Detecting Spectre Attacks by identifying Cache Side-Channel Attacks using Machine Learning

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Jonas Depoix
RheinMain University of Applied Sciences
Wiesbaden, Germany
jonas.depoix@student.hs-rm.d

Philipp Altmeyer
RheinMain University of Applied Sciences
Wiesbaden, Germany
philipp.b.altmeyer@student.hs-rm.de

Agenda

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Motivation

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- Spectre and Meltdown pose considerable threats
- Spectre software mitigations have drawbacks
  - Mitigations have to be implemented and deployed for every individual application
    - Vendors have to provide updates
    - Users have to keep their applications up to date
  - Considerable performance impact
  - Customers of cloud providers are at great risk
    - An up to date VM can be vulnerable to other VMs running on the same hypervisor

Motivation

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Real-time detection system for Spectre attacks could ...

- … keep users safe, even when they use vulnerable software
- … potentially be run with less performance impact, than mitigations
- … be run on hypervisors by cloud providers, to identify malicious VMs

➢ We wanted to implement a **real-time detection system for Spectre attacks**, to test if it is a feasible alternative/supplement to software mitigations

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Approach

Concept

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How does our real-time detection system for Spectre work?

- We mitigate Spectre, by shutting down cache side-channel attacks
- We exploit that cache side-channel attacks have side-effects as well
  - Memory has to be accessed frequently and repeatedly
  - Side-channel attacks induce distinct cache usage patterns

Concept

How does our real-time detection system for Spectre work?

1. Track cache usage with Hardware Performance Counters
   - Special purpose CPU registers
   - Counts occurrences of certain CPU events
     - E.g. clock cycles, L3 cache hits, L3 cache misses, …
   - Can be attached to individual threads, processes, or the entire CPU
2. Classify processes as malicious or benign using a neural network
   - Good at detecting patterns in data
   - Effective at solving classification tasks

Selected HPCs

- L3 cache misses (L3_TCM)
  - Side-channel attacks cause high cache miss rates
- L3 cache accesses (L3_TCA)
  - Reference for total cache activity
- Total instructions (TOT_INS)
  - Reference for CPU load
  - Malicious process has higher rate of cache misses ⇔ executen instructions

Data set

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11 scenarios for training and validation

- Server workloads
  - Wordpress CMS (PHP)
  - Ghost CMS (Node.js)
- Desktop workloads
  - stress
  - Web browsing
- Spectre implementations
  - Variants 1 and 2 implementations written in C
  - Variant 1 JavaScript implementation

➢ Selected HPCs are recorded over 60 seconds in 100 ms intervals

Implementation

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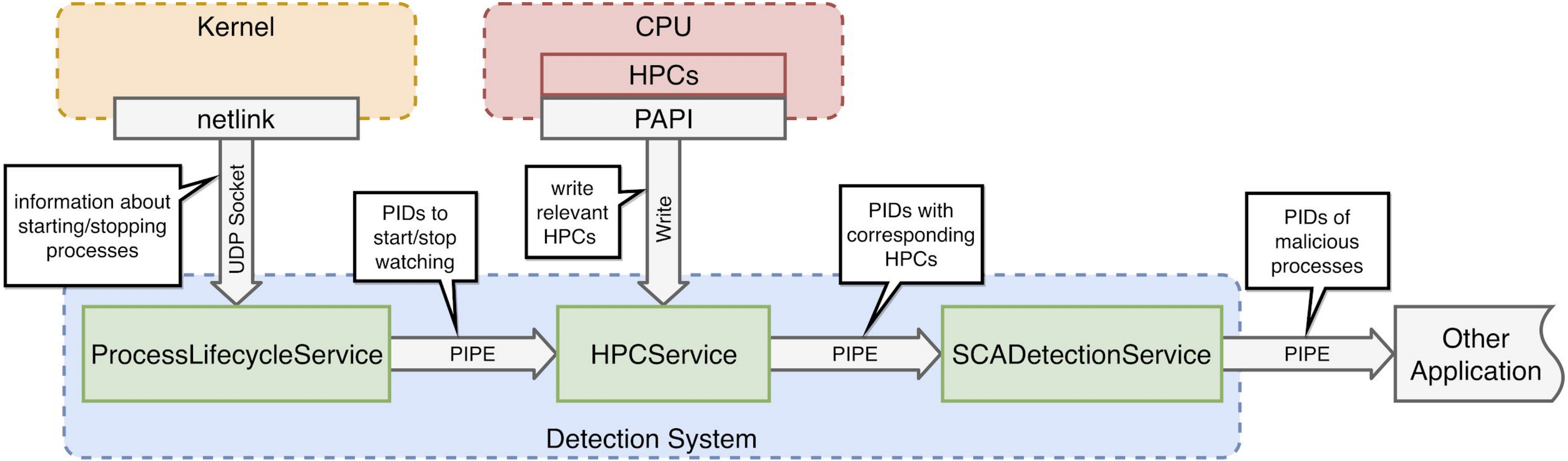

Results

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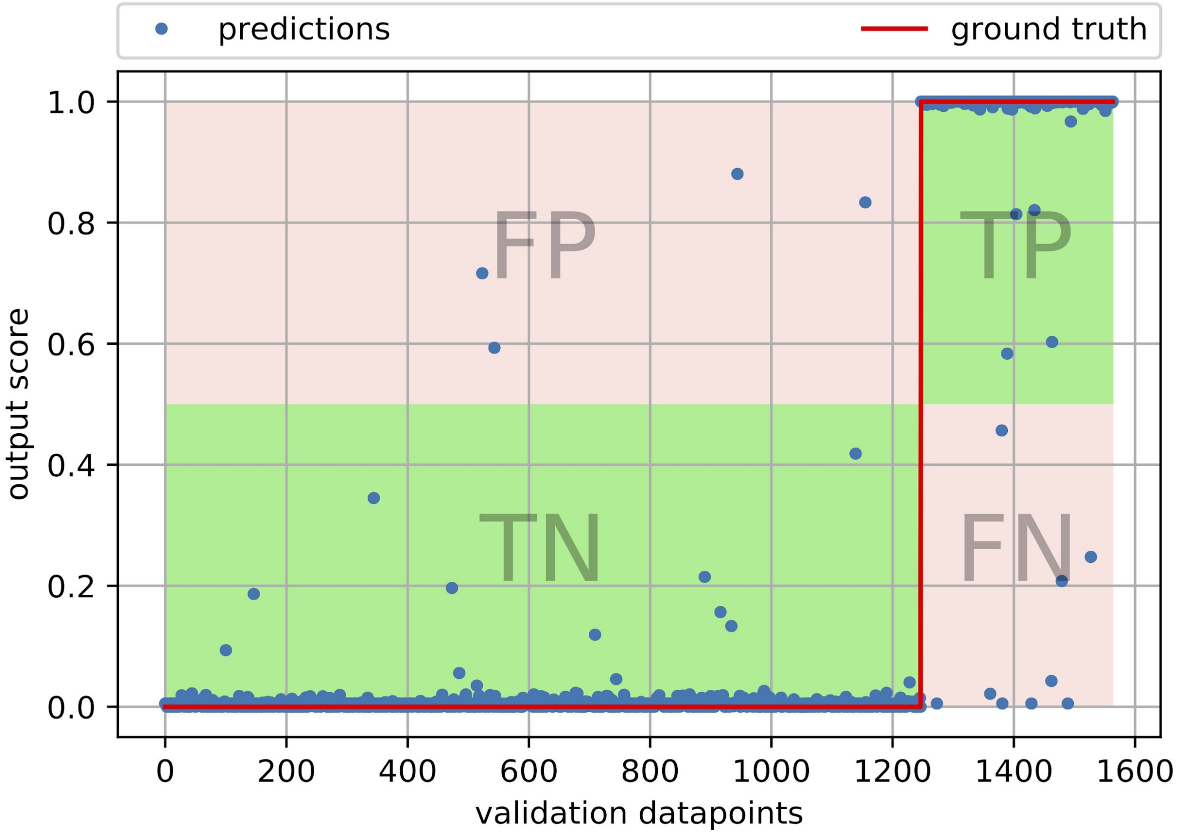
Ground truth	
# datapoints	**1564**
# positives	317
# negatives	1247

Predictions	
Accuracy (total)	**99.23%**
Accuracy (positives)	97.16%
Accuracy (negatives)	99.67%
F-score	**0.9716**
# true positives (TP)	308
# false positives (FP)	4
# true negatives (TN)	1243
# false negatives (FN)	9



Demo

Conclusion

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- We have successfully implemented a real-time detection system for Spectre attacks
  - Accuracy above 99%
  - Detecting side-channel attacks by analyzing HPCs with neural networks shows great potential

➢ **Real-time detection is a feasible alternative/supplement to software mitigations**

Future Work

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- Performance could be improved
- Neural network could be trained on a wider variation of Spectre implementations
- Neural network should be trained on a wider variation of CPU models
- Test if detection system is applicable to Meltdown
- Test if detection system is applicable to cross-VM attacks

Thank you for your attention!

Any questions?