# SAPPAN Innovations in DGA Detection

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 833418.

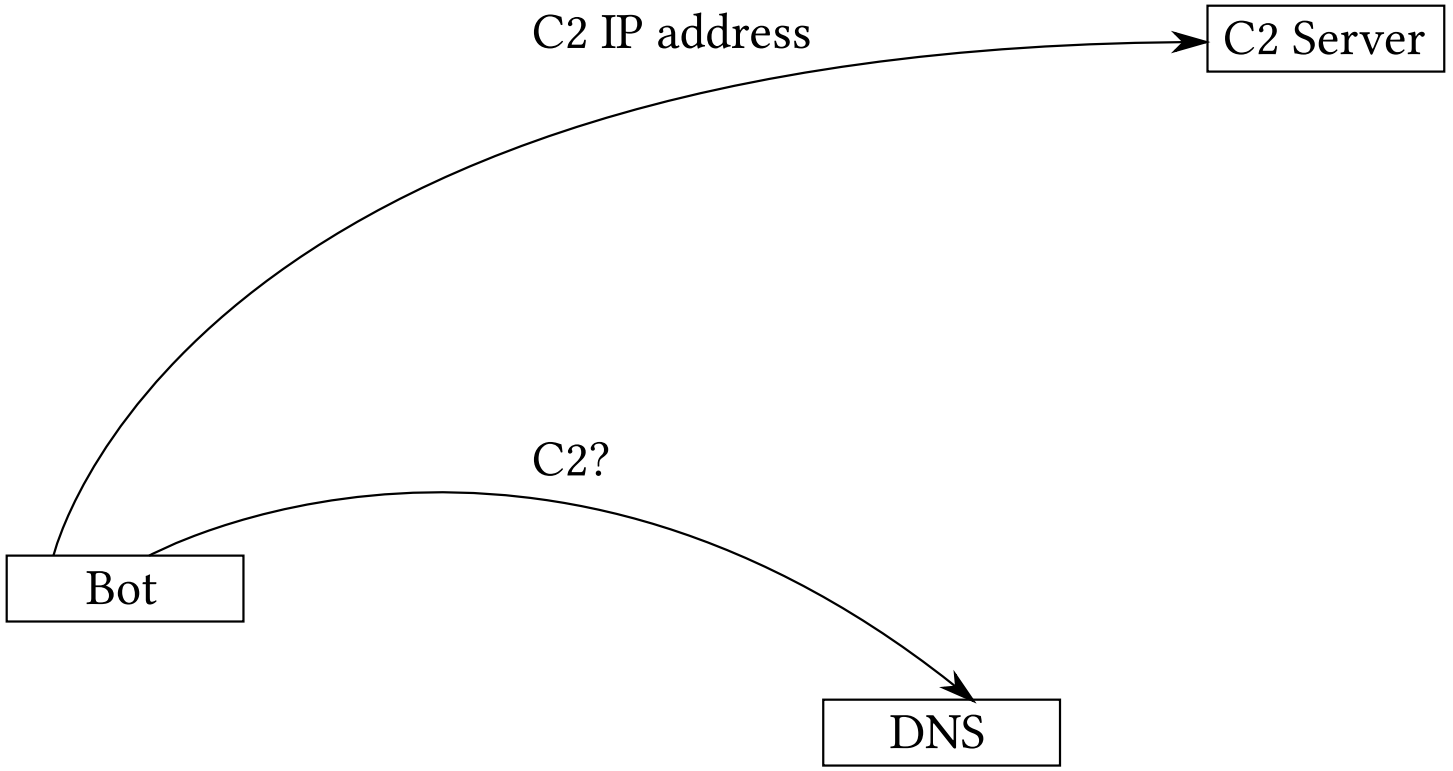
SAPPAN
*SHARING AND AUTOMATION FOR PRIVACY PRESERVING ATTACK NEUTRALIZATION*

Co-funded by the Horizon 2020 programme of the European Union

IT SEC Research Group IT-Security | RWTH AACHEN UNIVERSITY

# Domain Generation Algorithms (DGAs)

## Traditional bot communication



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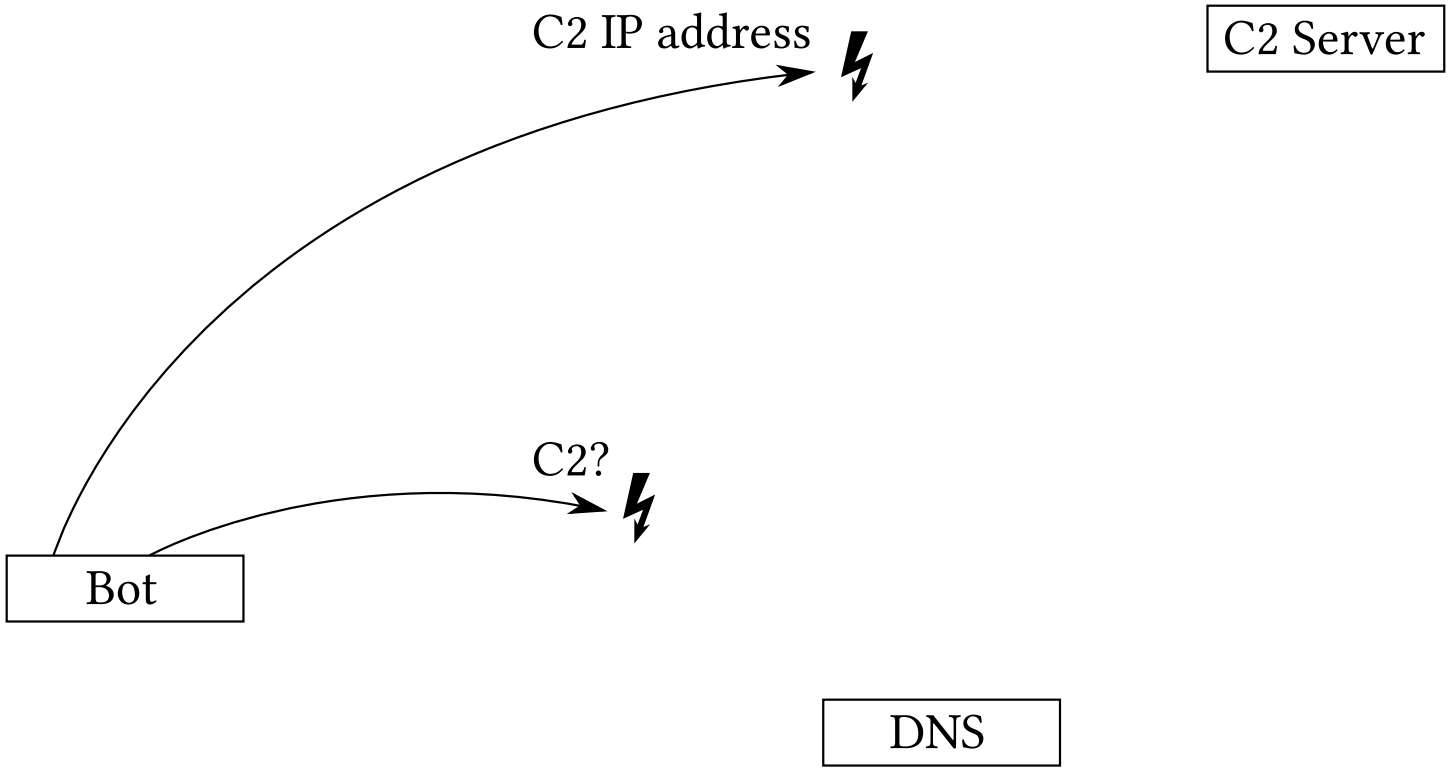
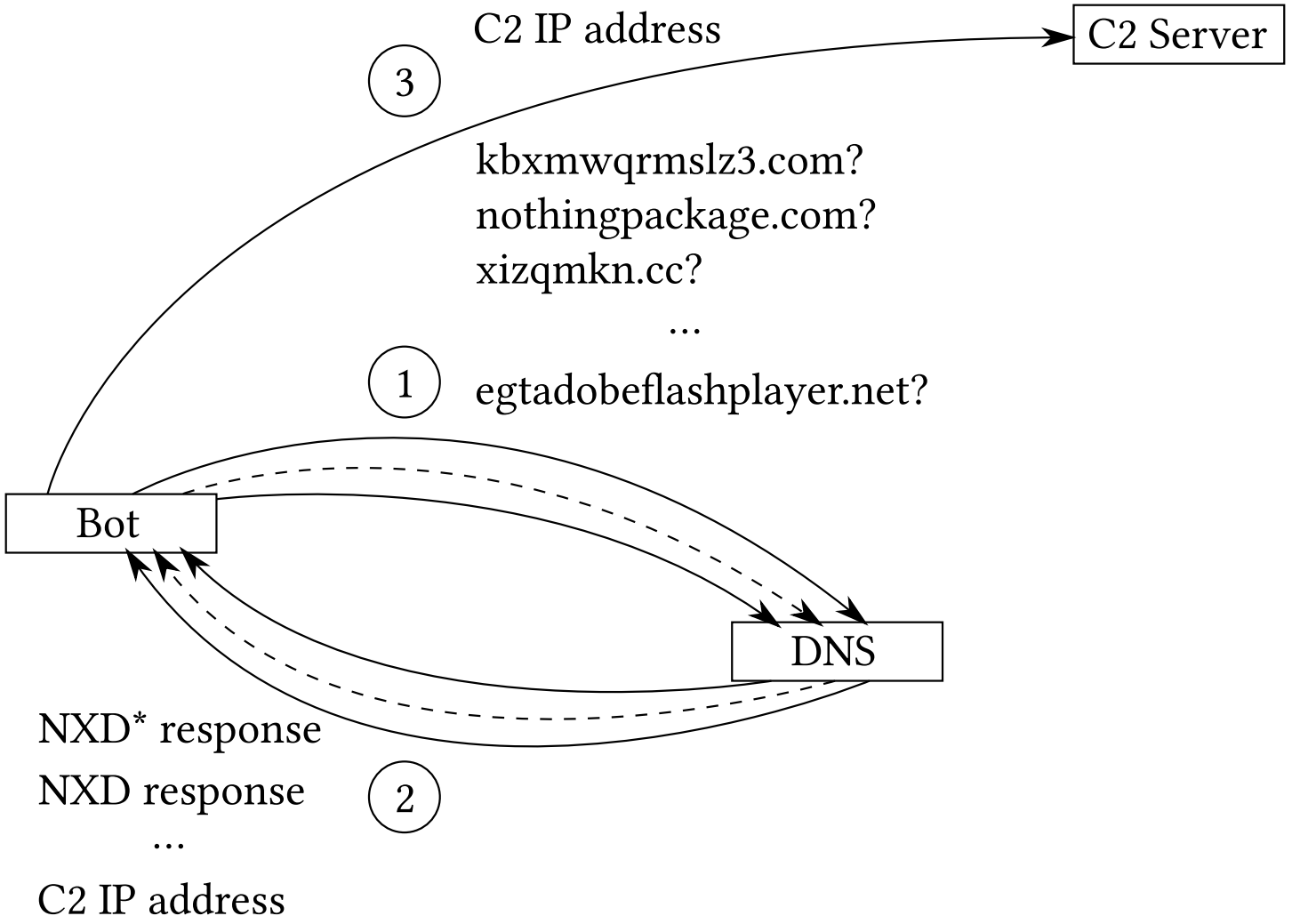


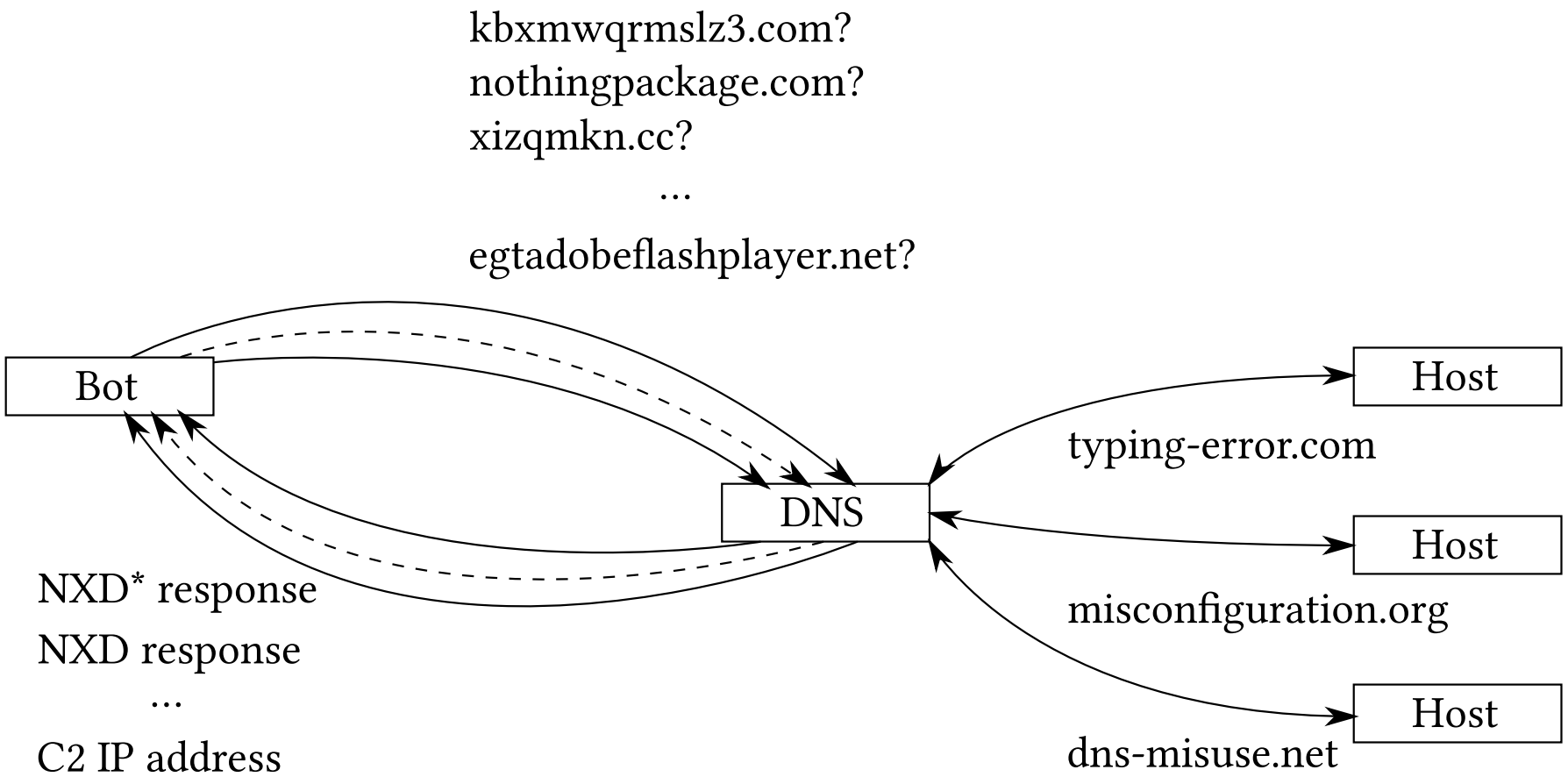

→ **Easy to block fixed domains or IP addresses**

# Domain Generation Algorithms (DGAs)




*non-existent domain (NXD)

# Domain Generation Algorithms (DGAs)

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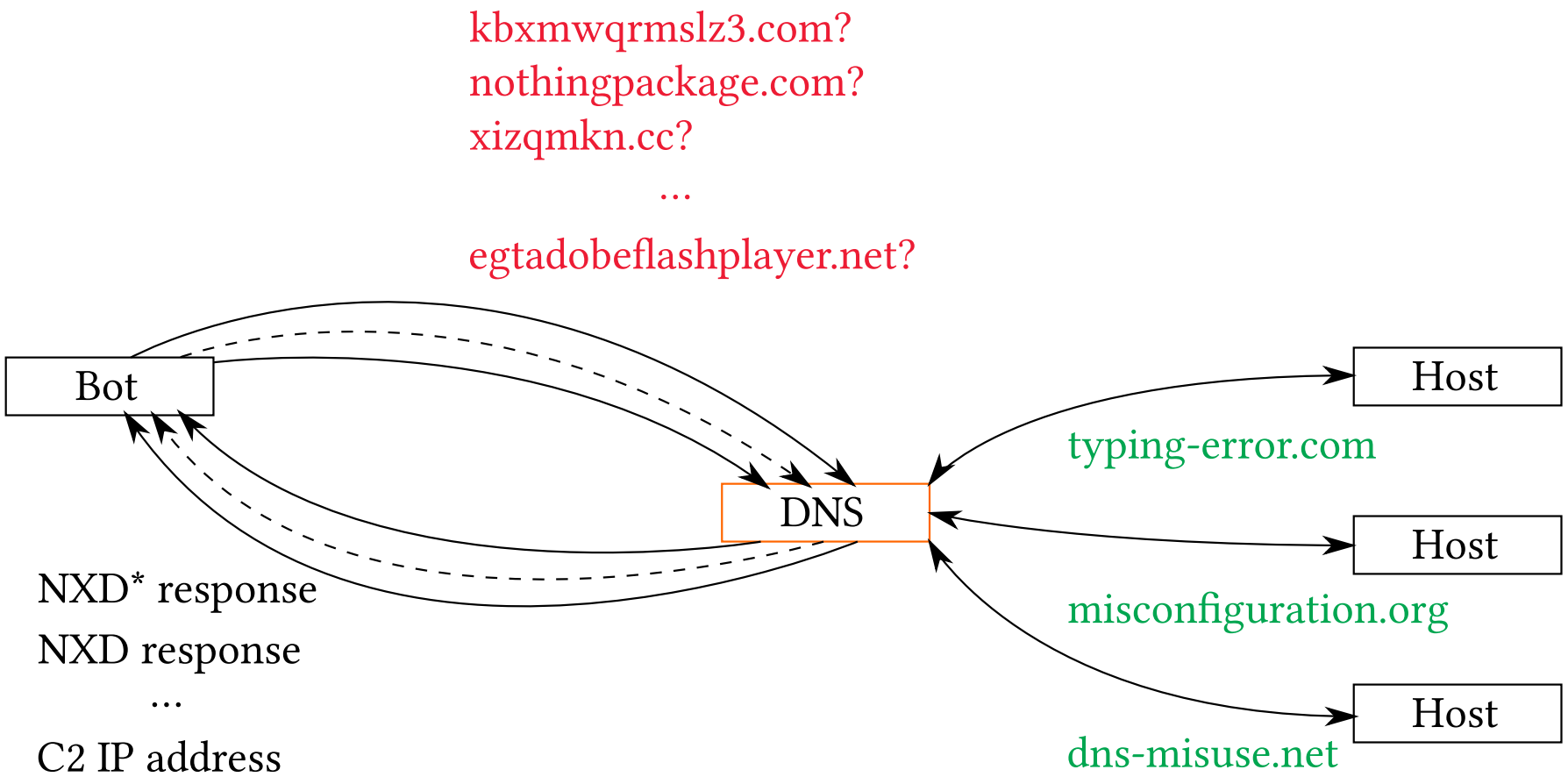
# Domain Generation Algorithms (DGAs)

## DGA binary classification

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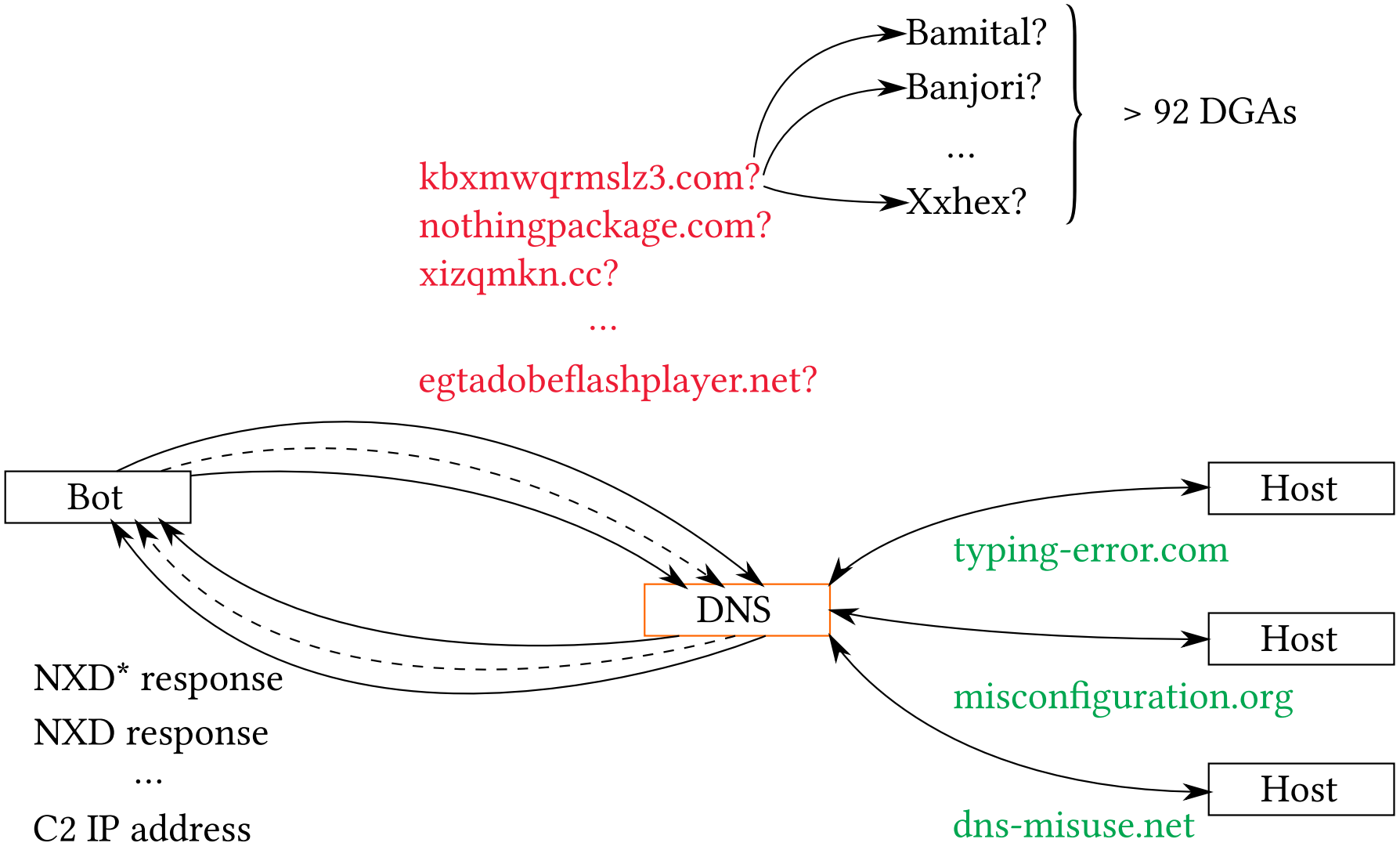


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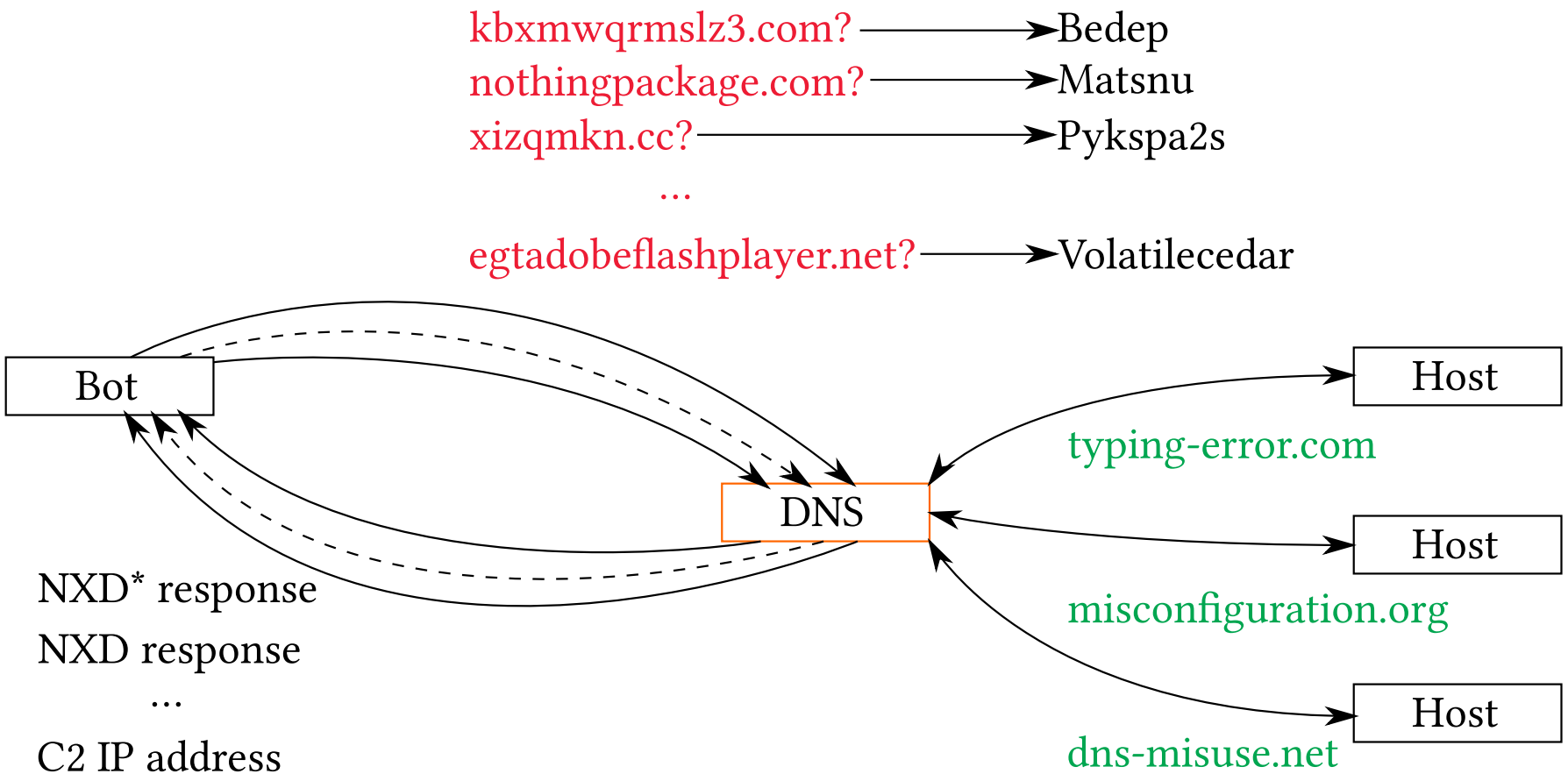
# Domain Generation Algorithms (DGAs)

## DGA multiclass classification

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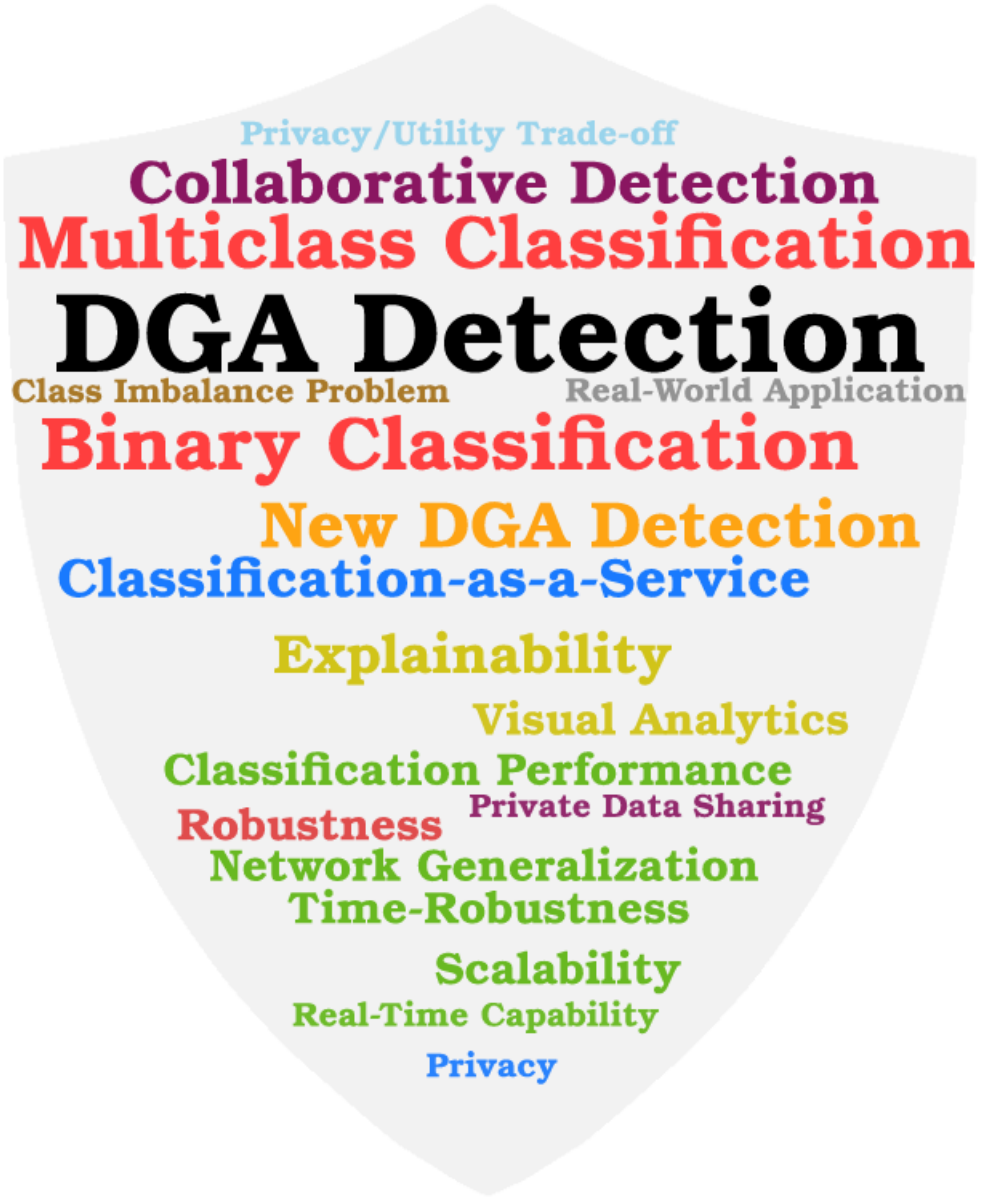
# Use-case DGA Detection in SAPPAN

Research driven approach

- 7 peer-reviewed accepted papers on DGA detection
- 1 paper currently under review

Real-world application of research results

- Classifiers are real-time capable & scalable
- Integration of research into existing Security Information and Event Management (SIEM) solutions



# DGA Binary Classification

Problem:

- How to separate benign from malicious domains?

B-ResNet: ResNet-based DGA binary classifier

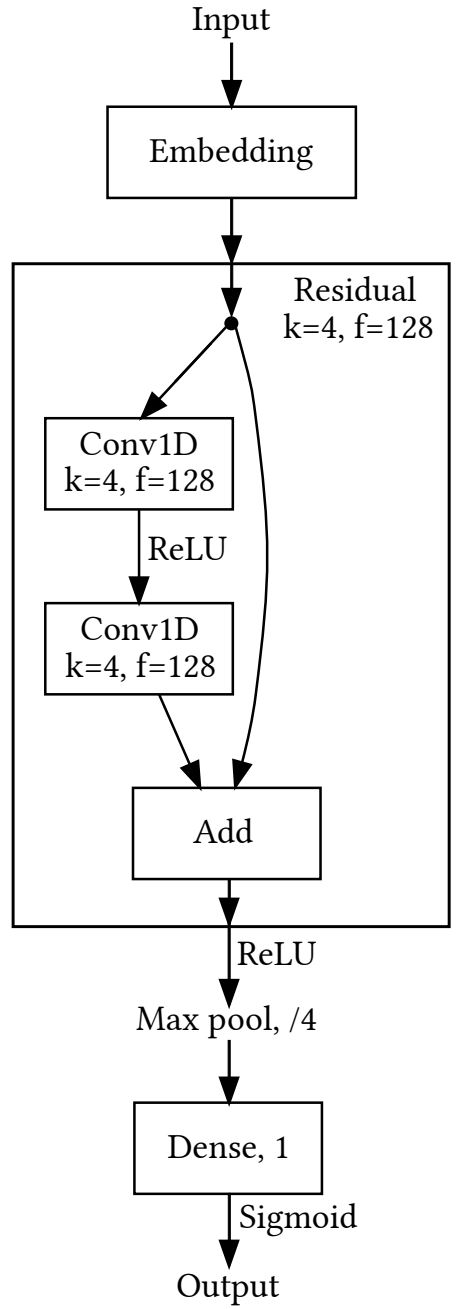
- Introduction of skip connections between convolutional layers

→ eases training and counteracts vanishing gradient problem

Comparative study with the state-of-the-art

- Reduction in false positive rate (FPR)
- B-ResNet generalizes well to different networks
  → Classification can be outsourced as a service
- B-ResNet is time-robust (even after 17 months)

→ Classifier is real-time capable



# DGA Multiclass Classification

Problem:

- How to attribute domains to either the benign class or to the DGA that generated the domain?

M-ResNet: ResNet-based DGA multiclass classifier

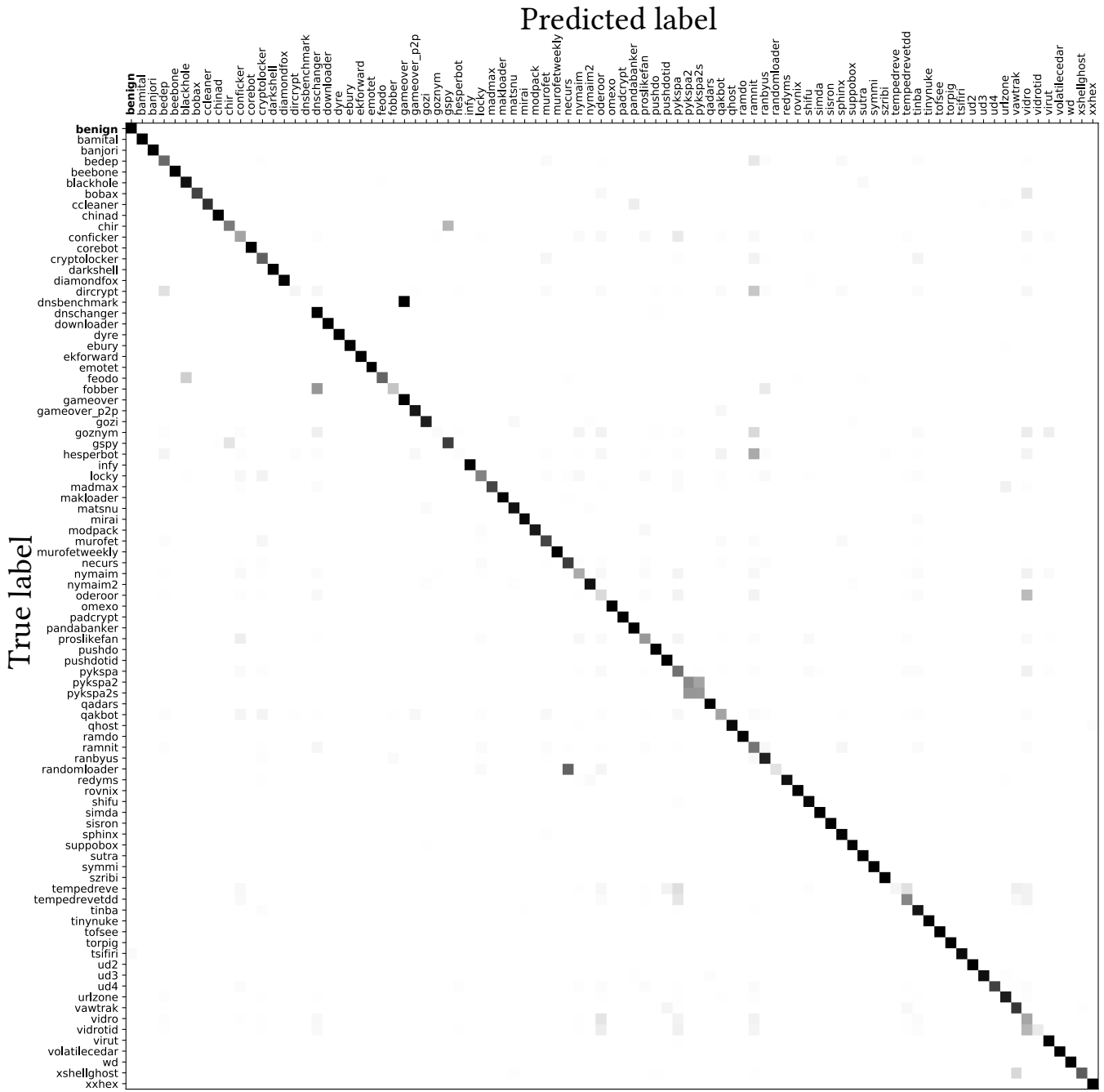
- Build up of 11 residual blocks

Comparative study with the state-of-the-art

- 30% less training time
- Improvement of over 5% in macro f1-score

→ Enables detection of several classes with high confidence

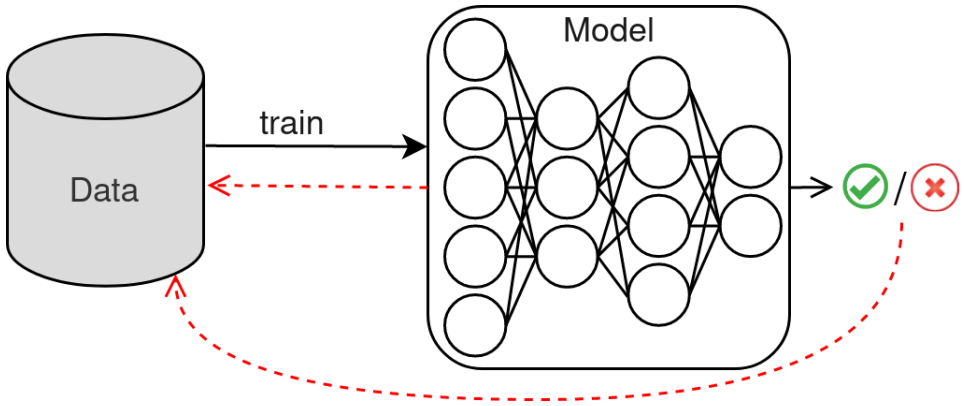
→ Classifier is real-time capable



# Class Imbalance Problem I

Problem:

- Performance of a classifier heavily depends on the used training data
- Sample distribution is heavily imbalanced
- Including underrepresented DGAs:
  - Effect on overall classification performance?
  - Ability to detect/attribute samples of underrepresented DGAs?



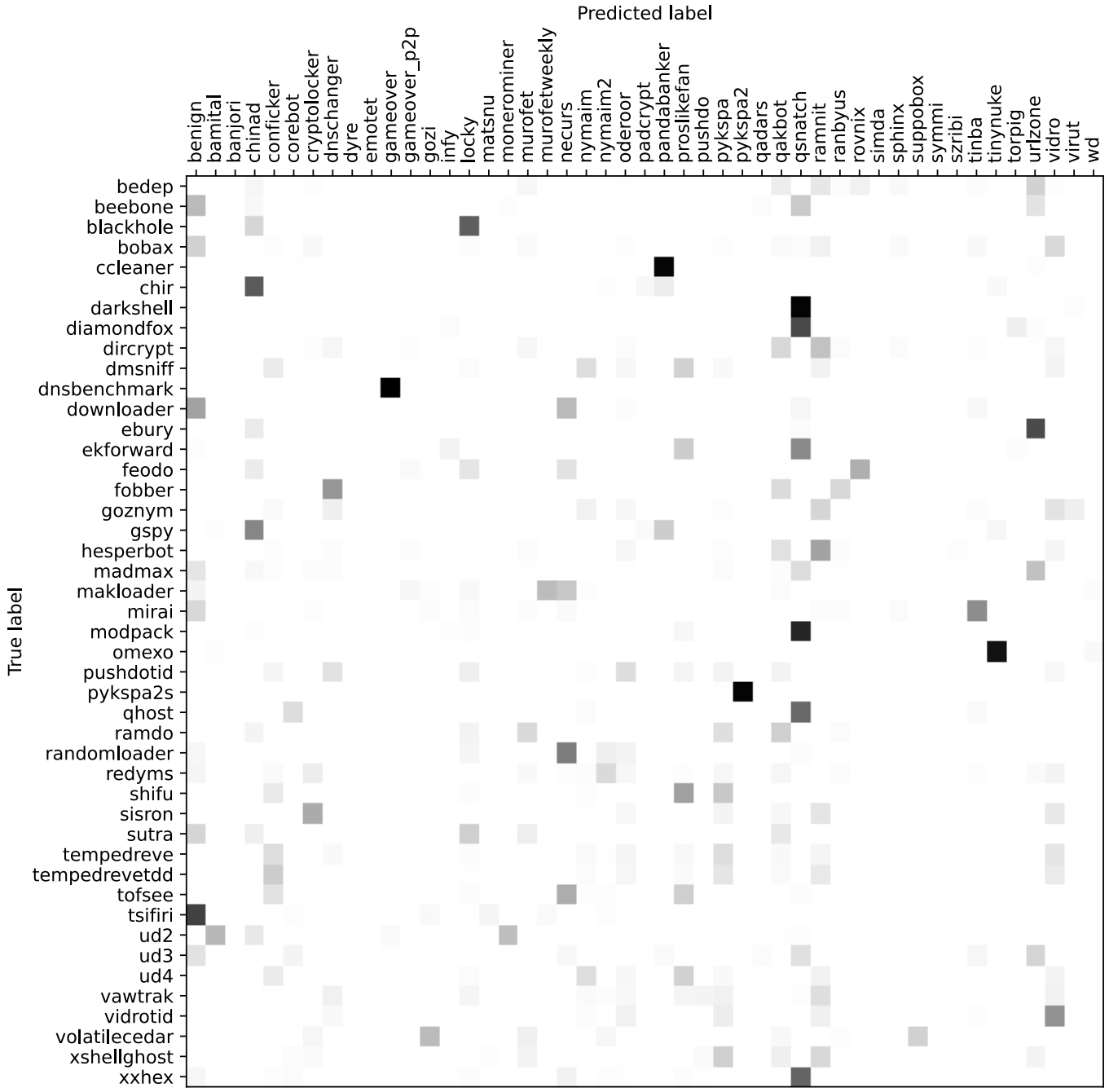

Comprehensive study

- Both classification tasks benefit from samples of weakly represented DGAs
  - Binary classification:
    - Improvement of over 10% in detection performance
  - Multiclass classification:
    - For 22/46 classes f1-score > 90%
    - For 11 classes f1-score > 99%
- No significant influence on the classification of well represented classes

# Class Imbalance Problem II - Out-Of-Distribution (OOD) Classification

Experiment:

- Train on samples of well represented group
- Classify samples of weakly represented group



# Class Imbalance Problem II - Out-Of-Distribution (OOD) Classification

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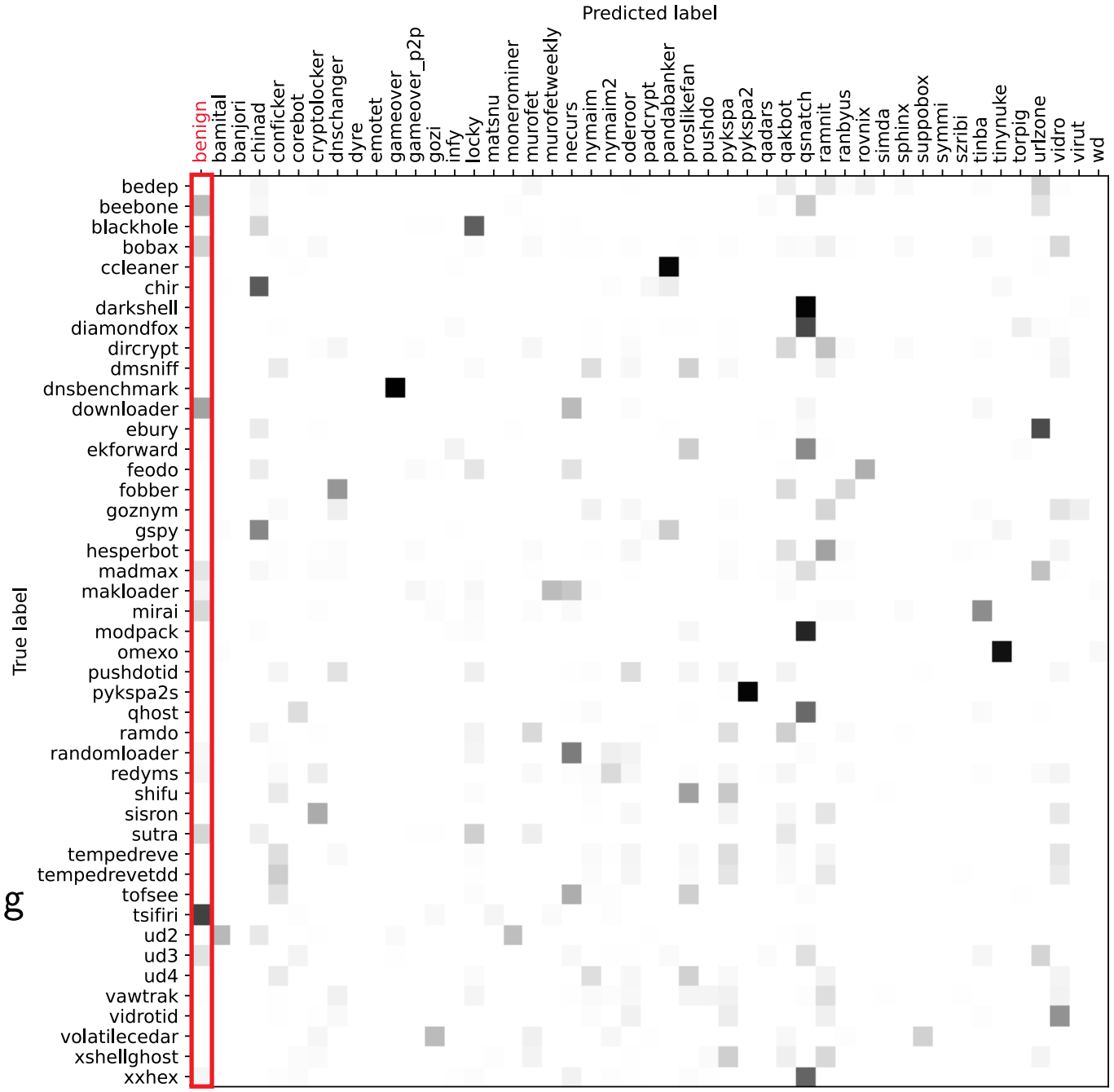
OOD samples are spread over malicious classes

Huge fraction is attributed to the benign class

→ These samples would be missed by an Intrusion Detection System (IDS)

→ Include weakly represented DGAs to the training



# Explainability I - Explainable AI Research

Problem:

- State-of-the-art deep learning classifiers behave like black boxes
- Difficult to evaluate their line of reasoning
  → Lack of confidence

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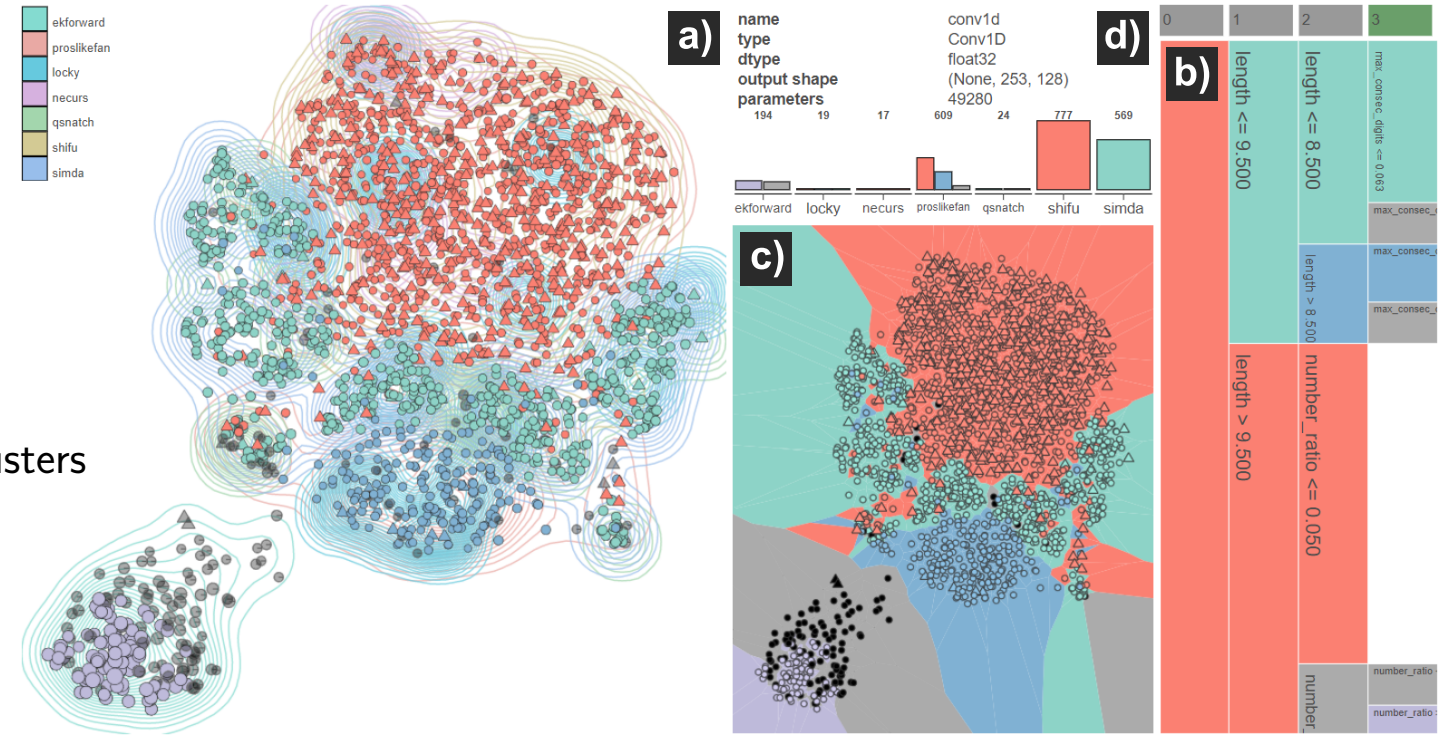
Two approaches in SAPPAN:

1. Visual analytics system:
   - Provide understandable interpretations for predictions of deep learning classifiers
   - Cluster activations of a model's neurons
   - Leverage decision trees in order to explain clusters



# Explainability II - Feature-based DGA Detection

◤: EXPLAIN-OvR$_{Union}$ ◢: ResNet.MI

## 2. Feature-based classifier: EXPLAIN

- Random forest based classifier
- Competitive & context-less
- Explainable by design
  → Predictions are easier to interpret as they can be traced back to characteristics of used features

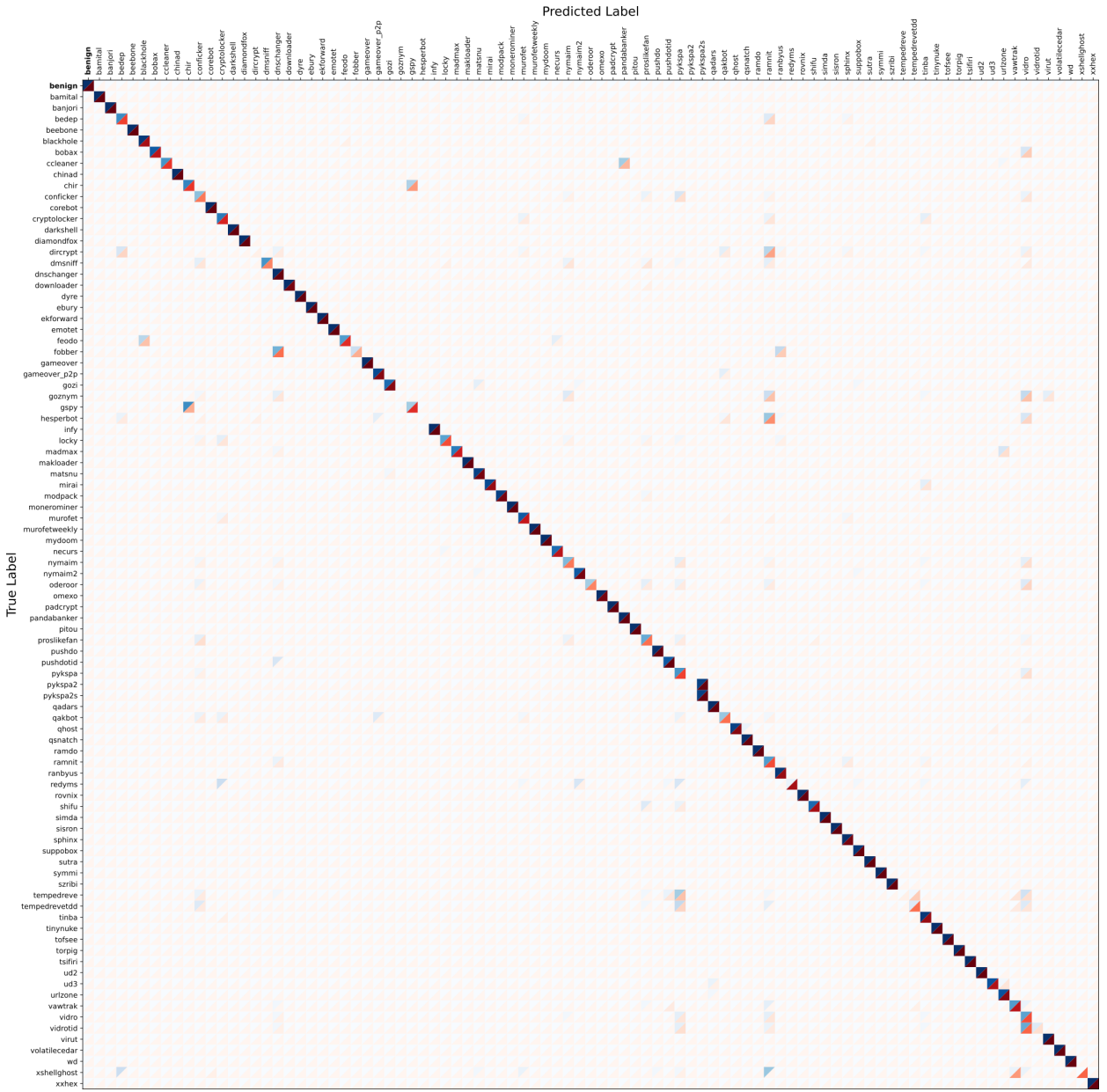
## Studied 136 context-less features

- 42 feature gathered from related work
- 94 features newly developed

## 136 Features divided in

- 64 linguistic: e.g. domain contains numbers?, vowel-ratio
- 17 structural: e.g. domain length
- 55 statistical: e.g. n-gram frequency distributions, entropy

→ Classifier is real-time capable



## Collaborative Machine Learning - Privacy-Preserving Intelligence Sharing

Problem:

- How to improve detection by collaboration?
- Decision models are directly influenced by sensitive training data
- Models are susceptible to leak such sensitive information

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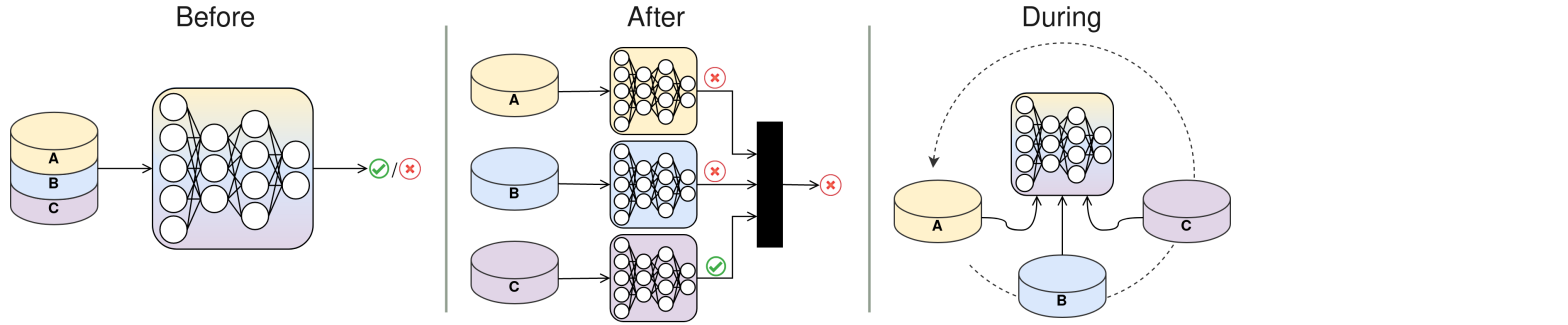
Improve generalization and performance by sharing intelligence at different stages of model training:




- Raw Data Sharing
- Ensemble Classification
- Feature Extractor Sharing
- Federated Learning
- Teacher-Student Learning

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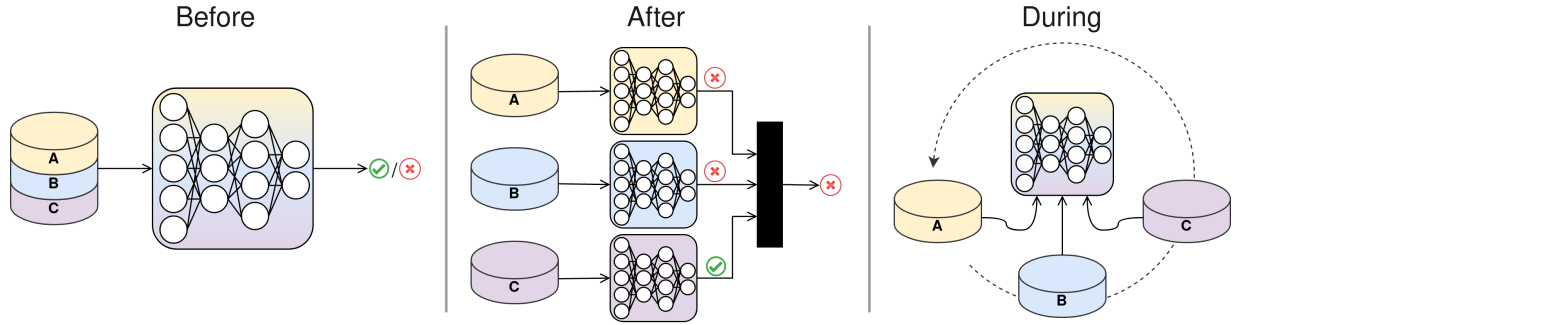


- Raw Data Sharing
- Ensemble Classification
- Feature Extractor Sharing
- Federated Learning
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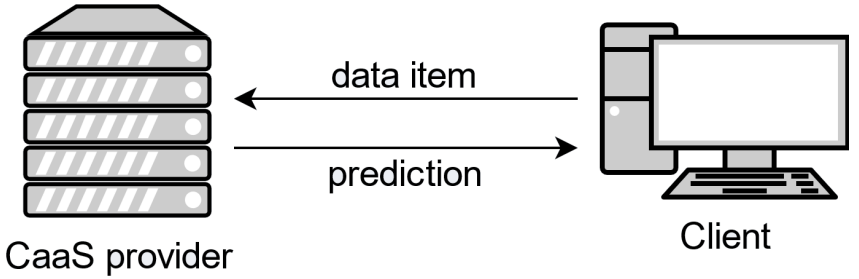
Our empirical study shows Feature Extractor Sharing and Federated Learning perform best:

- Significant reduction of false positive rate (FPR), up to 50% compared to single-party
- Reduction rate of FPR correlates with increasing number of parties
- Preliminary privacy-utility trade-off study

# Privacy-Preserving Classification as a Service (CaaS)

Problem:

- Real-world training data is mandatory for well performing classifiers
- What about resource constrained devices?
- Domain names / trained models may contain privacy-critical information




Naive application of privacy-preserving ML frameworks to existing DGA detection classifiers

→ Single inference can cost additional: 13 min inference latency, 234 GB communication

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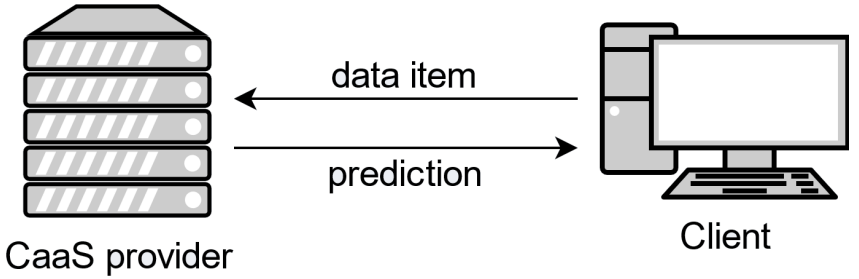


Naive application of privacy-preserving ML frameworks to existing DGA detection classifiers

→ Single inference can cost additional: 13 min inference latency, 234 GB communication

Comprehensive study & proposed model simplifications:

- Reduction in inference latency of up to 95%
- Reduction in communication complexity of up to 97%
- Accuracy penalty of less than 0.17%

→ Still, future work is required to make privacy-preserving CaaS feasible!

# DGA Detection - Current Research & Future Work

Robustness

- NX-classifiers more robust against adversarial attacks
- Usage of adversarial machine learning to improve robustness

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## New DGA detection

- Real-world experiment: 6 unknown DGAs, 1 unknown Bamital seed
- Adaptive new DGA detection system

```
manipulation-want-date.pw
refers-spare-criticism.pp.ua
fashioned-achieve-disable.pro
```

**(a) Unknown DGA 1**

```
go2mysuite.eu
citrixgo2mypc.co.uk
gotomobileaccess.com
```

**(b) Unknown DGA 2**

```
dv4050fc.co.ir
thrsssk05.co.ir
thrl0pg13.co.ir
```

**(c) Unknown DGA 3**

```
www.c75ff6bd.com
www.94e47d25.com
www.41019163.com
```

**(d) Unknown DGA 4**

```
2b4b1d67-b38a-40c1-ba3e-af73245d7b14.com
86a94dd8-5724-4b9a-8a7a-bea8733f7e60.com
adcb3f60-d260-478a-99f2-ac24eea1de16.com
```

**(e) Unknown DGA 5**

```
egbva1b5pmgh7fb.jmrbqoa6i67zdlrwhj.com
27422j8tqot.8chcu-tza86fxaz-df70y9-t0o.com
bt-7hb7k0aqyyr-61d8o5d.dg08rz6qobme421f.com
```

**(f) Unknown DGA 6**

```
02836ae5435c57300fc95bf13e9ba7bb.info
073fcdb286615c7a6ac348f9a1ab0250.info
08211a534fad3885624a92573cc2af44.info
```

**(g) Unknown seed of *Bamital***

# DGA Detection - Current Research & Future Work

## Robustness

- NX-classifiers more robust against adversarial attacks
- Usage of adversarial machine learning to improve robustness

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→ **Combining all research to a single detection system**

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# Impact of SAPPAN Innovations

# Impact of SAPPAN Innovations I

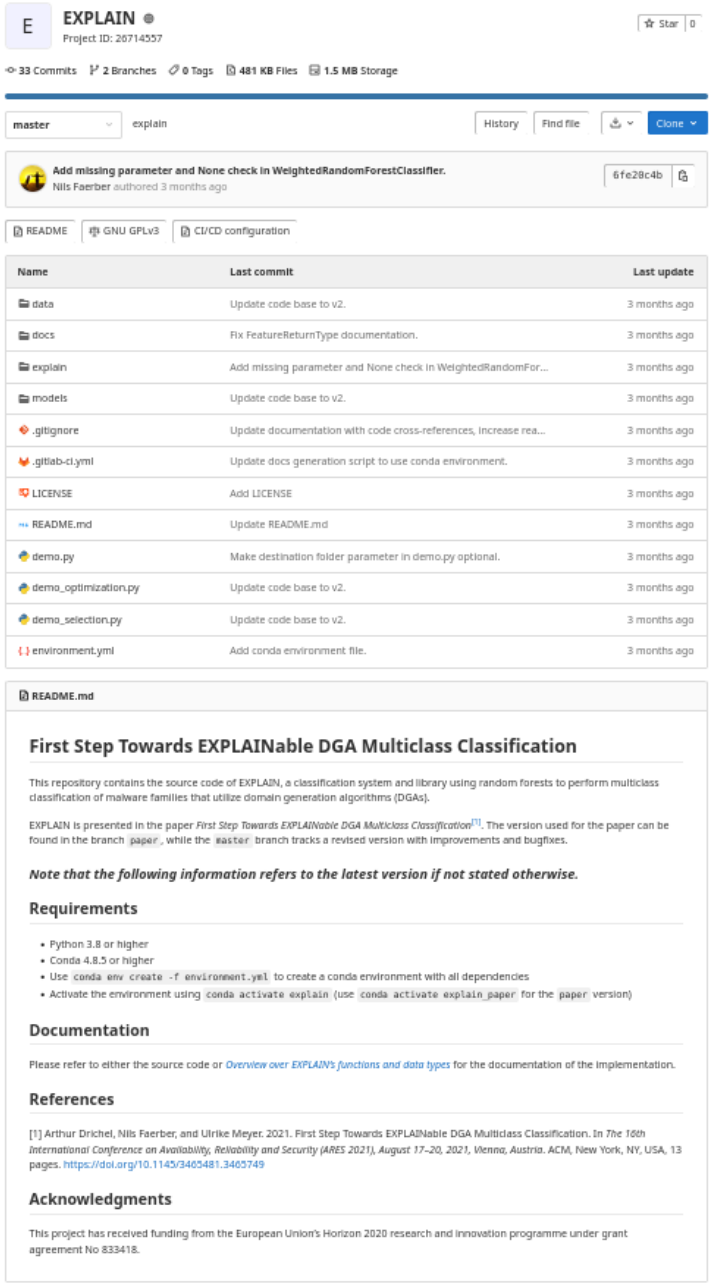
Research impact

- Improved state-of-the-art in various aspects
- 7 peer-reviewed accepted papers on DGA detection
- 1 paper currently under review

Open source software

- Binary & multiclass ResNet-based DGA models
- EXPLAIN: Feature-based multiclass classifier (https://gitlab.com/rwth-itsec/explain)

→ Classifiers are real-world applicable



E **EXPLAIN**
Project ID: 26714557
Star 0

33 Commits | 2 Branches | 0 Tags | 481 KB Files | 1.5 MB Storage

master | explain | History | Find file | Clone

Add missing parameter and None check in WeightedRandomForestClassifier.
Nils Faerber authored 3 months ago | 6fe28c4b

README | GNU GPLv3 | CI/CD configuration

| Name | Last commit | Last update |
|---|---|---|
| data | Update code base to v2. | 3 months ago |
| docs | Fix FeatureReturnType documentation. | 3 months ago |
| explain | Add missing parameter and None check in WeightedRandomFor... | 3 months ago |
| models | Update code base to v2. | 3 months ago |
| .gitignore | Update documentation with code cross-references, increase rea... | 3 months ago |
| .gitlab-ci.yml | Update docs generation script to use conda environment. | 3 months ago |
| LICENSE | Add LICENSE | 3 months ago |
| README.md | Update README.md | 3 months ago |
| demo.py | Make destination folder parameter in demo.py optional. | 3 months ago |
| demo_optimization.py | Update code base to v2. | 3 months ago |
| demo_selection.py | Update code base to v2. | 3 months ago |
| environment.yml | Add conda environment file. | 3 months ago |

README.md

**First Step Towards EXPLAINable DGA Multiclass Classification**

This repository contains the source code of EXPLAIN, a classification system and library using random forests to perform multiclass classification of malware families that utilize domain generation algorithms (DGAs).

EXPLAIN is presented in the paper *First Step Towards EXPLAINable DGA Multiclass Classification*[1]. The version used for the paper can be found in the branch `paper`, while the `master` branch tracks a revised version with improvements and bugfixes.

***Note that the following information refers to the latest version if not stated otherwise.***

**Requirements**

- Python 3.8 or higher
- Conda 4.8.5 or higher
- Use `conda env create -f environment.yml` to create a conda environment with all dependencies
- Activate the environment using `conda activate explain` (use `conda activate explain_paper` for the `paper` version)

**Documentation**

Please refer to either the source code or *Overview over EXPLAIN's functions and data types* for the documentation of the implementation.

**References**

[1] Arthur Drichel, Nils Faerber, and Ulrike Meyer. 2021. First Step Towards EXPLAINable DGA Multiclass Classification. In *The 16th International Conference on Availability, Reliability and Security (ARES 2021), August 17–20, 2021, Vienna, Austria.* ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3465481.3465749

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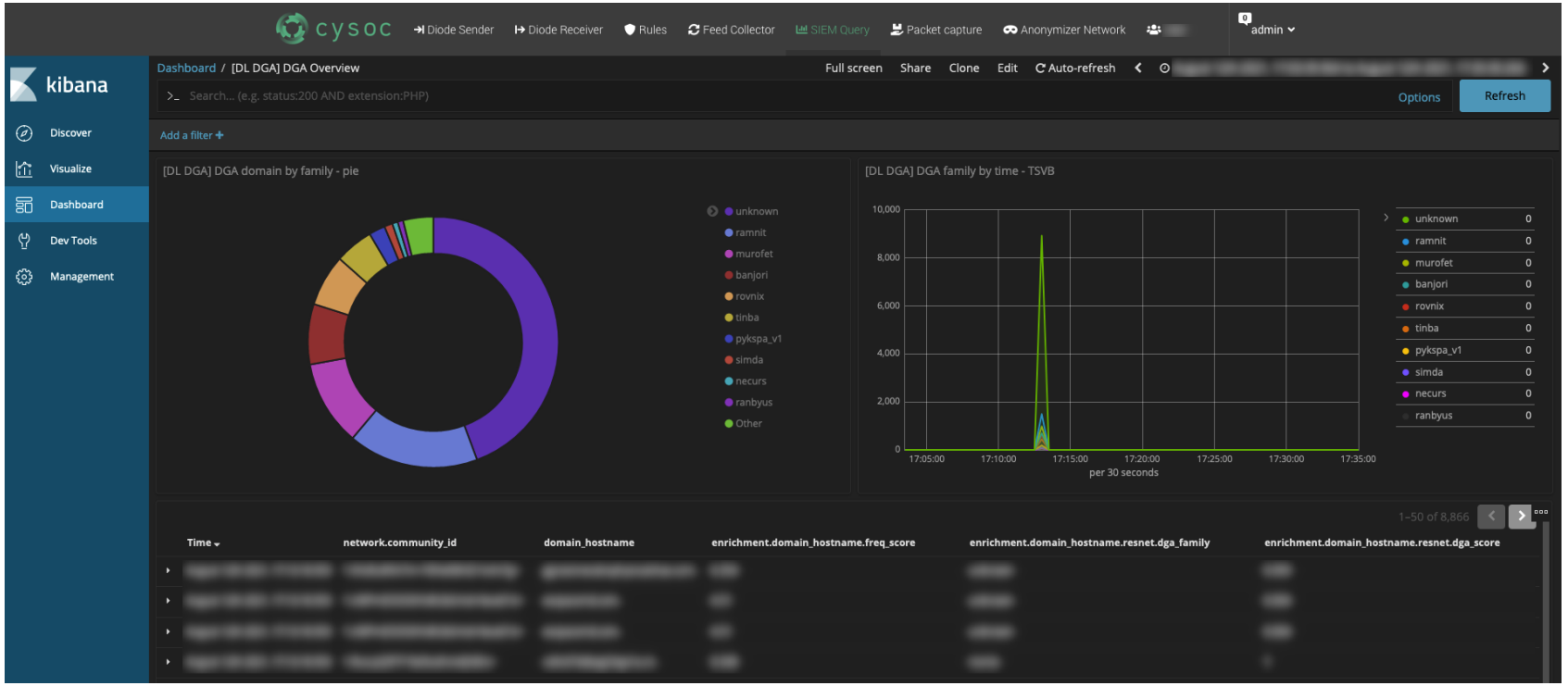
# Impact of SAPPAN Innovations II

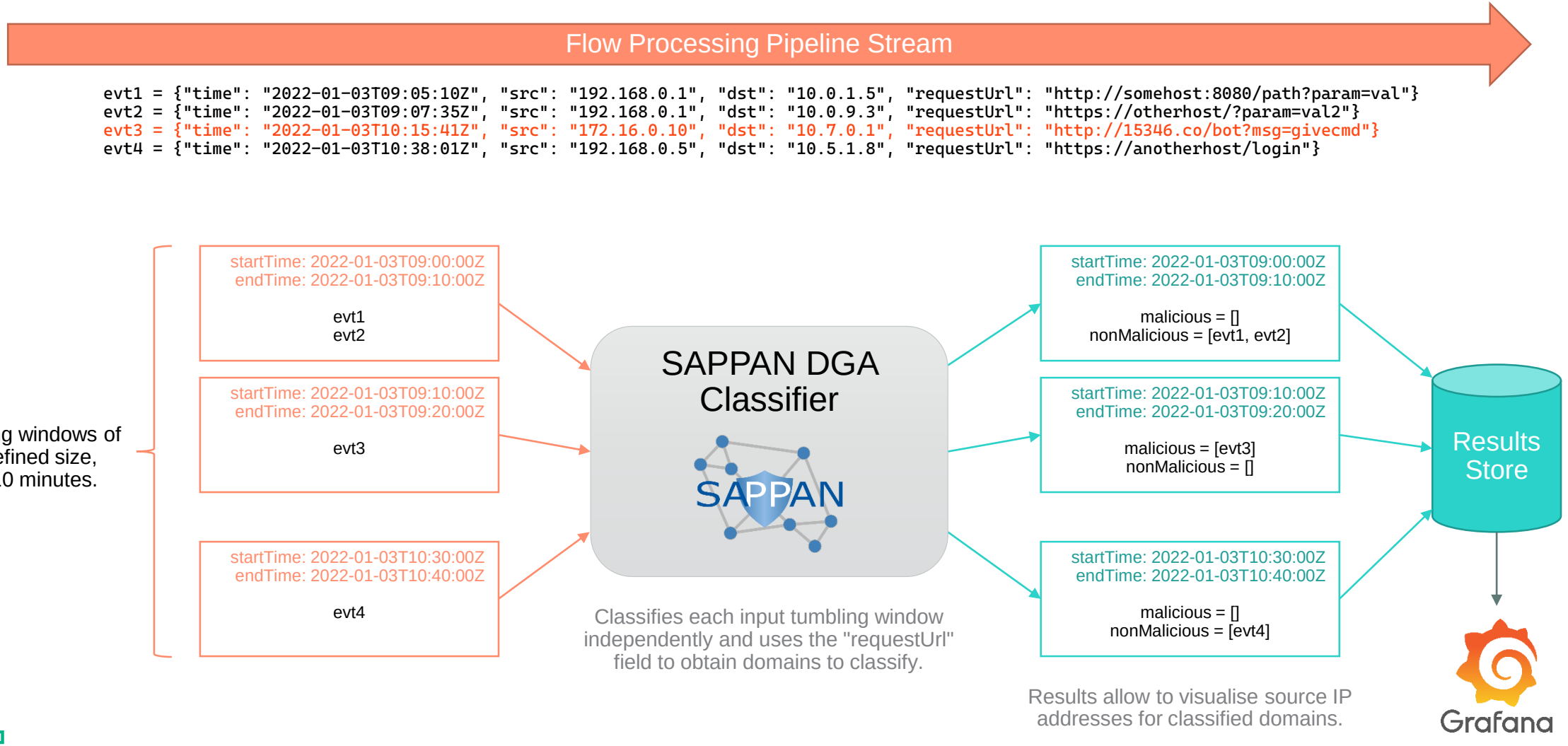
Integration of research into existing SIEM solutions:




Facilitating the work of Security Operation Center (SOC) analysts

- Improvement of detection performance
- Reduction of false positives
- Providing explanations for predictions

# Solution Design: SAPPAN DGA Classifier



# Thank You
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