CAMP: Compositional Amplification Attacks against DNS

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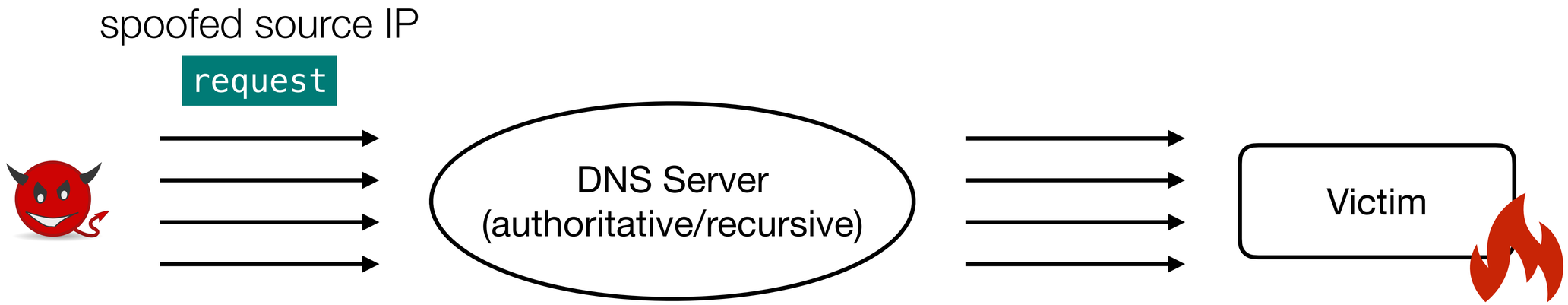
Common DNS-related DoS attacks

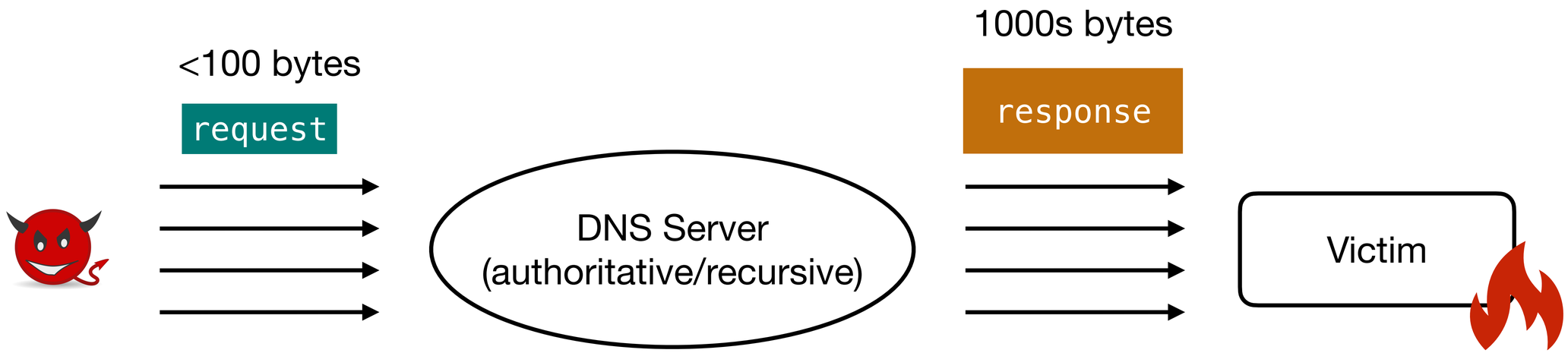
Reflection



Common DNS-related DoS attacks

MAF = 1

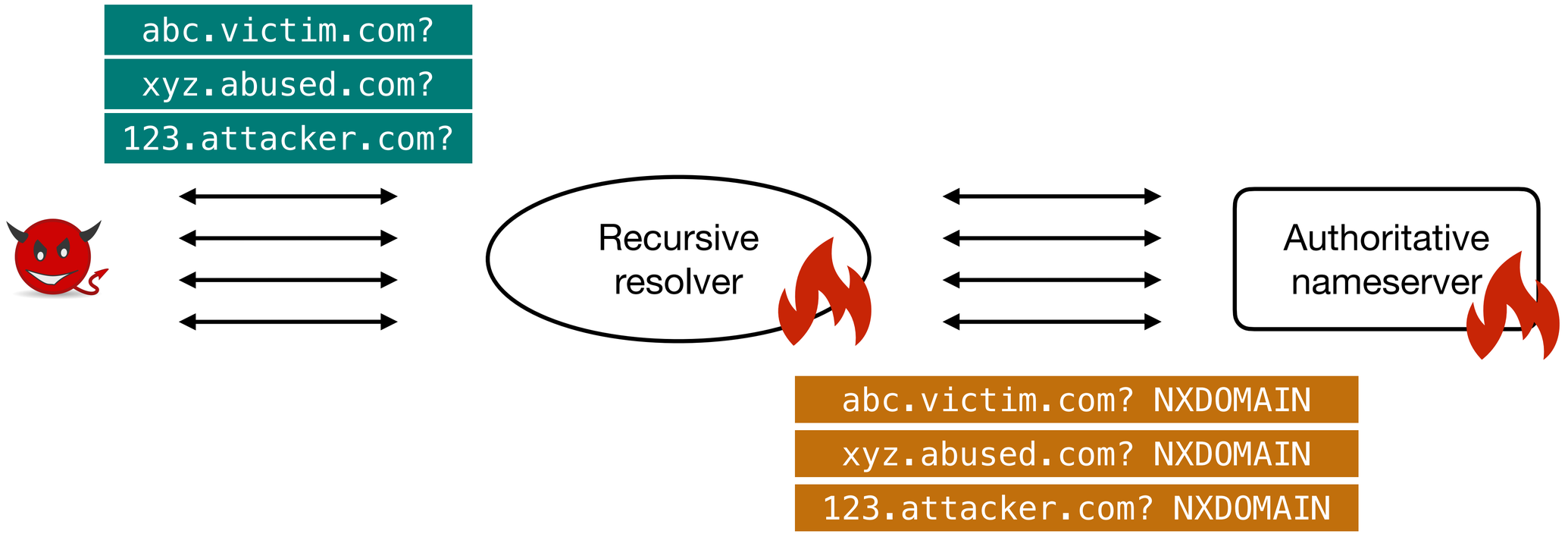
Reflection with ***simple amplification***



Common DNS-related DoS attacks

MAF = 1

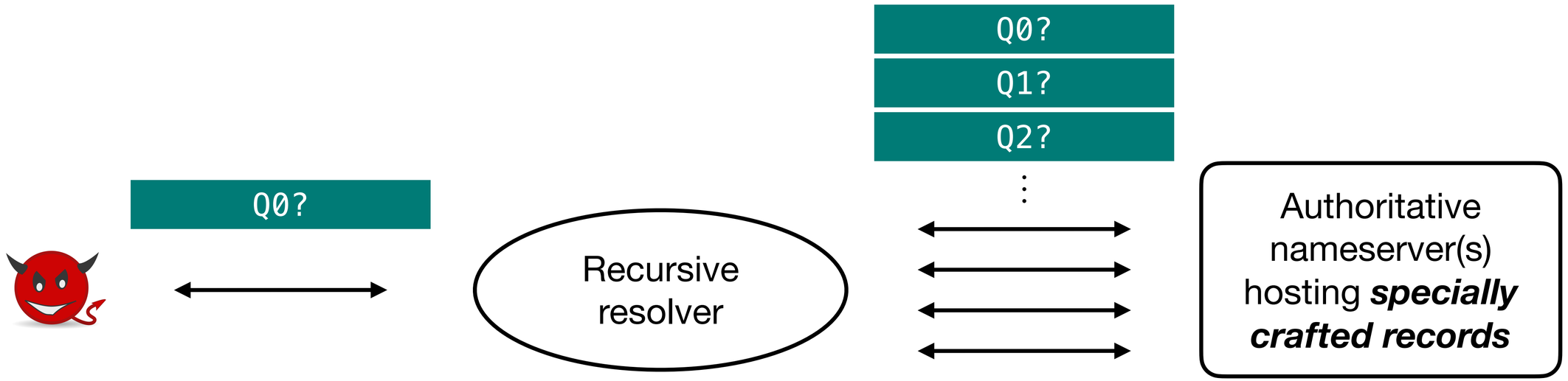
Pseudo-random Subdomain (PRSD) ***without amplification***



Rise of application-layer amplification

MAF > 1

Each ***single client request*** triggers ***excessive resolver queries***



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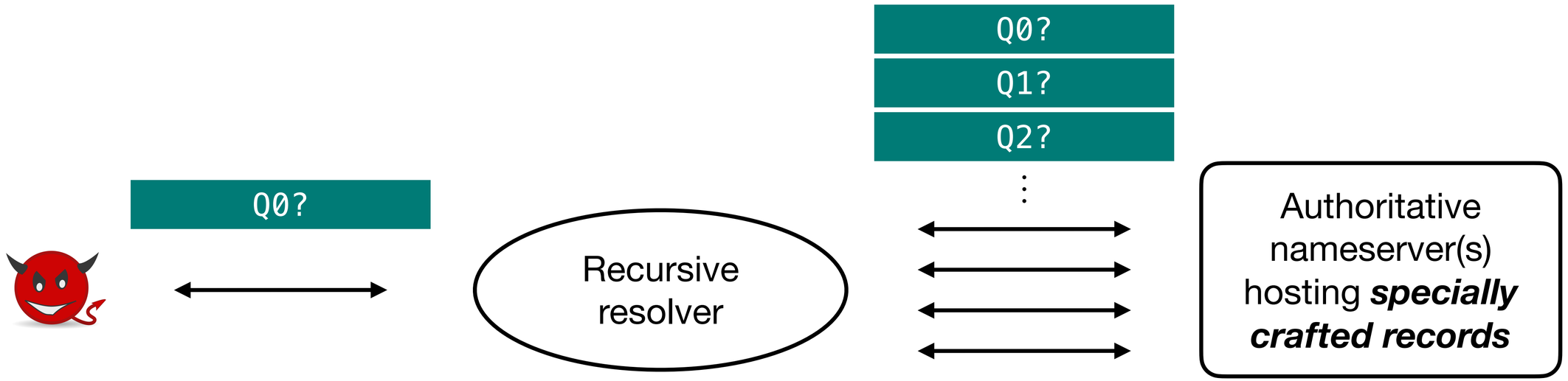

Advantages over PRSD

- Low attack request rate

Rise of application-layer amplification

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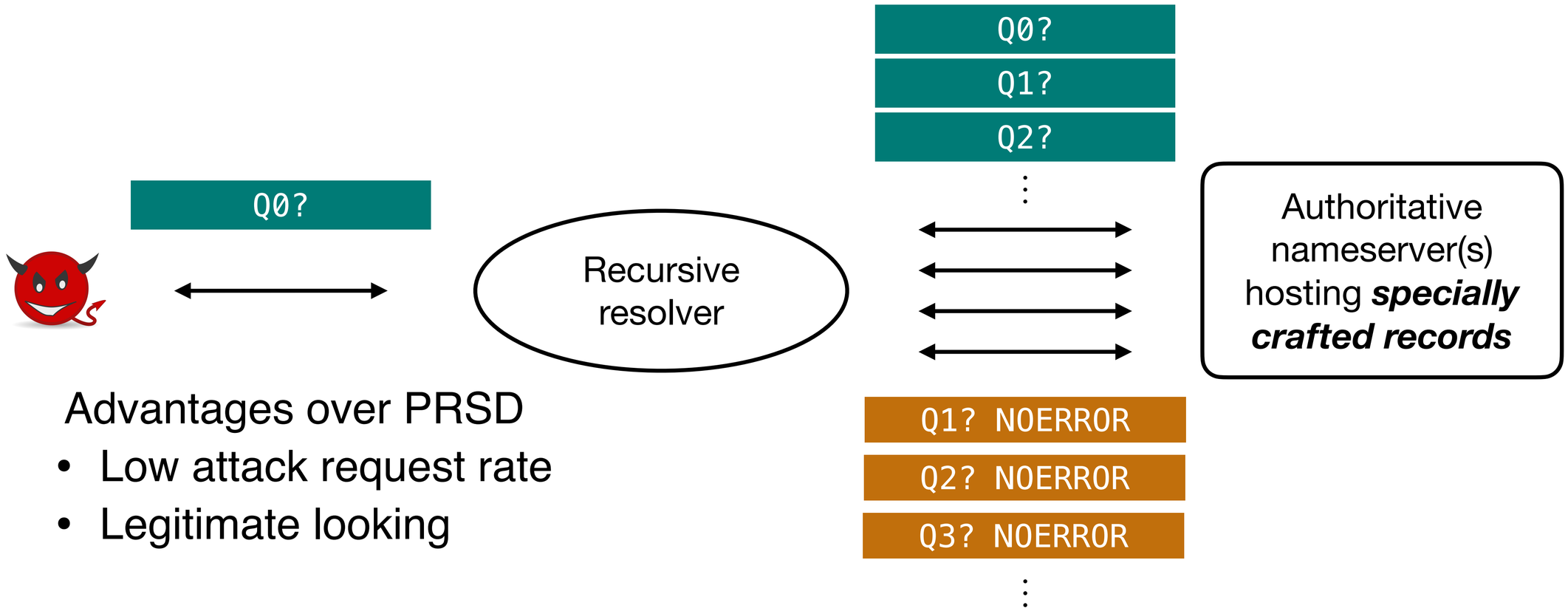


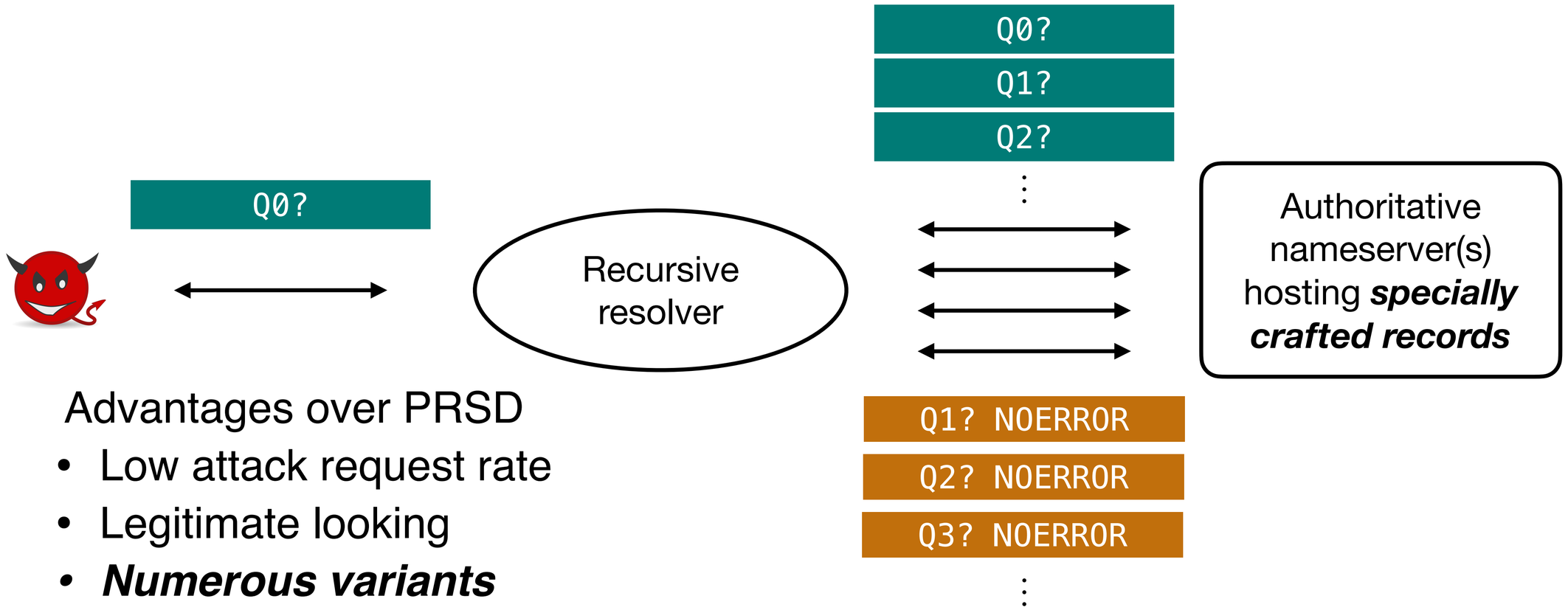
Advantages over PRSD

- Low attack request rate
- Legitimate looking

Rise of application-layer amplification

MAF > 1

Each ***single client request*** triggers ***excessive resolver queries***



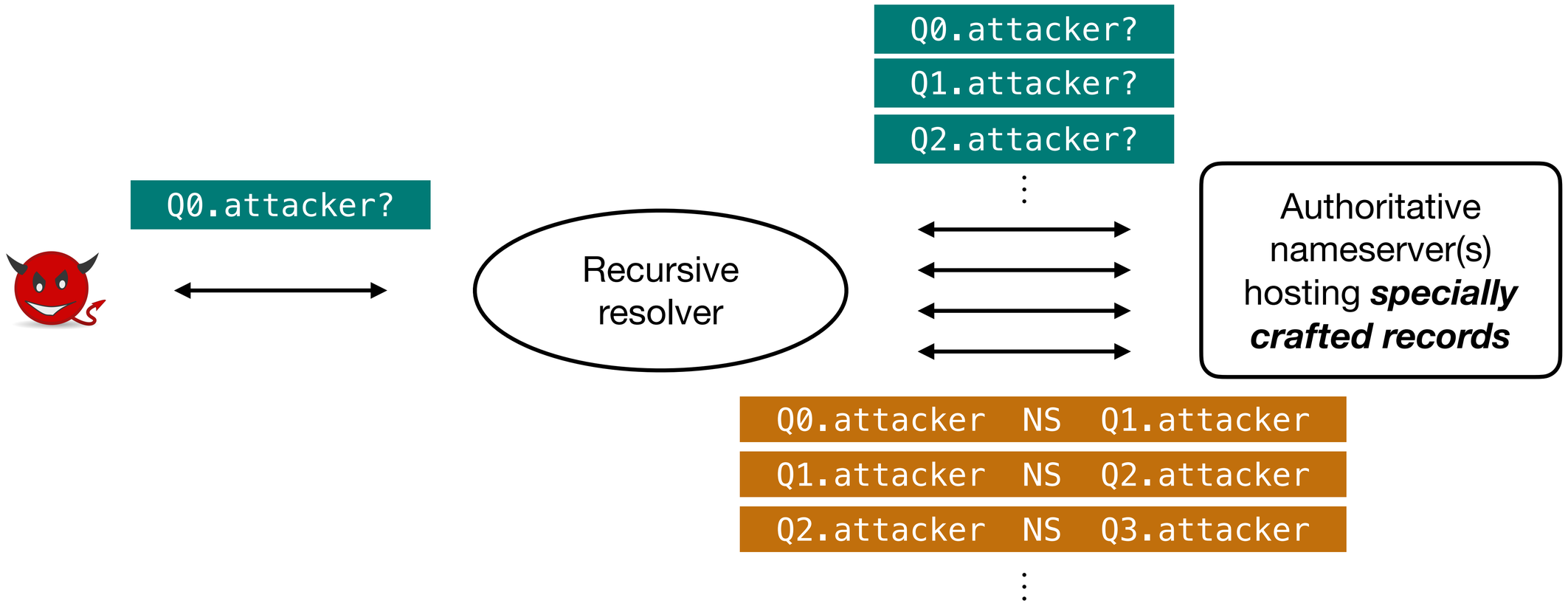
Advantages over PRSD

- Low attack request rate
- Legitimate looking
- ***Numerous variants***

Rise of application-layer amplification

MAF = #NS recursions

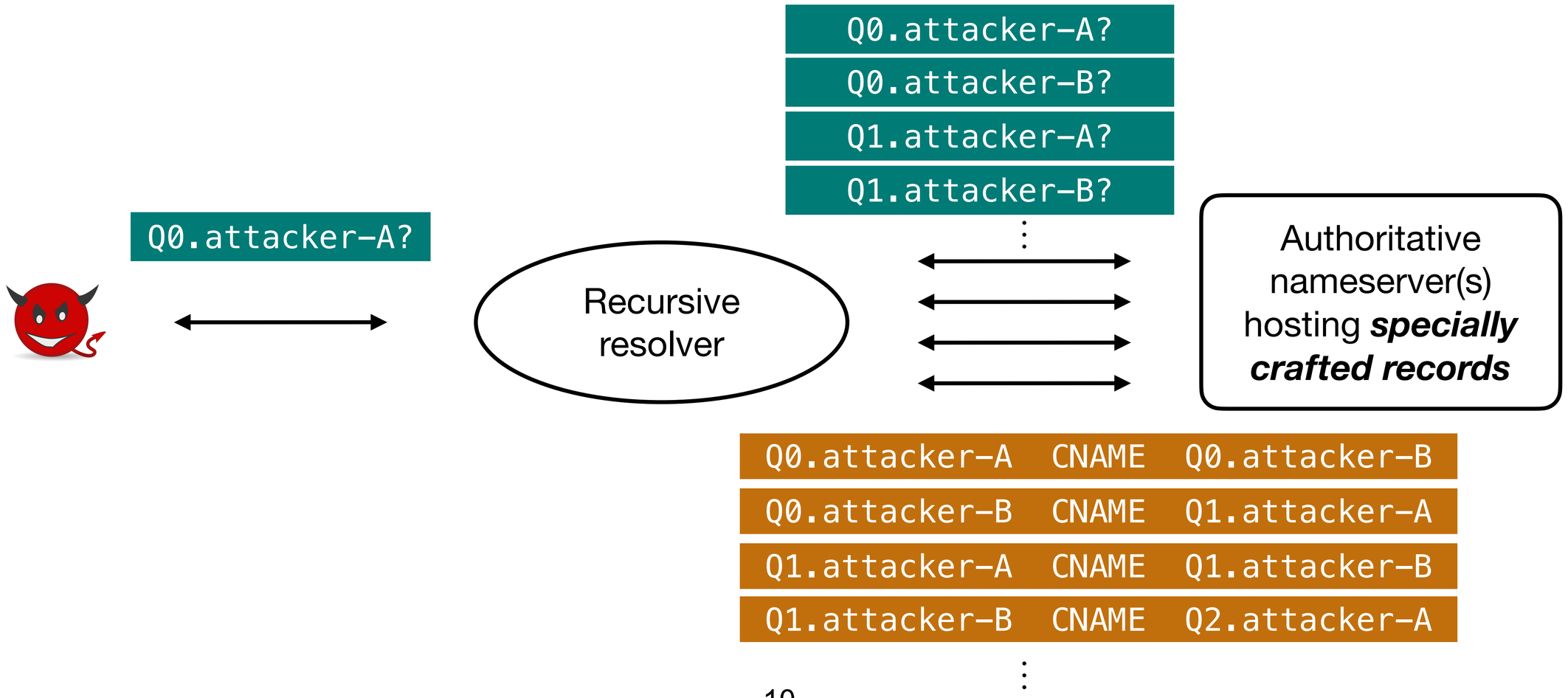
iDNS attack (Maury, 2015): “indefinitely” delegating nameserver



Rise of application-layer amplification

MAF = #Qry rewrites

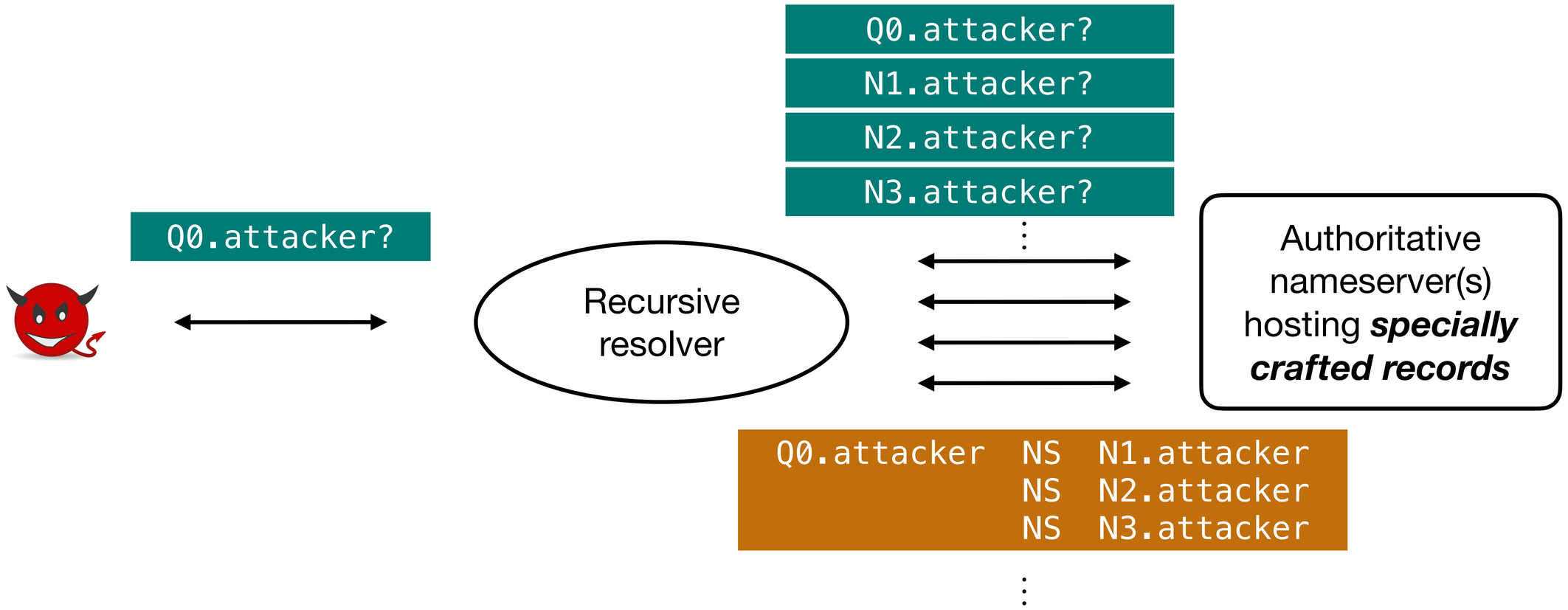
Unchained attack (Bushart and Rossow, 2018): CNAME chain chasing



Rise of application-layer amplification

MAF = #NS fetches

NXNSAttack (Afek et al., 2020): proactive and parallel NS fetching



Rise of application-layer amplification

Questions:

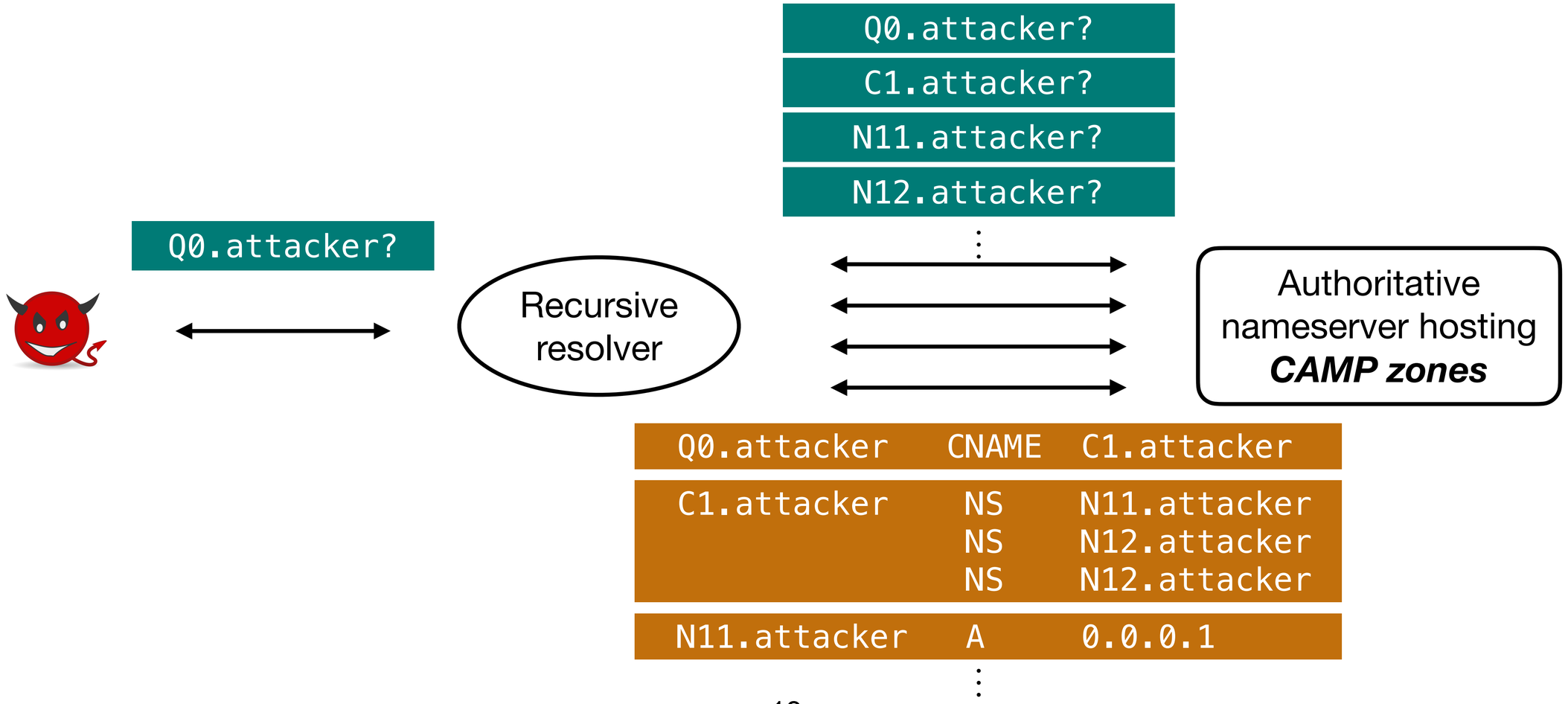
How many more such vulnerabilities are out there?

What is the maximum achievable MAF?

CAMP: compositional amplification attacks

MAF = X*Y

Compose ***amplification primitives*** to produce ***multiplicative effects***

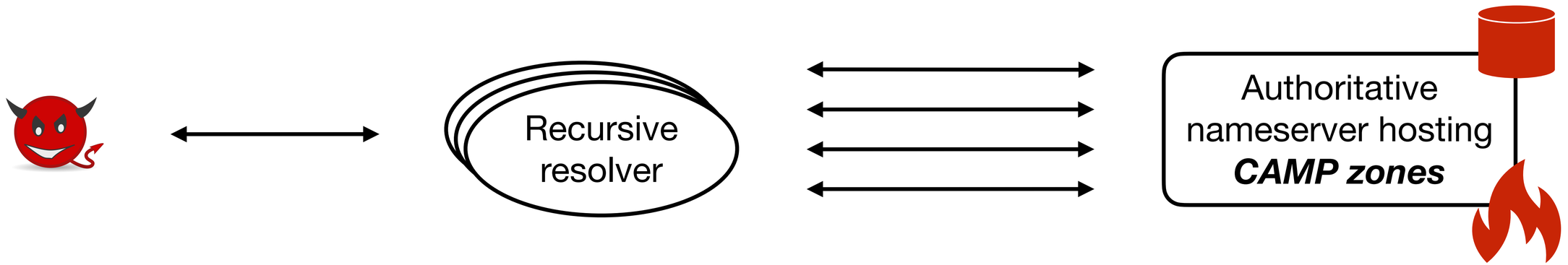


CAMP: compositional amplification attacks

MAF = X*Y

Possible target: nameserver where attacker can set up CAMP zones

Likely victim: public DNS hosting services

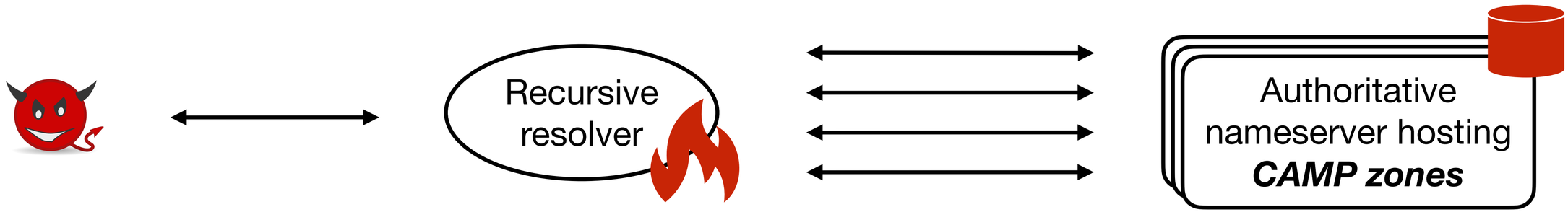


CAMP: compositional amplification attacks

MAF = X*Y

Possible target: resolver accessible to attacker

Major impact on cache-missing requests from normal clients

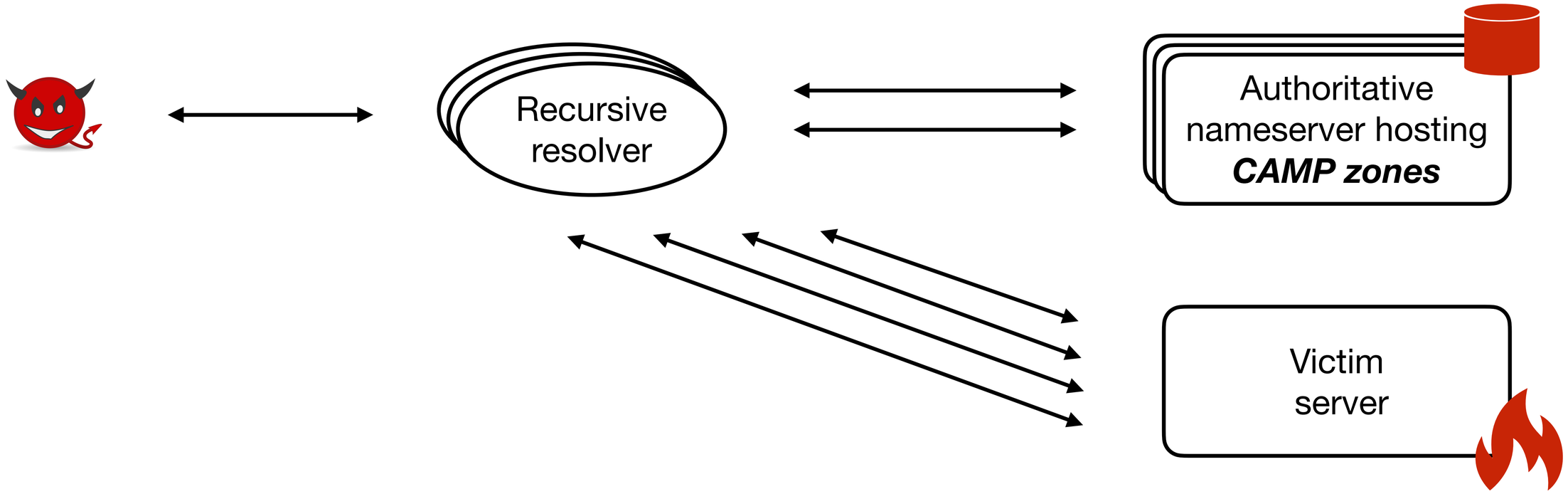


CAMP: compositional amplification attacks

MAF = X*Y

Possible target: arbitrary nameserver

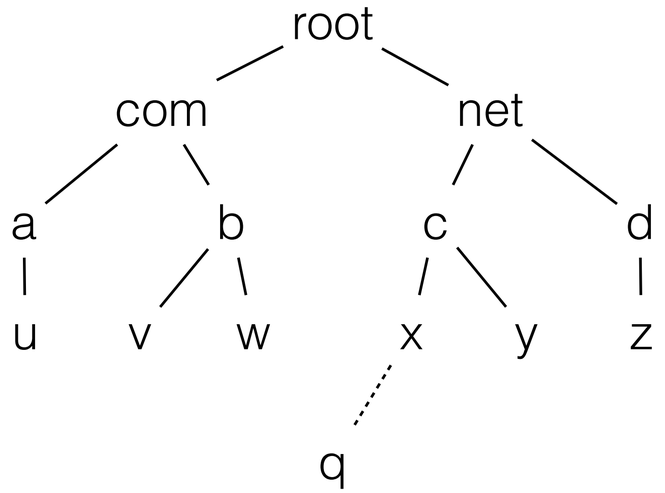
Let NS records in fanout primitives (see later) point to the victim



Taxonomy of amplification primitives

Names queried in amplified resolution

Base Q0 —> {Q1, Q2, Q3, …} ***Derivatives***



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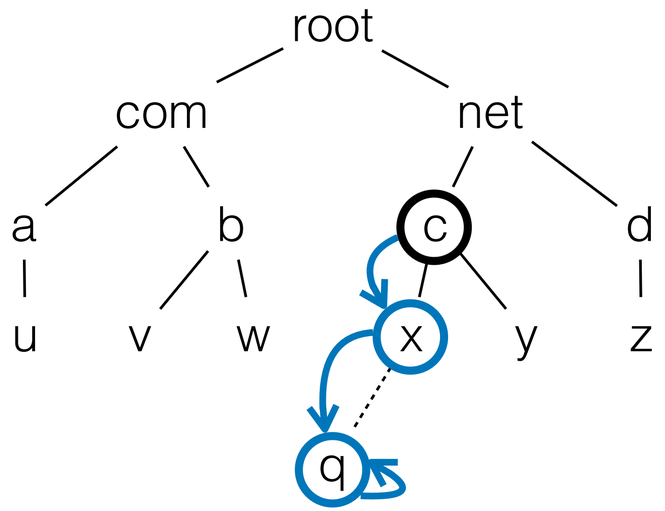
All names on the
same path of DNS hierarchy

Self-probing



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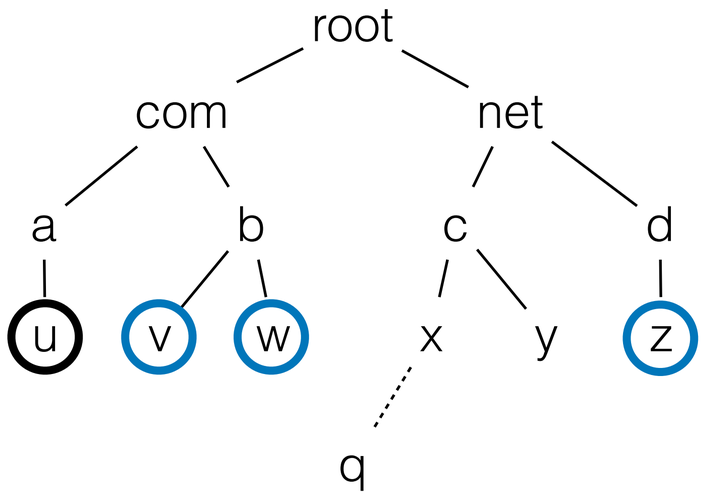

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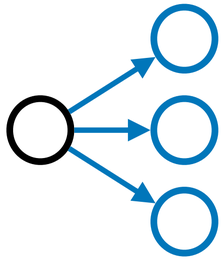
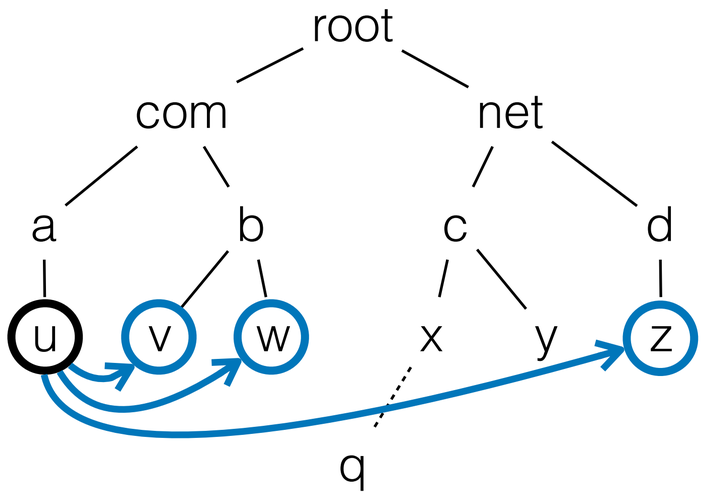
All derivatives are independently queryable

Fanout





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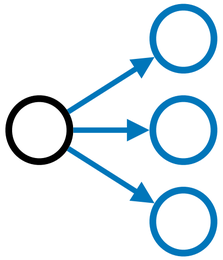
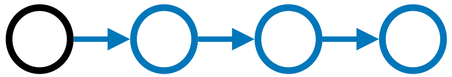
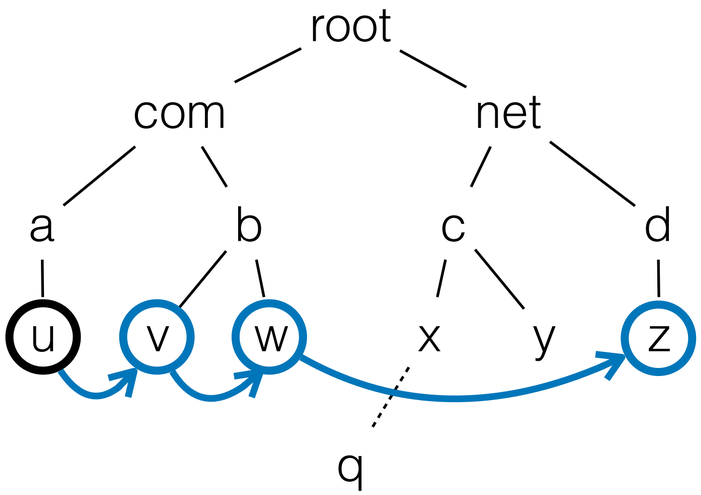


Every derivative depends uniquely on another (or the base)

Chaining





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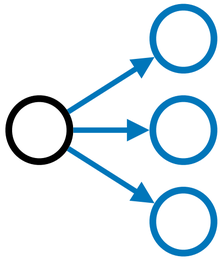

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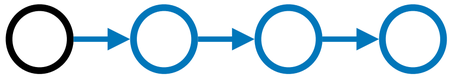
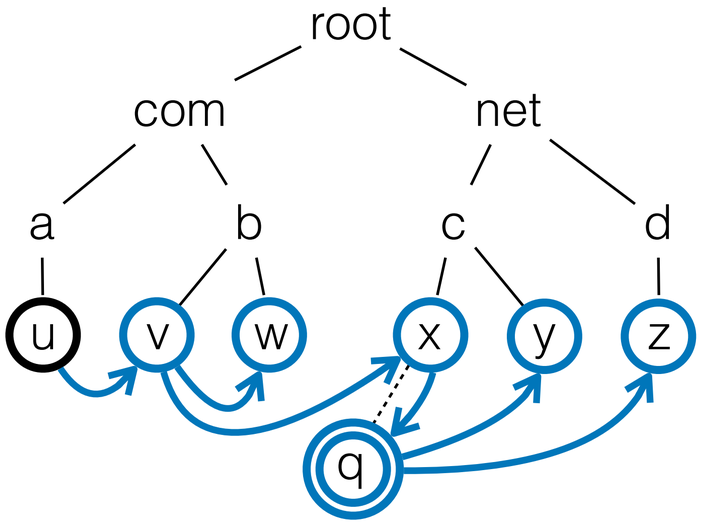


Allow untangling complex resolution!



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Query name minimization (Q.M.)

Dense delegation (D.D.)

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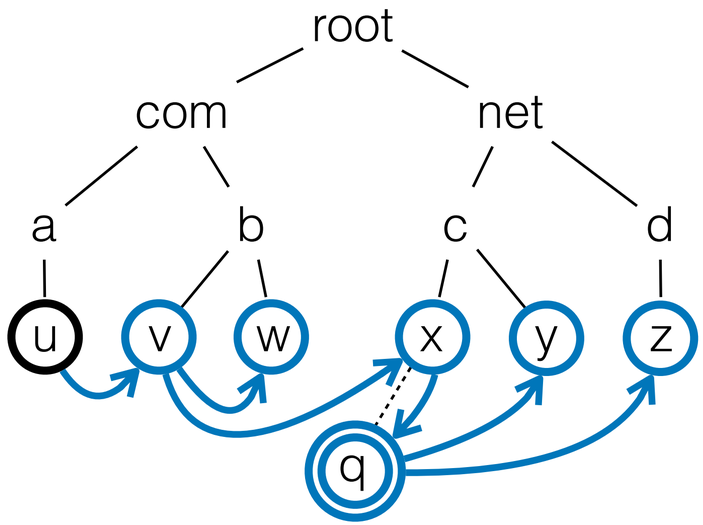
Fanout

Every derivative depends uniquely on another (or the base)

Chaining



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Fanout

Concurrent

Failover (F.O.)

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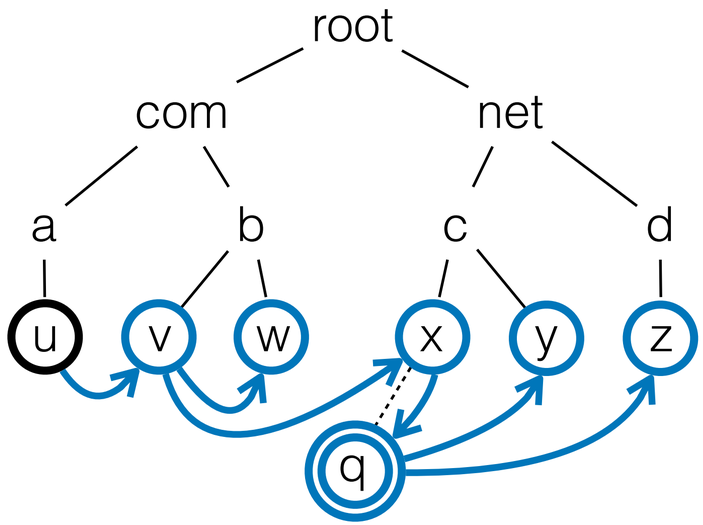
Chaining



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Concurrent (F.O.)

Failover

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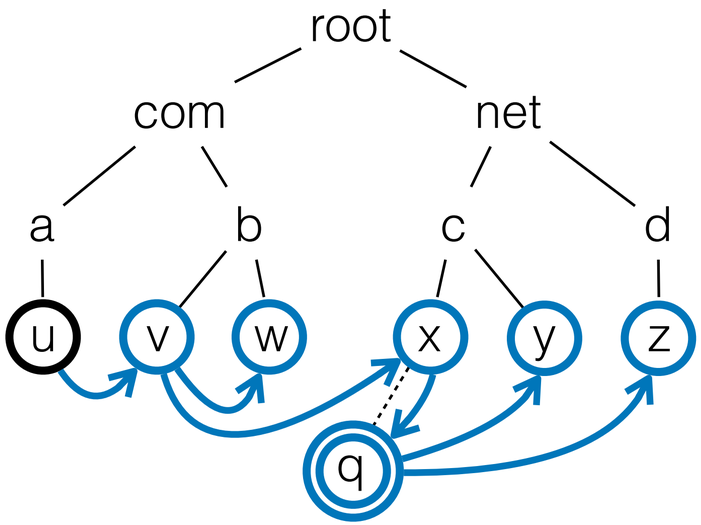
Chaining

Referral (R.C.)

Rewrite (W.C.)



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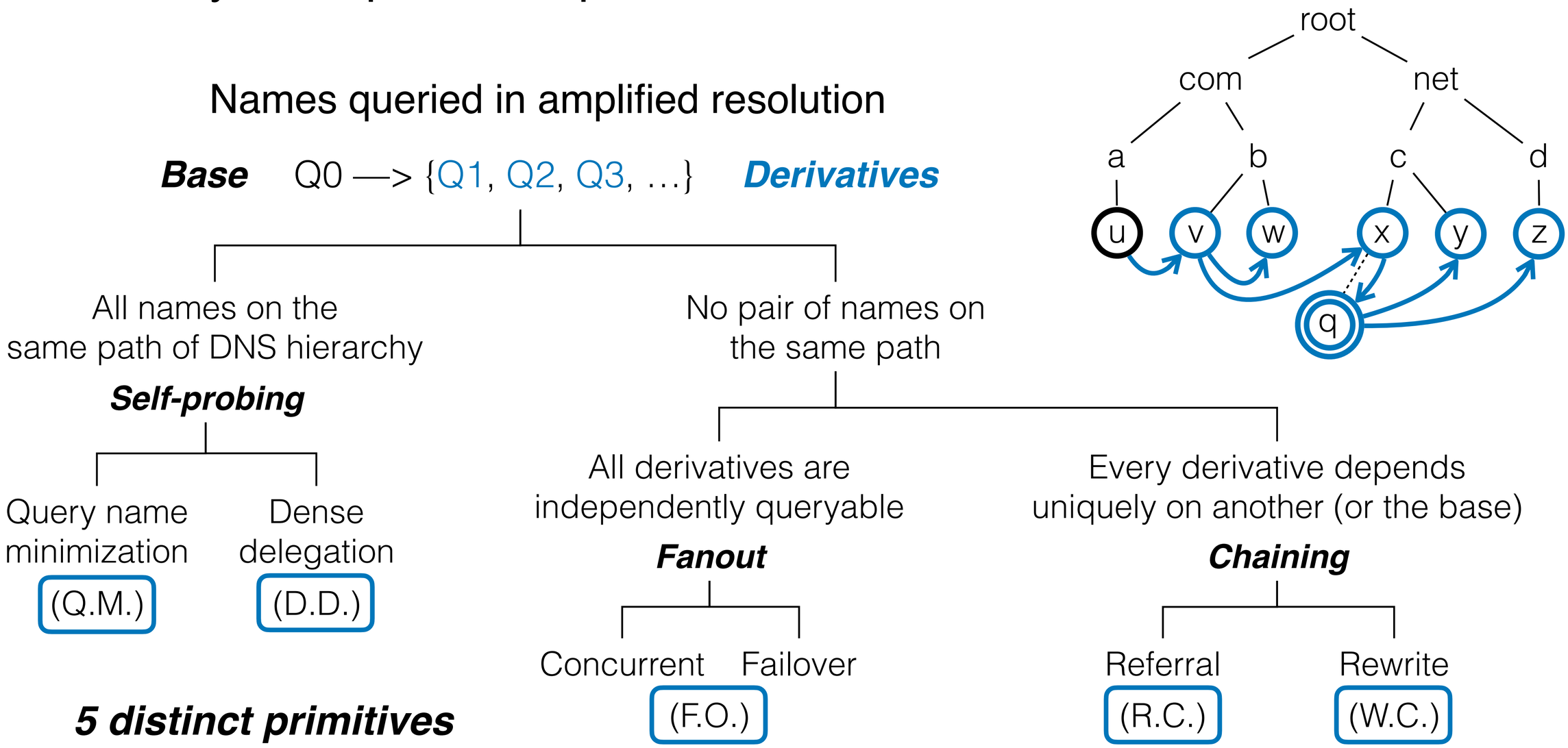
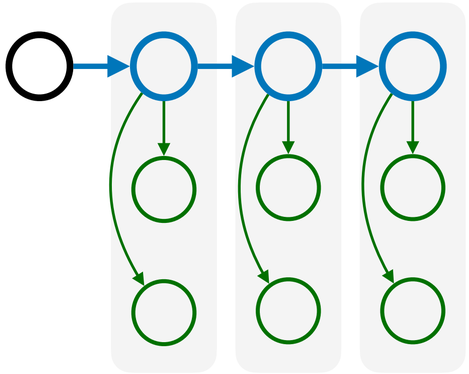


Composability analysis

Observation: one amplification primitive's derivative can be another primitive's base

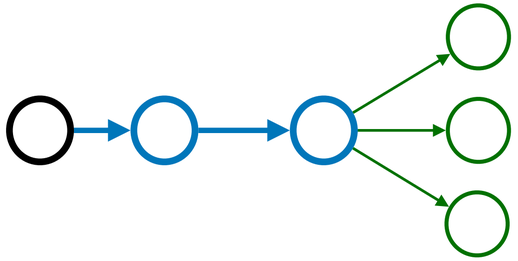
primary ***secondary***

Focus on ***regular multiplicative*** compositions

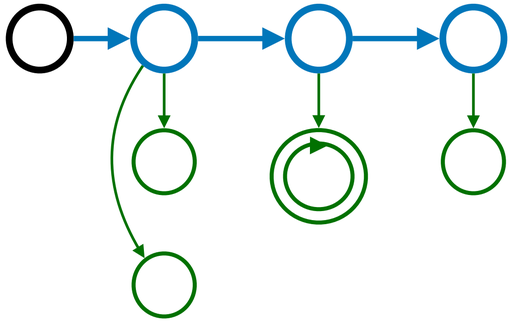


secondaries of same type & size

additive



irregular



Composability analysis

Results: 16 out of 25 conceivable compositions are constructible

Compo-sability		Secondary				
		F.O.	R.C.	W.C.	Q.M.	D.D.
Primary	F.O.	✔	✔	✔	✔	✔
	R.C.	✘	✘	✘	✔	✔
	W.C.	✔	✔	✘	✔	✔
	Q.M.	✘	✘	✘	✘	✘
	D.D.	✔	✔	✔	✔	✔

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		F.O.	R.C.	W.C.	Q.M.	D.D.
Primary	F.O.	✔	✔	✔	✔	✔
	R.C.	✘	✘	✘	✔	✔
	W.C.	✔	✔	✘	✔	✔
	Q.M.	✘	✘	✘	✘	✘
	D.D.	✔	✔	✔	✔	✔

All from ***legitimate DNS features***, only one exception

"The domain name used as the value of an NS record, or part of the value of an MX record ***must not be an alias****."*

RFC2181

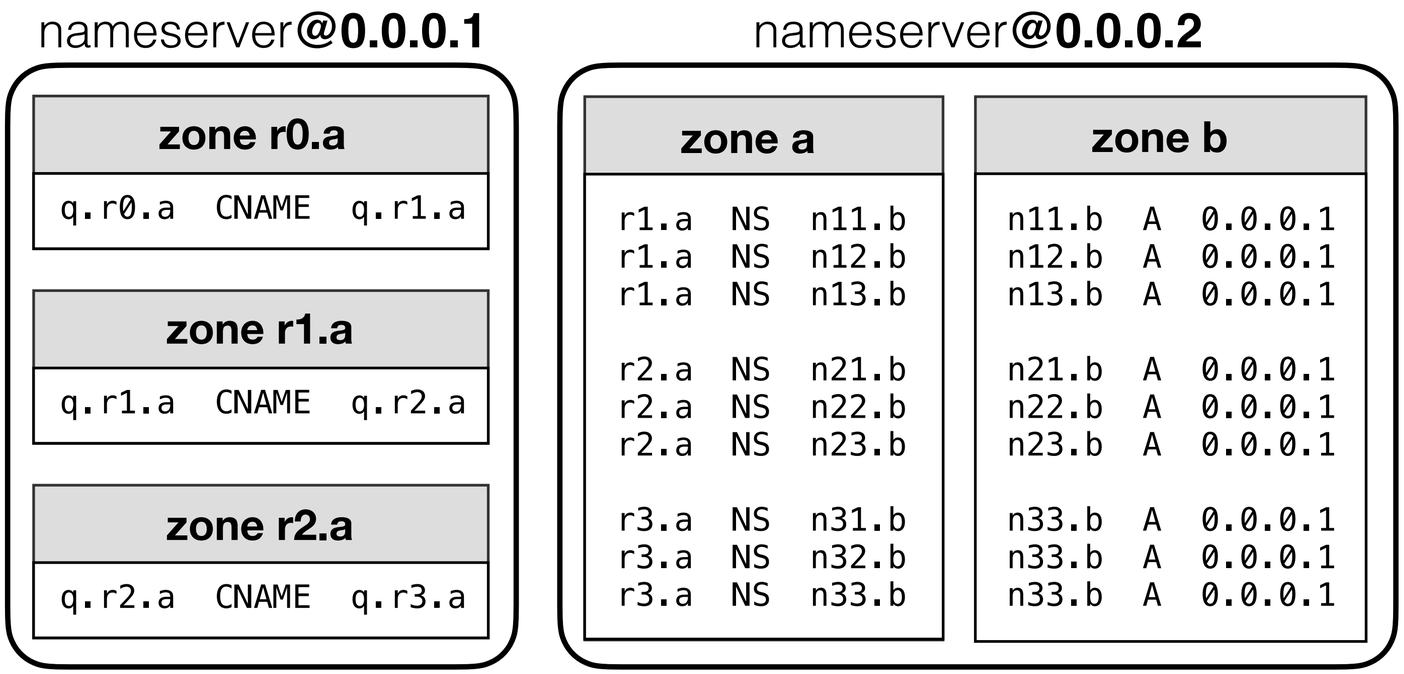
Many implementations are *non-compliant*…

Composability analysis

Static construction with pre-installed zones files

Compo-sability		Secondary				
		F.O.	R.C.	W.C.	Q.M.	D.D.
Primary	F.O.	✔	✔	✔	✔	✔
	R.C.	✘	✘	✘	✔	✔
	W.C.	✔	✔	✘	✔	✔
	Q.M.	✘	✘	✘	✘	✘
	D.D.	✔	✔	✔	✔	✔

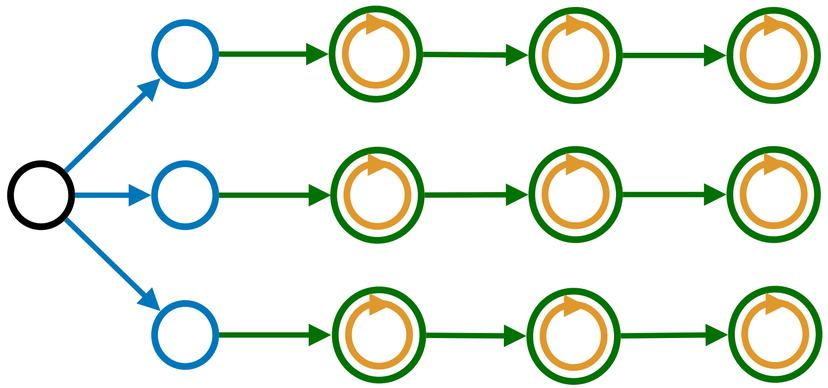
Example: Rewrite Chain X Fanout



Composability analysis

Exponentially many ***multi-dimensional*** (regular or irregular) compositions!

Example: **Fanout** X **Chain** X **Self-probing**



Validation on major DNS implementations

Message amplification factor (MAF)* measured on a controlled local testbed

Primary	F.O.				W.C.			R.C.	D.D.				F.O.	W.C.	D.D.
Secondary	F.O.	R.C.	W.C.	Q.M.	F.O.	R.C.	Q.M.	Q.M.	F.O.	R.C.	W.C.	Q.M.	W.C.	F.O.	W.C.
Tertiary	-	-	-	-	-	-	-	-	-	-	-	-	Q.M.	R.C.	Q.M.
Compo. Index	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
BIND	31	36	21	21	**119**	**136**	82	8	80	50	2	21	26	**731**	2
Unbound	12	17	73	61	28	60	**112**	43	30	67	**241**	**201**	**726**	23	**2400**
PowerDNS	57	57	56	91	24	31	99	98	21	30	53	90	97	11	97

*MAF = #queries received by focal nameserver
<= #queries sent by the amplifying resolver

Resolver Limits	BIND 9.18.4	Unbound 1.16.0	PowerDNS 4.7.3
Concurrent NS queries	5	3	1
Failover NS queries	-	3	9
Total NS queries^	-	6	10
Referral chain length	7	4	15
Rewrite chain length	17	12	12
QMIN iterations	5	10	10
DDLG iterations	>20	>20	>20
Max queries per cli. req.	100	32	60/100

^Resovler queries for IPv6 nameserver disabled

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Message amplification factor (MAF)* measured on a controlled local testbed

Primary	F.O.				W.C.			R.C.	D.D.				F.O.	W.C.	D.D.
Secondary	F.O.	R.C.	W.C.	Q.M.	F.O.	R.C.	Q.M.	Q.M.	F.O.	R.C.	W.C.	Q.M.	W.C.	F.O.	W.C.
Tertiary	-	-	-	-	-	-	-	-	-	-	-	-	Q.M.	R.C.	Q.M.
Compo. Index	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
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Highlight #1: CAMP can bypass
query limits on individual features

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Tertiary	-	-	-	-	-	-	-	-	-	-	-	-	Q.M.	R.C.	Q.M.
Compo. Index	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
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Highlight #2: CAMP can exceed ***global query limit per client request***

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Rewrite chain length	17	12	12
QMIN iterations	5	10	10
DDLG iterations	>20	>20	>20
Max queries per cli. req.	100	32	60/100

*MAF = #queries received by focal nameserver
<= #queries sent by the amplifying resolver

^Resovler queries for IPv6 nameserver disabled

Validation on major DNS implementations

Message amplification factor (MAF)* measured on a controlled local testbed

Primary	F.O.				W.C.			R.C.	D.D.				F.O.	W.C.	D.D.
Secondary	F.O.	R.C.	W.C.	Q.M.	F.O.	R.C.	Q.M.	Q.M.	F.O.	R.C.	W.C.	Q.M.	W.C.	F.O.	W.C.
Tertiary	-	-	-	-	-	-	-	-	-	-	-	-	Q.M.	R.C.	Q.M.
Compo. Index	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
BIND	31	36	21	21	**119**	**136**	82	8	80	50	2	21	26	**731**	2
Unbound	12	17	73	61	28	60	**112**	43	30	67	**241**	**201**	**726**	23	**2400**
PowerDNS	57	57	56	91	24	31	99	98	21	30	53	90	97	11	97

Highlight #3: CAMP can ***grow exponentially in #dimensions***

Resolver Limits	BIND 9.18.4	Unbound 1.16.0	PowerDNS 4.7.3
Concurrent NS queries	5	3	1
Failover NS queries	-	3	9
Total NS queries^	-	6	10
Referral chain length	7	4	15
Rewrite chain length	17	12	12
QMIN iterations	5	10	10
DDLG iterations	>20	>20	>20
Max queries per cli. req.	100	32	60/100

*MAF = #queries received by focal nameserver
<= #queries sent by the amplifying resolver

^Resovler queries for IPv6 nameserver disabled

Concluding remarks

First systematic study of application-layer amplification intrinsic to DNS

Analysis framework can incorporate new features, e.g., SVCB record

CAMP can explore the full amplification potential of a resolver

100—1000s of MAFs on real-world resolvers

Amplification can be upper-bounded but not eliminated

Mitigation at protocol-, impl-, and operation-level

Disclosure status

Initially to BIND, Unbound, and PowerDNS, patched with better query limiting

To international DNS entities via Swiss National Cyber Security Centre NCSC

Thank you!
Questions?

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