SAPPAN Innovation in DGA Detection

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Research Group IT-Security

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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

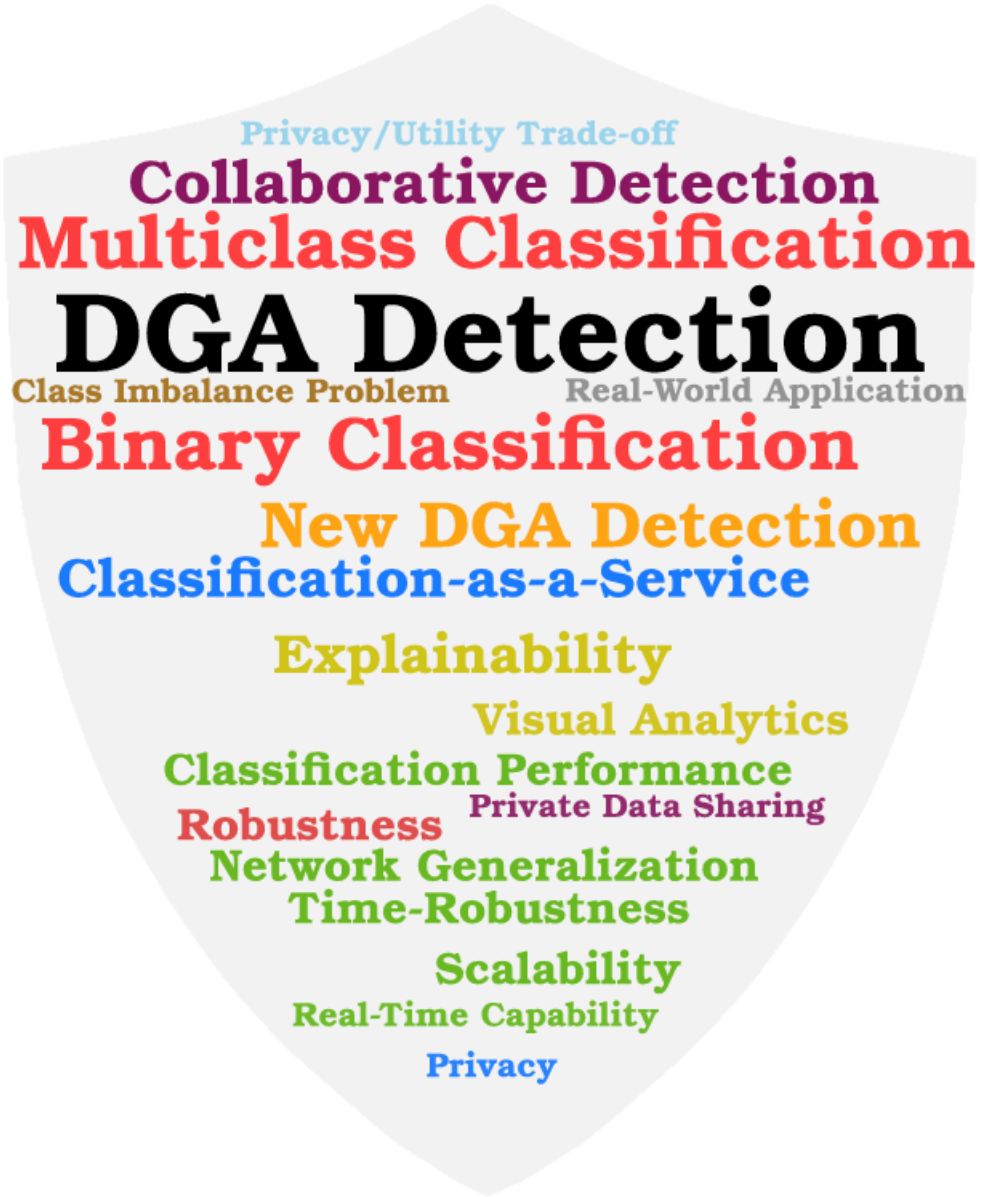
Use-case DGA Detection in SAPPAN

Research driven approach

- 6 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

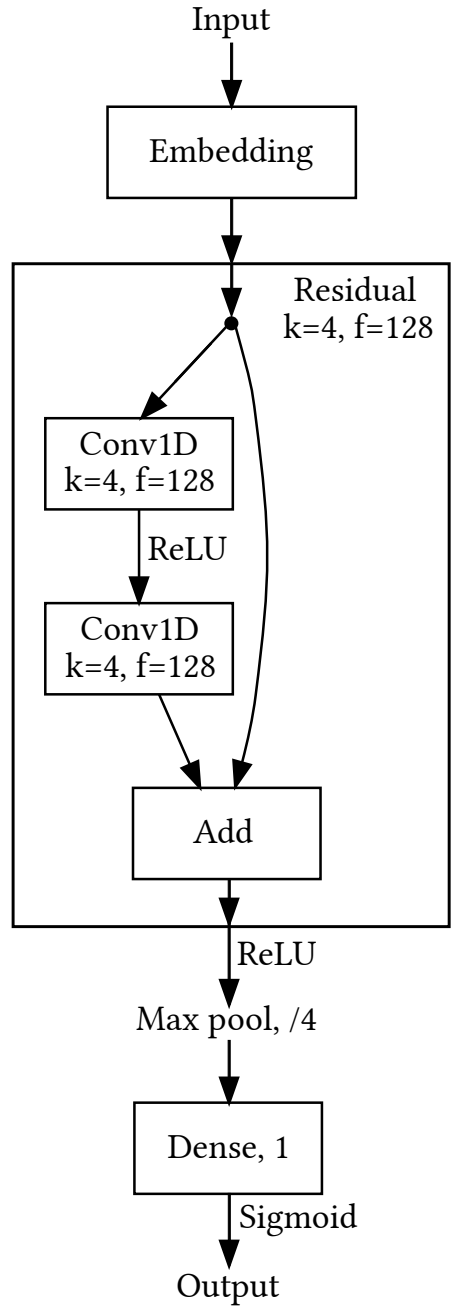
- Introduction of skip connections between convolutional layers

→ 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

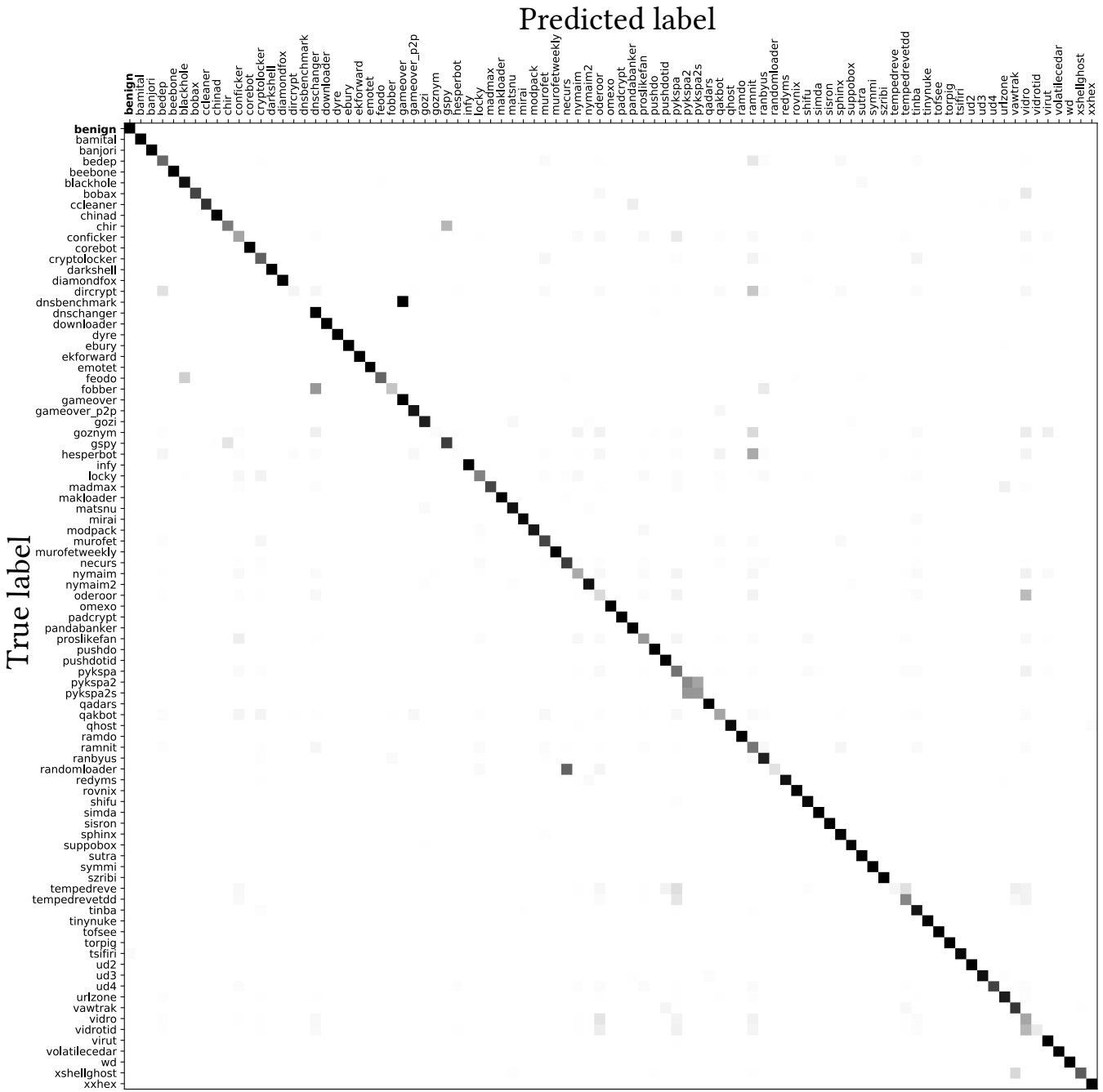
- Build up of 11 residual blocks

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

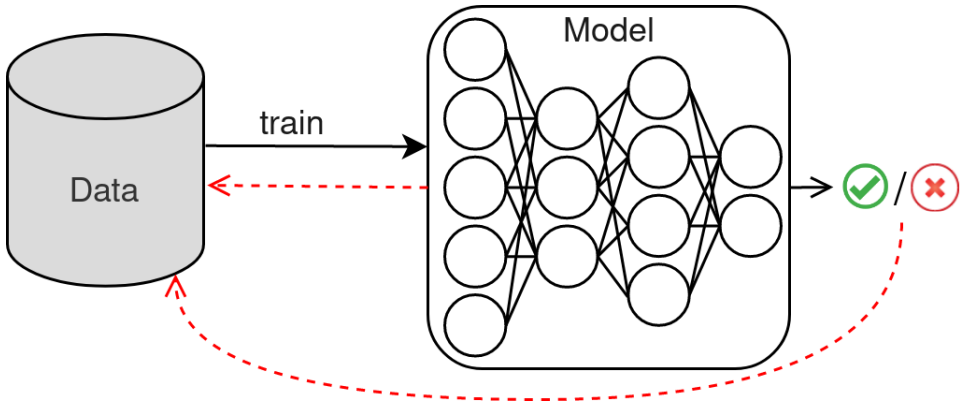
→ Classifier is real-time capable



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?



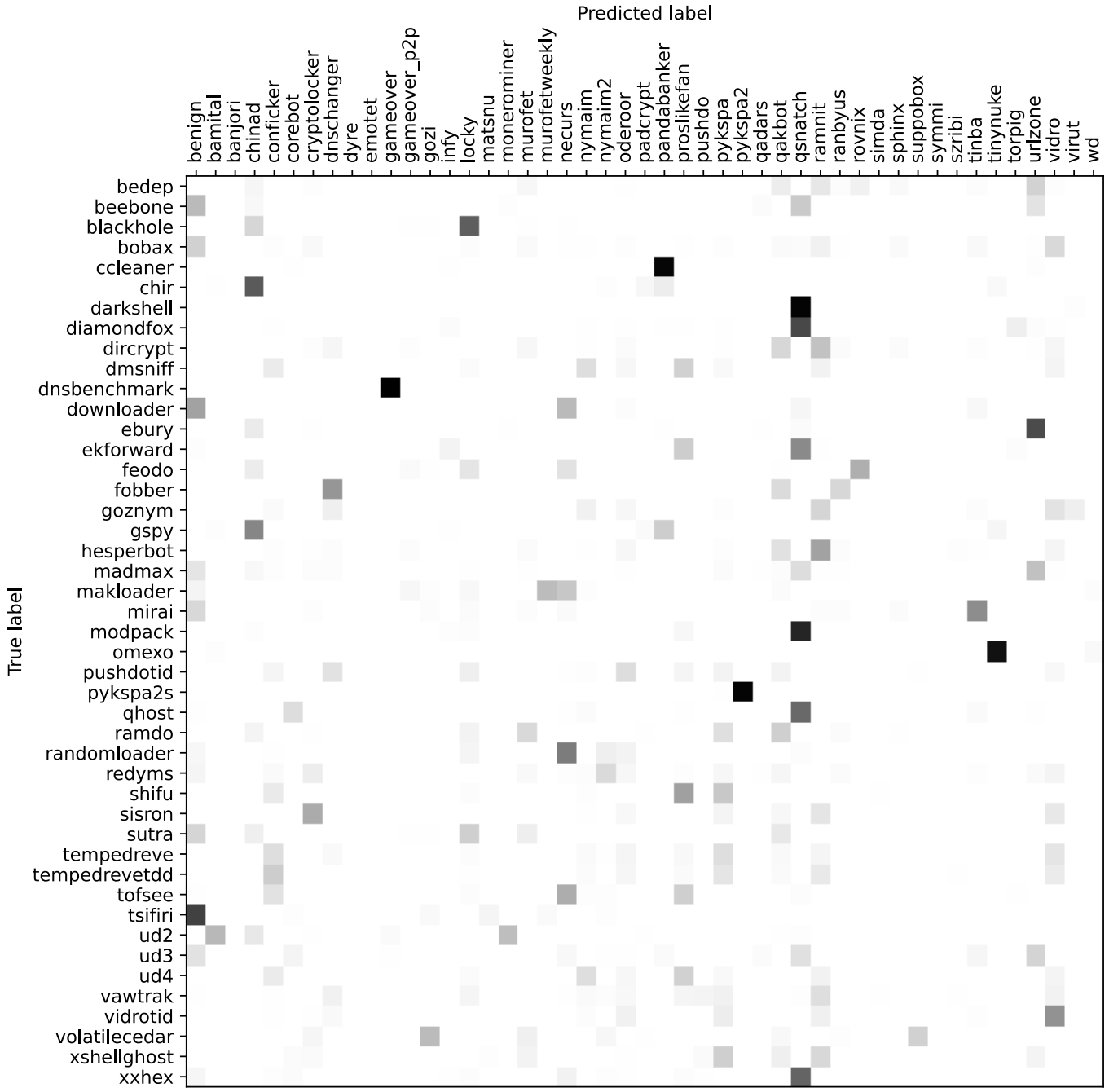
Comprehensive study

- 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

Experiment:

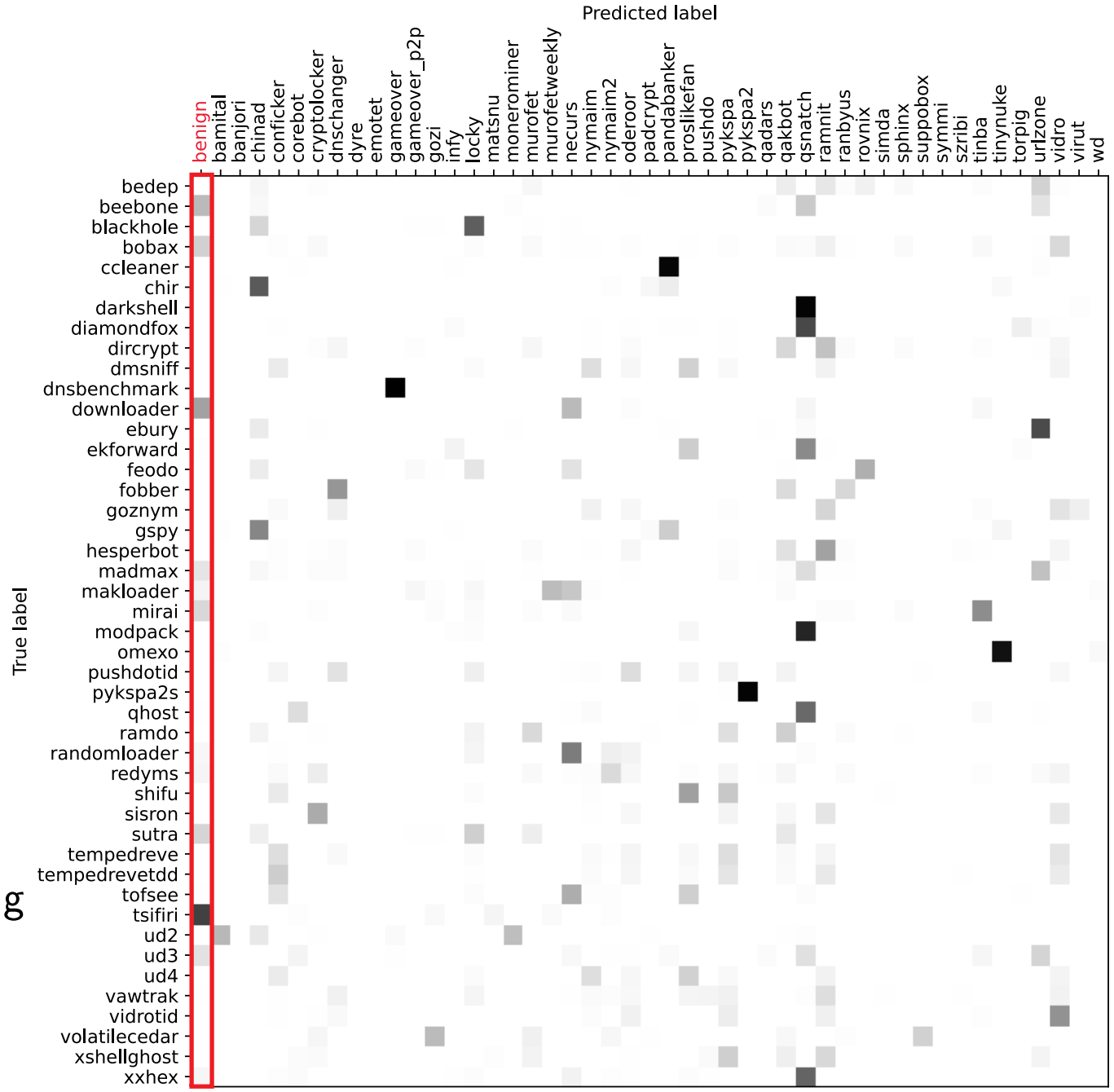
- Train on samples of well represented group
- Classify samples of weakly represented group

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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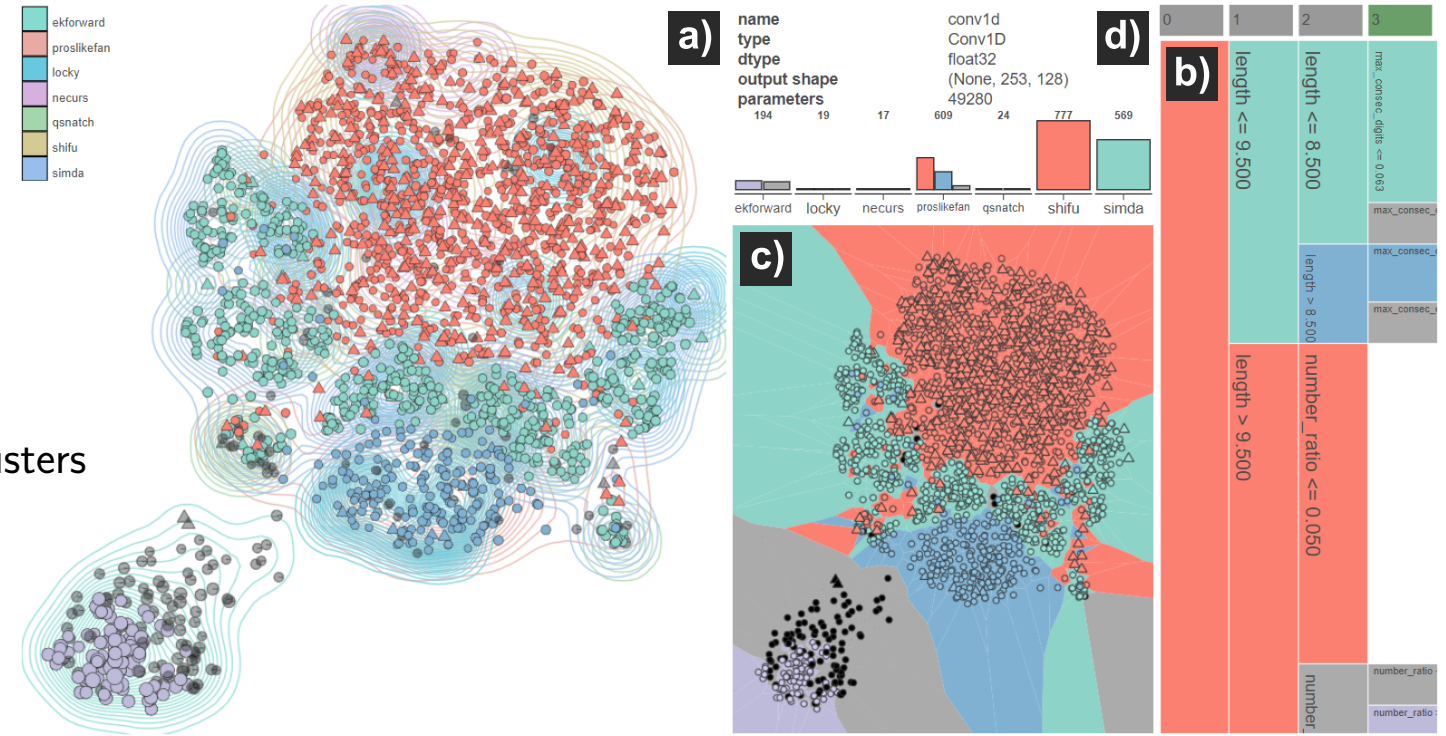
Two approaches in SAPPAN:

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

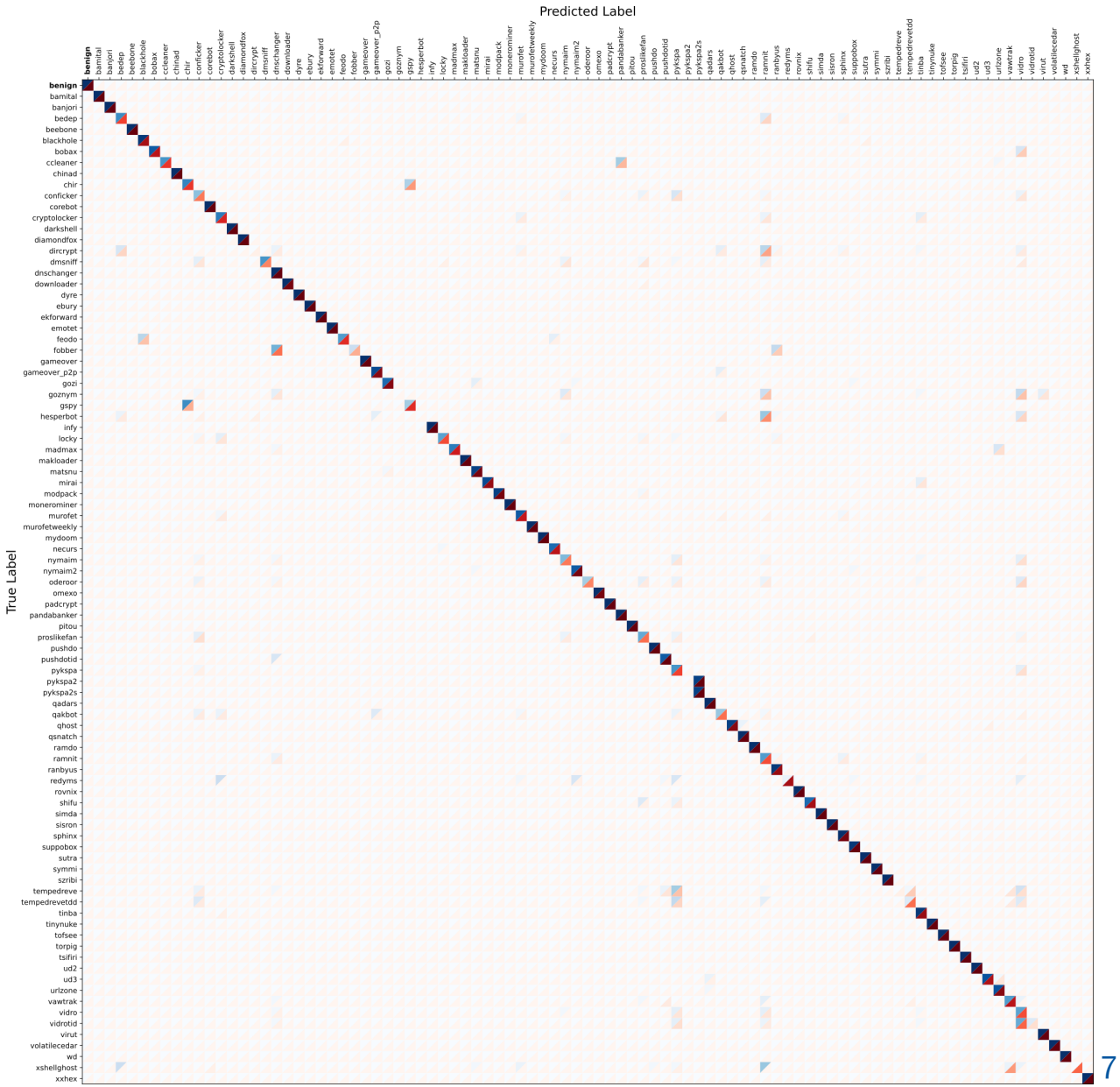
Studied 136 context-less features

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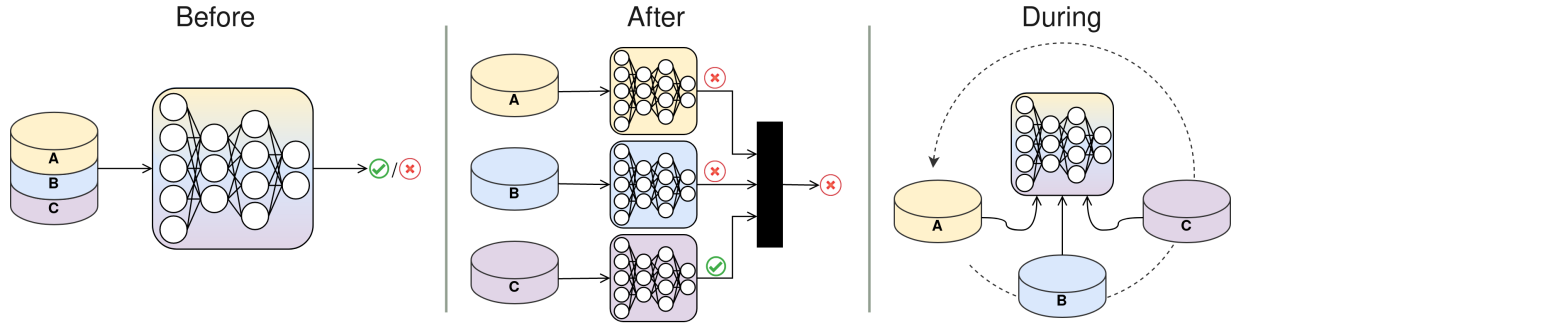
Improve generalization and performance by sharing intelligence at different stages of model training:



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

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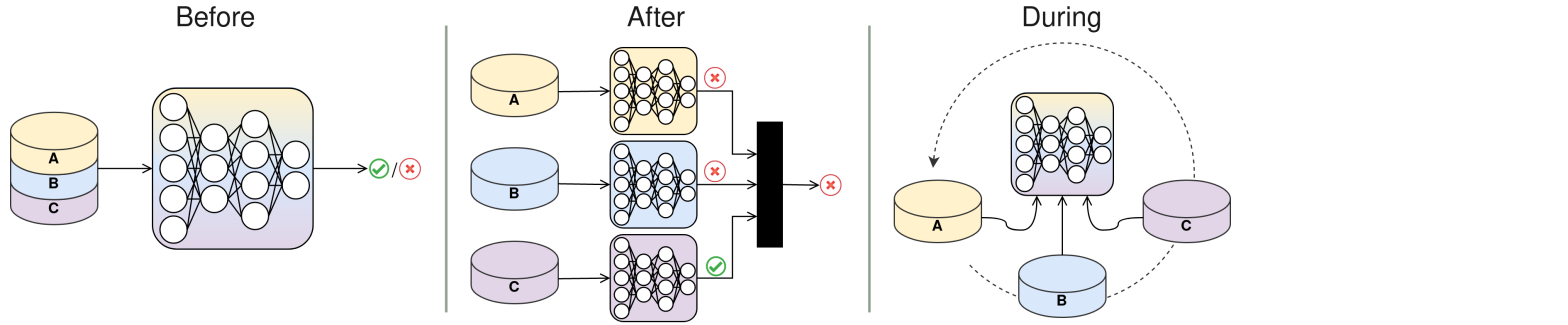

- Raw Data Sharing
- Ensemble Classification
- Feature Extractor Sharing
- Federated Learning
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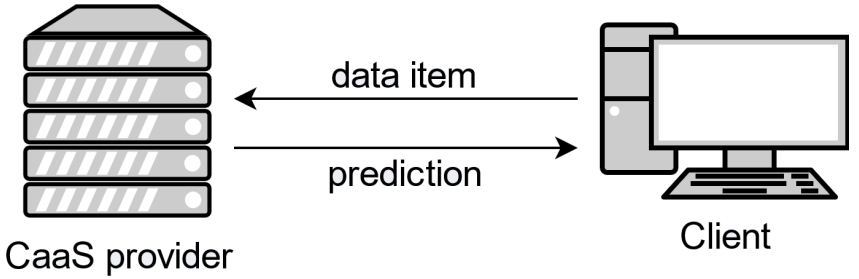
Our empirical study shows Feature Extractor Sharing and Federated Learning perform best:

- 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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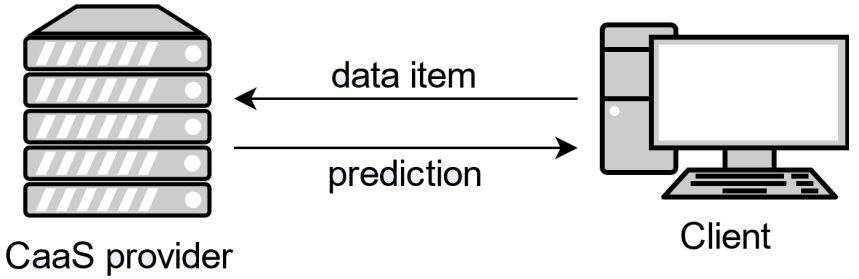

Naive application of privacy-preserving ML frameworks to existing DGA detection classifiers

→ 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
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bt-7hb7k0aqyyr-61d8o5d.dg08rz6qobme421f.com
```

(f) Unknown DGA 6

```
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073fcdb286615c7a6ac348f9a1ab0250.info
08211a534fad3885624a92573cc2af44.info
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(g) Unknown seed of *Bamital*

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DGA detection on resolving traffic

- Detecting active C&C server

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→ Combining all research to a single detection system

Impact of SAPPAN Innovations

Impact of SAPPAN Innovations I

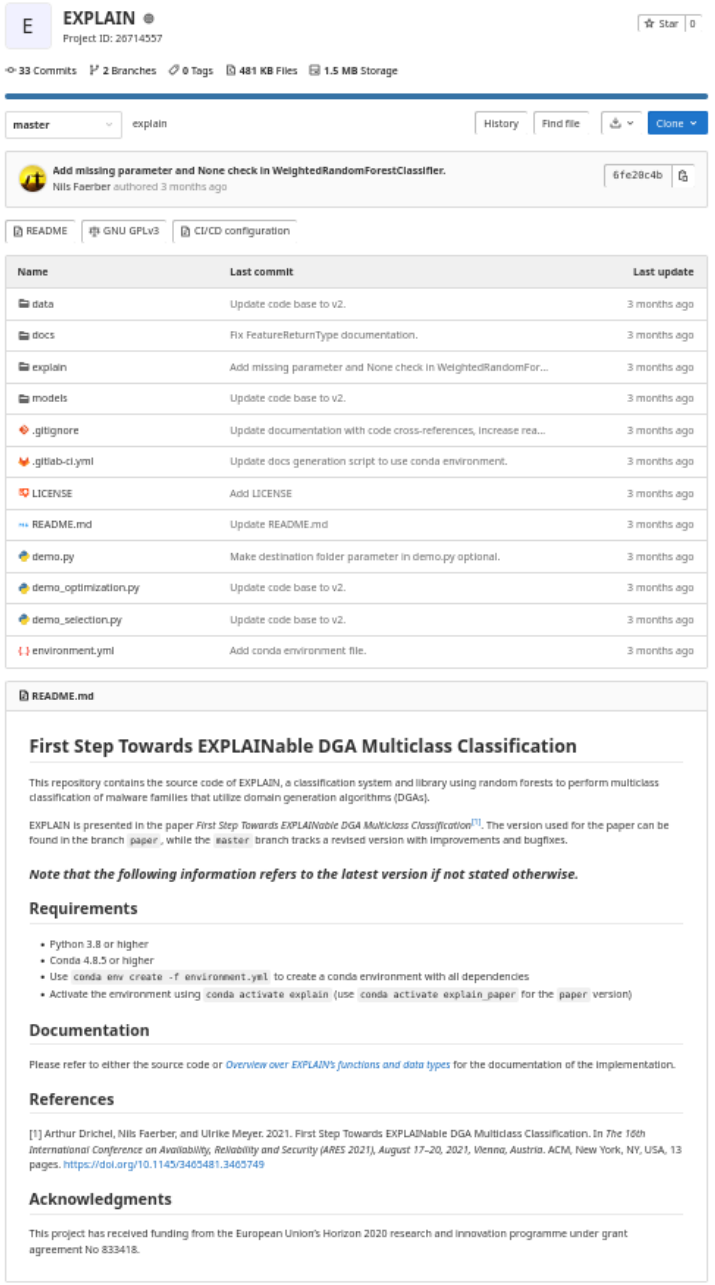
Research impact

- Improved state-of-the-art in various aspects
- 6 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



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

Acknowledgments

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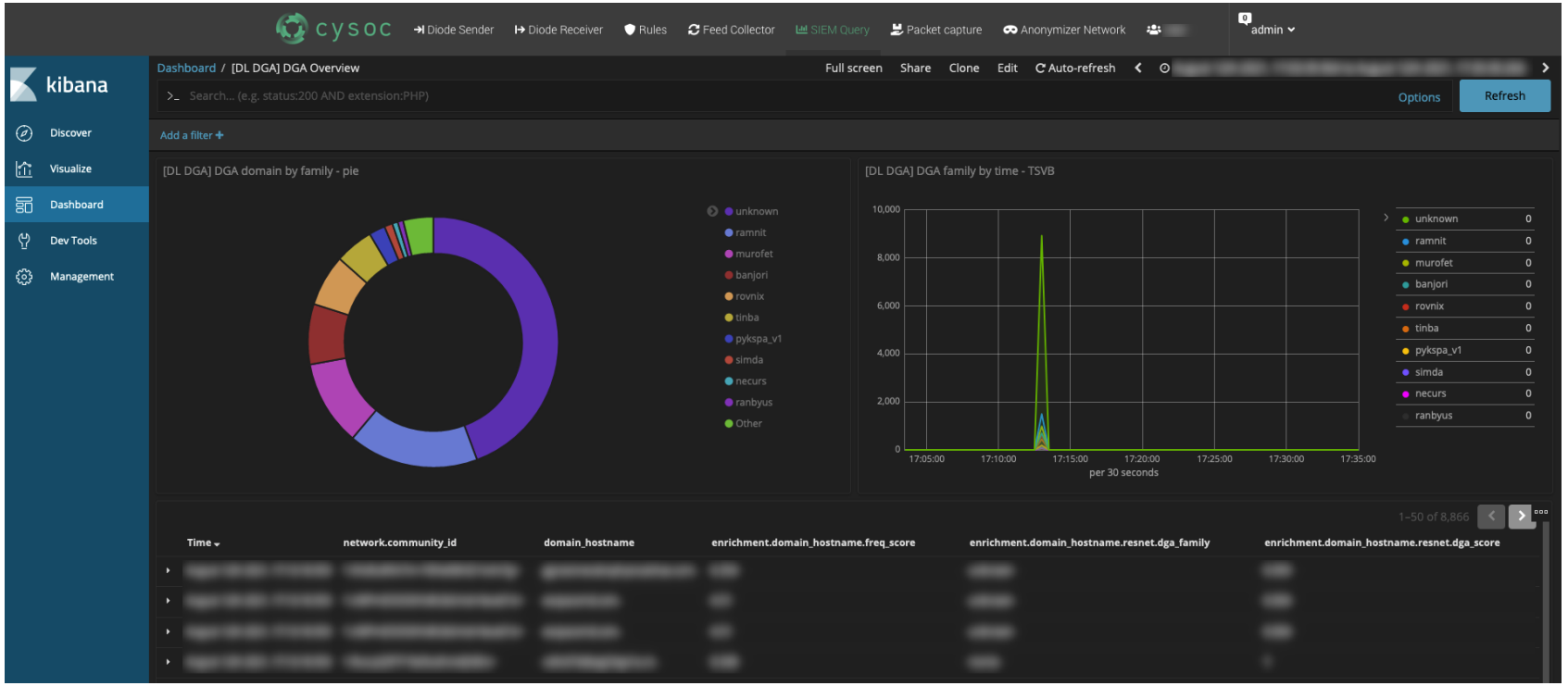
Impact of SAPPAN Innovations II

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

Thank You
For Your Attention

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