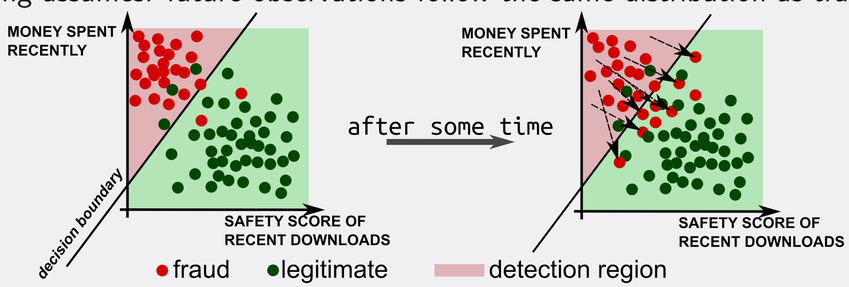
Game Theoretic Optimization of Detecting Malicious Behavior

Ing. Raman Samusevich, Advisor: Mgr. Viliam Lisy, Ph.D., Co-advisors: Ing. Tomas Pevny, Ph.D., O2 CZ Security Division

We present a novel method which improves the state-of-the-art and was developed in collaboration with industry. We implemented it as an improvement of a fraud detection system at O2 Czech Republic and supported its deployment into the production environment.

Problem

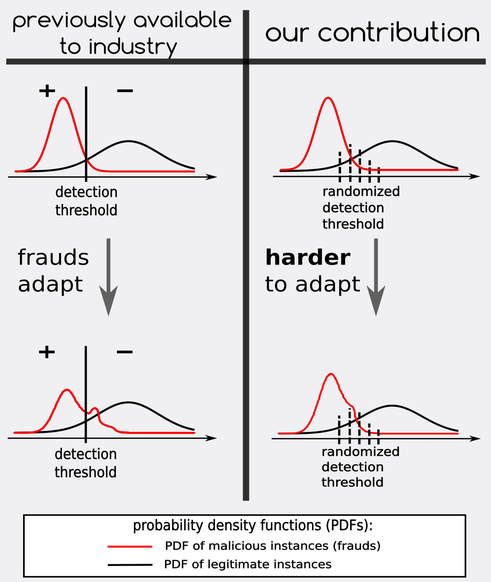
- Telecommunication fraud $\rightarrow$ \$150 million losses annually. Challenge: adaptivity of frauds.
- Challenge in many security applications of machine learning (fraud detection, computer network intrusion detection, spam filtering): attackers adapt in order to avoid detection. But classical machine learning assumes: future observations follow the same distribution as training data.



- Emerging methods to limit the adaptability are not yet applicable in the most practical settings.

Our Contributions

- Unlike in the majority of existing methods, threshold **randomization** to complicate detection avoidance.
- **First** method with **data-driven** modeling of attackers (frauds) with **no restrictions** on a used machine learning algorithm, **no restrictions** on training data
- **First** game-theoretic optimization enabling **control over false alarms rate** (crucial in security)
- **Enhances a general state-of-the-art model:**
  - Rigorous theoretical analysis of the general model (**12 discovered and formally proven facts**)
  - **New scalable algorithms**, improved worst-case complexity compared to existing baselines:
    - Computation of Nash equilibrium generally belongs to PPAD complexity class, for the model we developed a linear time algorithm
    - Strong Stackelberg equilibrium: instead of solving a linear number of linear programs using general solvers $\rightarrow$ a quadratic time algorithm; for randomization under false alarm restriction: a cubic time algorithm.

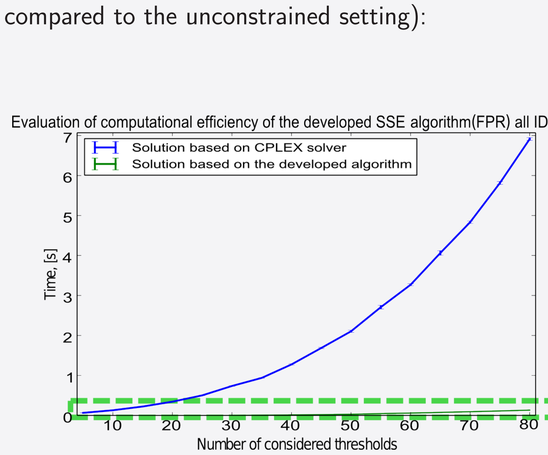


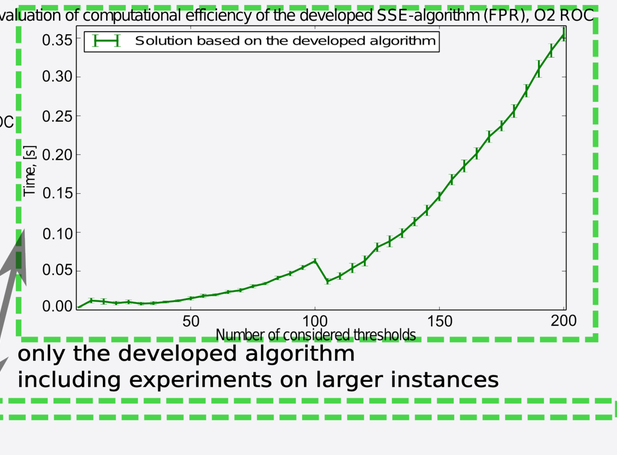
- Method uses data-driven modeling of adversaries from another state-of-the-art model
  - Introducing applicability to domains with **continuous features**
  - Preserving possibility to model **bounded adaptability** of adversaries, **variability of adversaries**
- Preparing a journal publication based on the thesis

Experimental Evaluation and Deployment

Evaluation of the General Model Enhancements

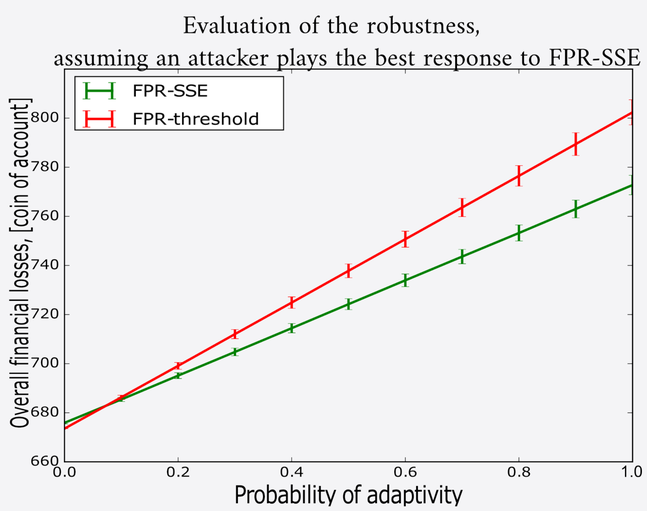
- 170 ROC curves of real-world computer network intrusion detection systems, O2 CZ fraud detection module ROC curve, parameters of the general model generated at random
- Dramatic **improvement in running time and scalability**, thus the method remains applicable to larger datasets
  - Nash equilibrium algorithm: **three orders of magnitude faster** on instances twice as large
  - Strong Stackelberg equilibrium algorithm: **an order of magnitude faster** on instances twice as large
  - Strong Stackelberg equilibrium is the best fit for security, false alarm rate restriction is crucial in practice. Enforcing the restriction leads to performance sacrifice (>3 times worse value of the defender's utility function compared to the unconstrained setting):





Deployment: module for a fraud detection system at O2 Czech Republic

- Method used to improve robustness of a machine learning module implemented by the author as the last line of defense for the fraud detection system at O2 Czech Republic
- Training dataset used to create a classifier
- Validation dataset used to derive randomization of a classification threshold
- Test dataset used to estimate performance against both static and adaptive populations
- Results of evaluation:
  - Application of the method did not result in a notable decrease of performance against static population
  - The method can improve robustness of the classifier against adaptive opponents
  - **Management decided to deploy it to production**



raman.samusevich@gmail.com, viliam.lisy@agents.fel.cvut.cz