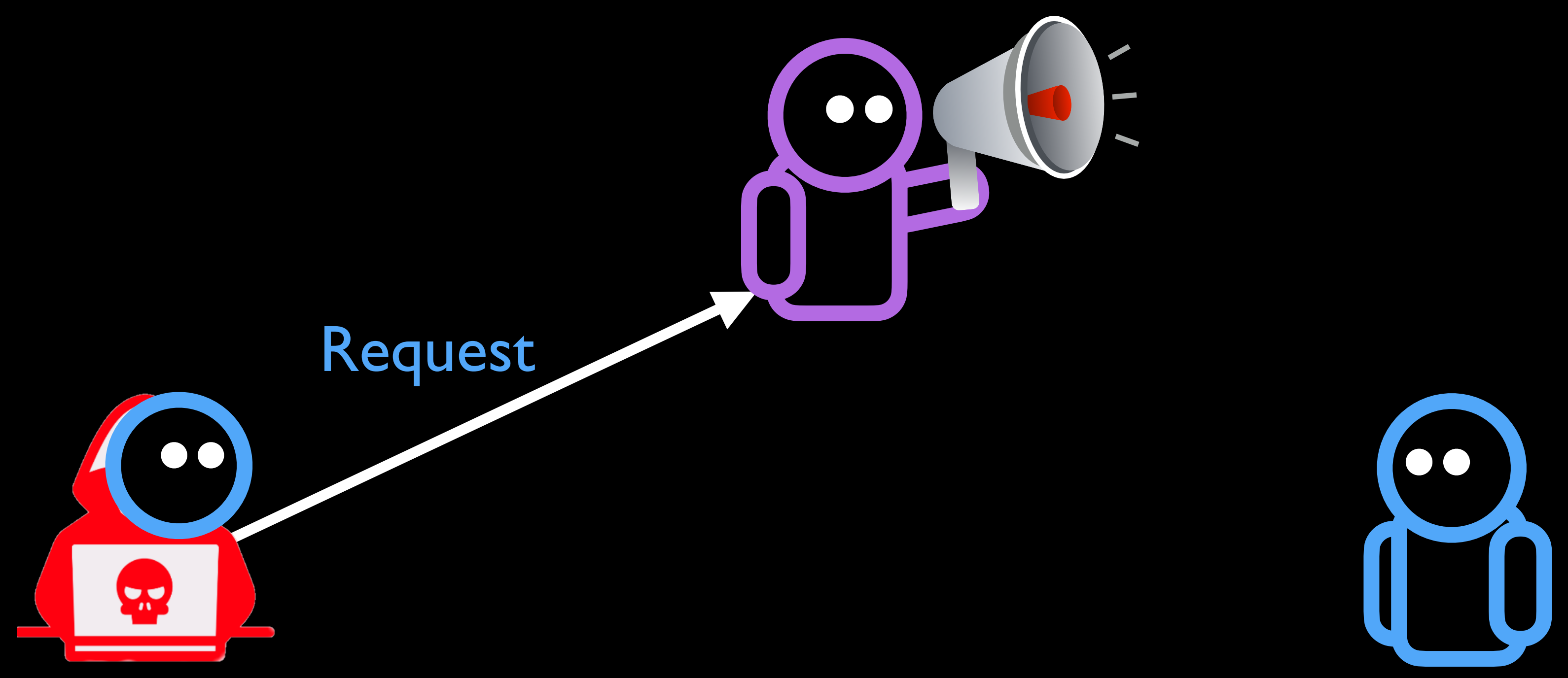

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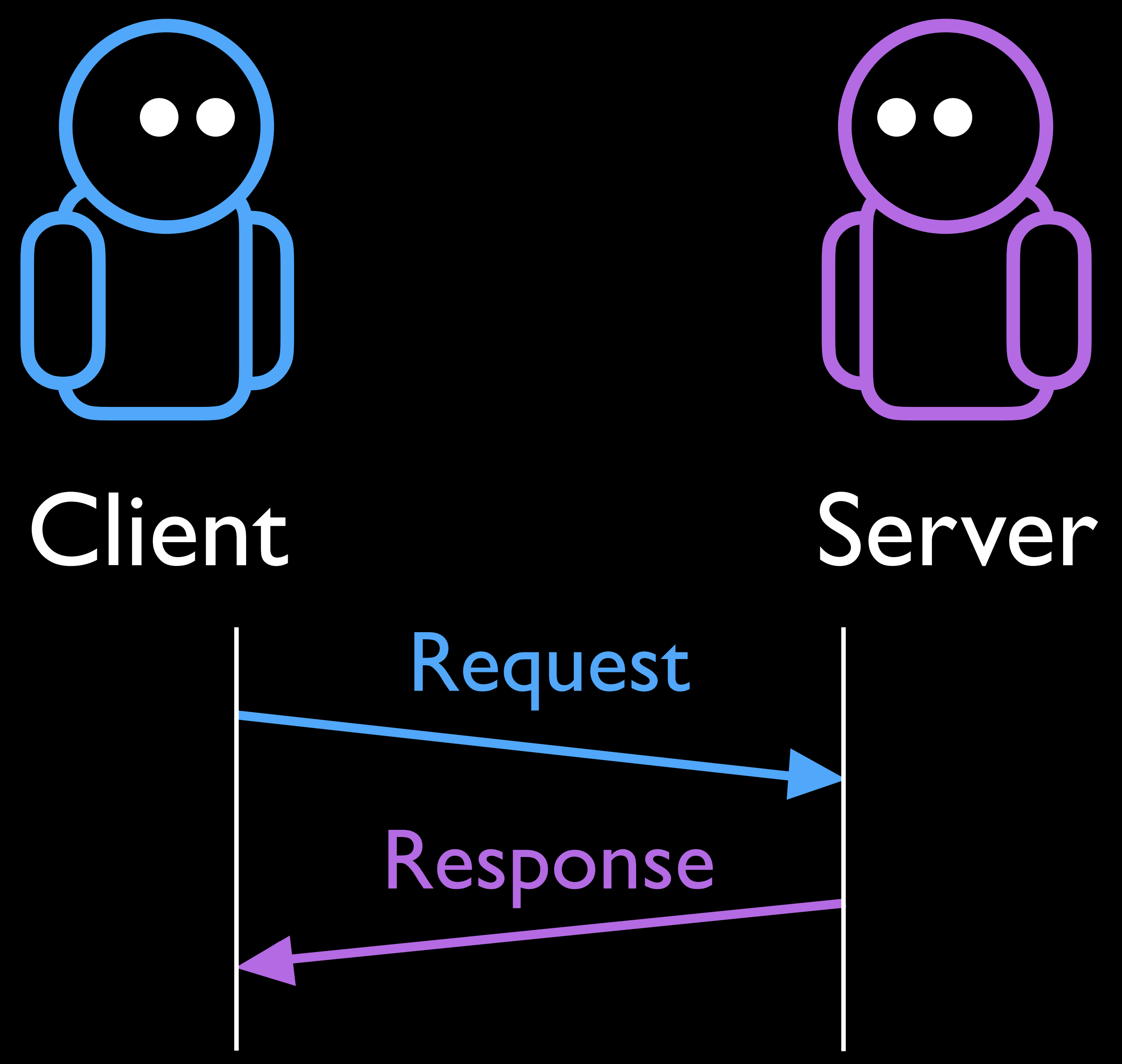
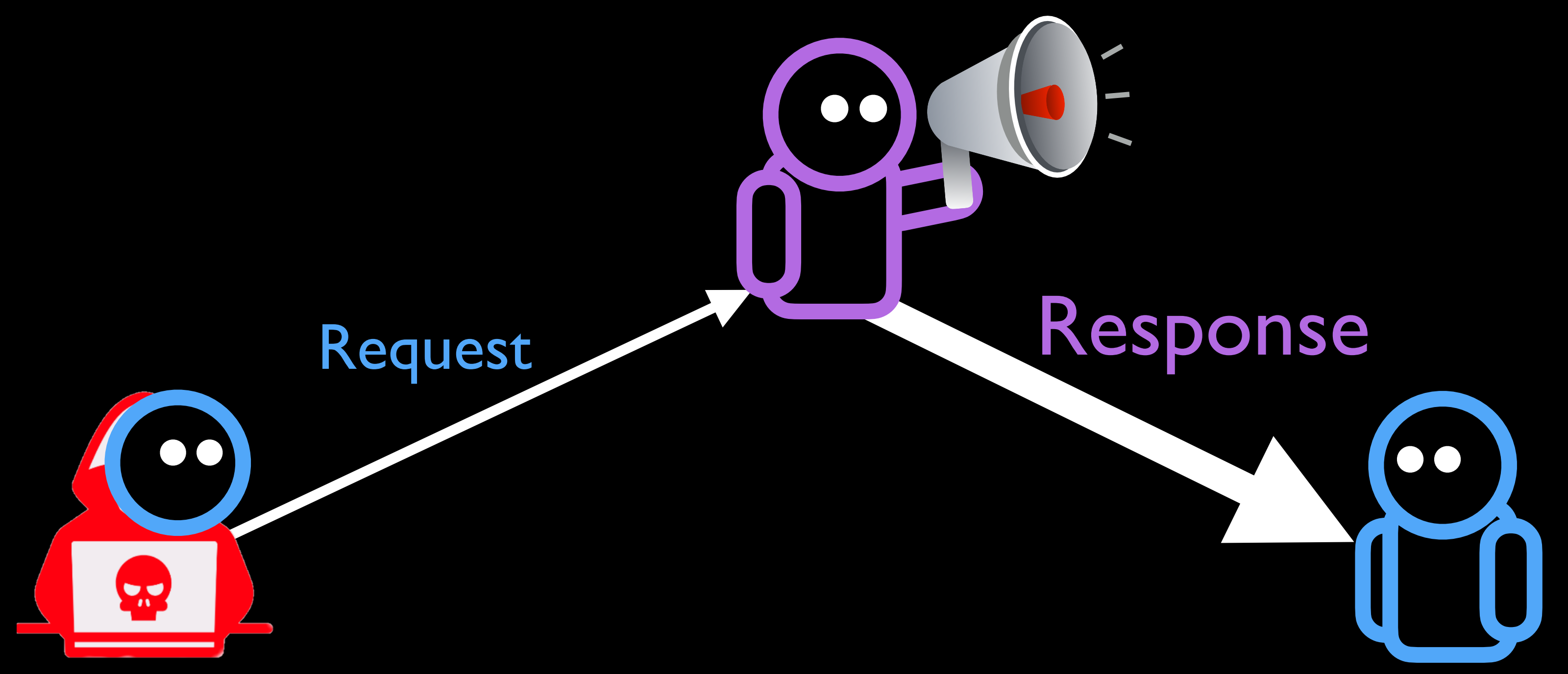
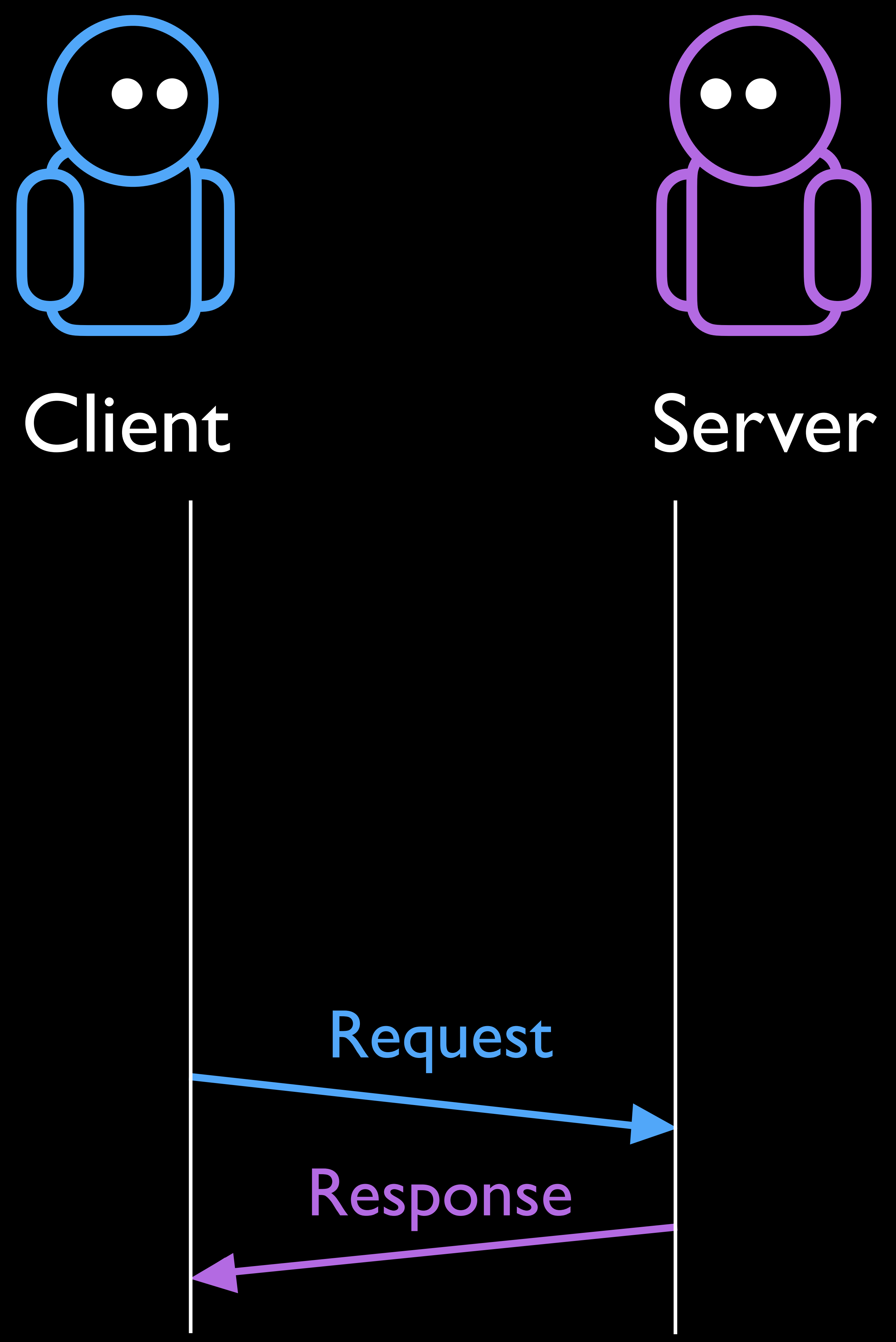
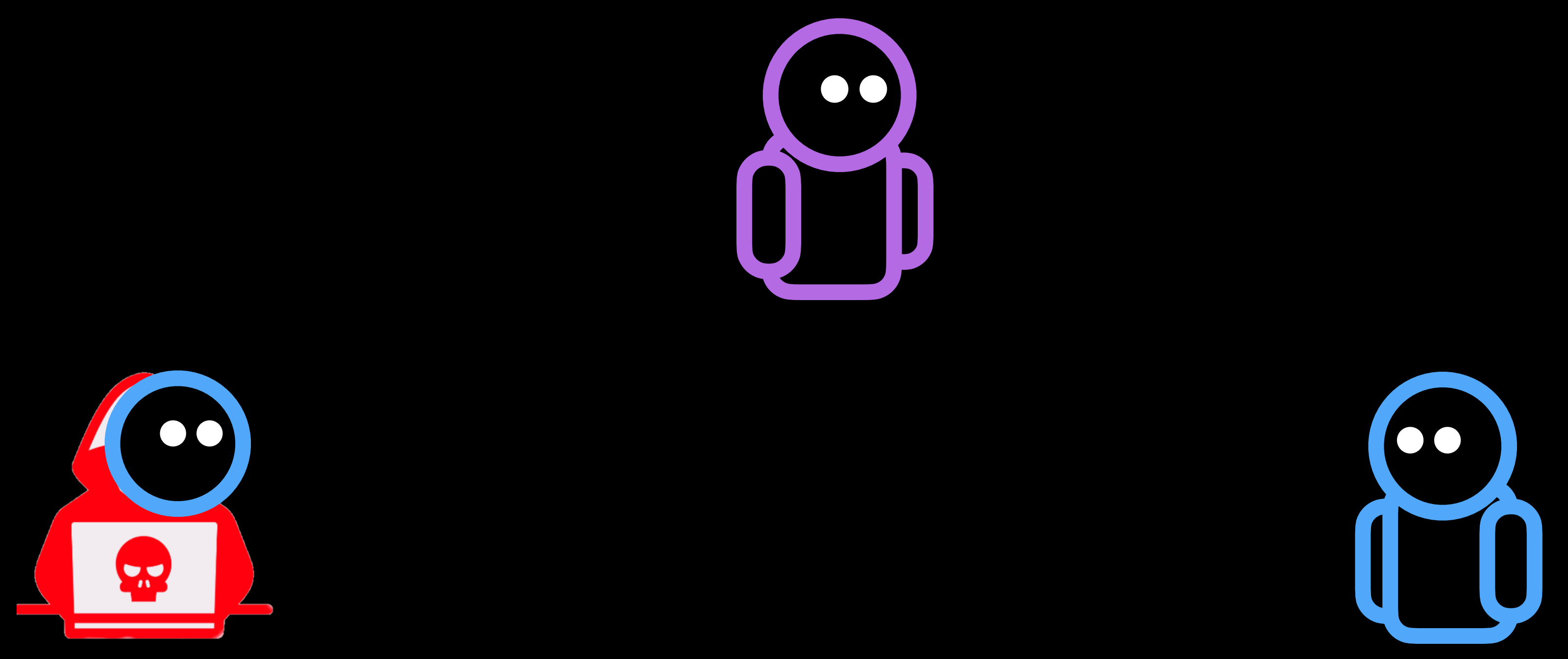




Reflected amplification attacks

TCP requires a threeway handshake





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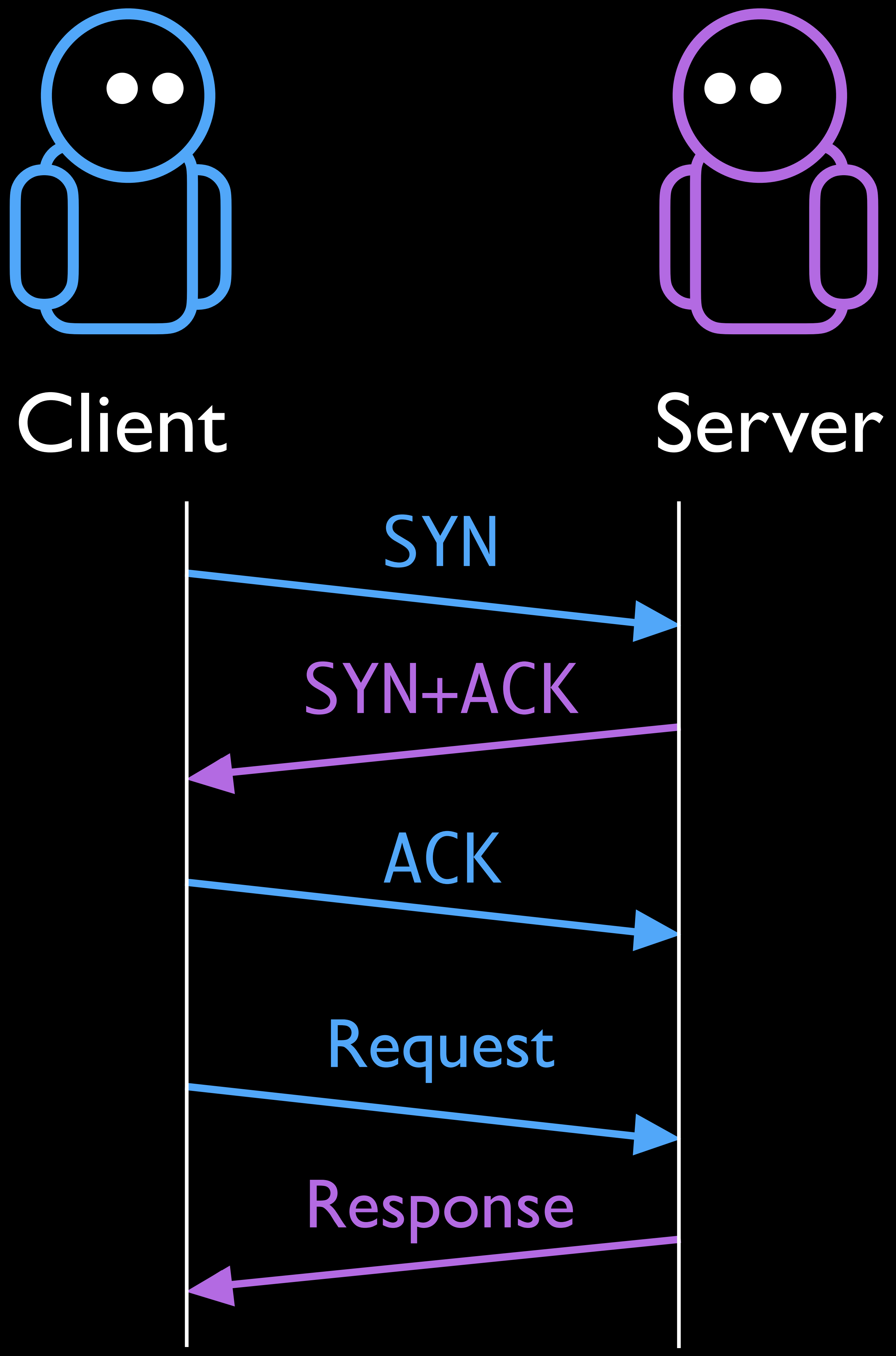

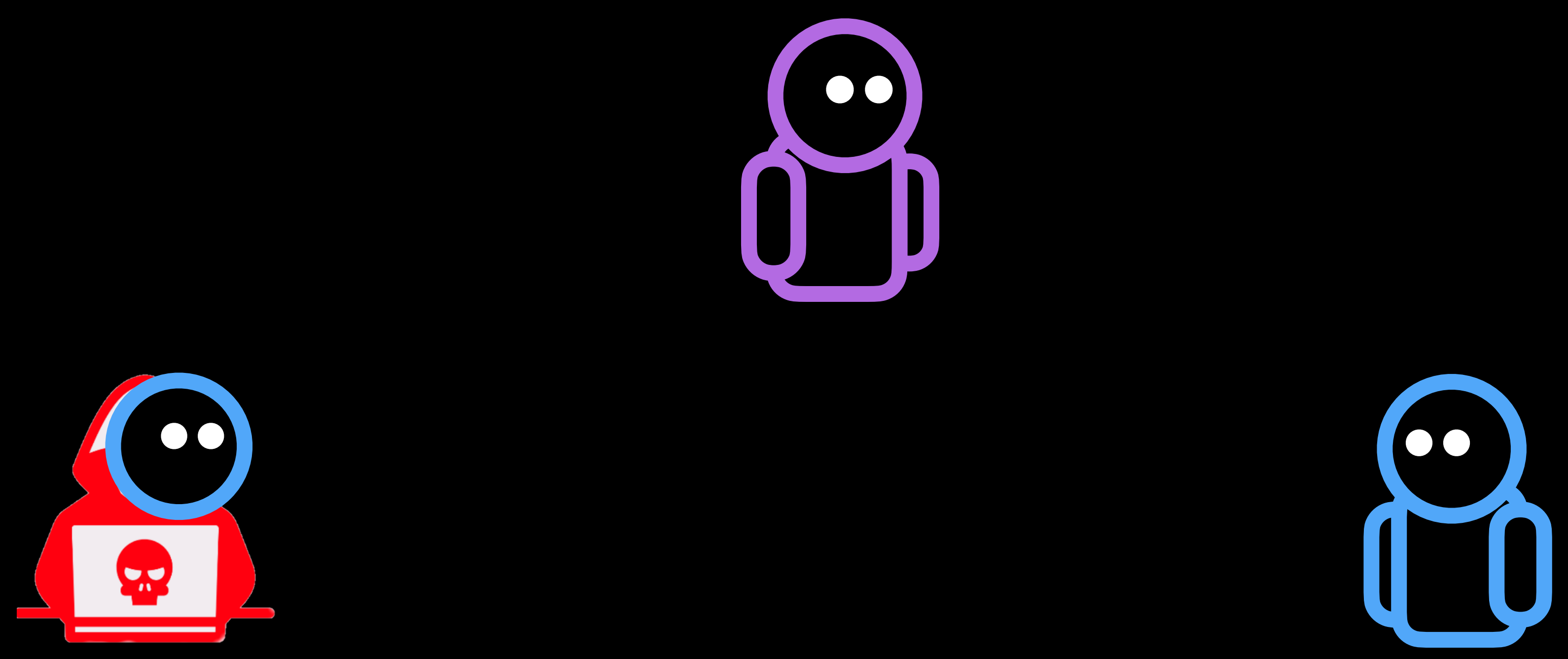

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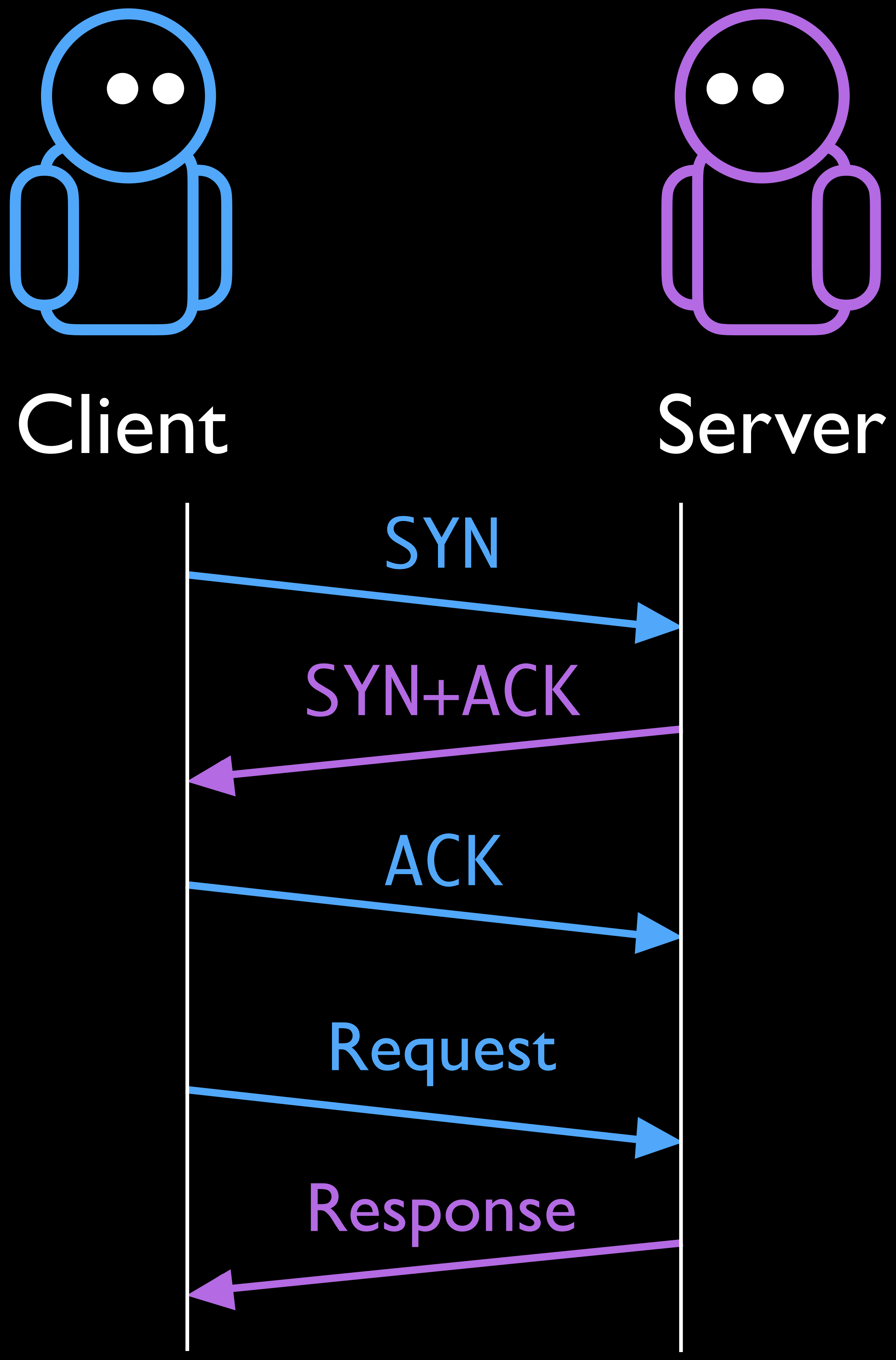

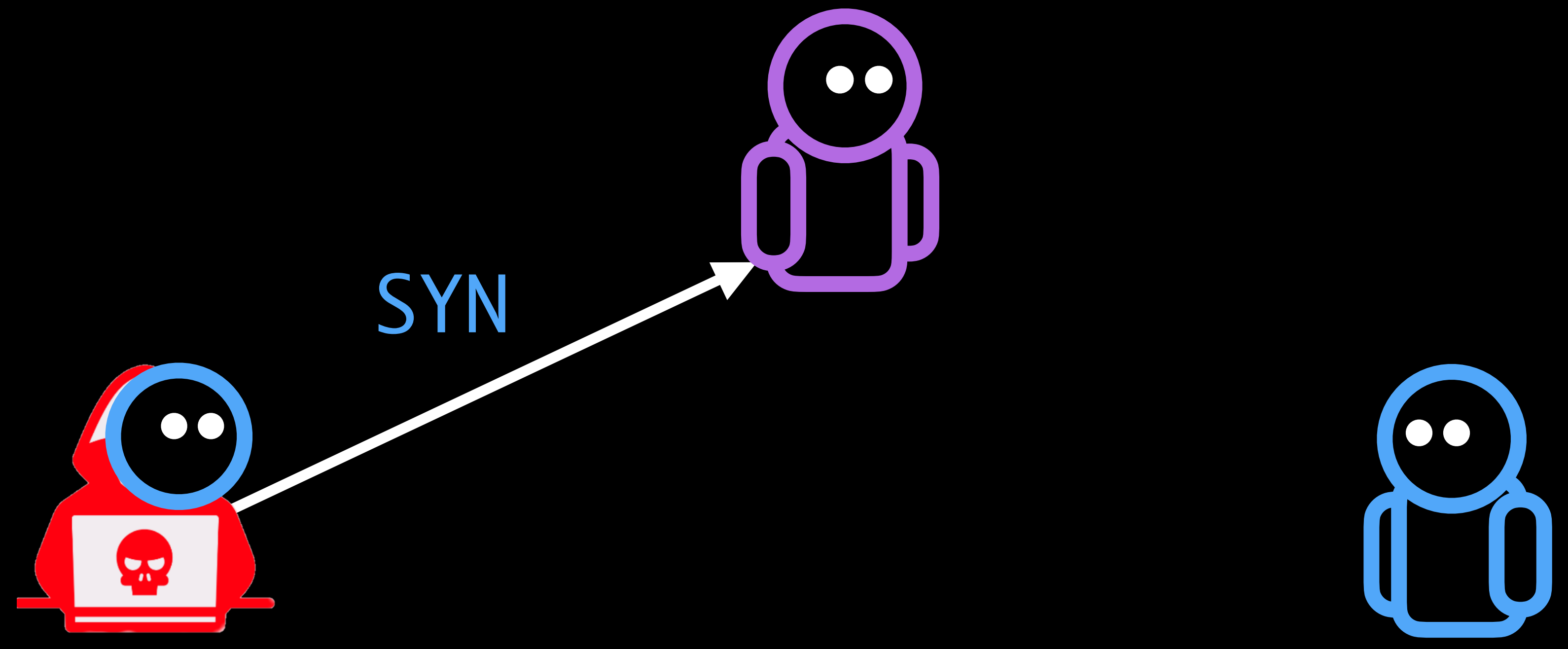

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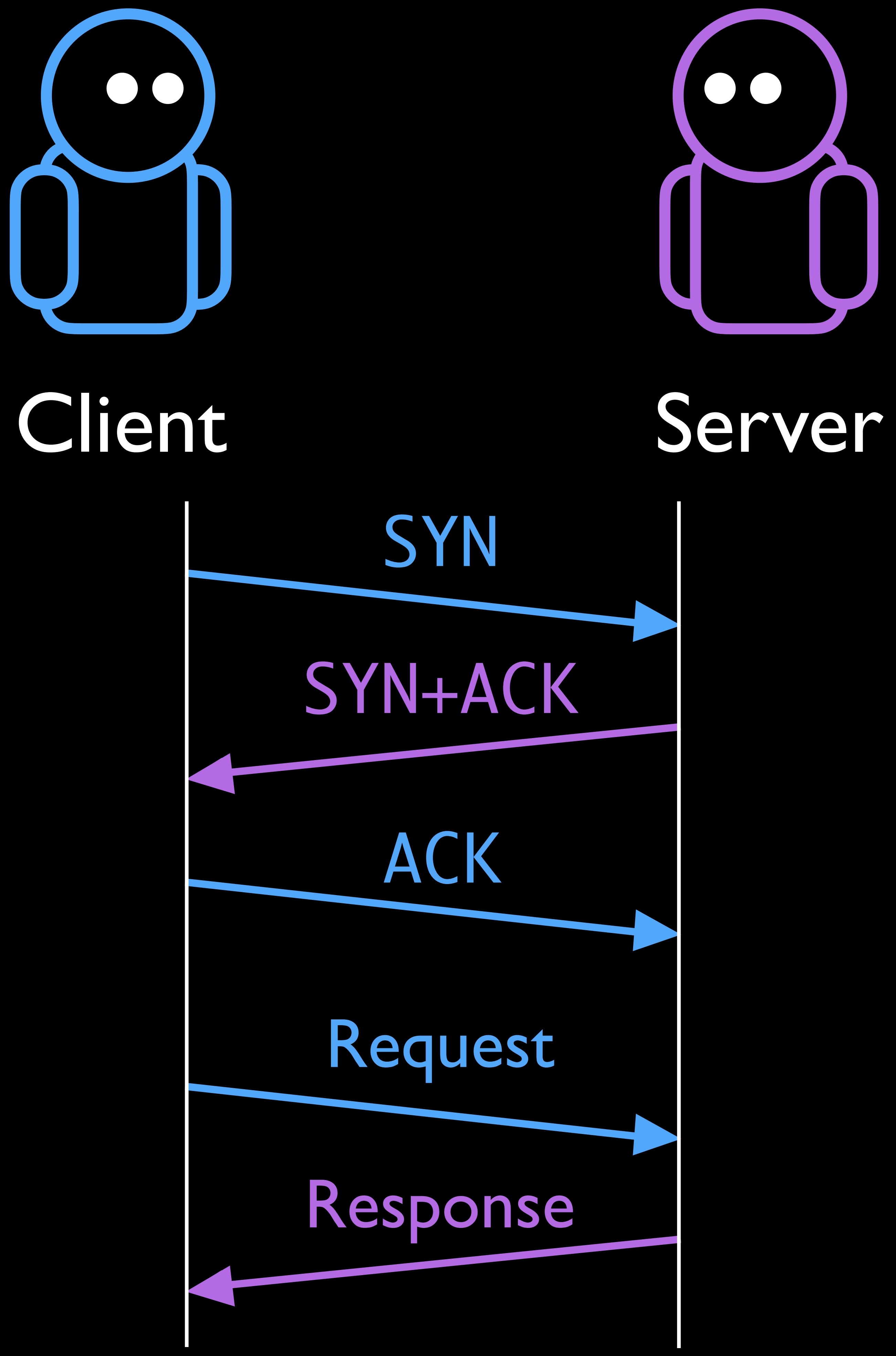

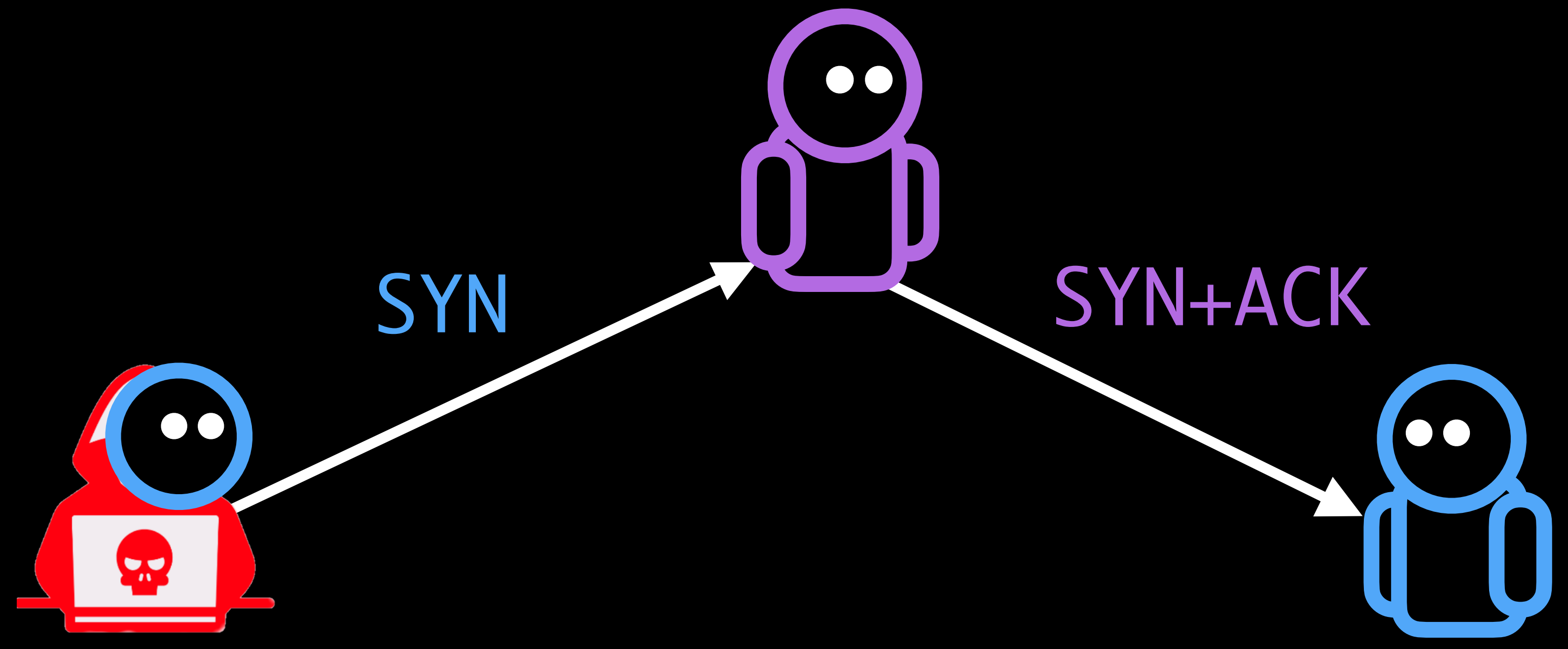

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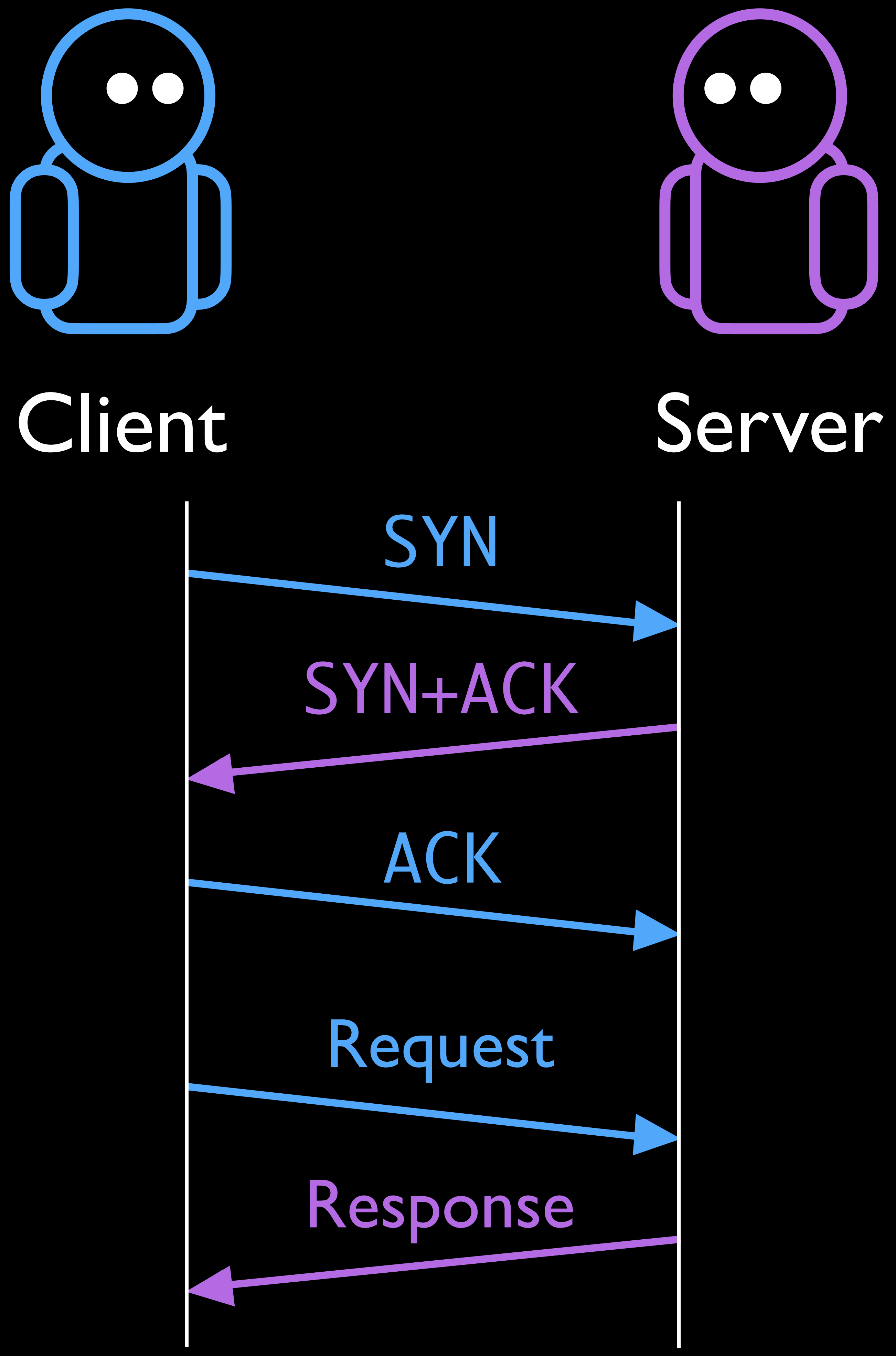

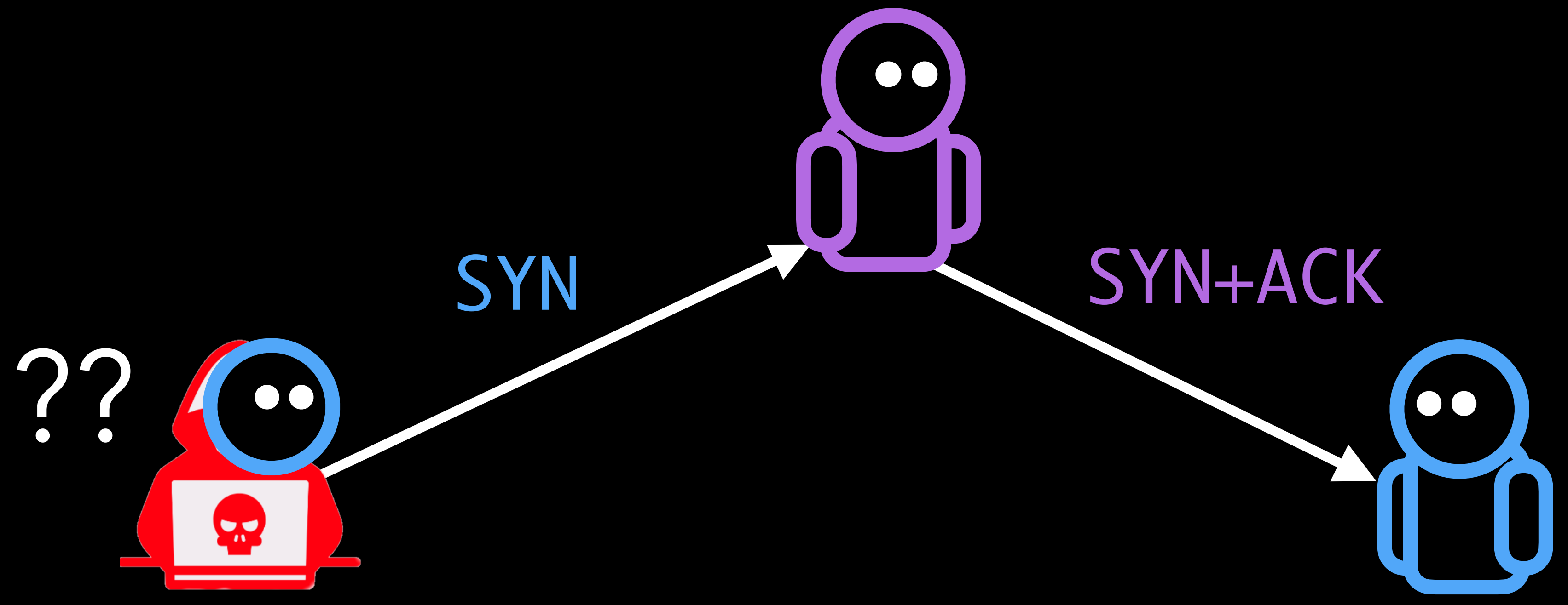

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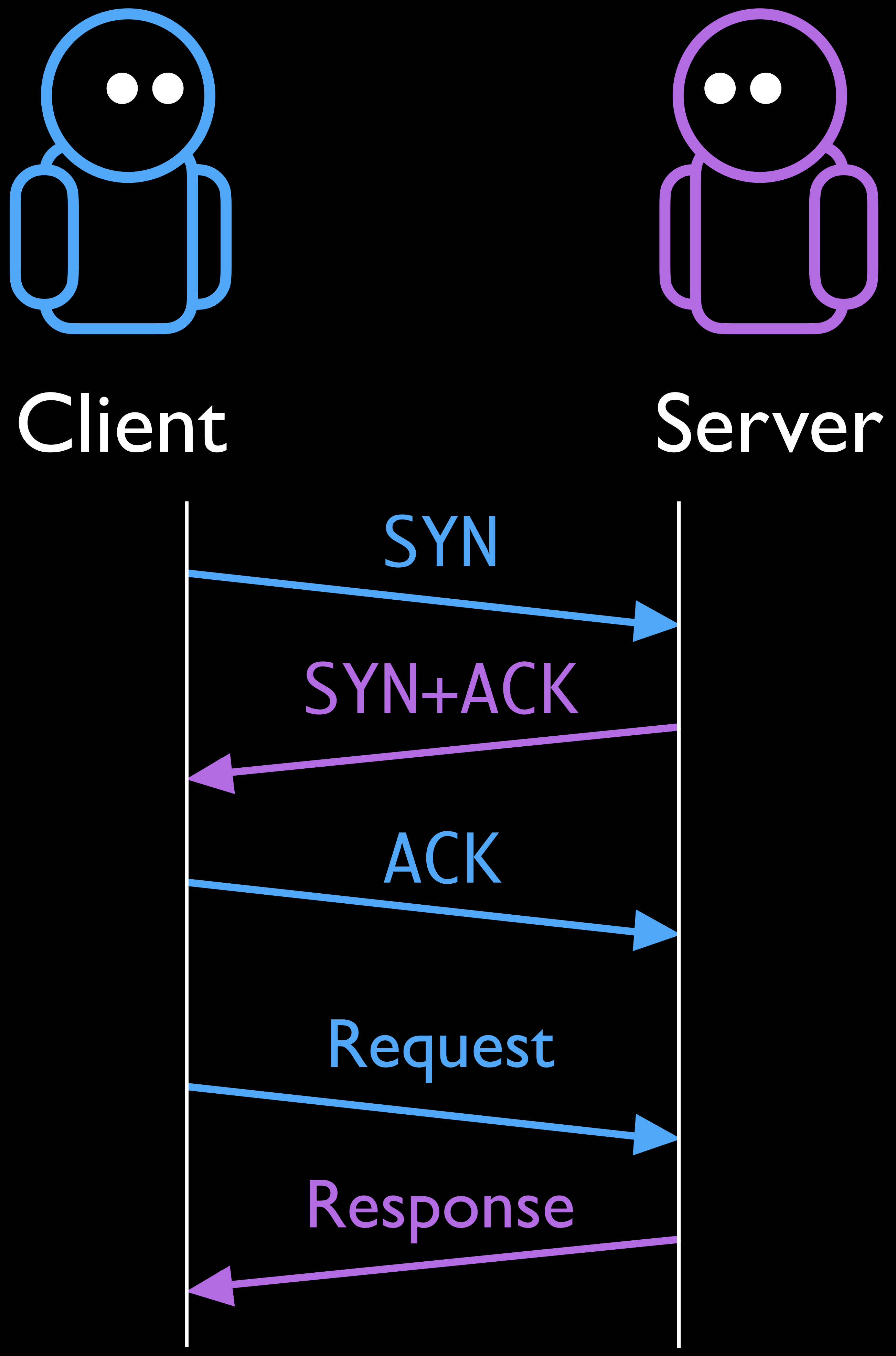

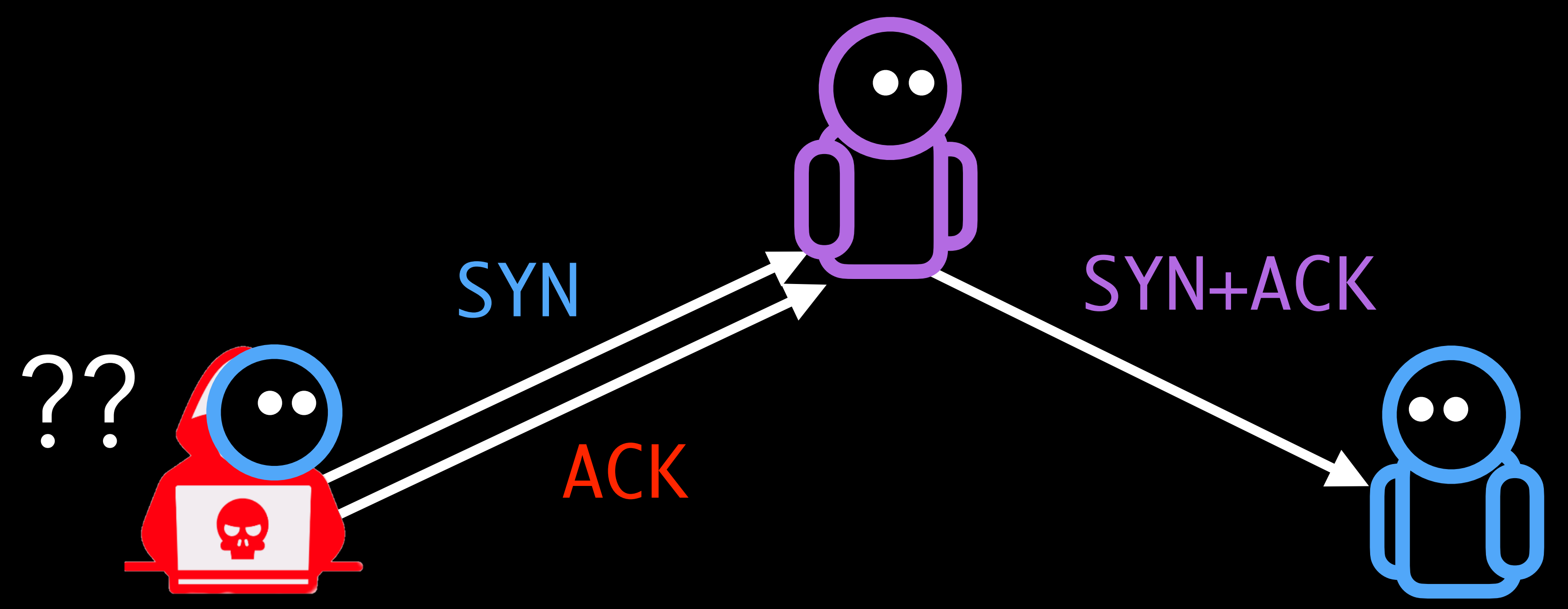

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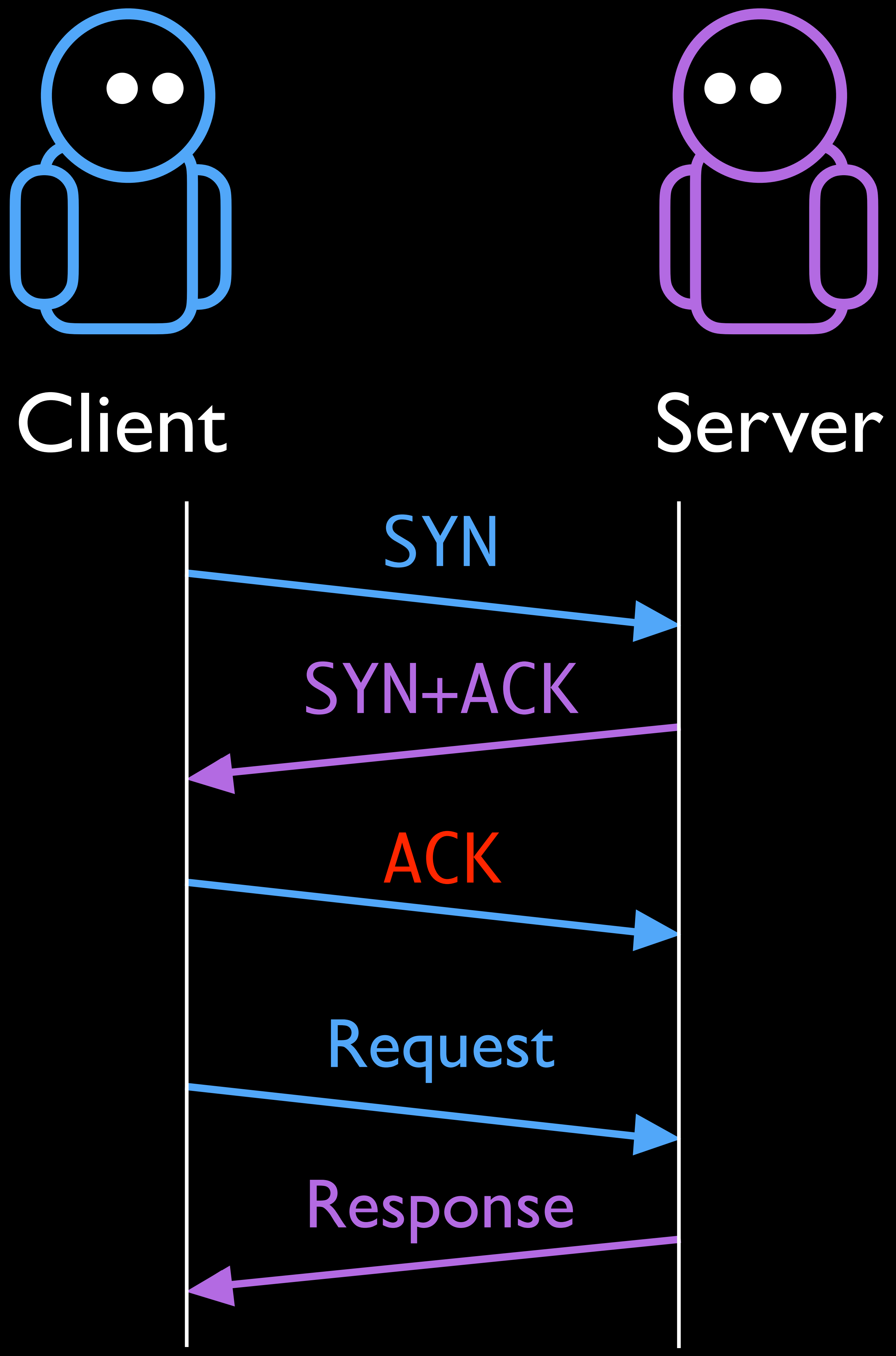

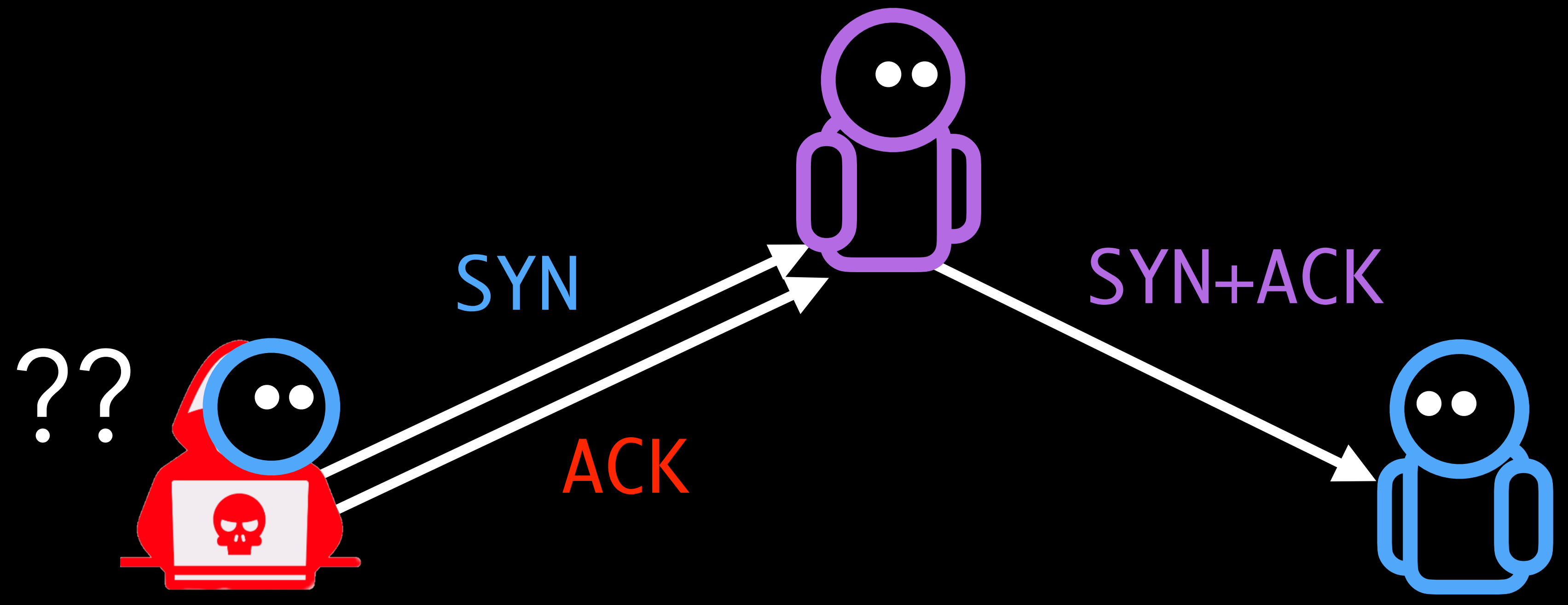

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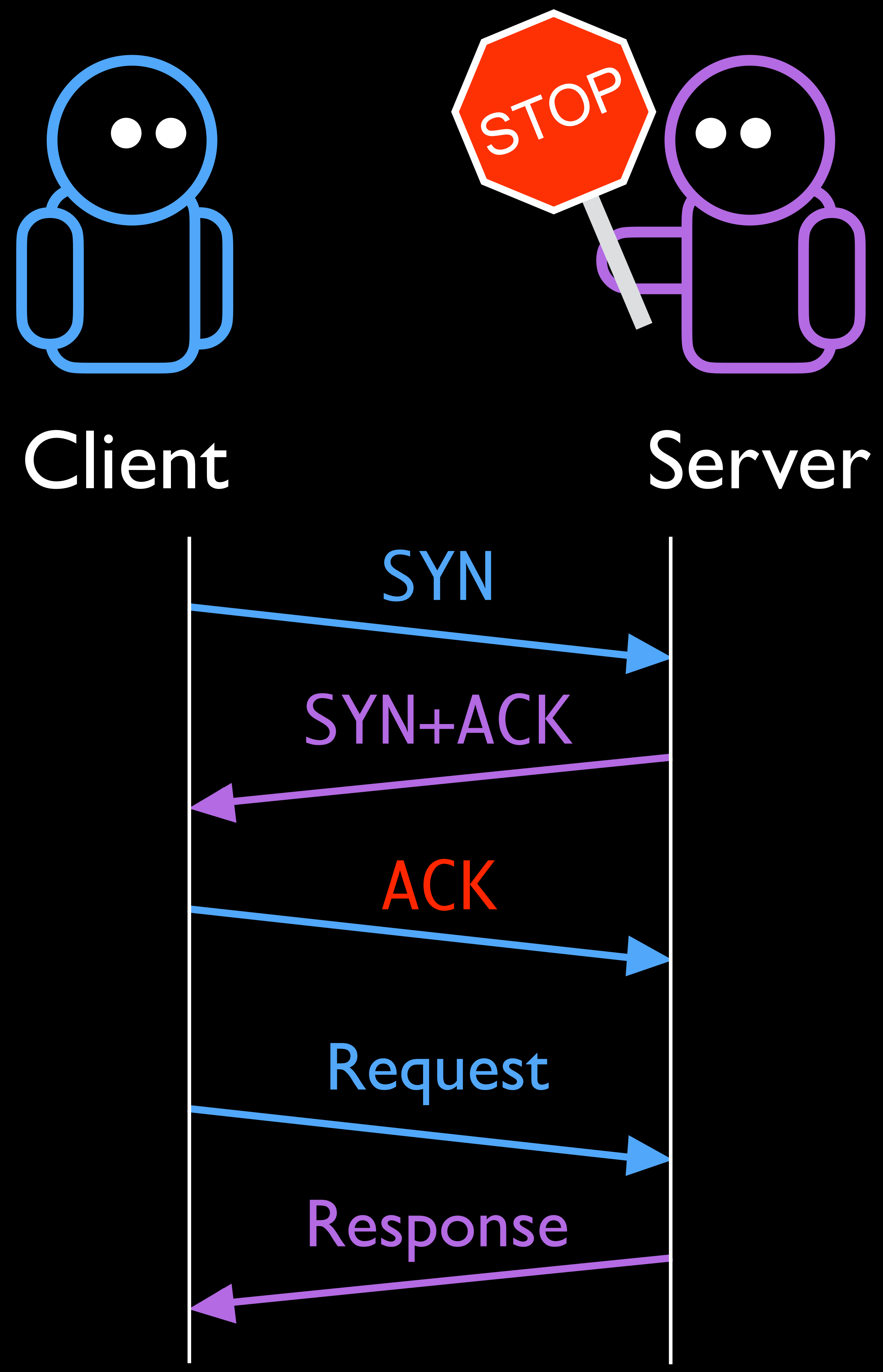

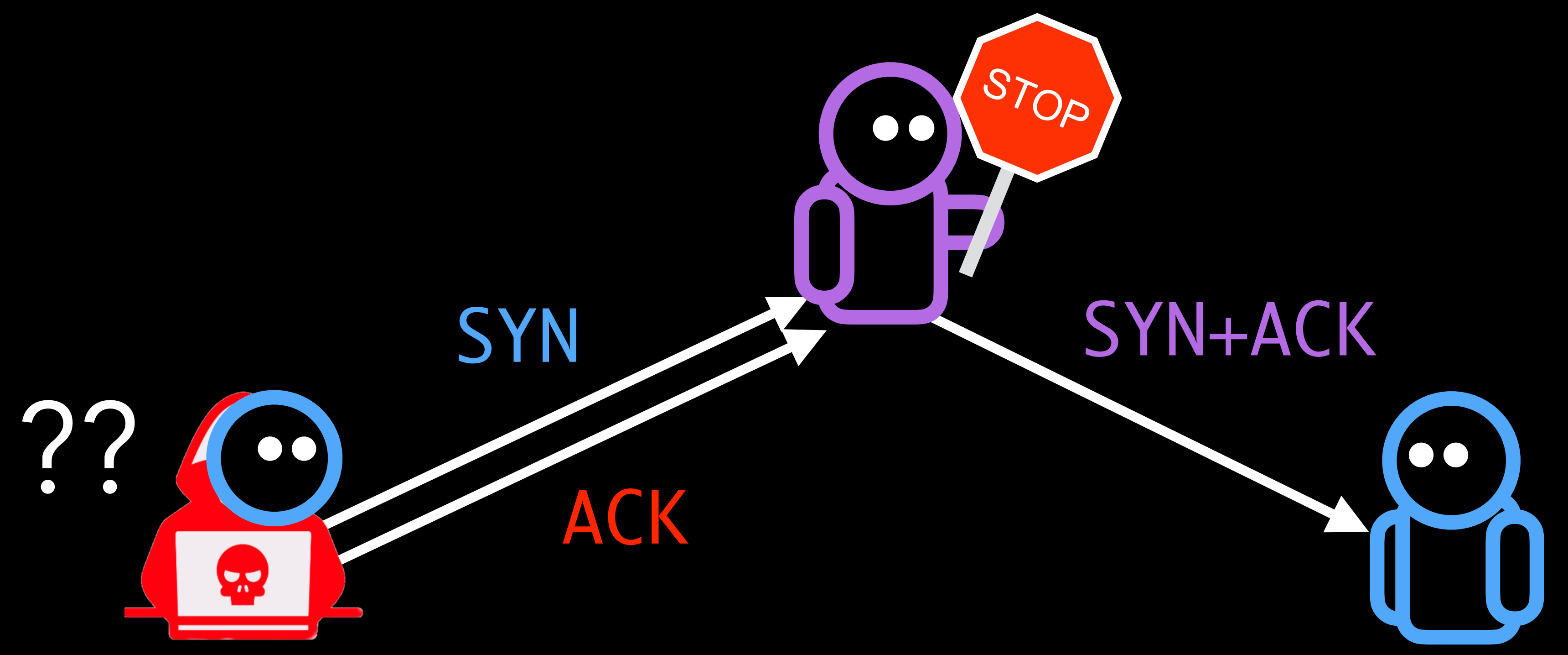

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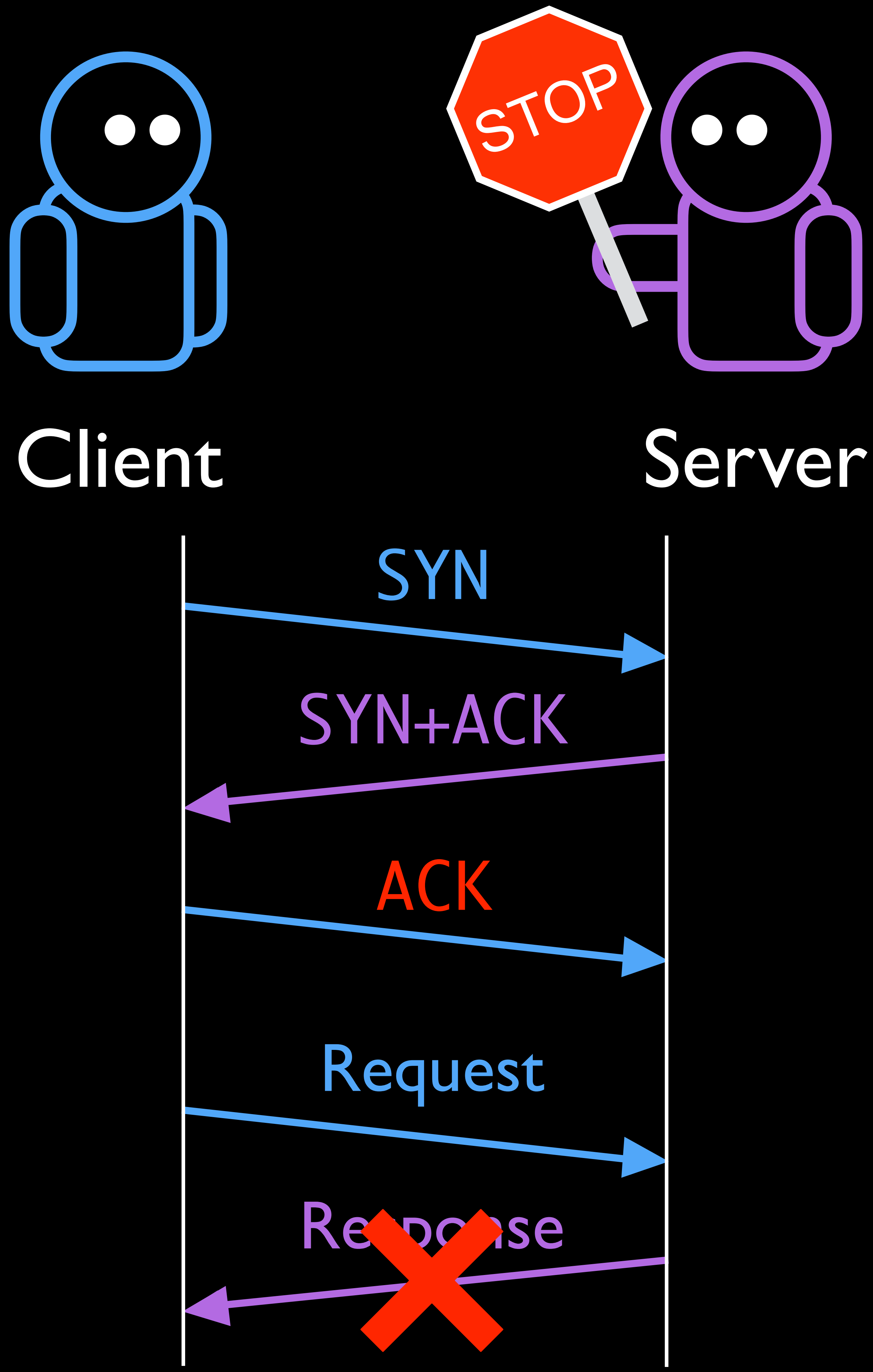

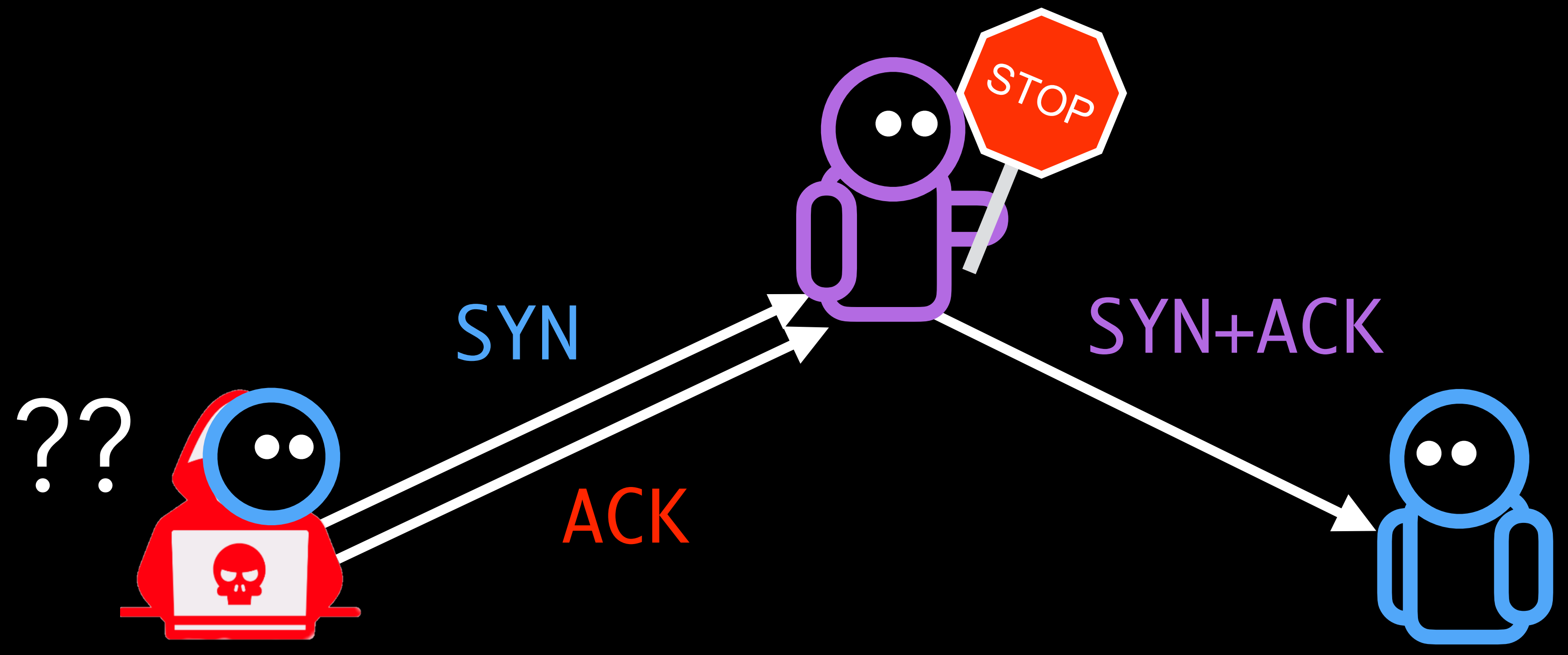

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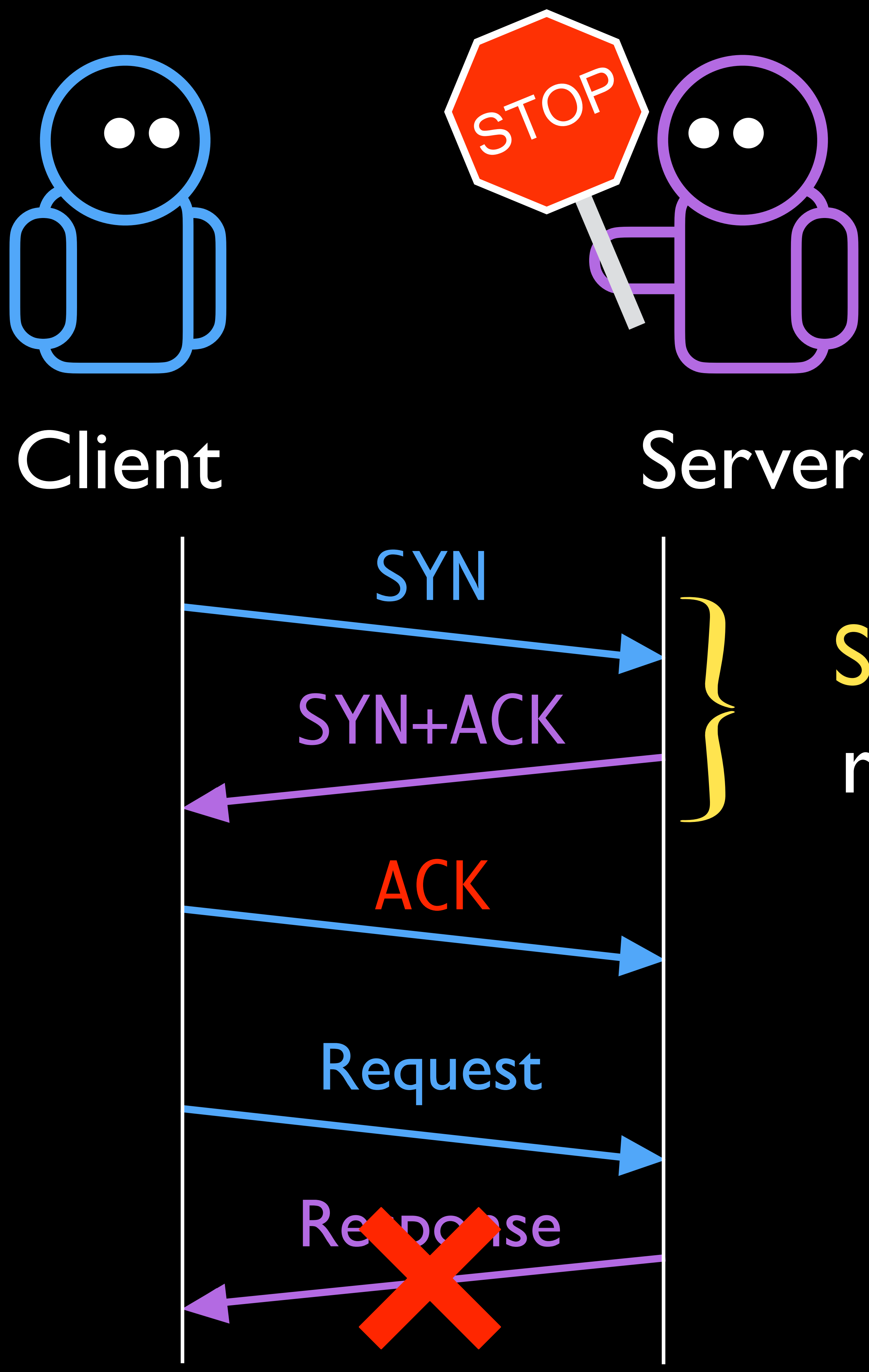
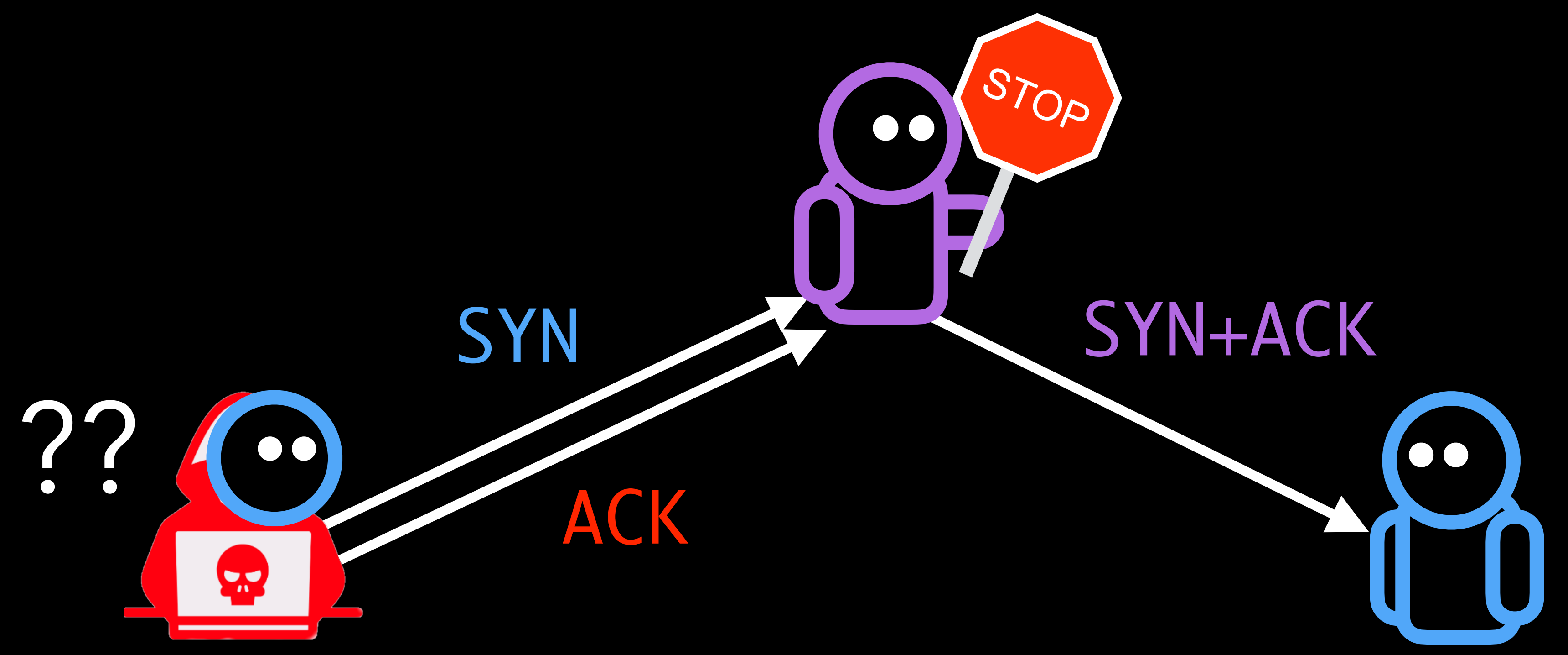
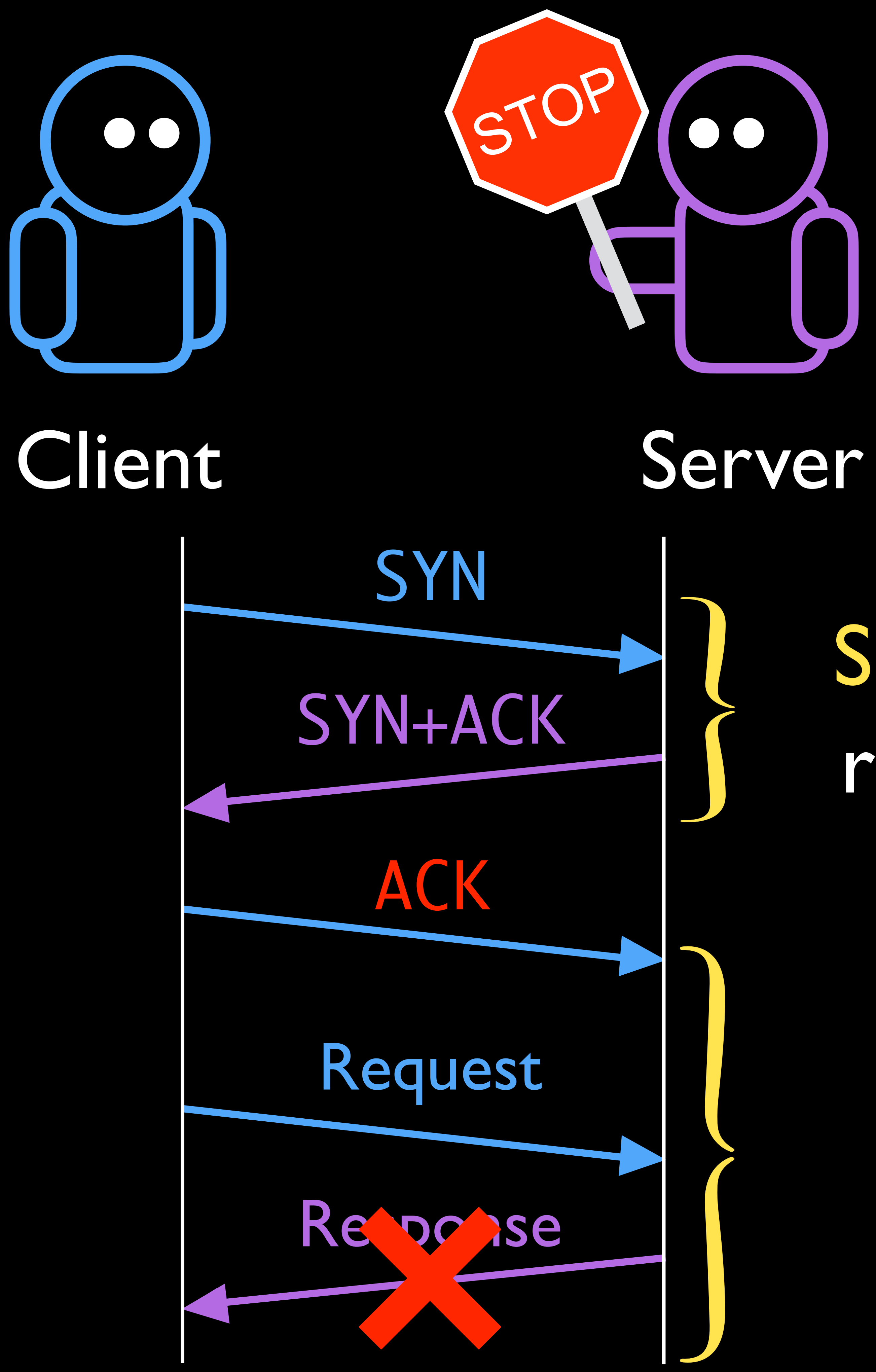




Some amplification due to retransmitted SYN+ACKs

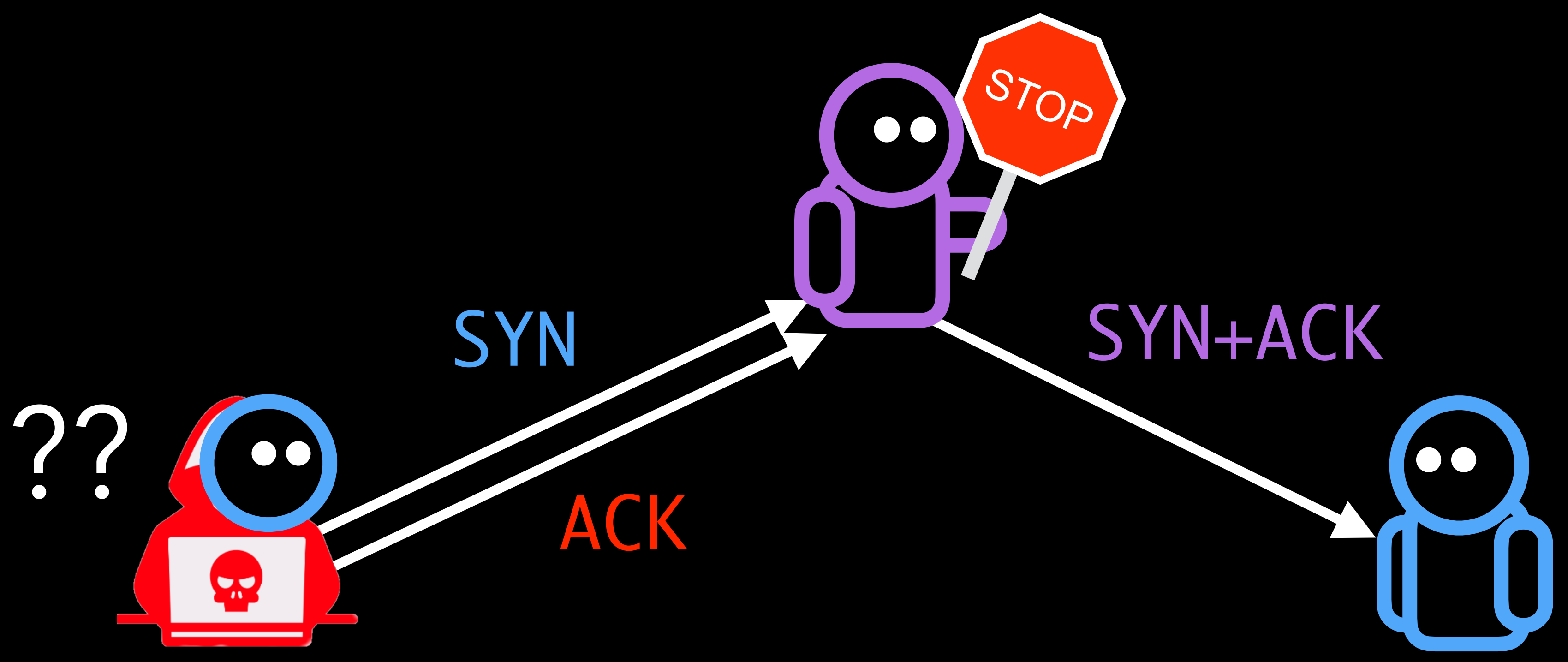
Reflected amplification attacks

TCP requires a threeway handshake



Some amplification due to retransmitted SYN+ACKs

This was believed to be off-limits to attackers



Our findings

TCP-based reflected amplification is *possible* and *effective*

- ► Five distinct attacks
- ► Millions of amplifiers
- ► Amplification factors in the millions

Found *infinite amplification* and identified *root causes*

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Found *infinite amplification* and identified *root causes*

Use middleboxes as amplifiers!

Weaponizing middleboxes

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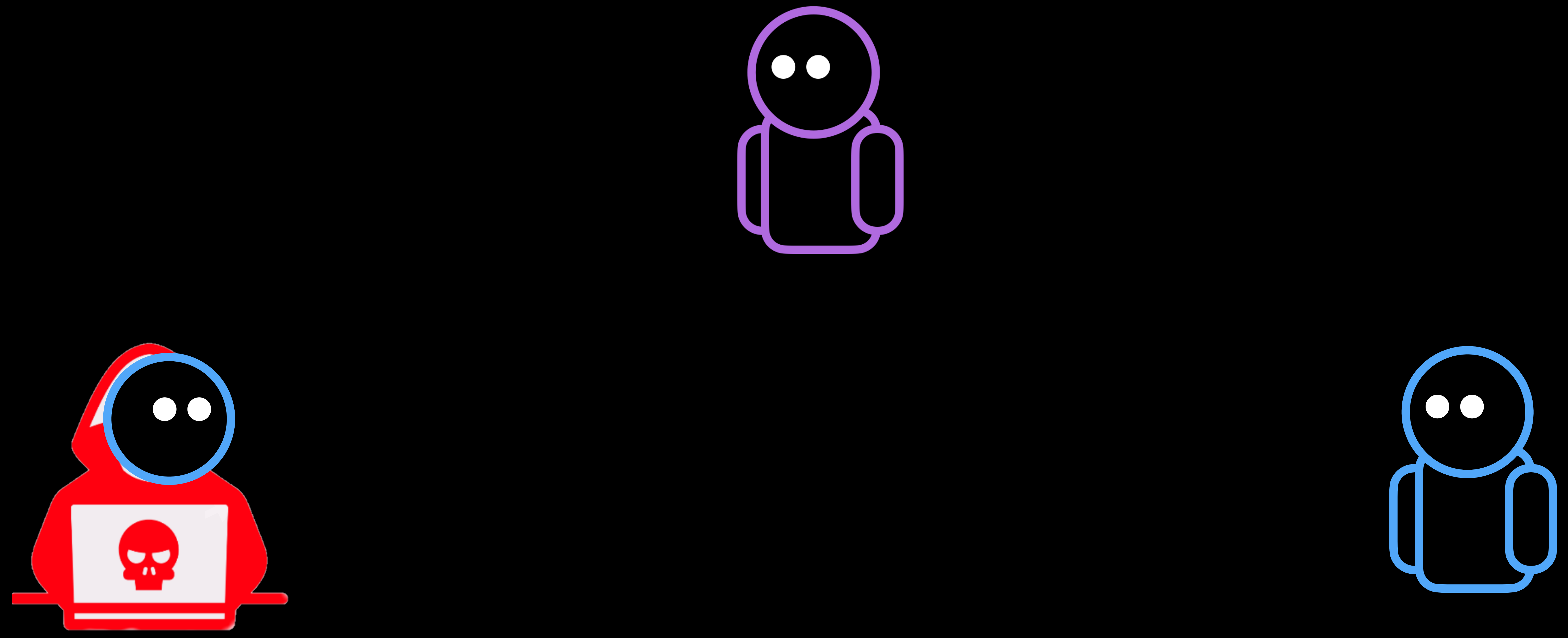

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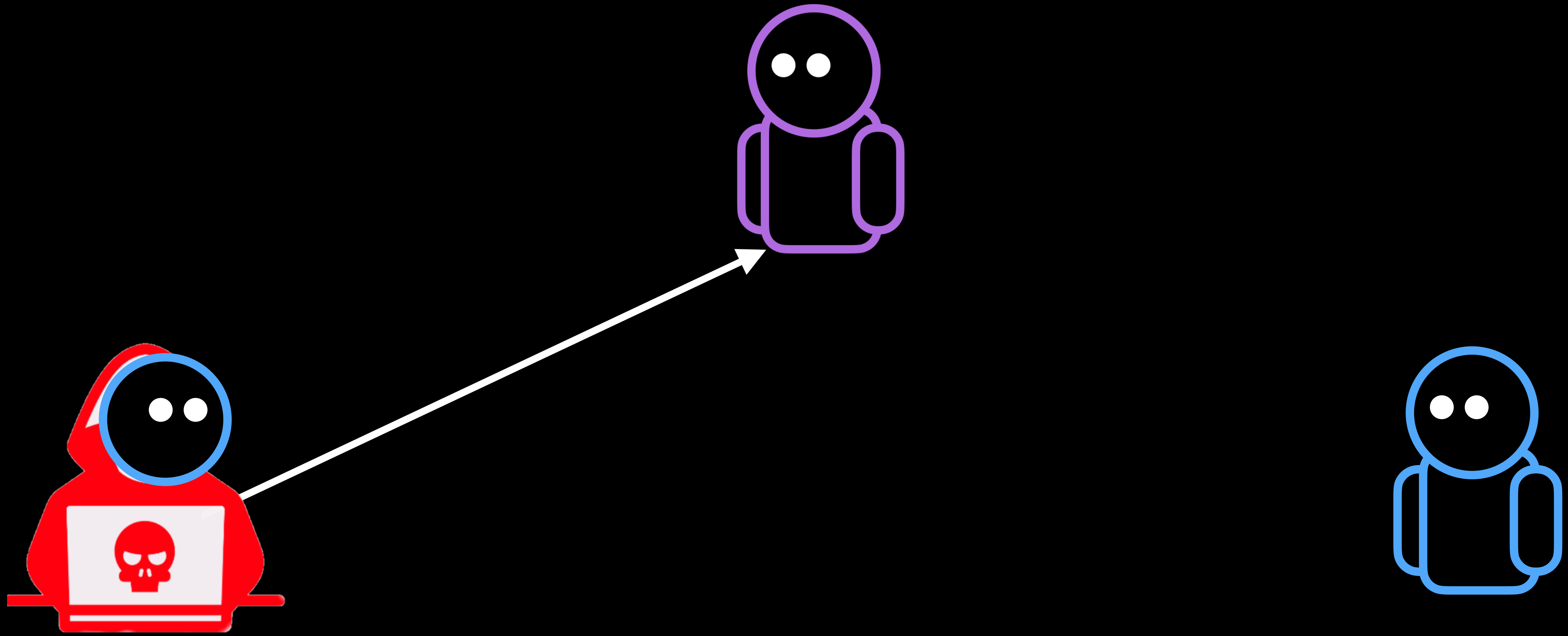

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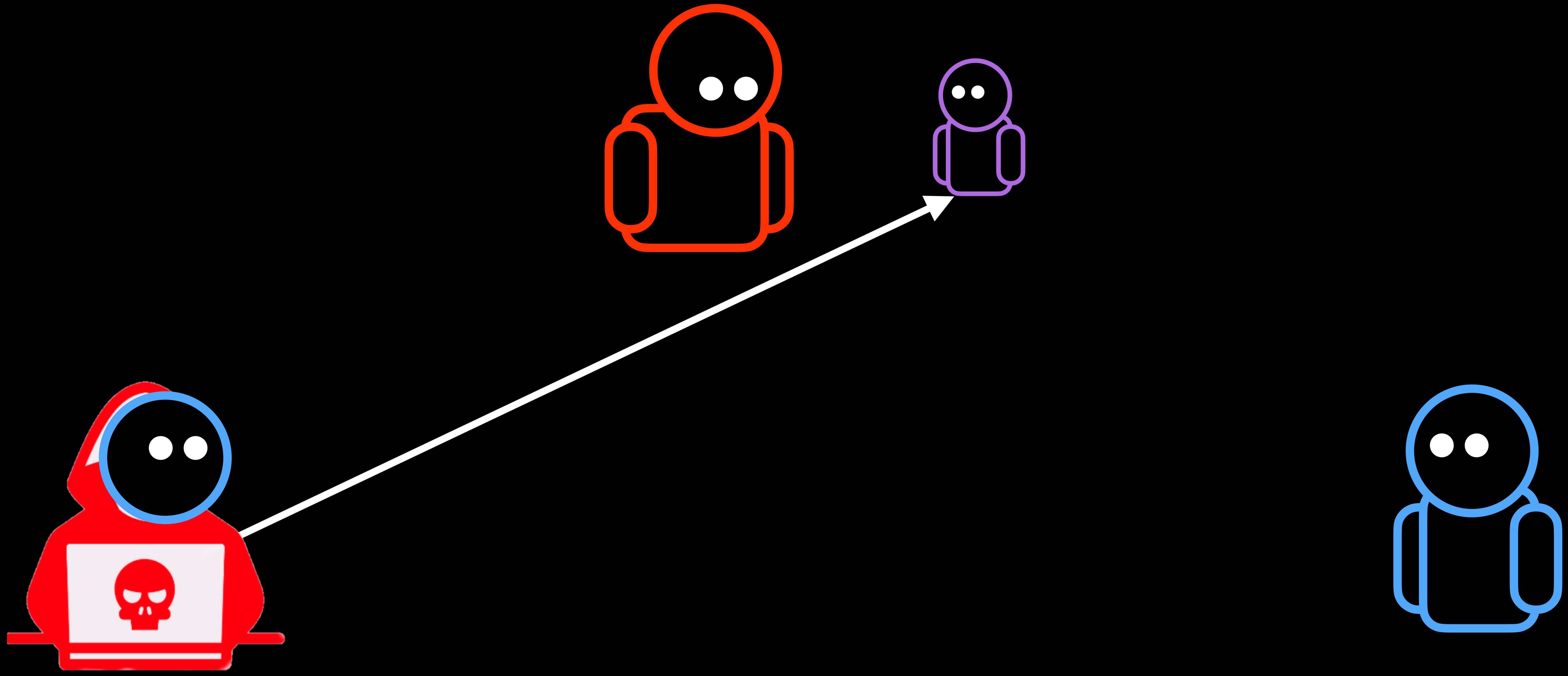

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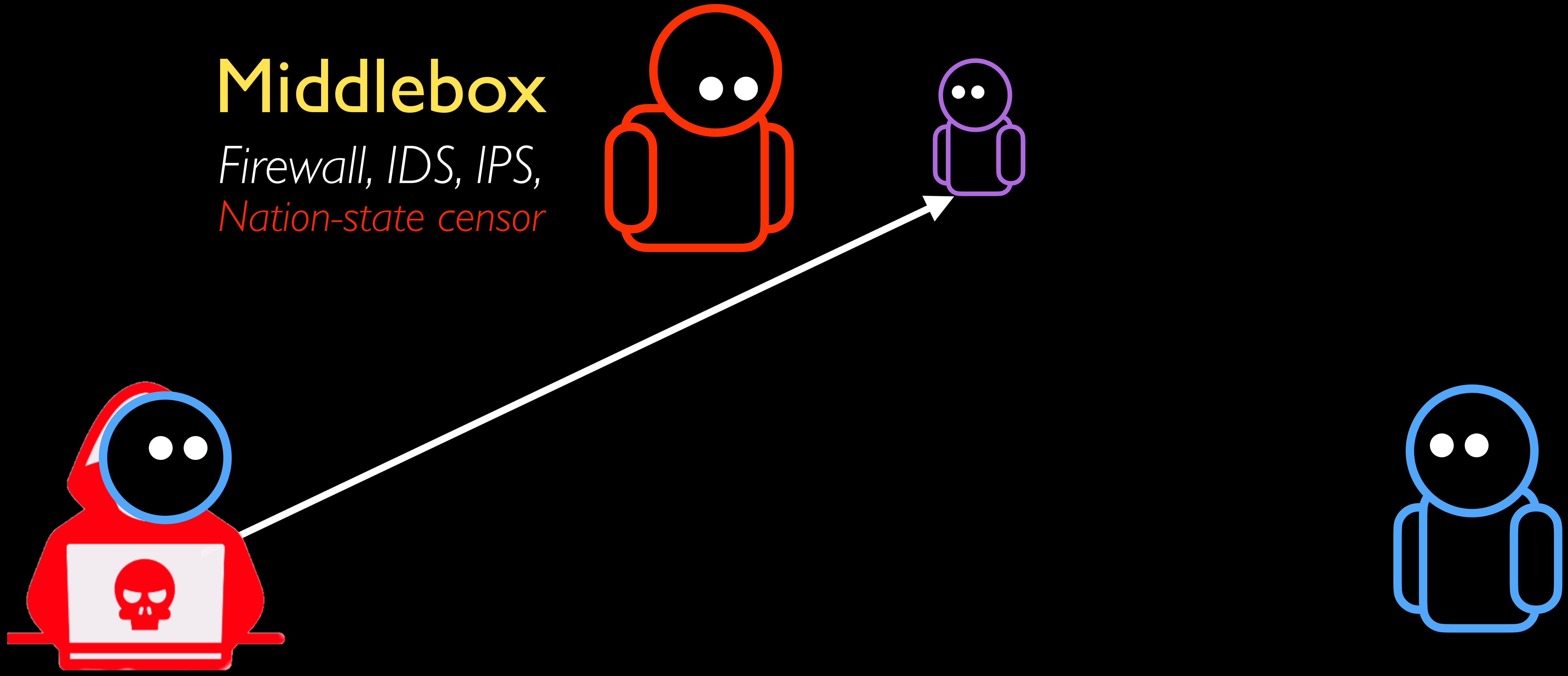

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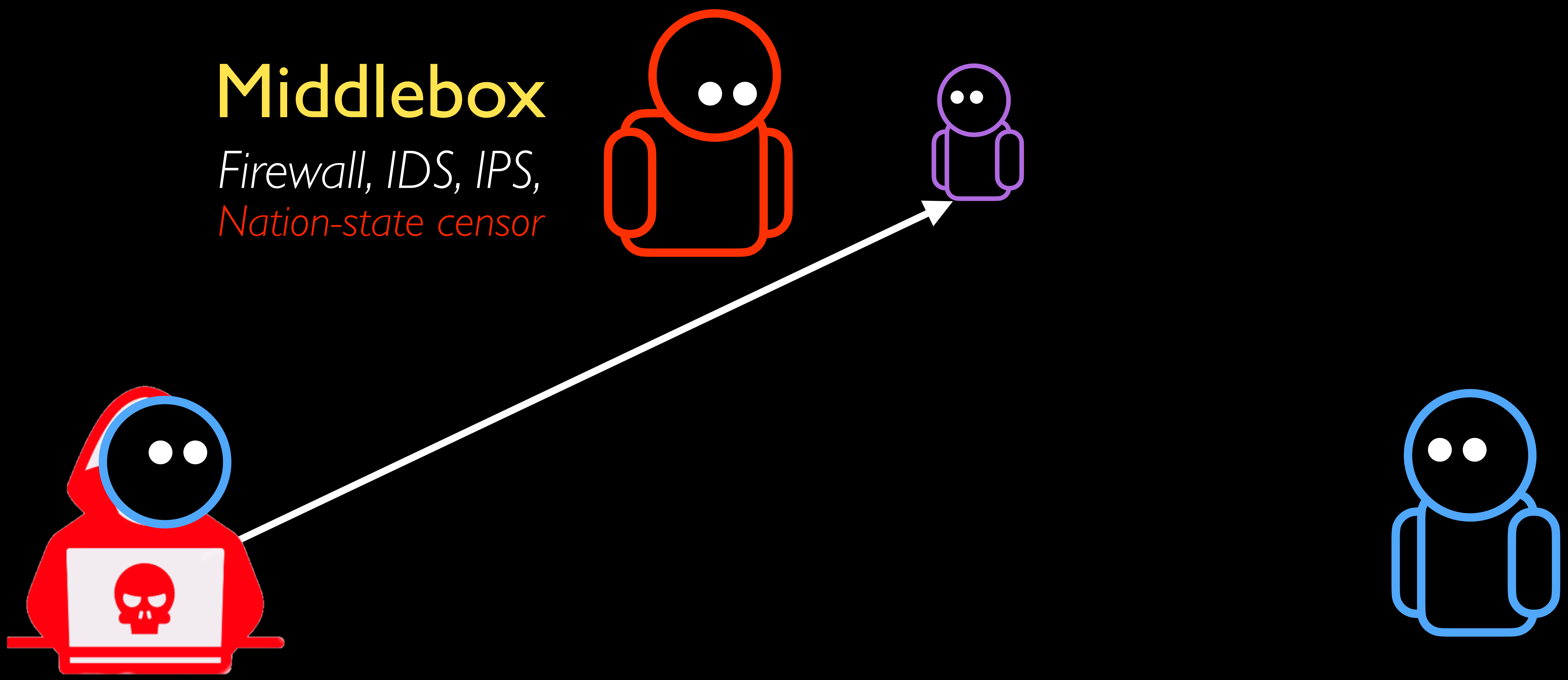
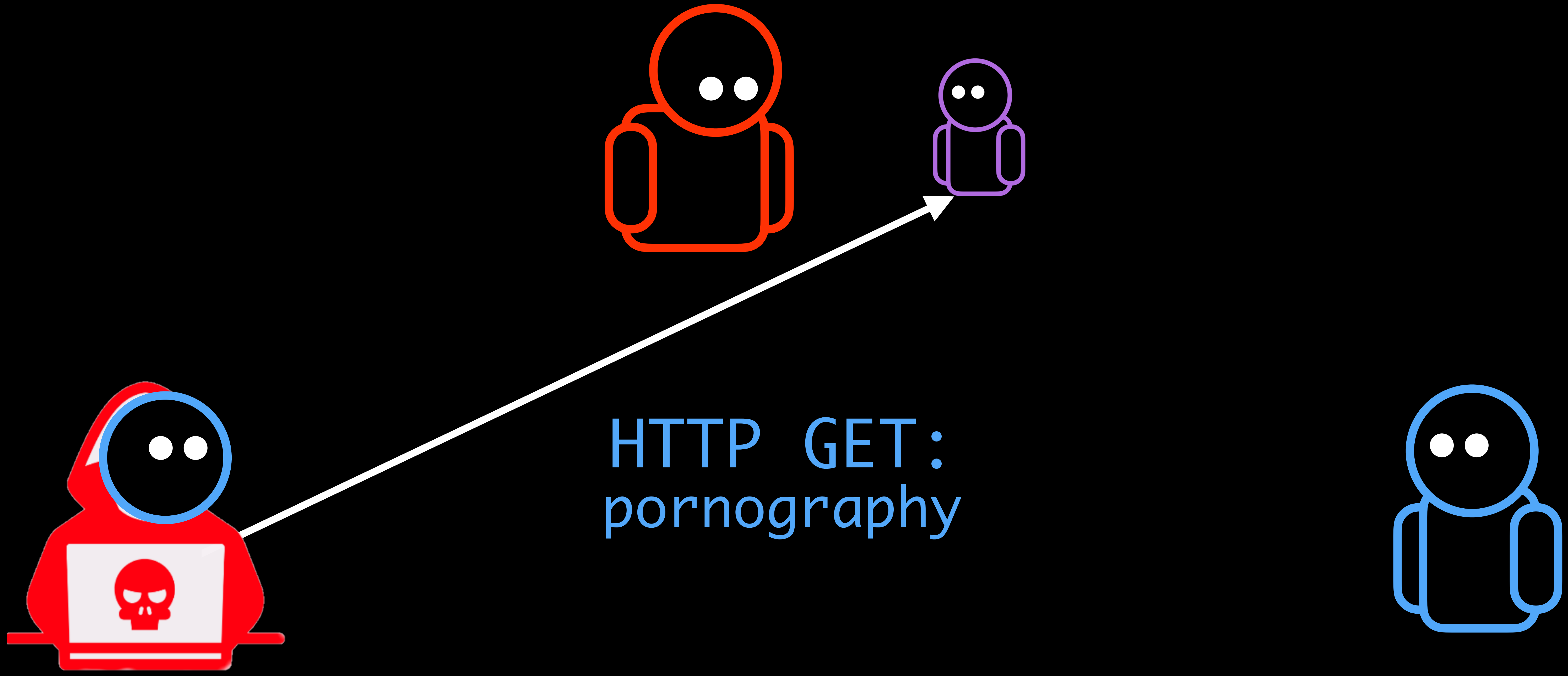


① Middleboxes expect to miss some packets

Weaponizing middleboxes



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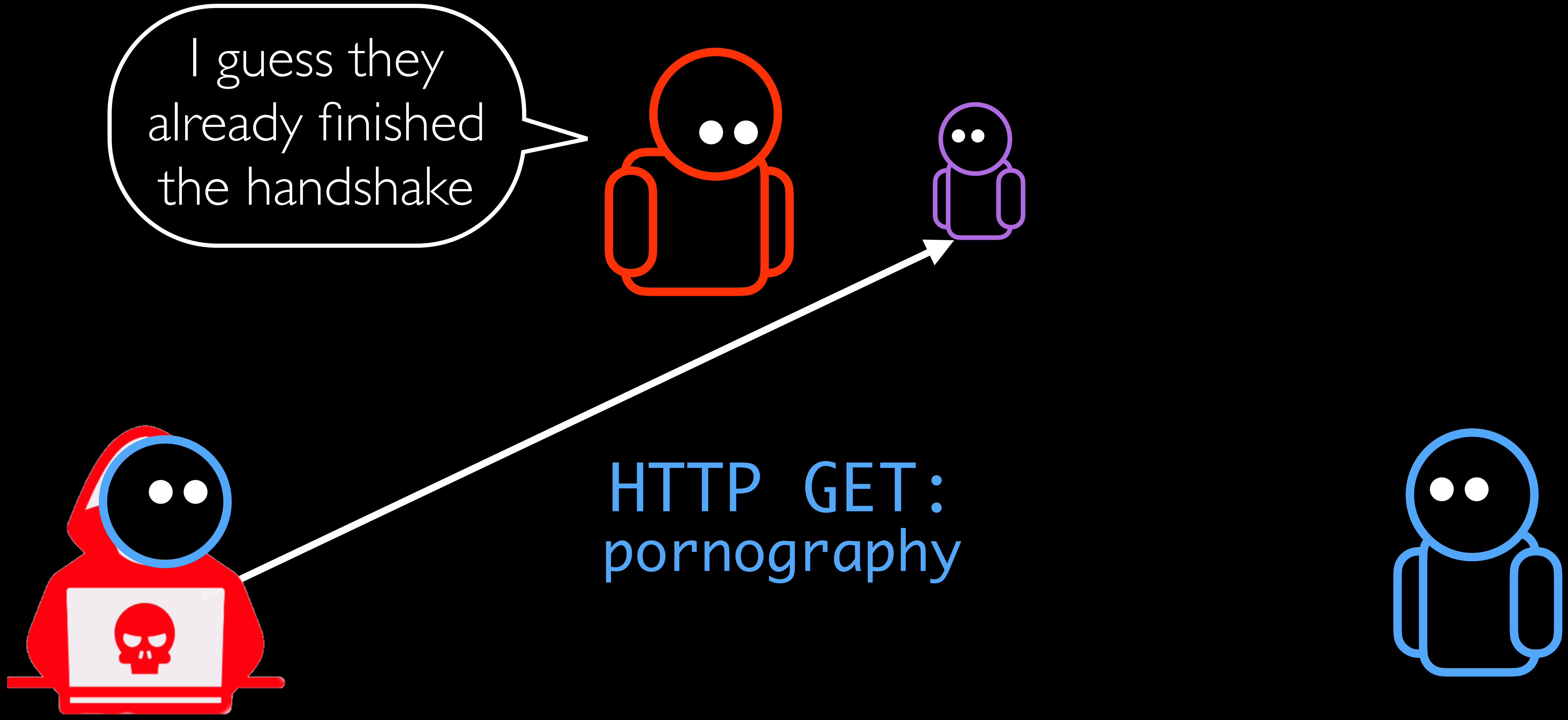

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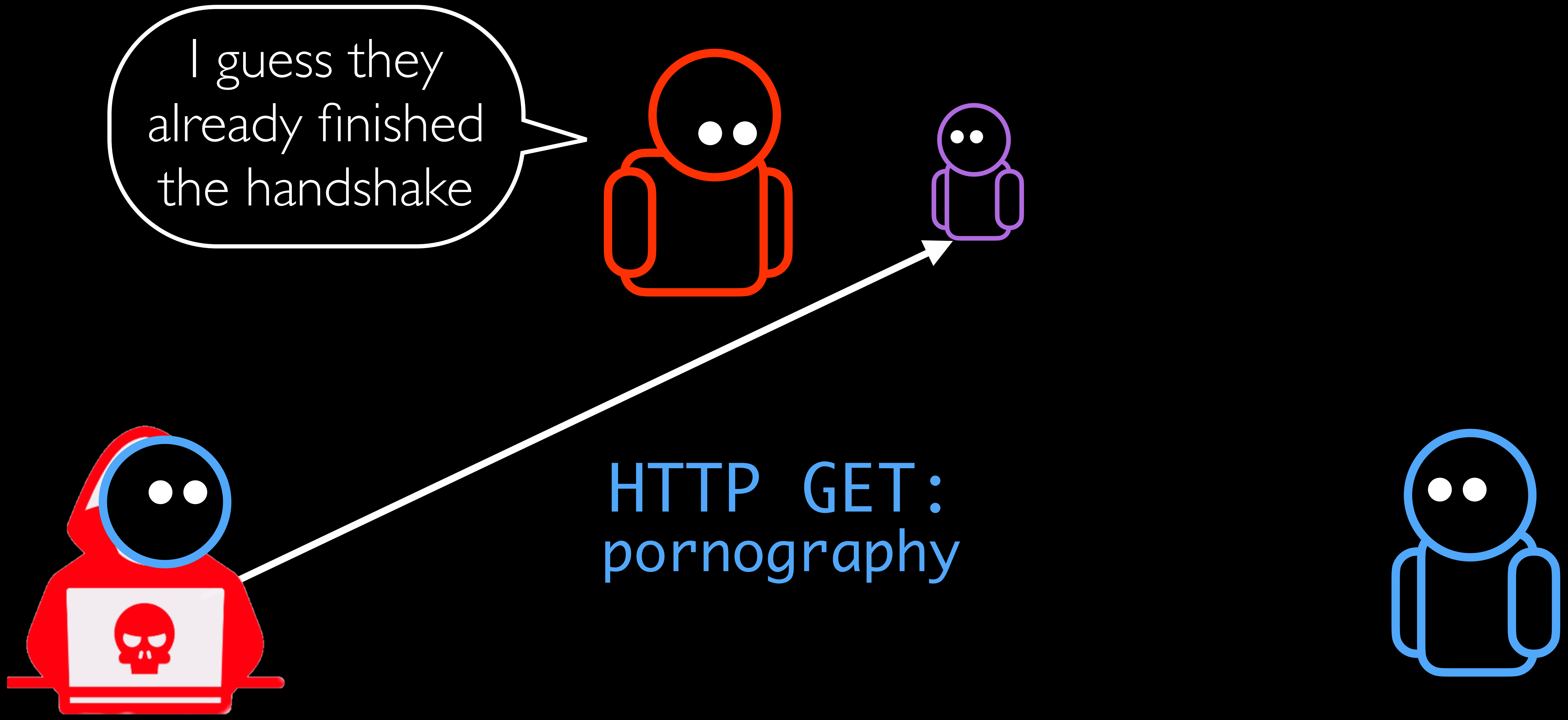

① Middleboxes expect to miss some packets

② Middleboxes *inject traffic* to block connections

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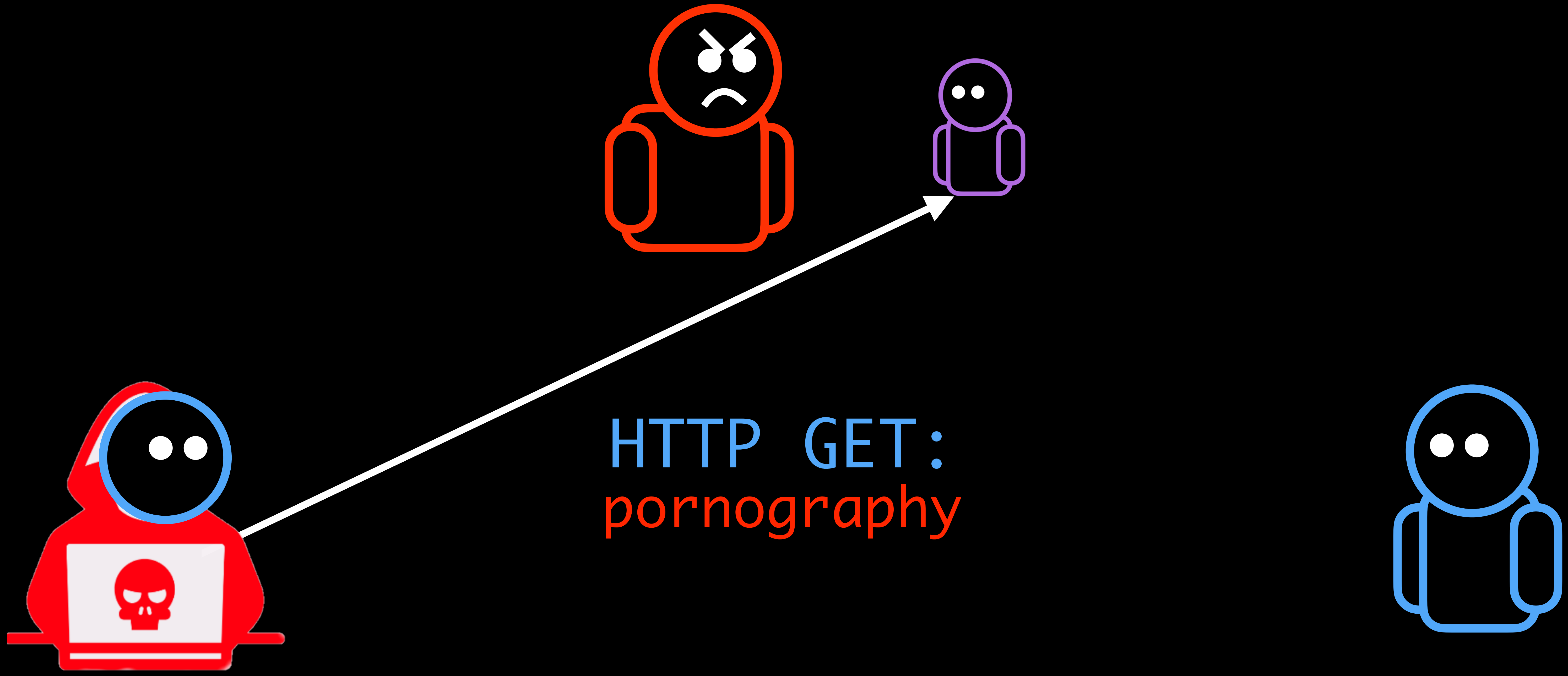

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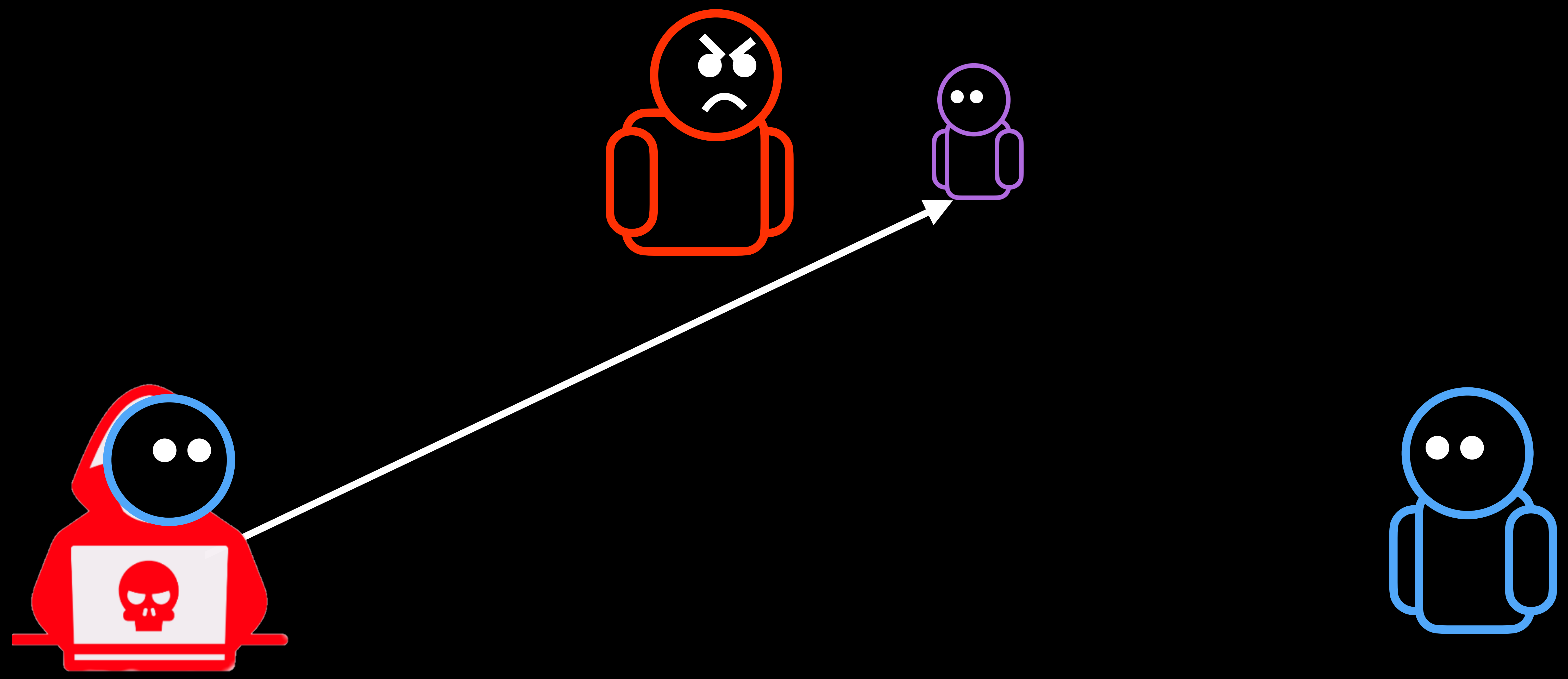

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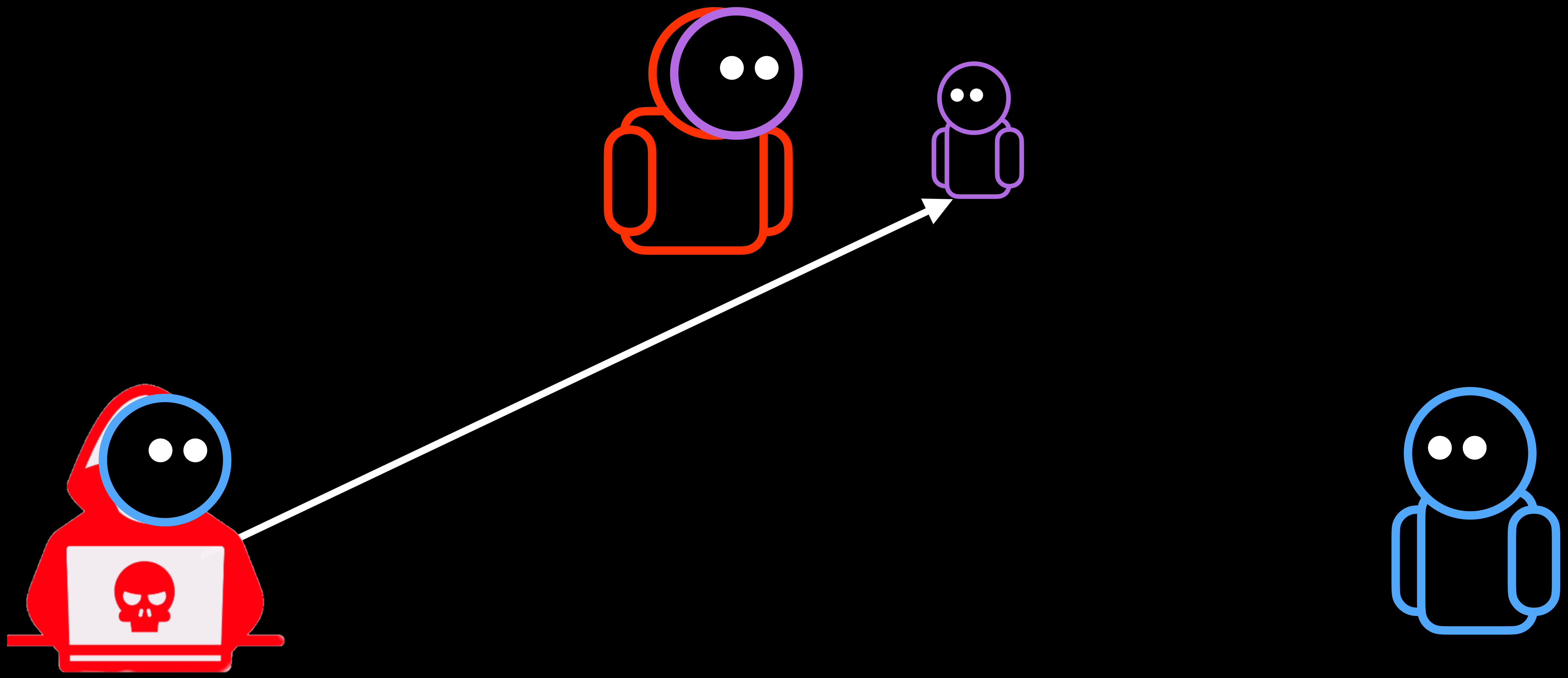

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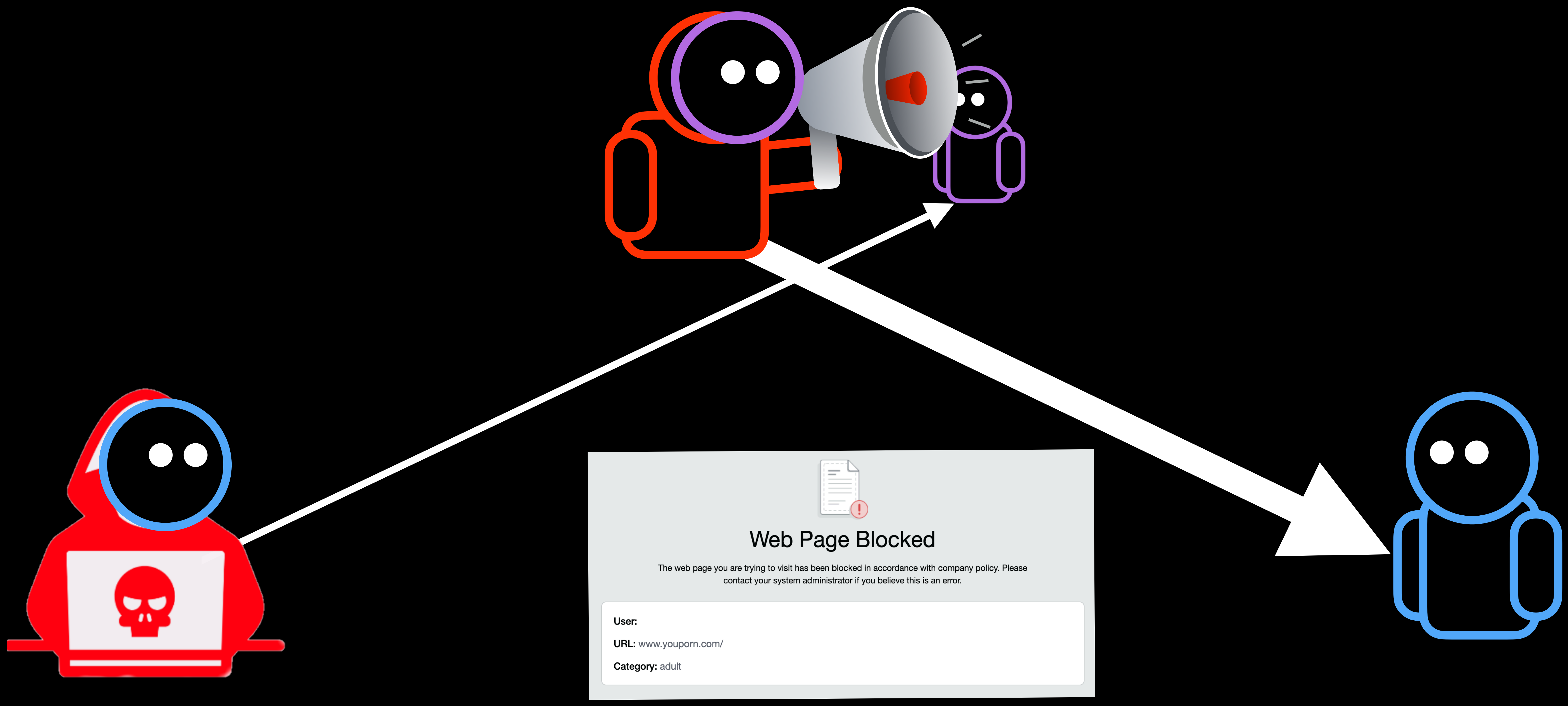


Web Page Blocked

The web page you are trying to visit has been blocked in accordance with company policy. Please contact your system administrator if you believe this is an error.

User:

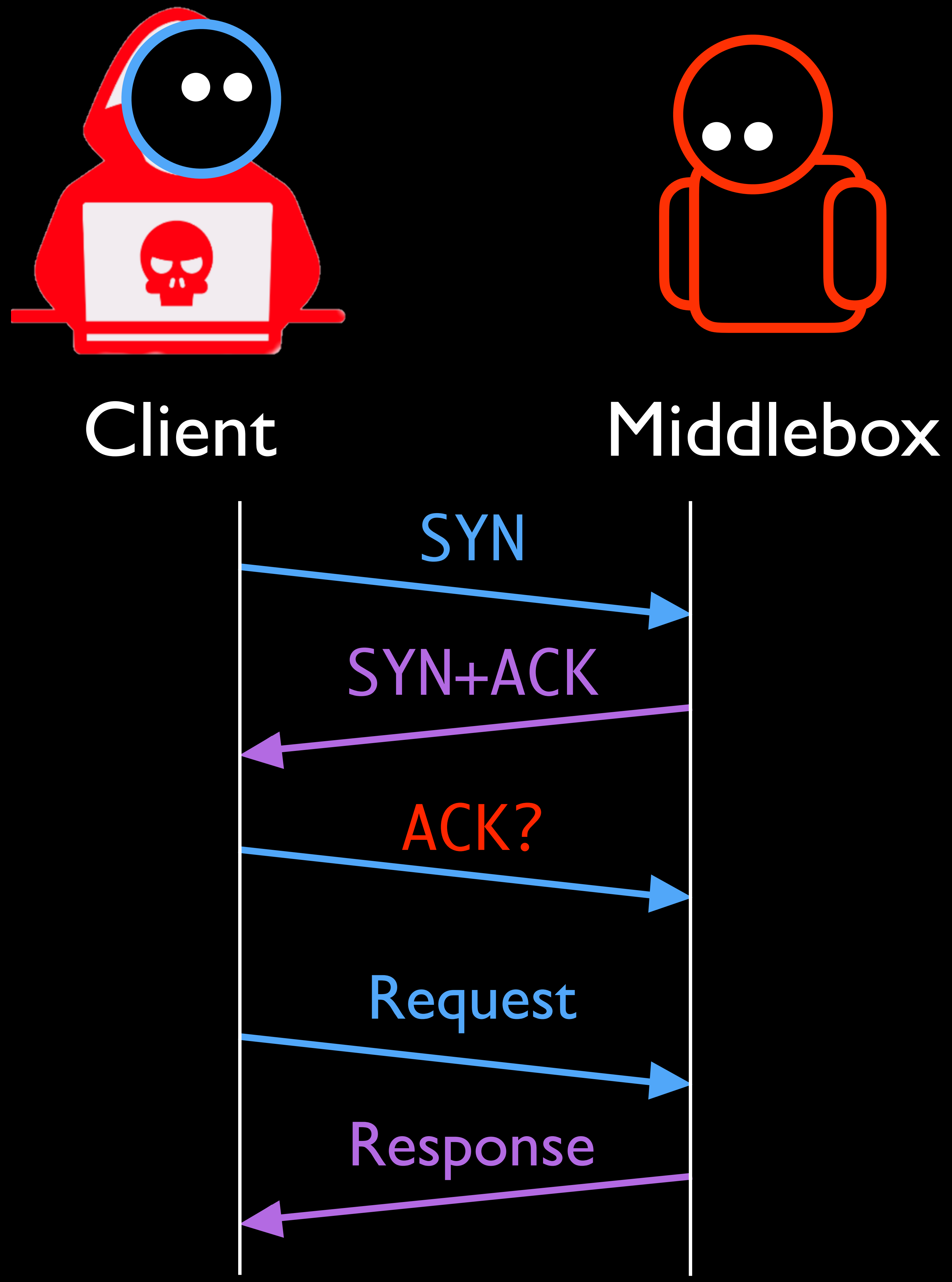
URL: www.youporn.com/

Category: adult

① Middleboxes expect to miss some packets

② Middleboxes *inject traffic* to block connections

Middleboxes make TCP-based amplification possible



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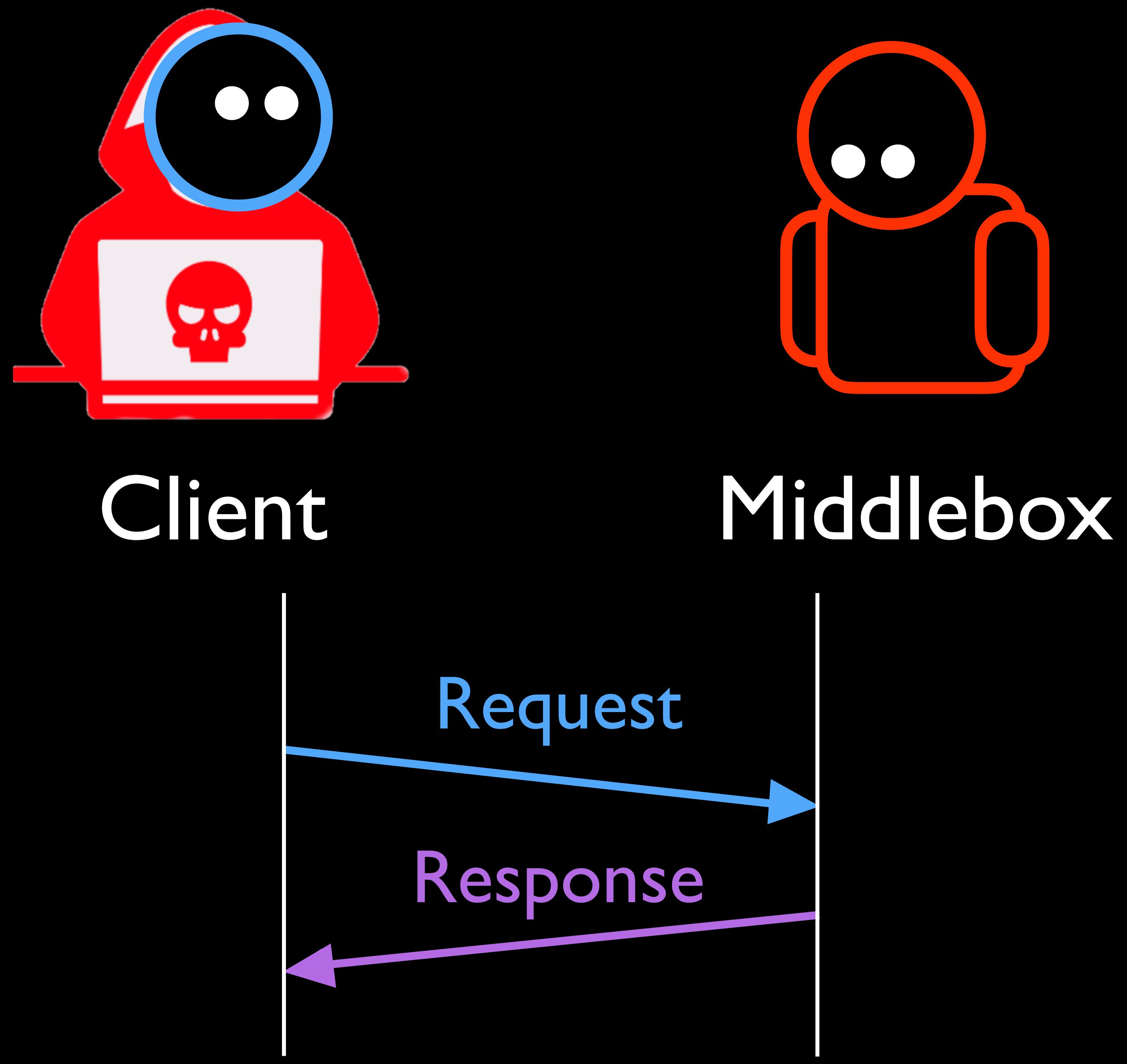

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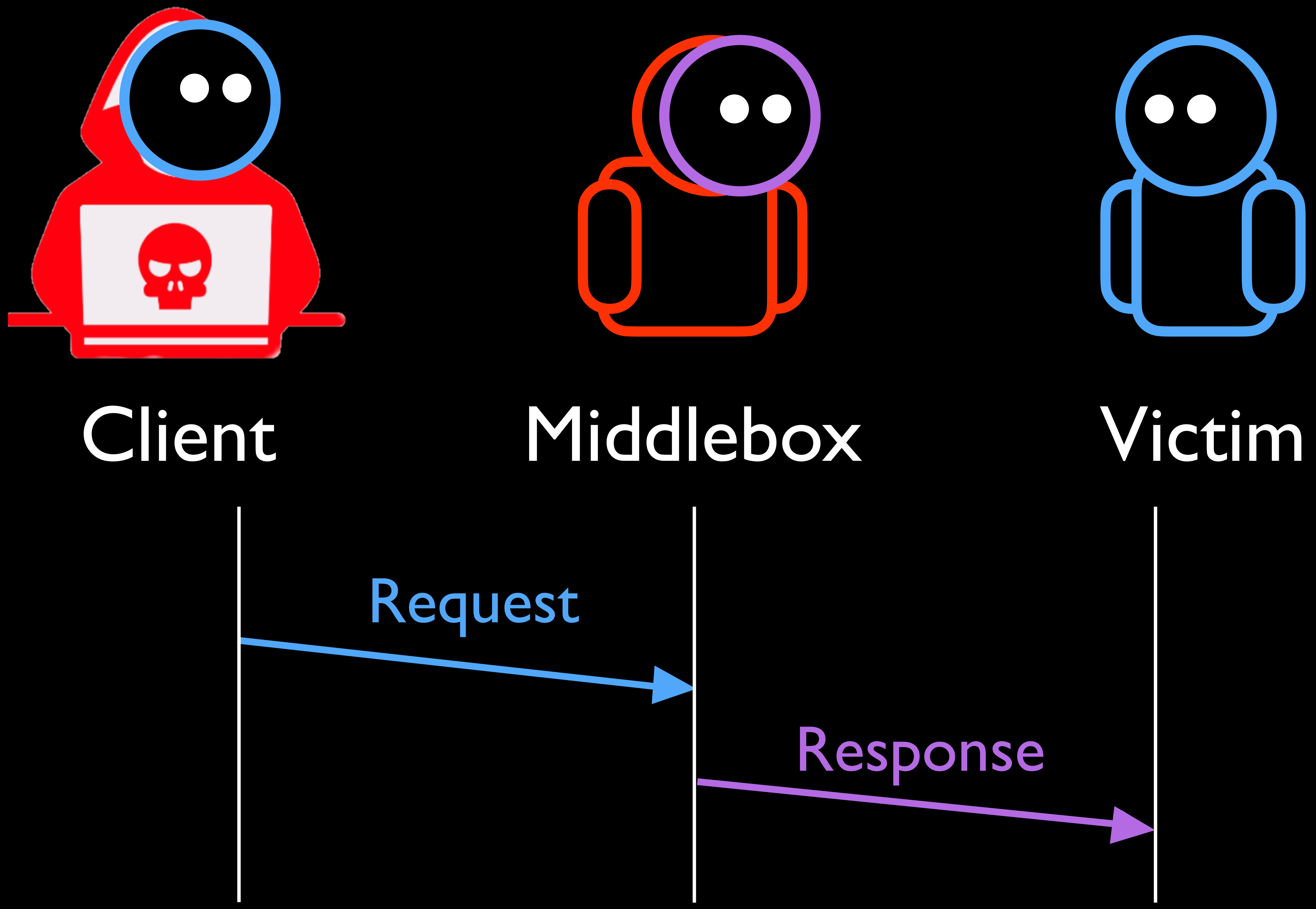

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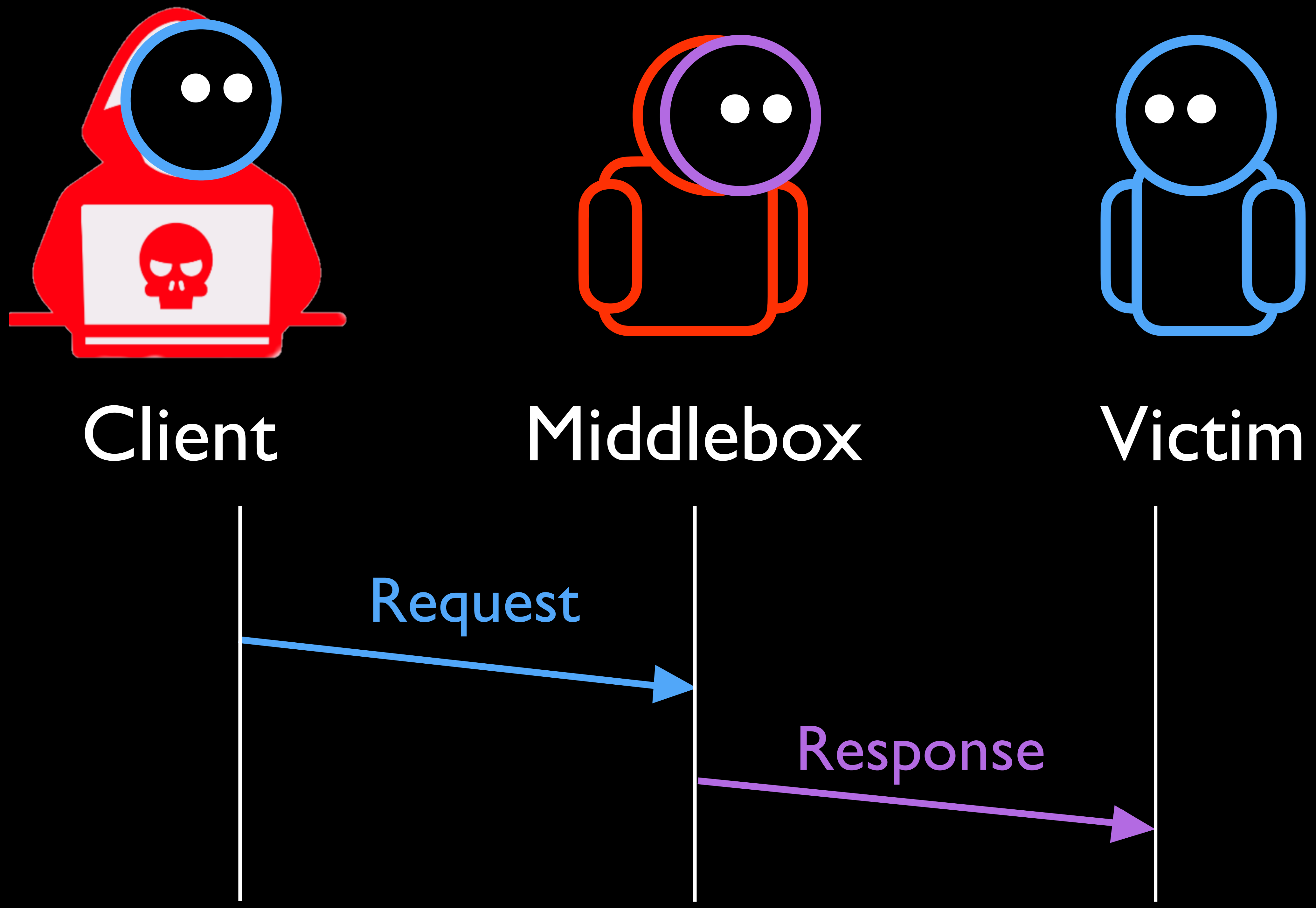
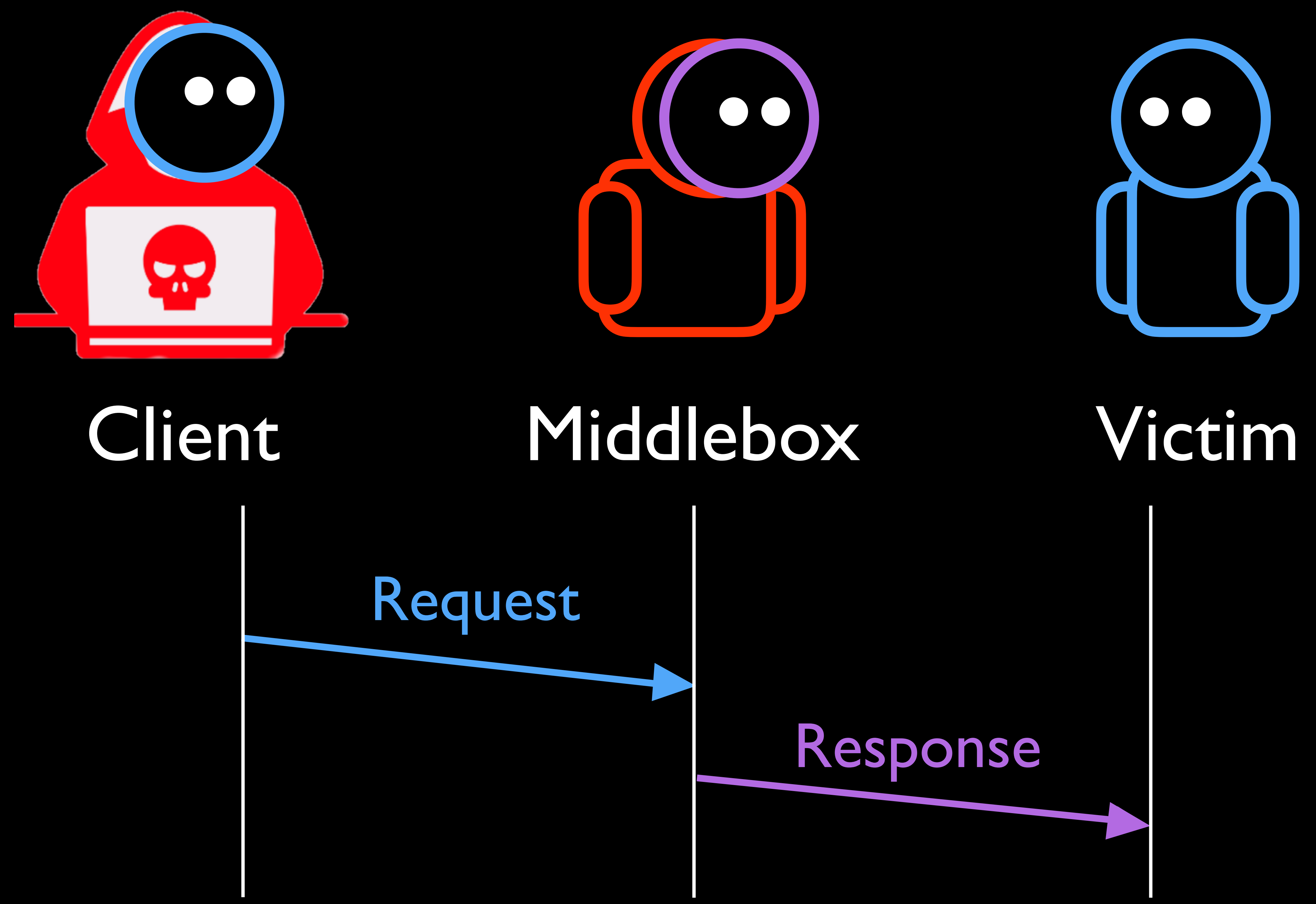


What packets best trigger middleboxes?

Middleboxes make TCP-based amplification possible

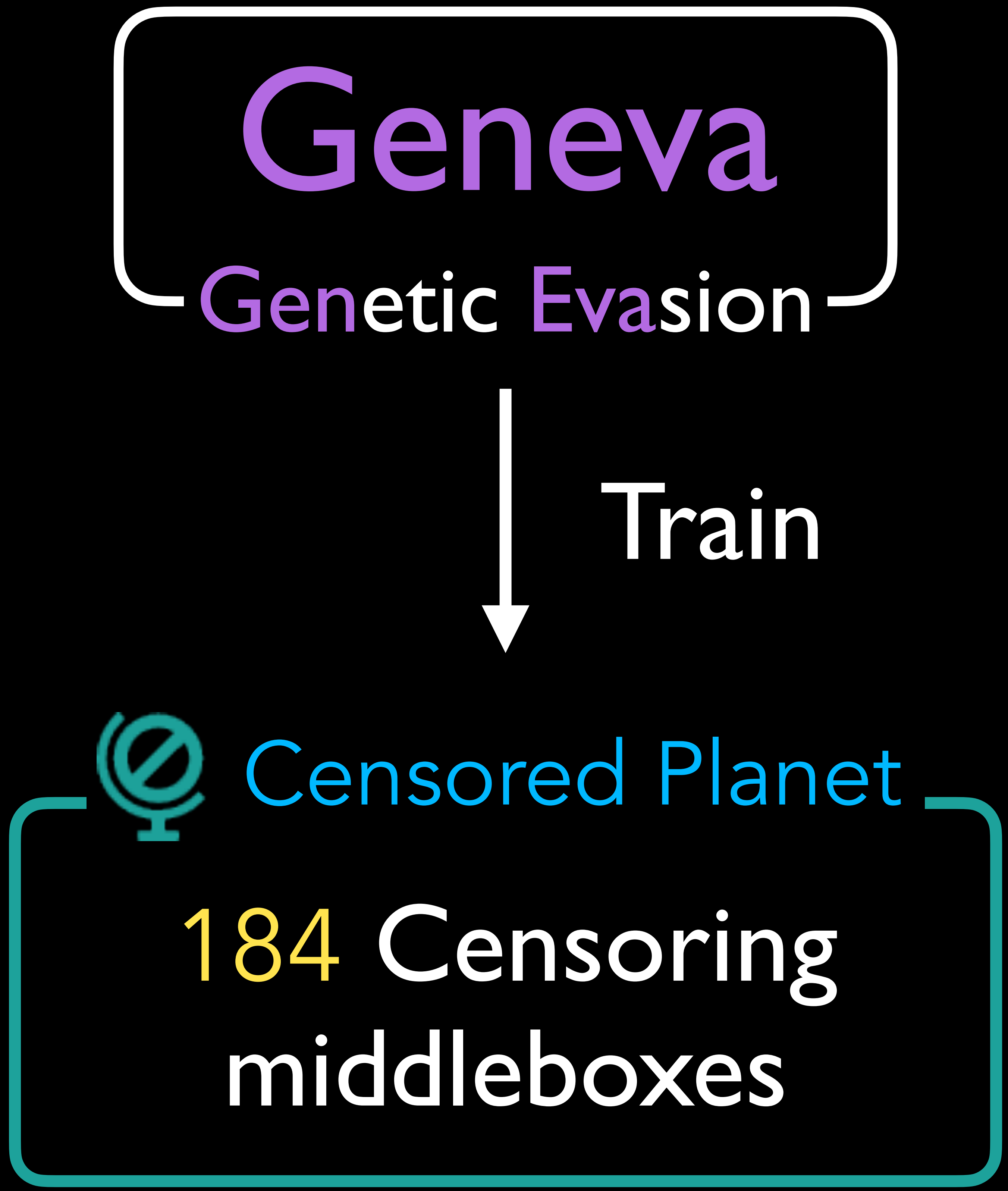


What packets best trigger middleboxes?

What amplifications are attainable?

Methodology

① Automated Discovery



Geneva

Genetic Evasion

Train

Censored Planet

184 Censoring middleboxes

Methodology

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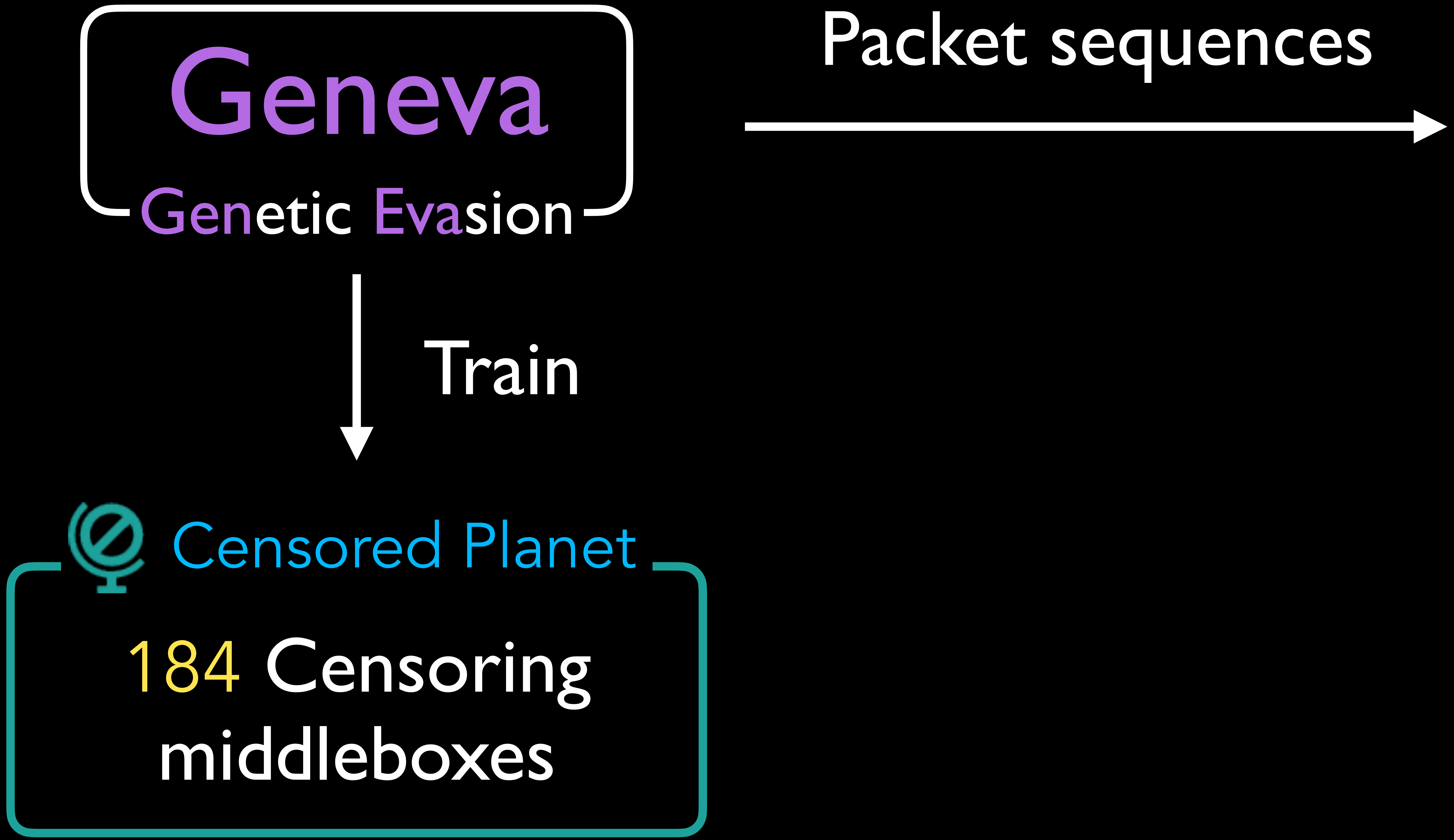

Geneva

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Packet sequences

Train

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184 Censoring middleboxes

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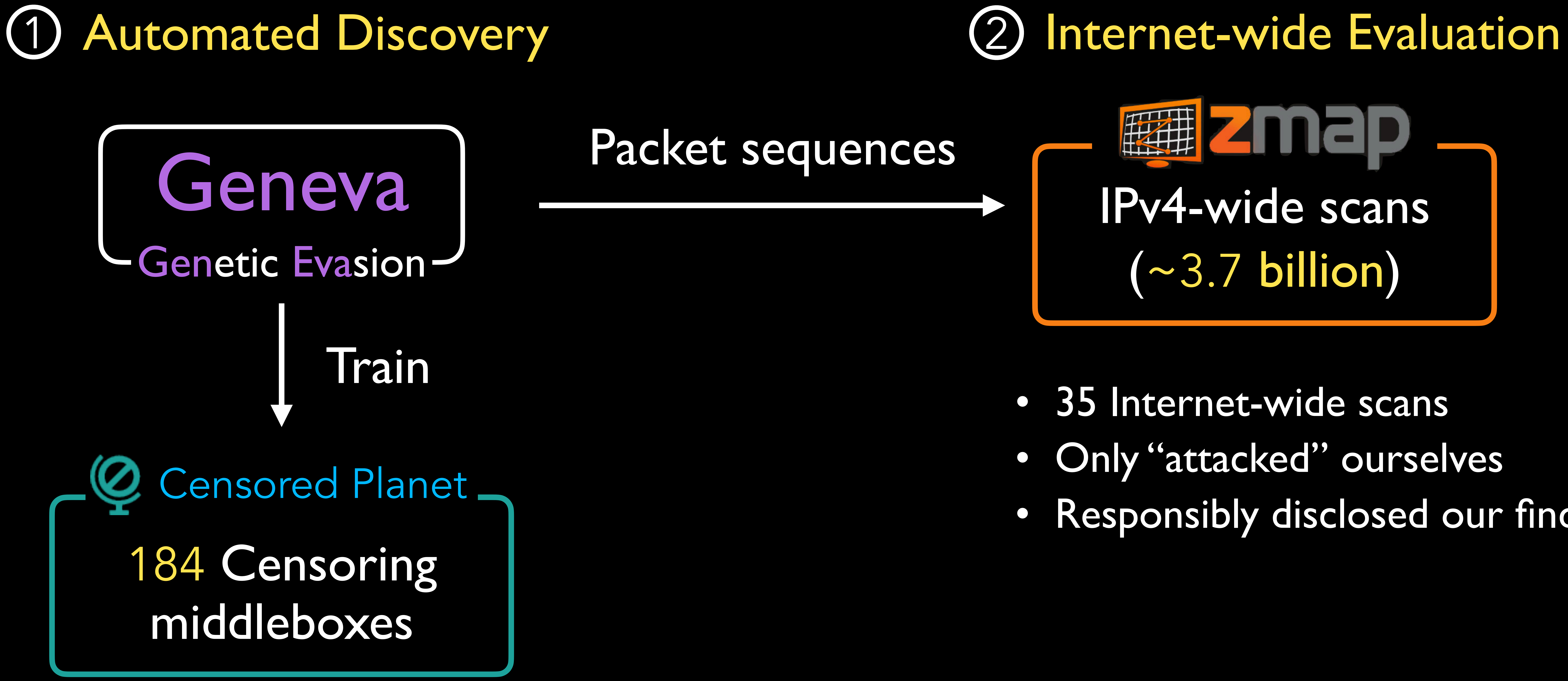

① Automated Discovery

Geneva

Genetic Evasion

Train

Censored Planet

184 Censoring middleboxes

Packet sequences

② Internet-wide Evaluation

zmap

IPv4-wide scans (~3.7 billion)

- 35 Internet-wide scans
- Only "attacked" ourselves
- Responsibly disclosed our findings

TCP-based amplification attacks

Issue an HTTP request for forbidden content

Packet sequences

SYN *with Request*

Request

SYN ; Request

TCP-based amplification attacks

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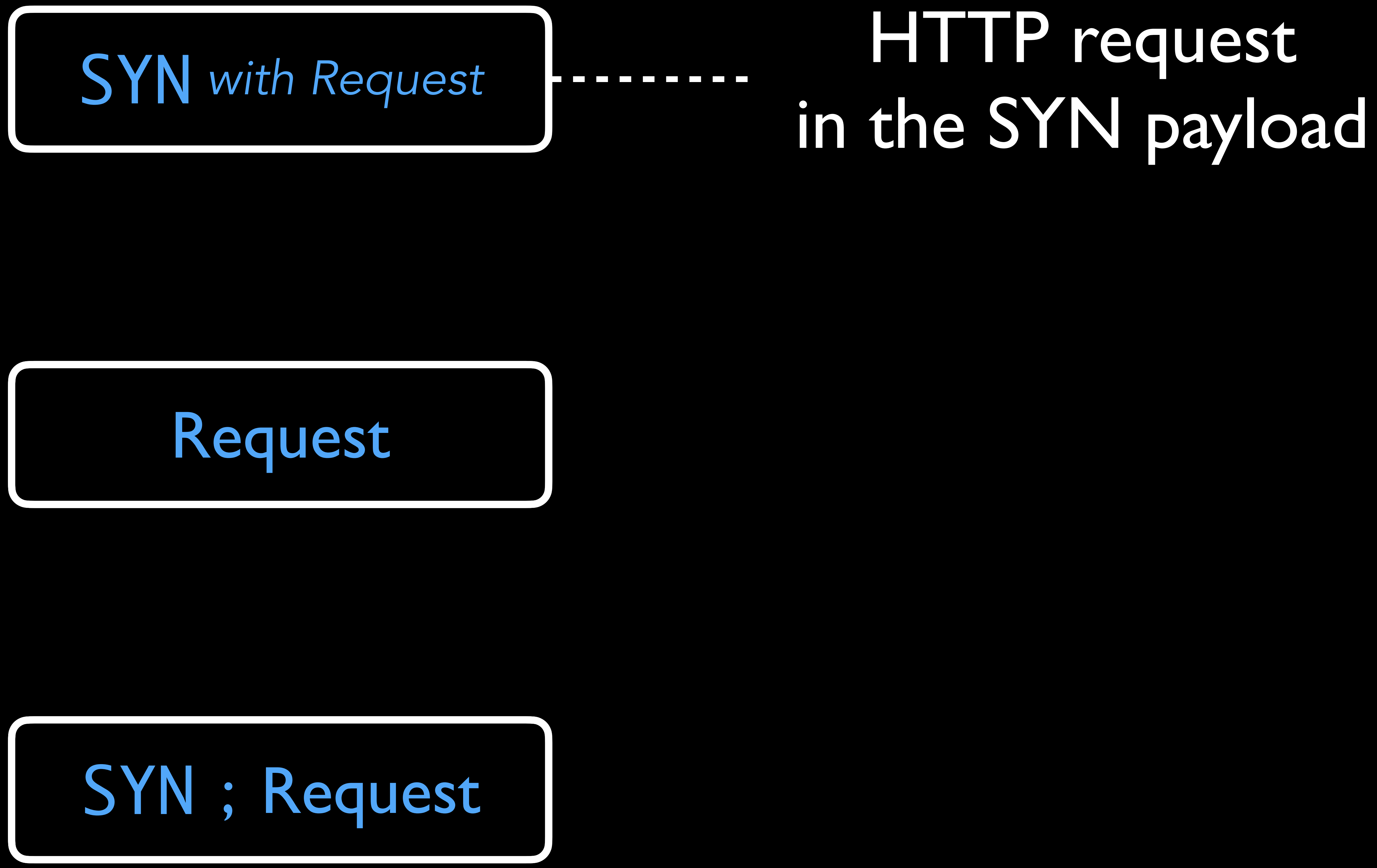

SYN *with Request*

HTTP request in the SYN payload

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SYN ; Request

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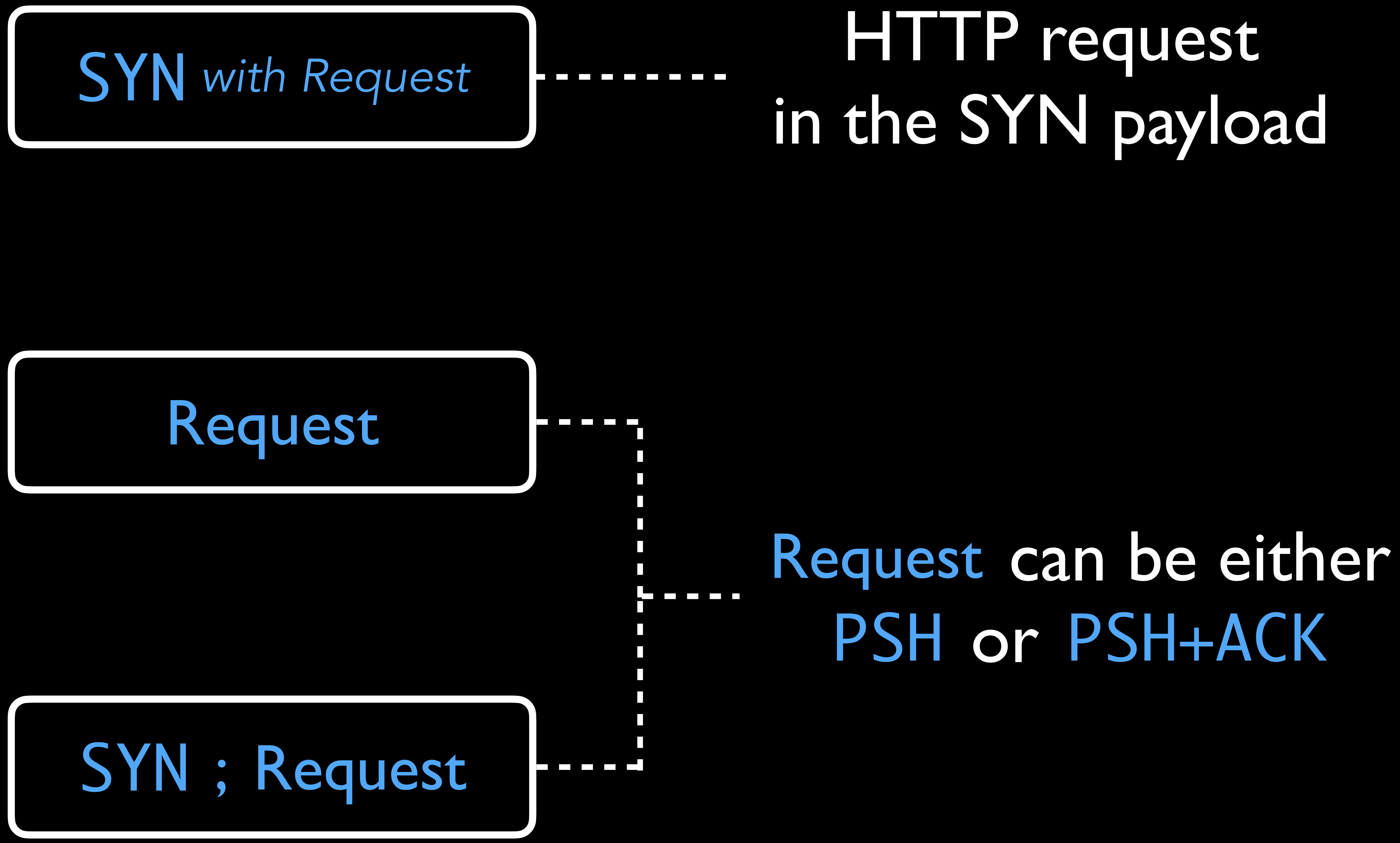

SYN *with Request*

HTTP request in the SYN payload

Request

SYN ; Request

Request can be either PSH or PSH+ACK

TCP-based amplification attacks

Issue an HTTP request for forbidden content

Packet sequences

SYN *with Request*

PSH

PSH+ACK

SYN ; PSH

SYN ; PSH+ACK

Middleboxes can be triggered without any ACK whatsoever

TCP-based amplification attacks

Packet sequences

SYN *with Request*

PSH

PSH+ACK

SYN ; PSH

SYN ; PSH+ACK

Variants

Details in the paper

Increased `TTL`

Increased `wscale`

TCP Segmentation

`FIN+CWR`

HTTP without \r\n

Increase amplification for small fractions of middleboxes

TCP-based amplification attacks

Packet sequences

- SYN *with Request*
- PSH
- PSH+ACK
- SYN ; PSH
- SYN ; PSH+ACK

Triggering domains

`www.youporn.com`	porn
`www.roxypalace.com`	gambling
`plus.google.com`	social
`www.bittorent.com`	file sharing
`www.survive.org.uk`	sex health

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Middleboxes differ in their bugs and their configurations

How can we evaluate this attack?

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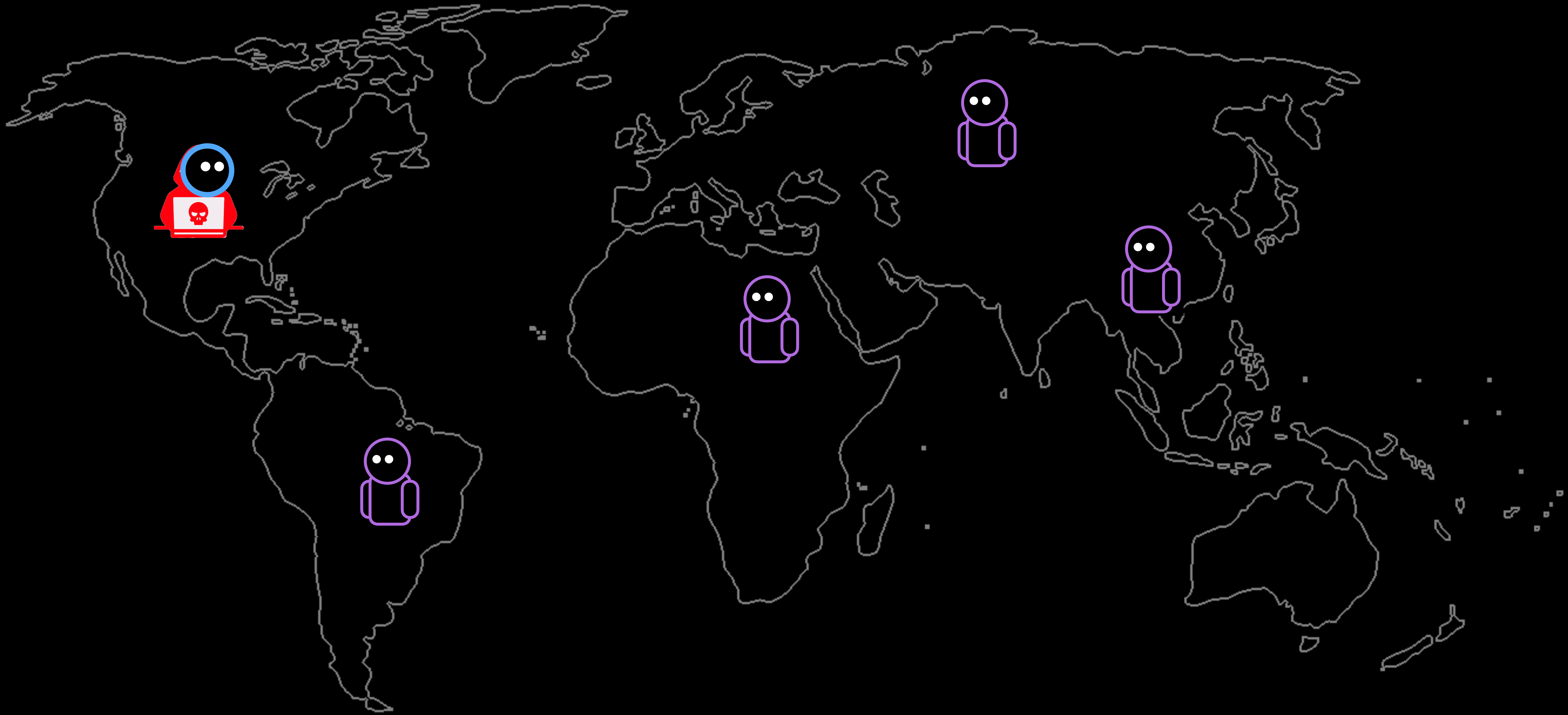

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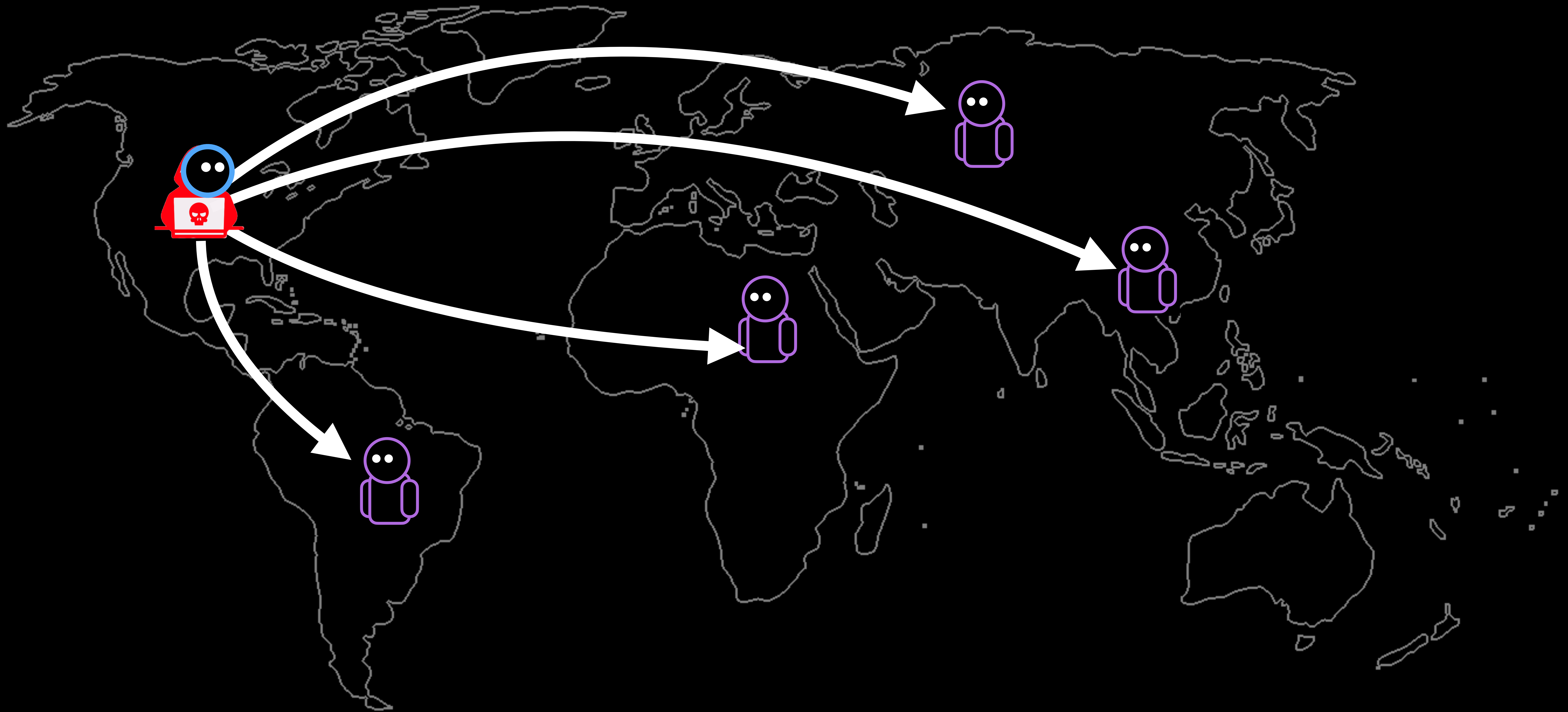

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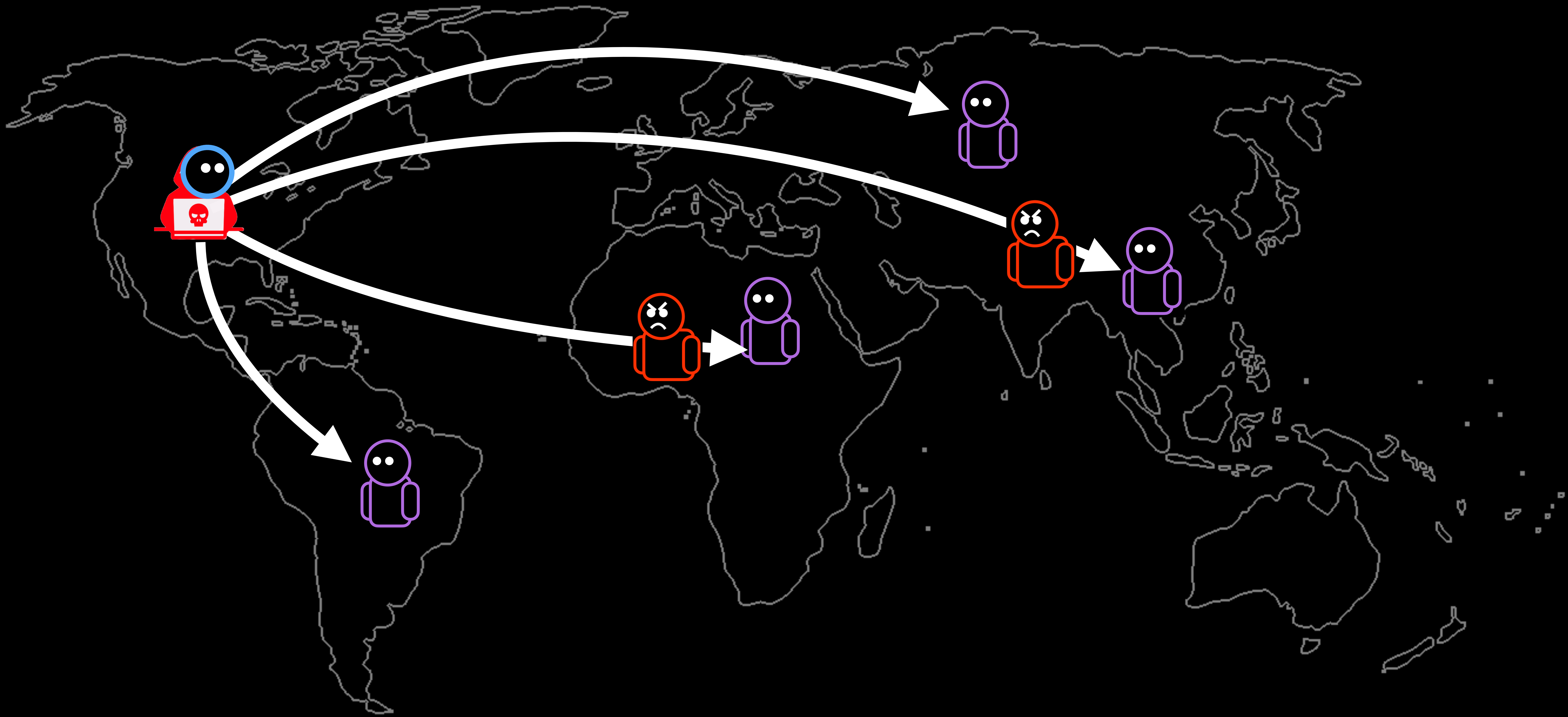

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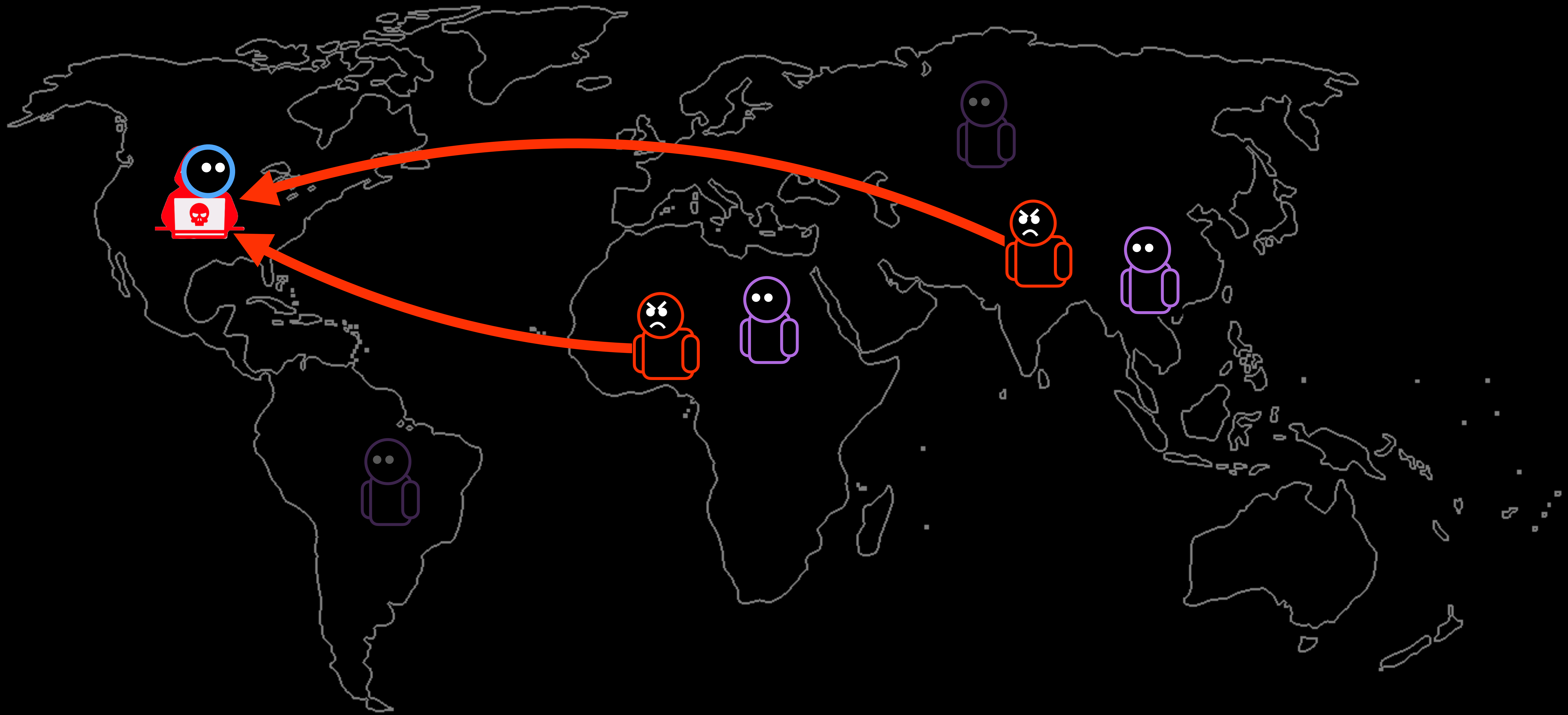

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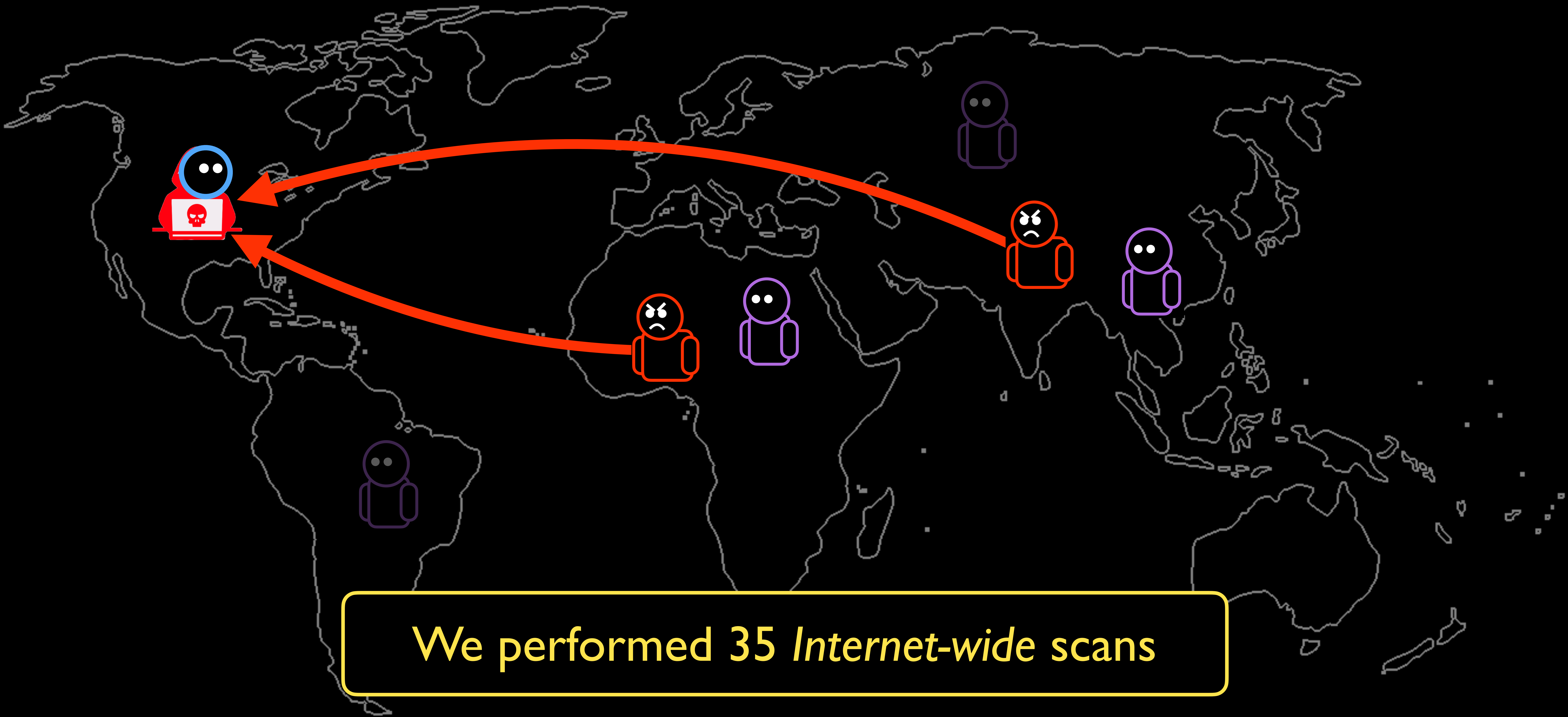
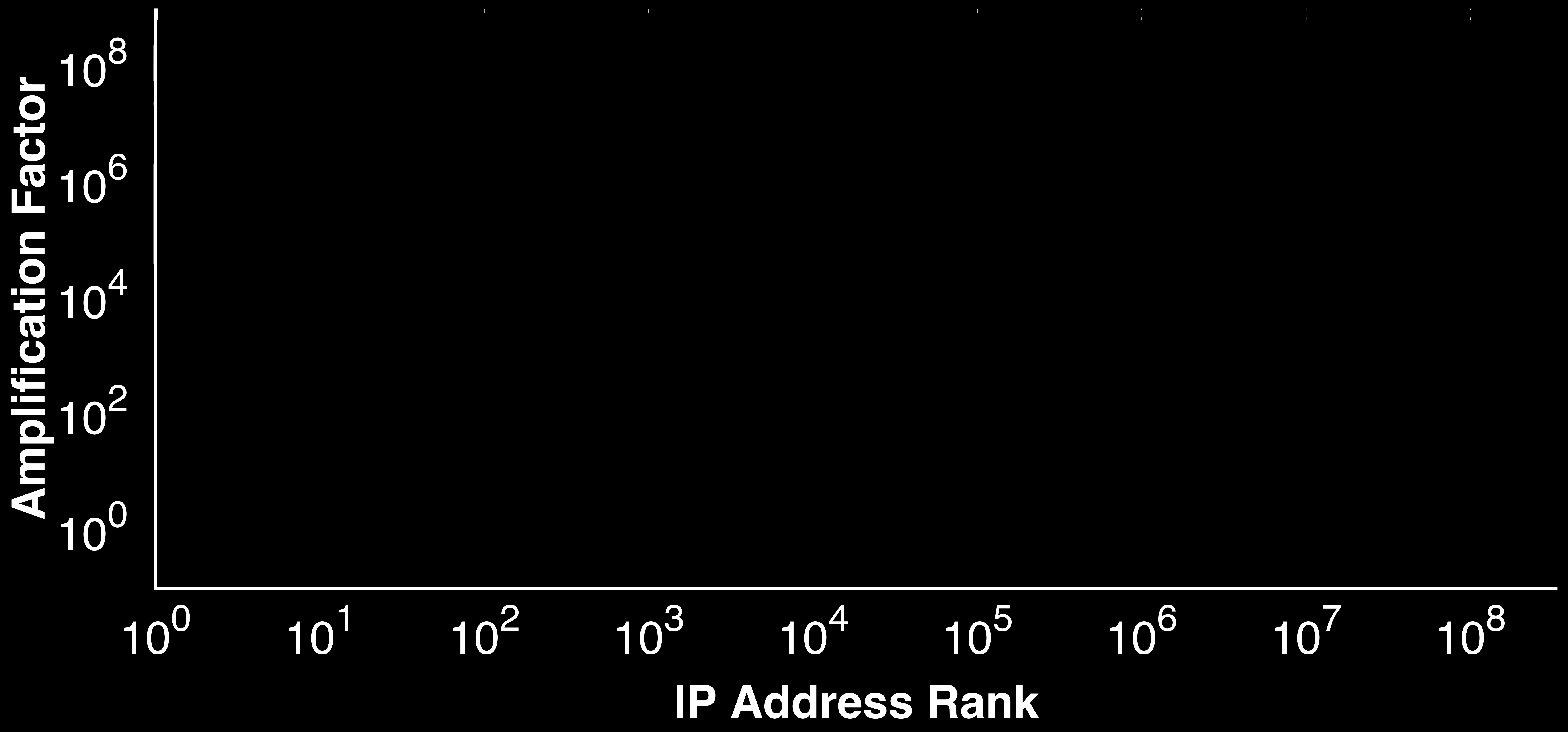


We performed 35 *Internet-wide* scans

Amplification by packet sequence



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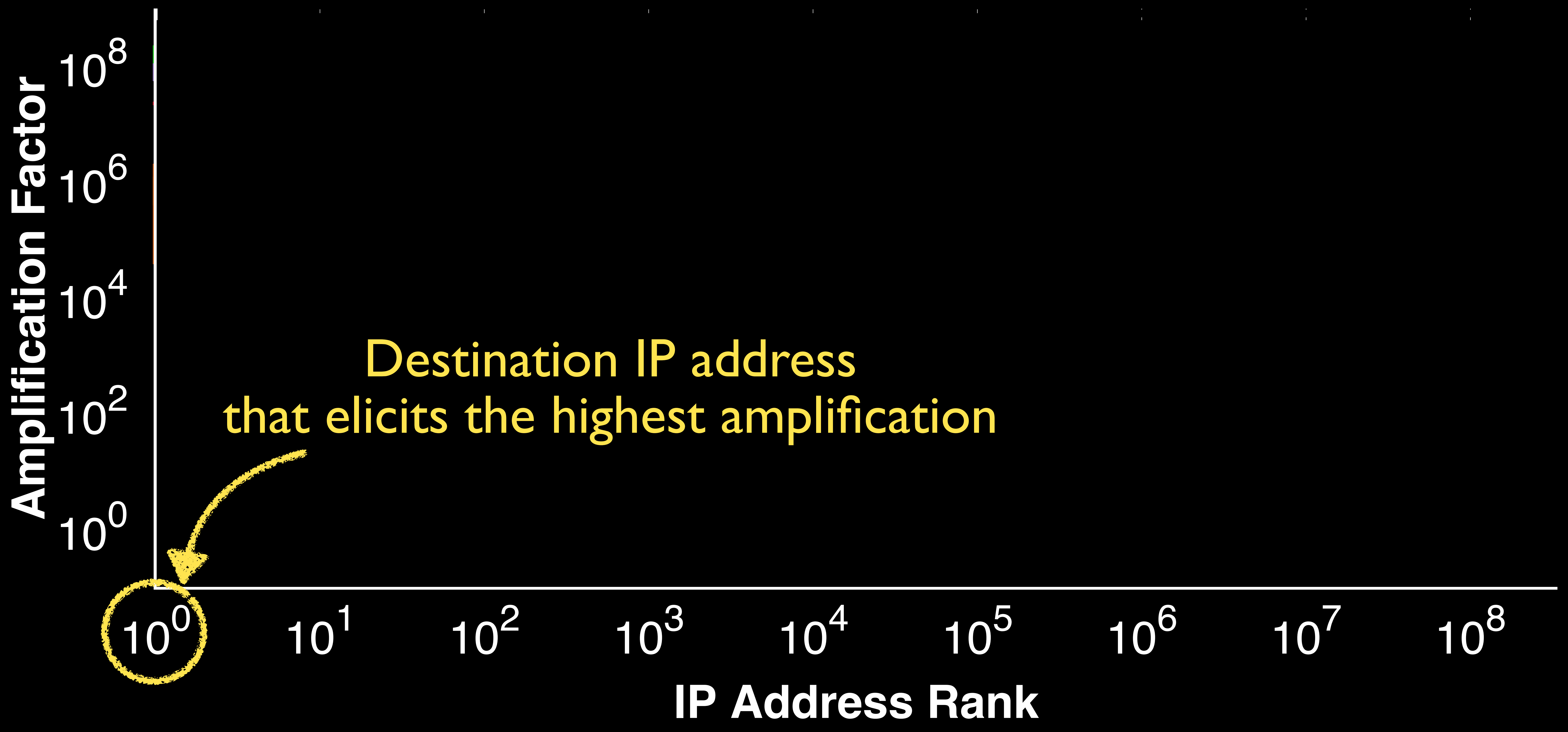
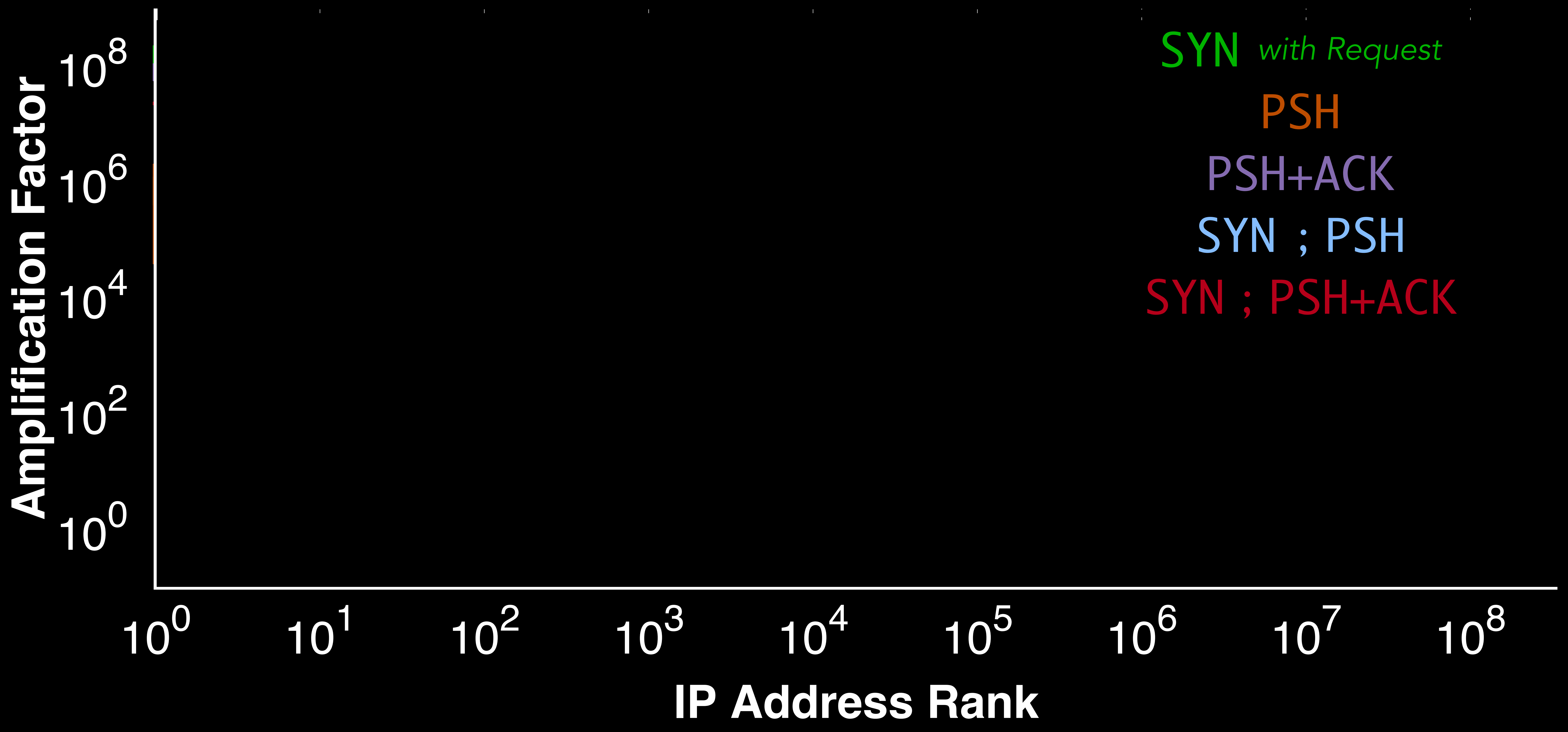


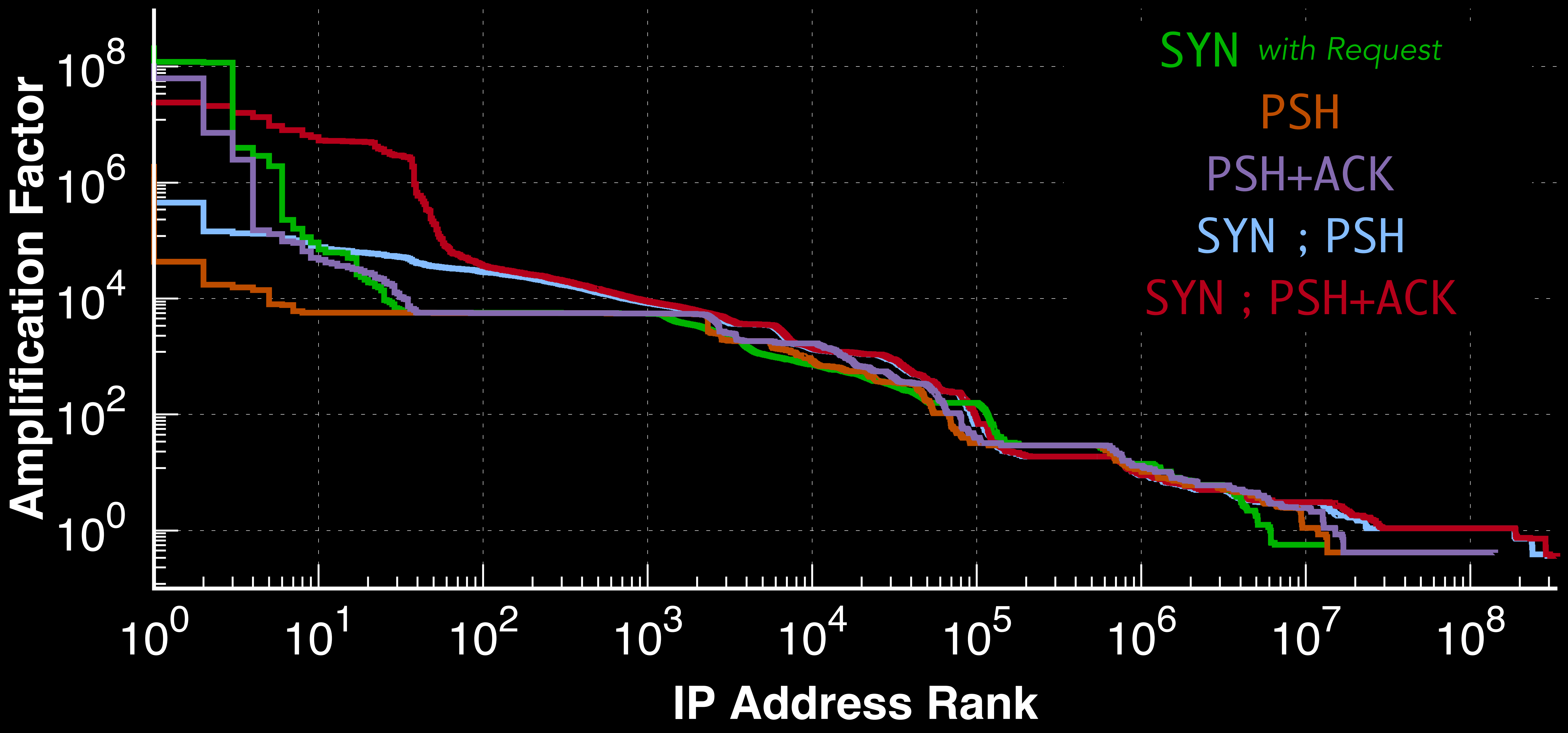
Destination IP address
that elicits the highest amplification

Amplification by packet sequence



Amplification by packet sequence

Triggered with `www.youporn.com`



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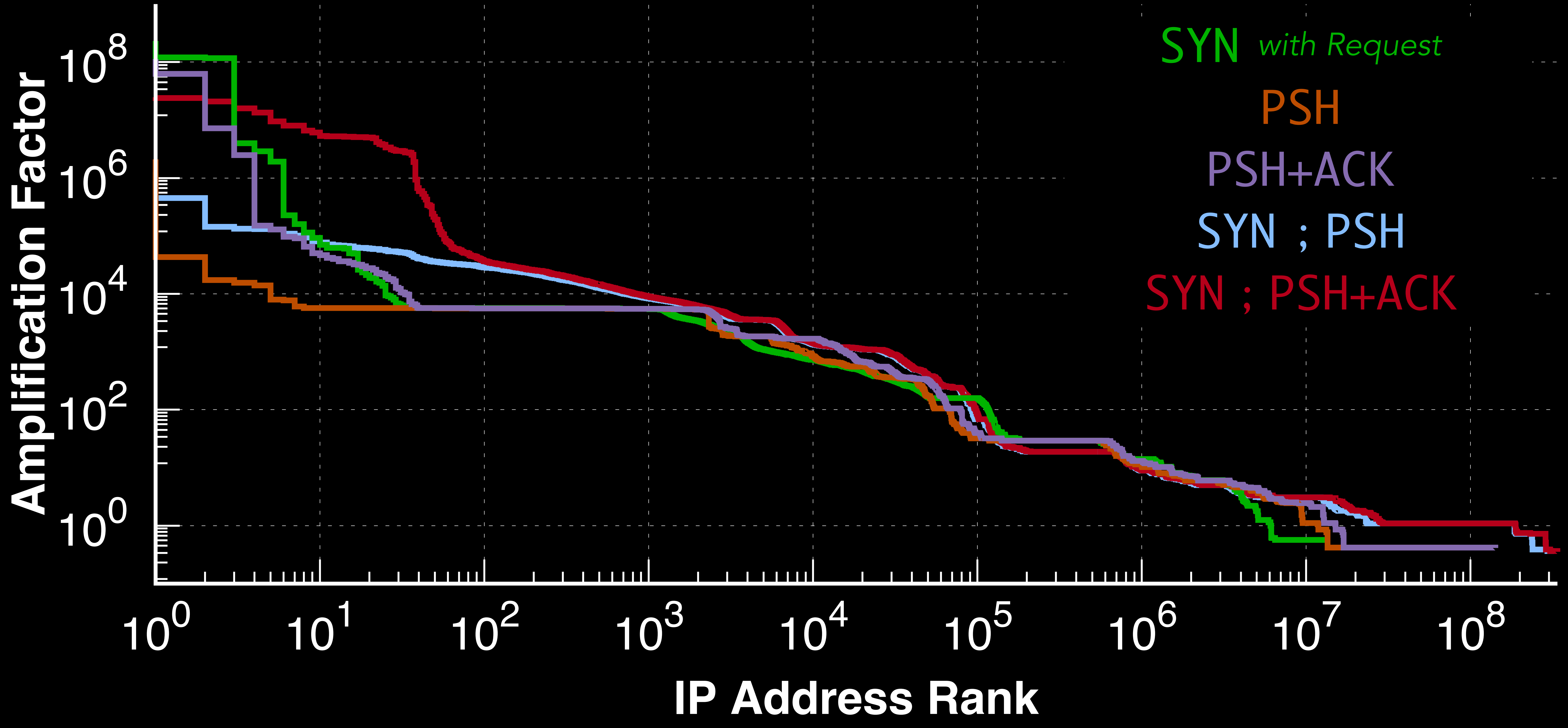

Packet sequences differ in amplification and number of amplifiers

Amplification by packet sequence

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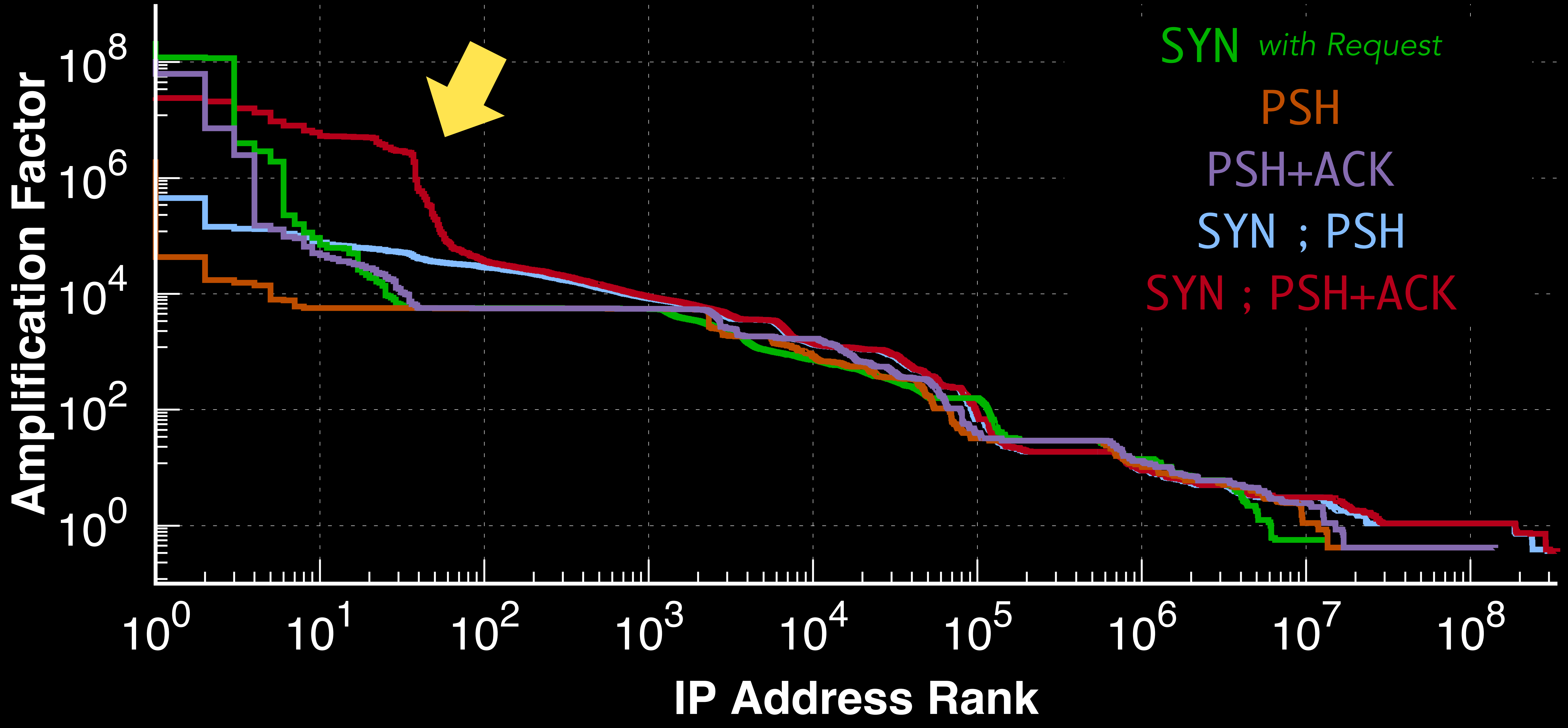

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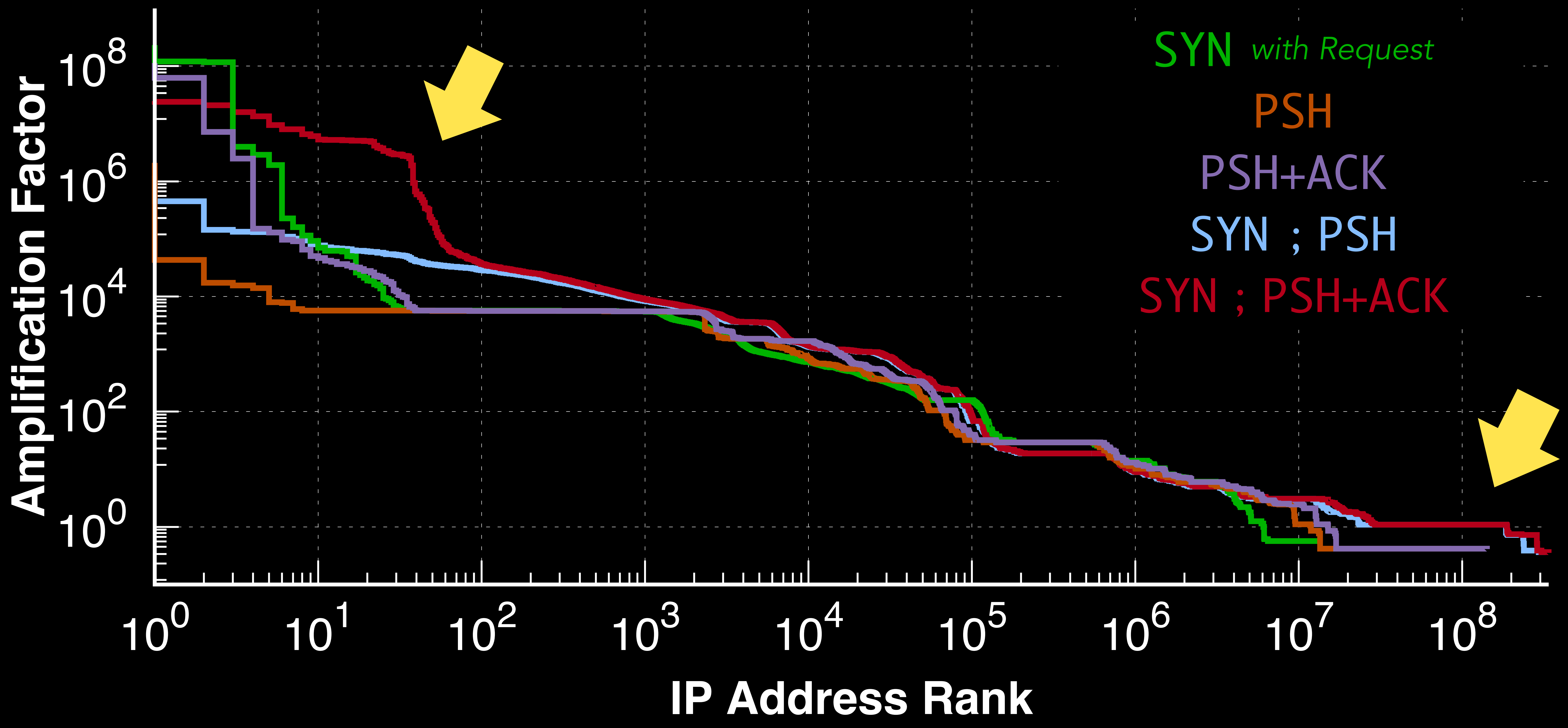
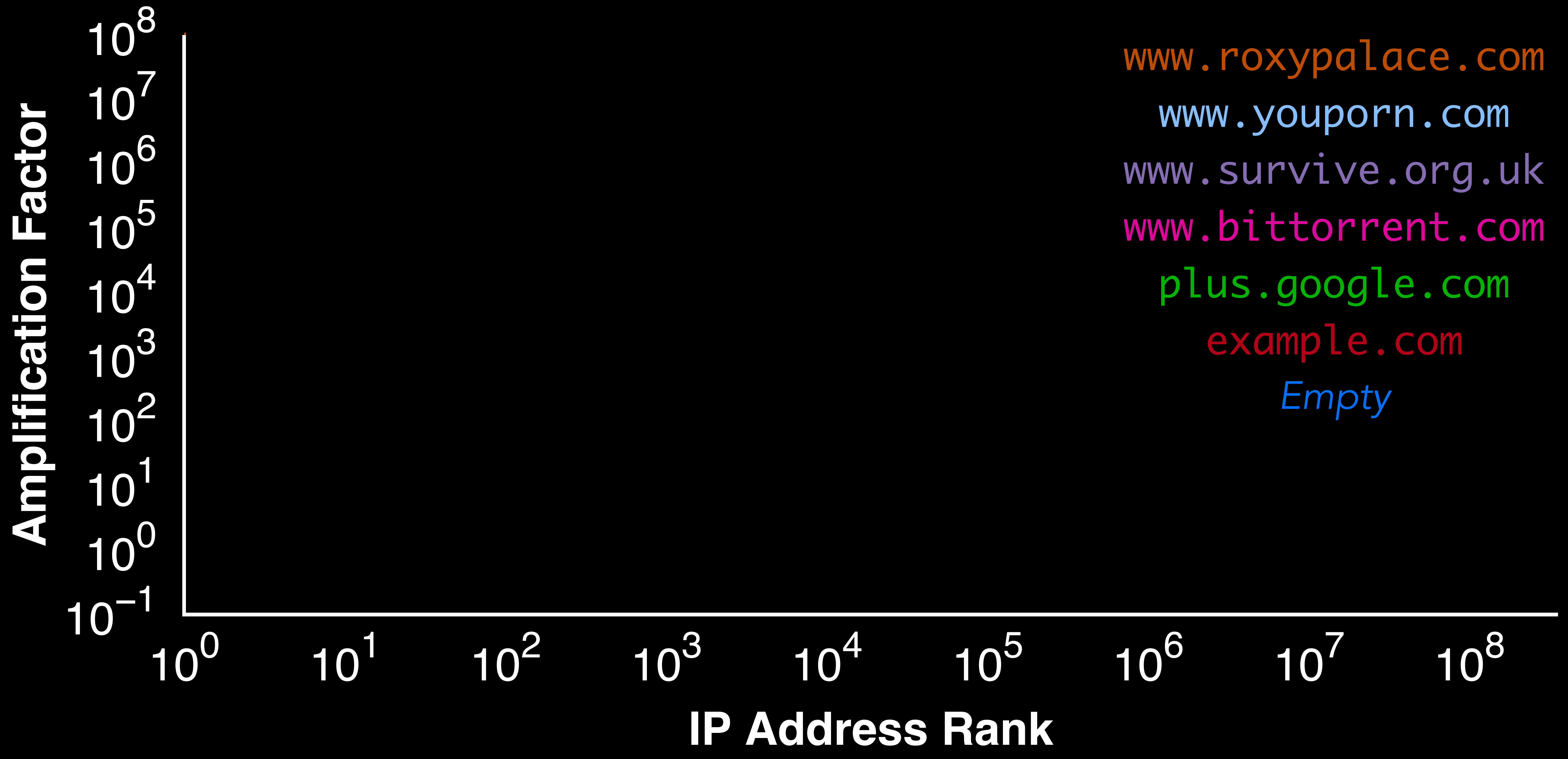
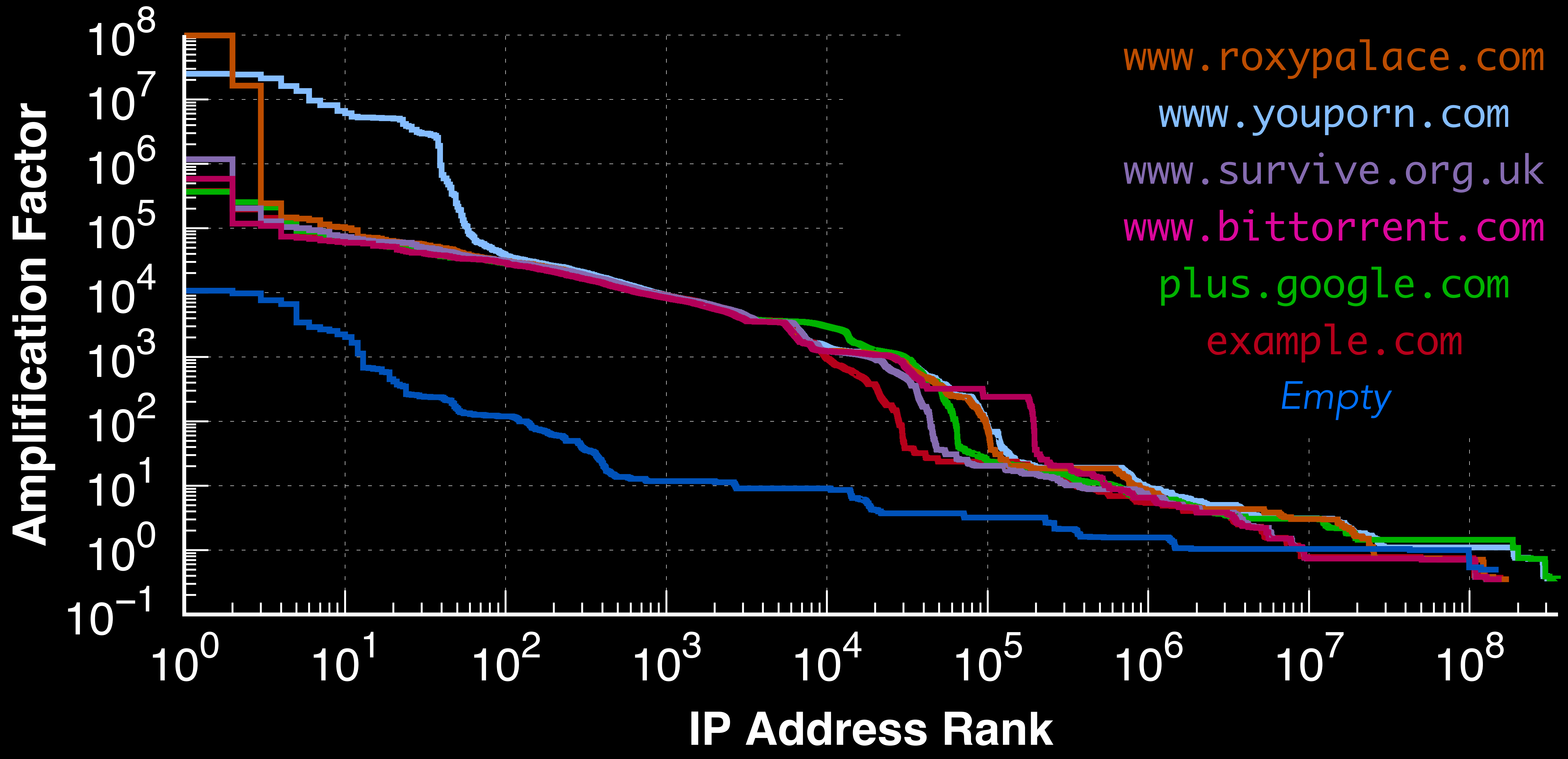


Packet sequences differ in amplification and number of amplifiers

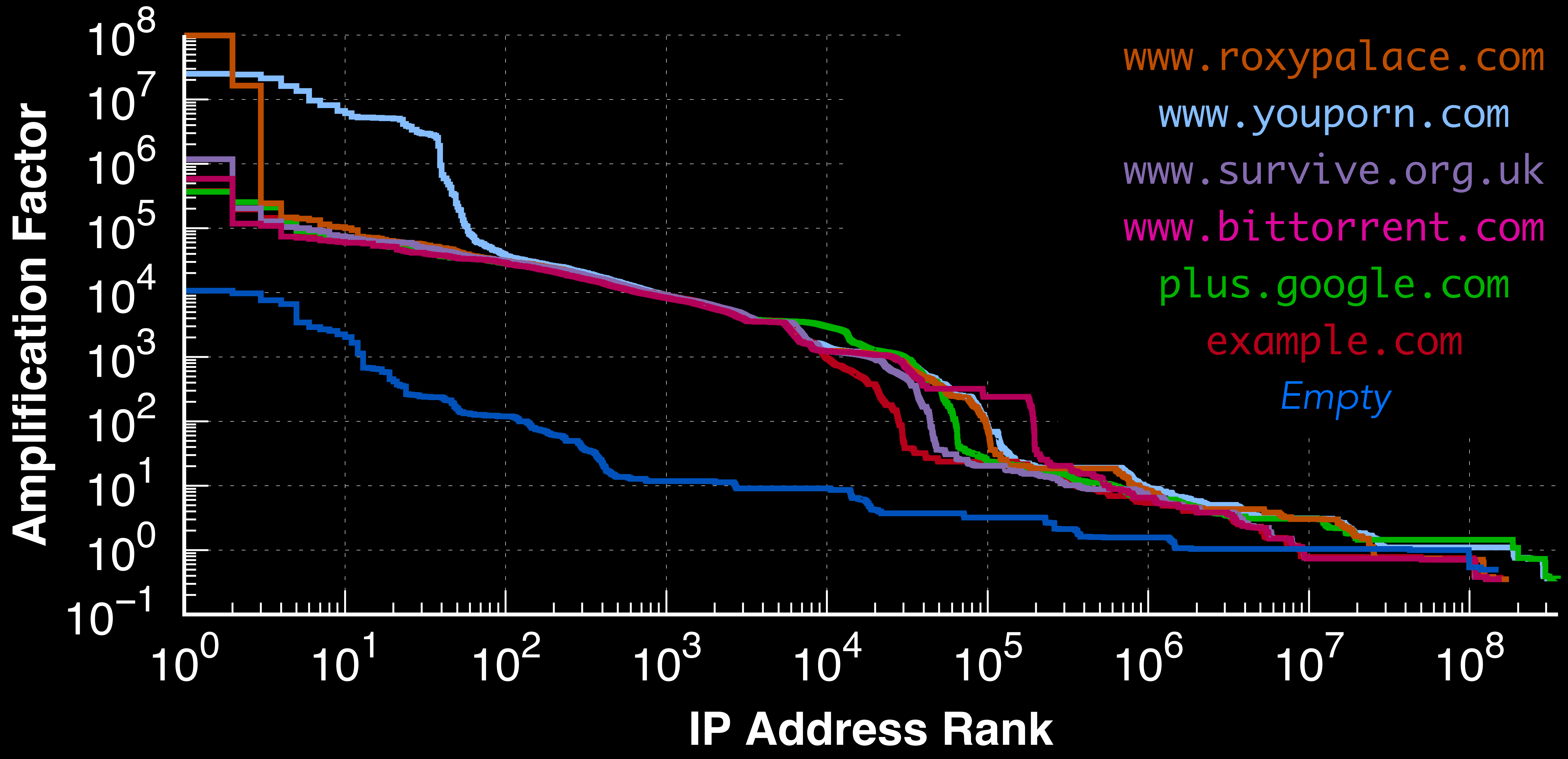
Amplification by triggering domain



Amplification by triggering domain



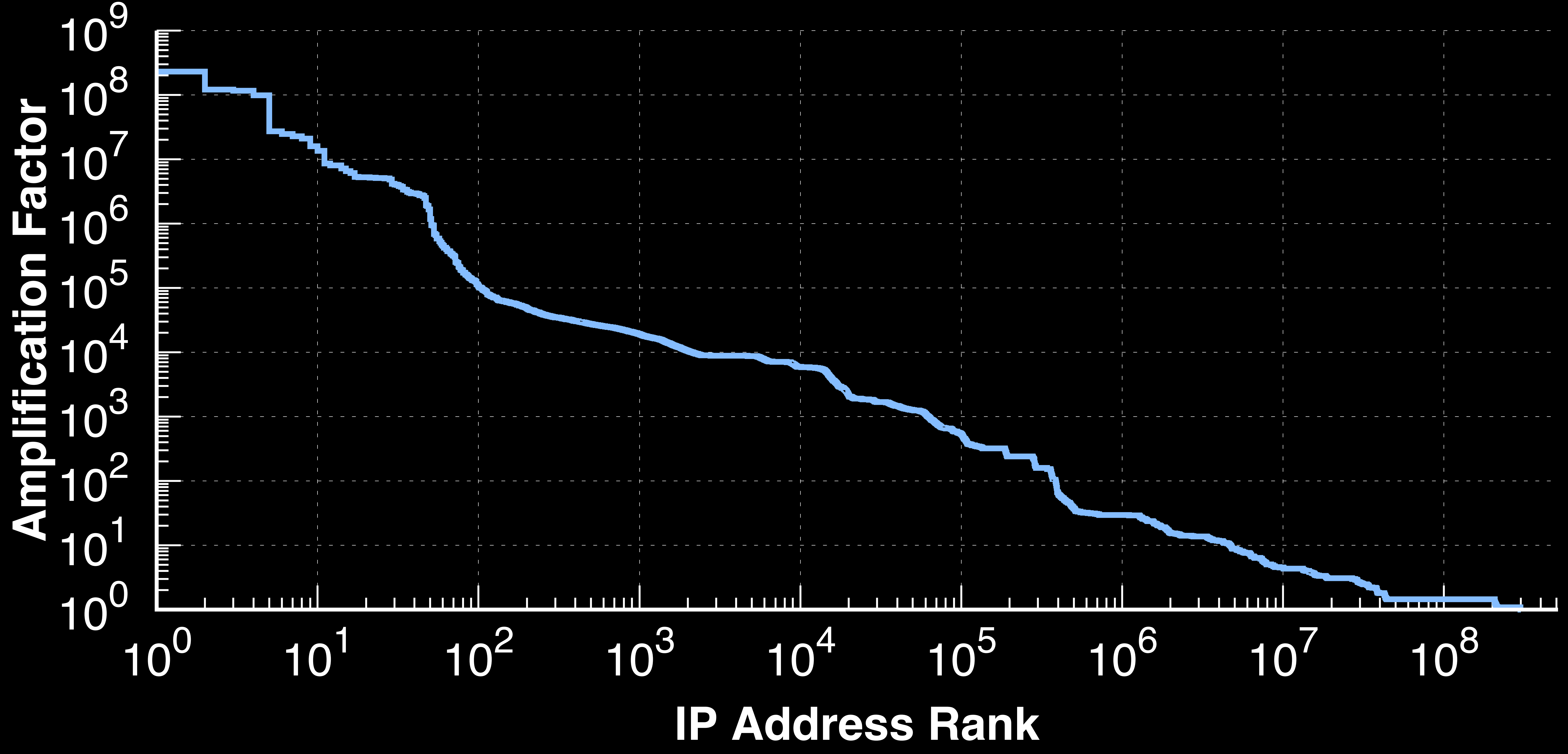
Amplification by triggering domain



Different triggering domains can yield drastically different amplification

Maximum amplification

Assuming a perfectly-informed attacker



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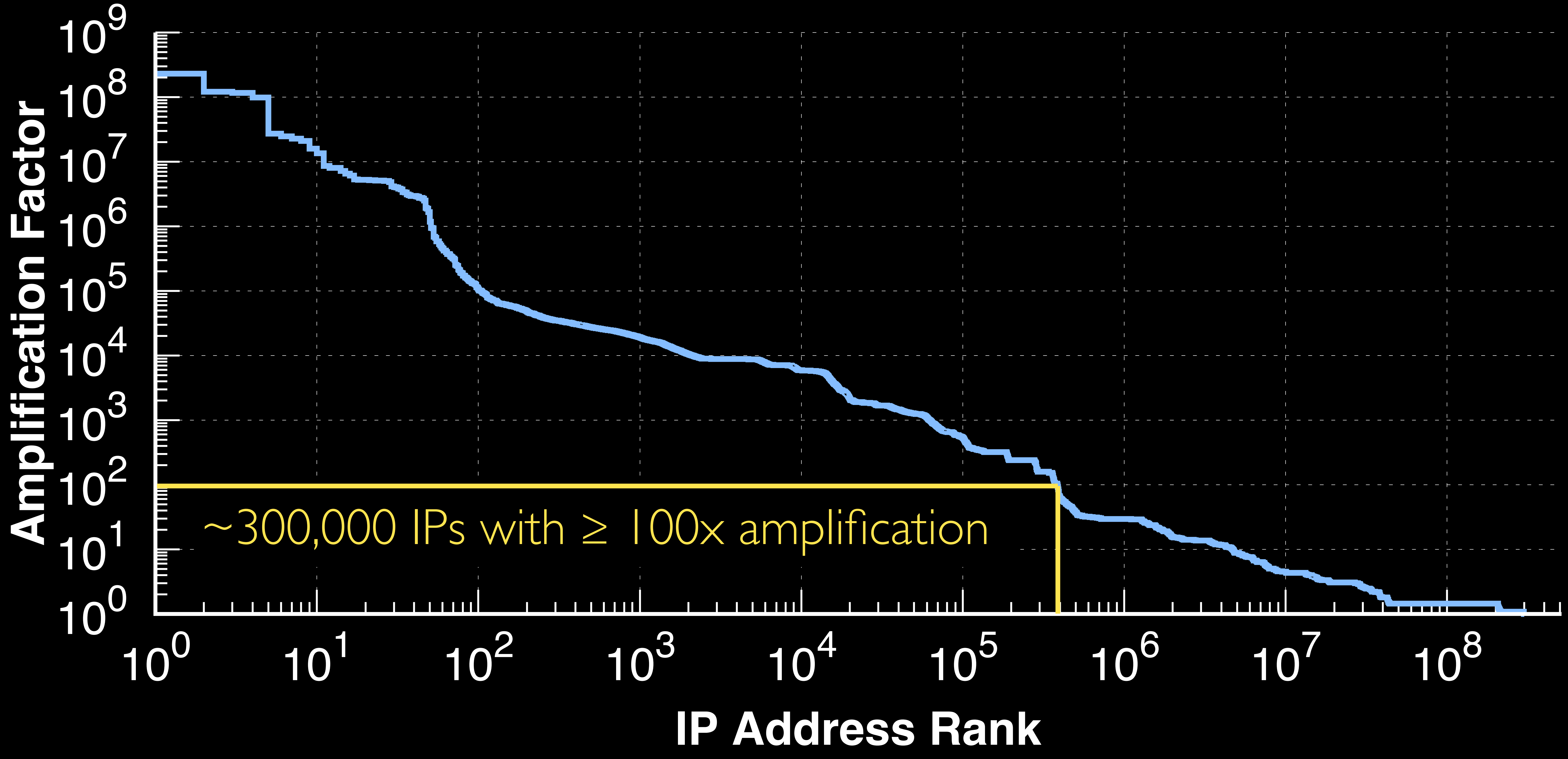

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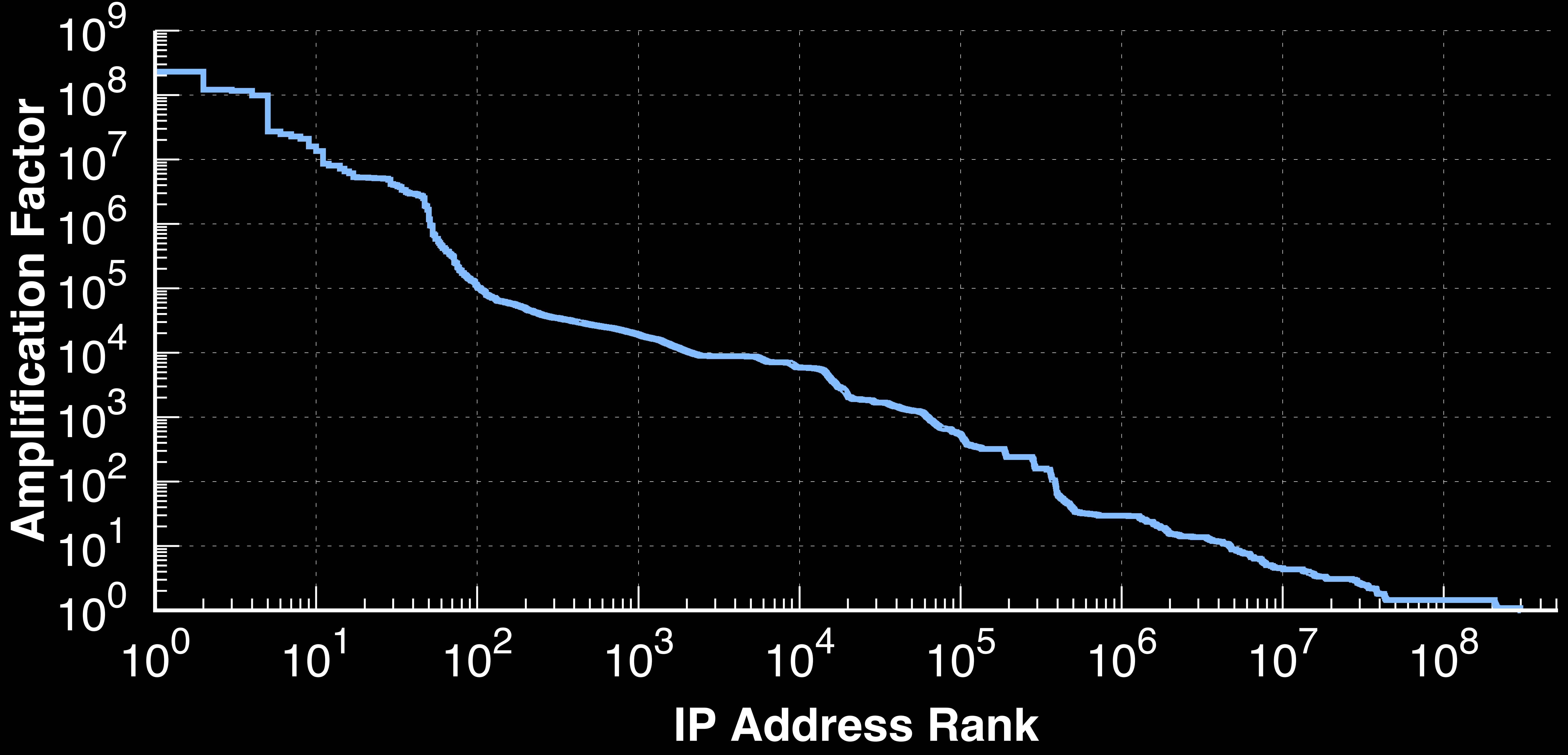

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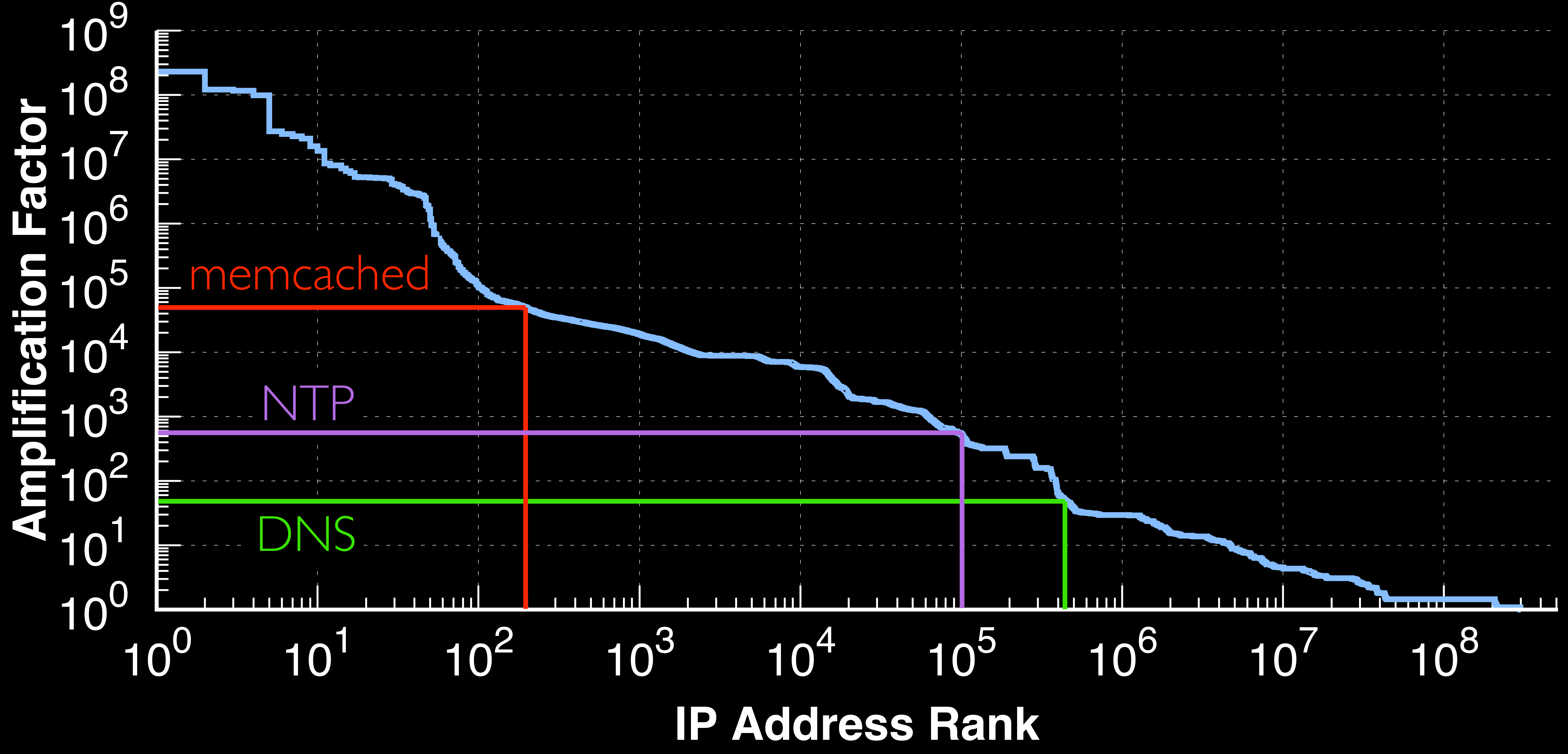

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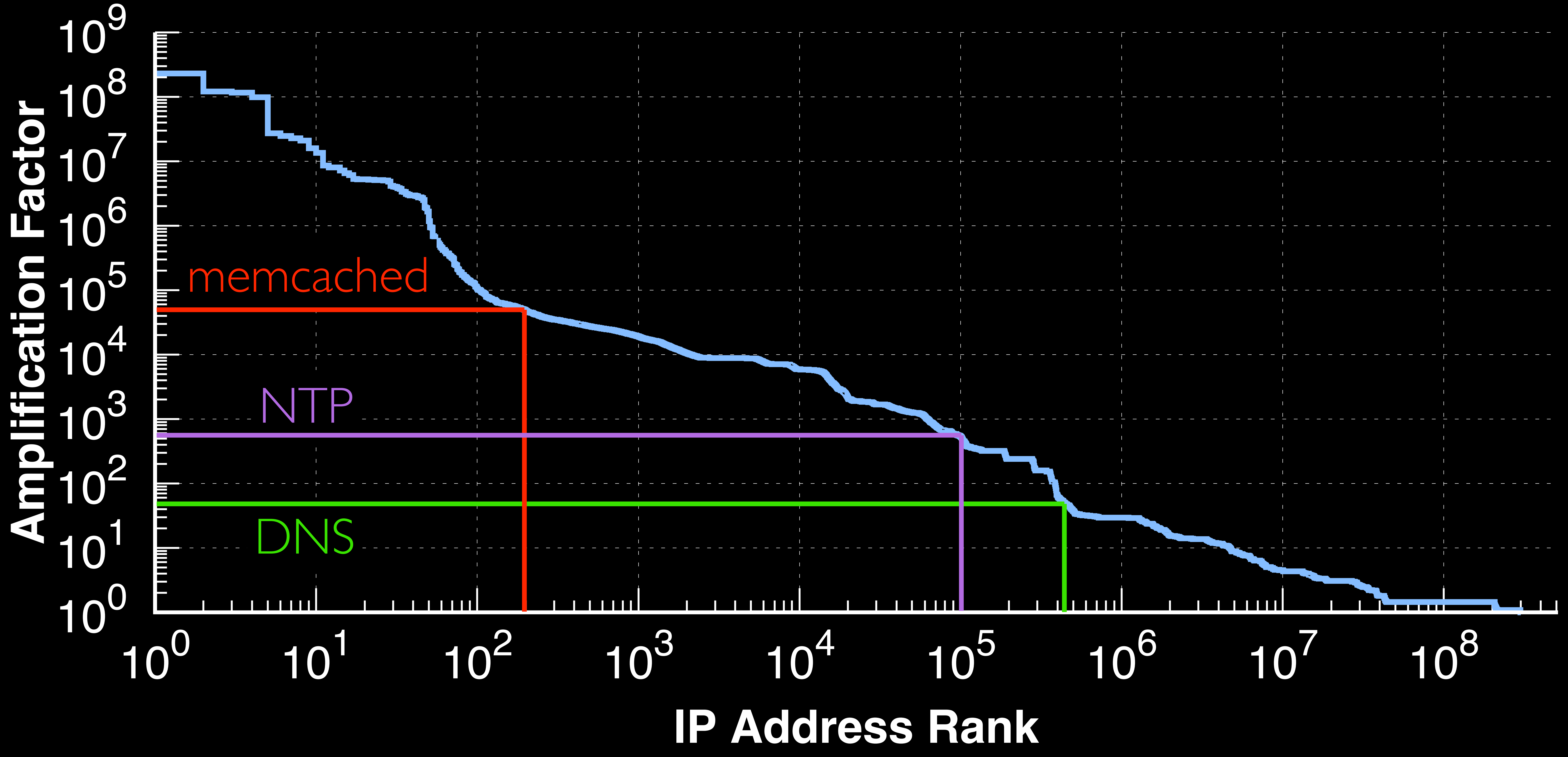

TCP-based amplification is at least as powerful as UDP-based alternatives

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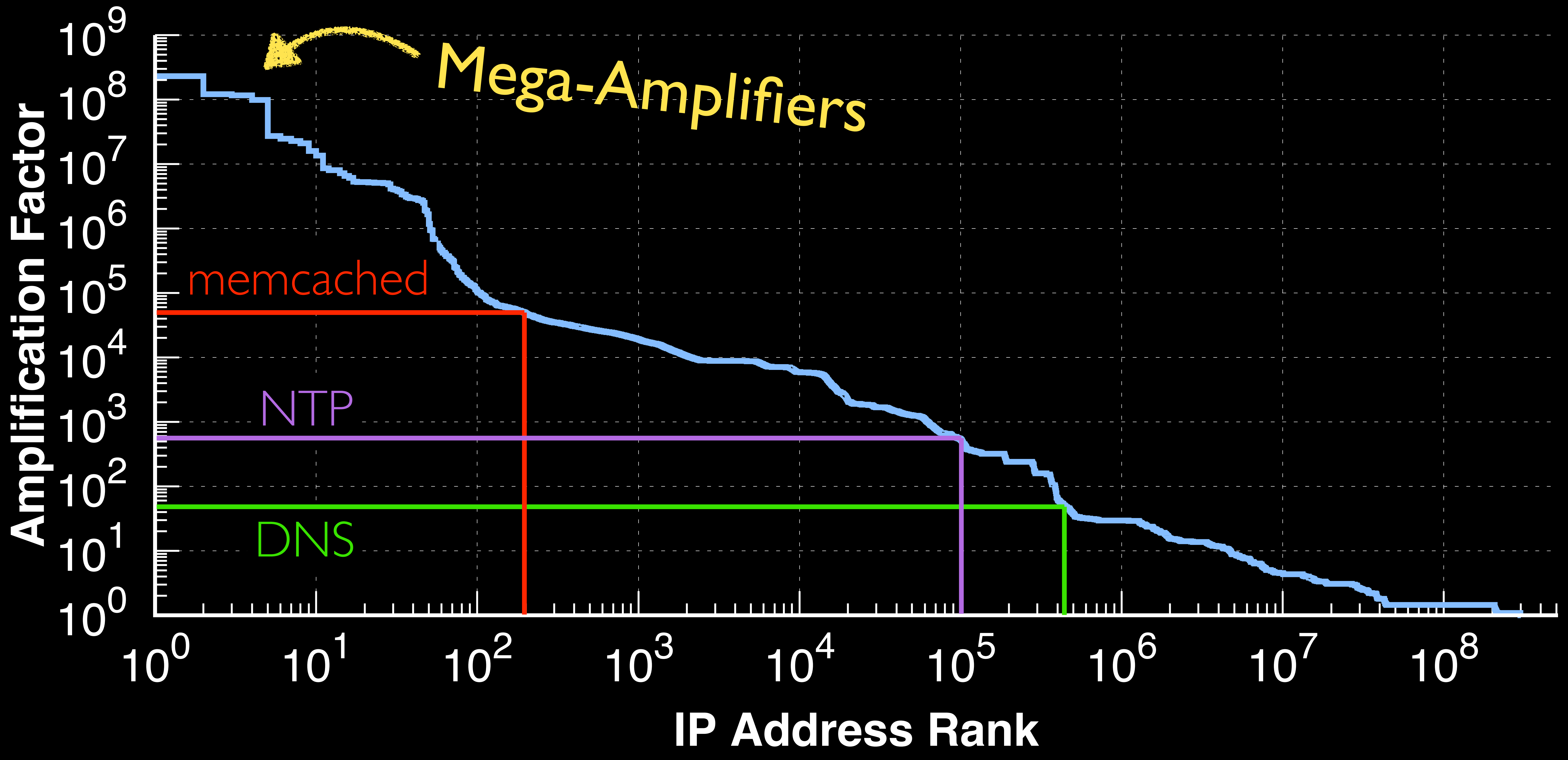
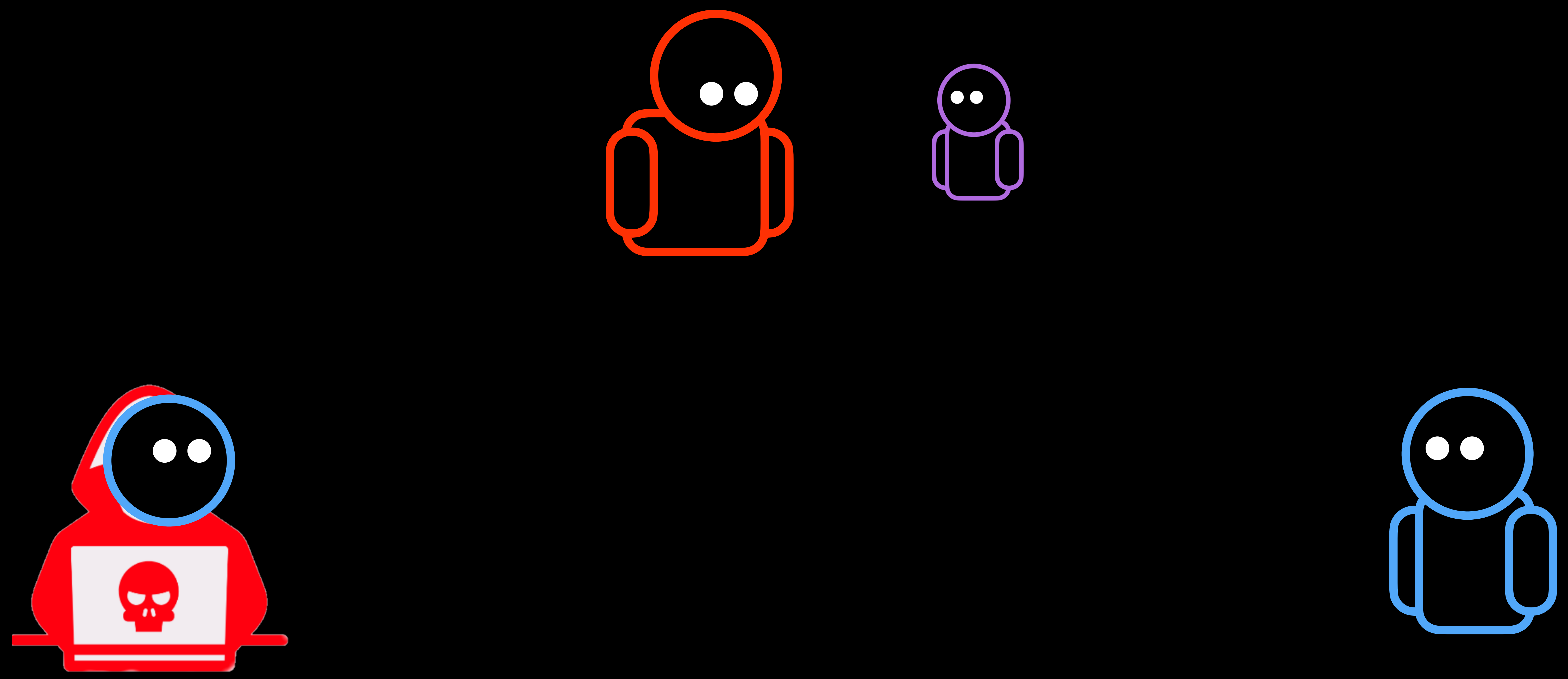


TCP-based amplification is at least as powerful as UDP-based alternatives

Mega-amplifier cause #1: Victim-sustained loops



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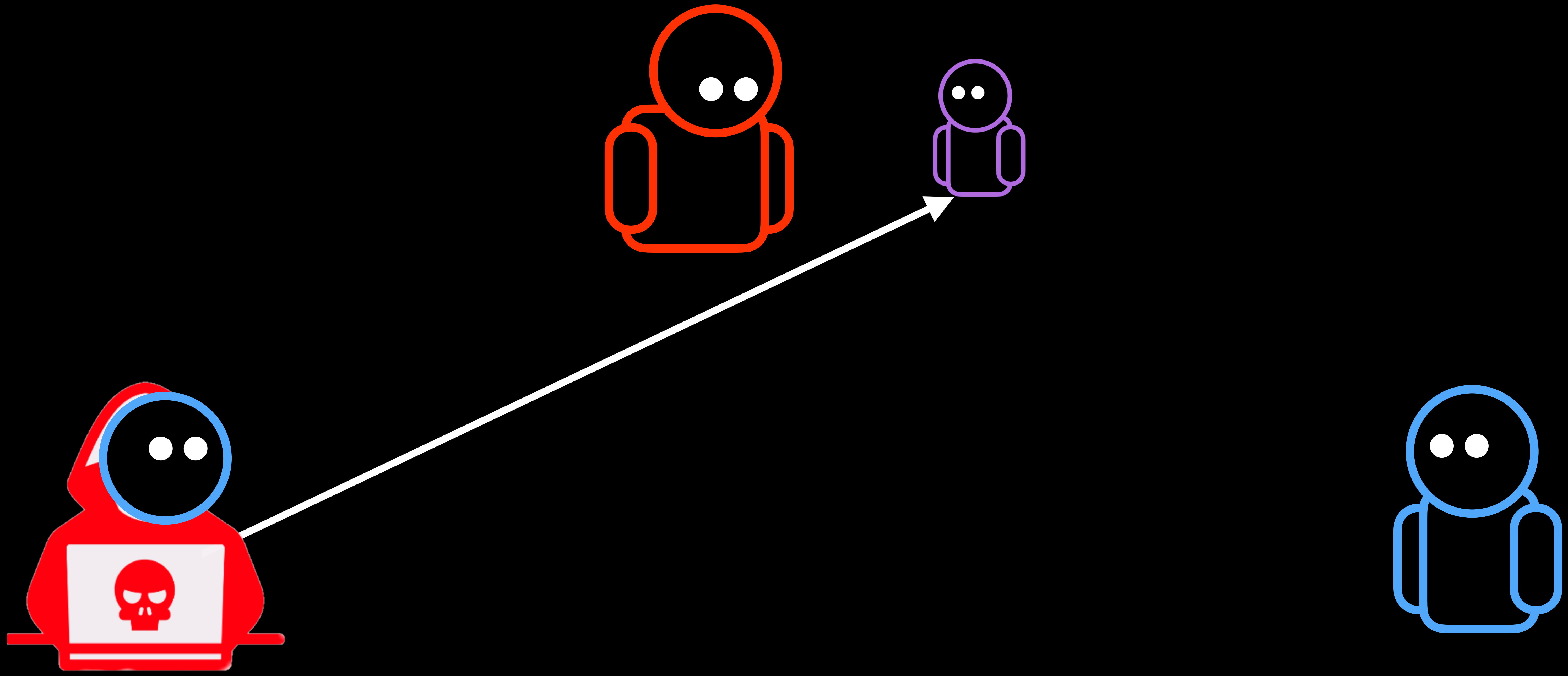

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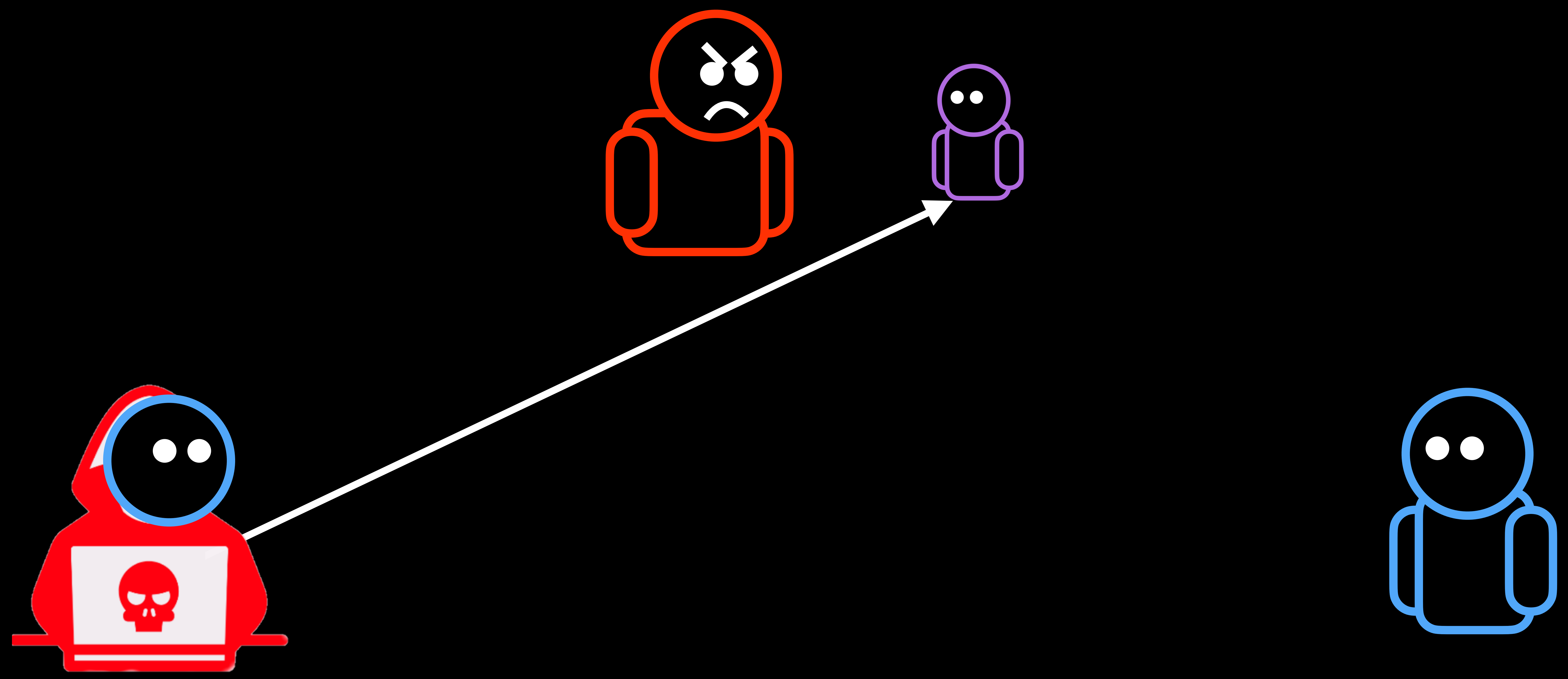

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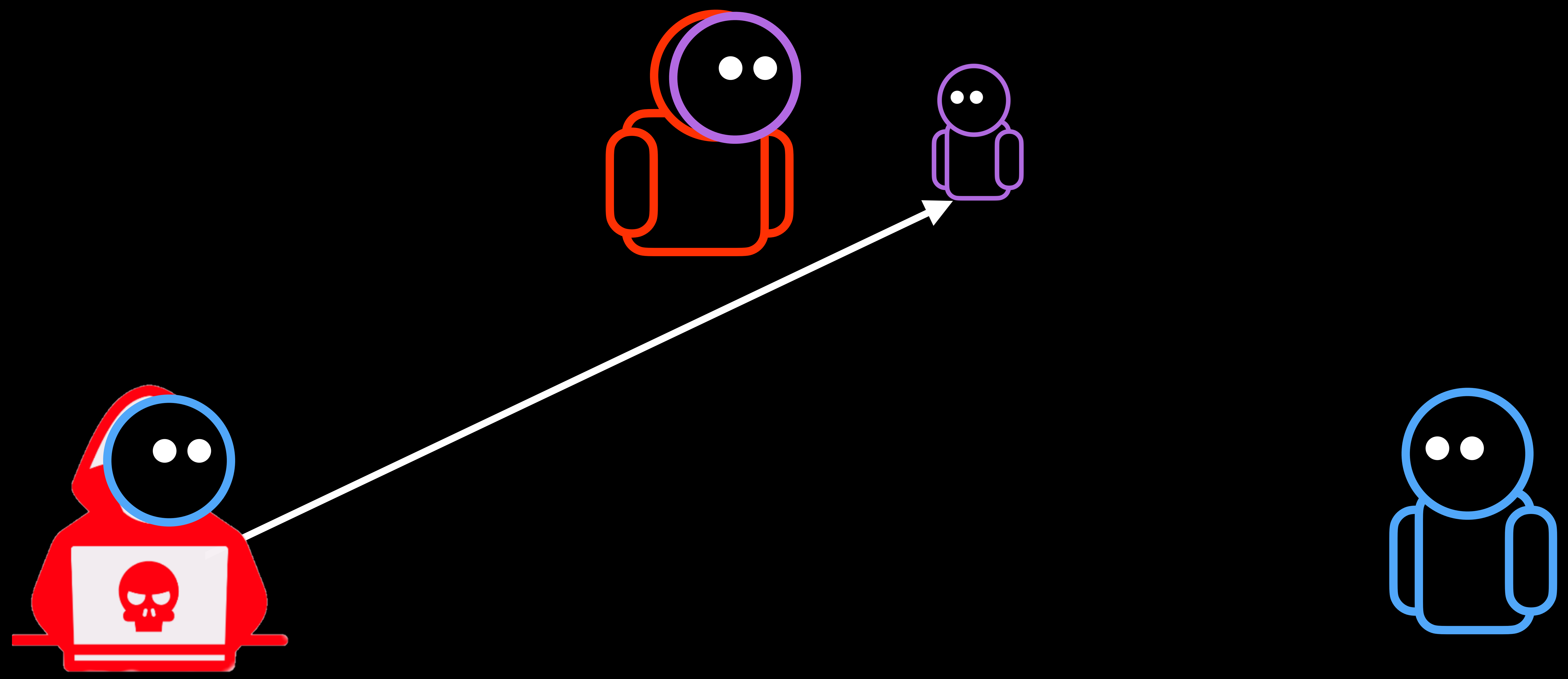

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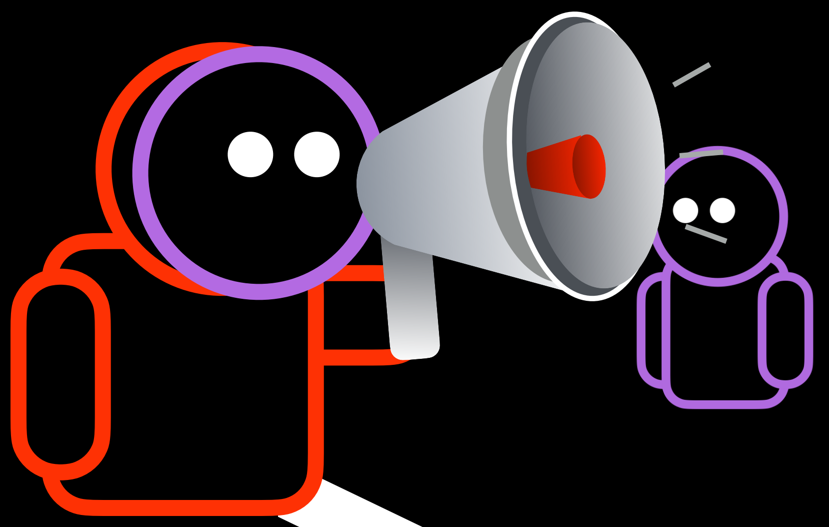

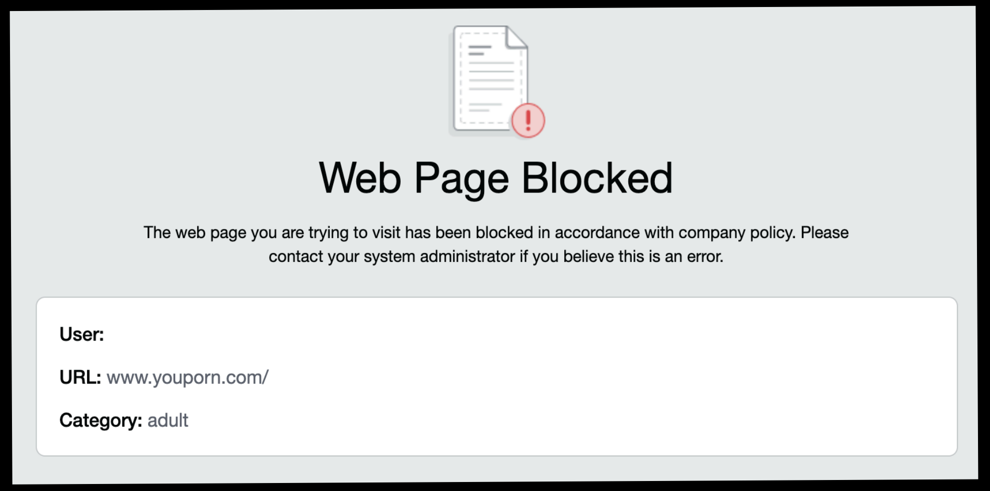

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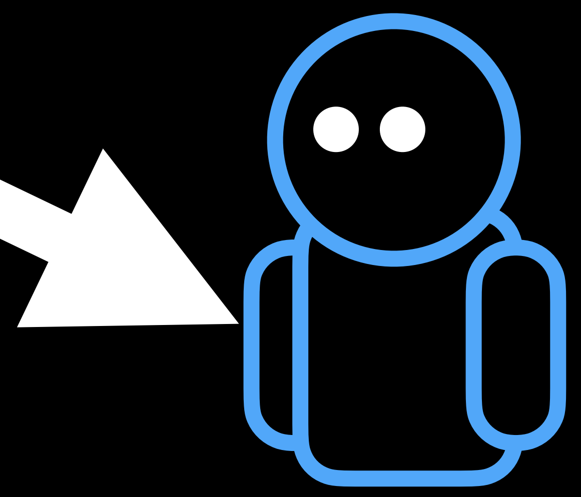
The web page you are trying to visit has been blocked in accordance with company policy. Please contact your system administrator if you believe this is an error.

User:

URL: www.youporn.com/

Category: adult



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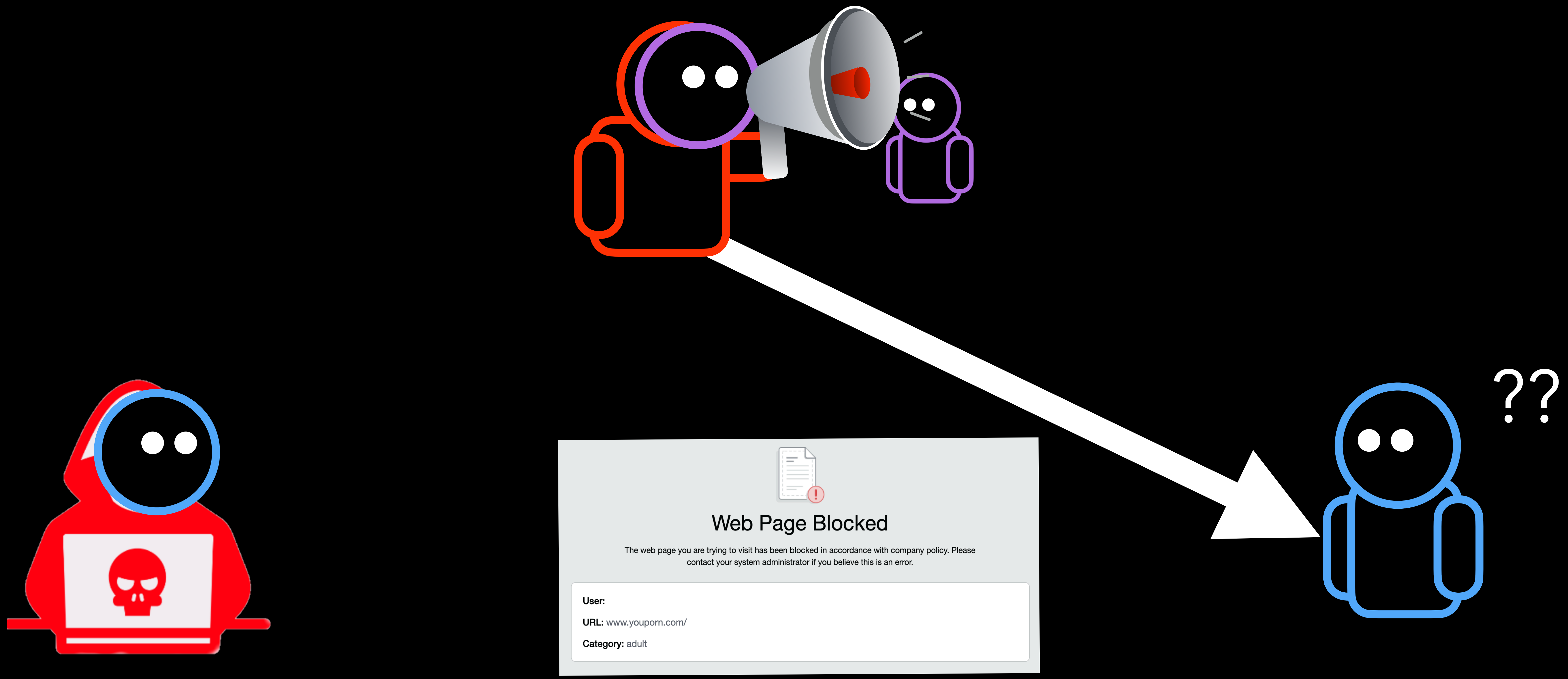

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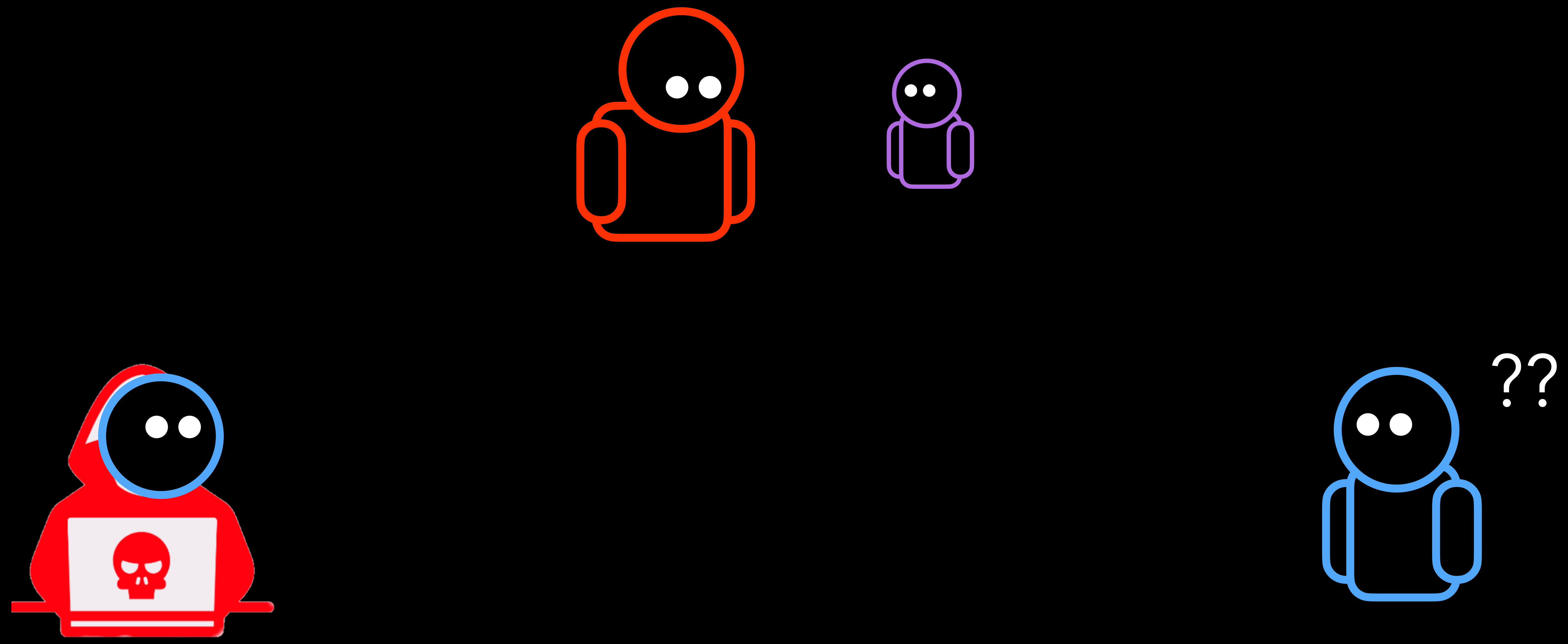
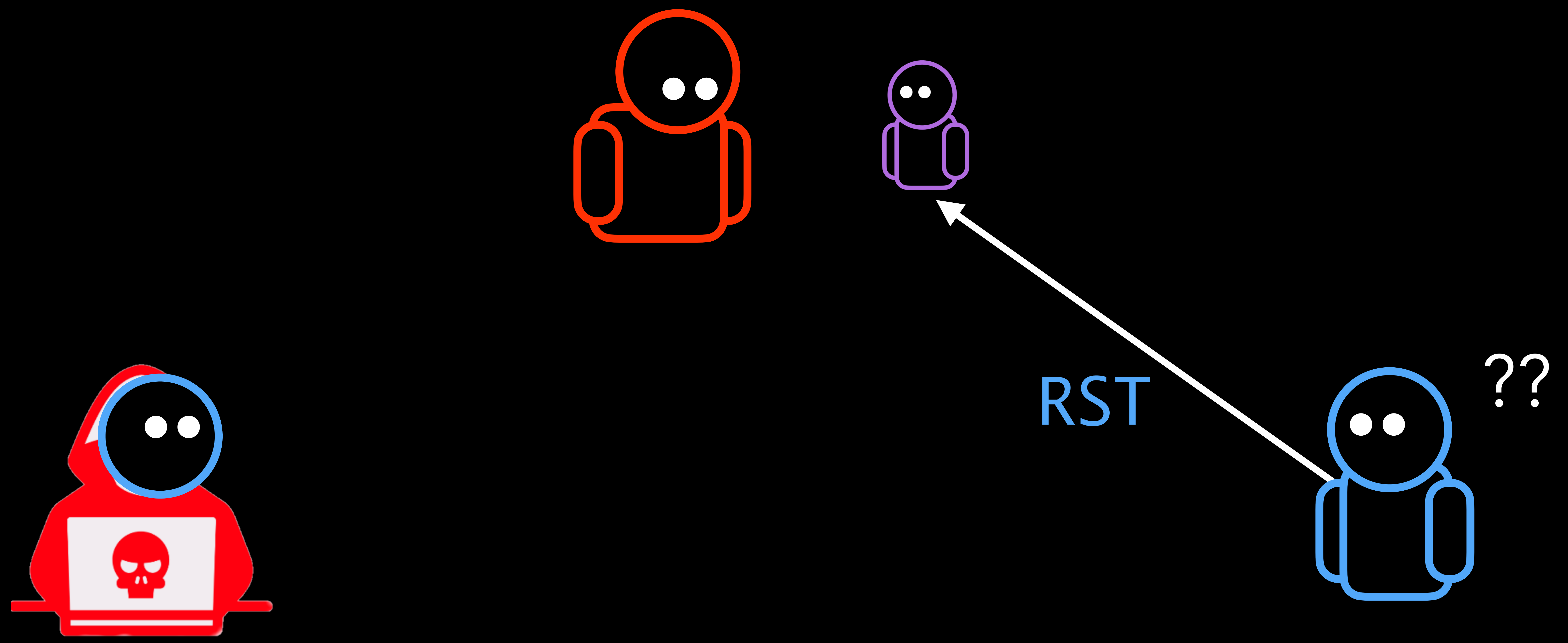


Proper client behavior

Mega-amplifier cause #1: Victim-sustained loops



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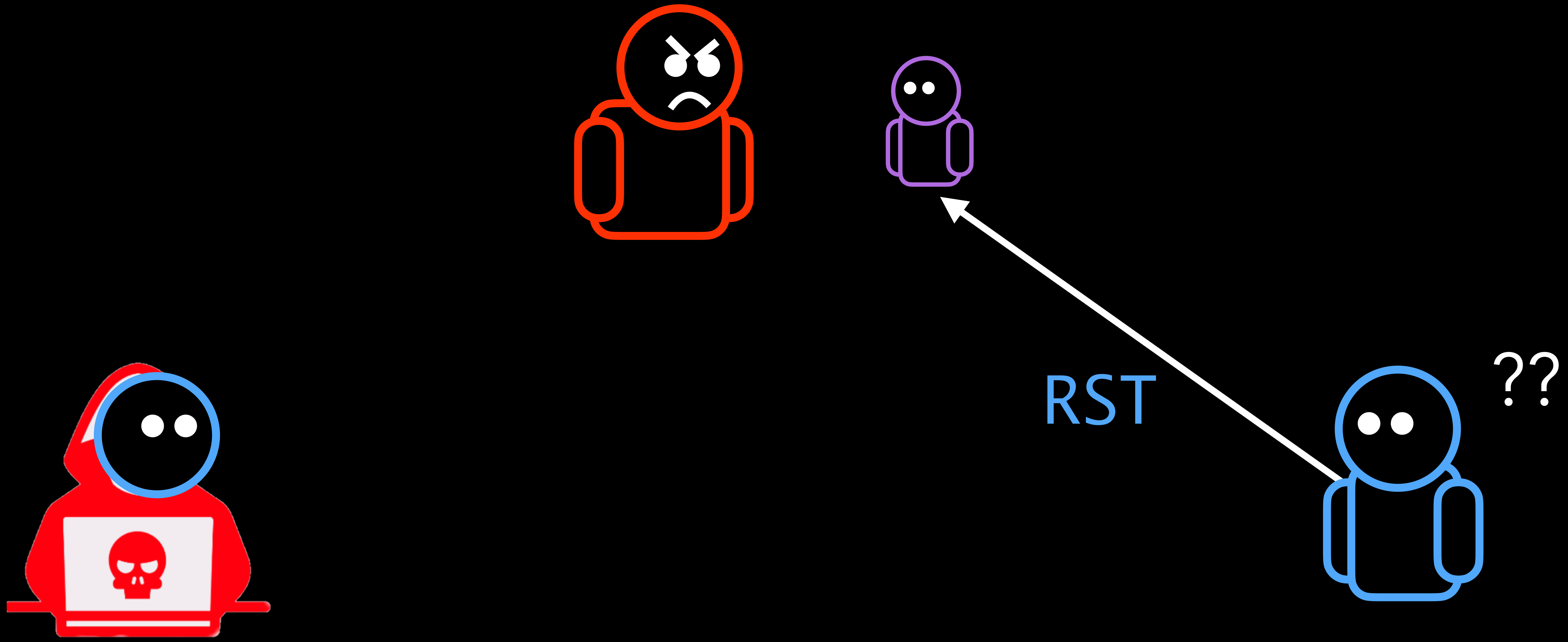
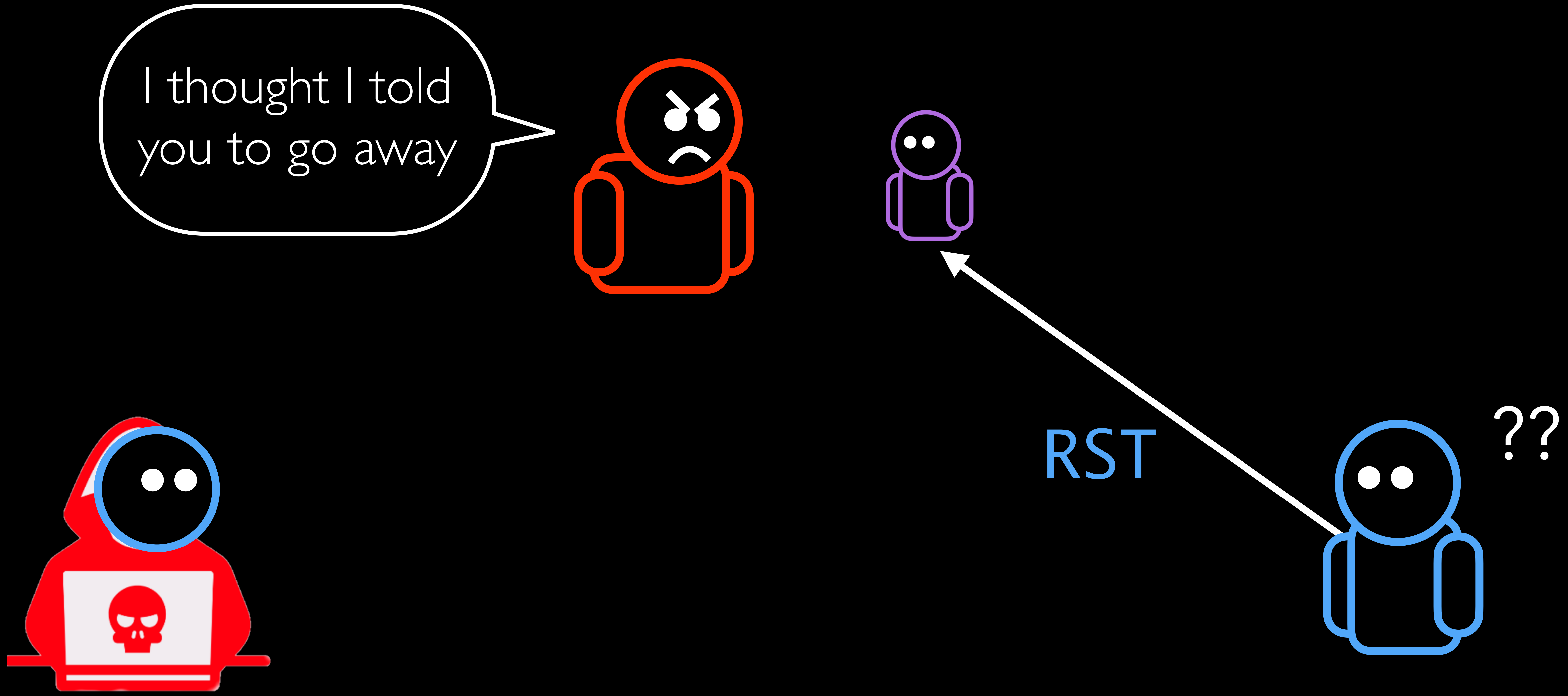


Sometimes, *any* packet re-triggers censorship

Mega-amplifier cause #1: Victim-sustained loops



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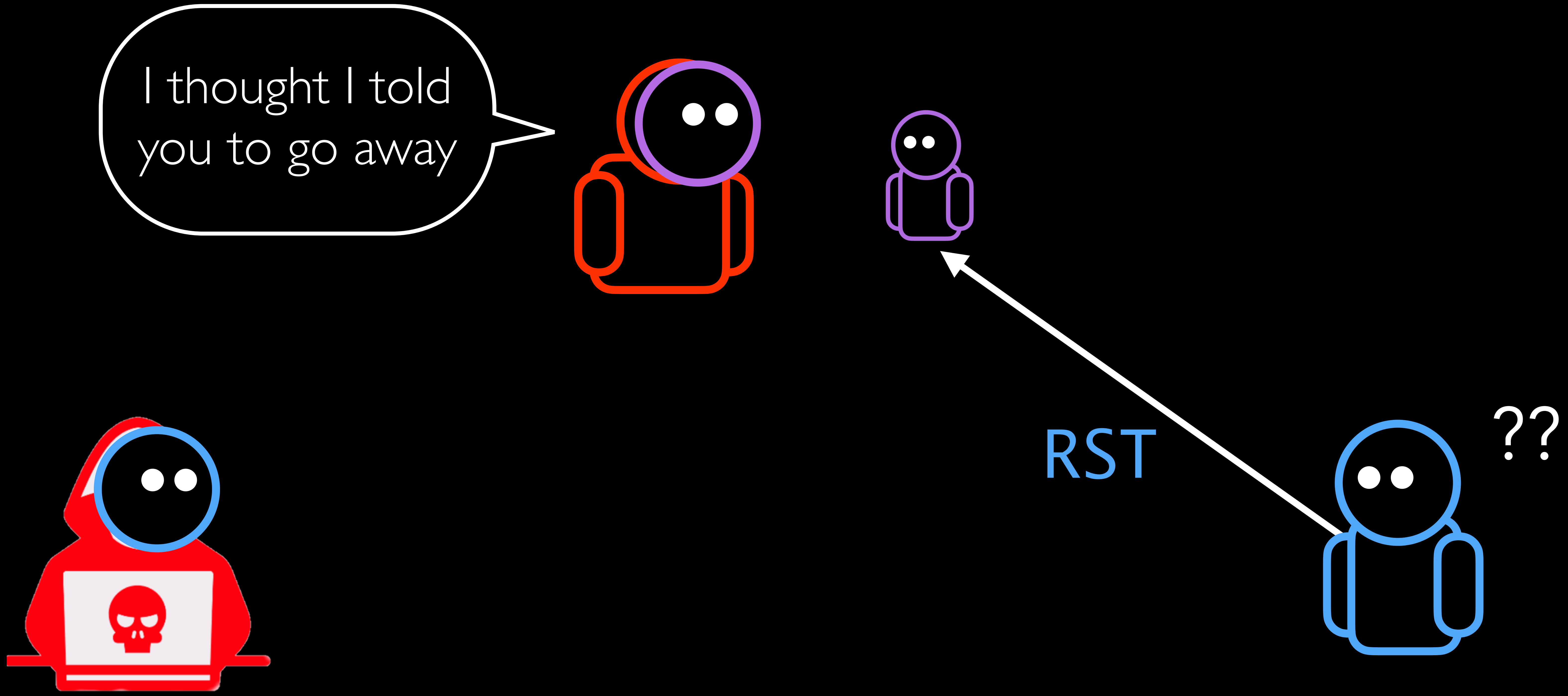

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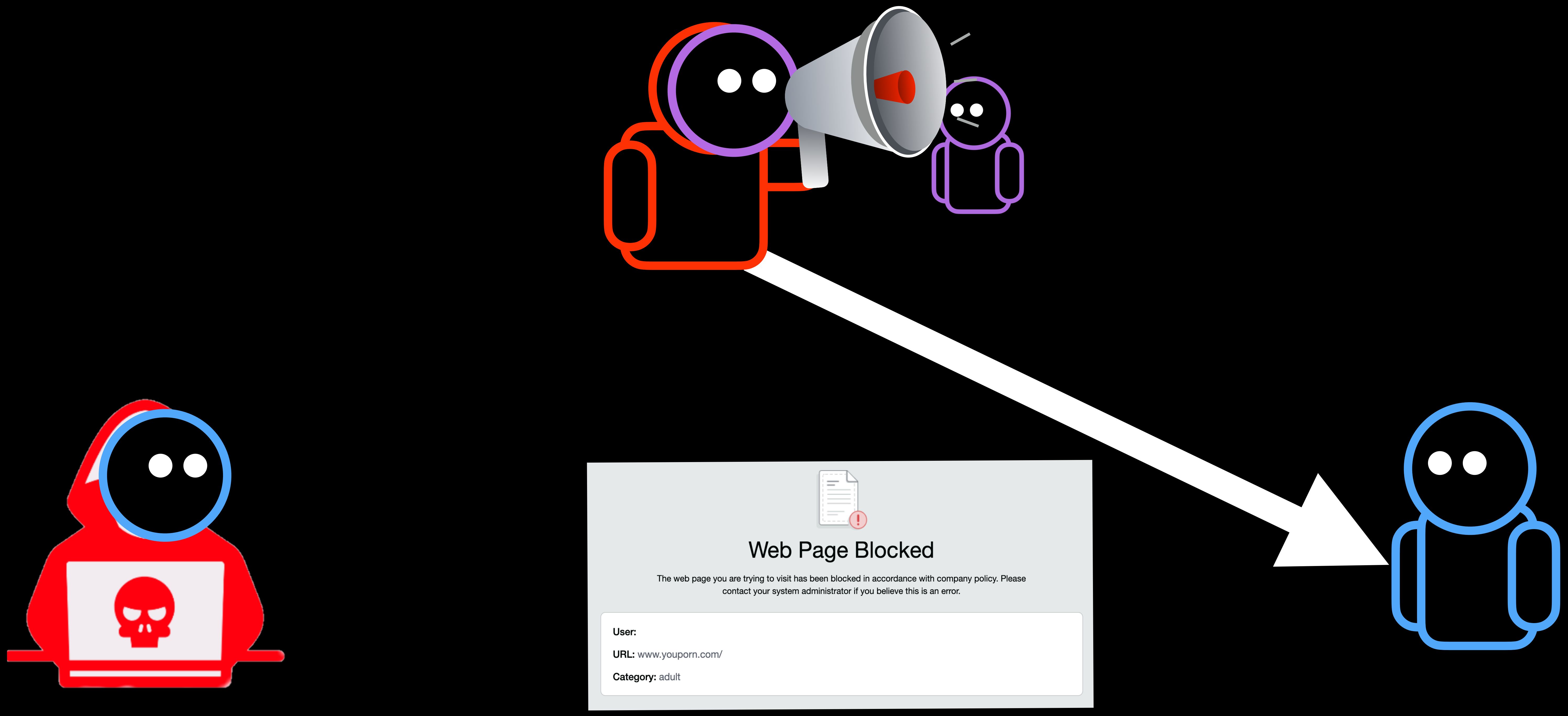

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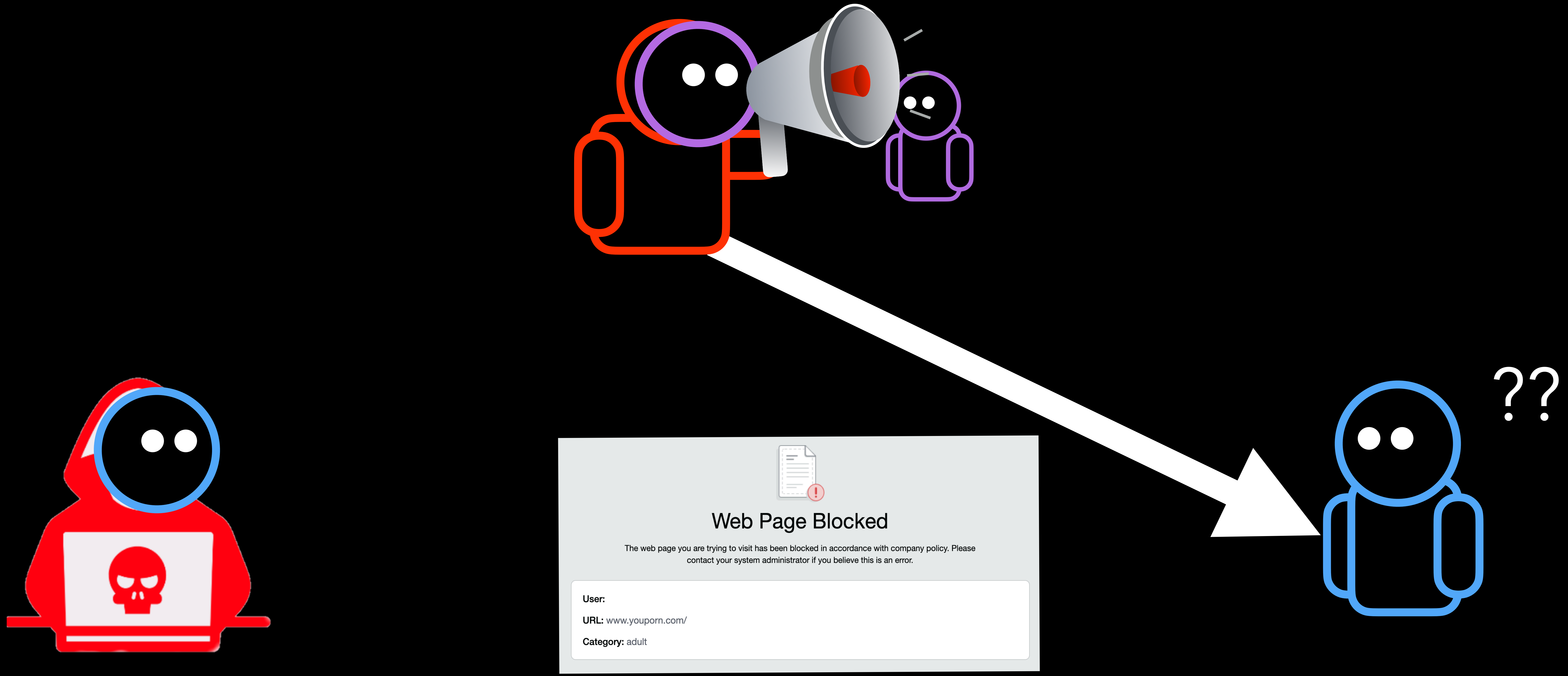

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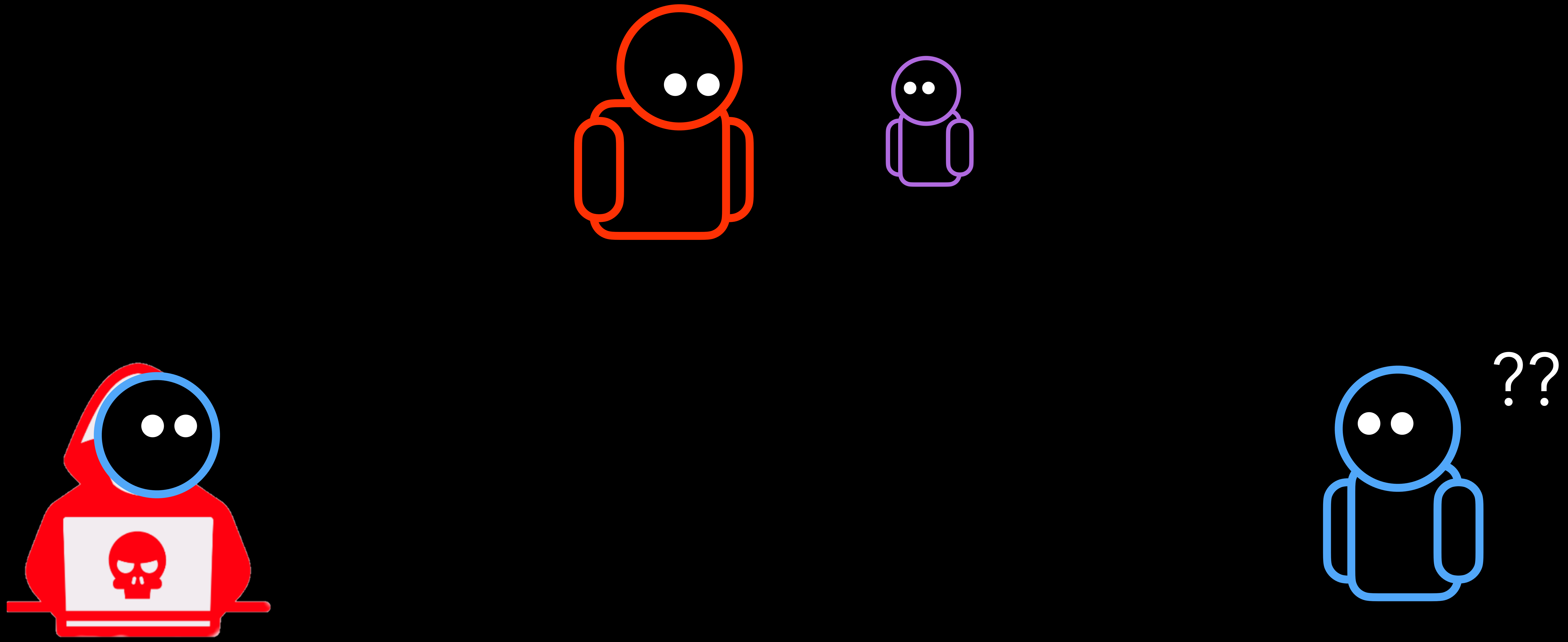

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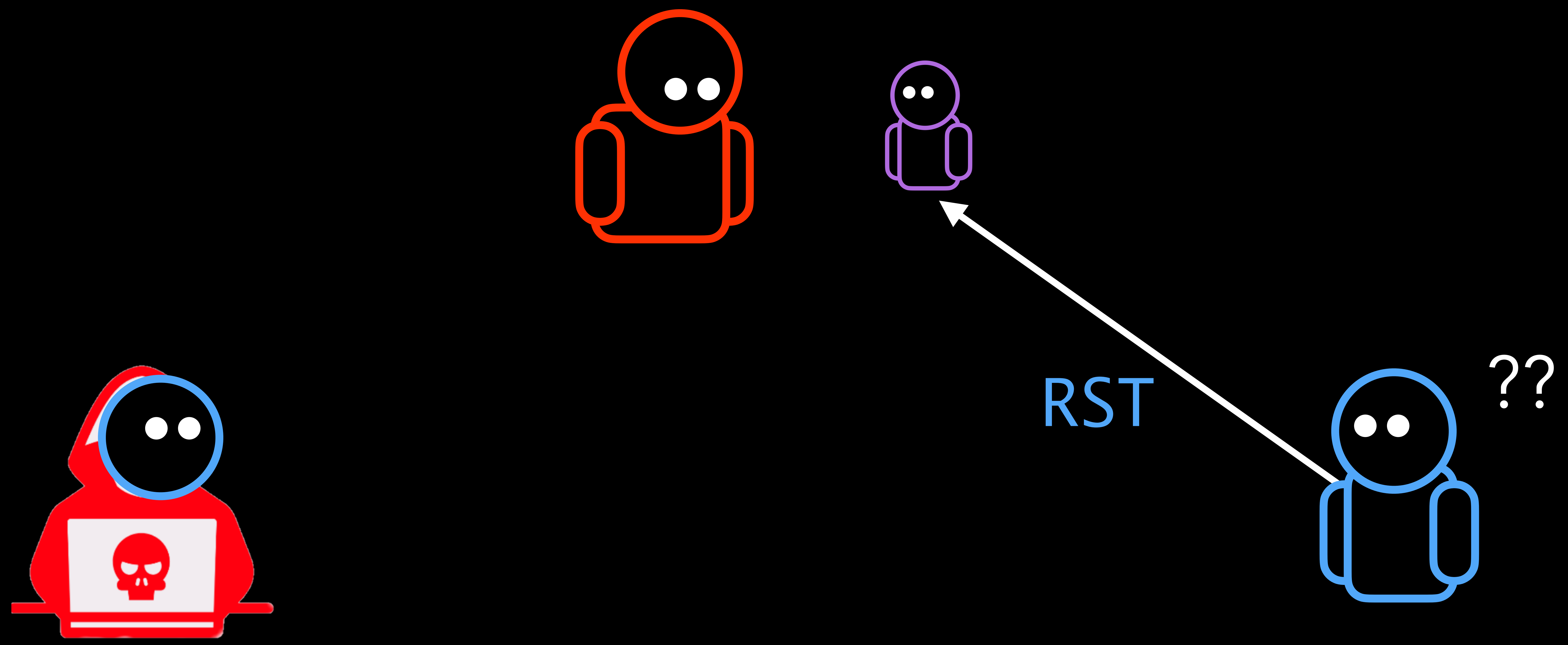
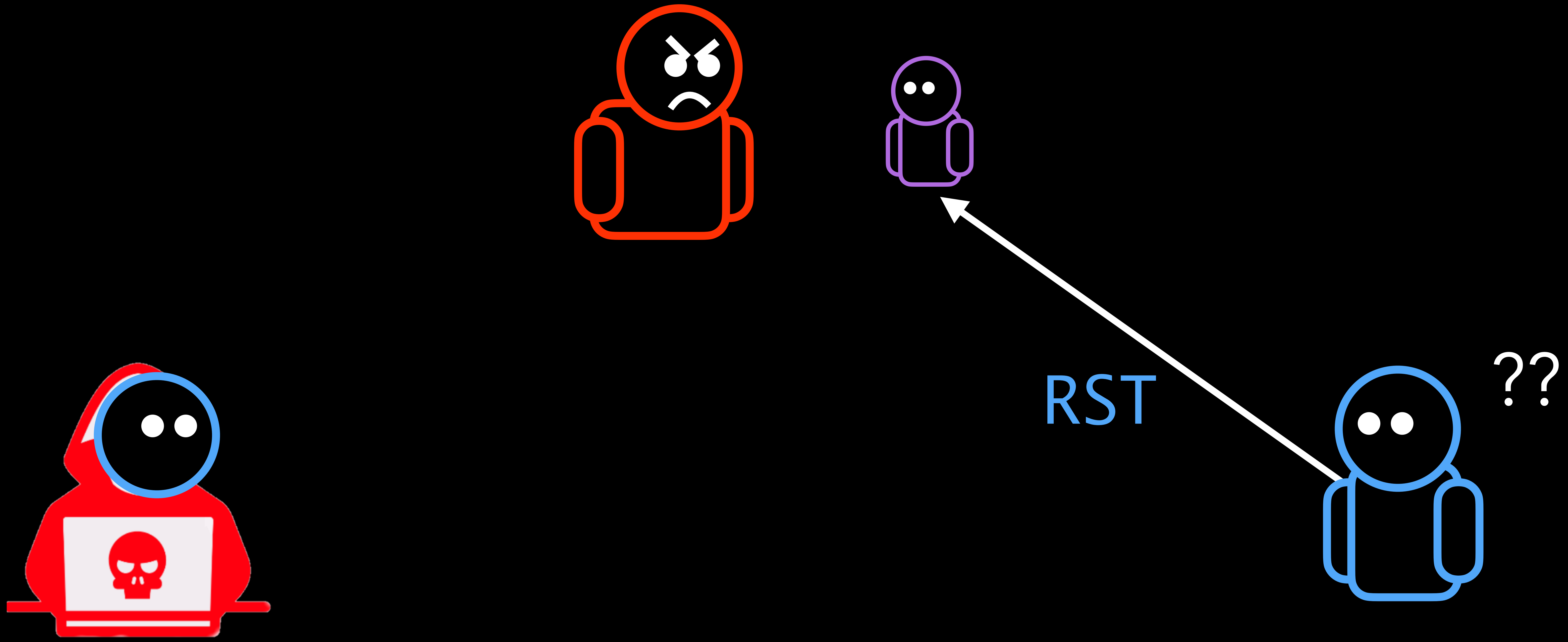


Mega-amplifier cause #1: Victim-sustained loops



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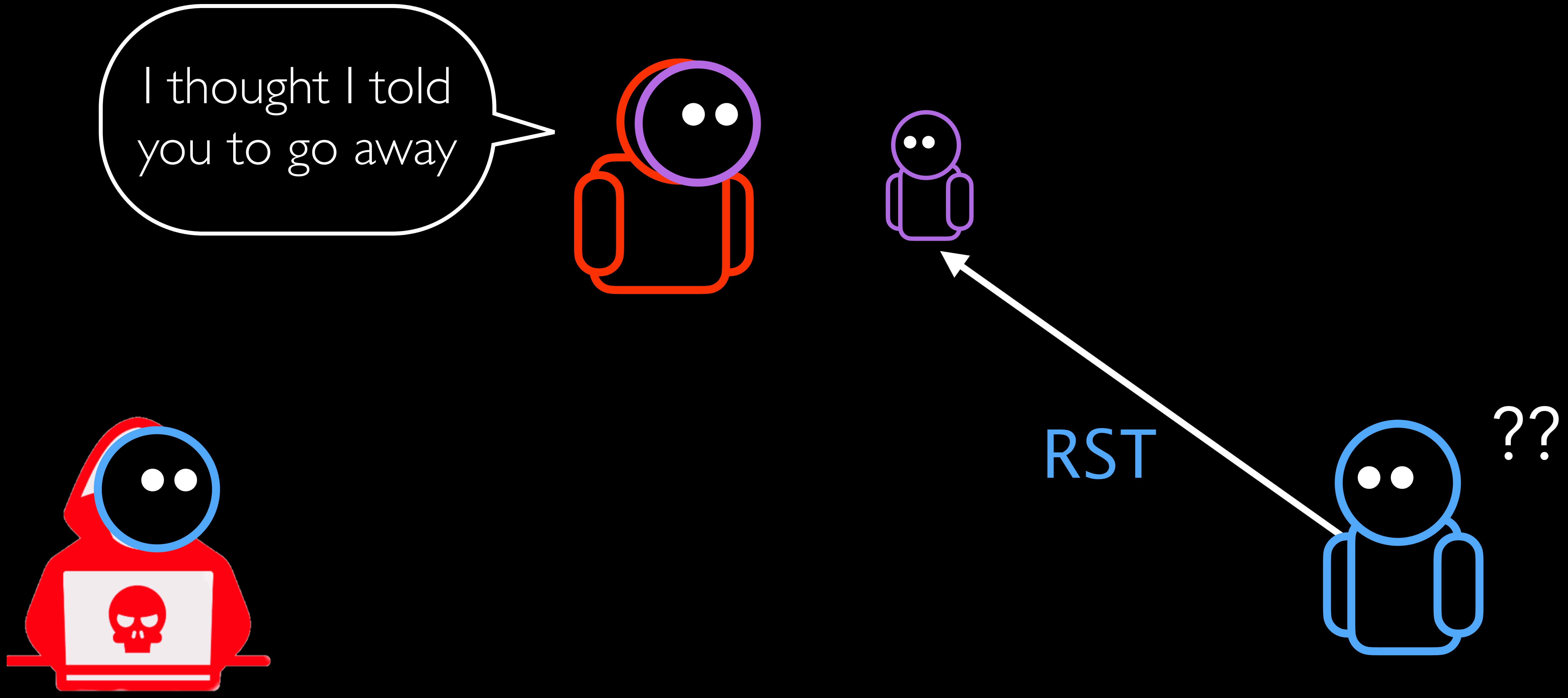

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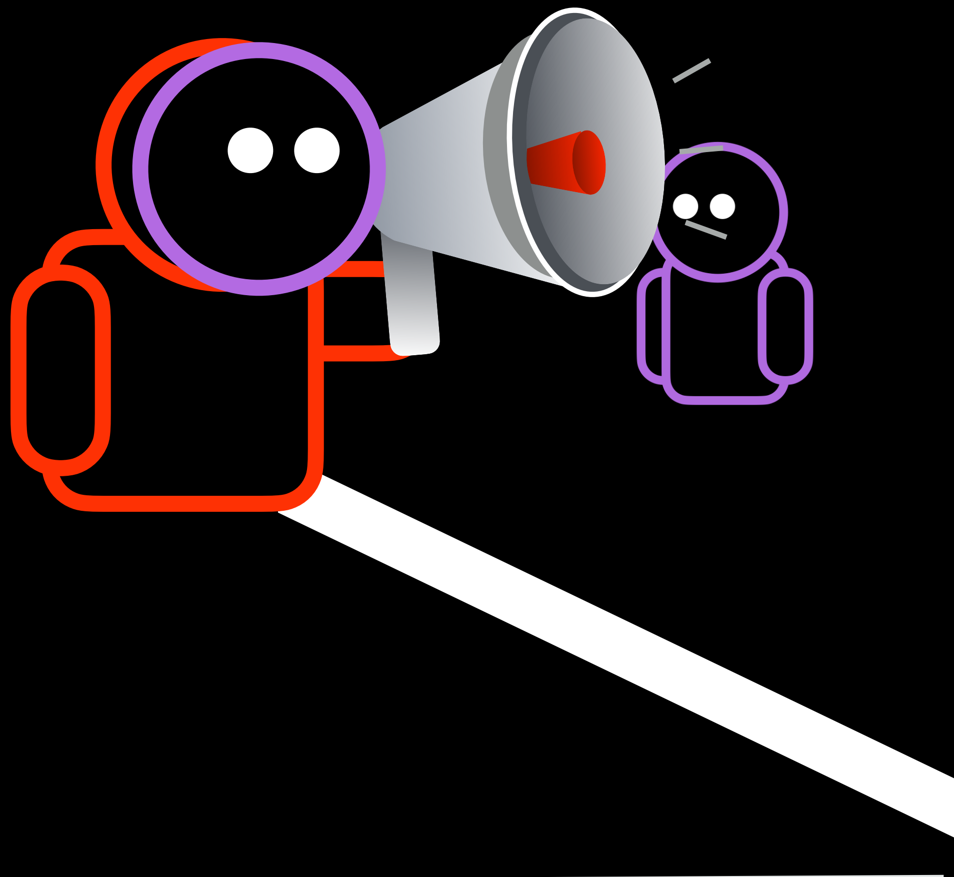

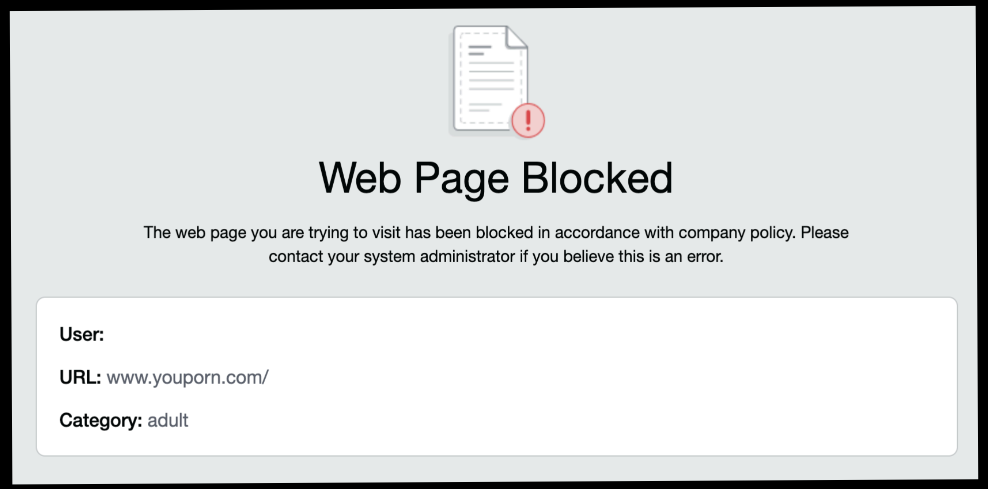

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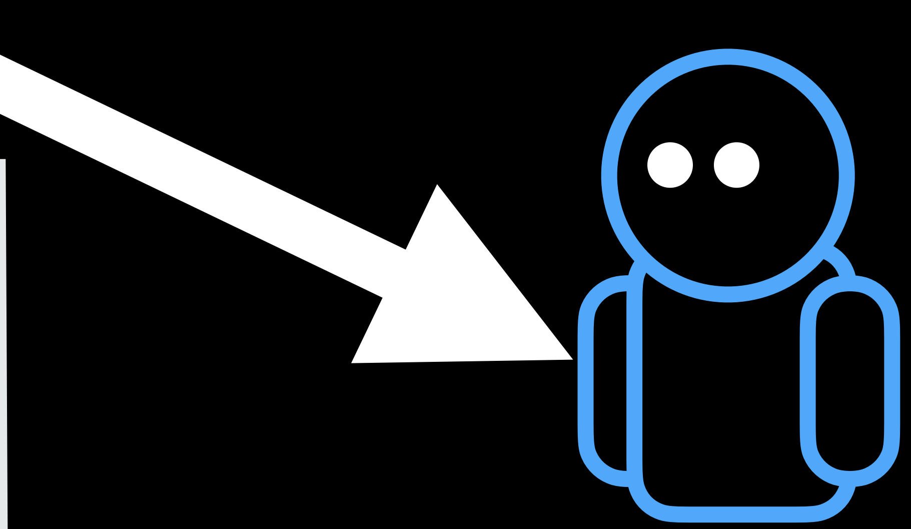
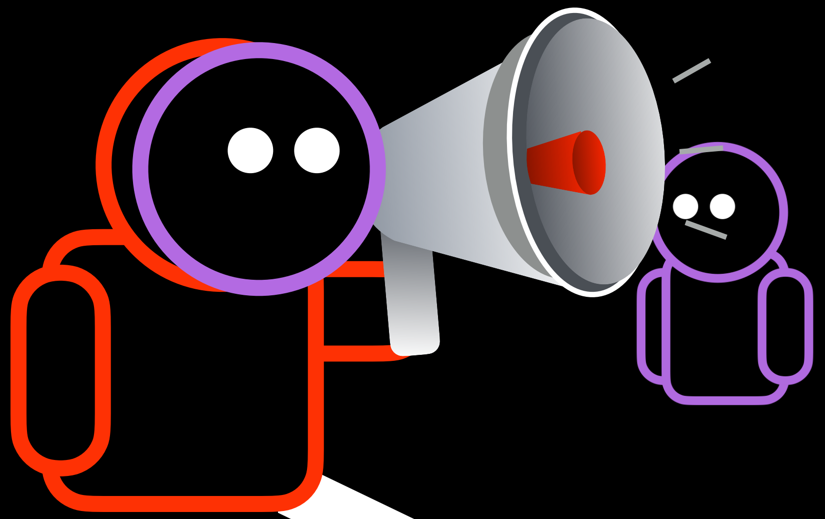
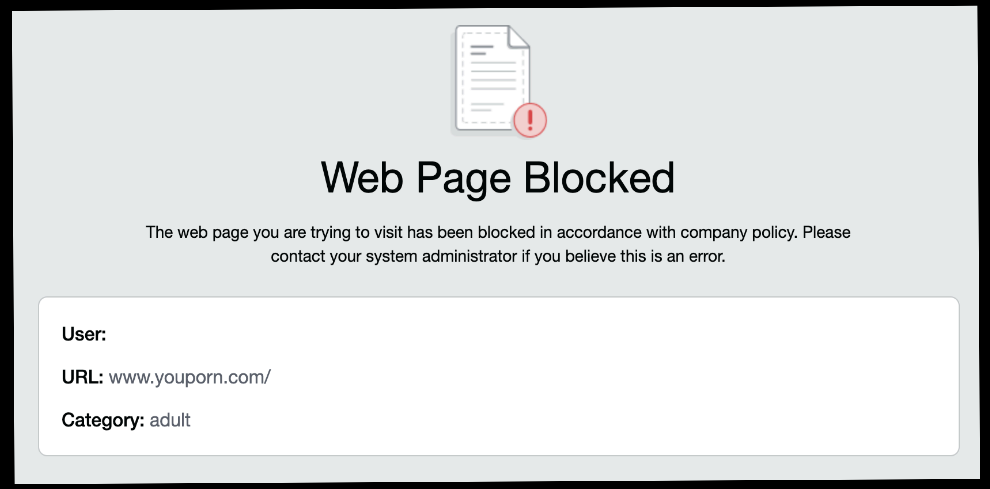


Mega-amplifier cause #1: Victim-sustained loops





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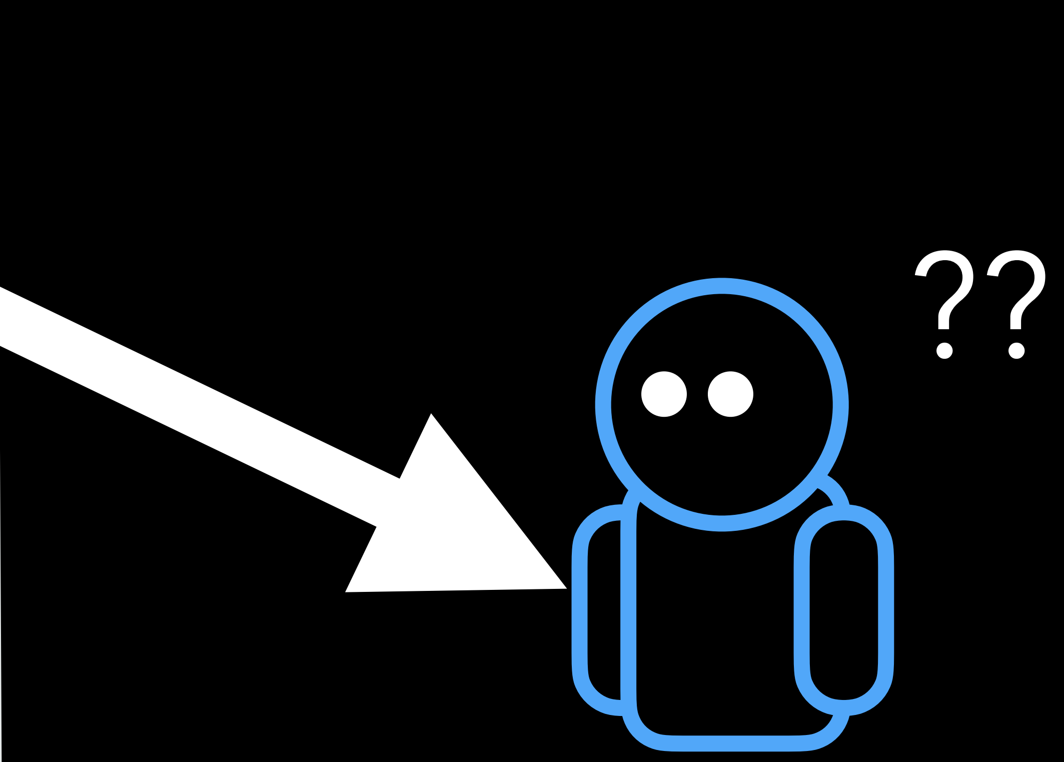
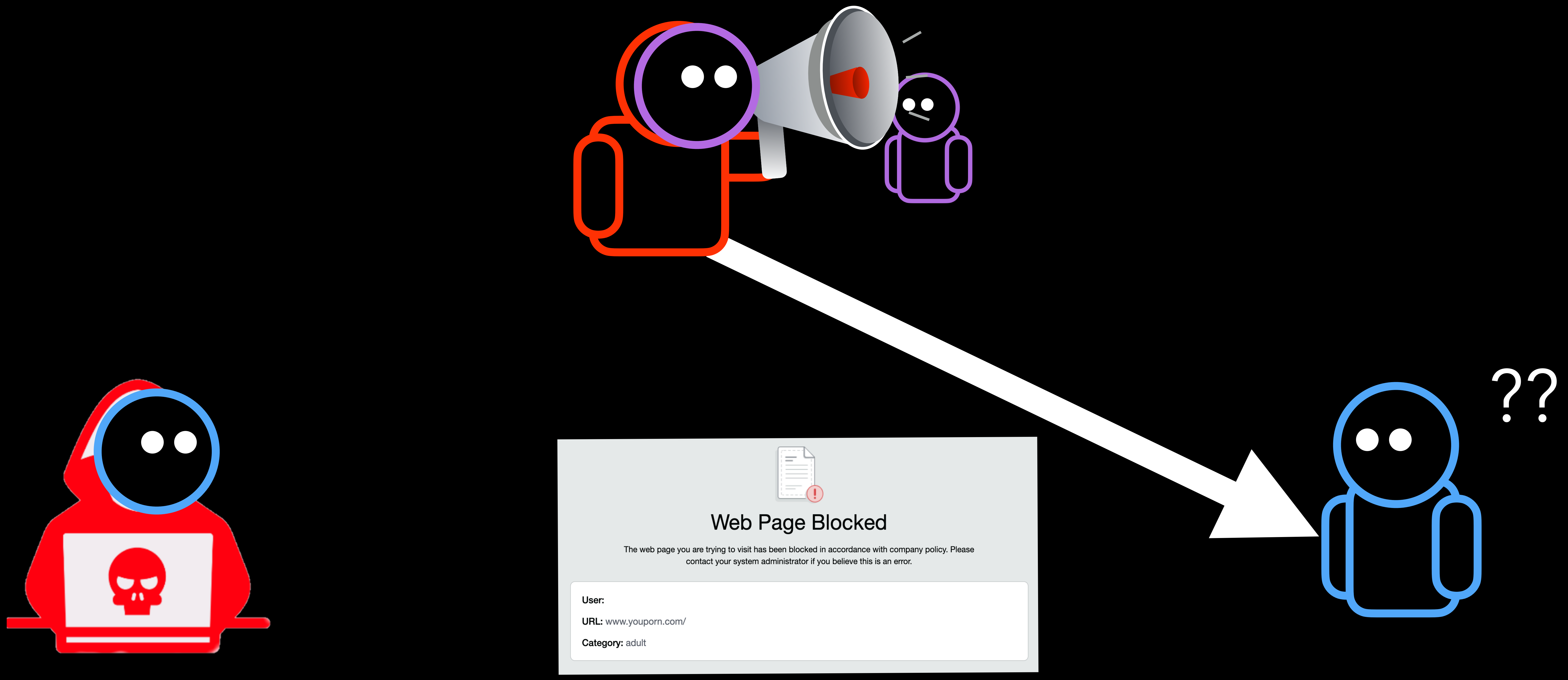


Mega-amplifier cause #1: Victim-sustained loops



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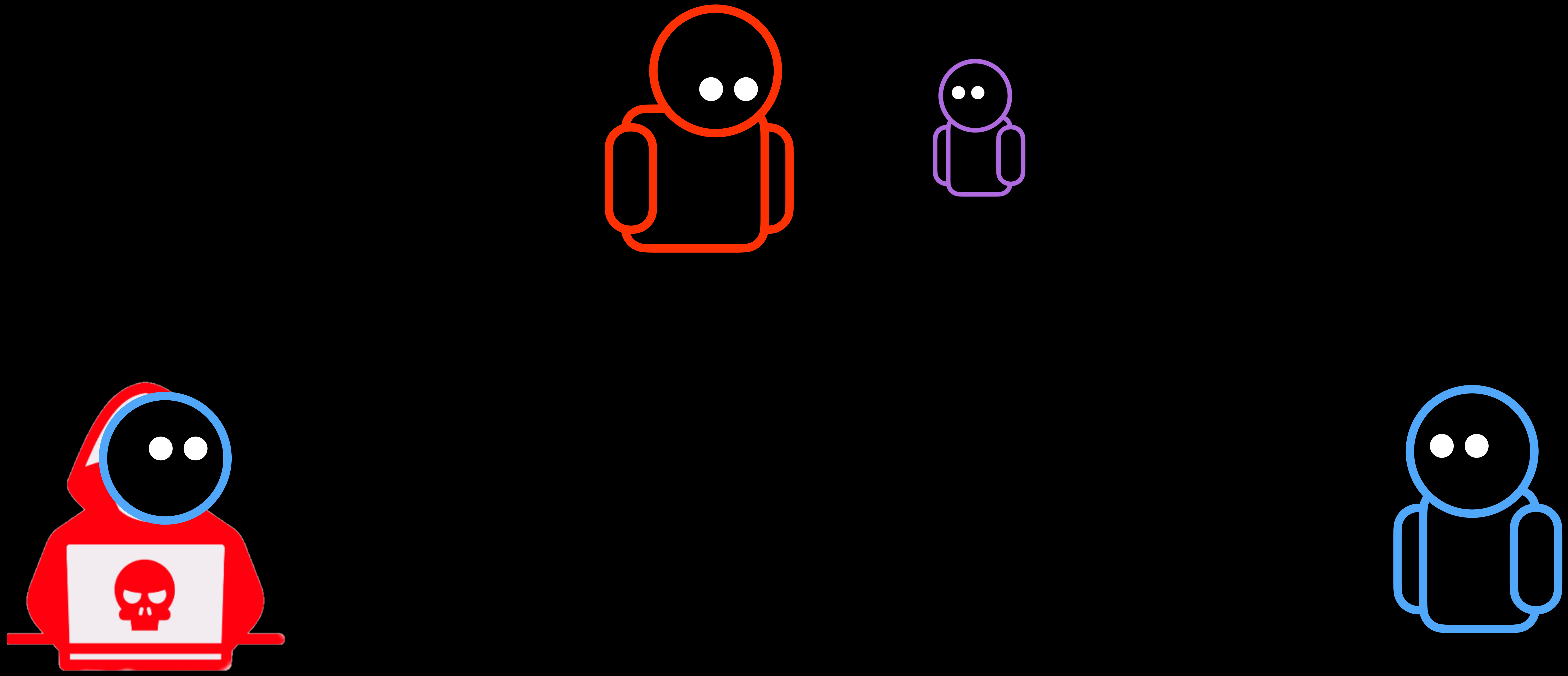
Category: adult

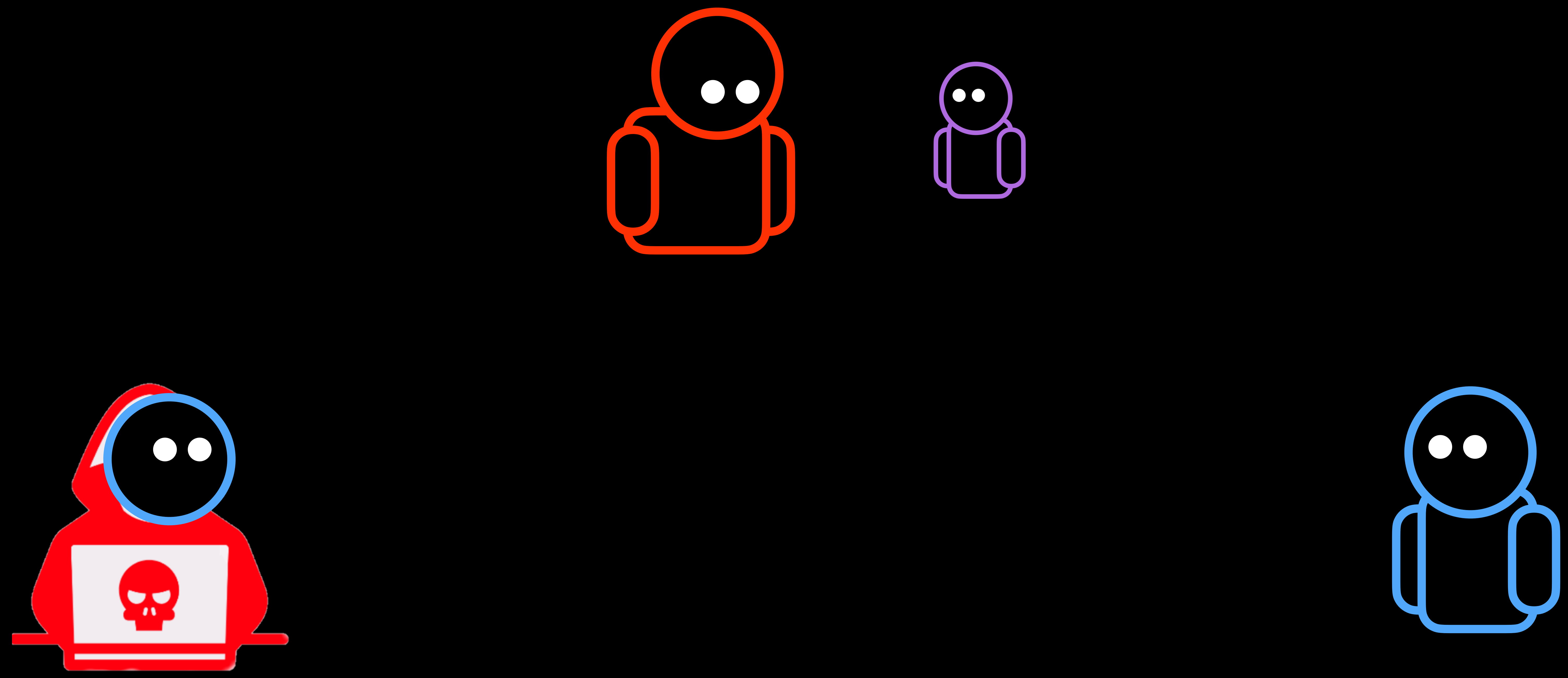
Victim-sustained amplification can be effectively *infinite*

Attacks the victim’s downlink *and* uplink

Mega-amplifier cause #2



Mega-amplifier cause #2



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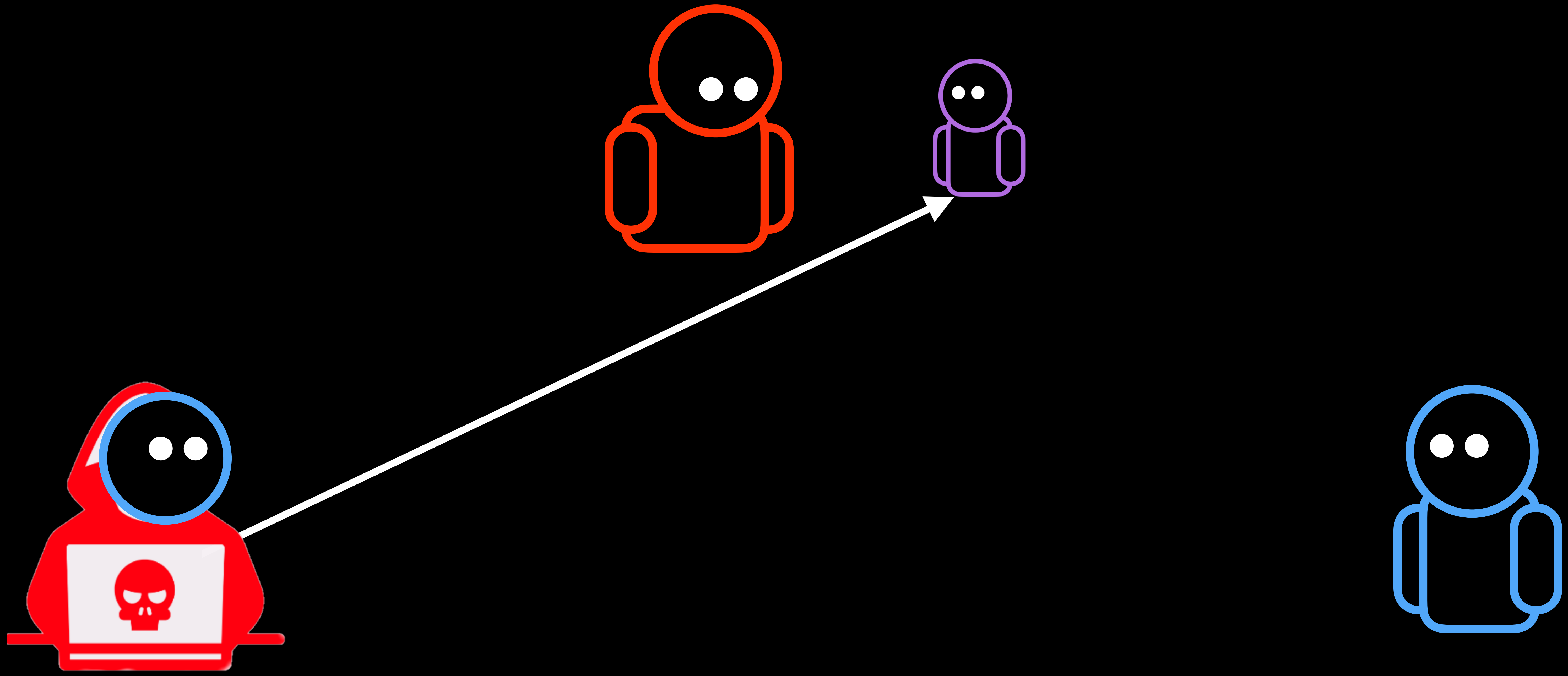

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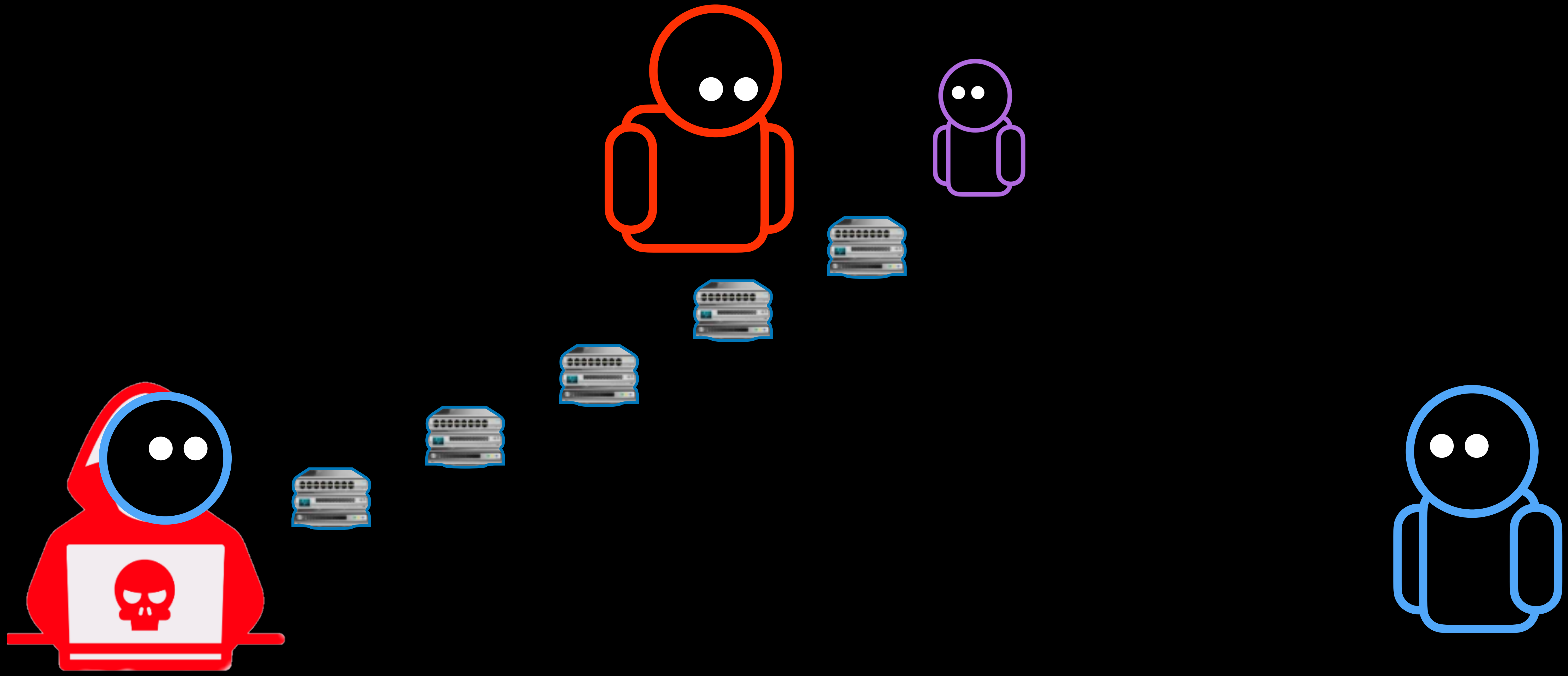

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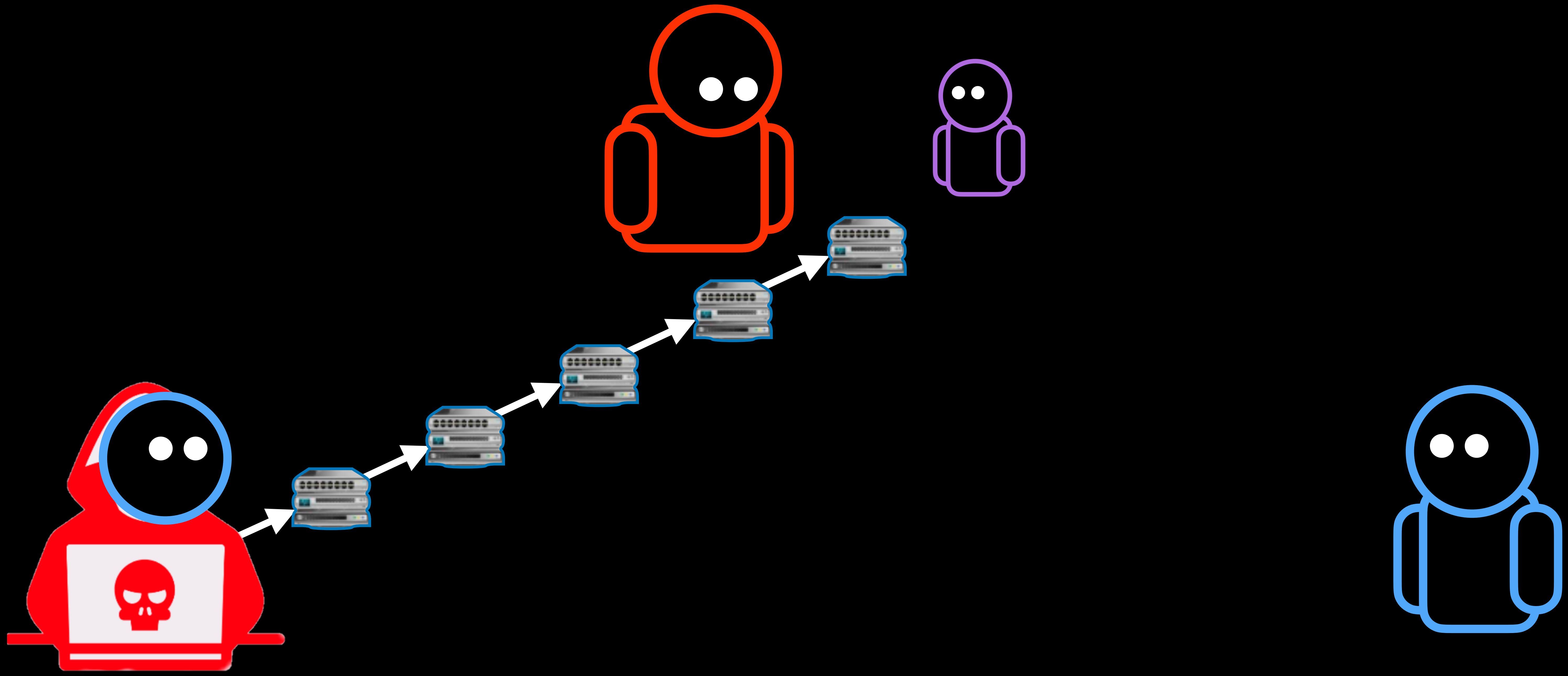

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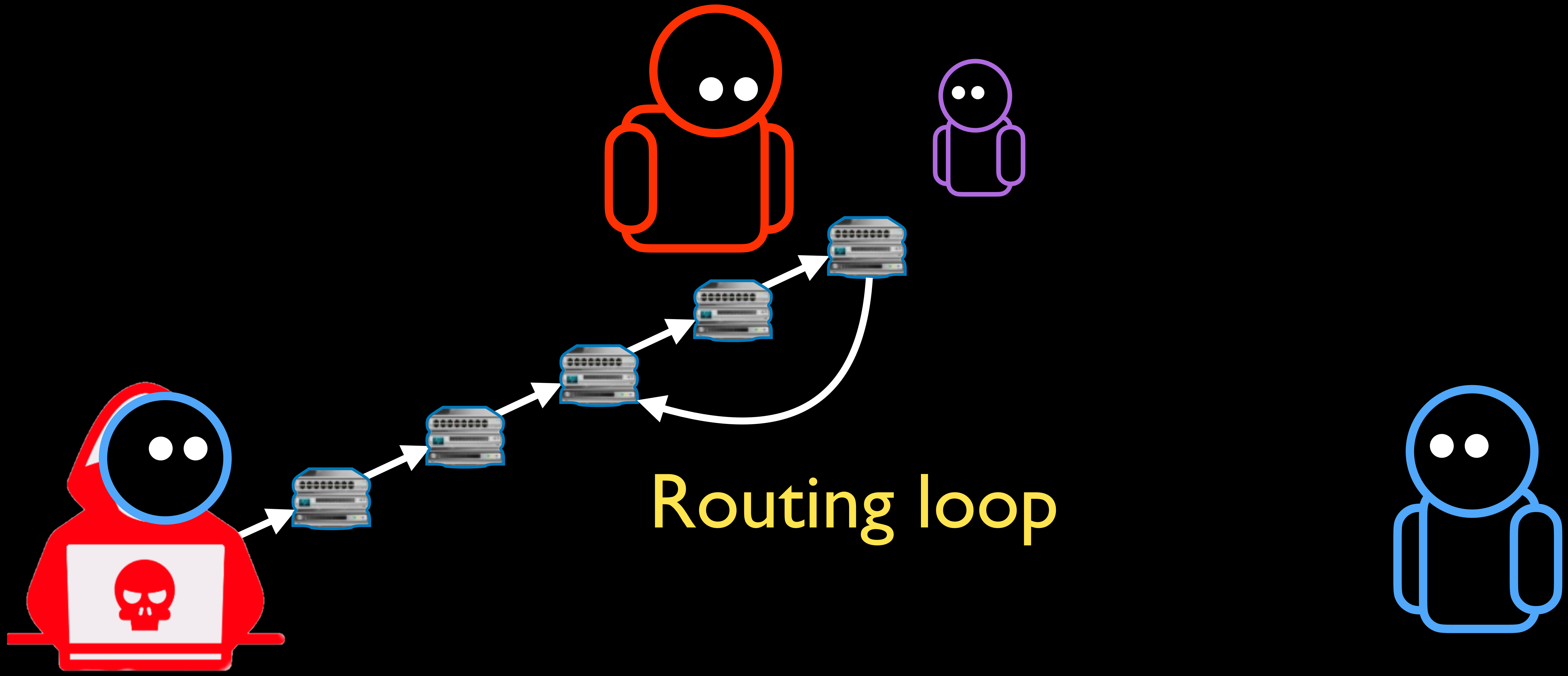
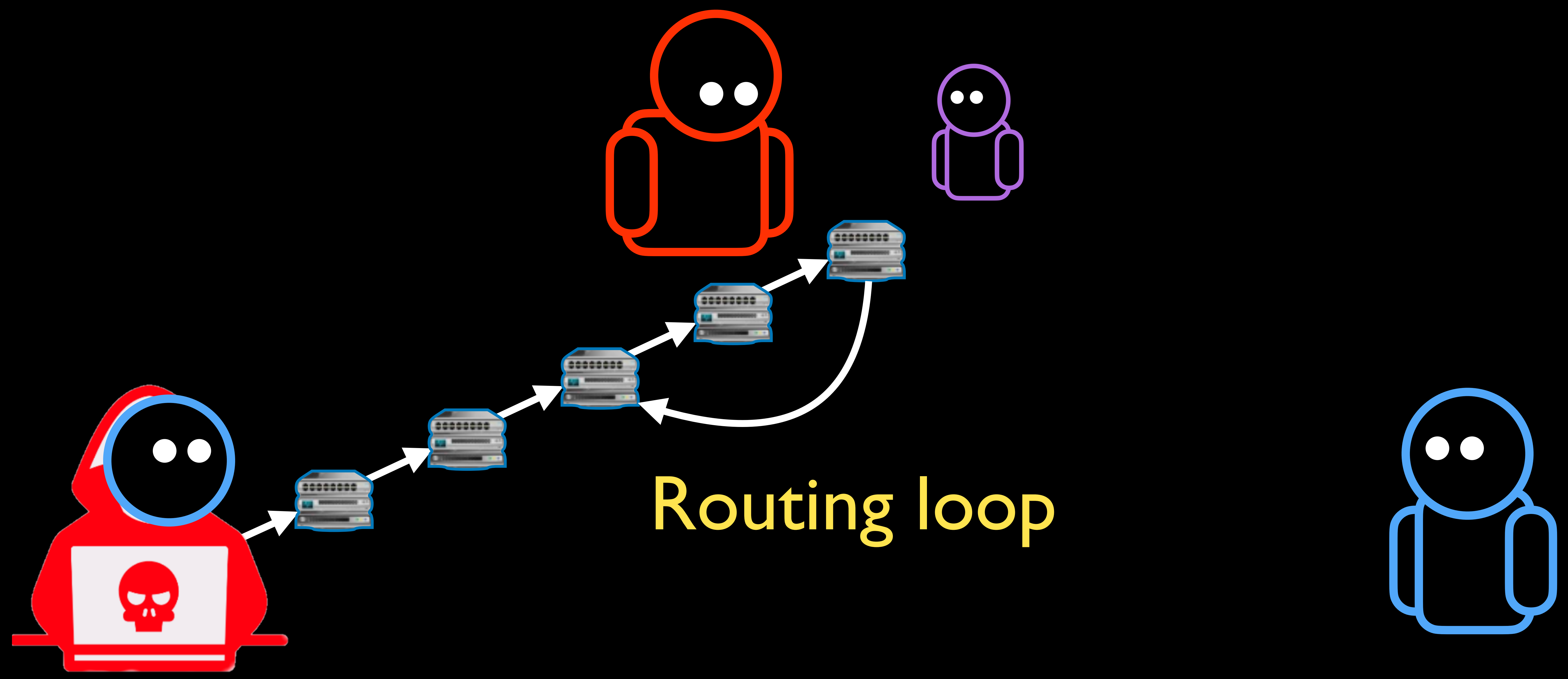
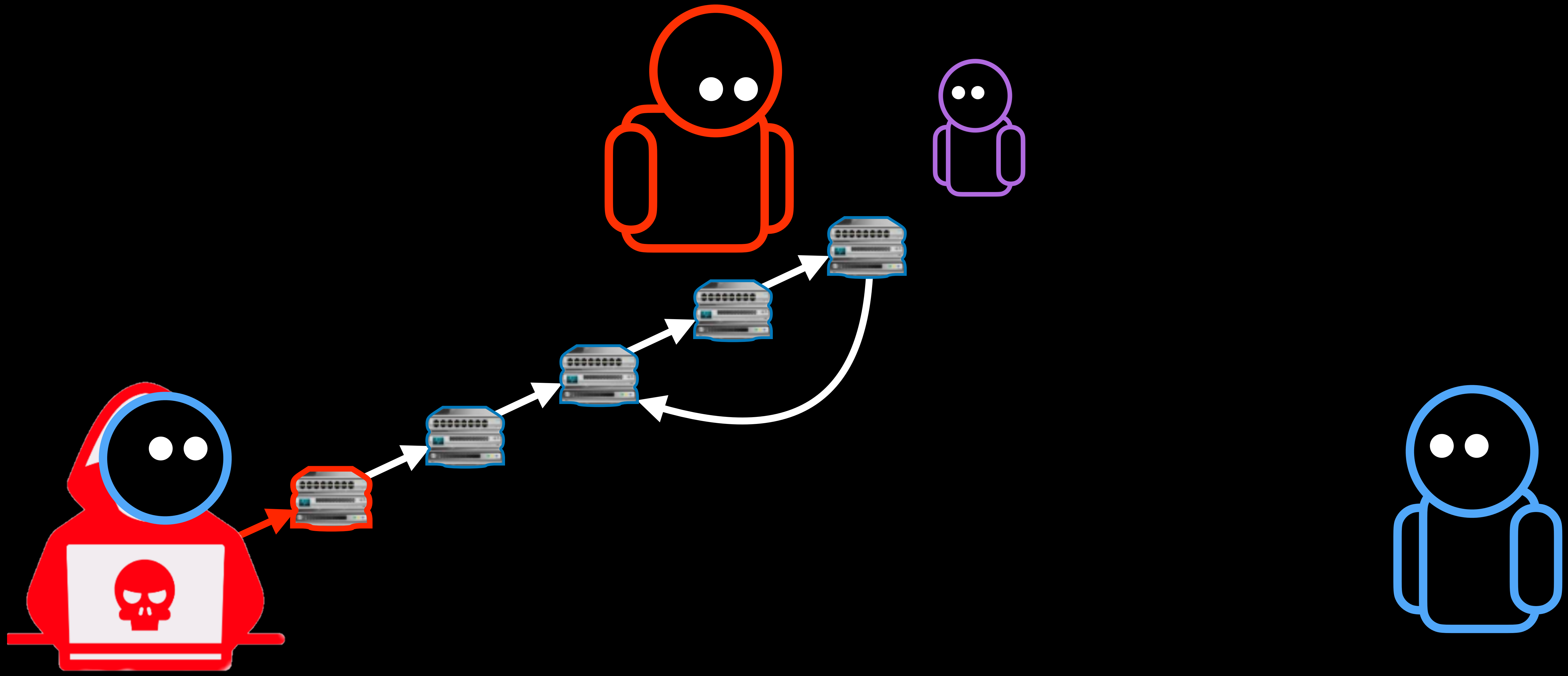


Mega-amplifier cause #2: Routing loops

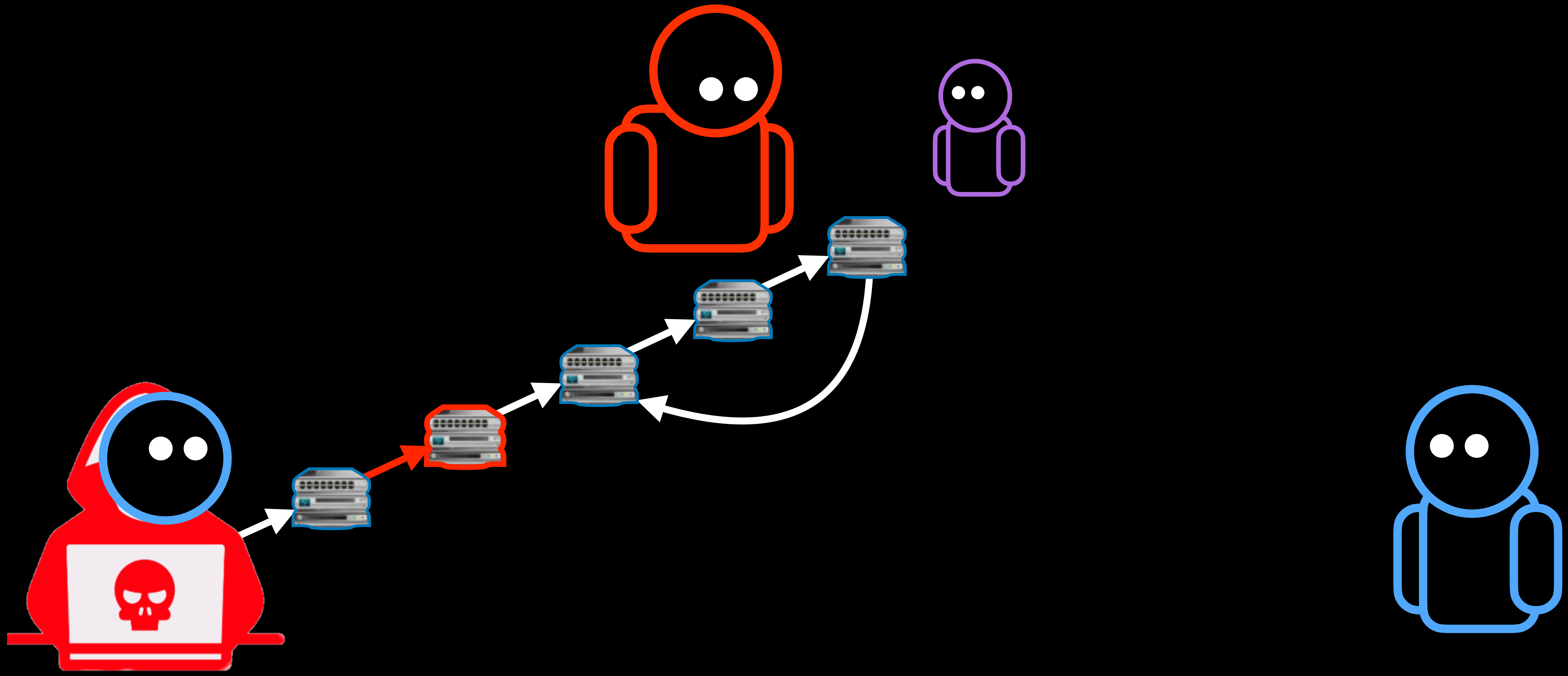


Routing loop

Mega-amplifier cause #2: Routing loops



Mega-amplifier cause #2: Routing loops



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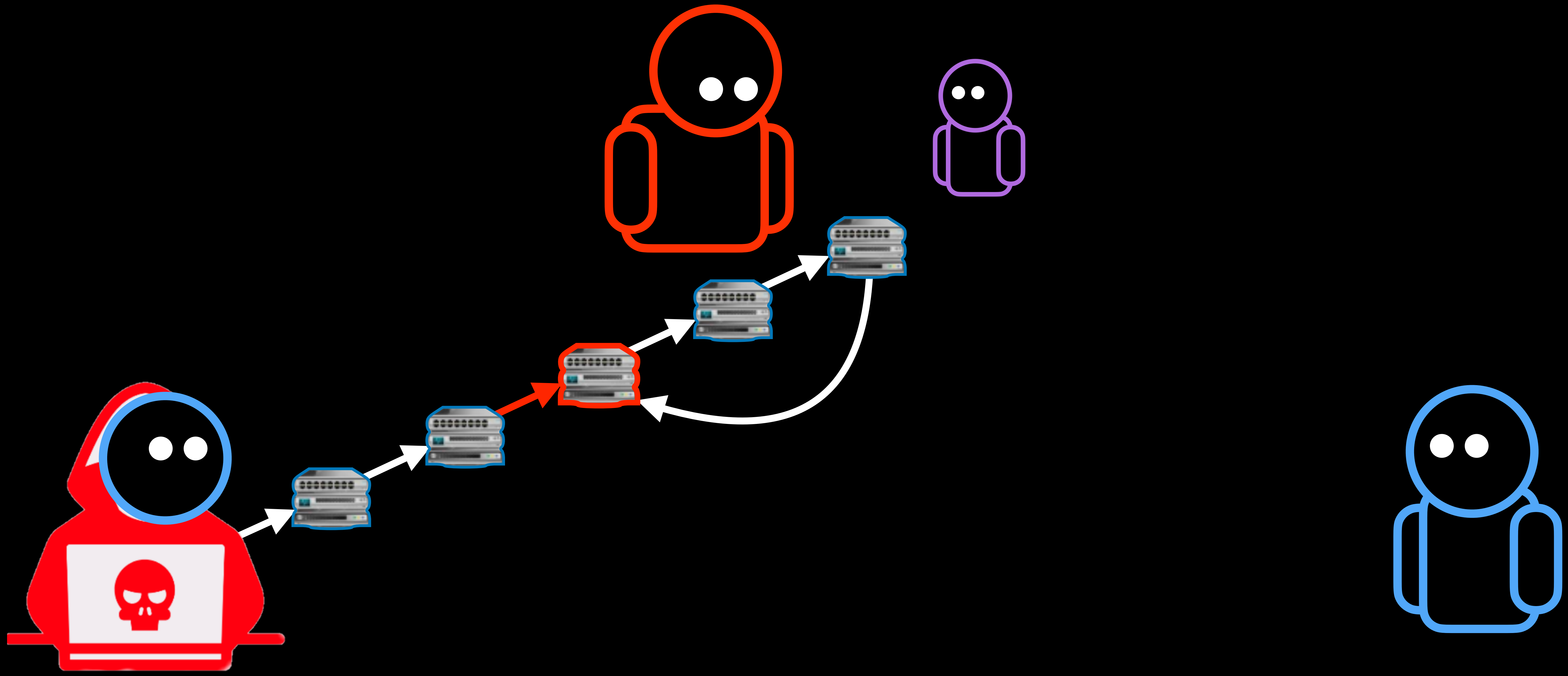

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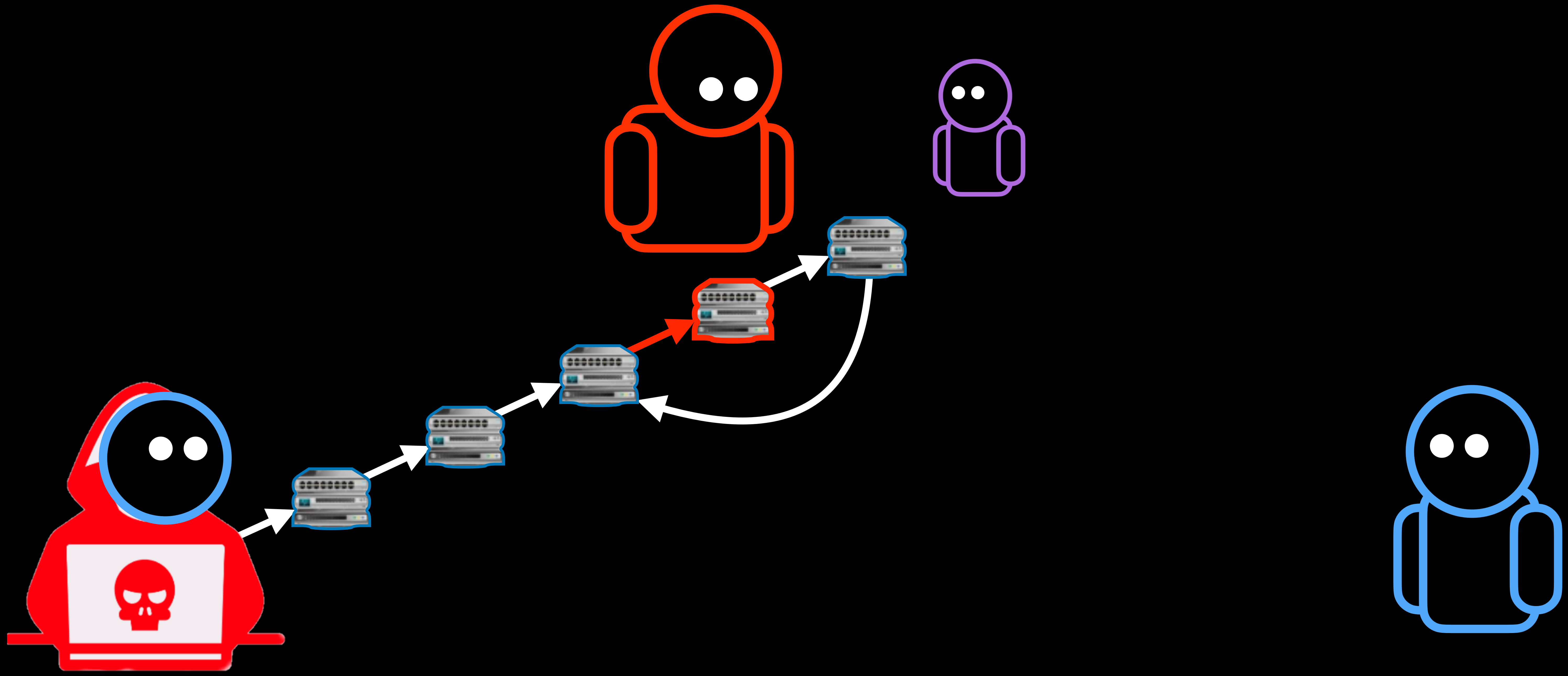

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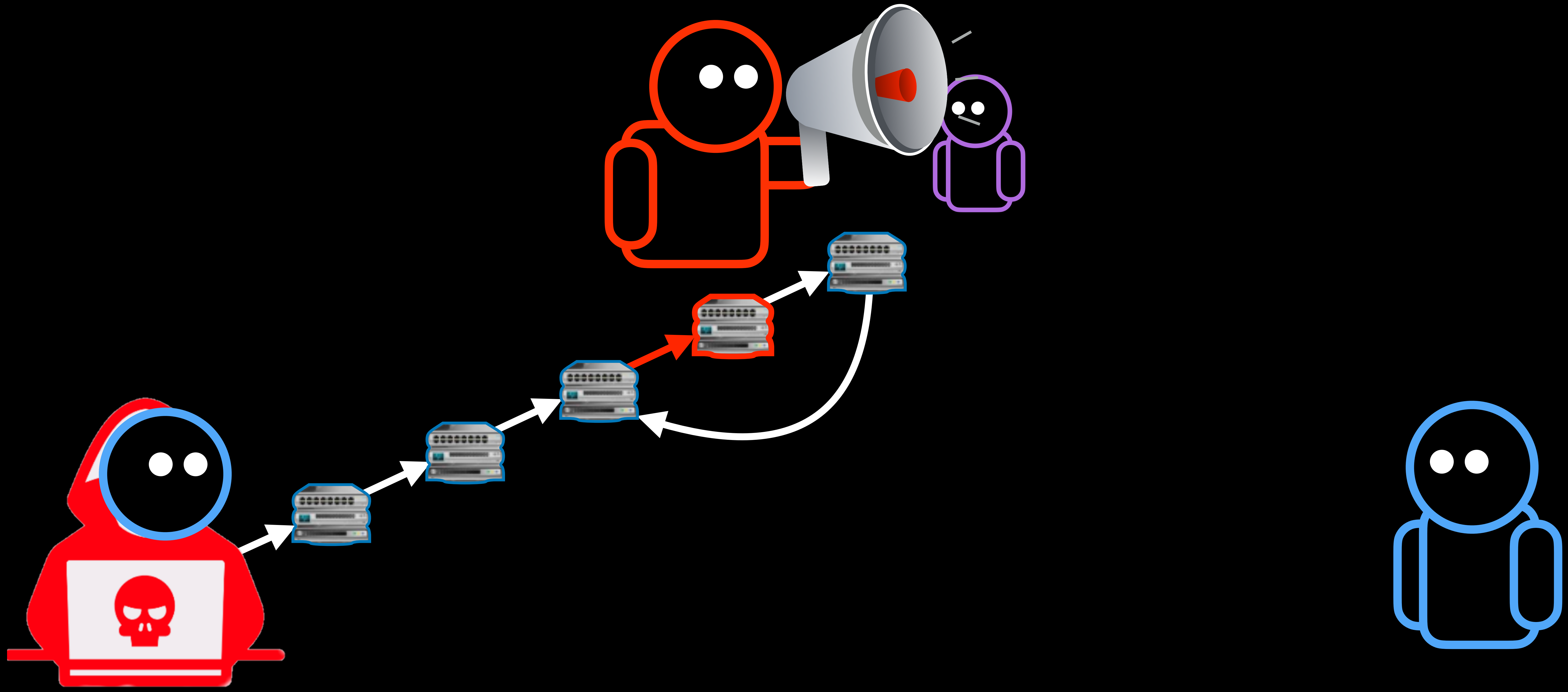

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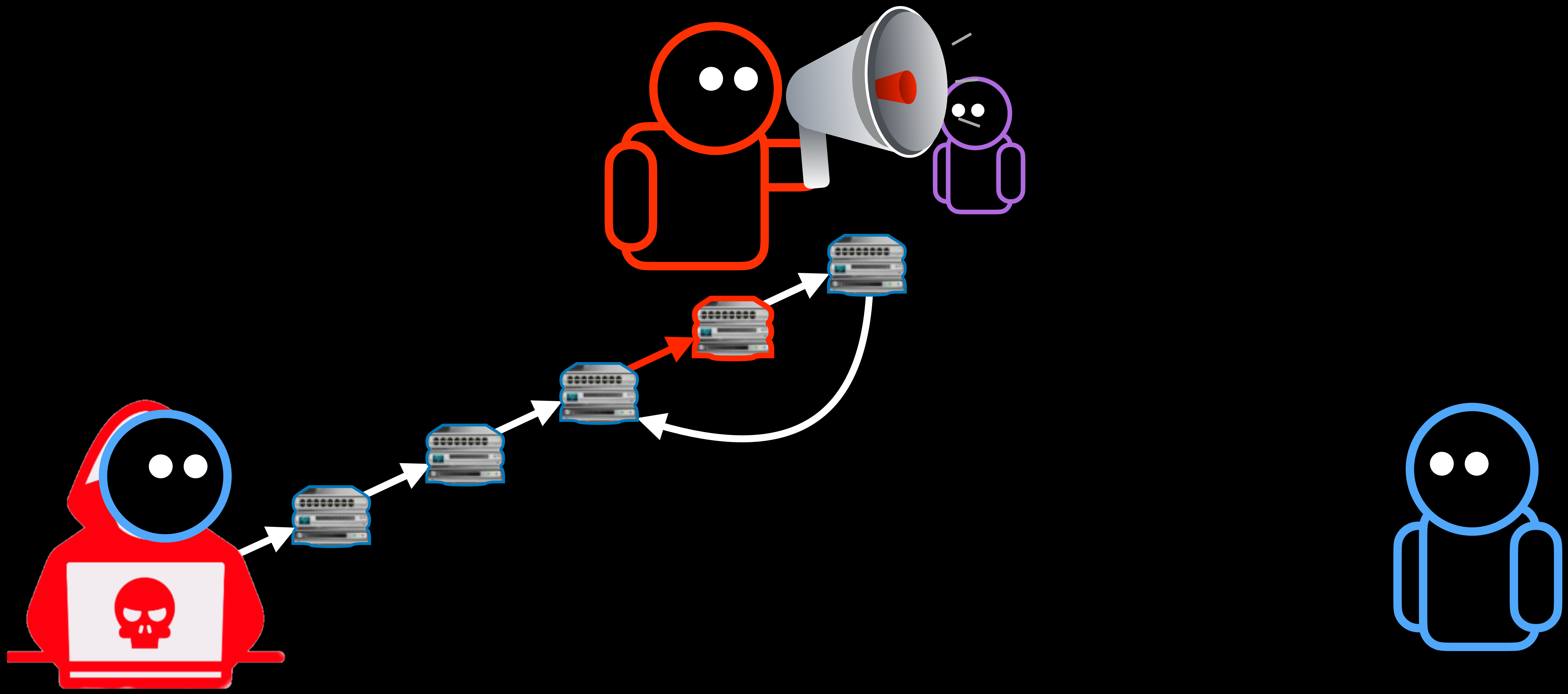

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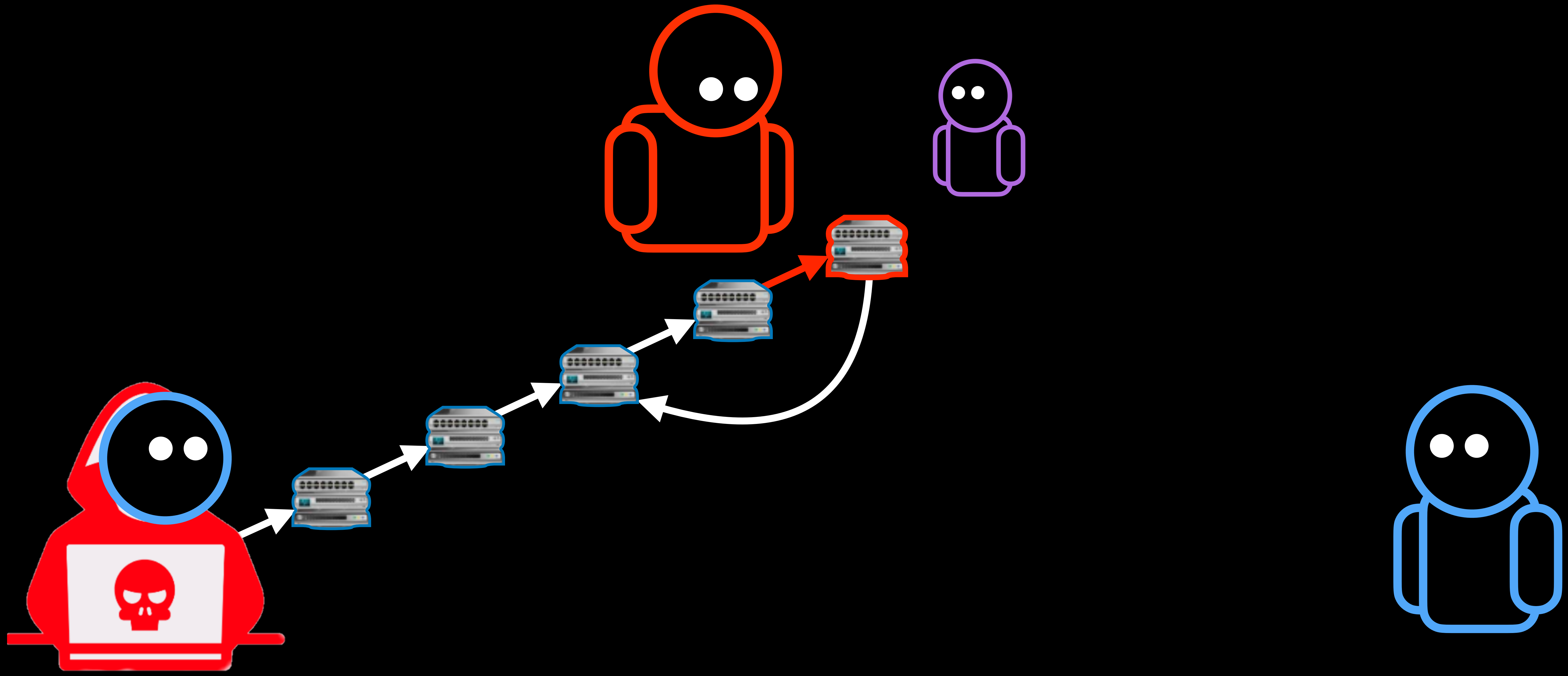
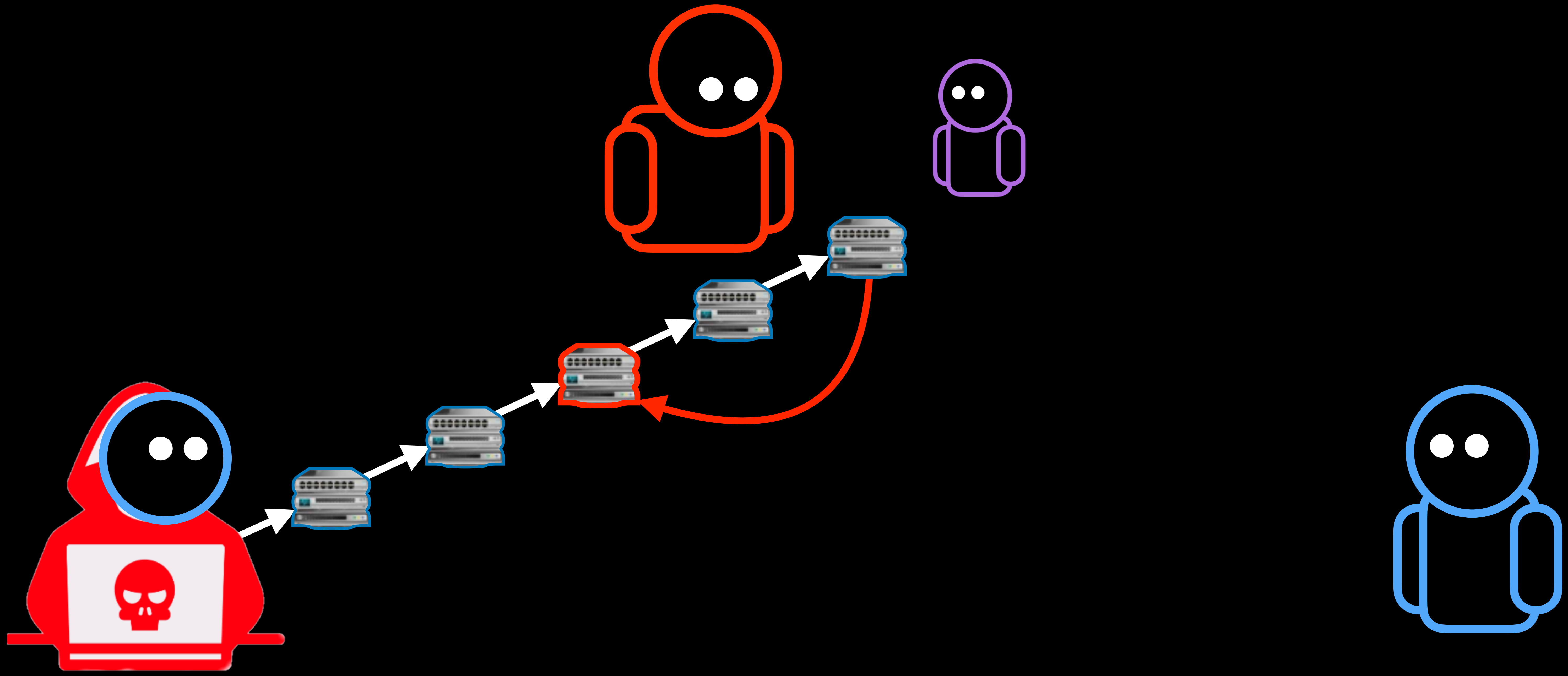


Mega-amplifier cause #2: Routing loops



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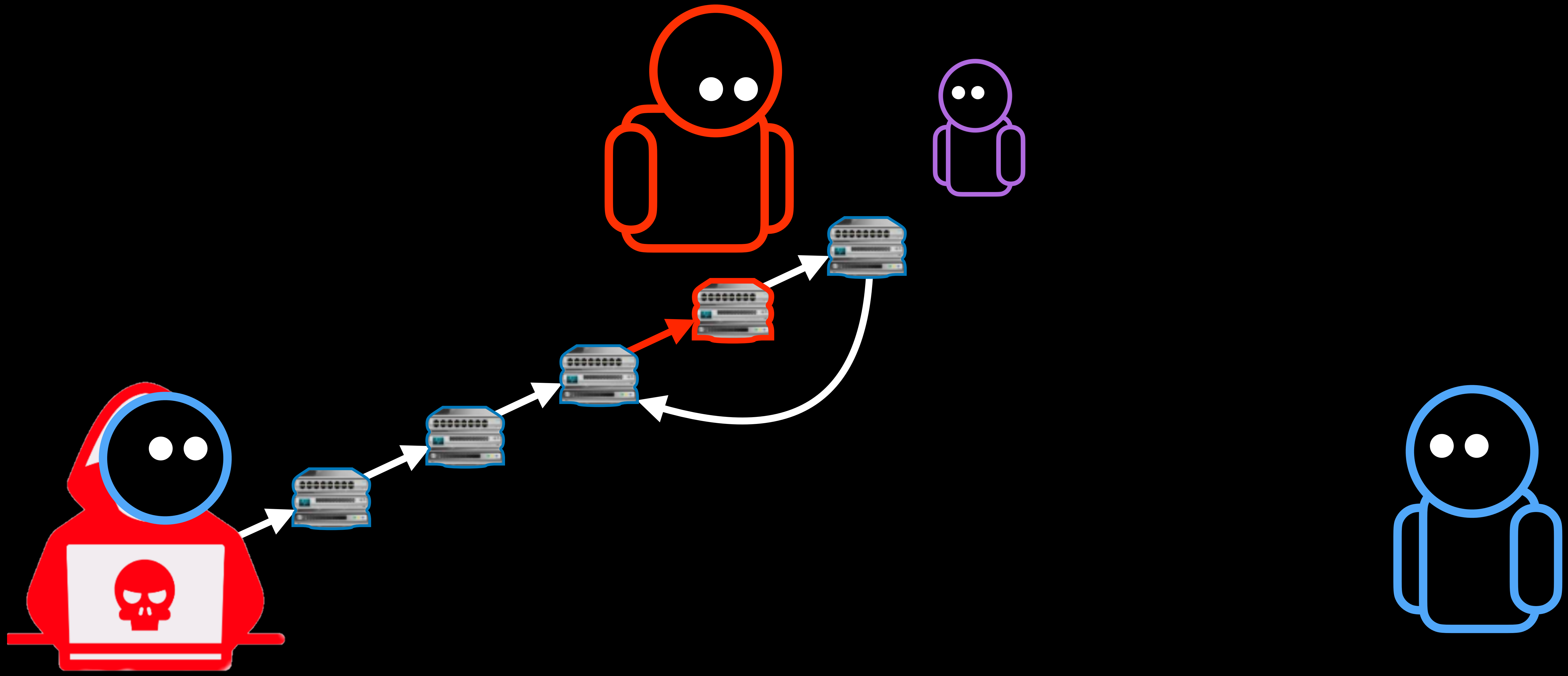

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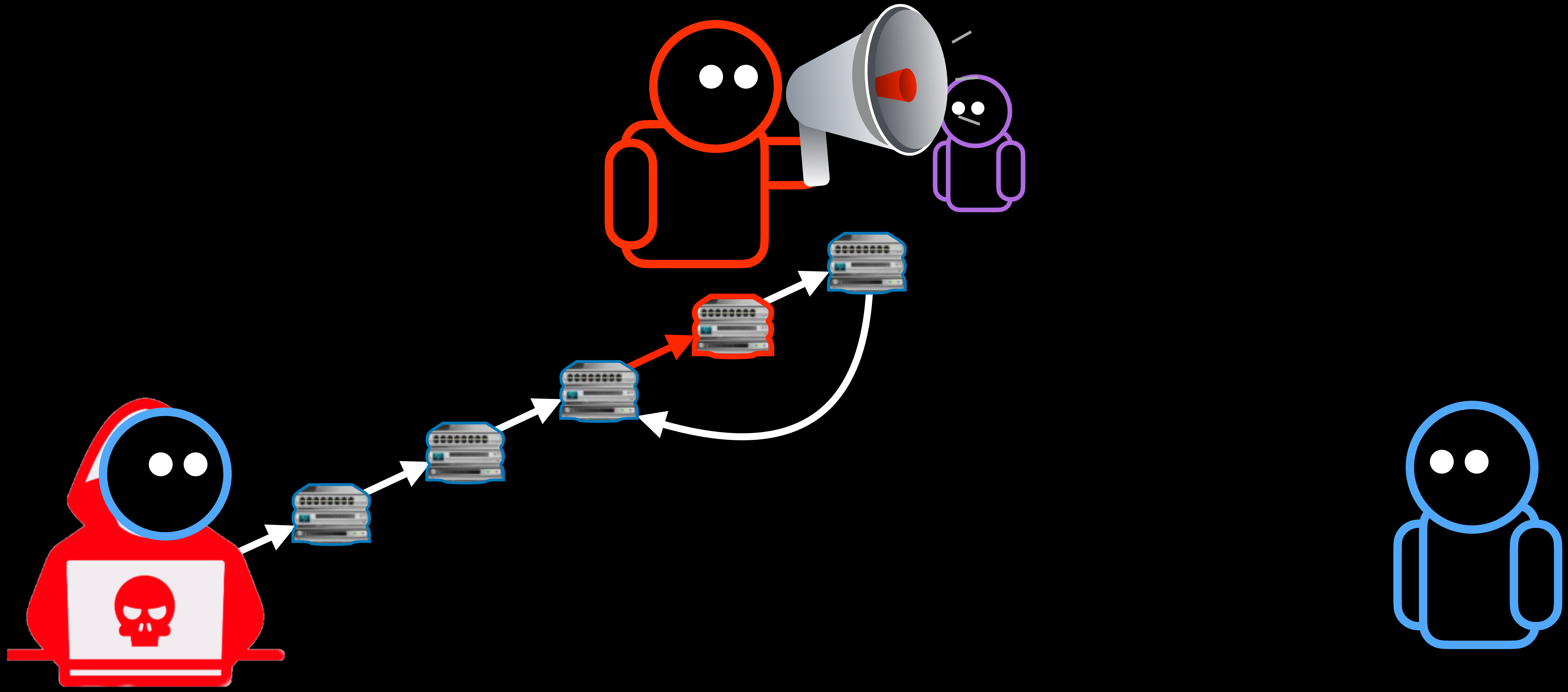

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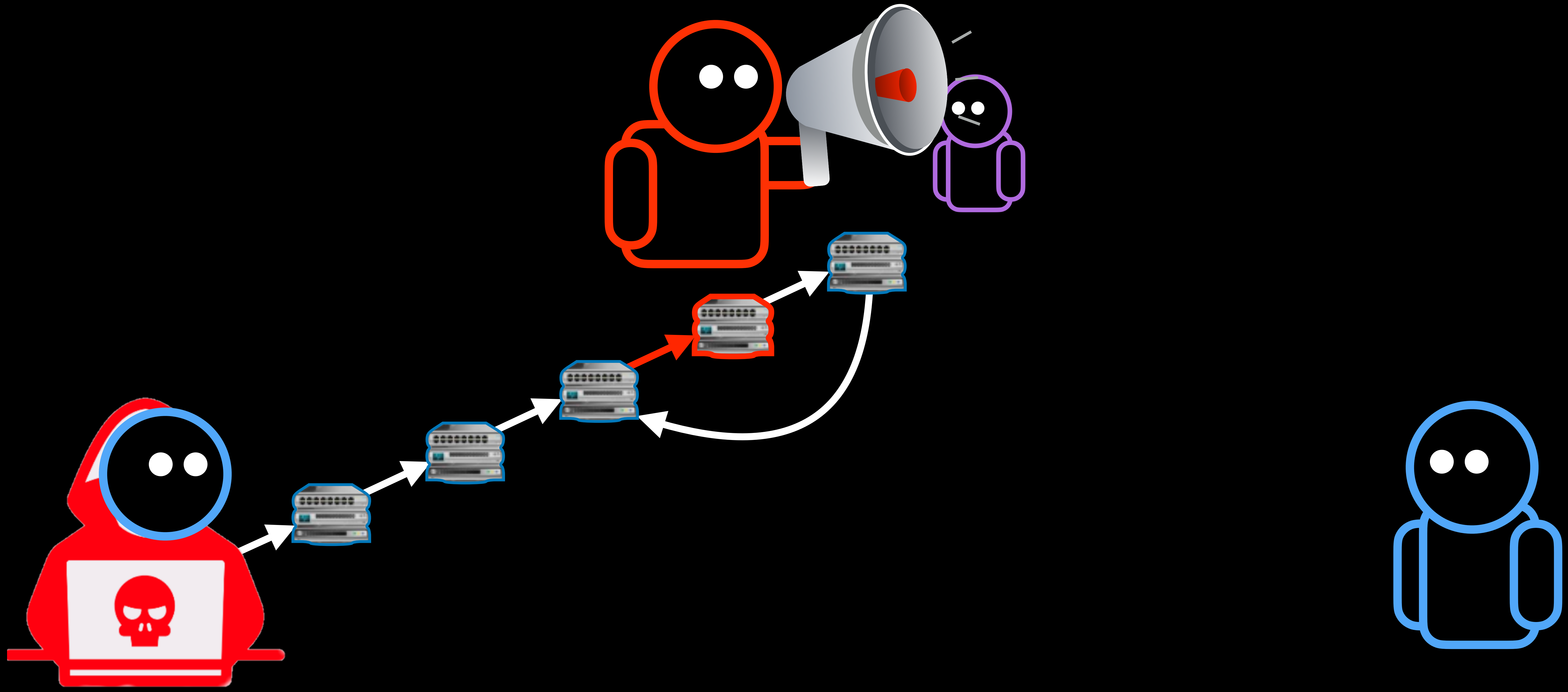

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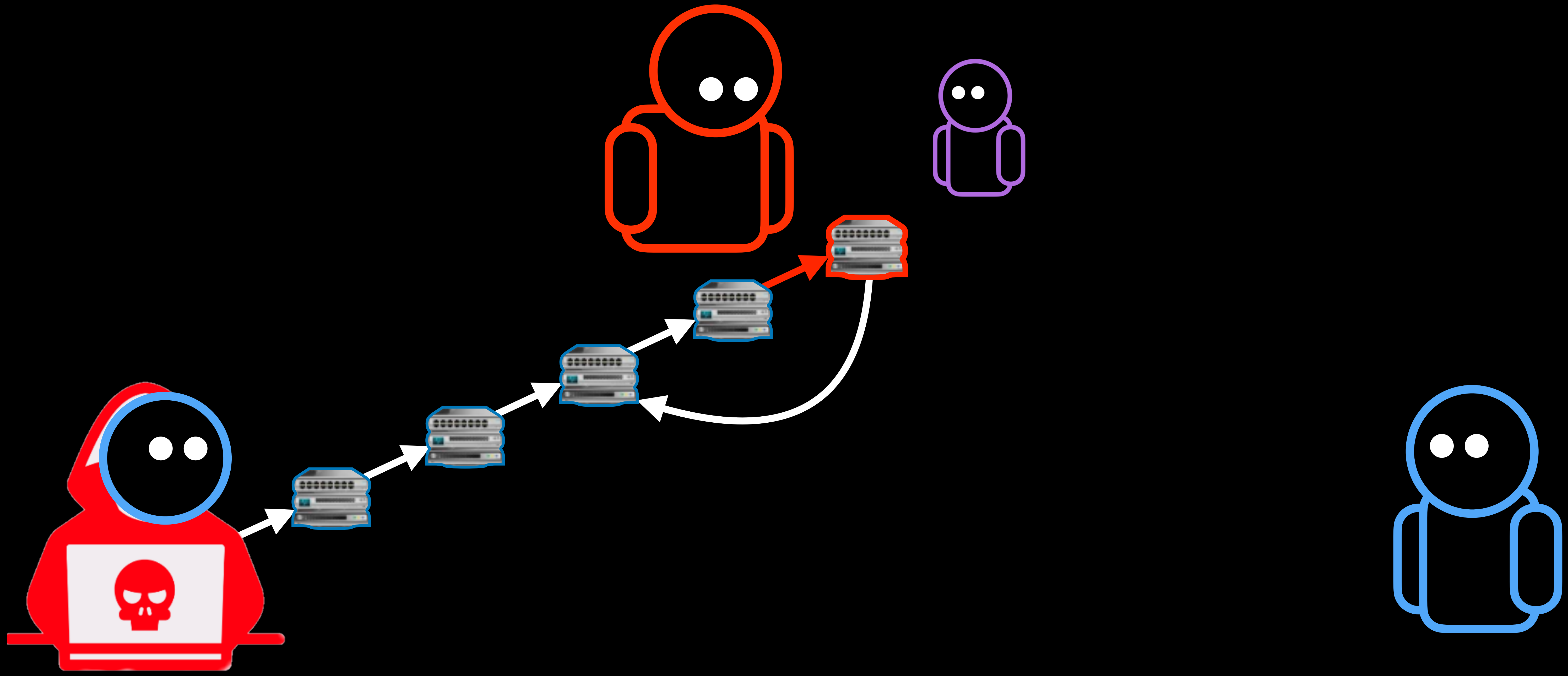

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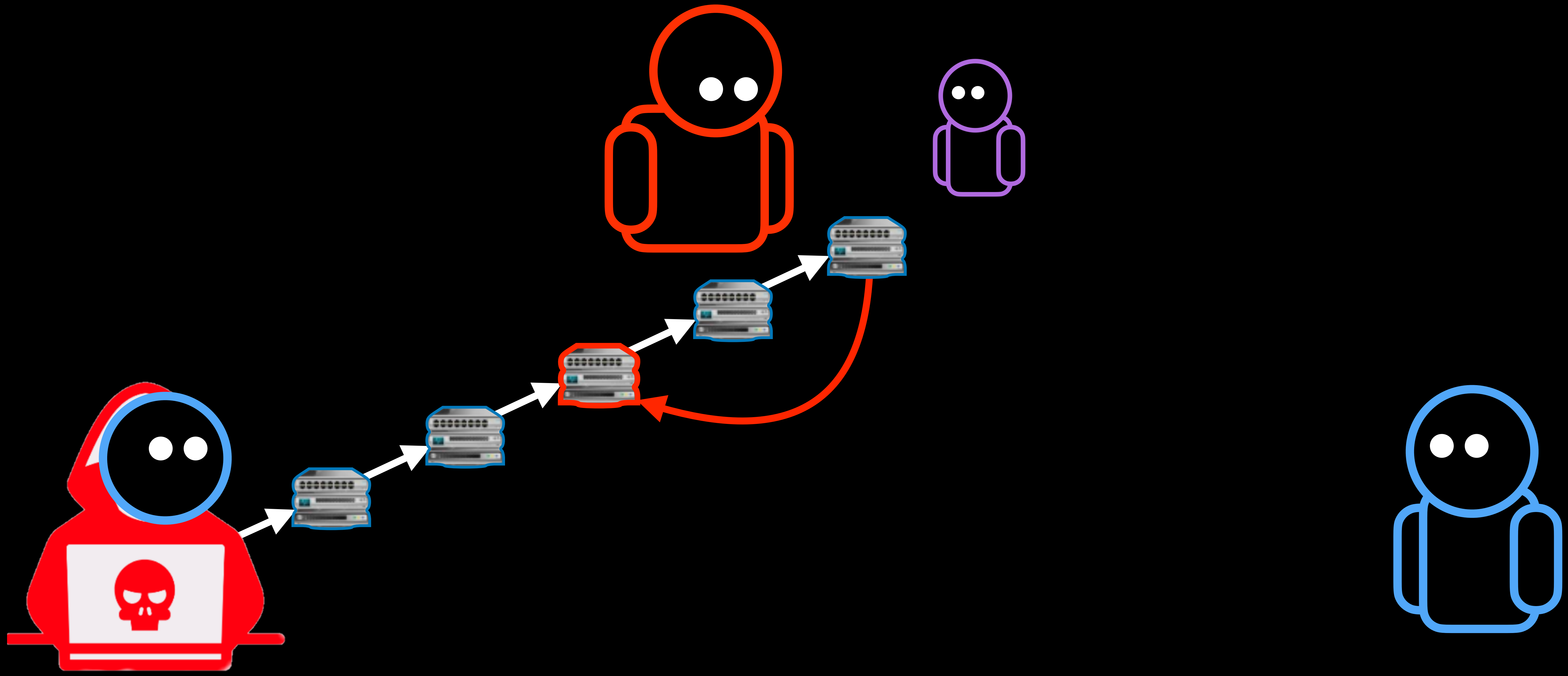

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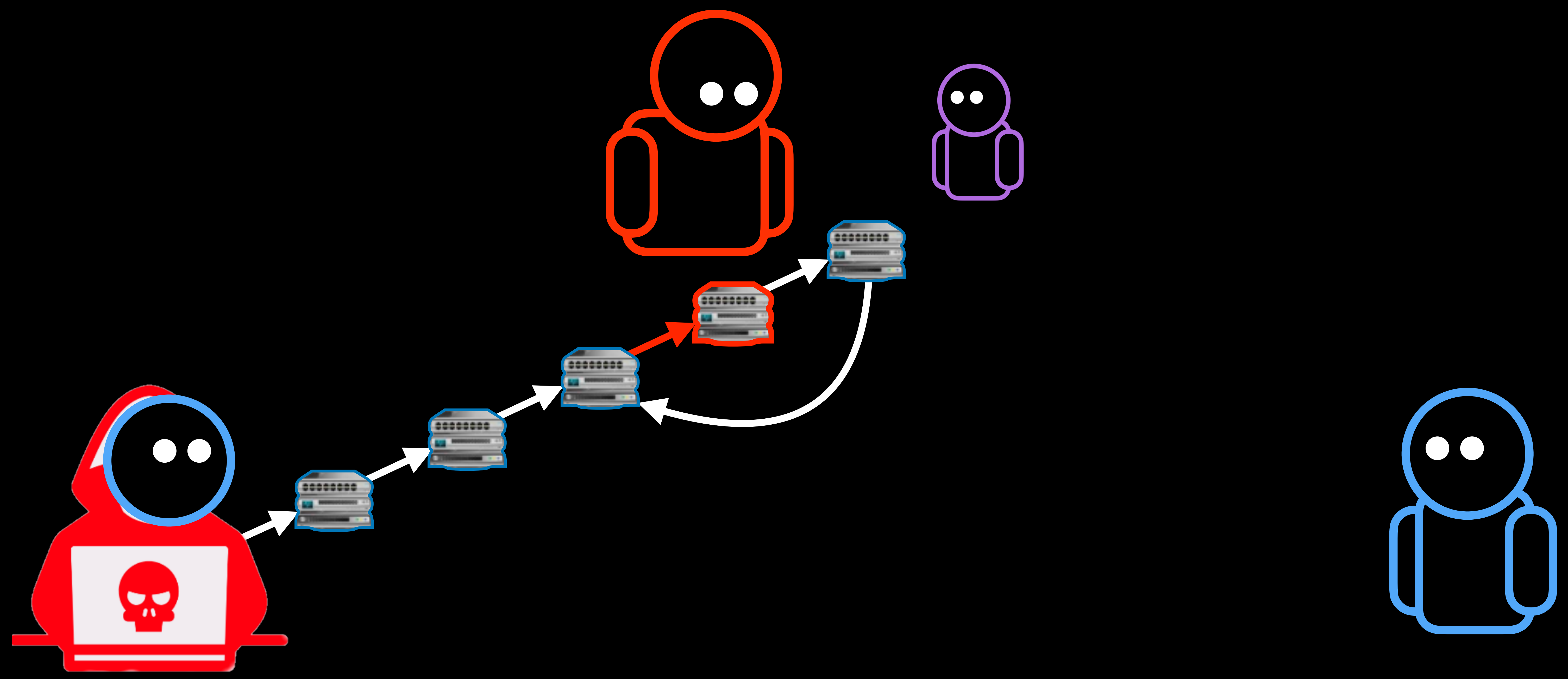

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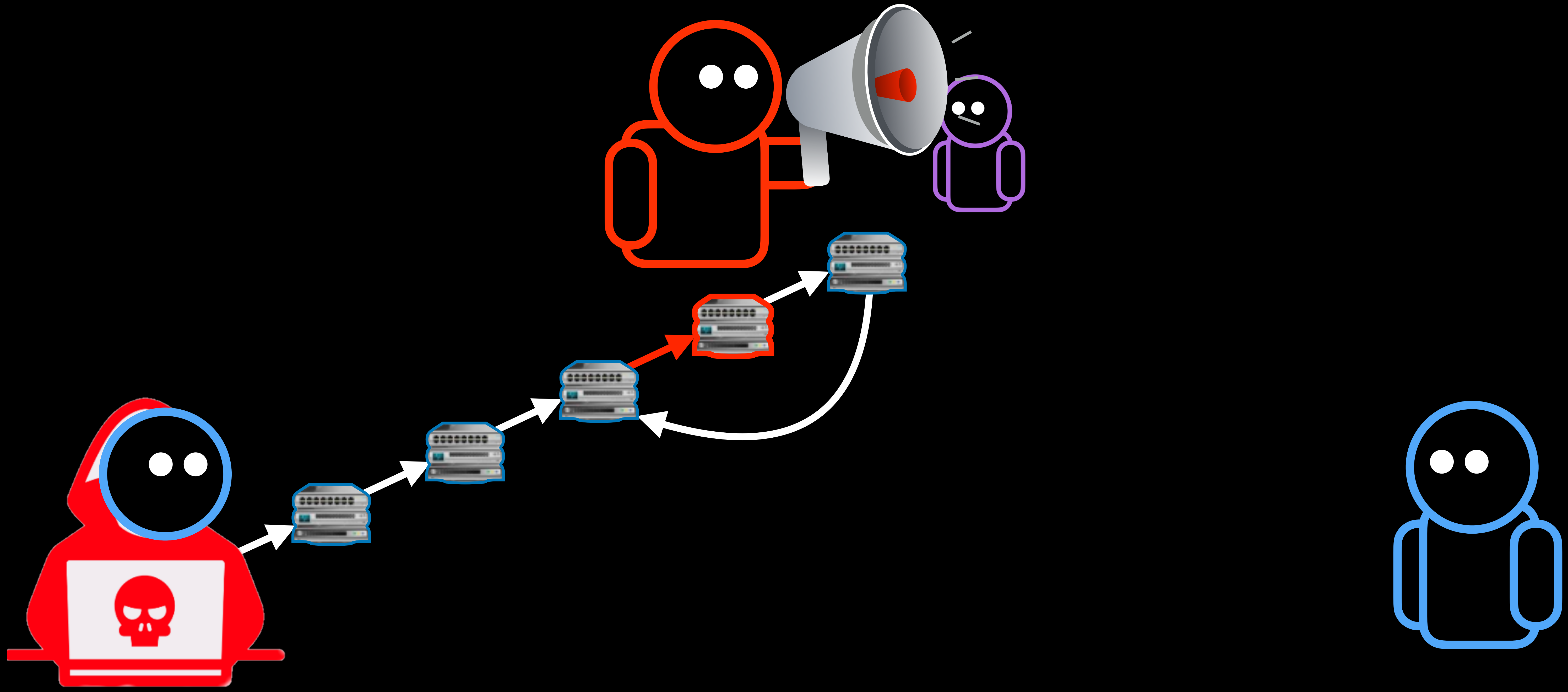

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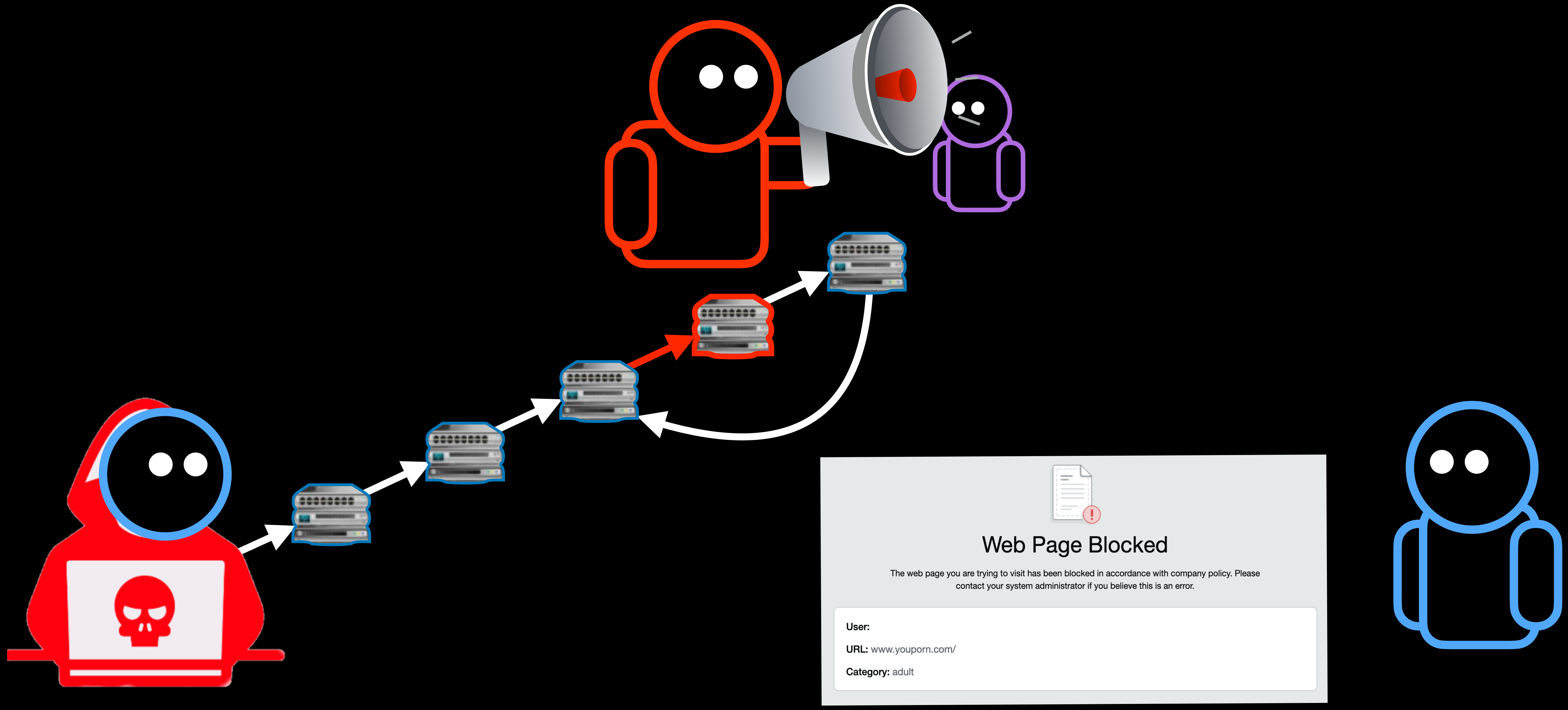


Web Page Blocked

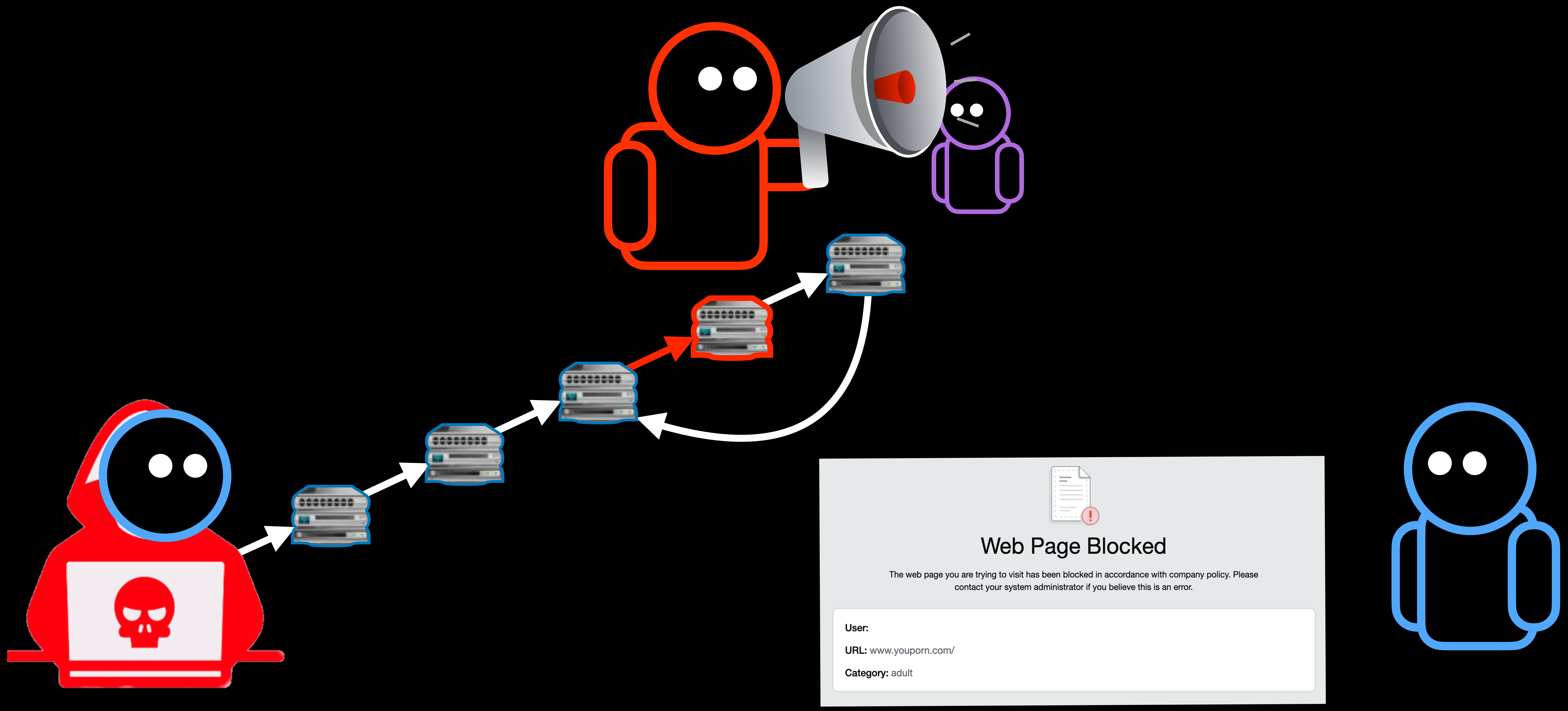
The web page you are trying to visit has been blocked in accordance with company policy. Please contact your system administrator if you believe this is an error.

User:

URL: www.youporn.com/

Category: adult

Mega-amplifier cause #2: Routing loops



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Finite routing loops ⇒ Greater amplification with higher TTL

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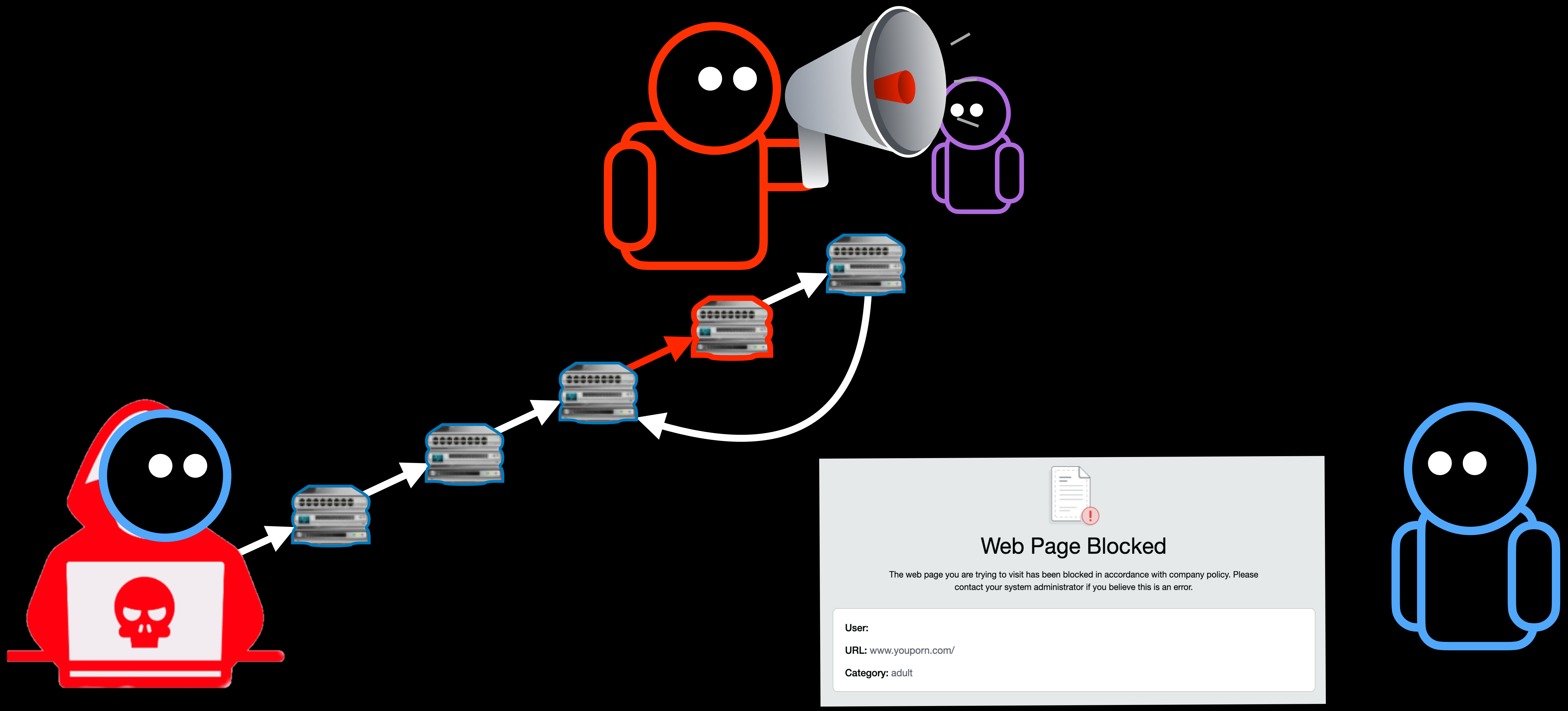

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Finite routing loops ⇒ Greater amplification with higher TTL

Infinite routing loops ⇒ *Infinite amplification*

Notable Amplifiers

∞	🇷🇺	ISP in Russia
949,387x	🇺🇸	Holiday Inn & Suites, Salt Lake City, USA
93,352x	🇧🇭	National Bank of Bahrain
9,084x	🇺🇸	Private Residence in Richardson Texas, USA
4,471x	🇺🇾	LACNIC Regional IP address Registry
1,265x	🇨🇳	International Bank Center, GuangZhou
312x	🇧🇪	University of Ghent, Belgium
239x	🇺🇸	City of Jacksonville, Florida
20x	🇸🇦	Entire Country of Saudi Arabia

Even defensive middleboxes pose a threat to the Internet

Responsible Disclosure

6 months prior to publication

CERTs

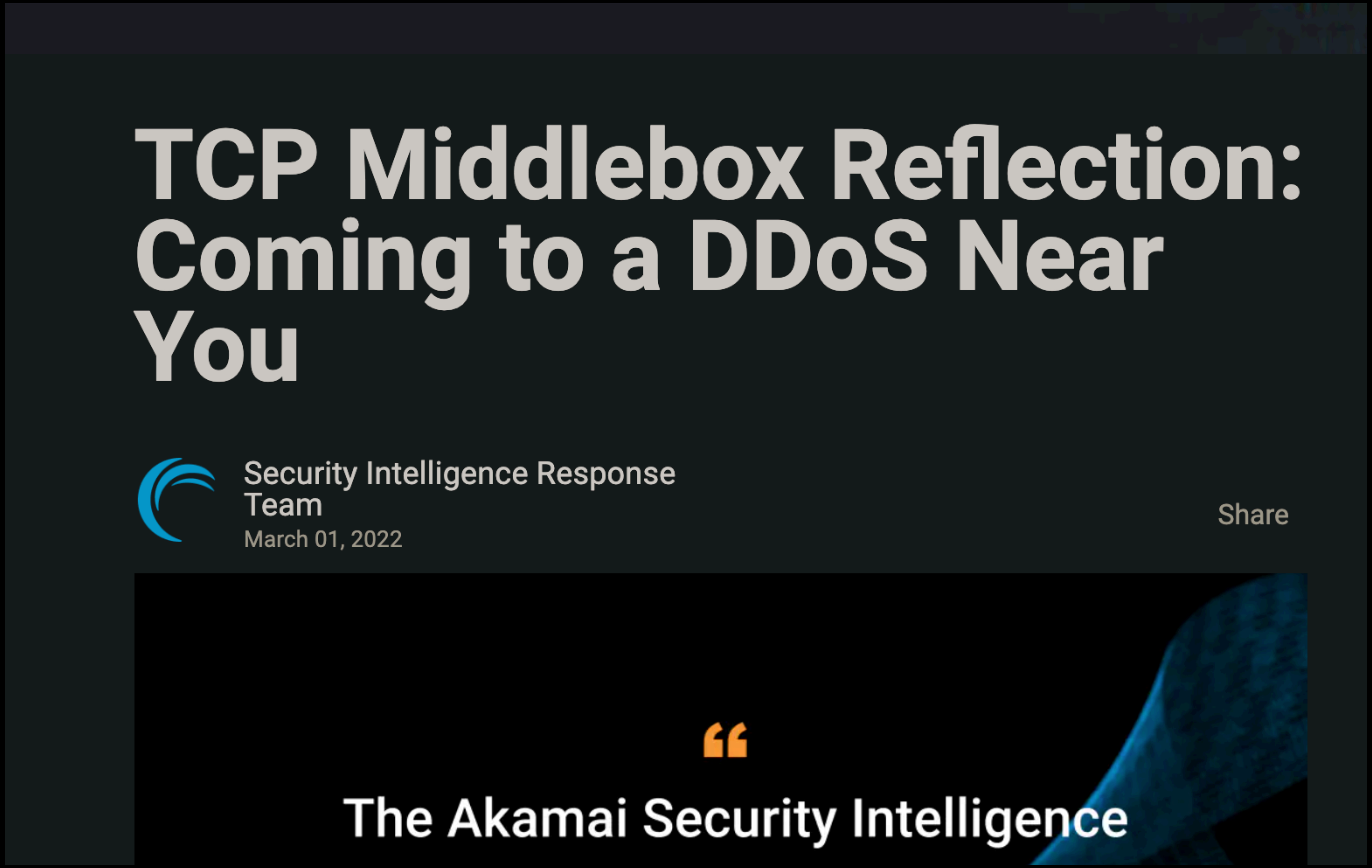
Firewall Manufacturers

DDoS Protection

Other details in the paper

Middlebox fingerprints	Fingerprints of packets from middleboxes
Confirmed middleboxes	TTL limited experiments to confirm most reflectors are middleboxes
Routing loop analysis	Details on prefixes that have abusable routing loops
National firewalls	Analysis of impact of national firewalls

In the Wild



TCP Middlebox Reflection: Coming to a DDoS Near You

Security Intelligence Response Team
March 01, 2022

“The Akamai Security Intelligence

…peaking at 11 Gbps at 1.5 Mpps…

Middleboxes complicate defenses

Respond with larger amounts of data

With unexpected TCP flags

While ignoring protocol signals to stop

```
17:54:20.399947 IP X.X.X.X.45678 > Z.Z.Z.Z.443: Flags [S], seq 0:33, win 8192, length 33
17:54:20.685491 IP Z.Z.Z.Z.443 > X.X.X.X.45678: Flags [S], seq 1300:2156, win 8760, options [mss 1360], length 856
17:54:20.685521 IP X.X.X.X.45678 > Z.Z.Z.Z.443: Flags [R.], seq 0, ack 2157, win 0, length 0
17:54:20.685563 IP Z.Z.Z.Z.443 > X.X.X.X.45678: Flags [S], seq 0:1300, win 8760, options [mss 1360], length 1300
17:54:20.685568 IP X.X.X.X.45678 > Z.Z.Z.Z.443: Flags [R.], seq 0, ack 4294966441, win 0, length 0
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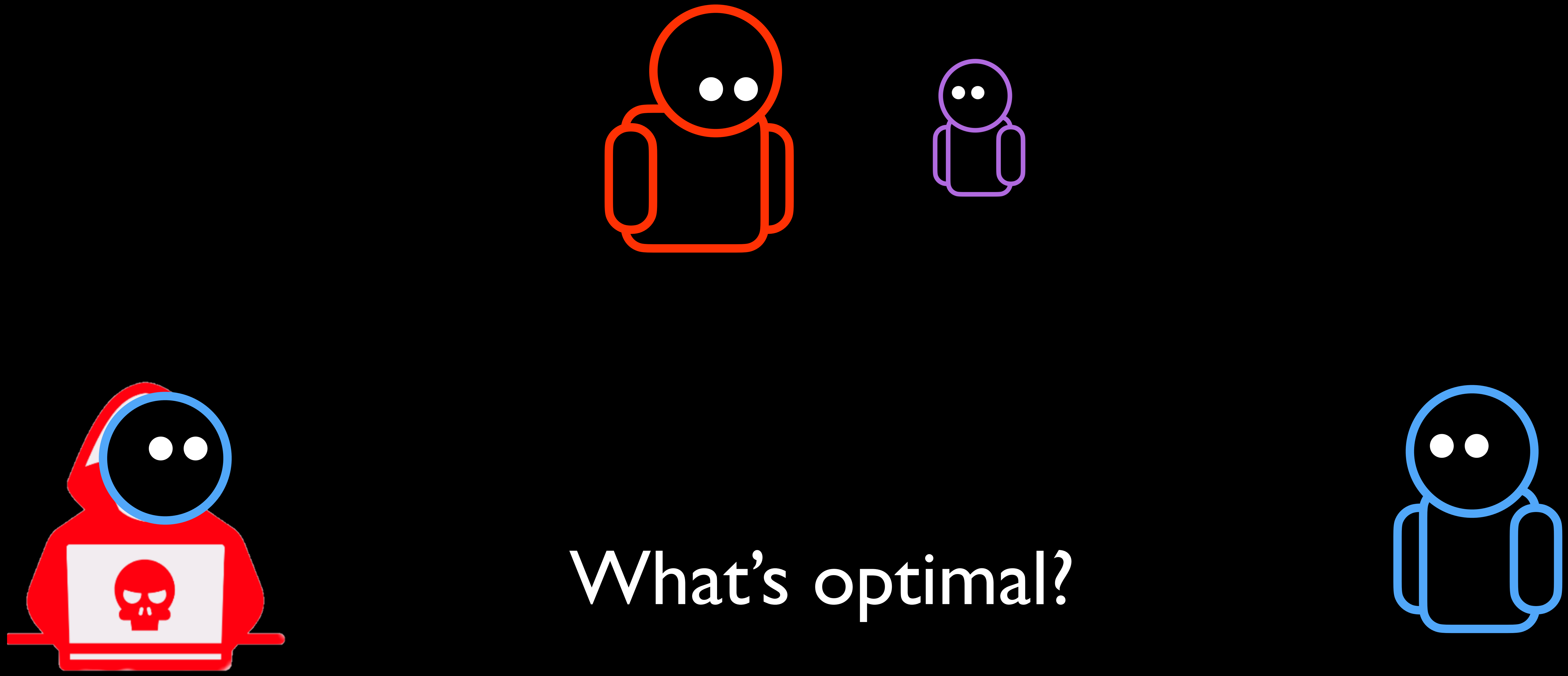
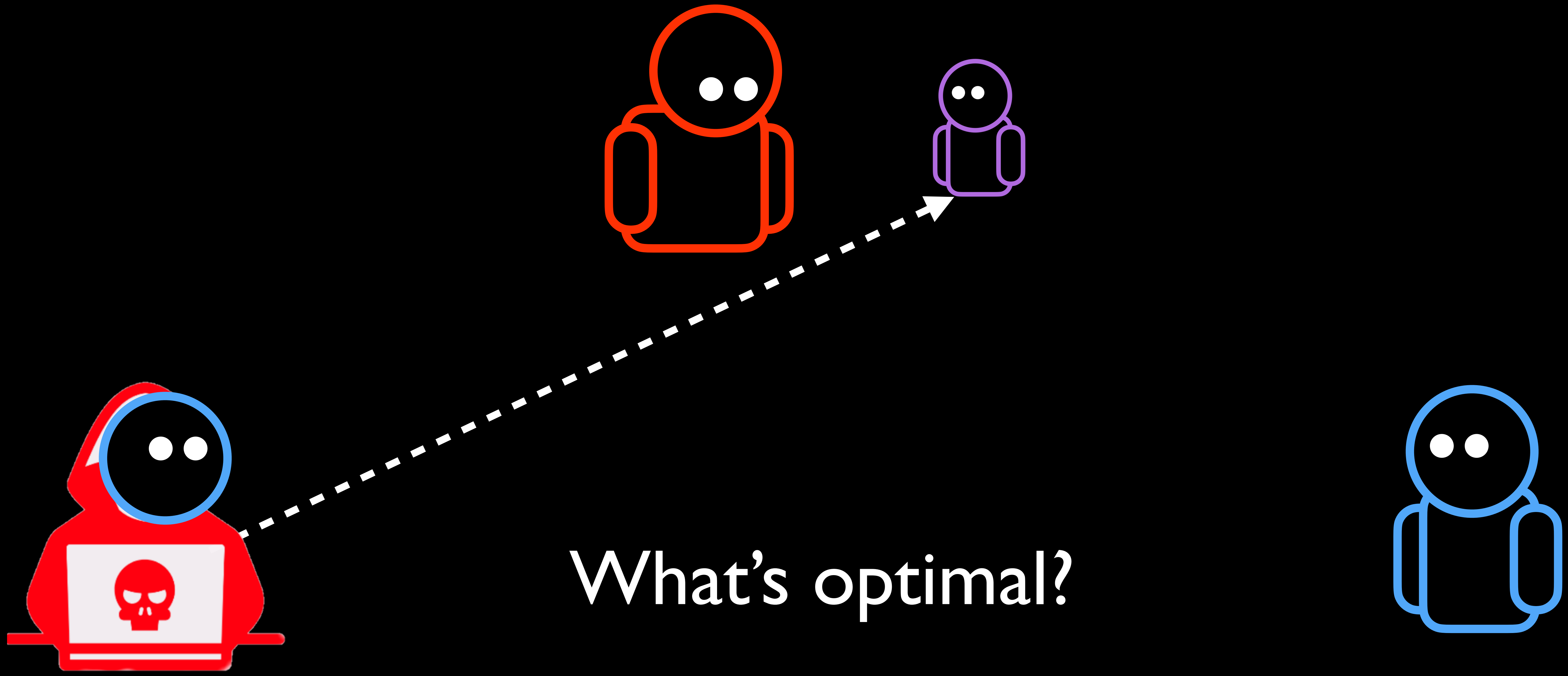
Attackers are still optimizing



What's optimal?

Attackers are still optimizing



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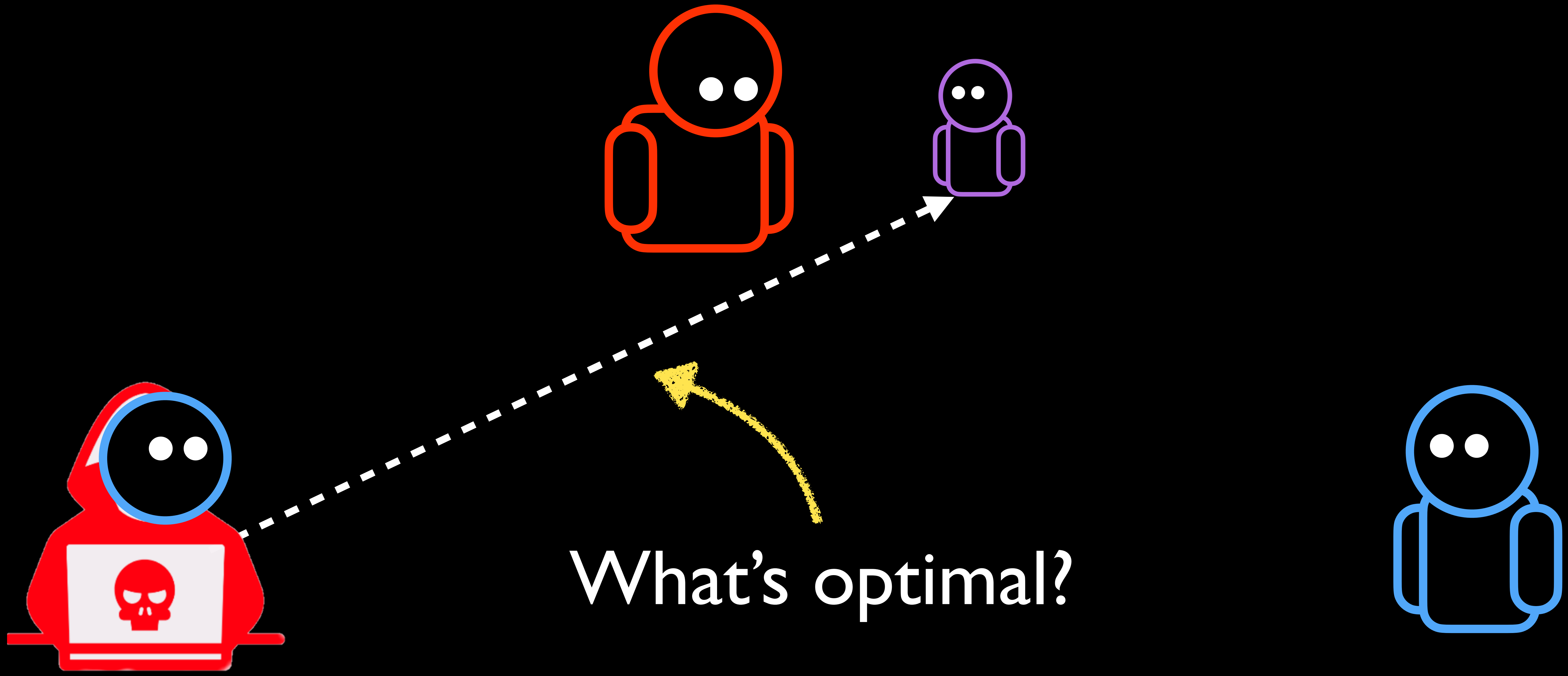


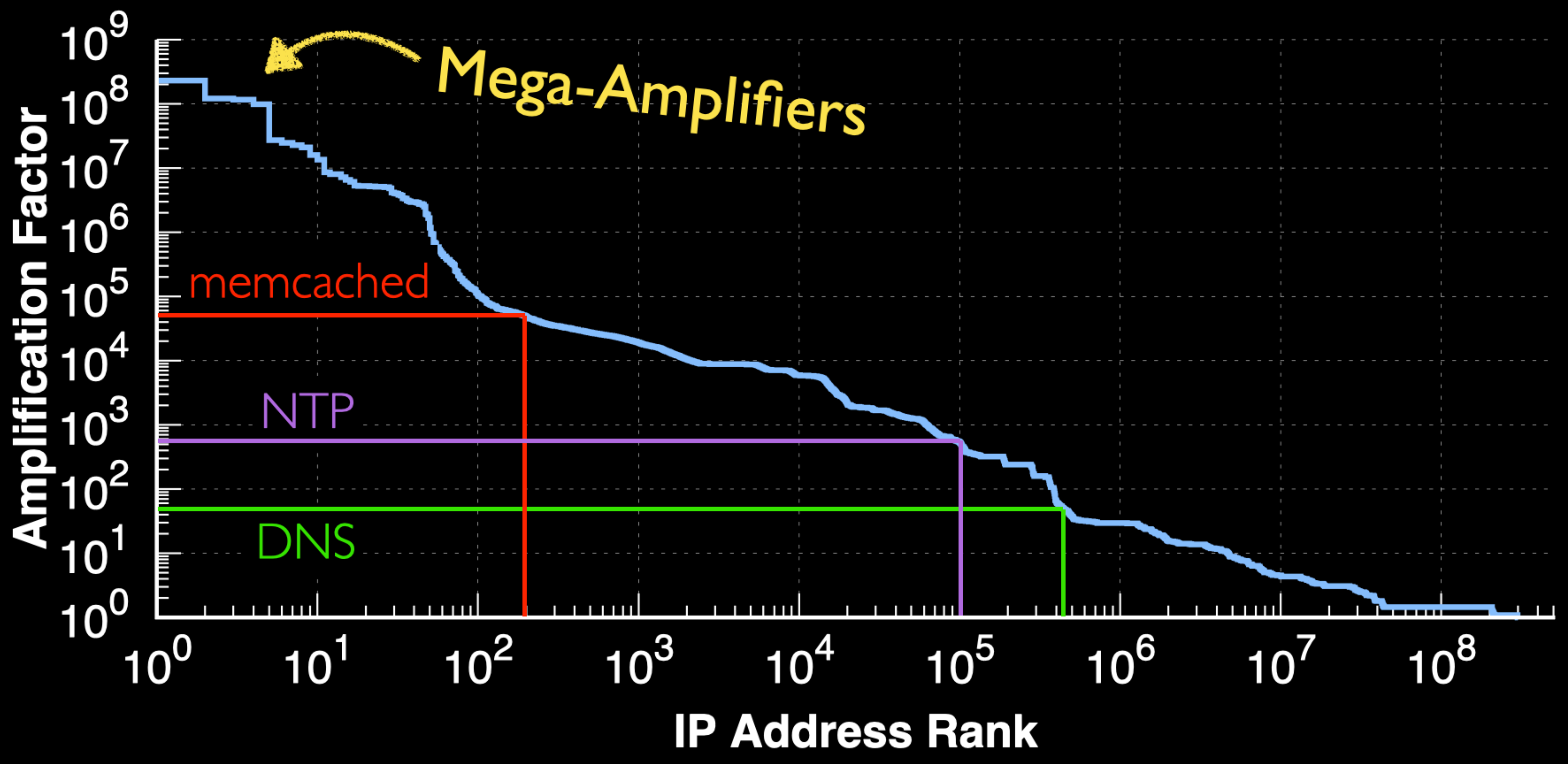
What's optimal?

Weaponizing Middleboxes

Middleboxes make
TCP-based reflected amplification
possible and *effective*

Automated discovery of
new amplification attacks

Root causes of ∞-amplification:
Victim-sustained & Routing-loops



Code and website censorship.ai