PHOENIX & CERBERUS

We haz botnets!

HackInBO, Bologna, 23 May 2015

Stefano Schiavoni, Edoardo Colombo
Federico Maggi
Lorenzo Cavallaro
Stefano Zanero

Politecnico Di Milano & Royal Holloway, University of London

POLITECNICO
DI MILANO

$ WHOAMI

$ WHOAMI

- Frequent traveller

$ WHOAMI

- Frequent traveller
- Assistant professor (NECST @ POLIMI)

$ WHOAMI

- Frequent traveller
- Assistant professor (NECST @ POLIMI)
- Founder, Secure Network

$ WHOAMI

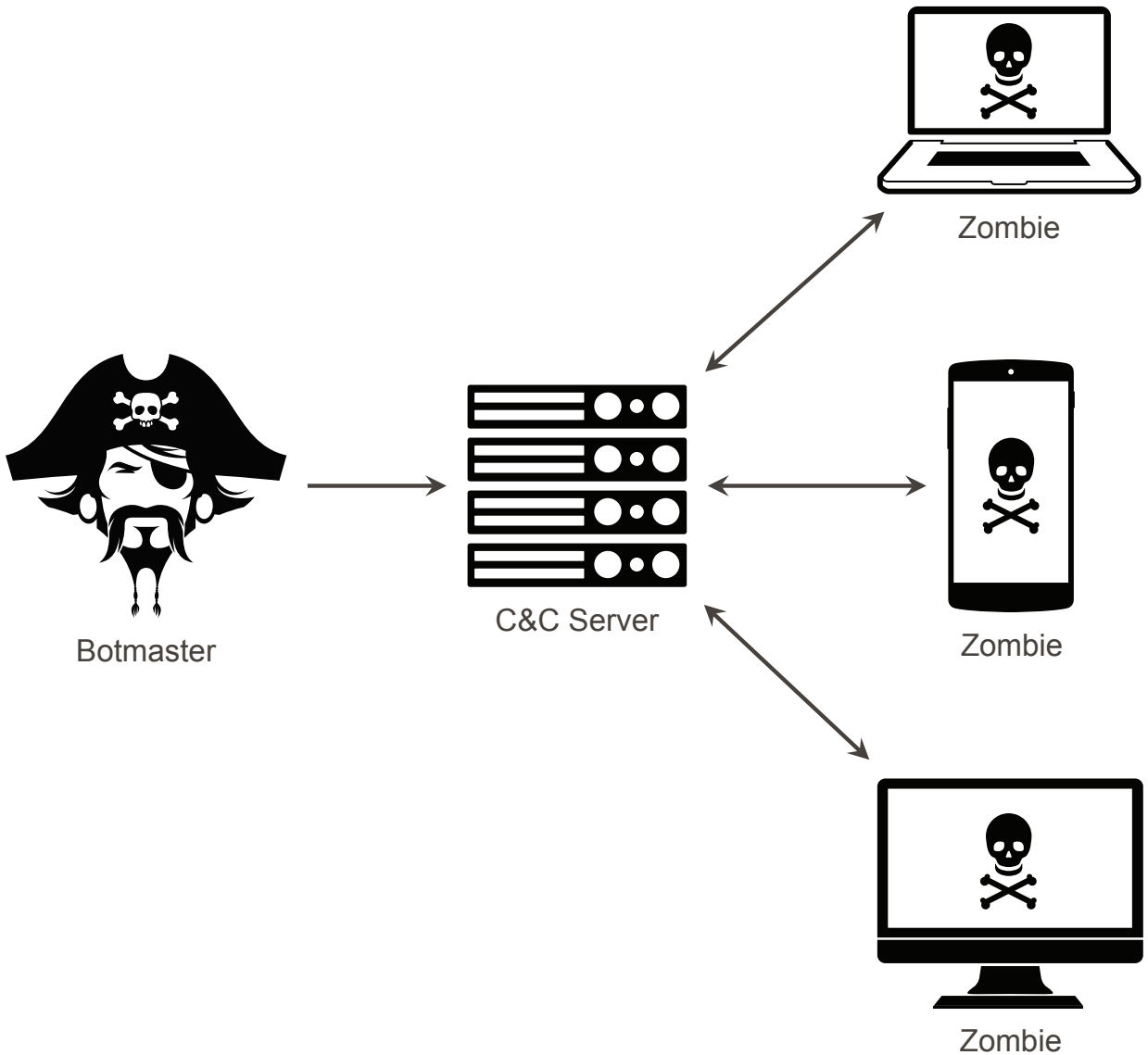
- Frequent traveller
- Assistant professor (NECST @ POLIMI)
- Founder, Secure Network
- Volunteerism workaholic (IEEE, ISSA)

$ WHOAMI

- Frequent traveller
- Assistant professor (NECST @ POLIMI)
- Founder, Secure Network
- Volunteerism workaholic (IEEE, ISSA)
- Black Hat Review Board

BOTNETS

BOTNETS > REMINDER OF DEFINITIONS



CENTRALIZED BOTNETS > C&C CHANNEL

Bot

Botmaster

CENTRALIZED BOTNETS > C&C CHANNEL

Bot

commands

Botmaster

botmaster → **bot** commands to execute, attacks to launch

CENTRALIZED BOTNETS > C&C CHANNEL

Bot

commands

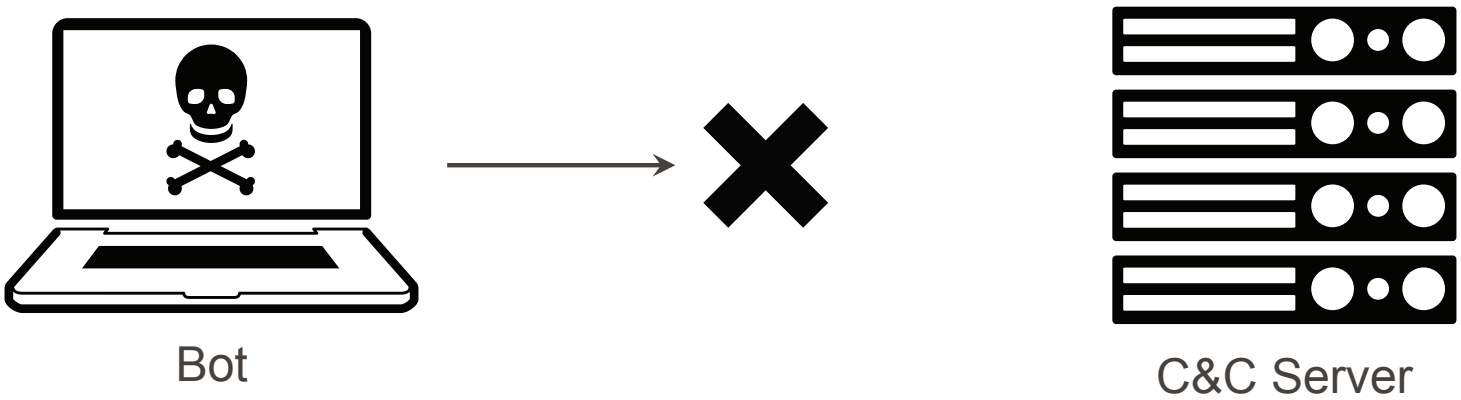
data, feedback

Botmaster

botmaster → **bot** commands to execute, attacks to launch

bot → **botmaster** harvested information, feedbacks

CENTRALIZED BOTNETS > MITIGATION



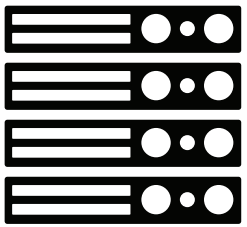
- **C&C channel:** single point of failure.
- **Rallying Mechanisms:** the countermeasure.

BOTNETS > DOMAIN GENERATION ALGORITHMS

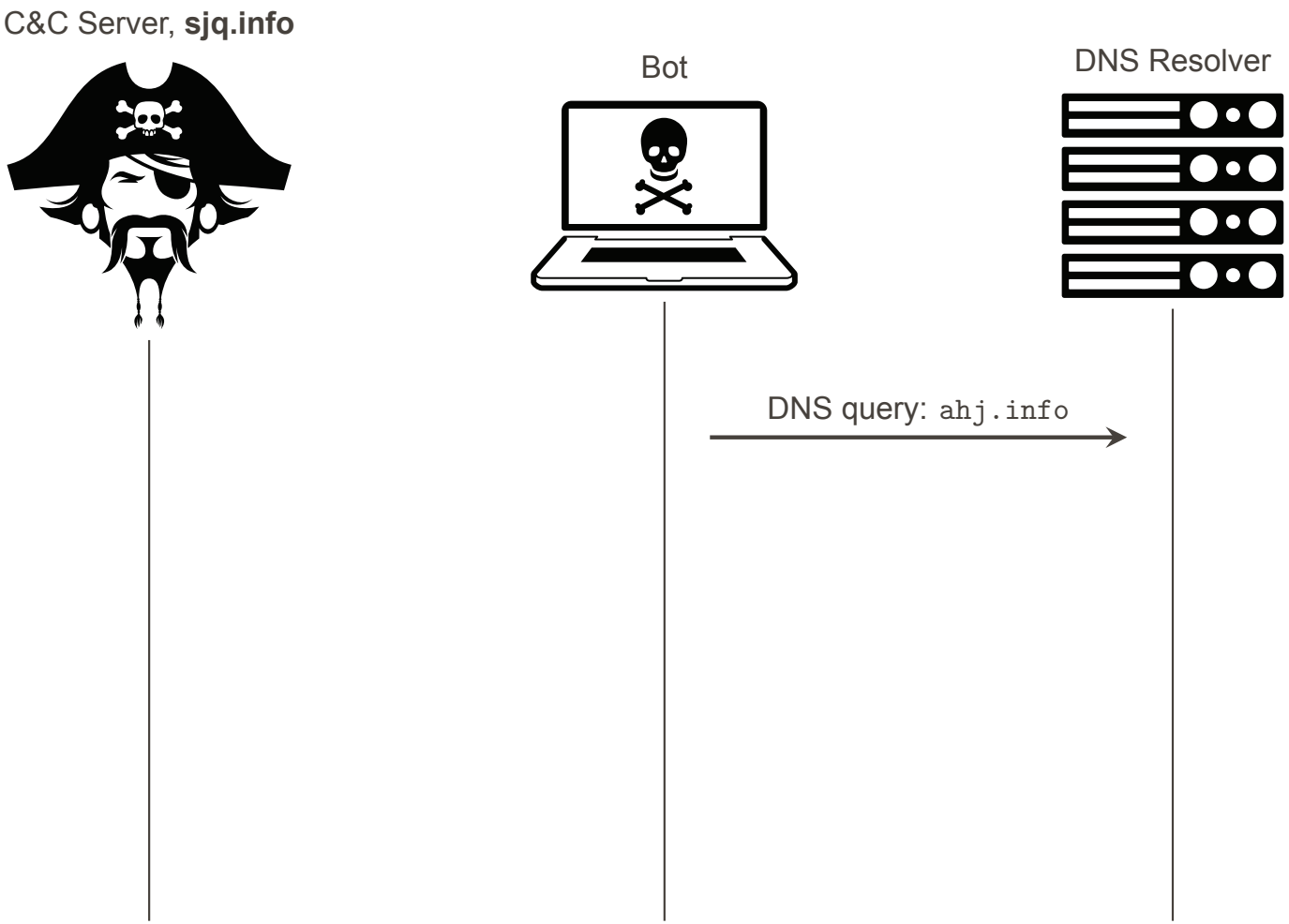
C&C Server, **sjq.info**

Bot

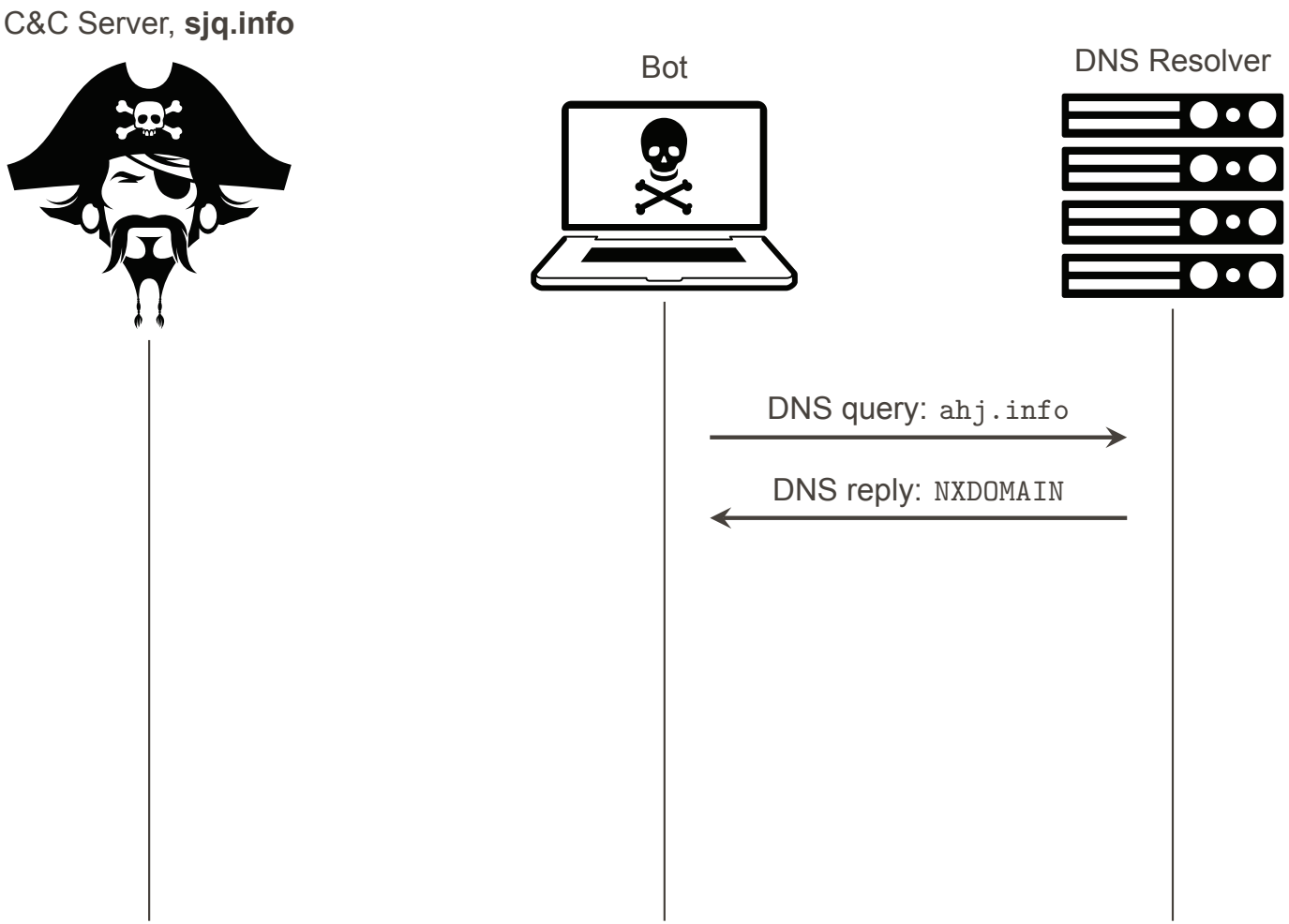
DNS Resolver



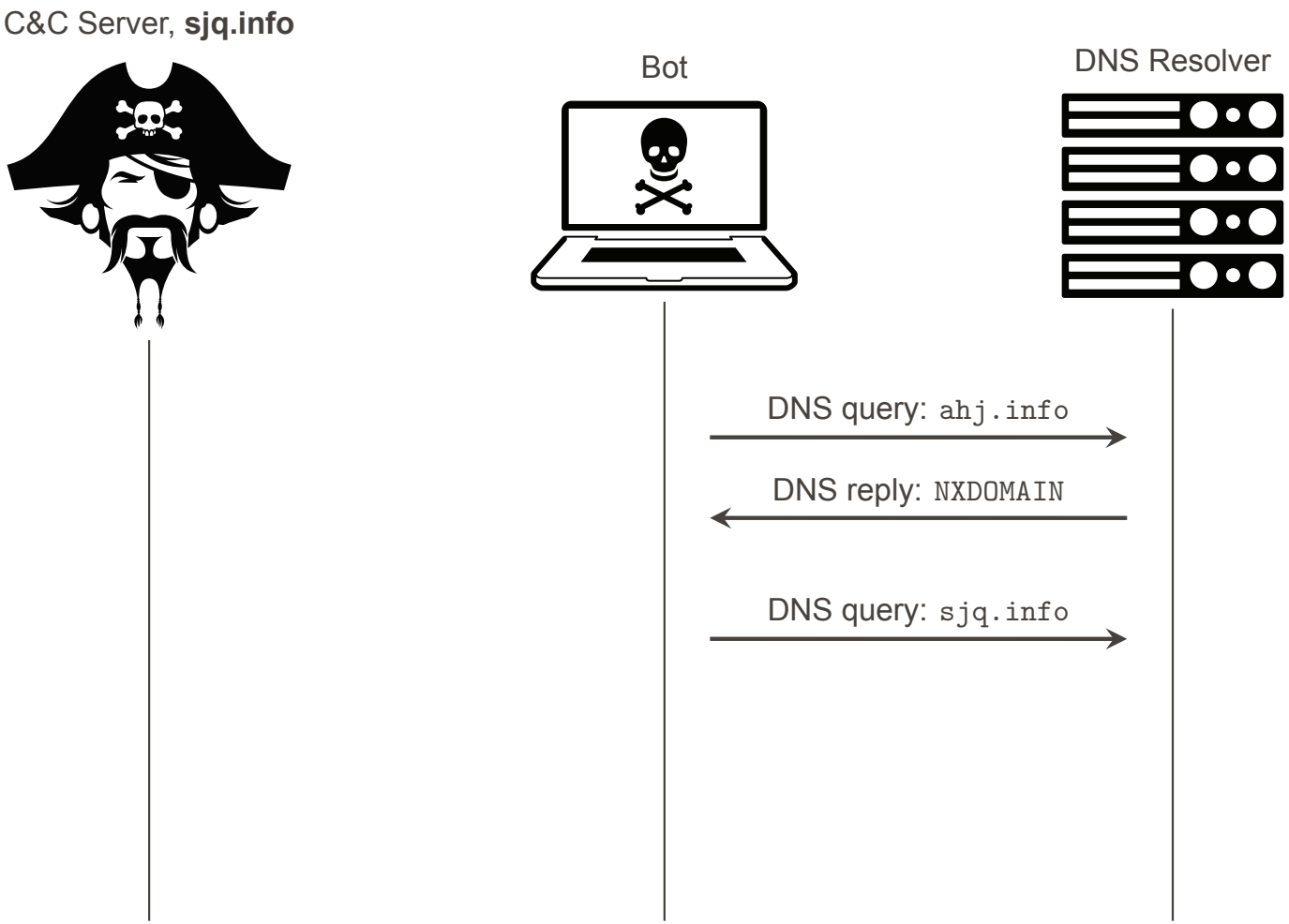
BOTNETS > DOMAIN GENERATION ALGORITHMS



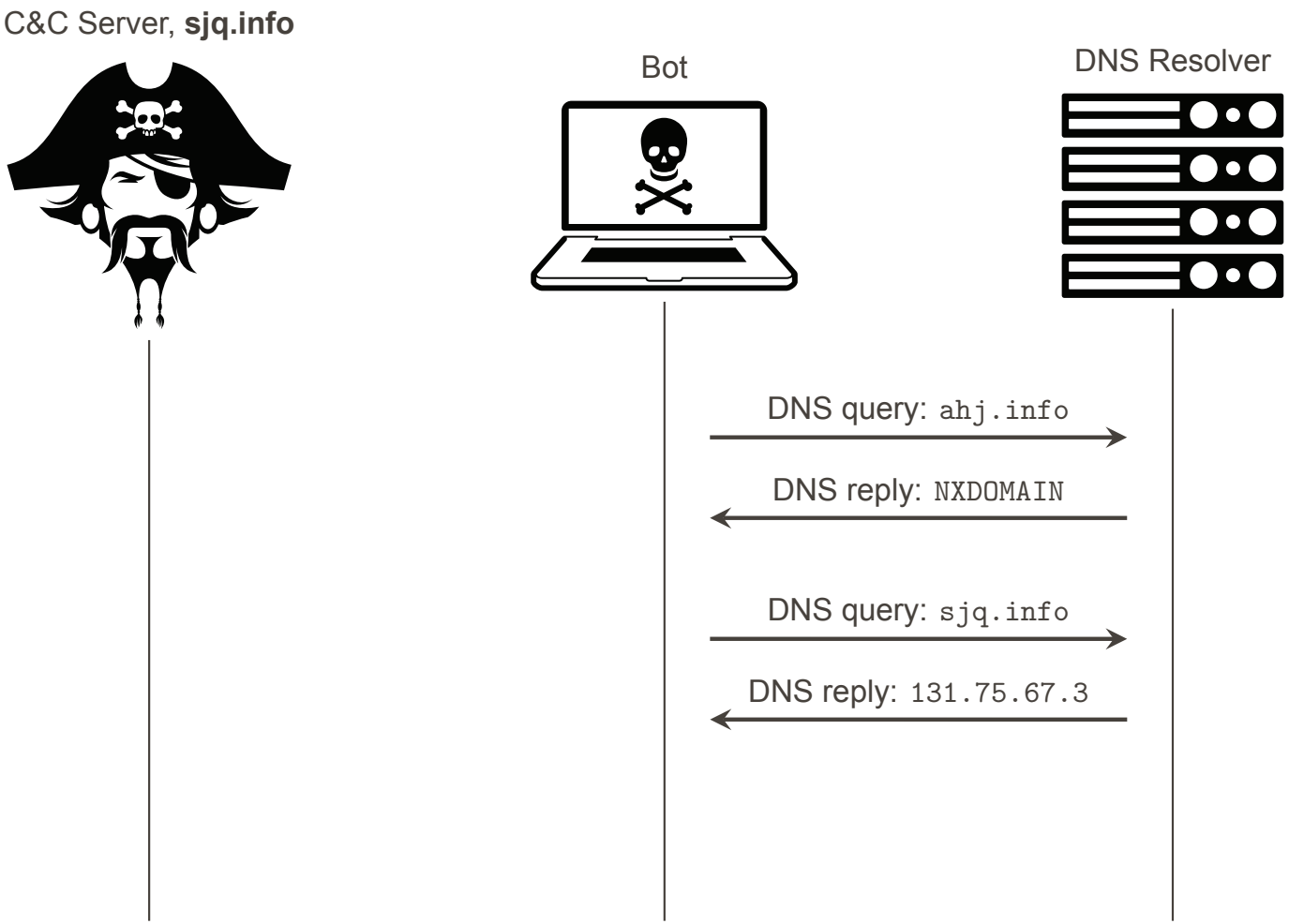
BOTNETS > DOMAIN GENERATION ALGORITHMS



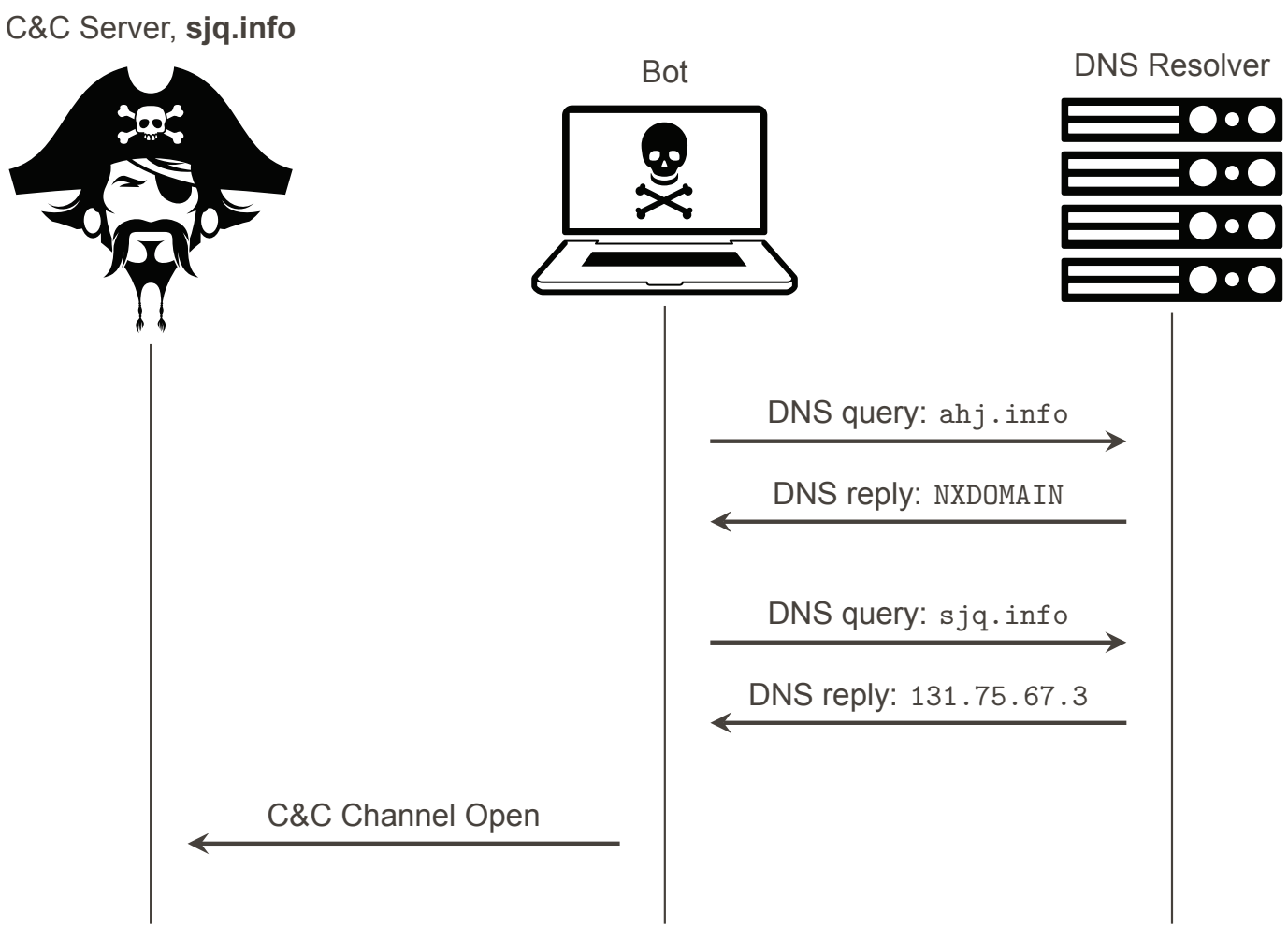
BOTNETS > DOMAIN GENERATION ALGORITHMS



BOTNETS > DOMAIN GENERATION ALGORITHMS



BOTNETS > DOMAIN GENERATION ALGORITHMS



DGA > BENEFITS FOR THE BOTMASTERS

- **Asymmetry** Botmasters Vs Defenders
  - → Thousands of domain names,
  - → only one is the right one.
- **Blacklists** do not work well

STATE OF THE ART > DNS MONITORING

Limitations of current **research approaches**:

Limitations of current **research approaches**:

- **Supervised:** require labeled data

Limitations of current **research approaches**:

- **Supervised:** require labeled data
  - → "That domain name is known to be DGA generated",
  - → "That other domain is not".

Limitations of current **research approaches**:

- **Supervised:** require labeled data
  - → "That domain name is known to be DGA generated",
  - → "That other domain is not".
- Work at the **lower levels** of the **DNS hierarchy:**
  - → not so easy to deploy,
  - → privacy (visibility of the hosts' IP addresses).

PHOENIX

STATE OF THE ART > PHOENIX

Phoenix clusters DGA-generated domains from a list of of **domains known to be used by botnets**.

The core of Phoenix is its ability to **separate DGA from non-DGA** domains, using **linguistic features**.

(in a few slides)

PHOENIX > DISCOVERING DGA-GENERATED DOMAINS

Sources of malicious domains:

- **EXPOSURE** http://exposure.iseclab.org
- **MLD** http://www.malwaredomainlist.com
- ...and of course some **reversing** :-)

PHOENIX > DGA VS. NON-DGA

Meaningful Word Ratio (English dict)

$d = \texttt{facebook.com}$

$$R(d) = \frac{|\texttt{face}| + |\texttt{book}|}{|\texttt{facebook}|} = 1$$

likely **non-DGA generated**

$d = \texttt{pub03str.info}$

$$R(d) = \frac{|\texttt{pub}|}{|\texttt{pub03str}|} = 0.375.$$

likely **DGA generated**

PHOENIX > DGA VS. NON-DGA

N-gram Popularity (English dict)

$d =$ `facebook.com`

`fa`	`ac`	`ce`	`eb`	`bo`	`oo`	`ok`
109	343	438	29	118	114	45

mean: $S_2 = 170.8$

likely **non-DGA generated**

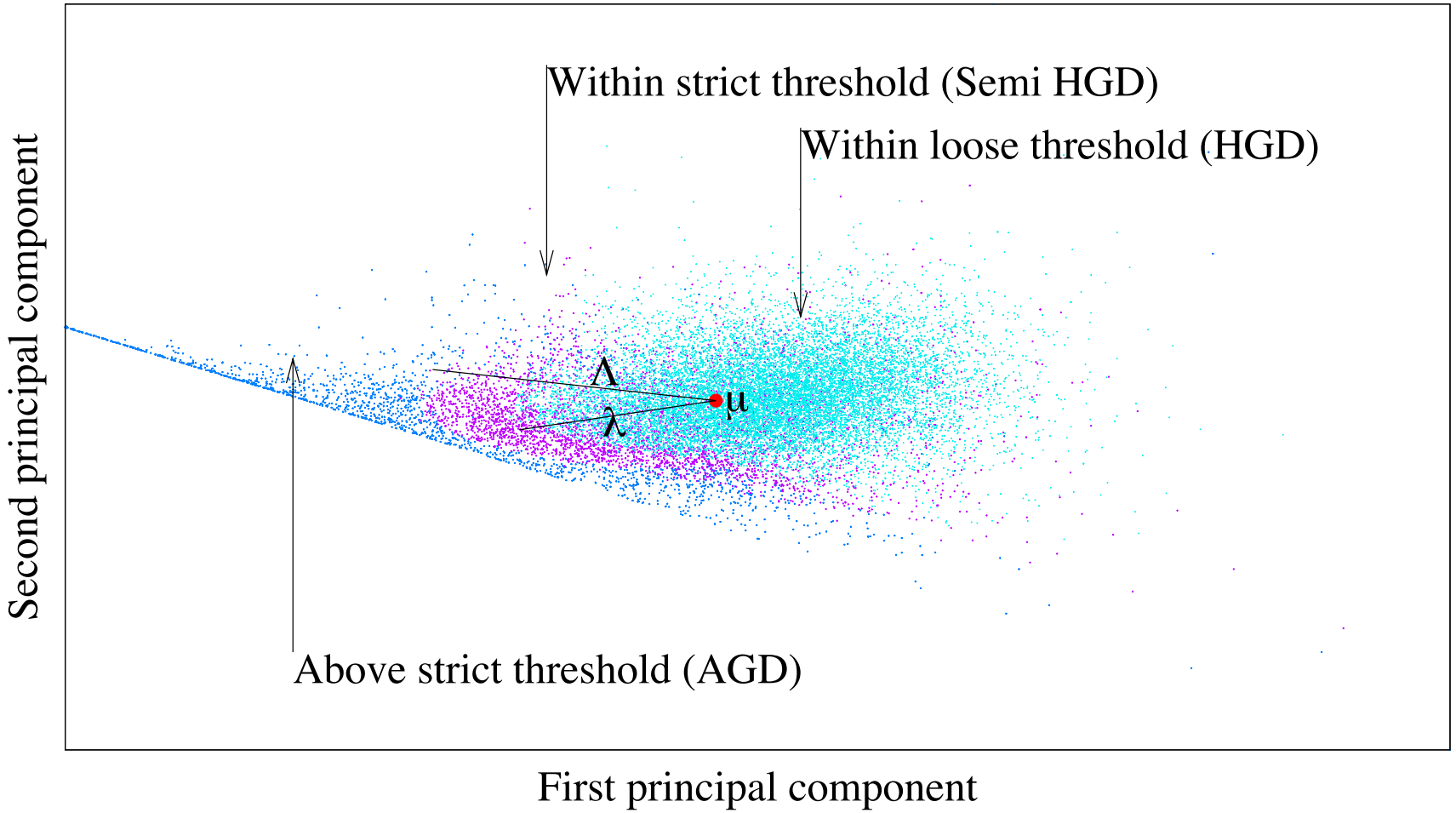
$d =$ `aawrqv.com`

`aa`	`aw`	`wr`	`rq`	`qv`
4	45	17	0	0

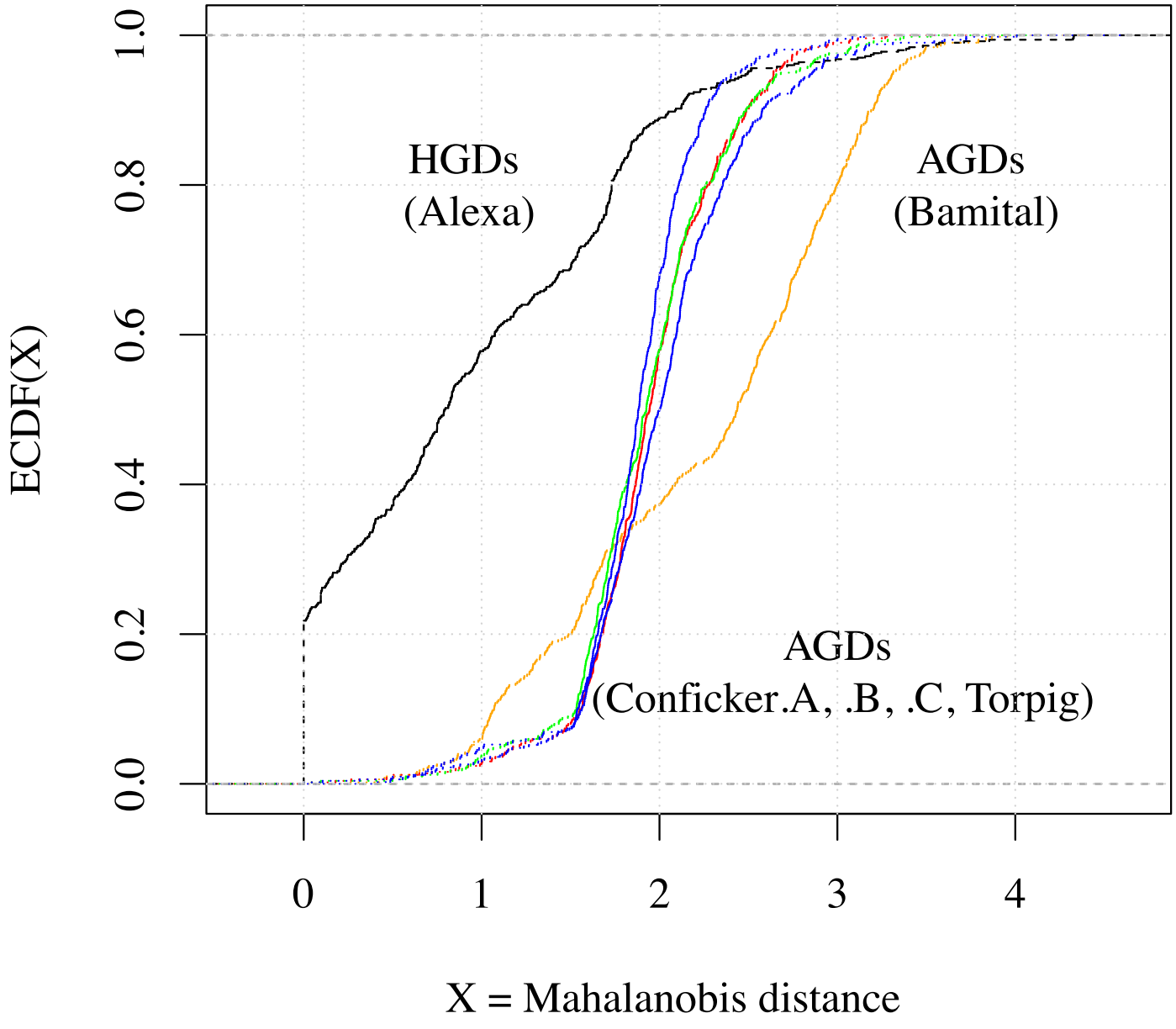
mean: $S_2 = 13.2$

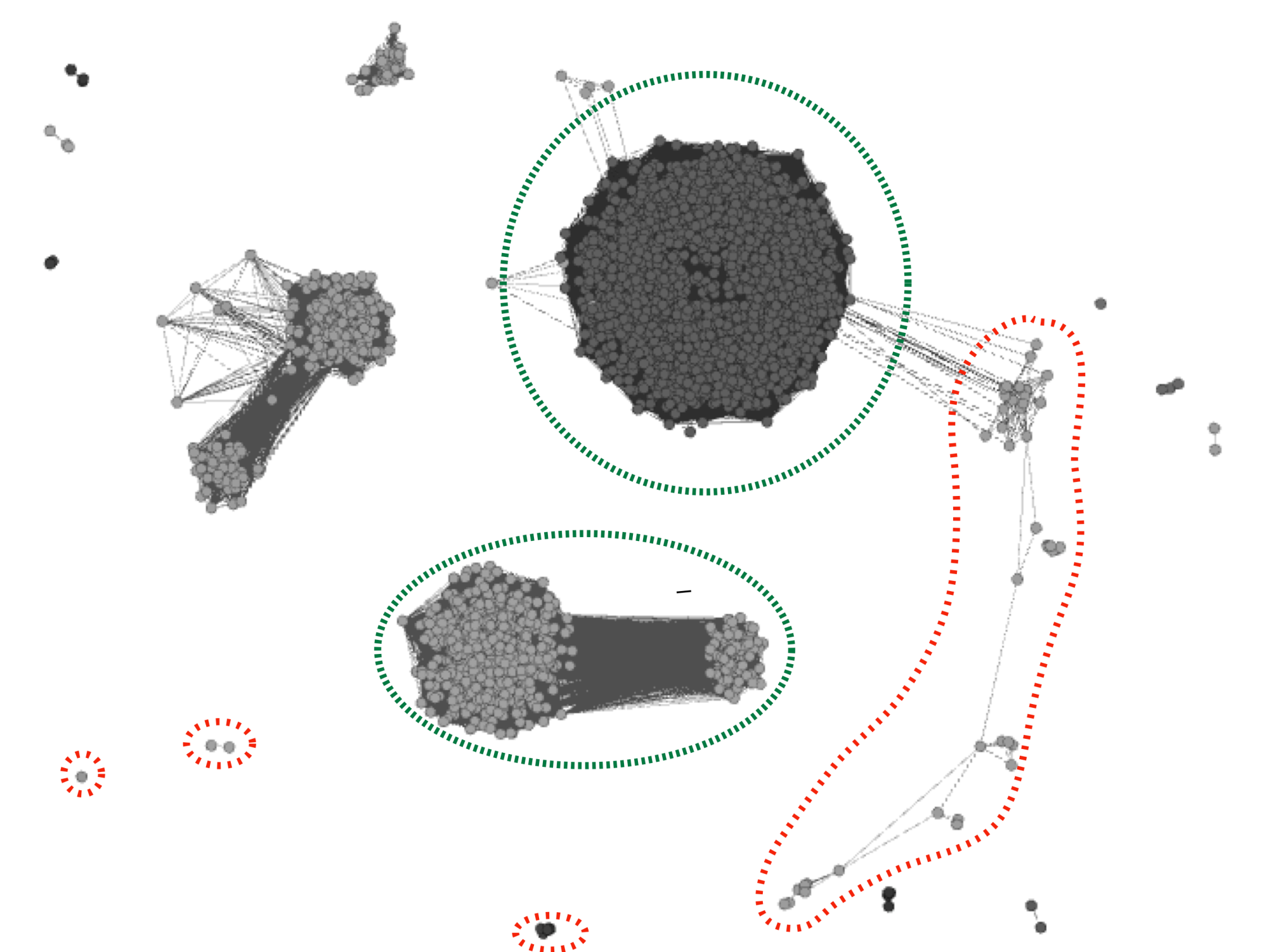
likely **DGA generated**

PHOENIX > DGA VS NON-DGA



PHOENIX > BOTNETS

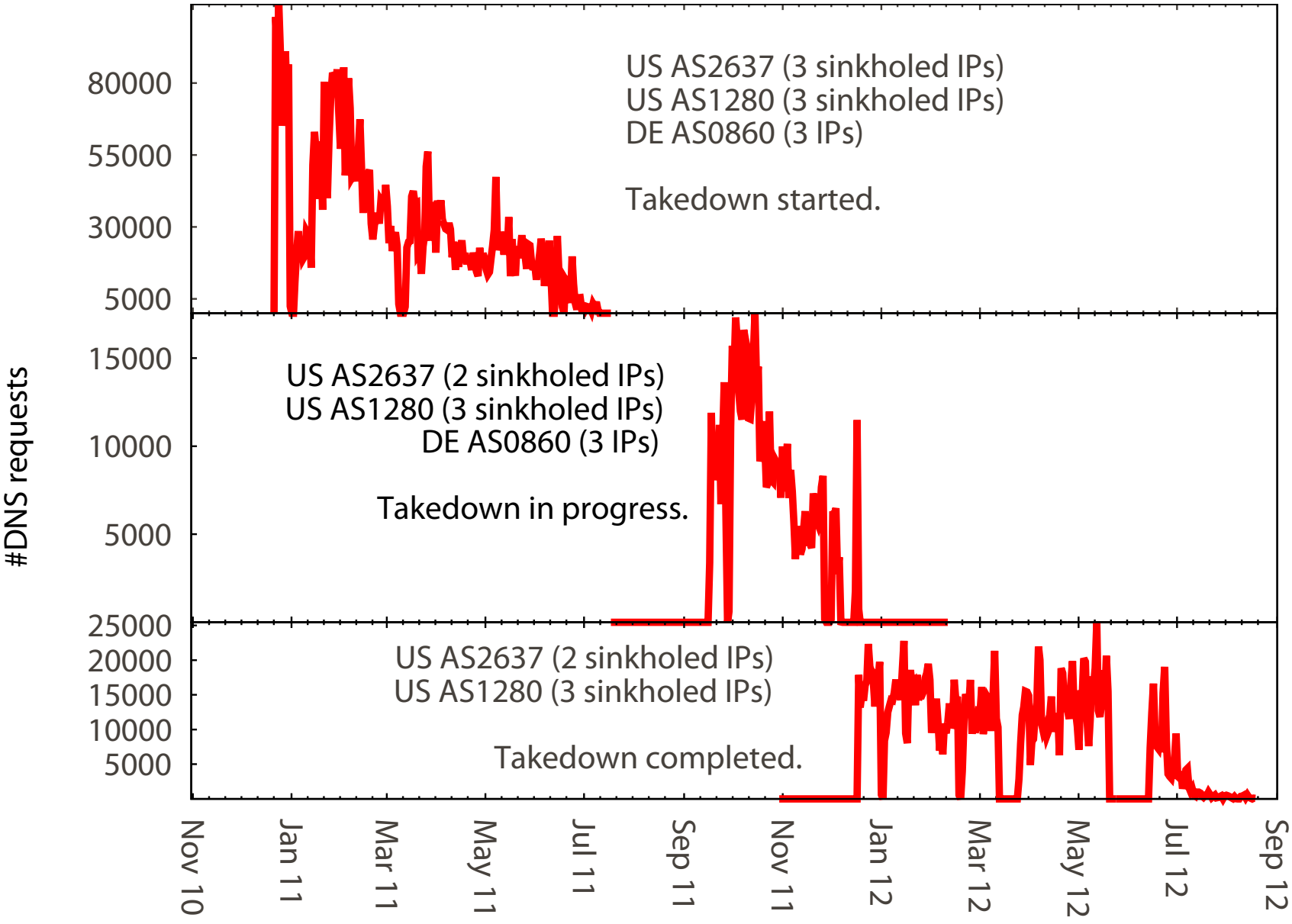




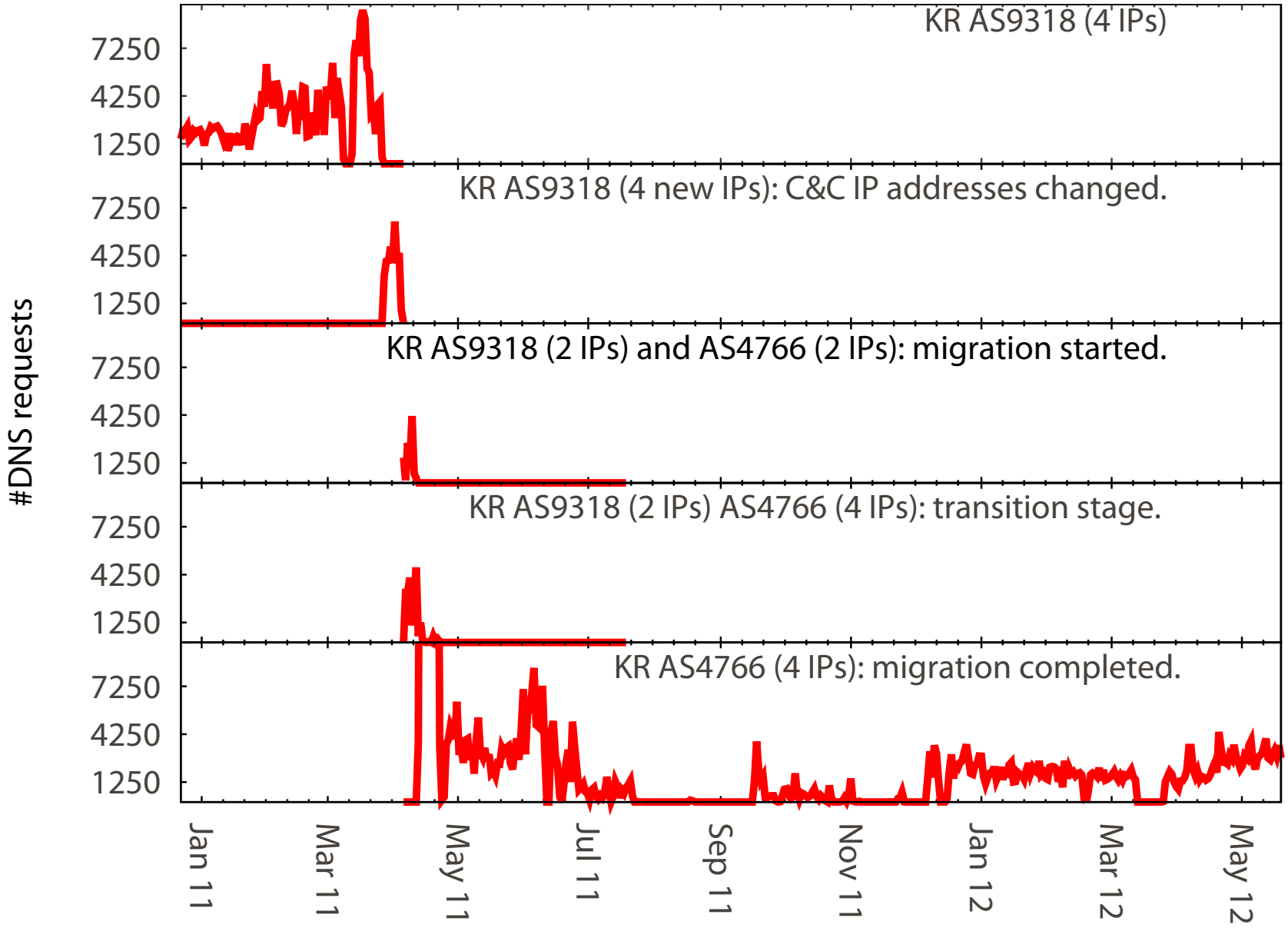
PHOENIX > RESULTS (1 WEEK)

Cluster f105c		Cluster 0f468	
IPs:	176.74.176.175	IPs:	217.119.57.22
	208.87.35.107		91.215.158.57
			178.162.164.24
			94.103.151.195
Domains:	cvq.com	Domains:	jhhfghf7.tk
	epu.org		faukiijjj25.tk
	bwn.org		pvgvy.tk
(Botnet:	Palevo)	(Botnet:	Sality)

PHOENIX > TRACKING MIGRATIONS



PHOENIX > TRACKING MIGRATIONS



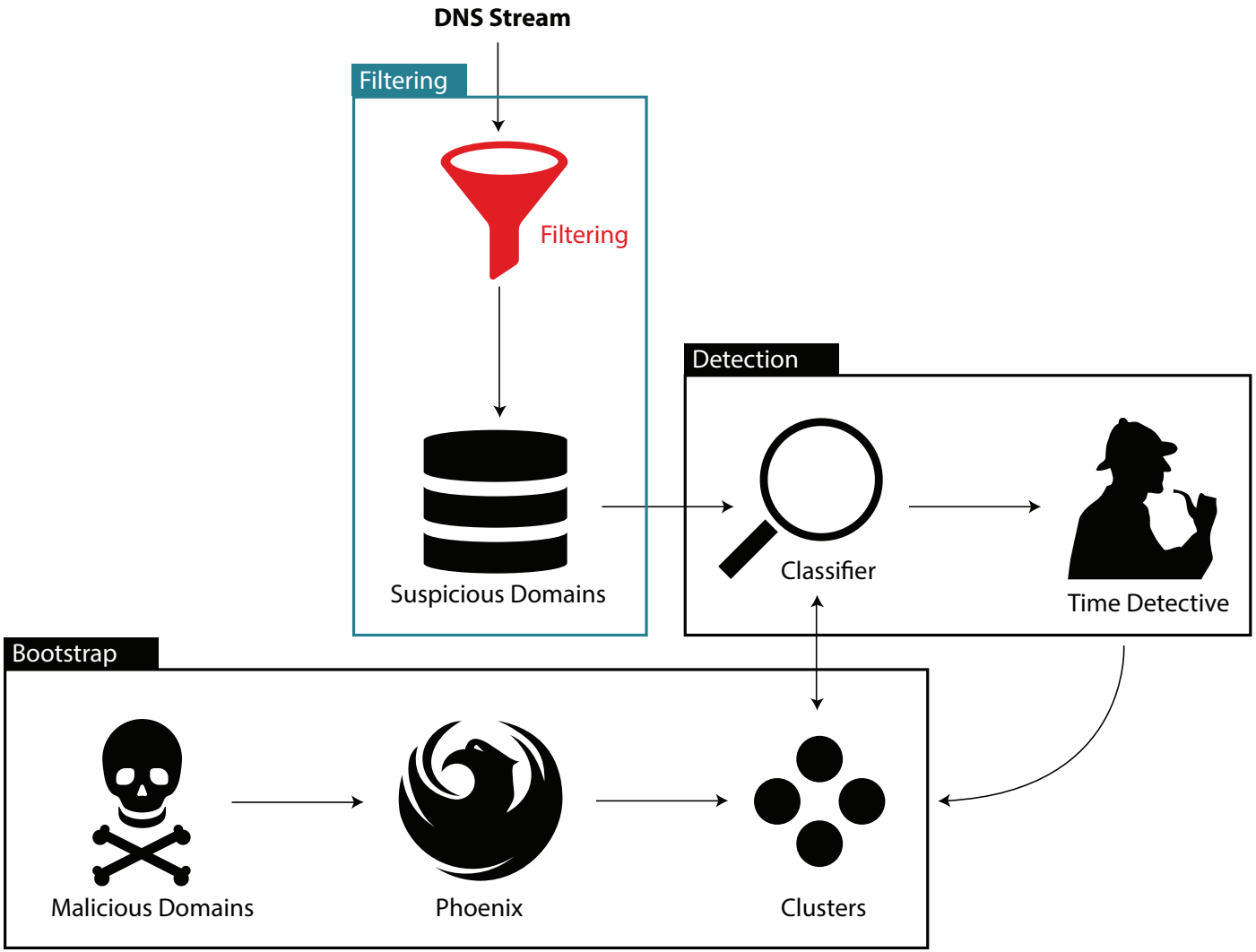
PHOENIX > SHORTCOMINGS

Leverages historical DNS data:

- **Unable** to deal with **new DGAs**
- Unseen "domain→IP" mapping are simply **discarded.**

CERBERUS

CERBERUS > FILTERING



Insight a malicious domain automatically generated will not become popular.

Alexa Top 1M Whitelist

We whitelist the domains that appear in the Alexa Top 1M.

Insight a malicious domain automatically generated will not belong to a CDN `r4---sn-a5m7lnes.example.com`.

CDN Whitelist

We whitelist the domains that belong to the most popular CDN networks (e.g., YouTube, Google, etc.) and advertisement services.

Insight an attacker will register a domain with a TLD that does not require clearance.

TLD Whitelist

We whitelist the domains featuring a Top Level Domain that requires authorization by a third party authority before registration (e.g. `.gov`, `.edu`, `.mil`).

Insight How fast is fast?

- 2-3 years ago: TTL < 100.
- Nowadays: TTL > 300 seconds.

Why? To save money :-) See BH-US 2013 talk[1].

TTL

We filter out all those domains featuring a Time To Live outside this bound.

[1] https://media.blackhat.com/us-13/US-13-Xu-New-Trends-in-FastFlux-Networks-Slides.pdf

Insight we are looking for DGA-generated domains.

Phoenix's DGA Filter

We filter out domains likely to be generated by humans.

Insight the attacker will register the domain just a few days before the communication will take place.

Whois

We query the Whois server and discard the domains that were registered more than Δ days before the DNS query.

RECAP ON FILTERING

Starting with 50,000 domains:

20,000 **TTL > 300** seconds;

19,000 **not** in the **Alexa Top 1M** list;

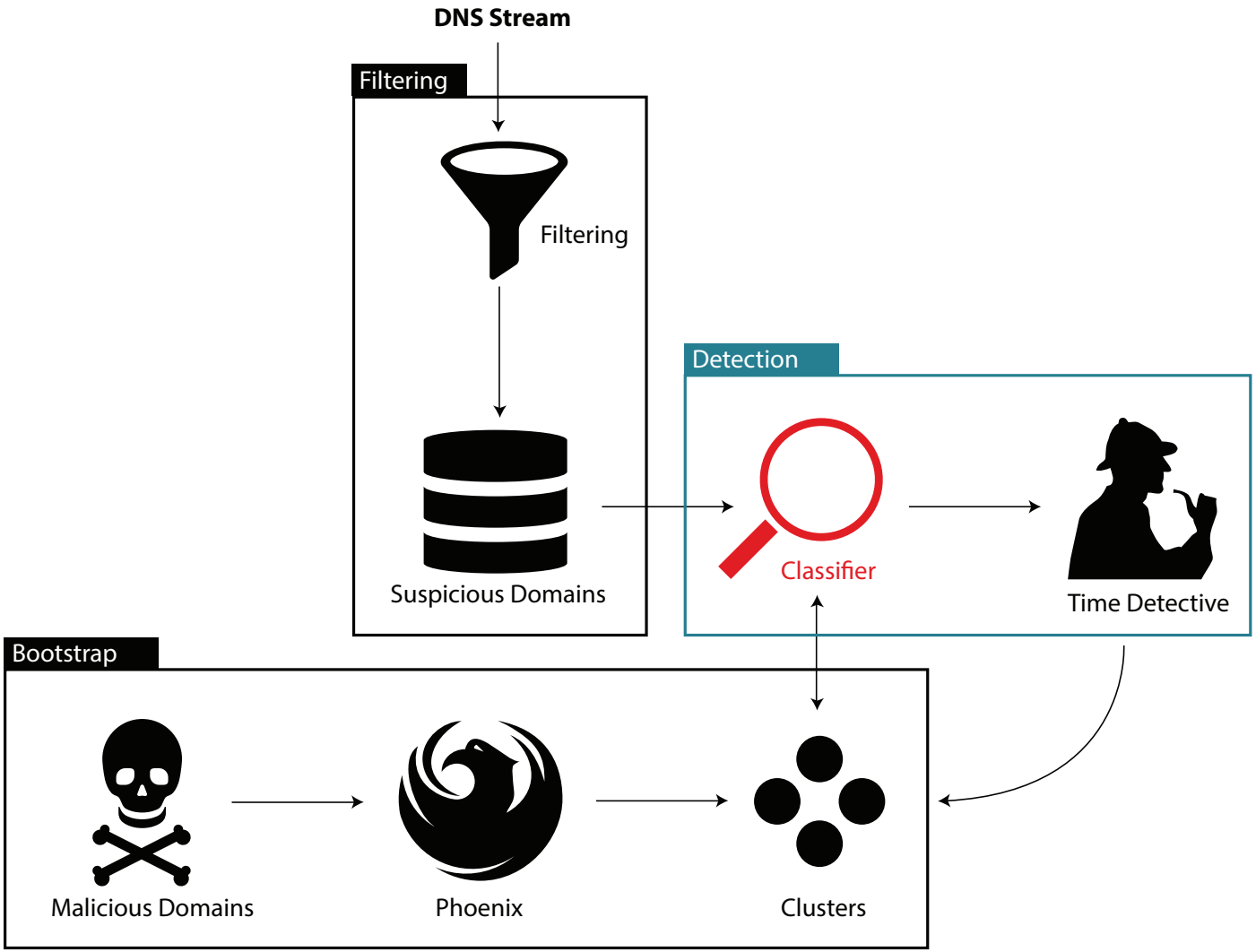
15,000 **not** in the most popular **CDNs**;

800 **likely** to be **DGA generated**;

700 **no** previous **authorization**;

300 **younger than** Δ days $\longleftarrow$ suspicious.

CERBERUS > FILTERING



CLASSIFIER > CLASSIFICATION

576.wap517.net
69.43.161.180

Cluster A

69.43.161.180

379.ns4000wip.com
418.ns4000wip.com
285.ns4000wip.com

Cluster B

69.43.161.180

391.wap517.net
251.wap517.net
340.wap517.net

Cluster C

…

CLASSIFIER > CLASSIFICATION

Cluster A

69.43.161.180

379.ns4000wip.com
418.ns4000wip.com
285.ns4000wip.com

Cluster B

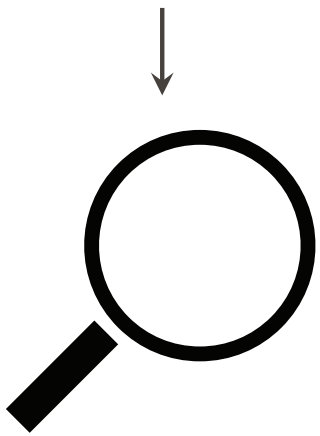
69.43.161.180

391.wap517.net
251.wap517.net
340.wap517.net

Cluster C

…

576.wap517.net
69.43.161.180



CLASSIFIER > CLASSIFICATION

Cluster A

69.43.161.180

379.ns4000wip.com
418.ns4000wip.com
285.ns4000wip.com

Cluster B

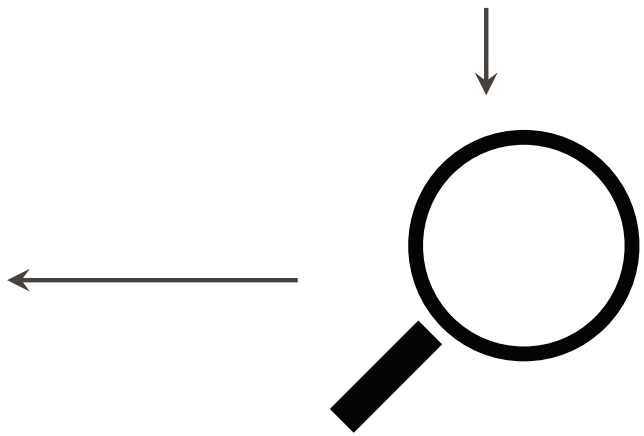
69.43.161.180

391.wap517.net
251.wap517.net
340.wap517.net

Cluster C

…

576.wap517.net
69.43.161.180



CLASSIFIER > CLASSIFICATION

Cluster A

69.43.161.180

379.ns4000wip.com
418.ns4000wip.com
285.ns4000wip.com

Cluster B

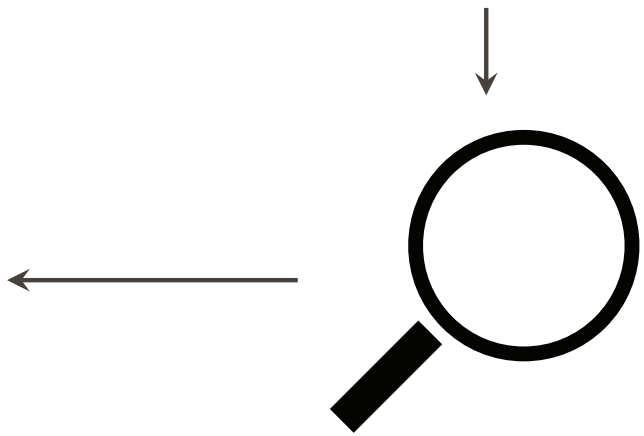
69.43.161.180

391.wap517.net
251.wap517.net
340.wap517.net

Cluster C

…

576.wap517.net
69.43.161.180



CLASSIFIER > CLASSIFICATION

Cluster A

69.43.161.180

379.ns4000wip.com
418.ns4000wip.com
285.ns4000wip.com

Cluster B

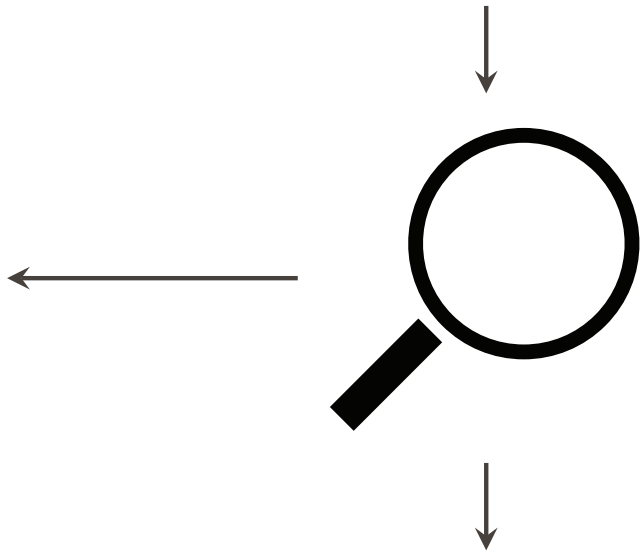
69.43.161.180

391.wap517.net
251.wap517.net
340.wap517.net

Cluster C

…

576.wap517.net
69.43.161.180



Train the Classifier on A, B

CLASSIFIER > CLASSIFICATION

Cluster A

69.43.161.180

379.ns4000wip.com
418.ns4000wip.com
285.ns4000wip.com

Cluster B

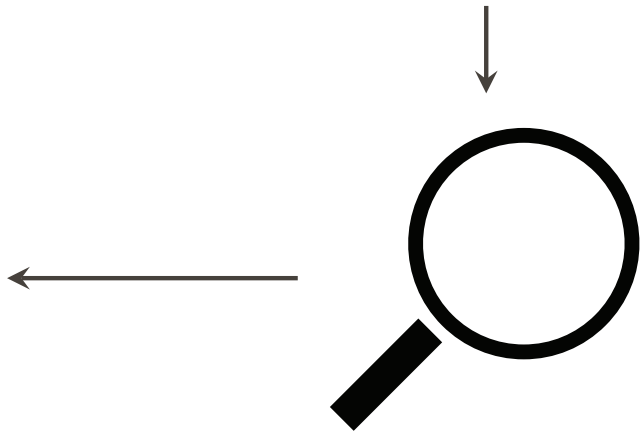
69.43.161.180

391.wap517.net
251.wap517.net
340.wap517.net

Cluster C

…

576.wap517.net
69.43.161.180



Train the Classifier on A, B

Assign 576.wap517.net to B

Developed at Royal Holloway in 2002, by Lodhi et al.

	c-a	c-t	a-t	c-r	a-r
ϕ(cat)	λ^2	λ^3	λ^2	0	0
ϕ(car)	λ^2	0	0	λ^3	λ^2

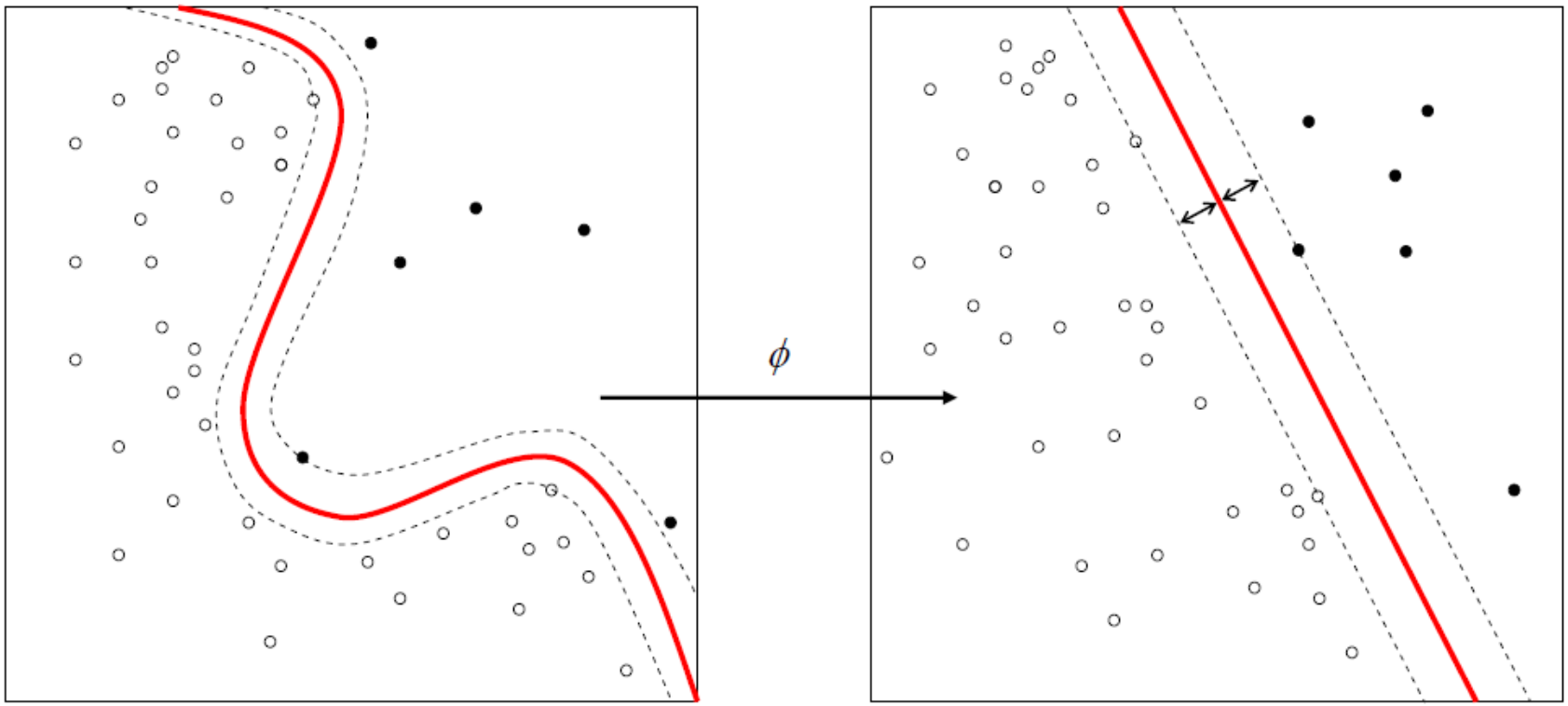
How many substrings of size $k = 2$?

$$\text{ker}(car, cat) = \lambda^4$$

$$\text{ker}(car, car) = \text{ker}(cat, cat) = 2\lambda^4 + \lambda^6$$

$$\text{ker}_n(car, cat) = \frac{\lambda^4}{(2\lambda^4 + \lambda^6)} = \frac{1}{(2 + \lambda^2)} \in [0, 1]$$

SVM: find one hyperplane or a set of them that has the largest distance to the nearest training data point of any class



RESULTS
on passive DNS data from
https://farsightsecurity.com/Services/SIE/

CLASSIFICATION > RESULTS

Training 1000, Testing 100
Overall Accuracy $\simeq$ 0.95

	a	b	c	d
a	100	0	0	0
b	1	92	6	1
c	2	0	98	0
d	3	0	6	91

a

---

caaa89e...d4ca925b3e2.co.cc
f1e01ac...51b64079d86.co.cc
b

---

kdnvfyc.biz
wapzzwvpwq.info
c

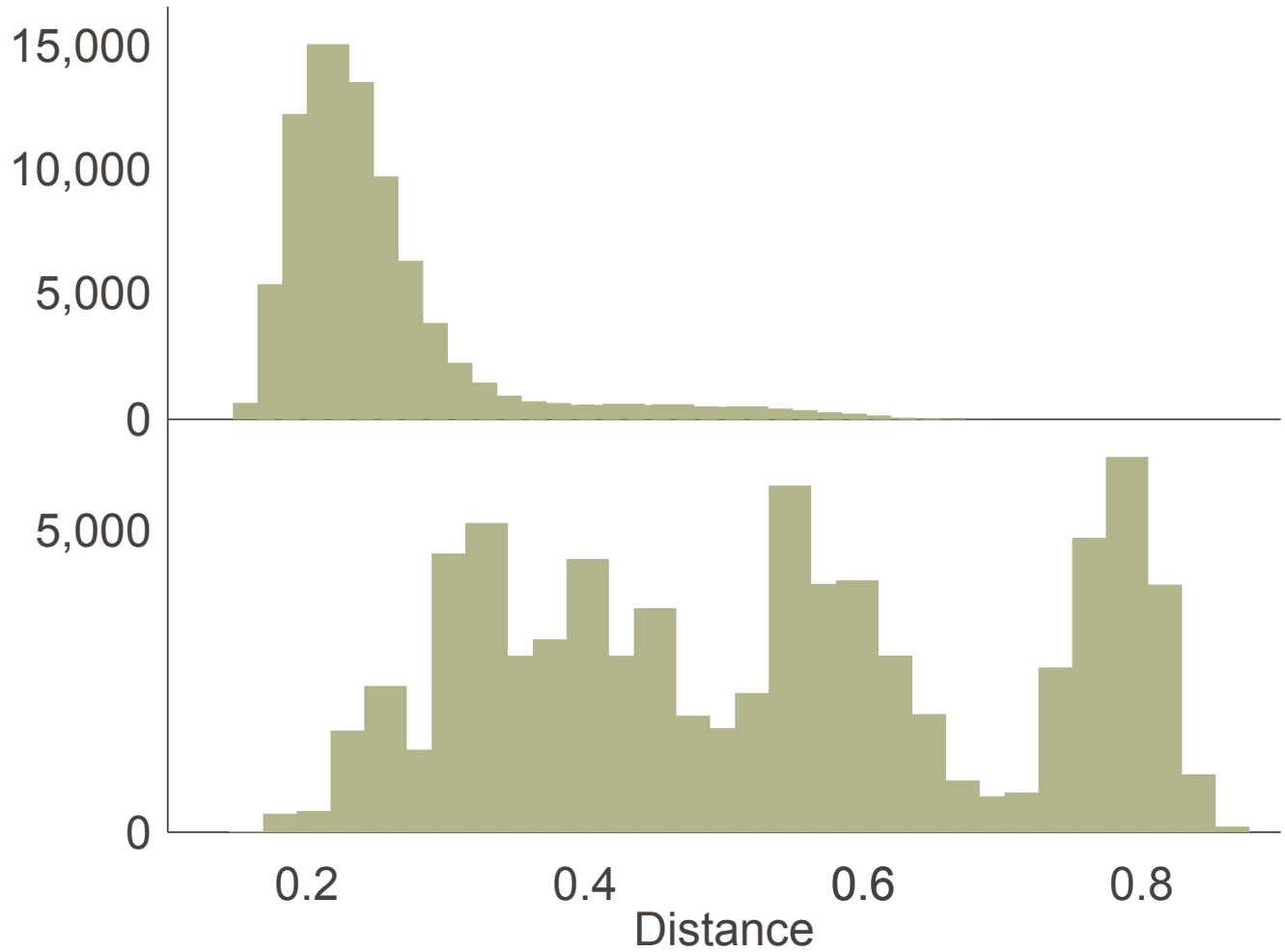
---

jhhfghf7.tk
faukiijjj25.tk
d

---

cvq.com
epu.org

CLASSIFICATION > PAIRWISE DISTANCES



The **Time Detective** discovers new botnets.

TIME DETECTIVE > PASSIVE DNS TRAFFIC

Every Δ the bots **contact** the C&C Server, on a **new domain**.

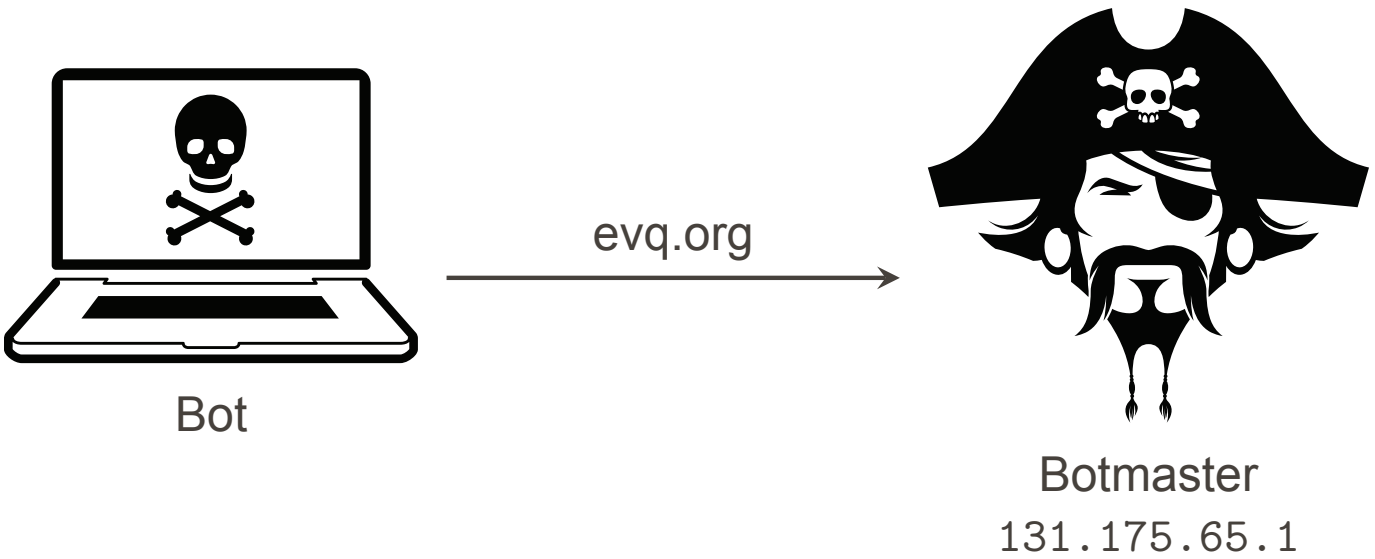
Bot

Botmaster

`131.175.65.1`

`131.175.65.1: {` `}`

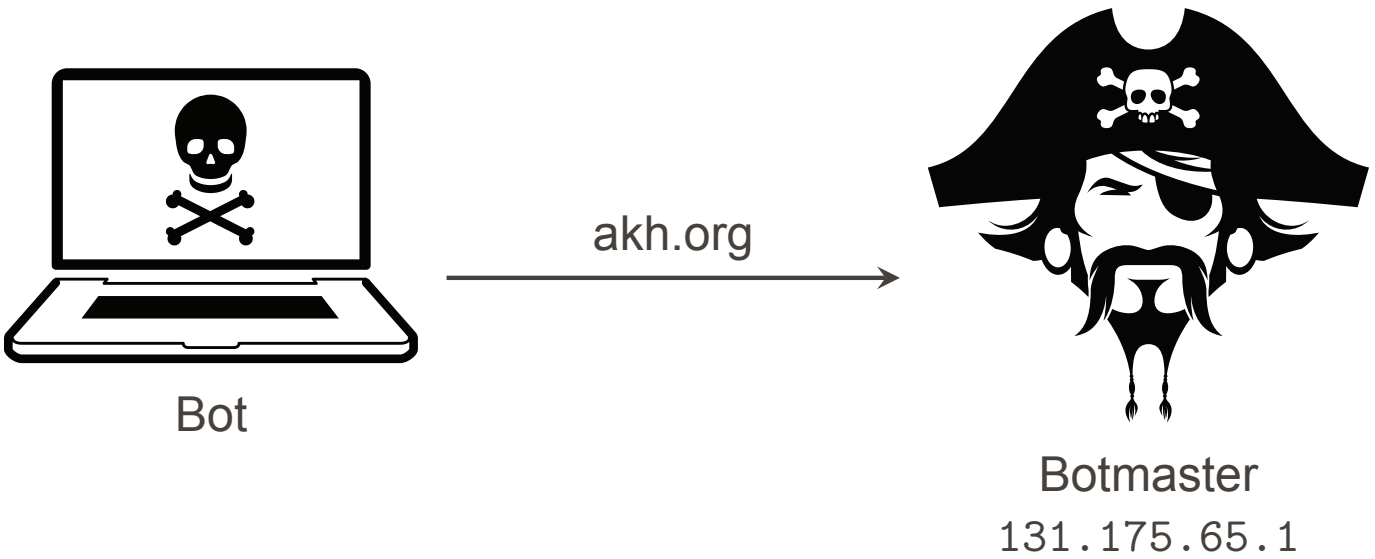
Every Δ the bots **contact** the C&C Server, on a **new domain**.



`131.175.65.1`: { evq.org }

TIME DETECTIVE > PASSIVE DNS TRAFFIC

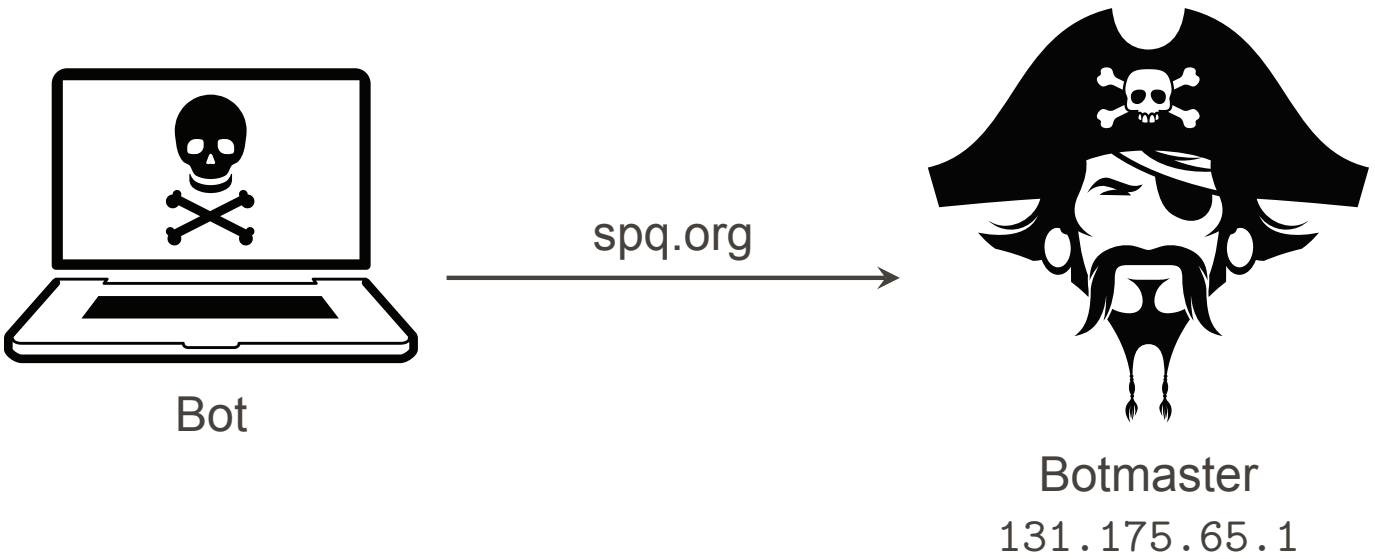
Every Δ the bots **contact** the C&C Server, on a **new domain**.



`131.175.65.1`: { evq.org , akh.org }

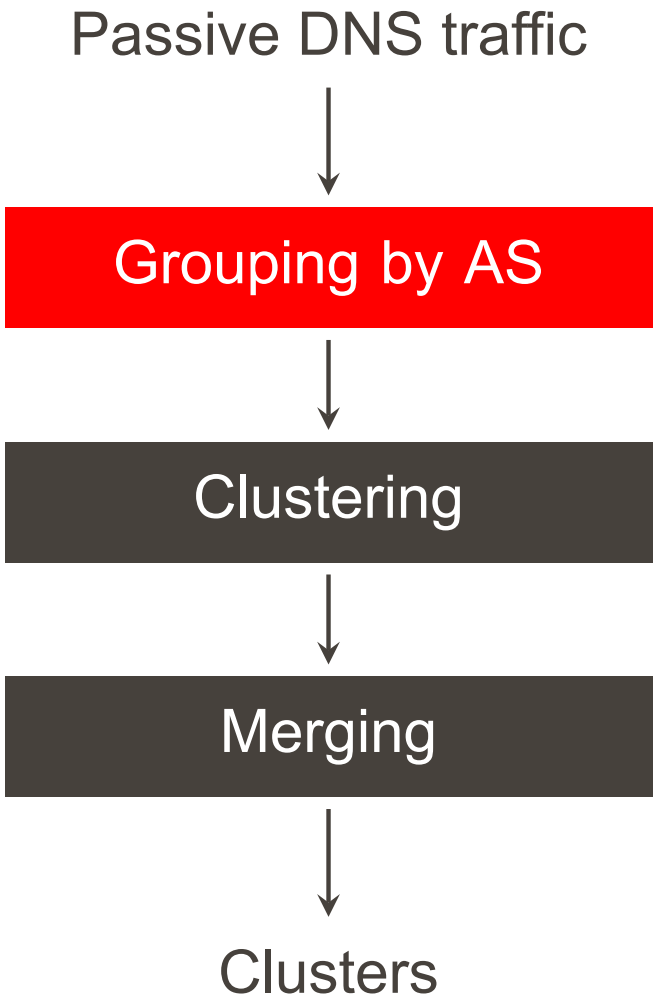
TIME DETECTIVE > PASSIVE DNS TRAFFIC

Every Δ the bots **contact** the C&C Server, on a **new domain**.

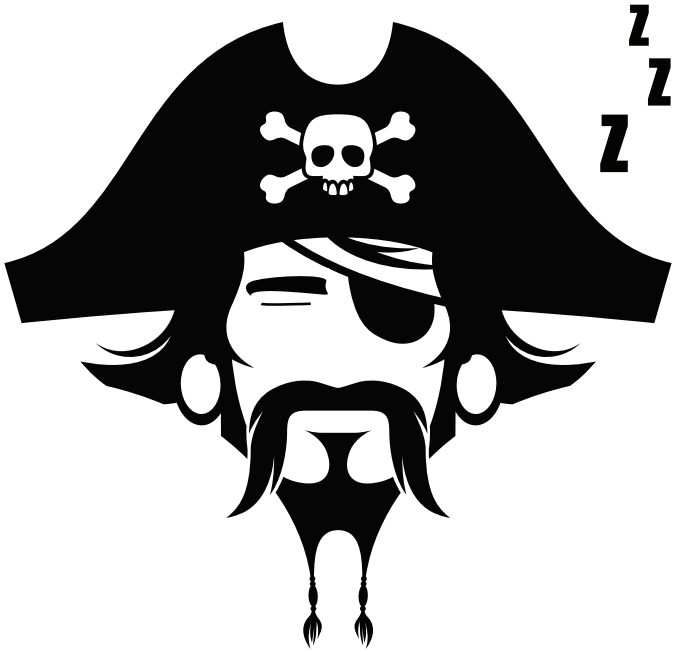


`131.175.65.1`: { evq.org , akh.org , spq.org }

TIME DETECTIVE > STEPS



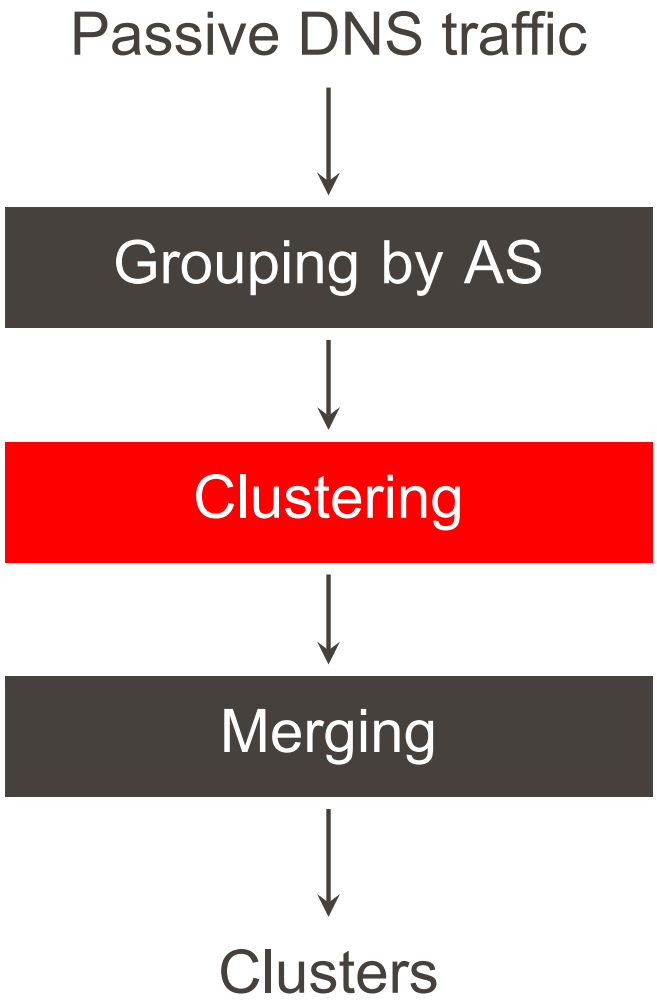
TIME DETECTIVE > GROUPING



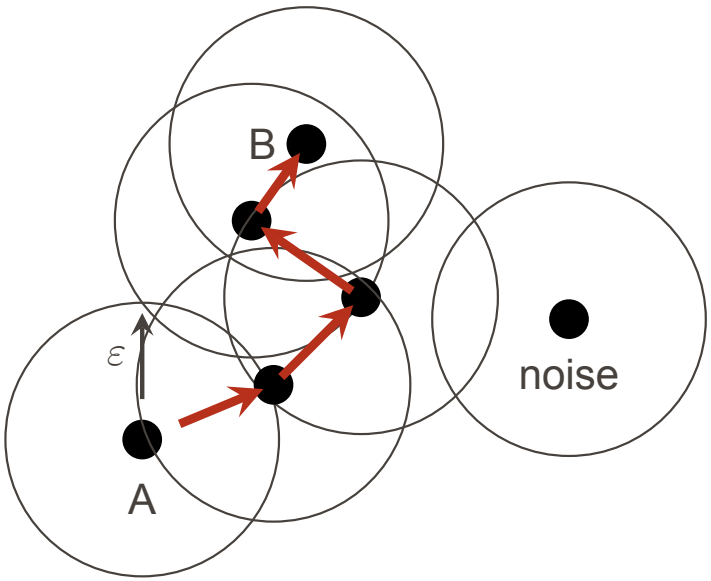
We assume a **lazy attacker** behavior: If (s)he finds an obliging AS, (s)he will buy a few IPs in there.

We group together the domains that point to IPs within the **same AS**.

TIME DETECTIVE > STEPS



DBSCAN



SSK as the distance

automatic tuning:

- $minPts$ domains per cluster,
- ε distance threshold.

CLUSTERING > TUNING MINPTS

$minPts = 7$ domains per cluster

Observation period in days.

Rationale: the bots will contact the C&C server at least **once a day**.

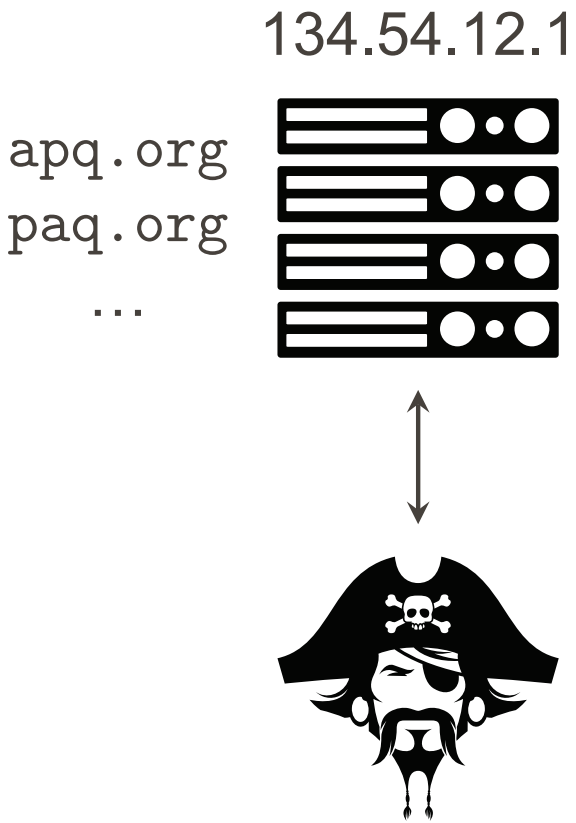
CLUSTERING > THRESHOLD

$$\frac{\text{intra-cluster distances}}{\text{inter-cluster distances}} \rightarrow 0 \text{ (minimize)}$$

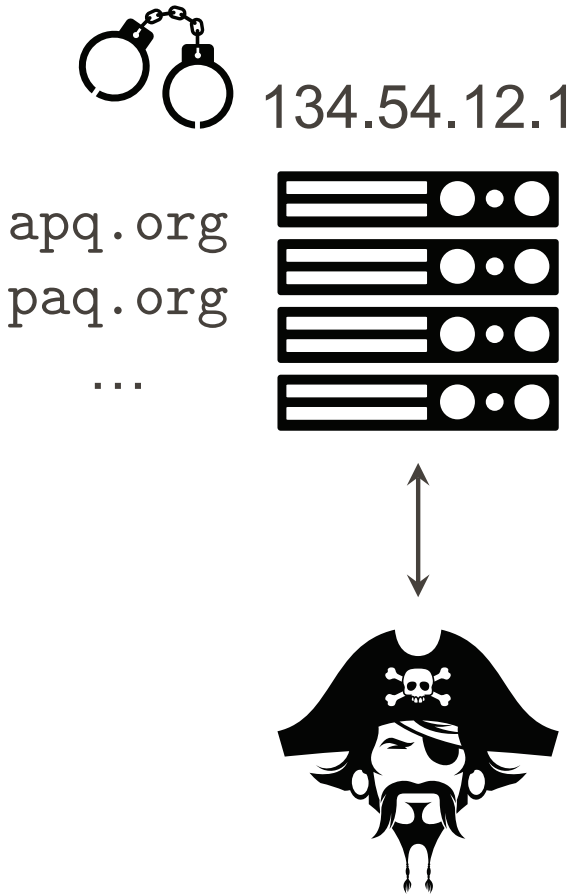
TIME DETECTIVE > MERGING

What if a new cluster is actually a **known botnet** that **migrated** the C&C server somewhere else?

TIME DETECTIVE > MERGING

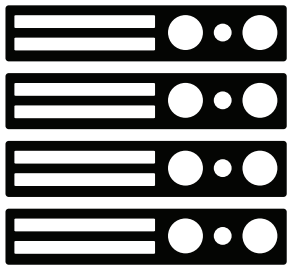


TIME DETECTIVE > MERGING



TIME DETECTIVE > MERGING

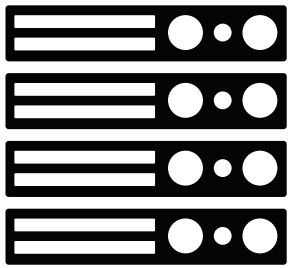
134.54.12.1



What t' h3ck!

TIME DETECTIVE > MERGING

134.54.12.1

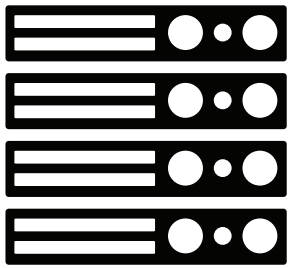


Migration

What t' h3ck!

TIME DETECTIVE > MERGING

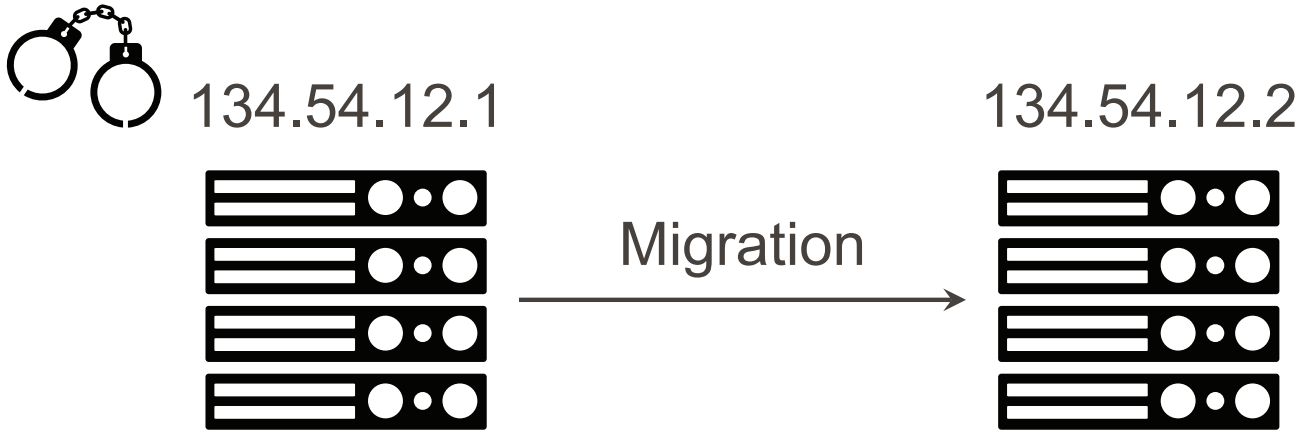
134.54.12.1



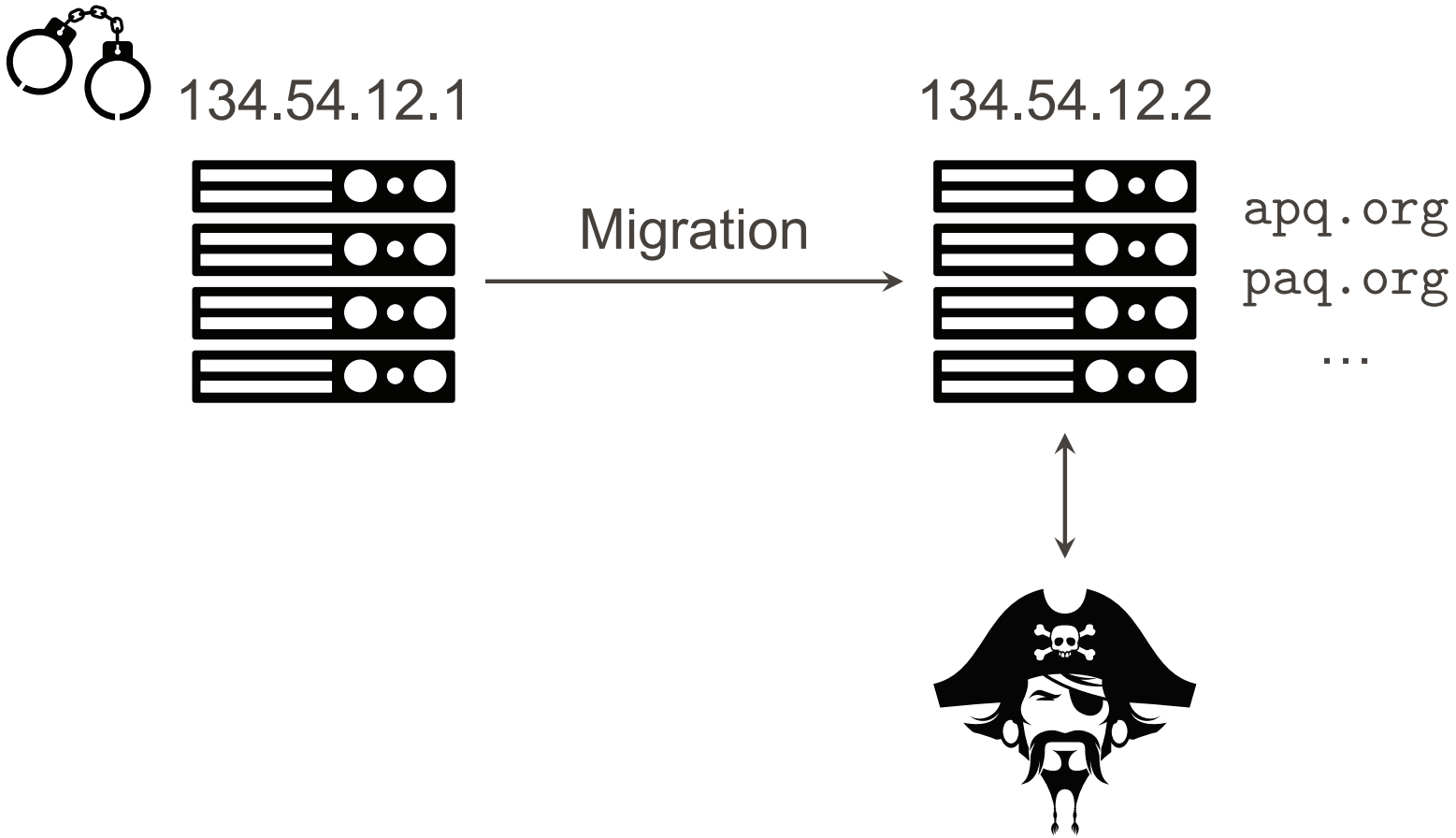
Migration

What t' h3ck!

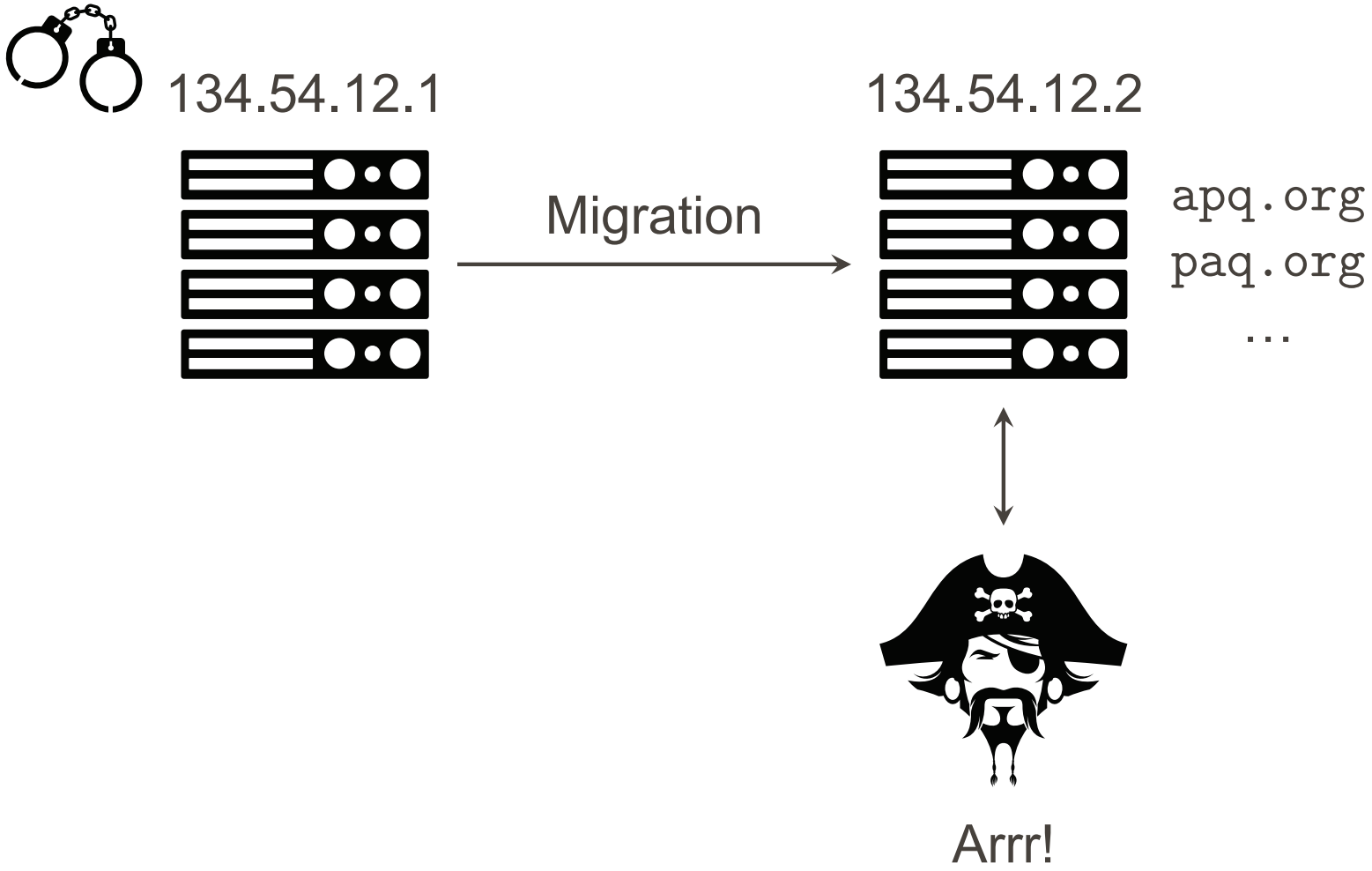
TIME DETECTIVE > MERGING



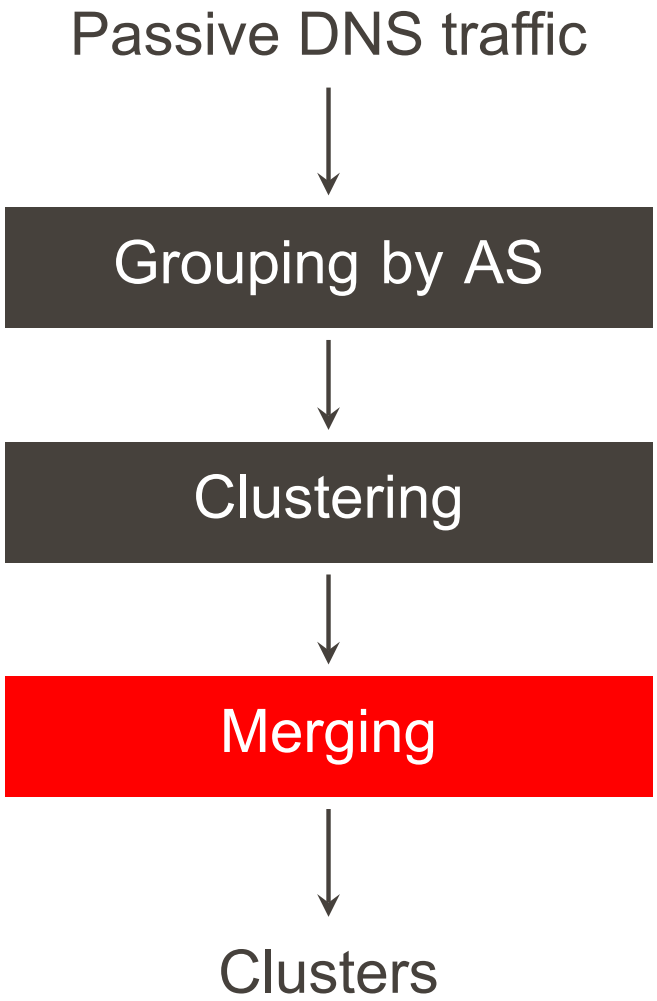
TIME DETECTIVE > MERGING



TIME DETECTIVE > MERGING



TIME DETECTIVE > STEPS



TIME DETECTIVE > MERGING

Suppose you have cluster A and B.

Suppose you have cluster A and B.

$$A = \begin{array}{c} \\ \texttt{dom}_1 \\ \texttt{dom}_2 \\ \vdots \\ \texttt{dom}_m \end{array} \begin{array}{c} \begin{array}{ccc} \texttt{dom}_1 & \cdots & \texttt{dom}_m \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,m} \\ d_{2,1} & \cdots & d_{2,m} \\ \vdots & \ddots & \vdots \\ d_{m,1} & \cdots & d_{m,m} \end{pmatrix} \end{array}$$

Suppose you have cluster A and B.

$$A = \begin{array}{c} \\ \texttt{dom}_1 \\ \texttt{dom}_2 \\ \vdots \\ \texttt{dom}_m \end{array} \begin{array}{c} \begin{array}{ccc} \texttt{dom}_1 & \cdots & \texttt{dom}_m \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,m} \\ d_{2,1} & \cdots & d_{2,m} \\ \vdots & \ddots & \vdots \\ d_{m,1} & \cdots & d_{m,m} \end{pmatrix} \end{array} \quad B = \begin{array}{c} \\ \texttt{dom}_1 \\ \texttt{dom}_2 \\ \vdots \\ \texttt{dom}_n \end{array} \begin{array}{c} \begin{array}{ccc} \texttt{dom}_1 & \cdots & \texttt{dom}_n \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,n} \\ d_{2,1} & \cdots & d_{2,n} \\ \vdots & \ddots & \vdots \\ d_{n,1} & \cdots & d_{n,n} \end{pmatrix} \end{array}$$

Suppose you have cluster A and B.

$$A = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_m \end{array} \begin{array}{c} \begin{array}{ccc} \mathtt{dom}_1 & \cdots & \mathtt{dom}_m \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,m} \\ d_{2,1} & \cdots & d_{2,m} \\ \vdots & \ddots & \vdots \\ d_{m,1} & \cdots & d_{m,m} \end{pmatrix} \end{array} \quad B = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_n \end{array} \begin{array}{c} \begin{array}{ccc} \mathtt{dom}_1 & \cdots & \mathtt{dom}_n \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,n} \\ d_{2,1} & \cdots & d_{2,n} \\ \vdots & \ddots & \vdots \\ d_{n,1} & \cdots & d_{n,n} \end{pmatrix} \end{array}$$

$$A \sim B = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_m \end{array} \begin{array}{c} \begin{array}{cccc} \mathtt{dom}_1 & \mathtt{dom}_2 & \cdots & \mathtt{dom}_n \end{array} \\ \begin{pmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,n} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m,1} & d_{m,2} & \cdots & d_{m,n} \end{pmatrix} \end{array}$$

TIME DETECTIVE > WELCH TEST

Stats to the rescue!

Stats to the rescue!

$$A = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_m \end{array} \begin{array}{c} \begin{array}{ccc} \mathtt{dom}_1 & \cdots & \mathtt{dom}_m \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,m} \\ d_{2,1} & \cdots & d_{2,m} \\ \vdots & \ddots & \vdots \\ d_{m,1} & \cdots & d_{m,m} \end{pmatrix} \end{array} \qquad A \sim B = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_m \end{array} \begin{array}{c} \begin{array}{cccc} \mathtt{dom}_1 & \mathtt{dom}_2 & \cdots & \mathtt{dom}_n \end{array} \\ \begin{pmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,n} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m,1} & d_{m,2} & \cdots & d_{m,n} \end{pmatrix} \end{array}$$

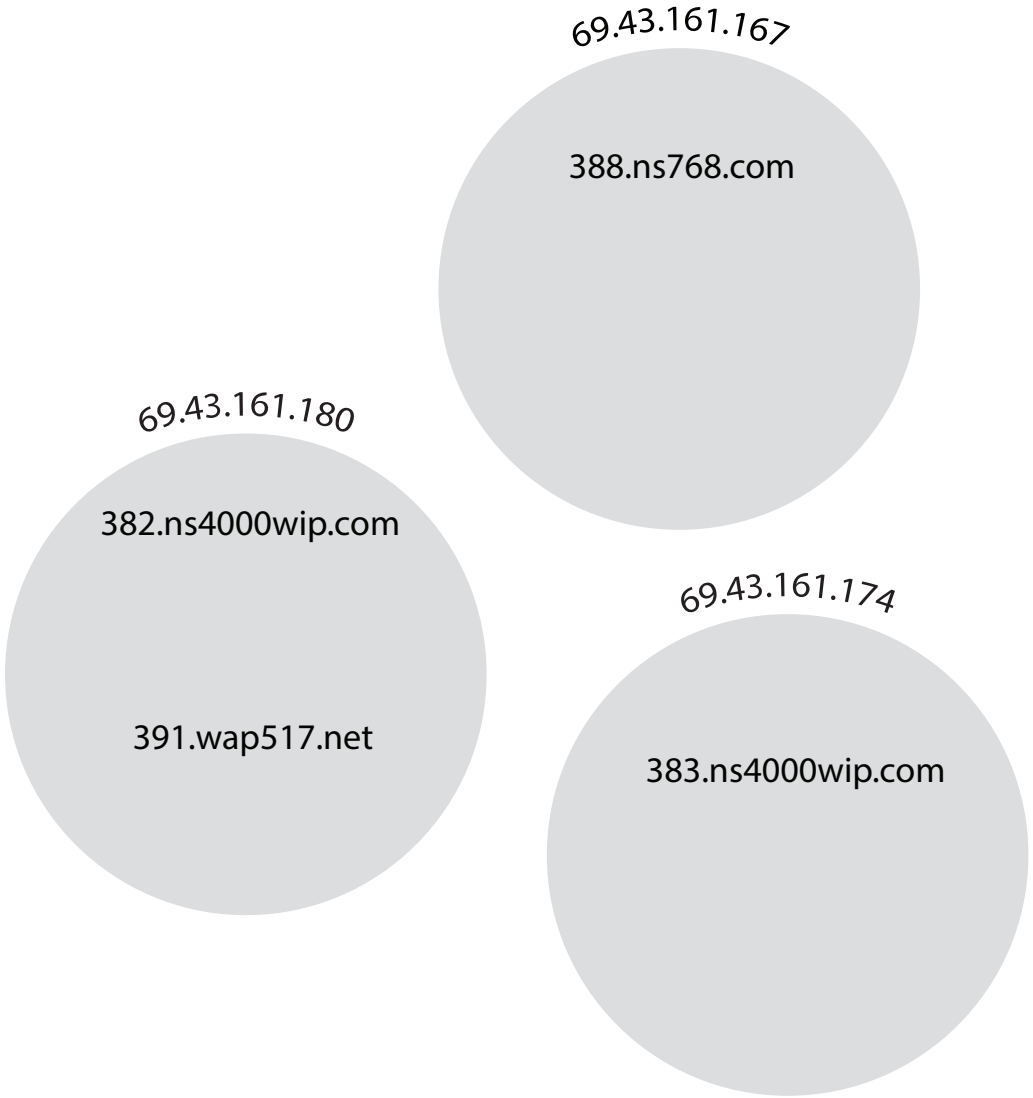
Stats to the rescue!

$$A = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_m \end{array} \begin{array}{c} \begin{array}{ccc} \mathtt{dom}_1 & \cdots & \mathtt{dom}_m \end{array} \\ \begin{pmatrix} d_{1,1} & \cdots & d_{1,m} \\ d_{2,1} & \cdots & d_{2,m} \\ \vdots & \ddots & \vdots \\ d_{m,1} & \cdots & d_{m,m} \end{pmatrix} \end{array} \quad A \sim B = \begin{array}{c} \\ \mathtt{dom}_1 \\ \mathtt{dom}_2 \\ \vdots \\ \mathtt{dom}_m \end{array} \begin{array}{c} \begin{array}{cccc} \mathtt{dom}_1 & \mathtt{dom}_2 & \cdots & \mathtt{dom}_n \end{array} \\ \begin{pmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,n} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m,1} & d_{m,2} & \cdots & d_{m,n} \end{pmatrix} \end{array}$$

Welch test: do A and $A \sim B$ have different intra-cluster distance distributions?

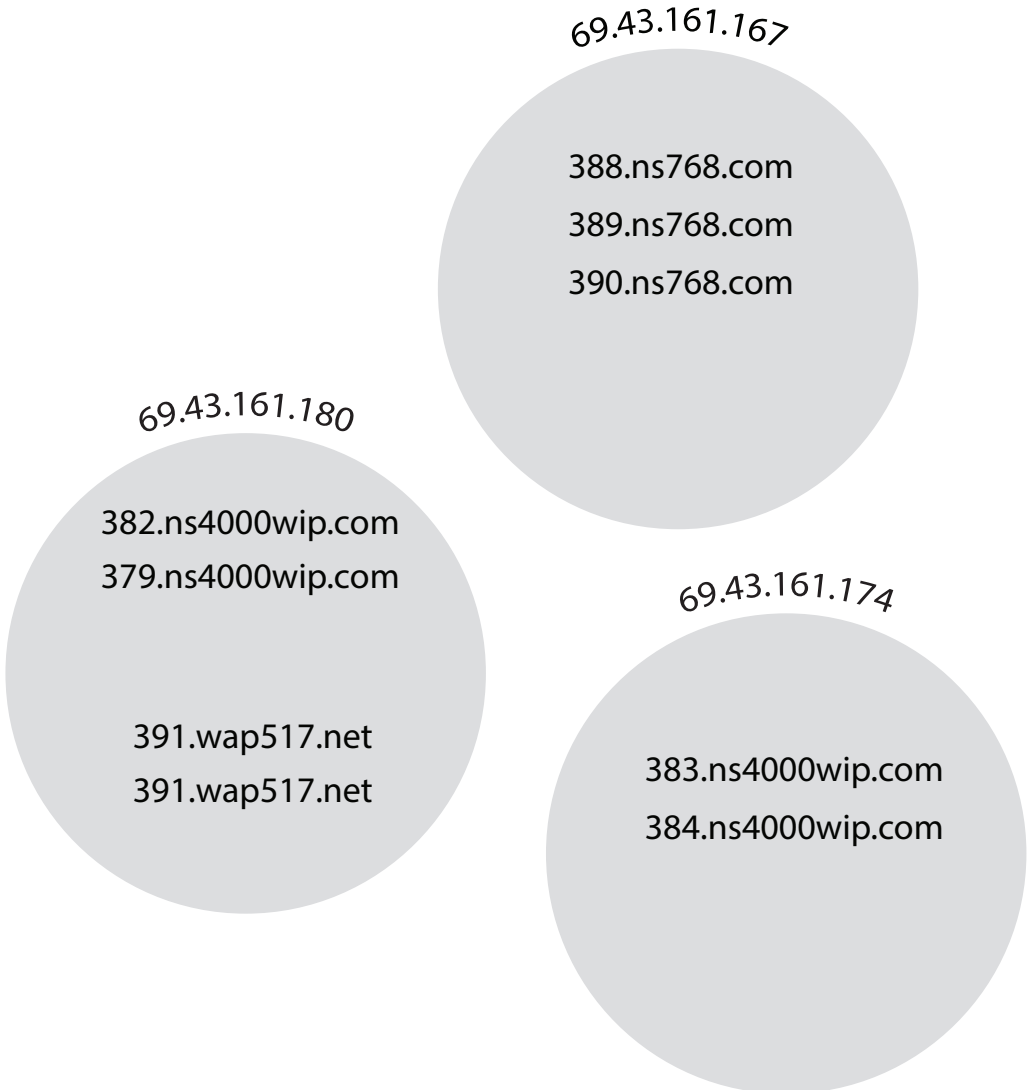
TIME DETECTIVE > EXAMPLE

Day 1



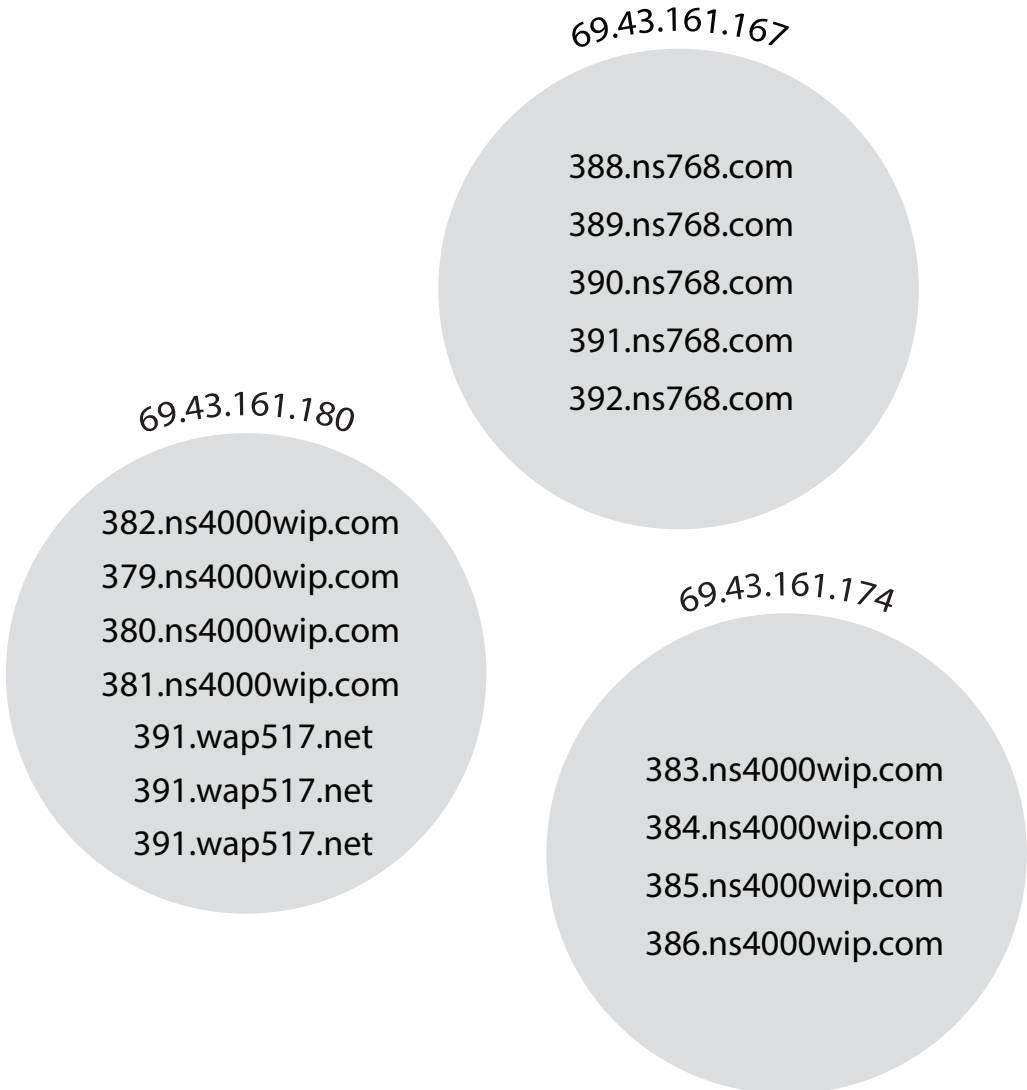
TIME DETECTIVE > EXAMPLE

Day 2



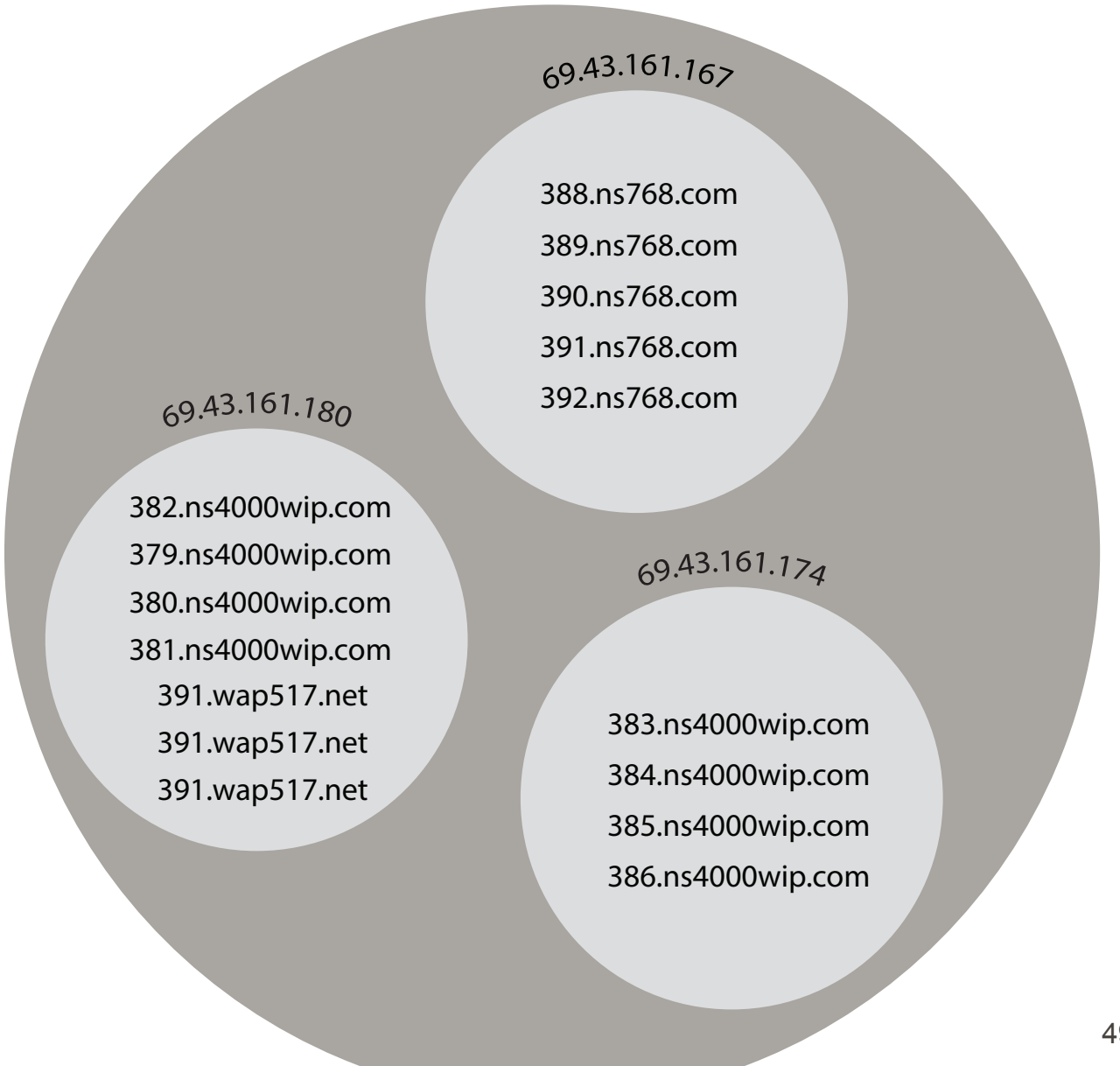
TIME DETECTIVE > EXAMPLE

Day 7



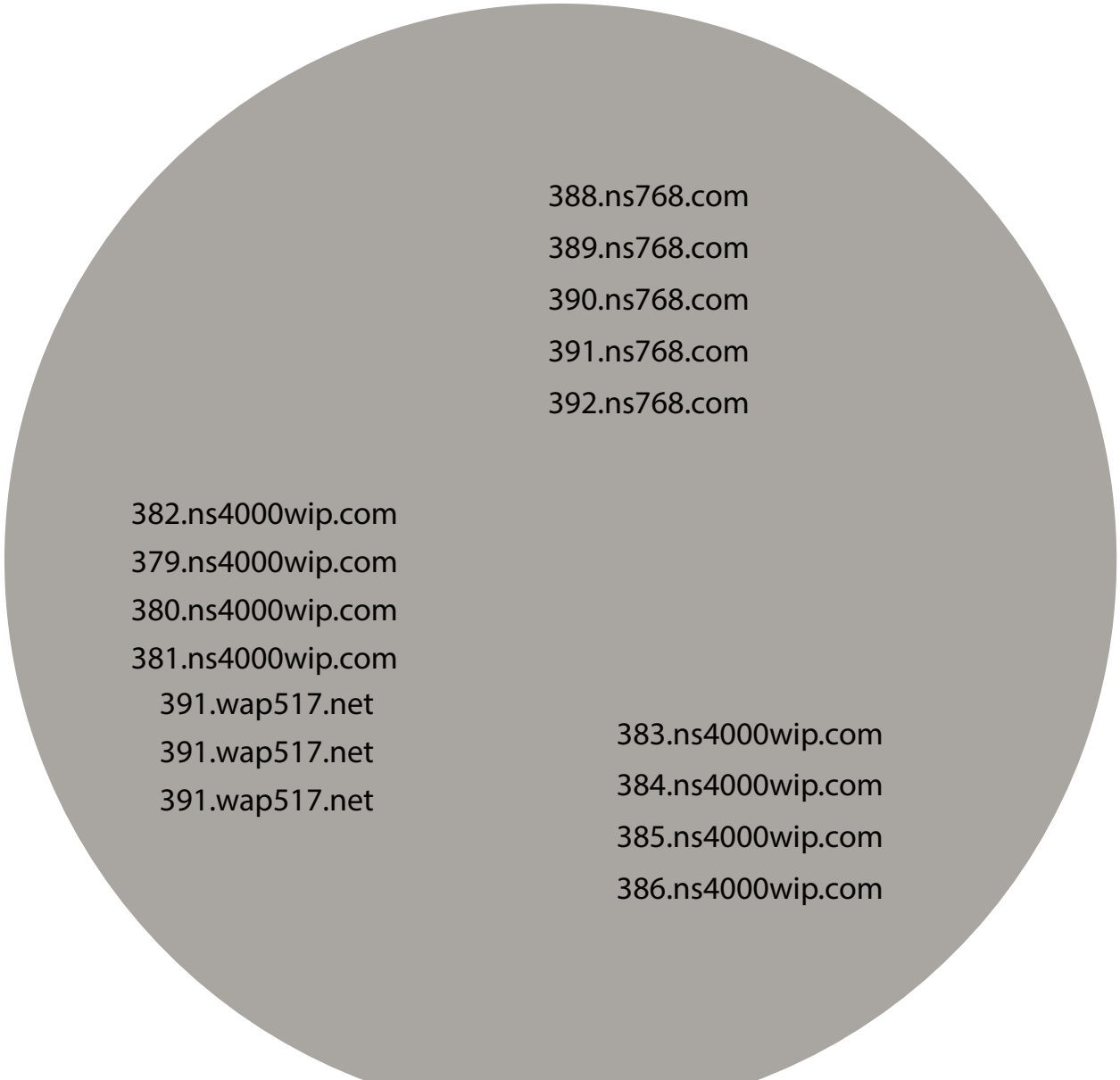
TIME DETECTIVE > EXAMPLE

AS 22489



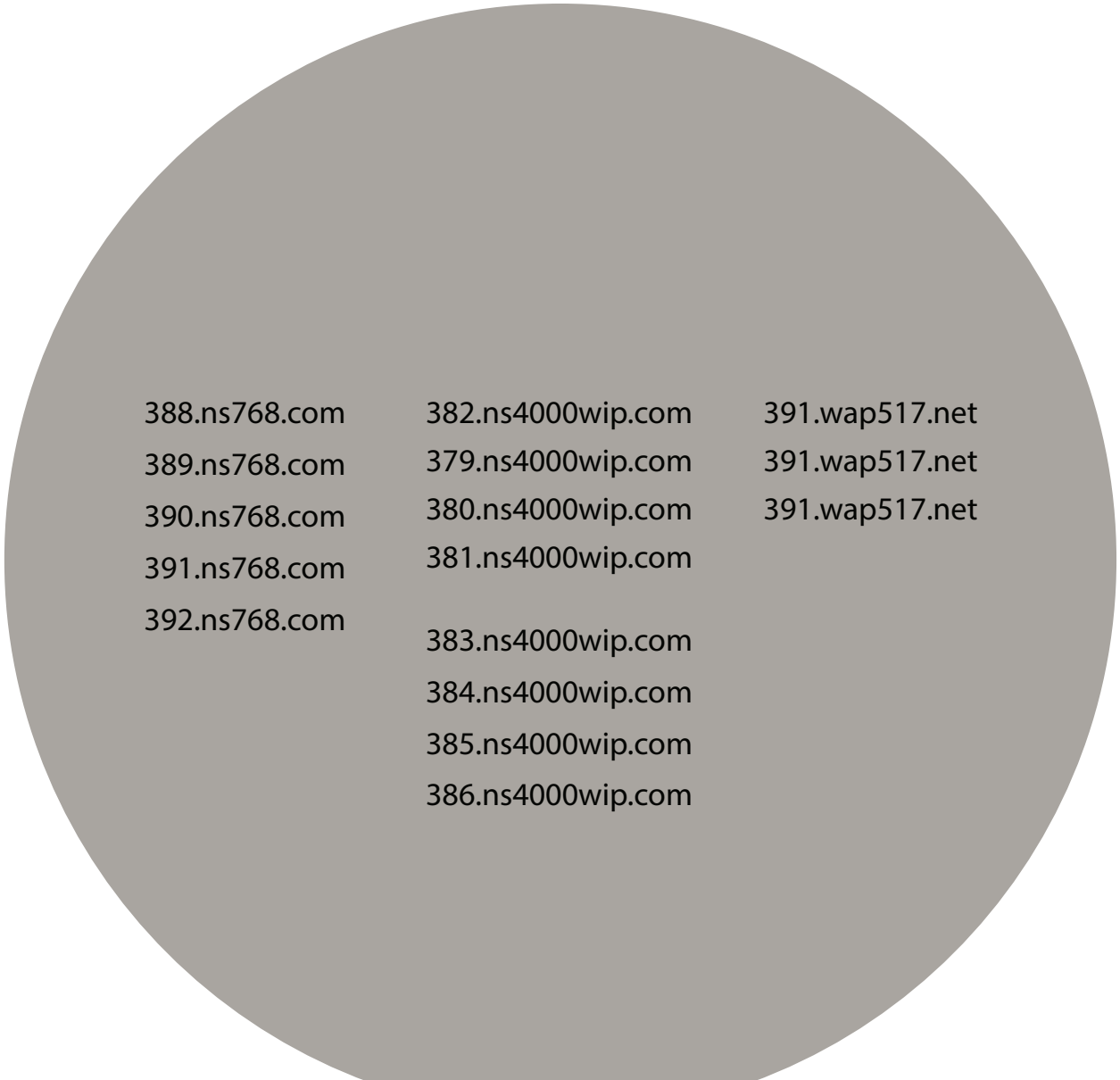
TIME DETECTIVE > EXAMPLE

Merge



TIME DETECTIVE > EXAMPLE

Cluster



TIME DETECTIVE > EXAMPLE

New clusters produced

Cluster 1	Cluster 2	Cluster 3
388.ns768.com	382.ns4000wip.com	391.wap517.net
389.ns768.com	379.ns4000wip.com	391.wap517.net
390.ns768.com	380.ns4000wip.com	391.wap517.net
391.ns768.com	381.ns4000wip.com	
392.ns768.com	383.ns4000wip.com	
	384.ns4000wip.com	
	385.ns4000wip.com	
	386.ns4000wip.com	

RESULTS
on passive DNS data from
https://farsightsecurity.com/Services/SIE/

TIME DETECTIVE > LABELING (1 WEEK)

187 domains classified as malicious and **labeled**.

Labeled 07e21	
Botnet:	Conficker
Domains:	`hhdboqazof.biz`
	`poxqmrfj.biz`
	`hcsddszzzc.ws`
	`tnoucgrje.biz`
	`gwizoxej.biz`
	`jnmuoiki.biz`

TIME DETECTIVE > CLUSTERING

3,576 domains were considered **suspicious** by Cerberus and **stored**, together with their IP address.

Then we ran the clustering routine to **discover new botnets**.

TIME DETECTIVE > CLUSTERING

Botnet	AS	IPs	Size
Sality	15456	62.116.181.25	26
Palevo	53665	199.59.243.118	40
Jadtre*	22489	69.43.161.180 69.43.161.174	173
Jadtre**	22489	69.43.161.180	37
Jadtre***	22489	69.43.161.167	47
Hiloti	22489	69.43.161.167	24
Palevo	47846	82.98.86.171 82.98.86.176 82.98.86.175	142
Jusabli	30069	69.58.188.49	73
Generic Trojan	12306	82.98.86.169 82.98.86.162 82.98.86.178 82.98.86.163	57

Cluster	IP	Sample Domains
Jadtre*	69.43.161.180	379.ns4000wip.com
	69.43.161.174	418.ns4000wip.com
		285.ns4000wip.com
Jadtre**	69.43.161.180	391.wap517.net
		251.wap517.net
		340.wap517.net
Jadtre***	69.43.161.167	388.ns768.com
		353.ns768.com
		296.ns768.com

TIME DETECTIVE > MERGING

Cluster a (Old)	
IPs:	176.74.76.175
	208.87.35.107
Domains	cvq.com
	epu.org
	bwn.org
	lxx.net

Cluster b (New)	
IPs:	82.98.86.171
	82.98.86.176
	82.98.86.175
	82.98.86.167
	82.98.86.168
	82.98.86.165
Domains	knw.info
	rrg.info
	nhy.org
	ydt.info

TIME DETECTIVE > MERGING

Cluster a (Old)	
IPs:	176.74.76.175
	208.87.35.107
Domains	cvq.com
	epu.org
	bwn.org
	lxx.net

Cluster b (New)	
IPs:	82.98.86.171
	82.98.86.176
	82.98.86.175
	82.98.86.167
	82.98.86.168
	82.98.86.165
Domains	knw.info
	rrg.info
	nhy.org
	ydt.info

Both belonging to the **Palevo botnet**.

TIME DETECTIVE > RECAP

- **187** malicious domains **detected and labeled**

TIME DETECTIVE > RECAP

- **187** malicious domains **detected and labeled**
- **3,576 suspicious** domains collected

TIME DETECTIVE > RECAP

- **187** malicious domains **detected and labeled**
- **3,576 suspicious** domains collected
- **47 clusters** of DGA-generated domains **discovered**

TIME DETECTIVE > RECAP

- **187** malicious domains **detected and labeled**
- **3,576 suspicious** domains collected
- **47 clusters** of DGA-generated domains **discovered**
- **319** new domains **detected in the next 24 hours**

CONCLUSIONS & FUTURE WORK

CONCLUSIONS

- discovers and characterizes unknown DGA-based activity,
- unsupervised,
- easy to deploy,
- privacy preserving.

FUTURE WORK

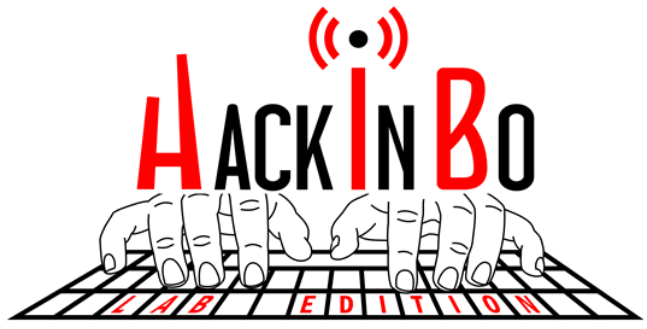
FUTURE WORK

`this-is-an-easy-way-to-evade-the-linguistic-filter.com`

FUTURE WORK

Release **Cerberus** as a web service. Hopefully!

THANK YOU



stefano.zanero@polimi.it
@raistolo