# Anomaly detection in DNS traffic

## Clustering-based approach

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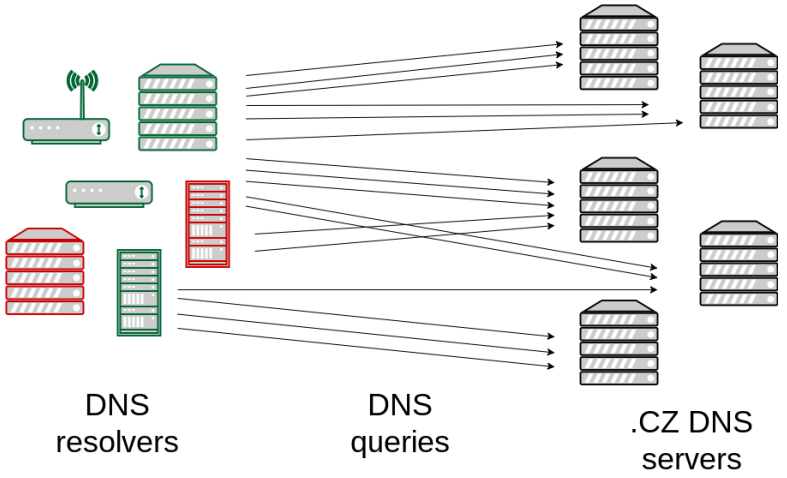
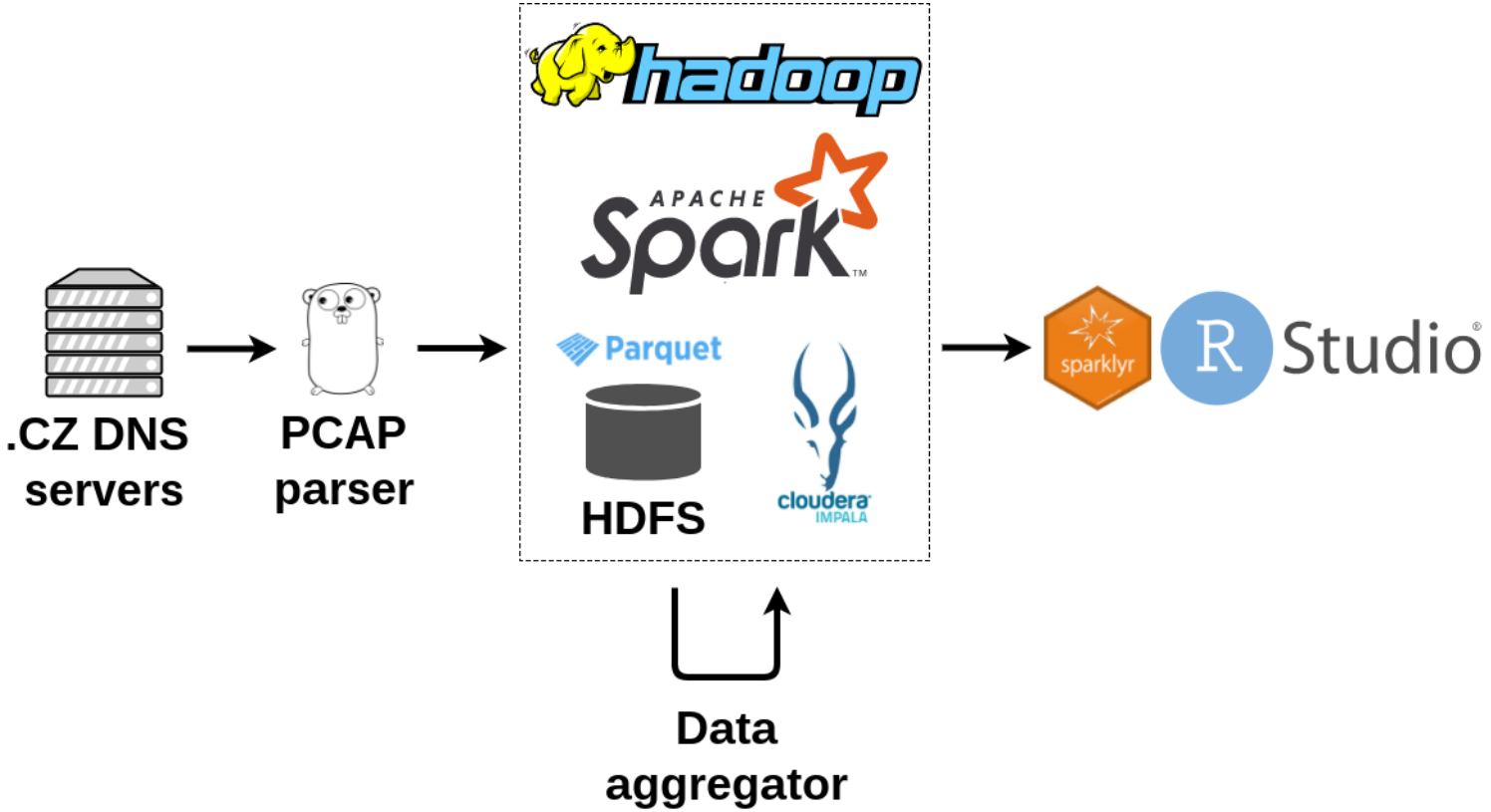
CZ DOMAIN REGISTRY

# Anomaly detection

- What is an anomaly?
  - Hard to define
    - Scanners?
    - Monitors?
    - Misconfigured resolvers?
  - **Unusual behaviour**



# Data flow

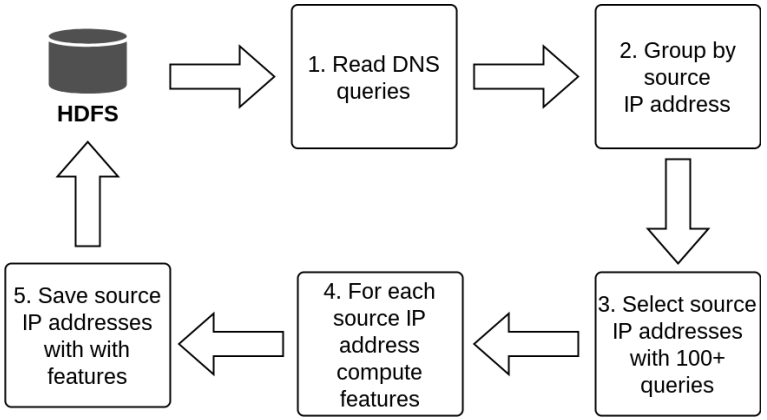

hadoop
APACHE
Spark
Parquet
HDFS
cloudera
IMPALA
sparklyr
R Studio
.CZ DNS servers
PCAP parser
Data aggregator

# Data aggregation

1) Group DNS queries by source IP address

2) For each source IP address compute statistics (features)

- Take only IP addresses which send min. 100 queries daily
- Time window = 1 day



# Features #1

- **Entropy (normalised Shannon Index)**
  - Source port
  - Transaction ID
- **Coefficient of variation ($C_V=\sigma/\mu$)**
  - Idletime
  - Packet length

# Features #2

- Amplification factor
- Mean domain name length
- Domain name diversity

# Features #3

- **Observed DNS QTYPEs**
  - A + AAAA
  - NS
  - DNSSEC RRs
  - Popular RRs
  - Weird RRs

# Features #4

- **Observed DNS RCODEs**
  - NOERROR
  - NXDOMAIN
- **Observed DNS FLAGs**
  - RD
  - EDNS0 DO

# Features #5

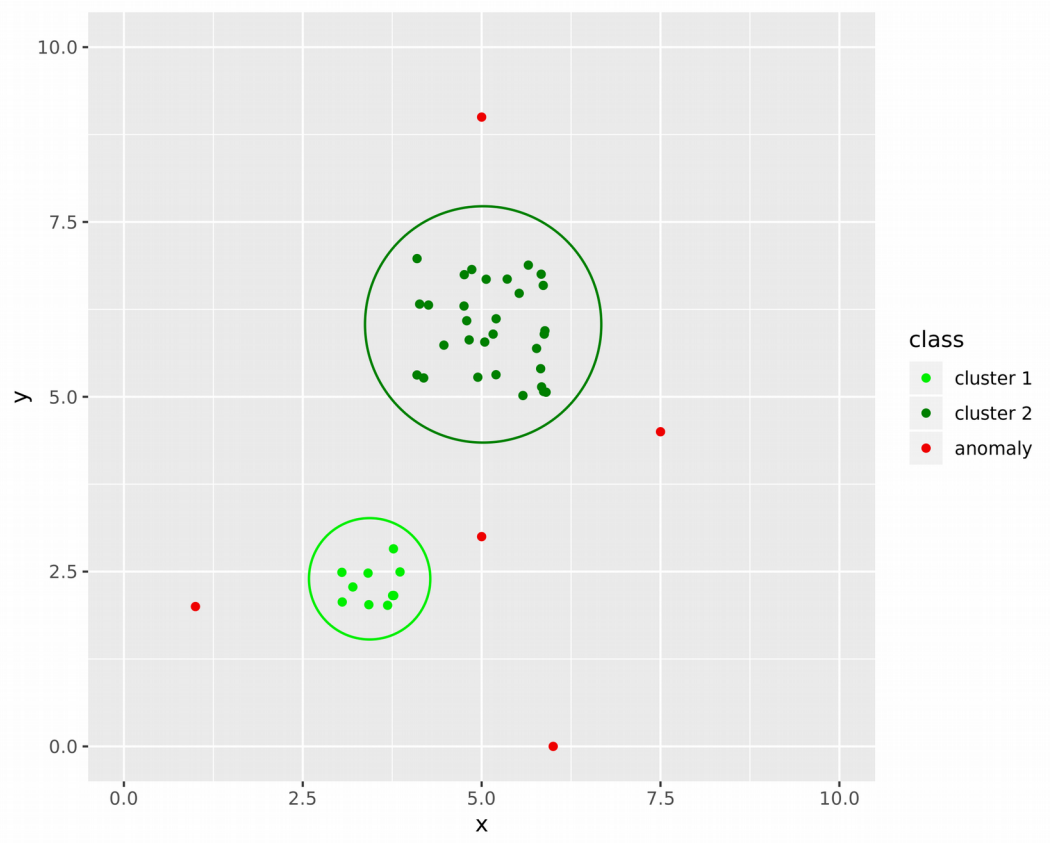
- **Observed DNS QCLASSes**
  - IN
- **Observed DNS OPCODEs**
  - QUERY

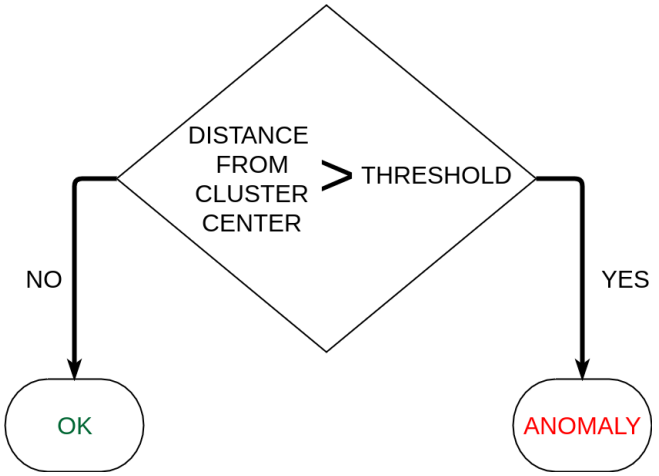
# Features – an example

- 217.31.204.130 on 23 October 2018 (CZ.NIC open DNS resolver)

| | |
|---|---|
| srcp_sh_ix_n | 0.9876179 |
| id_sh_ix_n | 0.9879639 |
| idletime_cv | 0.709647 |
| dn_len_mean | 11.57786 |
| dn_perc | 0.292901 |
| rcode_noerror_perc | 0.9828929 |
| rcode_nxdomain_perc | 0.01710712 |
| qtype_common_perc | 0.975649 |
| qtype_weird_perc | 0.001121778 |
| qtype_dnssec_perc | 0.1577407 |
| qtype_ns_perc | 0.01025492 |
| qtype_addr_perc | 0.9247106 |
| qclass_in_perc | 1 |
| edns_do_perc | 1 |
| flag_rd_perc | 0 |
| ampl_factor | 4.743633 |
| len_cv | 0.1132715 |
| opcode_query_perc | 1 |

# Anomaly detection concept



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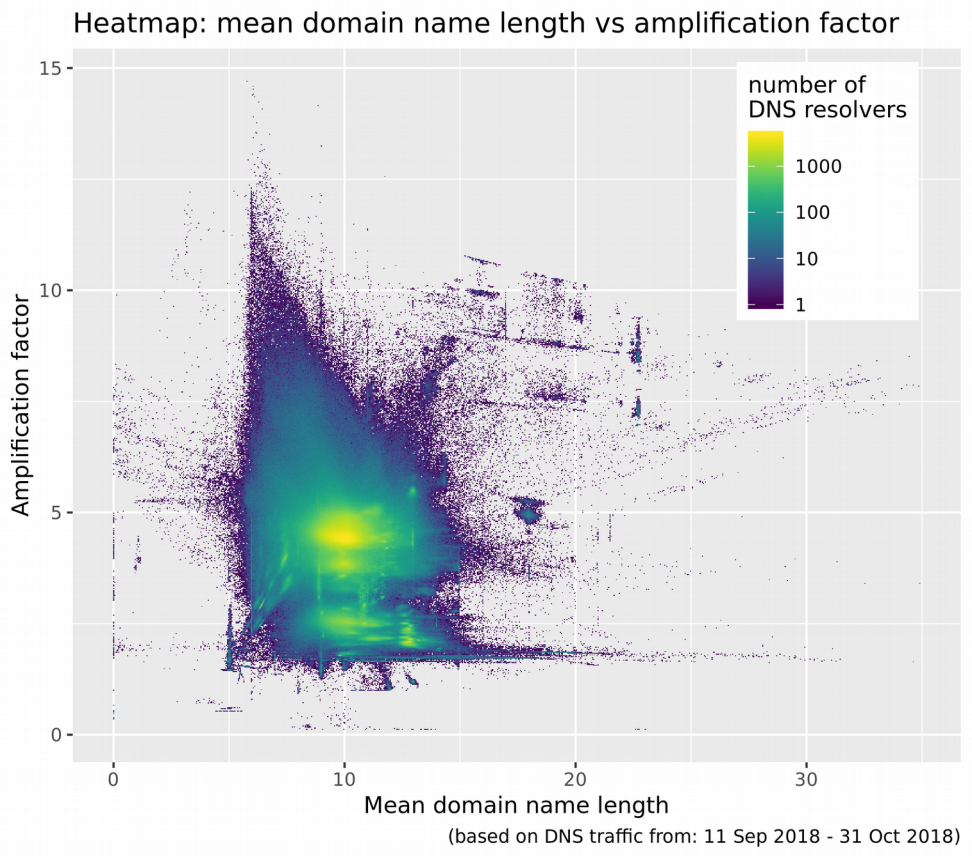


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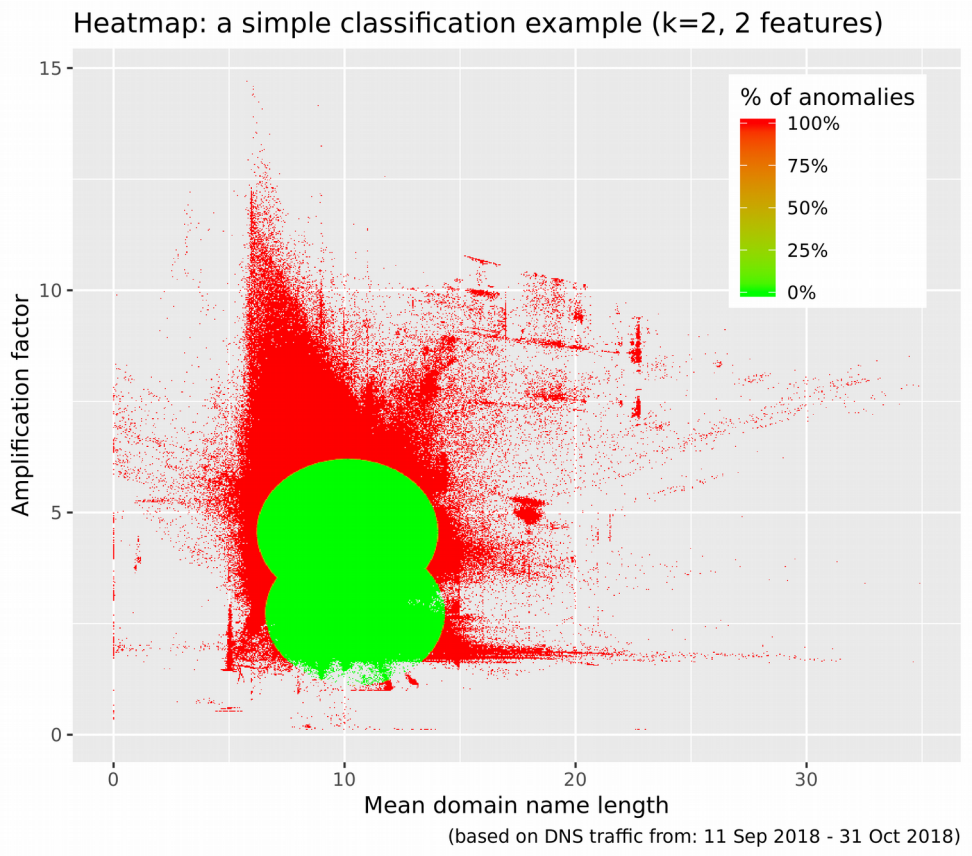
# Anomaly detection concept

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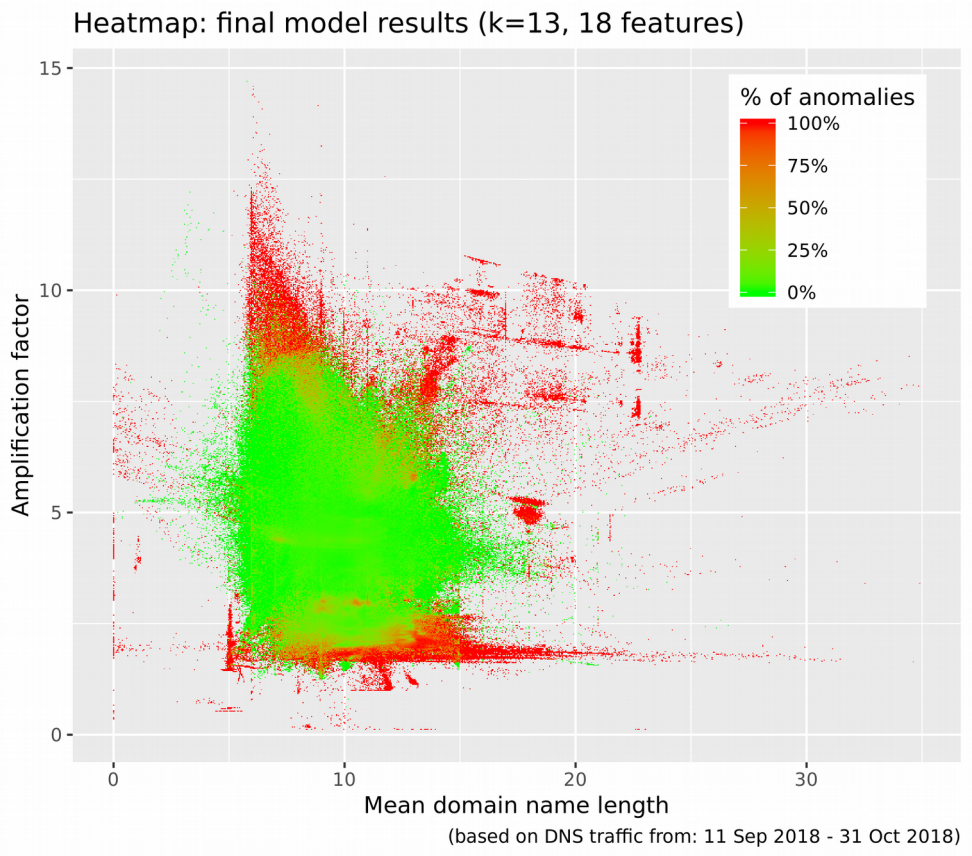


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# Model

- Spark MLlib
- K-means clustering
  - UDF to compute distance from cluster center
- MinMaxScaler
  - Entire dataset used for scaling (some features in training set were meaningful but had “near zero” variance)

# Model

- Training set
  - Real DNS resolvers (each RIPE Atlas probe was employed to query its local DNS resolver for whoami.akamai.net)
    - Gathered 3 430 unique IP addresses
    - 51 days = 137 701 observations
    - Filtered out weird observations

# Model

- Test/Validation set
  - Difficult to measure anomaly detection performance
  - Needed for grid search to select best model parameters (best F-score)

# Model

- Test/Validation set #1
  - Known anomalies
    - DNSMON
    - Domain name scanners
    - Misconfigured DNS resolvers

# Model

- Test/Validation set #2
  - Real DNS resolvers
    - DNS resolvers of RIPE Atlas probes
    - Google Public DNS
    - Cloudflare
    - Quad9
    - OpenDNS (Cisco)
    - Dyn
    - Level3
    - Yandex
    - CZ.NIC

# Model

- Model parameters
  - k = 13
  - Threshold (maximal distance from cluster center) = 3 * Q3 (third quartile)

# Model performance

F-score: **0.9894033**

- Known anomalies

| dataset | total | anomaly | %anomaly |
|---|---|---|---|
| dnsmon | 38 | 38 | 100.0 % |
| scanners | 25 | 25 | 100.0 % |
| scanners2 | 100 | 100 | 100.0 % |
| misconfigured | 99 | 99 | 100.0 % |
| dnsviz | 1 | 0 | 0.0 % |

# Model performance

F-score: **0.9894033**

- Real DNS resolvers

| dataset | total | anomaly | %anomaly |
|---|---|---|---|
| atlas_resolvers | 3193 | 48 | 1.5 % |
| google | 1250 | 0 | 0.0 % |
| quad9 | 224 | 0 | 0.0 % |
| opendns | 107 | 2 | 1.9 % |
| dyn | 107 | 3 | 2.8 % |
| level3 | 160 | 4 | 2.5 % |
| cloudflare | 180 | 2 | 1.1 % |
| yandex | 82 | 2 | 2.4 % |
| cznic | 2 | 0 | 0.0 % |

# Results

- DNS traffic from 11 Sept 2018 - 31 Oct 2018
  - 737 729 out of 9 918 267 observations **(7.4%)** were classified as **anomaly**
  - 8 649 294 465 out of 40 073 507 471 queries **(17.7%)** were originated from **anomalous source**

# Findings in ..one of the big ISPs

- 93.6 % of queries originated from **anomalous sources**

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- Feedback
  - They based on software vendor / OS recommendations

# Findings in AS15169 (Google LLC)

- 27.4 % of observations classified as **anomaly**
- 12 345 unique IP addresses
  - Only 1 387 IP addreses belonged to Google Public DNS
    - No observations classified as anomaly

# Findings in AS25192 (CZ.NIC, z.s.p.o.)

- 5th biggest in terms of query number
- 2 496 observations (**128 unique IP addresses**)
  - 525 (21 %) classified as **anomaly** (22 unique IP addresses)
- 1 731 755 782 queries
  - 87 432 646 (5 %) from **anomalous sources**

# Findings in AS25192 (CZ.NIC, z.s.p.o.)

- 32 out of 128 IP addresses were observed every day
  - 19 were **never anomalous** (0%)
  - 5 were **almost never anomalous** (<5%)
  - 7 were **always anomalous** (100%)
  - 1 was **almost always anomalous** (>90%)

# Findings in AS25192 (CZ.NIC, z.s.p.o.)

- **Always classified as anomaly (100%)**
  - Incigna monitoring system (IPv4+IPv6)
  - Domain name crawler
  - RIPE Atlas anchor (IPv4 + IPv6)
  - A monitoring system without name
  - DNS resolver for Hadoop cluster (IPv6)
- **Almost always classified as anomaly (>90%)**
  - DNS resolver for Hadoop cluster (IPv4)

# Findings in AS25192 (CZ.NIC, z.s.p.o.)

- **Never classified as anomaly (0%)**
  - Real DNS resolvers
- **Ocasionally classified as anomaly (<5%)**
  - DNS resolver for mail server
    - A configuration issue was discovered
  - NAT gateways

# Future work

- Add more classes
  - Scanner, monitor, misconfigured, under attack, etc.
- Extend / modify feature set
- Try different algorithms
- Collect better ground truth
- Visualise results

# Thank You

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