TsuKing: Coordinating DNS Resolvers and Queries into Potent DDoS Amplifiers

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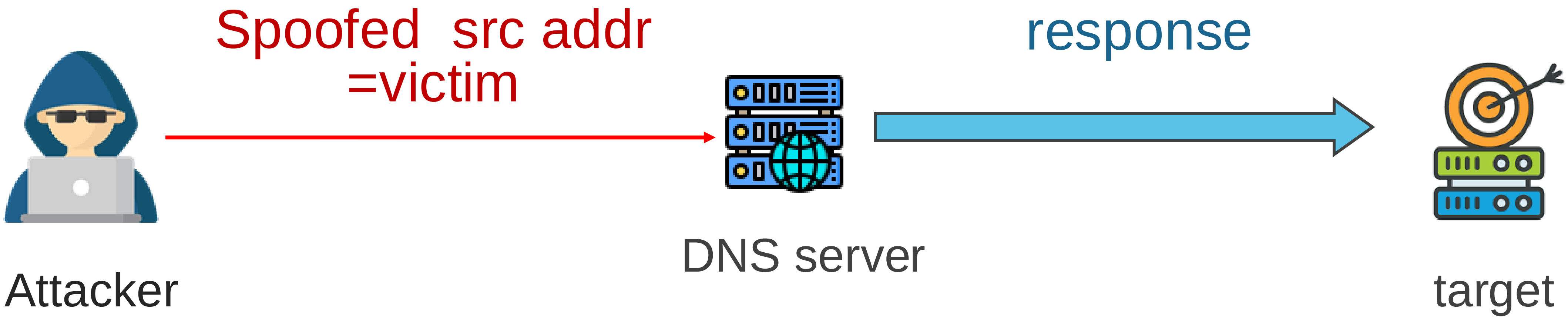
Slides Contributors: **Wei Xu** & **Xiang Li** & **Chaoyi Lu**

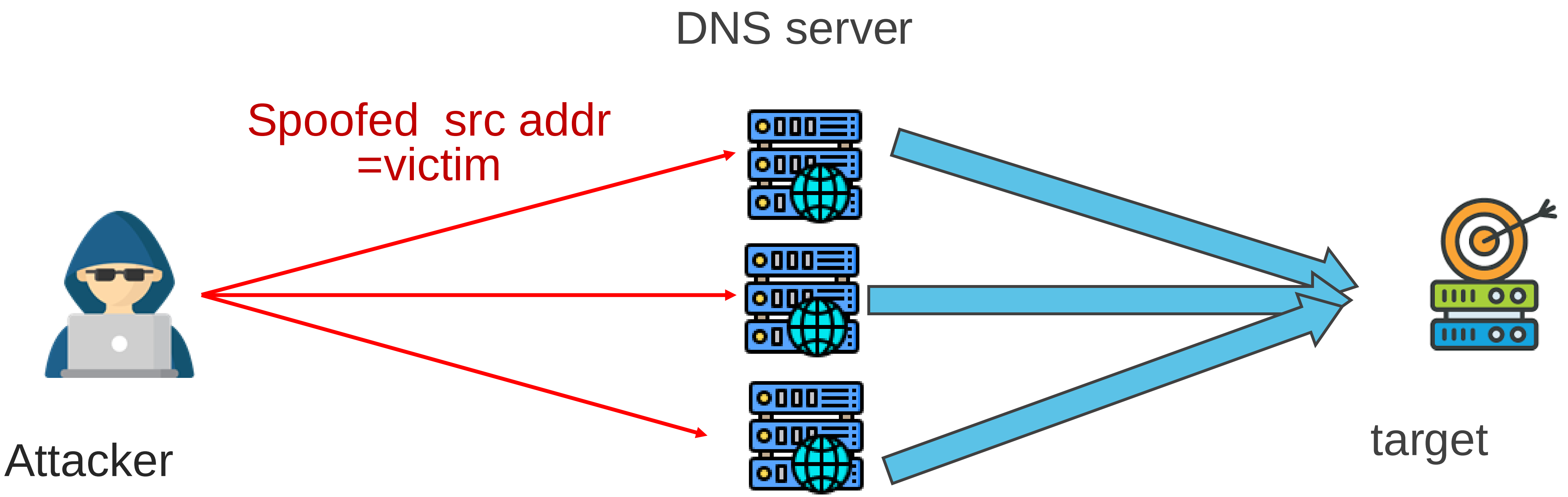
Tsinghua University, Dec. 2023

Reflection and Amplification DDOS by DNS



- Maximize the amplification potential of a **single DNS server.**
- IP Address Spoofing

Current DOS attack by DNS

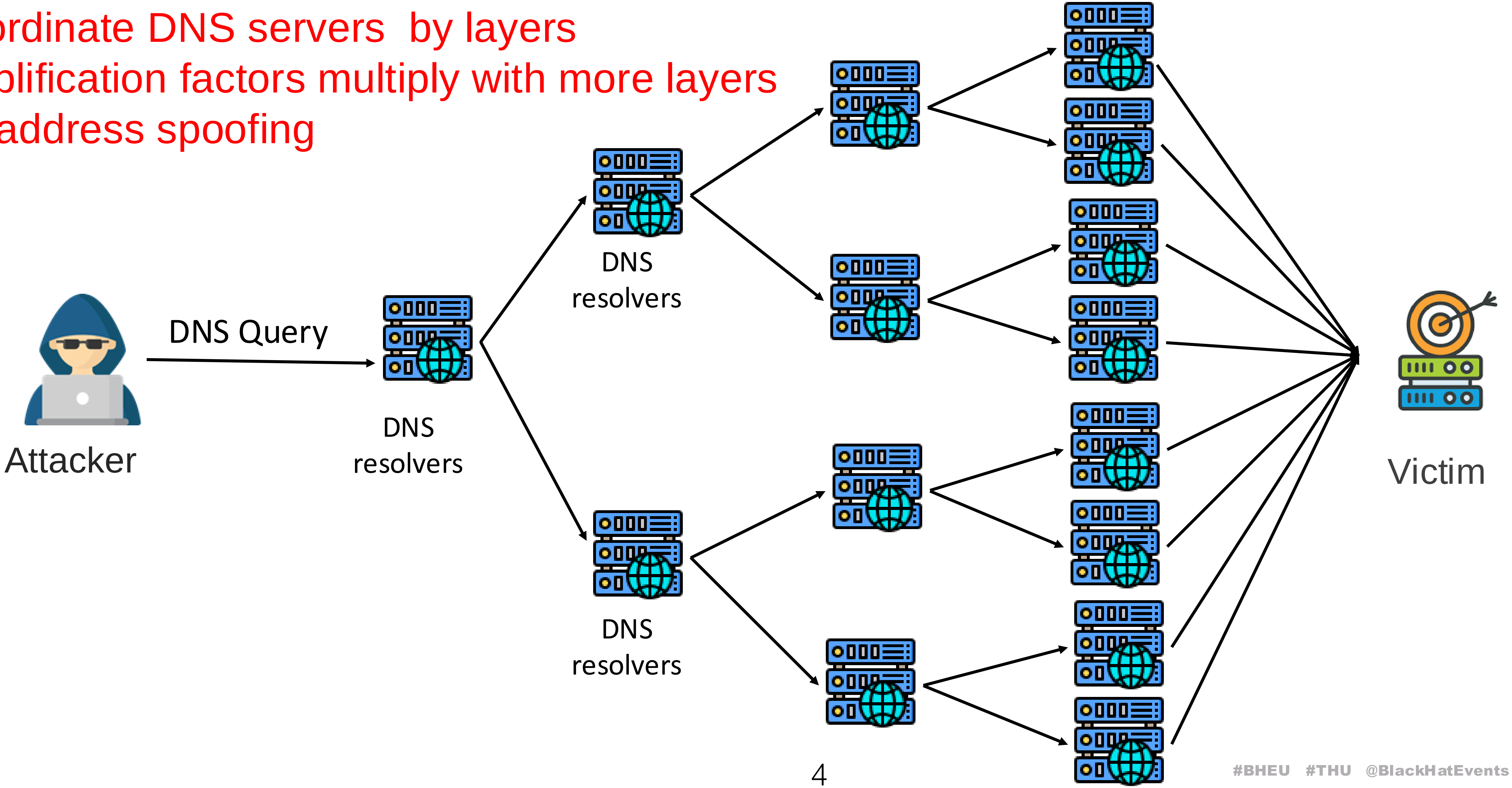


Send more queries to more servers, in parallel

Amplification factor unchanged

Tsuking Attack is different

- Coordinate DNS servers by layers
- Amplification factors multiply with more layers
- No address spoofing



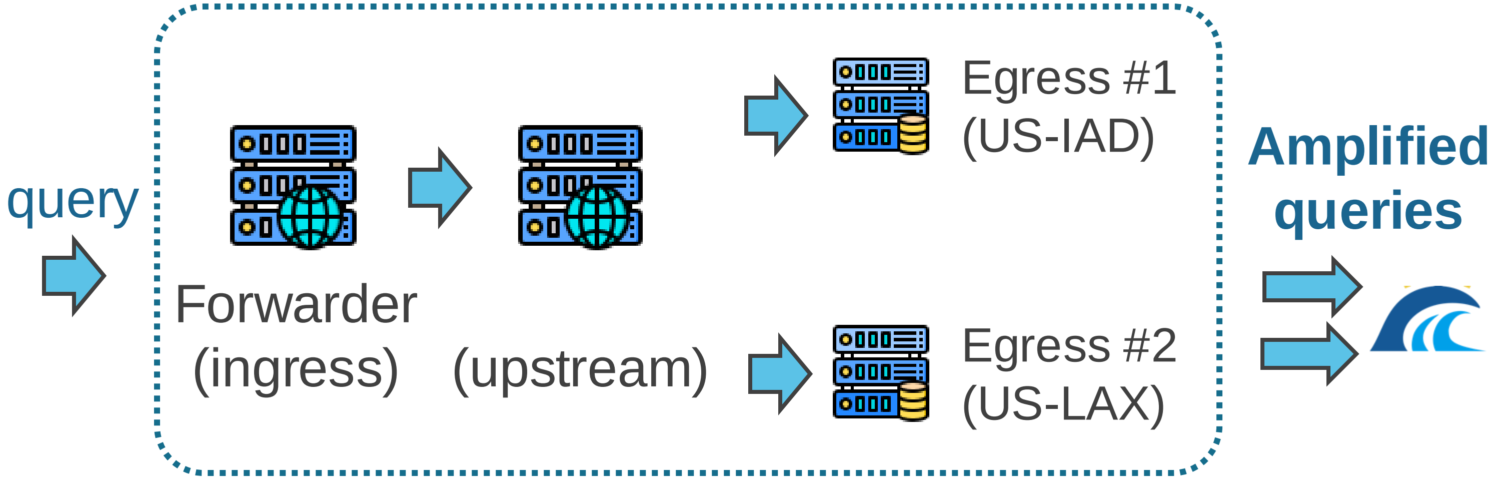
TsuKing: Tsunami + King

?

TsuKing: Tsunami + King

(Traffic amplification ability)

- ❖ cause: bogus implementation & complex resolving infrastructure



query

Forwarder (ingress)

(upstream)

Egress #1 (US-IAD)

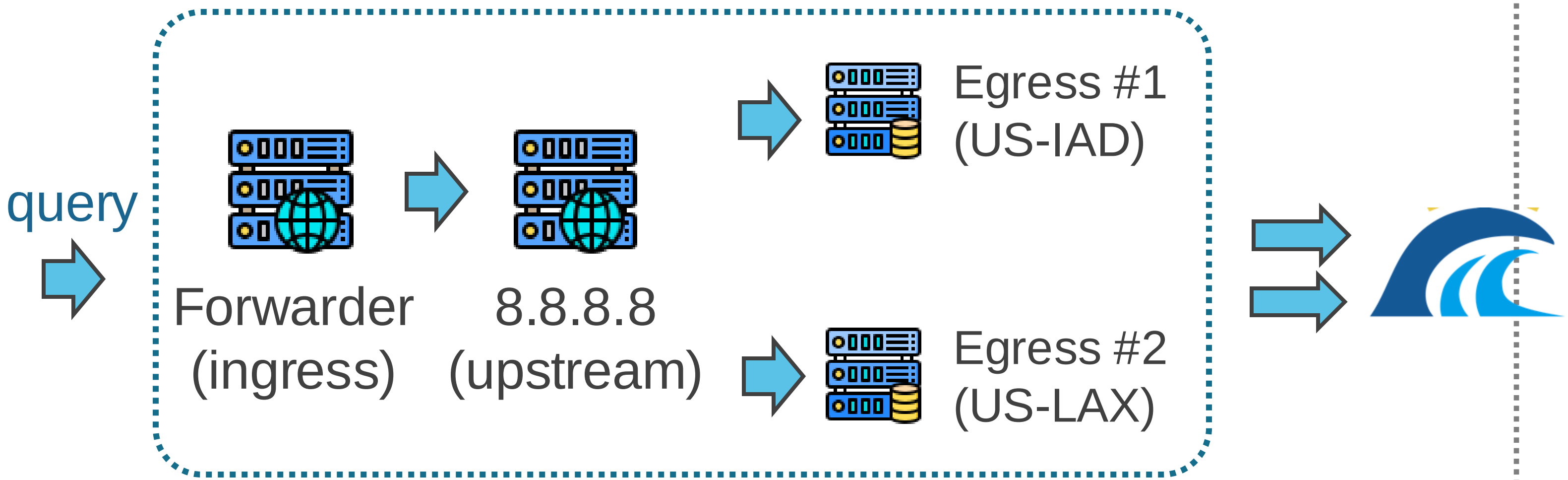
Egress #2 (US-LAX)

Amplified queries

TsuKing: Tsunami + King [1]

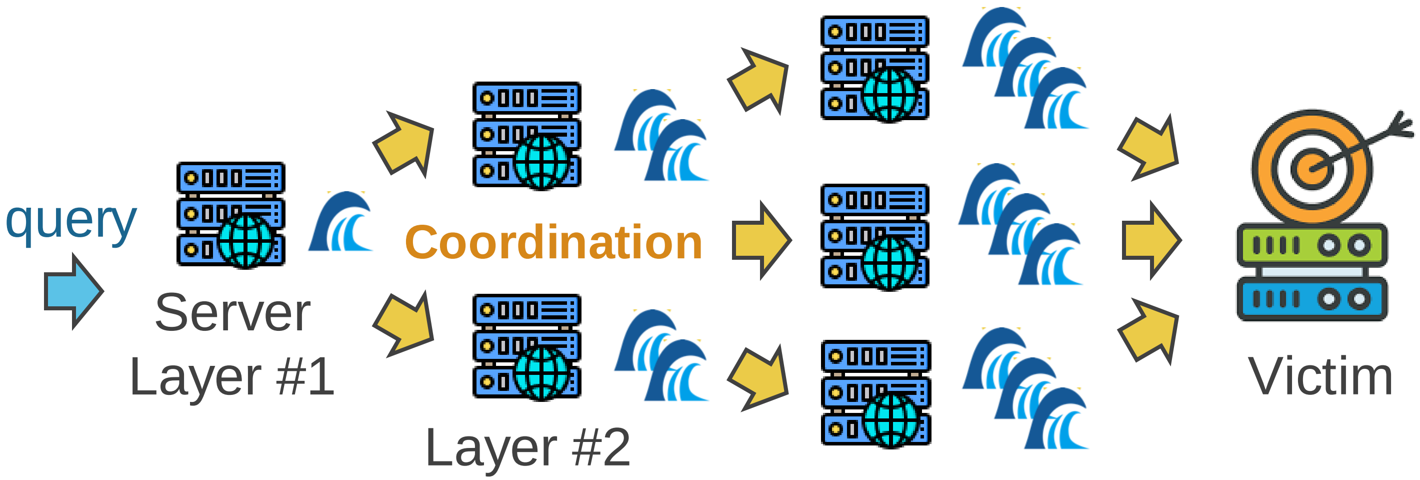
(Traffic amplification ability)

- ❖ Cause: DNS implementation choices & complex service infrastructure



(Server coordination ability)

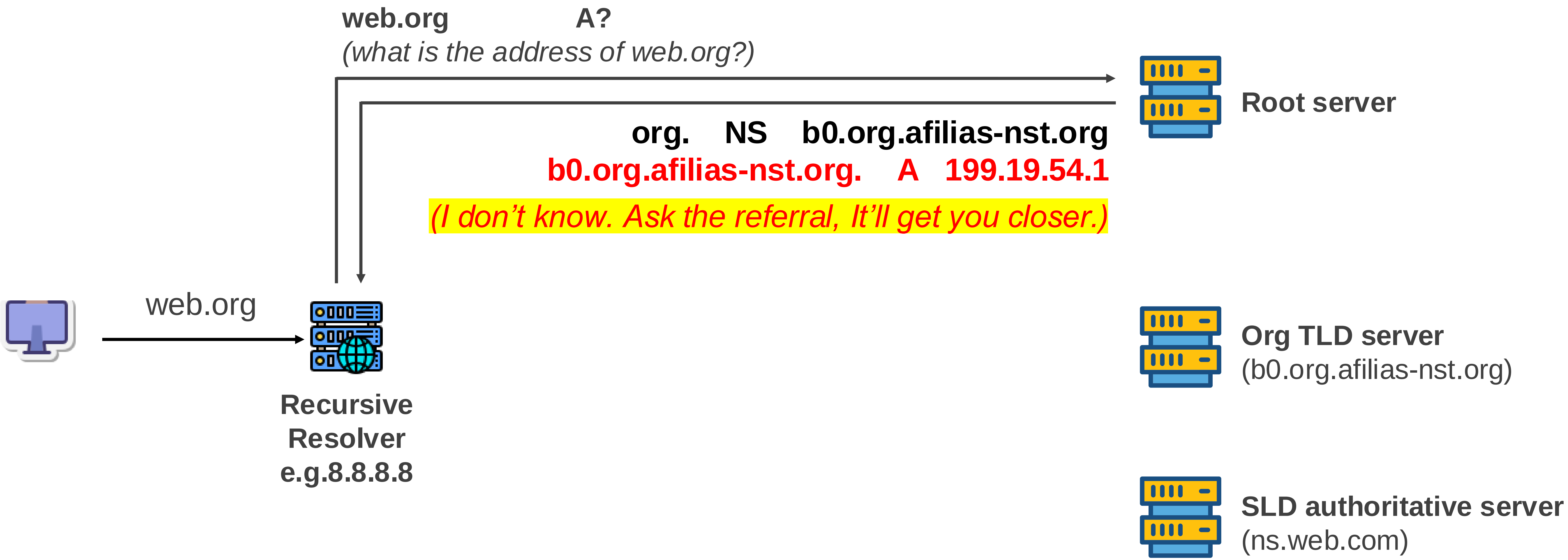
- ❖ Coordinates DNS server systems -> **3,000+✕ amplification factor (*king* of DoS)**



[1] King: estimating latency between arbitrary internet end hosts, ACM CCR 2002

DNS resolution guided by *referrals*

❖ Referrals *tell recursive resolvers who to ask next*



web.org **A?**

(what is the address of web.org?)

org. NS b0.org.afilias-nst.org

b0.org.afilias-nst.org. A 199.19.54.1

(I don’t know. Ask the referral, It’ll get you closer.)

web.org

Recursive Resolver e.g.8.8.8.8

Root server

Org TLD server
(b0.org.afilias-nst.org)

SLD authoritative server
(ns.web.com)

DNS resolution guided by *referrals*

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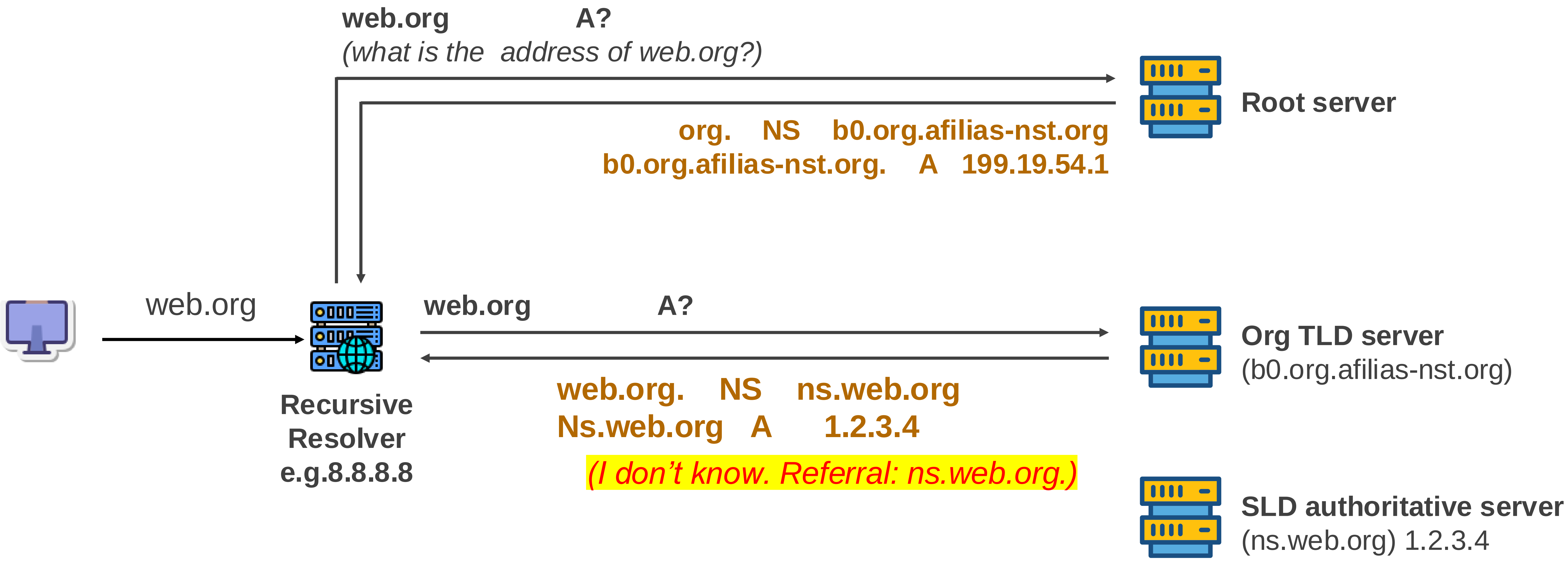

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web.org. NS ns.web.org

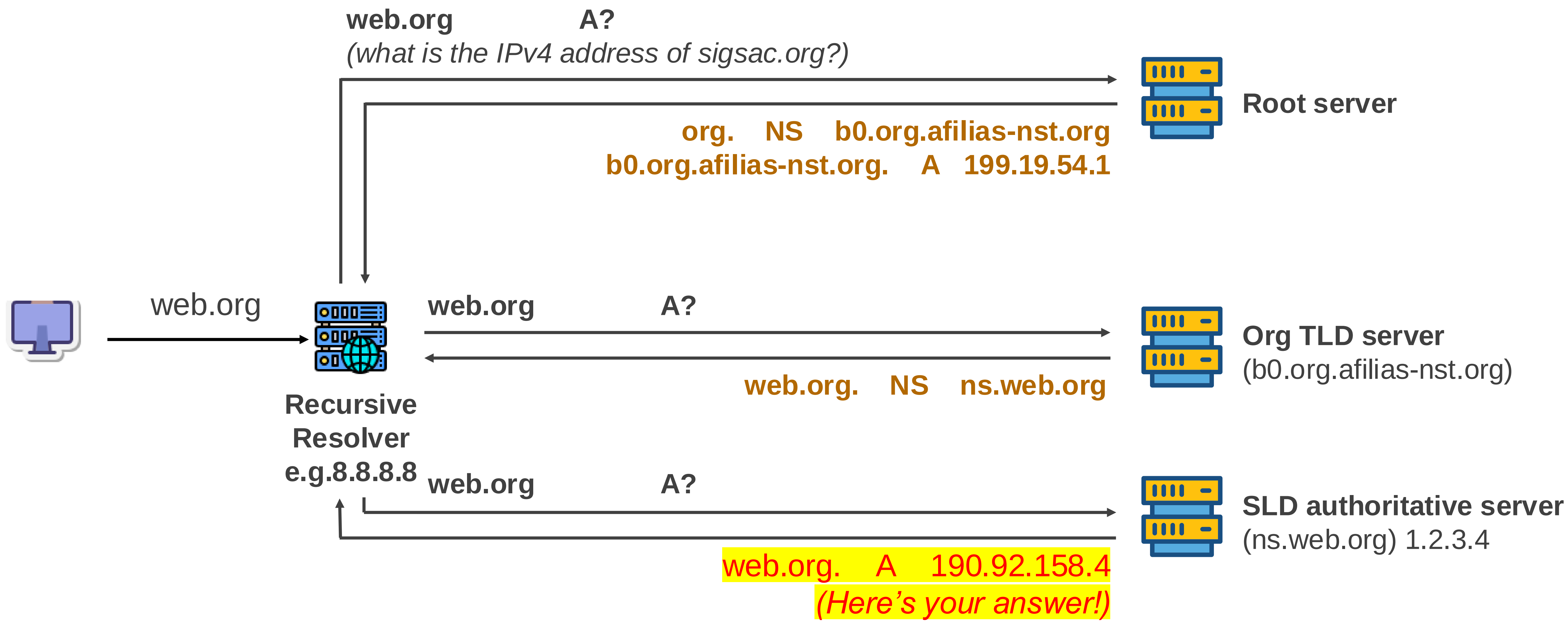
Ns.web.org A 1.2.3.4

(I don't know. Referral: ns.web.org.)

SLD authoritative server
(ns.web.org) 1.2.3.4

DNS resolution guided by *referrals*

- **Recursive DNS resolution guided by *referrals***
  - Referrals *tell recursive resolvers who to ask next*



web.org A?

(what is the IPv4 address of sigsac.org?)

Root server

org. NS b0.org.afilias-nst.org

b0.org.afilias-nst.org. A 199.19.54.1

web.org

Recursive Resolver e.g.8.8.8.8

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web.org A?

SLD authoritative server

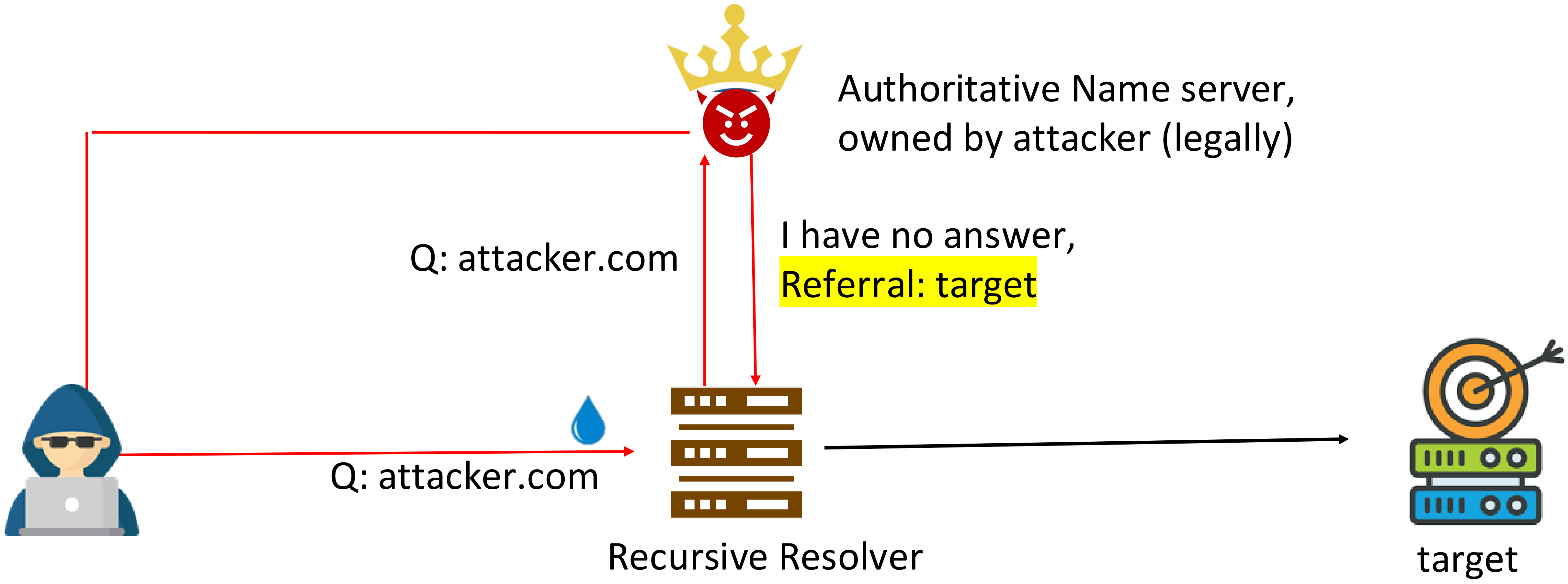
(ns.web.org) 1.2.3.4

web.org. A 190.92.158.4

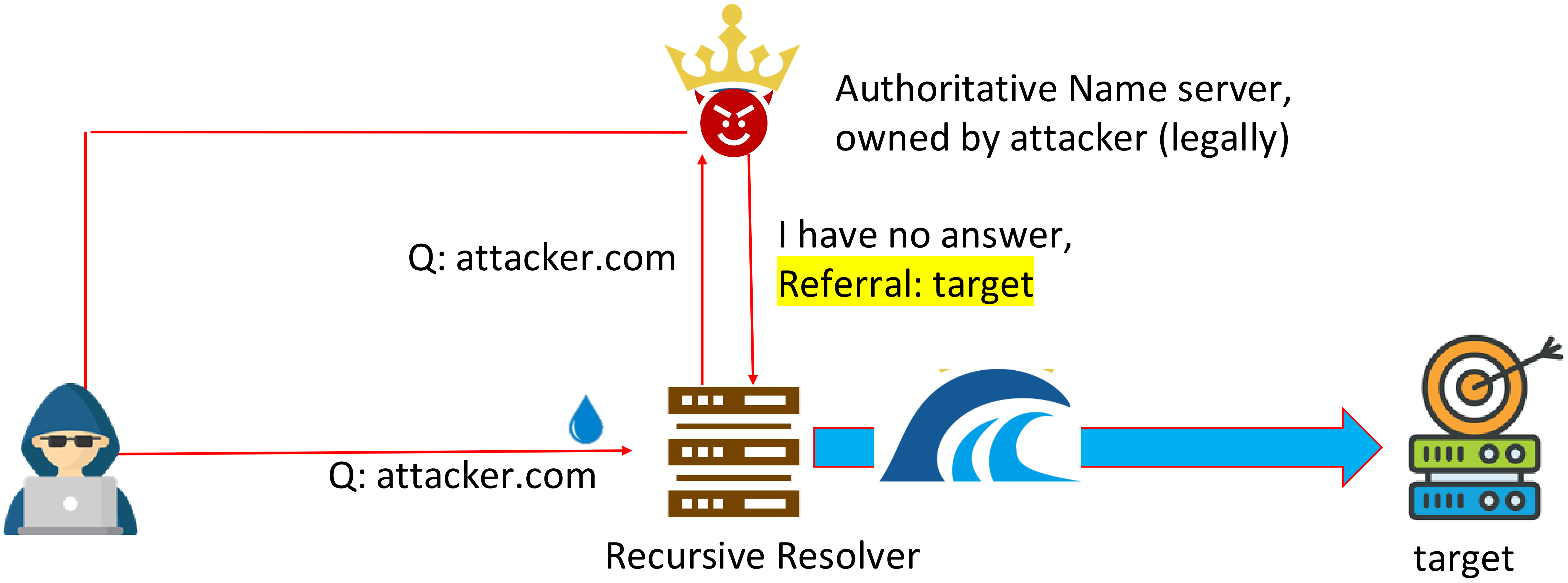
(Here's your answer!)

Threat model of TsuKing

❖ Attacker sends DNS query to recursive resolver for his own domain name



Threat model of TsuKing

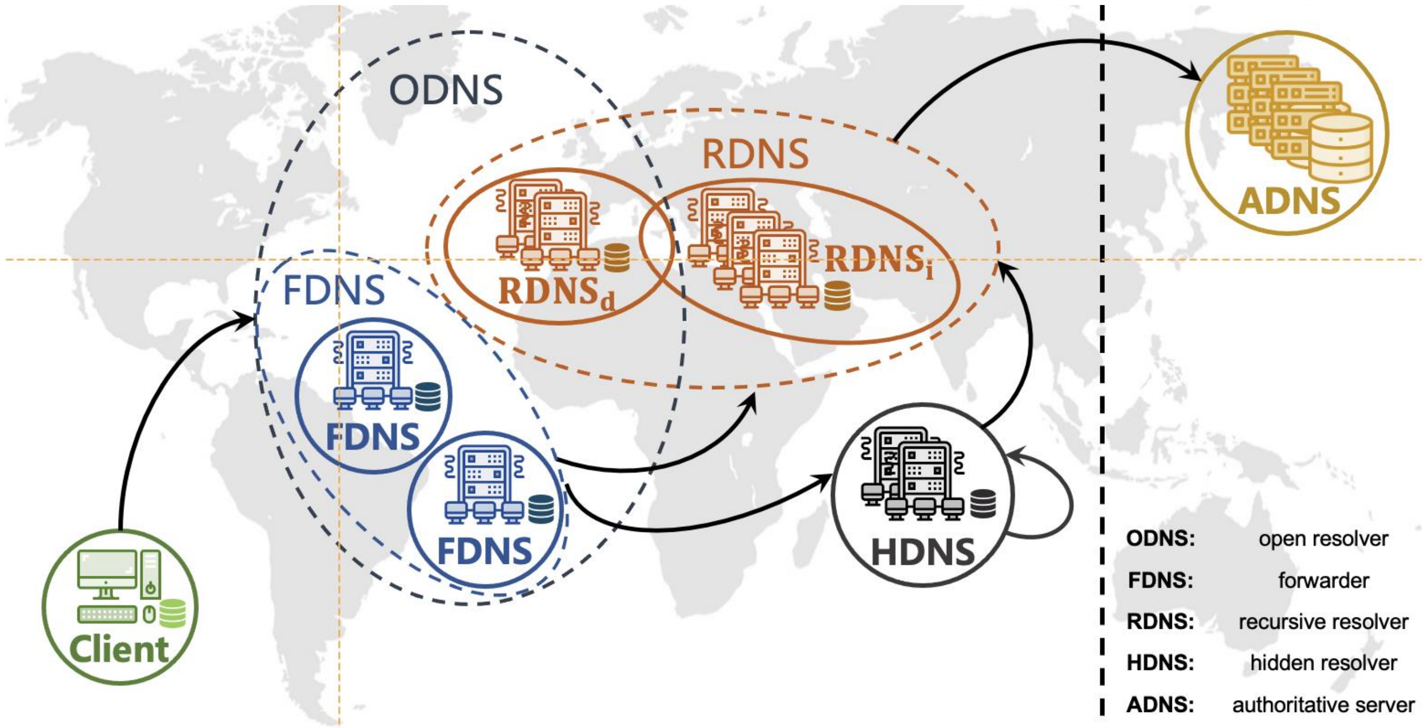


But where does the tsunami come from?

DNS as a complex infrastructure

- **Multiple *types* and *layers* of DNS servers**
  - DNS forwarders ➔ pass queries to upstream *(e.g., another forwarder)*
  - Large public DNS services ➔ complexes of load balancers, caches, egress servers, etc.

The complex DNS infrastructure



ODNS:	open resolver
FDNS:	forwarder
RDNS:	recursive resolver
HDNS:	hidden resolver
ADNS:	authoritative server

Schomp, et al. On Measuring the Client-side DNS Infrastructure, IMC 2013

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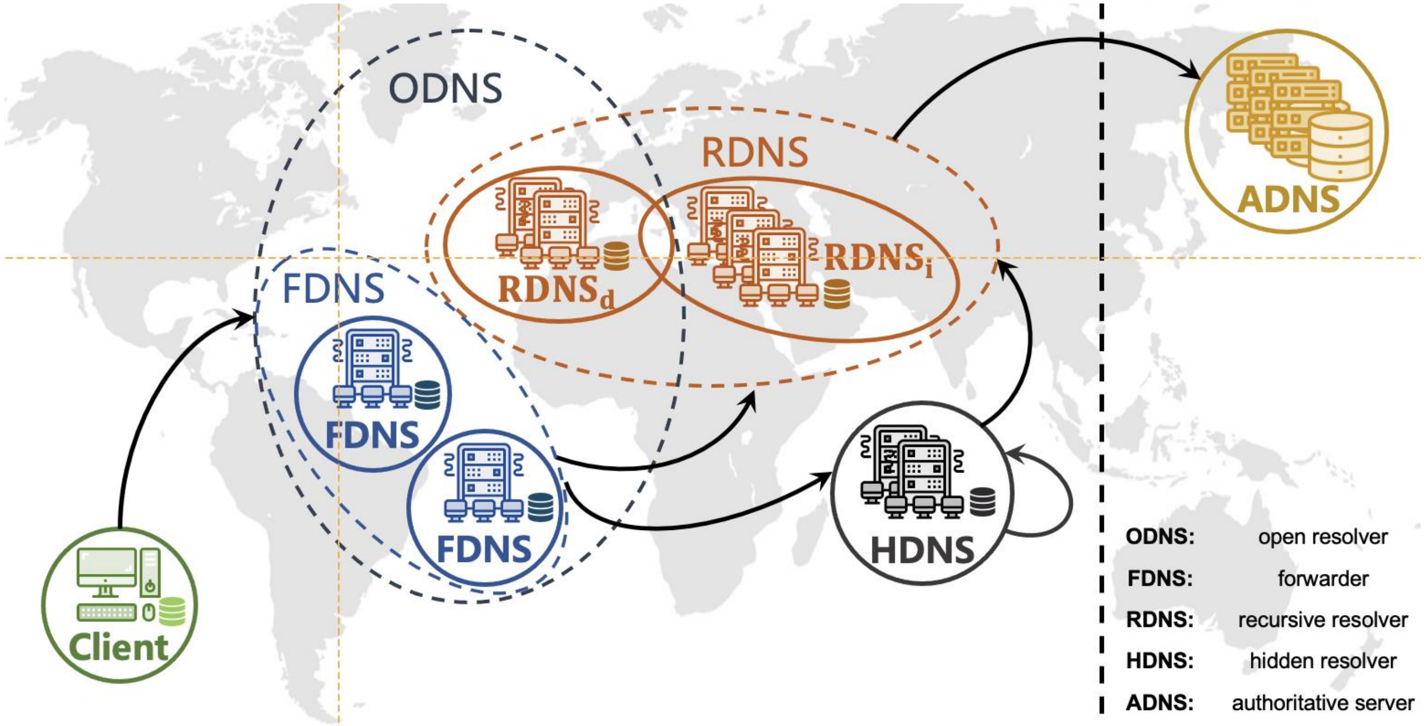

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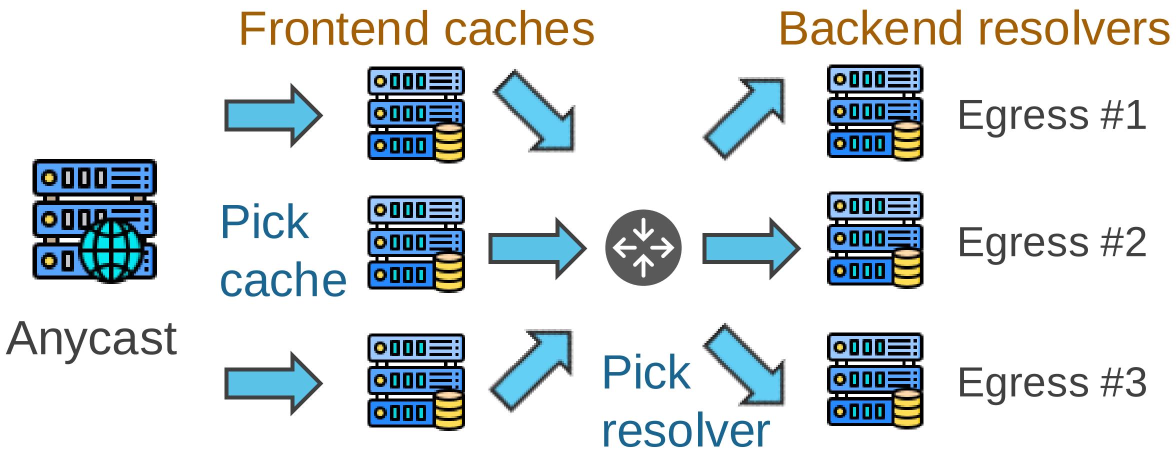
Large public DNS service

(e.g., Google Public DNS)



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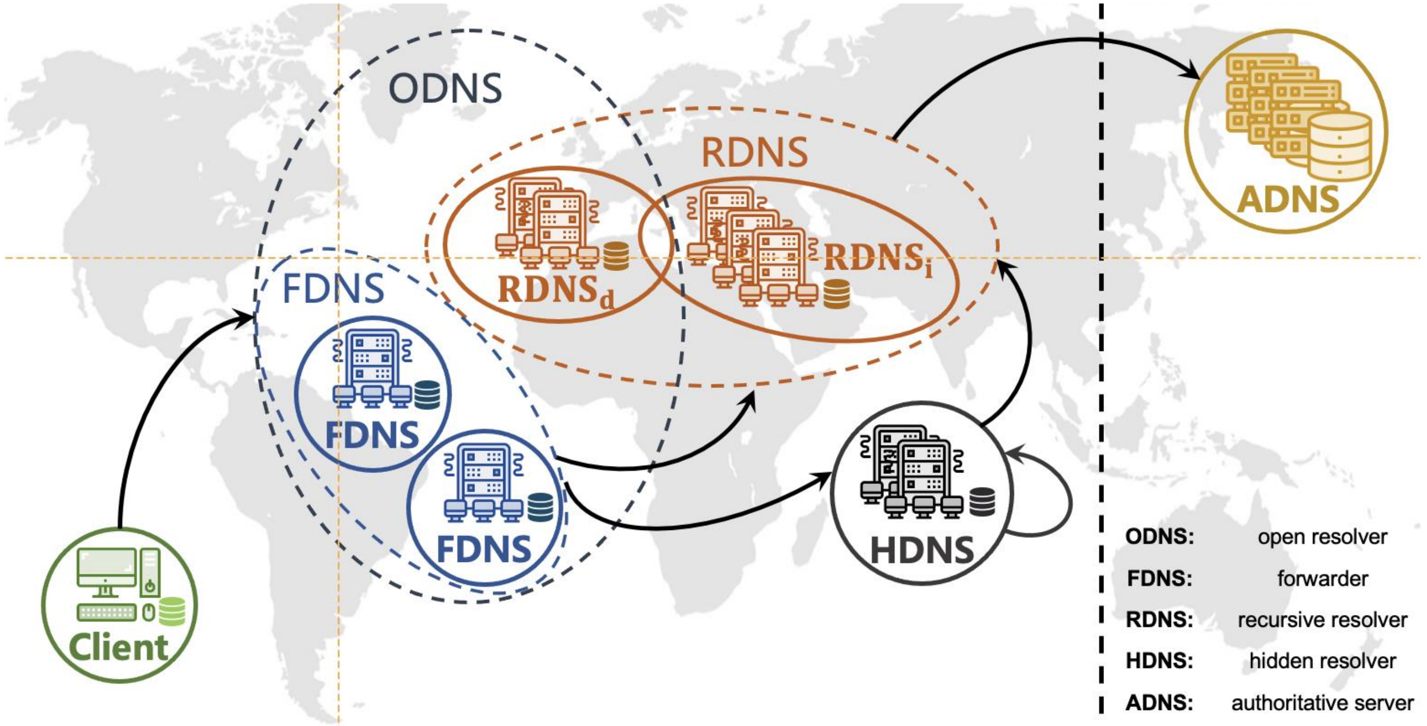

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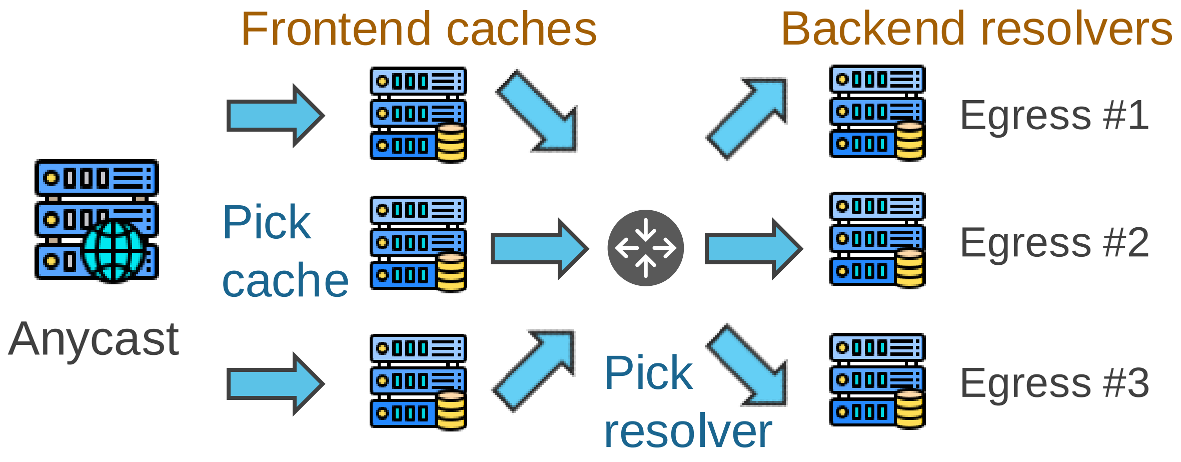


Frontend caches

Backend resolvers

Anycast

Pick cache

Pick resolver

Egress #1

Egress #2

Egress #3

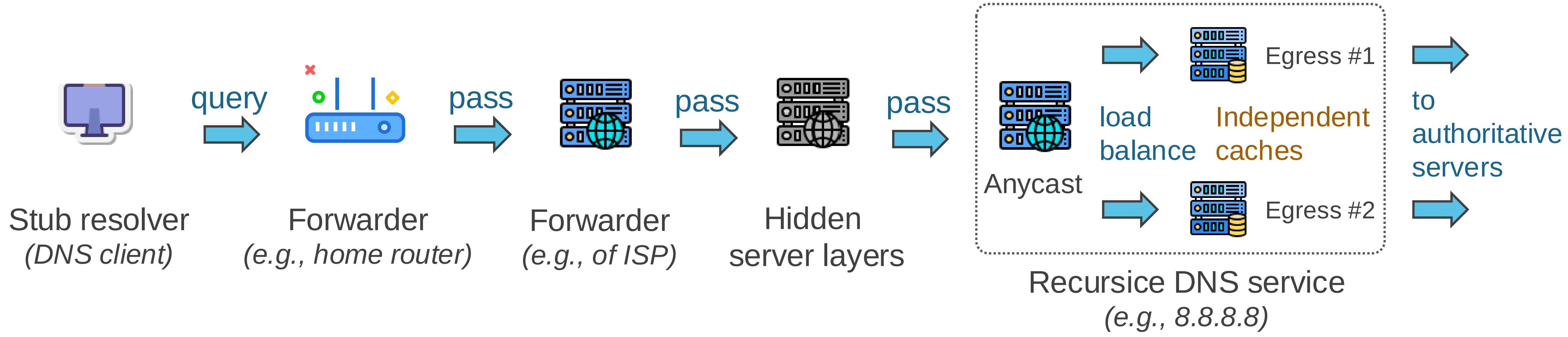
2.27 Million

Open DNS servers

* Data from Censys, Oct 2023

A typical domain name resolution path

- **Multiple *types* and *layers* of DNS servers**
  - DNS forwarders ➔ pass queries to upstream *(e.g., another forwarder)*
  - Large public DNS services ➔ complexes of load balancers, caches, egress servers, etc.
- **A *typical* DNS resolution path now looks like this**



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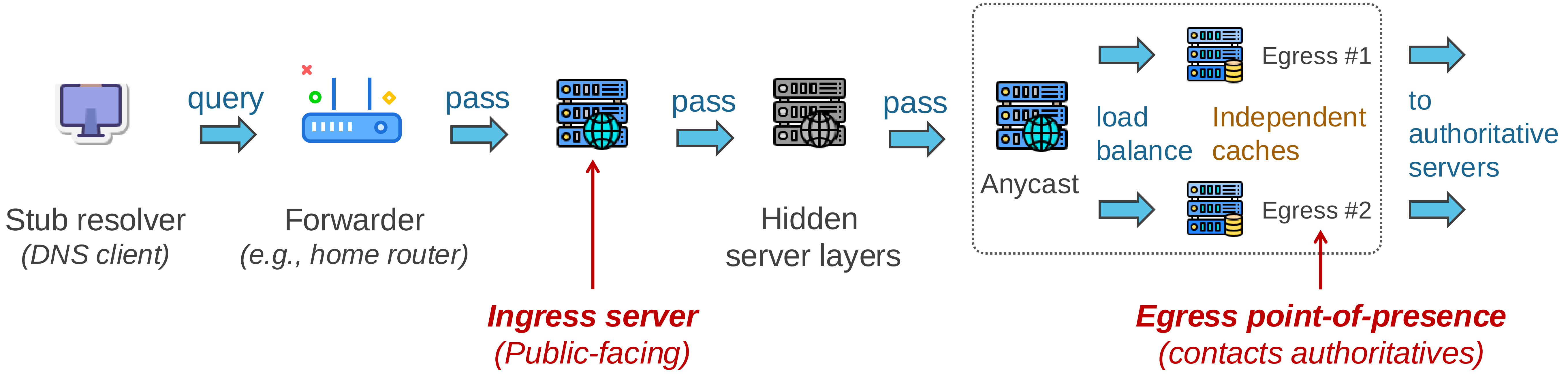
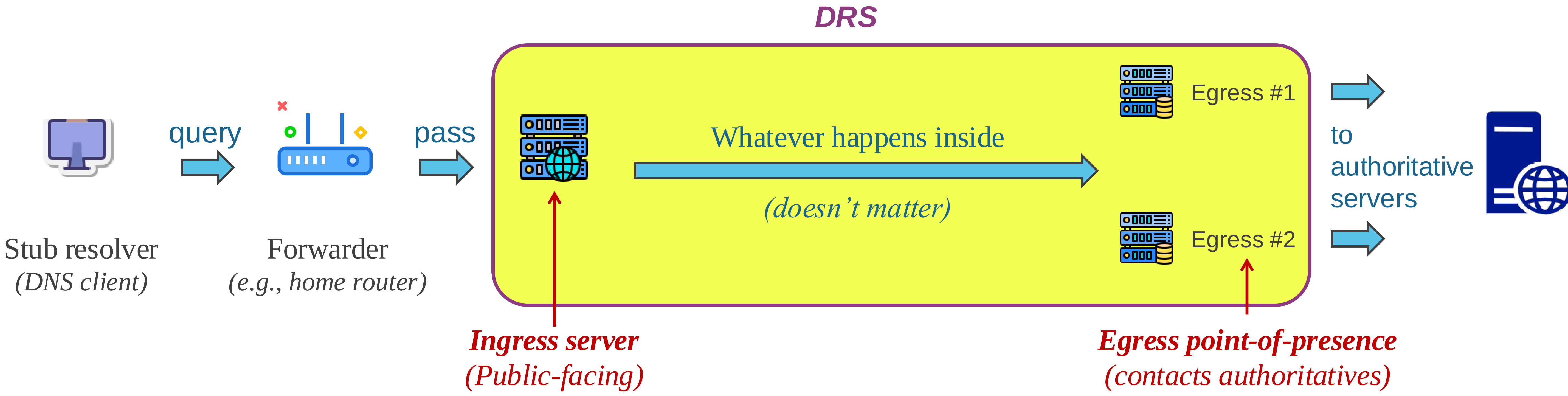


Definition of DNS Resolver System(DRS)

- **DNS resolver system (DRS)**
  - A public-facing DNS server, together with everything between it and authoritative servers
- **Black box inside**



DNS as a complex infrastructure

OK, I get it.
DNS resolver is a complex system.

But where does the power, or amplification, come from?

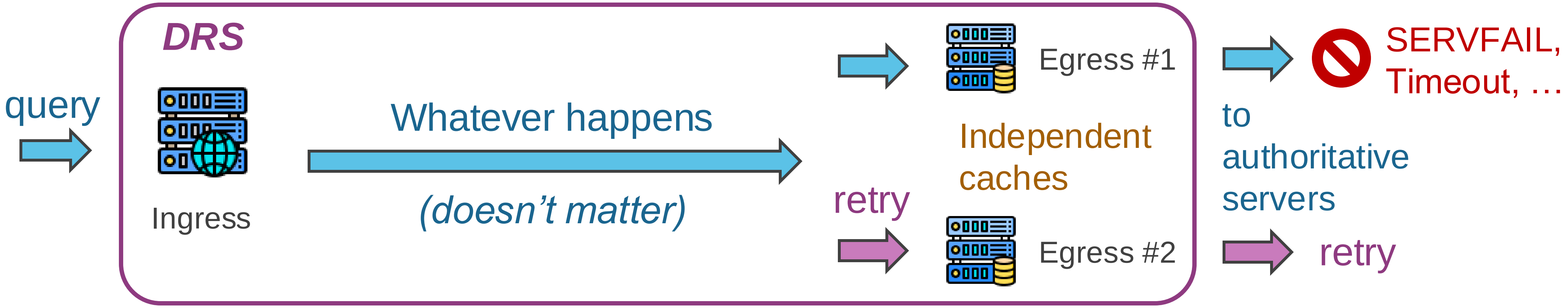
Amplification ability: DNS retries

- **DNS query could fail for variety of reasons**
  - Packet lost, server fail, routing problems
- **So upon failure, please *retry* for a few more times**
  - Adopted by mainstream DNS software
  - ***THE amplification potential exploited by our attack***

DNS software	# of retries
BIND9	13
Unbound	9
Knot	3

Amplification ability: DNS retries

- **For a DRS, retries may exit from *different egresses***
  - Egress servers don’t share cache
  - Prevents *query aggregation* and *cache hits*



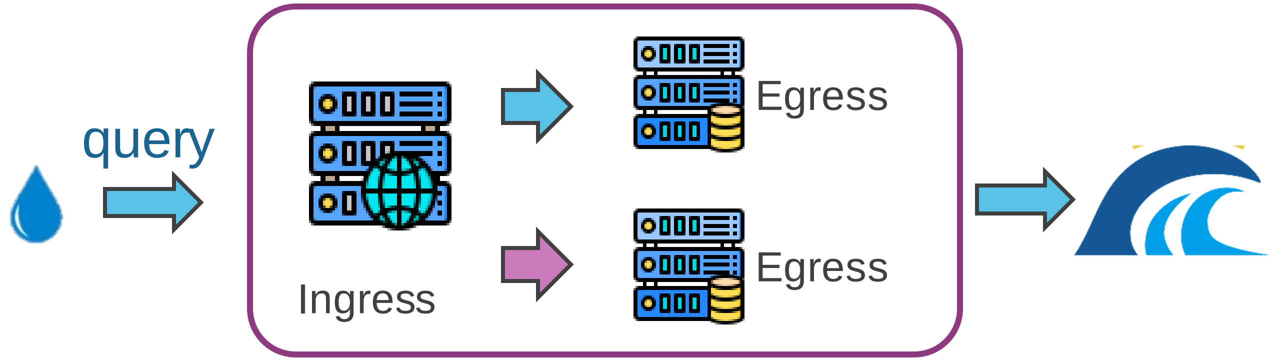
Amplification ability: DNS retries

Wait… You exploit retries?

That’s not even enough
to cause ripples!

Attack variant I: DNS-Retry

- Some bogus DRS implementations that retry aggressively
- In 1.3M DRS, 2.4% (>30,000) retry more than 100 times
- 529 DRSes retry more than 1,000 times
- Max # of retries by one DRS: ***117,541***



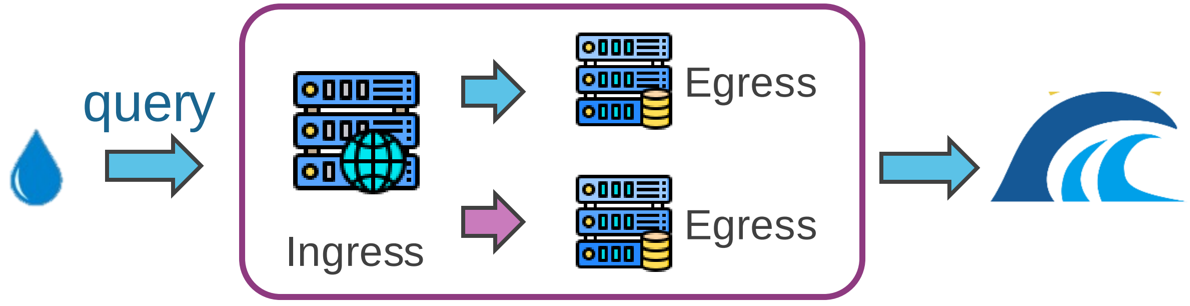
Amplification by one DRS only is big enough

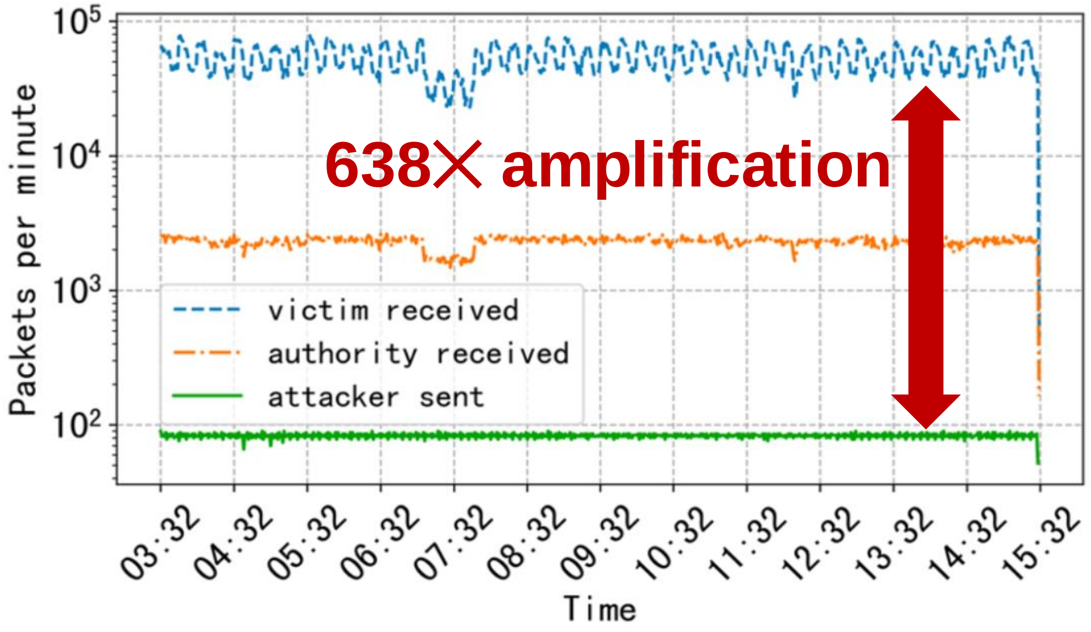
In 1.3M open DNS Resolver System(DRS)

# of retries	# of open DRSes	% of tested
> 2	925,500	69.8%
> 10	407,581	30.7%
> 100	31,660	2.4%
> 1,000	**529**	**0.04%**

DNS-Retry Evaluation

- **Evaluation in controlled environment**
  - Select 10 DRSes that retry aggresively
  - Attacker sends 1.3 pkt/s ➔ **Victim receives 882 pkt/s**





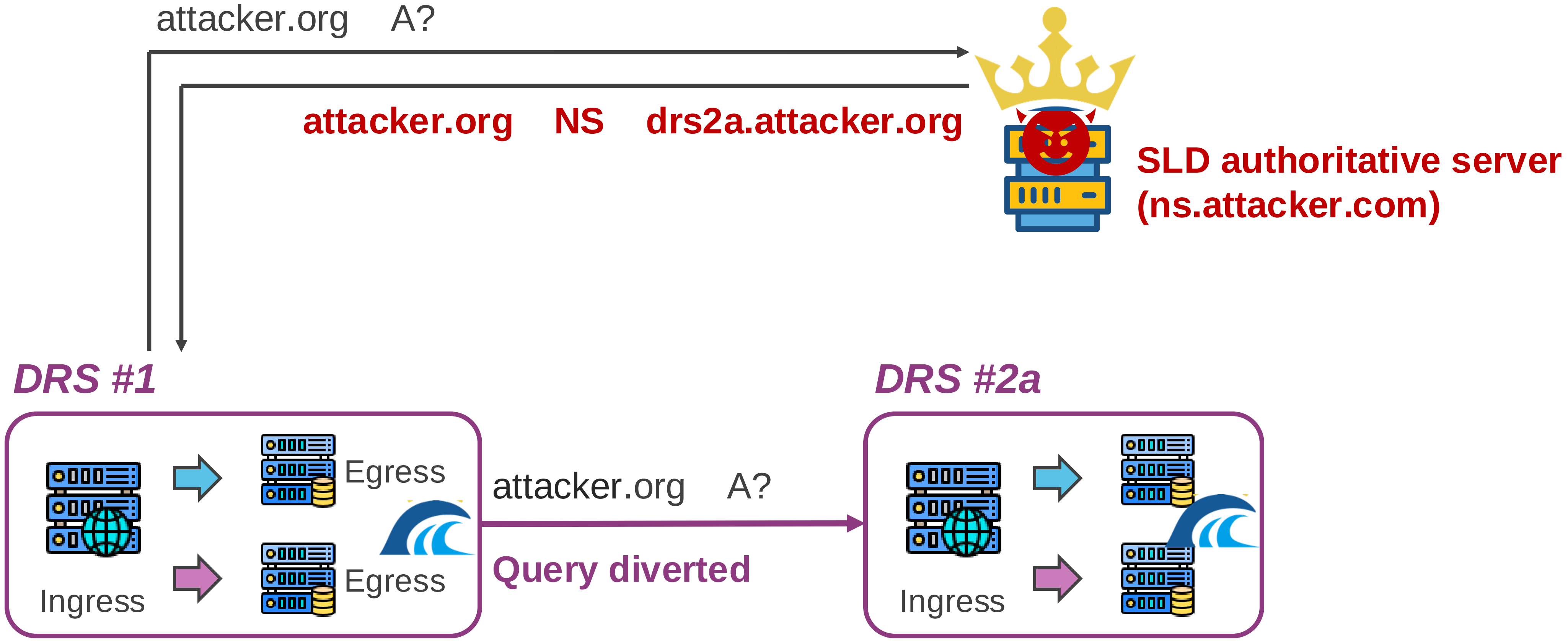
638✕ amplification

Alright, but lots of them are not aggressive at all.
Only modest retries…

Let’s *chain* these ripples into bigger waves!

Attack variant II: DNS-Chain

❖ Recursive DNS resolution guided by ***evil referrals***



attacker.org A?

attacker.org NS drs2a.attacker.org

SLD authoritative server (ns.attacker.com)

DRS #1

DRS #2a

attacker.org A?

Query diverted

Attack variant II: DNS-Chain

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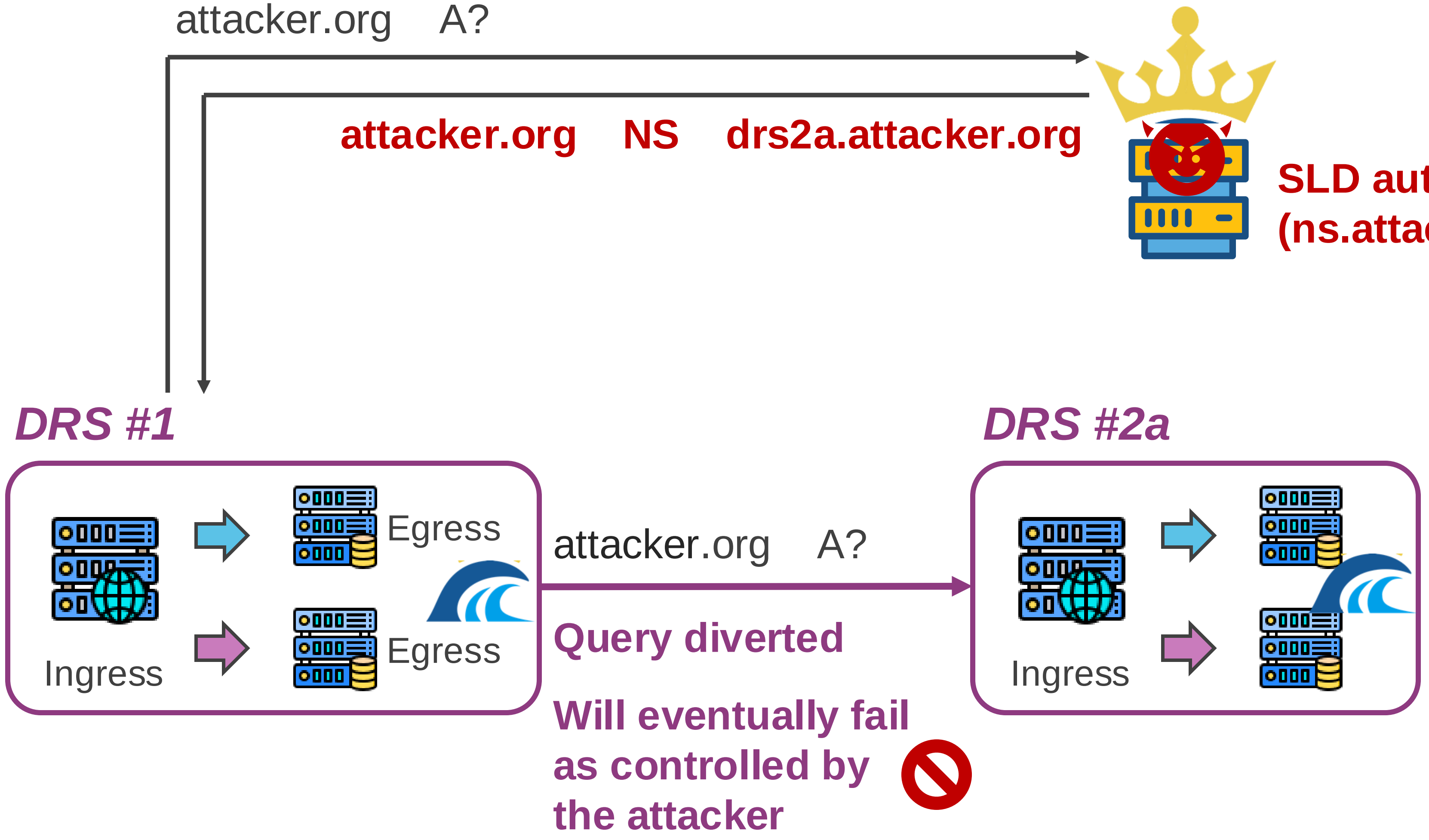

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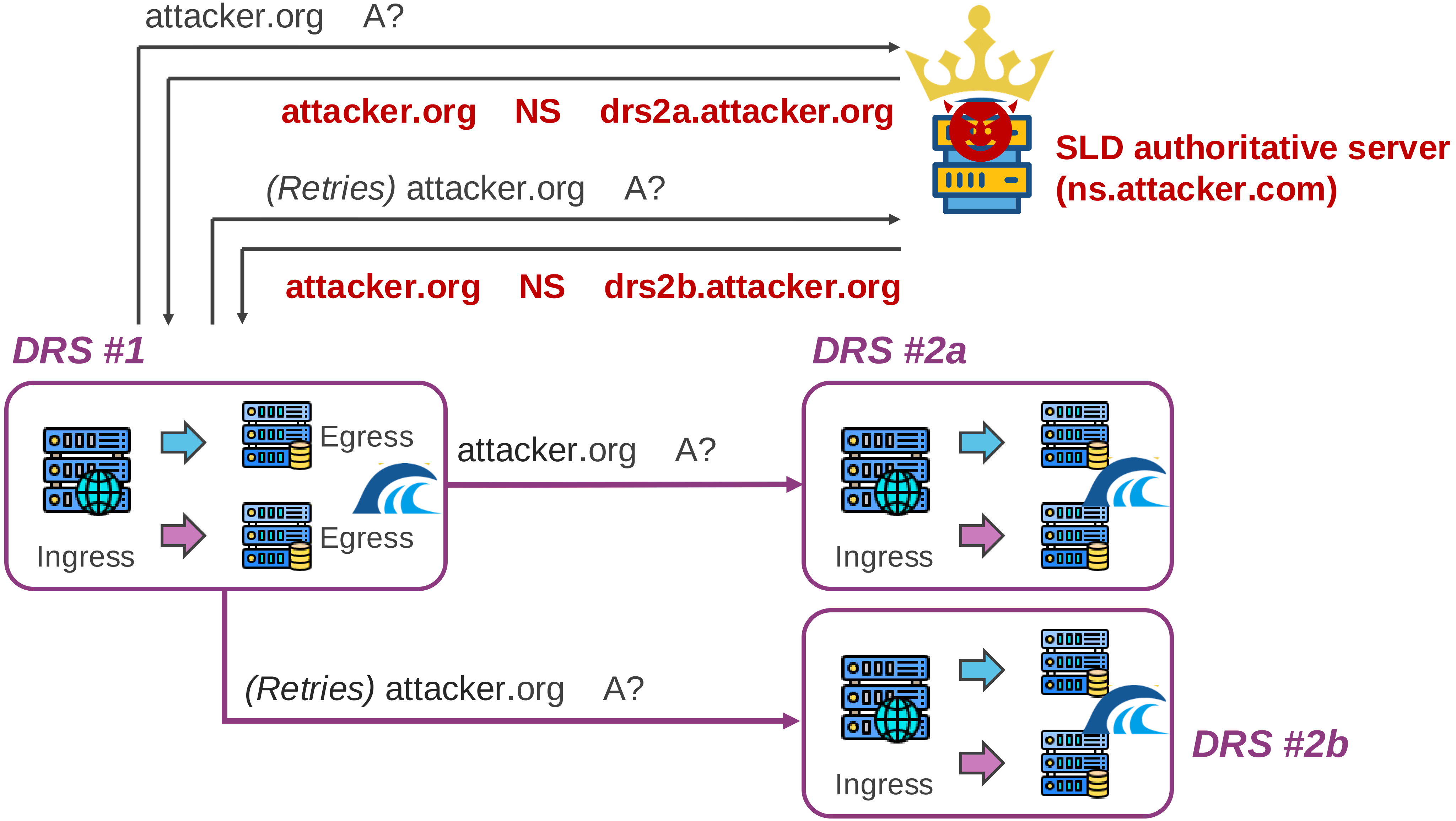
attacker.org A?

Query diverted

Will eventually fail as controlled by the attacker

Attack variant II: DNS-Chain

- Recursive DNS resolution guided by ***evil referrals***



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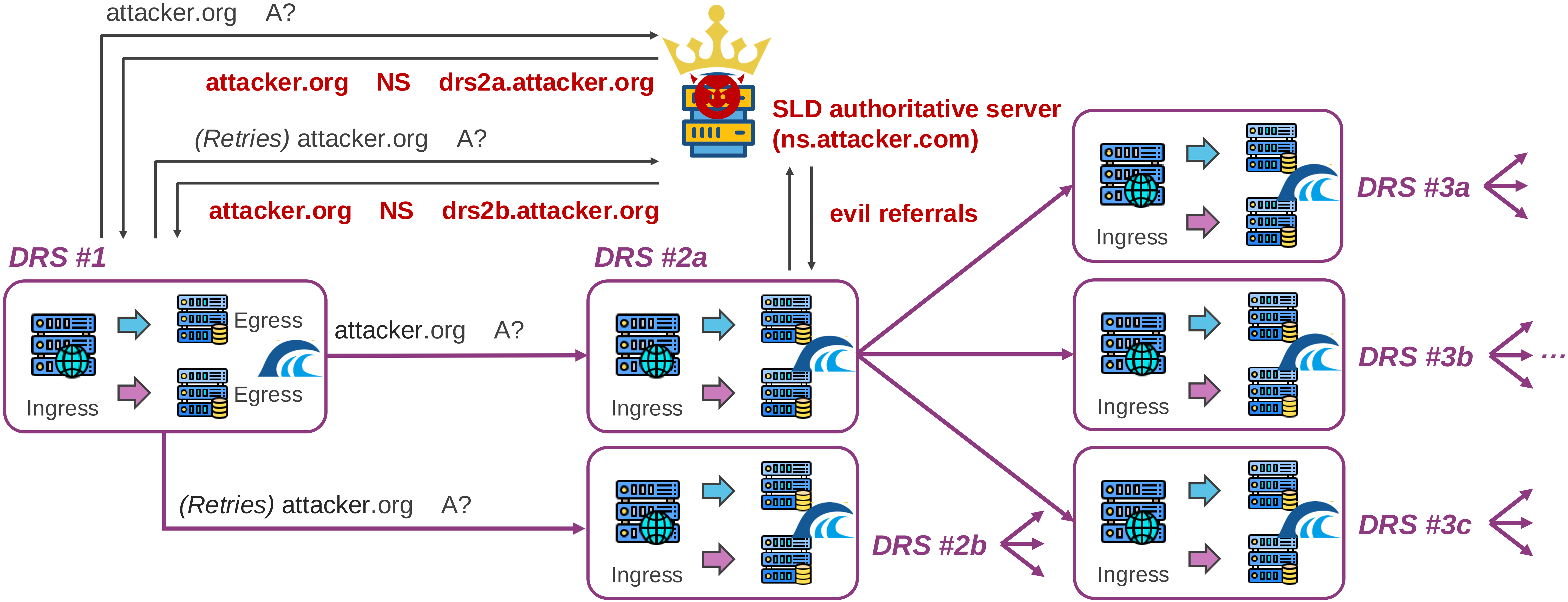
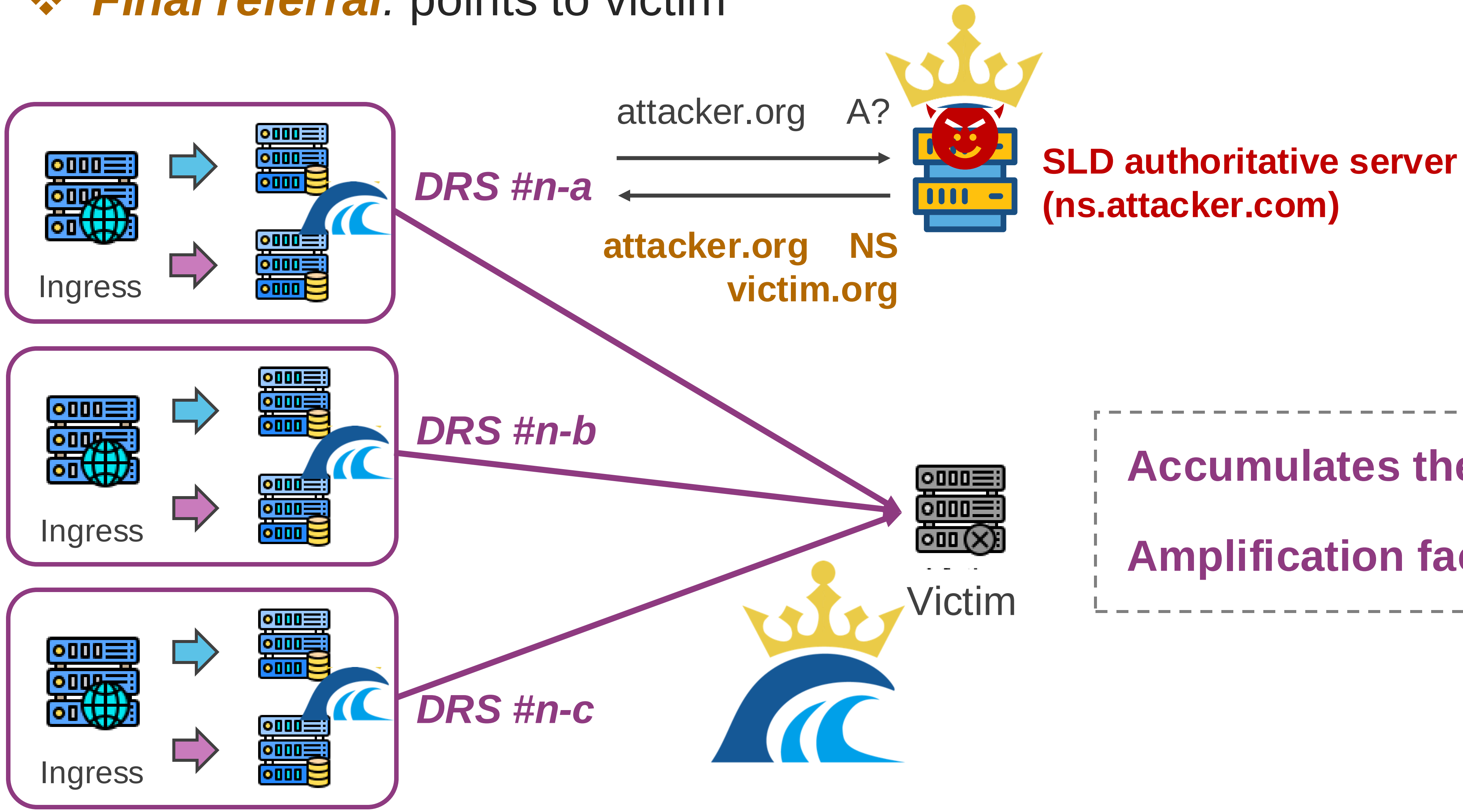


Attack variant II: DNS-Chain

- Recursive DNS resolution guided by *evil referrals*
  - ***Final referral:*** points to victim



Accumulates the power of layers of DRSes

Amplification factor *multiplies*

Seems plausible,
but can many DRSes be used?

What are the conditions of successful attacks?

Conditions of successful attacks

- **DRS *not honoring cleared RD bit* in DNS header**
  - RD (recursion desired) =0: *do not perform recursion, find answers locally in cache*
  - Usually *cleared by egress*, as authoritative servers cannot perform recursion
  - DRS honors RD ➔ *chain cannot continue*
  - ***27.2% of 1.3M tested DRSes do not honor***

Transaction ID	QR	Opcode	RD	Flags	Z	RCODE
QDCOUNT	ANCOUNT					
NSCOUNT	ARCOUNT					

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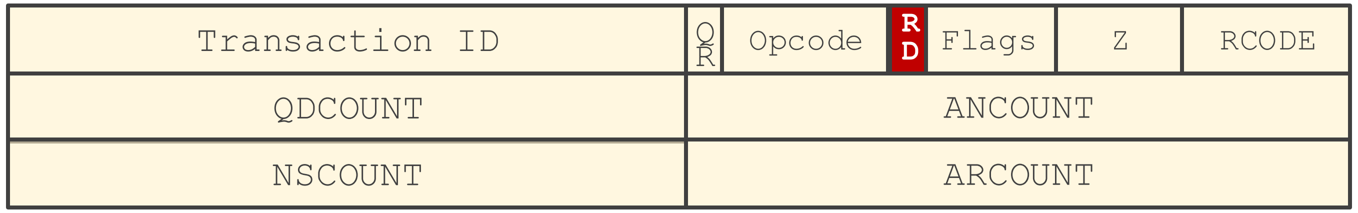

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- **DRS not deployed with negative caching** [RFC 2308]
  - Negative caching records DNS failures ➔ *effectively eliminates retries*
  - ***43% of 1.3M tested DRSes do not deploy***

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- **DRS has multiple egresses: *the more, the better***
  - ***52% of 1.3M tested DRSes have over 10 egresses***

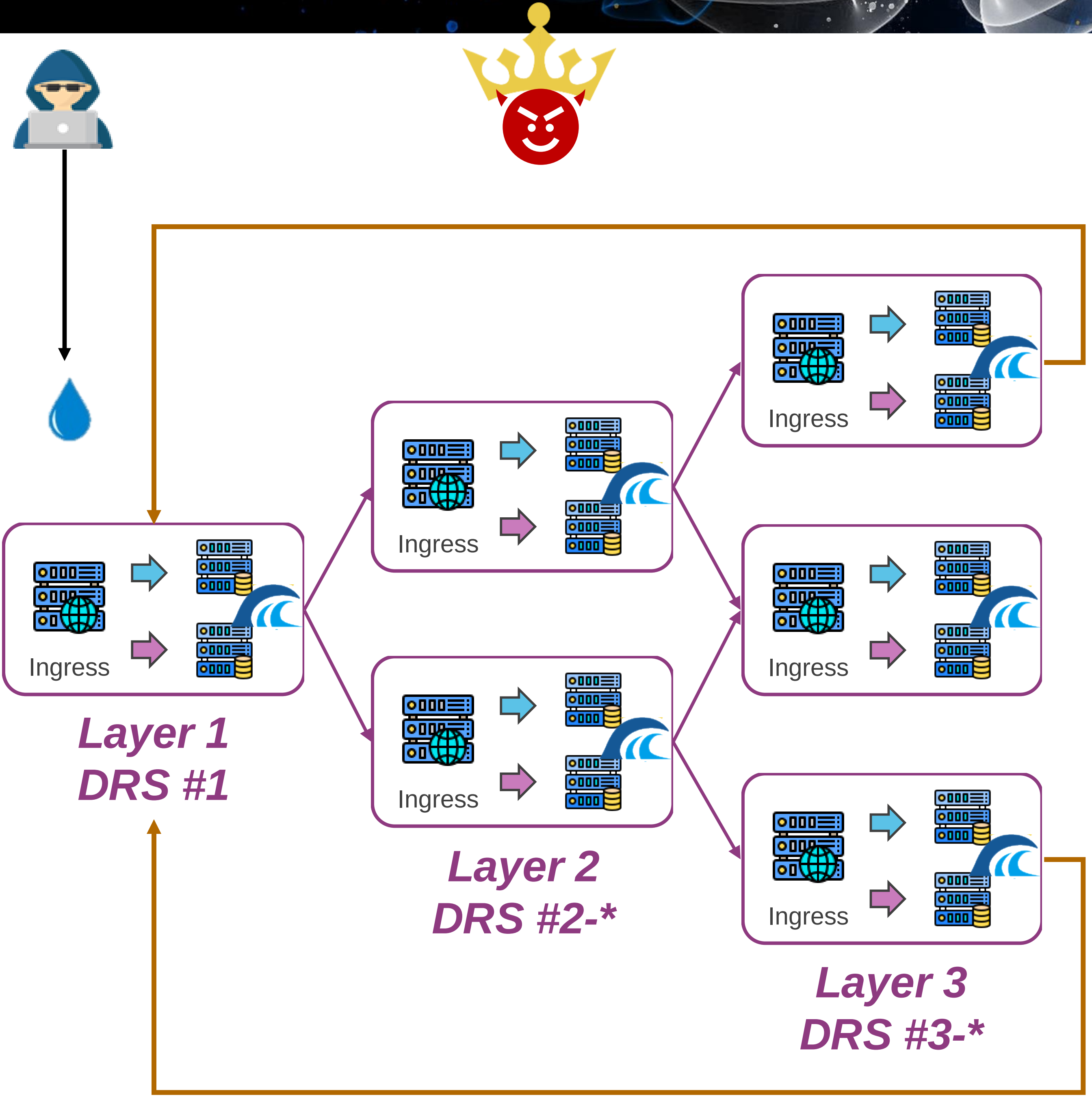
Evaluation of DNS-Chain

- ❖ **Evaluation in controlled environment**
  - ❖ We select from exploitable DRSes and coordinate them into ***layers***

Setting	# of DRSes coordinated in each layer							Amp. factor
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	
# 1	1	4	8	-	-	-	-	288
# 2	1	4	8	16	32	-	-	591
# 3	1	4	8	16	32	64	128	**3,702**

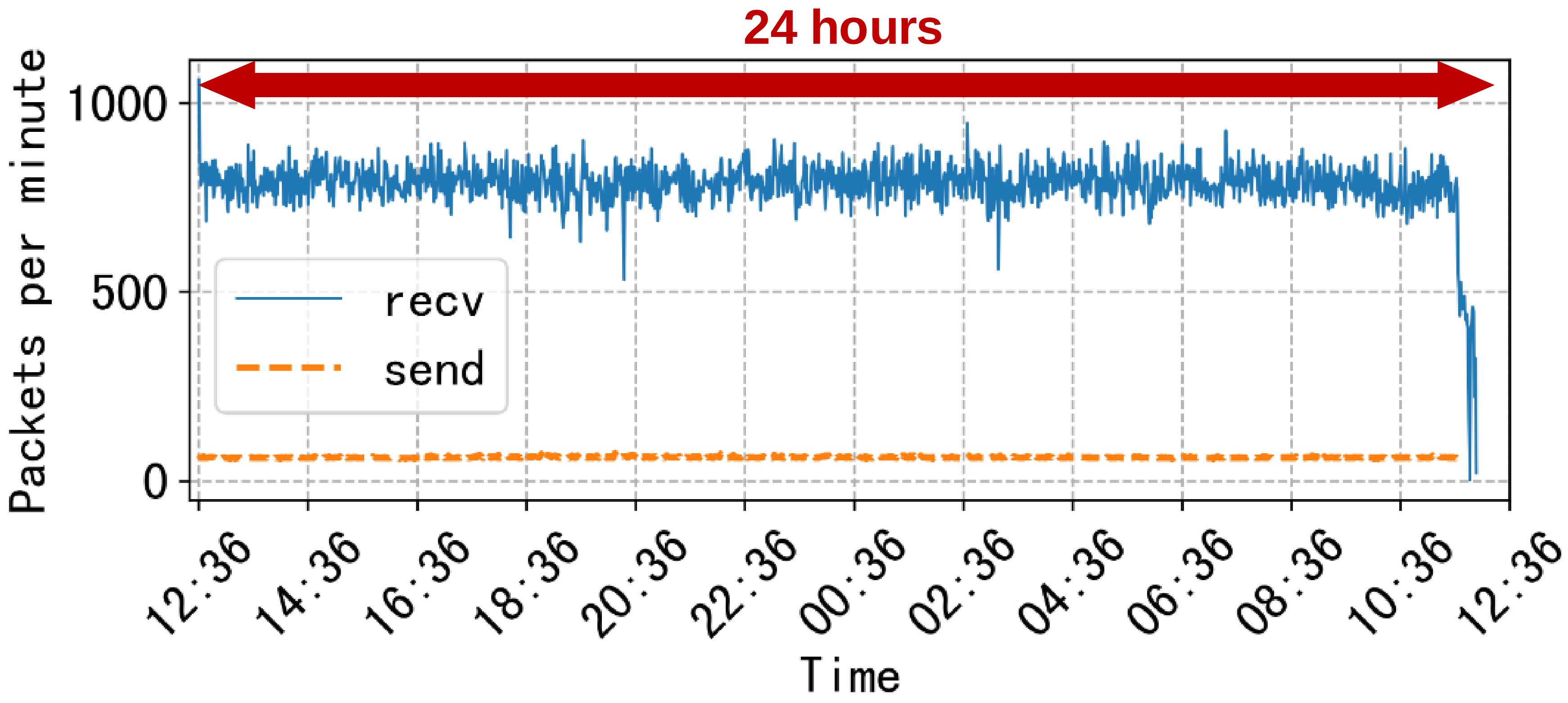
Attack variant III: DNS-Loop

- Modified from DNSChain, creating a *loop* of retry queries
  - ***Final referral:*** points back to DRS #1
- The victim and goal change now
  - ***ALL DRSes in the loop*** become victims
  - Goal is to exhaust their resources
  - *Increasing amplification factor is a non-goal*
- Attackers may also
  - Inject new rounds of retries to the loop
  - Simply by querying DRS #1



DNS-Loop Evaluation

- ❖ **Evaluation in controlled environment - can the loop last?**
  - ❖ Coordinates 7 layers of DRSes in the real network
  - ❖ layer #0 is our server, with *rate limit at 1 pkt/s(due to ethical considerations)*
  - ❖ Send only one DNS query Layer 0, to trigger the loop
  - ❖ ***Loop lasts for 24 hours until deliberate stop***


24 hours

Mitigation

What can we do to prevent this attack?

Correct bogus implementations such that attack conditions cannot be fulfilled.

Mitigations

- **Avoid aggressive retries**
  - A modest number of retries should suffice, as adopted by mainstream software
- **Follow DNS specifications**
  - Honor the DNS flags: if RD tells not to perform recursion, just don’t
- **Deploy additional mechanisms that add protection**
  - Negative caching: good to reduce retries
  - Egress and cache management: reduce independence between egress servers

Acknowledgement

DNS Software Vendors

unbound

POWERDNS

MIKROTIK

DNS service providers

AliDNS
公共解析服务

114DNS

腾讯云 DNSPOD

360安全DNS

Questions?

Paper website: https://tsuking.net

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