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A Deep Learning Based Anomaly Detection Approach for Intelligent Autonomous Systems

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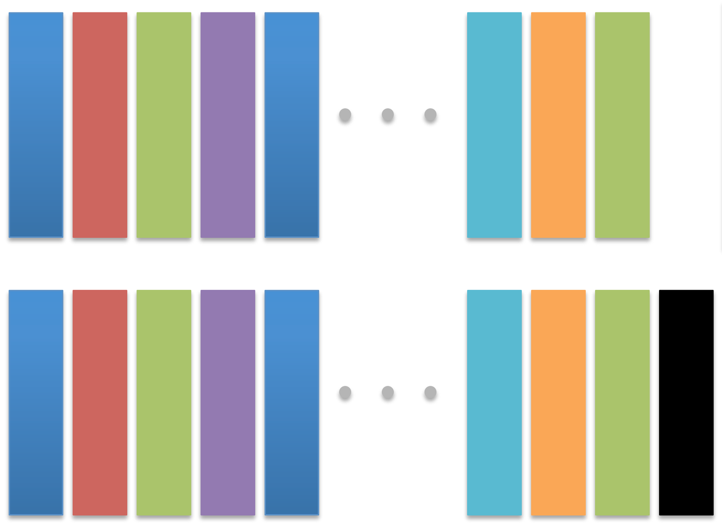
MOTIVATION

Given this sequence

Should this sequence occur?



Legend
Each color bar represents one of the all possible events (system calls) in the system.

- ❑ Advanced modern exploits characterize by their sophistication in stealthy attacks.
- ❑ **Code-reuse attacks** such as return-oriented programming and memory disclosure attacks allow attackers executing malicious instruction sequences on victim systems without injecting external code.
- ❑ This research proposes a new Deep Learning based anomaly detection technique that probabilistically models program control flows for behavioral reasoning and live monitoring.
- ❑ We aim to answer **the binary classification problem** of given a sequence of events $e_1e_2e_3\ldots e_k$ **whether or not the sequence should occur**?
- ❑ An event e_i in the sequence is a function call in a a given trace.

ANOMALY DETECTION ALGORITHM

- ❑ We defined an event as a function call. Each possible function call must be identified as they will form the vocabulary of events.
- ❑ The dynamic code behaviors can be learned by training the model with non-malicious program traces.
- ❑ At any time *t* each possible event (system call or library call) in the system is assigned a probability estimated with respect to the sequence of events observed until time *t-1*.
- ❑ At classification, the decision is made with respect to a pre-defined threshold of the *K*-top most probably sequences.

Input: Sequence of events in the system
Output: normal or anomalous

- **Step 1:** Define a finite set E of events $e_1, e_2, \ldots, e_N$ in the system. Events occur in a time-series fashion.
- **Step 2:** At time $t-1$, given an observed series of events $\{e_i{}^1, e_i{}^2, \ldots, e_i{}^{t-1}\}$ (with $i = 1, 2, \ldots or N$) find the set K of the top k events to occur in time t.
- **Step 3:** At time t, the sequence $\{e_i{}^1, e_i{}^2, \ldots, e_i{}^{t-1}, e_i{}^t\}$ is non-anomalous if $e_i{}^t \in K$, otherwise anomalous.

Algorithm 1: Anomaly detection algorithm

THREAT MODEL

The Eternal War

Attack	• Code Injection (e.g., Buffer Overflow)
Defense	• W⊕X (e.g., Windows DEP)
Attack	• Code Reuse (e.g., ROP)
Defense	• ASLR and variants
Attack	• Memory Disclosure (JIT-ROP): Enables Code Reuse
Defense	• Code Re-Randomization / **Deep Learning based Anomaly Detection**

❑ **Invalid and abnormal control flow of a program:**

- ✓ Code Injection
- ✓ Code Reuse
- ✓ Memory Disclosure

❑ **Can be caused by:**

- ✓ Human error (e.g., unauthorized use or operation of the program
- ✓ Software flaws (e.g., buffer overflow vulnerabilities)
- ✓ Attacks by remote attackers
- ✓ Malicious insiders (e.g., through drive-by downloads)

IMPLEMENTATION

MODEL

```
# -*- coding: utf-8 -*-
"""
Deep Learning Based Anomaly Detection Model
"""
# Imports
from __future__ import print_function
import torch
from   torch.autograd import Variable
```

python

PYTORCH
theano
TensorFlow

CUDA

GPU

❑ **Model**

- ✓ Based on Recurrent Neural Networks (RNN): Long-Short Term Memory (LSTM) and Gated Recurrent Unit (GRU)

❑ **Programming Language: Python**

- ✓ Compatible with several numerical computing libraries suitable for the use of GPUs
- ✓ Some examples: Pytorch, TensorFlow and Theano

❑ **Computing Library: PyTorch**

- ✓ Scientific computing package
- ✓ Replacement of Numpy to take advantage of the power of GPUs
- ✓ Python-friendly platform for neural networks (Deep Learning)

❑ **Parallel Computing Platform: CUDA**

- ✓ Programming model to use GPUs for general purpose computing

CONTRIBUTIONS

- ❑ Systems can be trained with data of benign flows only in isolation (the data is full available.)
- ❑ Flow sensitive anomaly detection. Given the execution paths P_1, P_2 and P_3 our technique captures their occurrence probabilities, vital for high-precision anomaly detection.

REFERENCE

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