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

Presented at **FGBS 2018**

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

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

Motivation

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

- 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

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

Motivation

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

Approach

Spectre

- Exploits hardware flaw in speculative execution
- Enables reading of protected memory
- Reverting of speculative execution leaves traces
  - Cache content
- Attacker uses side-channel to transfer protected memory

Concept

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

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

- 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

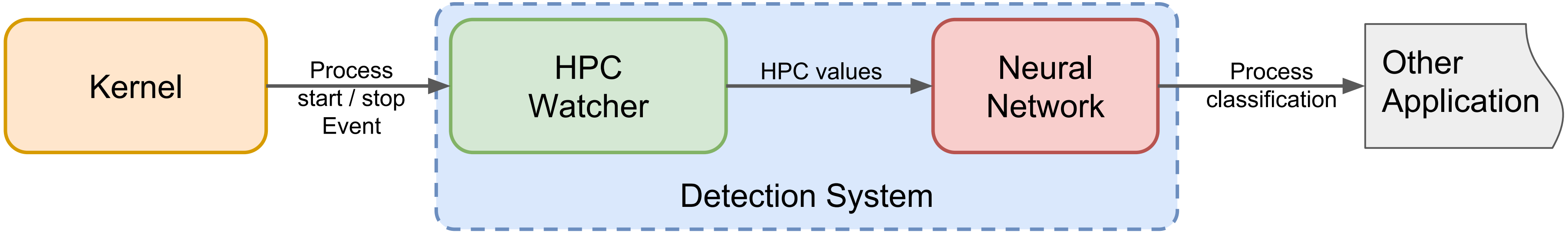
Data set

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

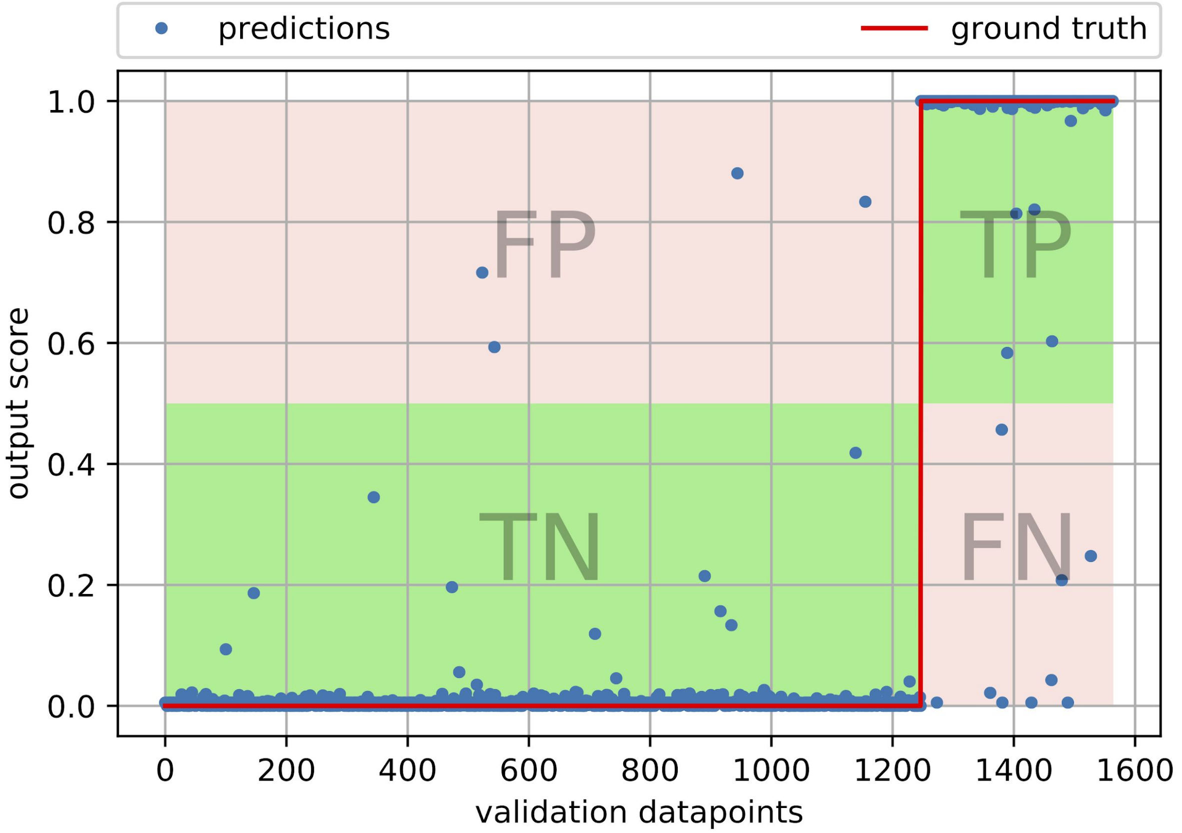


Results

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

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



Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

Demo

Conclusion

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

- 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

Hochschule **RheinMain**
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim

- 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?

https://github.com/jdepoix/spectre-real-time-detection