Spectre: A Dependable Introspection Framework via System Management Mode

Fengwei Zhang, Kevin Leach, Kun Sun, and Angelos Stavrou.
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Presented by Fengwei Zhang

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- Introduction
- Background
- System Framework
- Experimental Results
- Conclusion

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Introduction

- Malware detection and analysis remain an open research problem
- Traditionally, malware detection is provided by installing anti-malware tools (e.g., anti-virus) within the OS
- However, these detection tools are vulnerable to malware running at the same level (e.g., rootkits)
- 'Out-of-box' introspection mechanism proposed for malware detection and analysis (e.g., Virtual machine introspection)

Introduction

- Virtual Machine Intropsection (VMI) systems run malware within a VM and use analysis tool to introspect the malware from outside
- VMI systems have been widely adopted for malware detection and analysis. They isolate the malware detection software from a vulnerable guest [4, 5, 6]
- Limitations of VMI systems:
  - Large Trusted Computing Base (TCB) (e.g., Xen 4.2 has 208K lines of code)
  - Armored malware can detect the presence of a VM and alter its own execution (e.g., anti-VM techniques)
  - High performance overhead
- We present Spectre, a dependable introspection framework via system management mode

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Background

System Management Mode (SMM)

- A CPU mode on the x86 Architecture.
- After entering into SMM, it executes the System Management Interrupt (SMI) handler
- SMI handler stores at a sealed storage called System Management RAM (SMRAM)
- BIOS locks the SMRAM, and the SMRAM is inaccessible from any other CPU modes
- SMM-based systems
  - Integrity checking: HyperGuard [7], HyperCheck [8],
  - HyperSentry [1]
  - SMM rootkits [3, 2]
  - Attacks against SMM [9]

Background

Basic Input and Output System (BIOS) and Coreboot

- BIOS code is stored on-volatile ROM, and it is responsible for hardware initialization before OS starts.
- Coreboot is an open source project aimed to replace the BIOS in current computer
- Spectre uses a custom SMI handler in Coreboot

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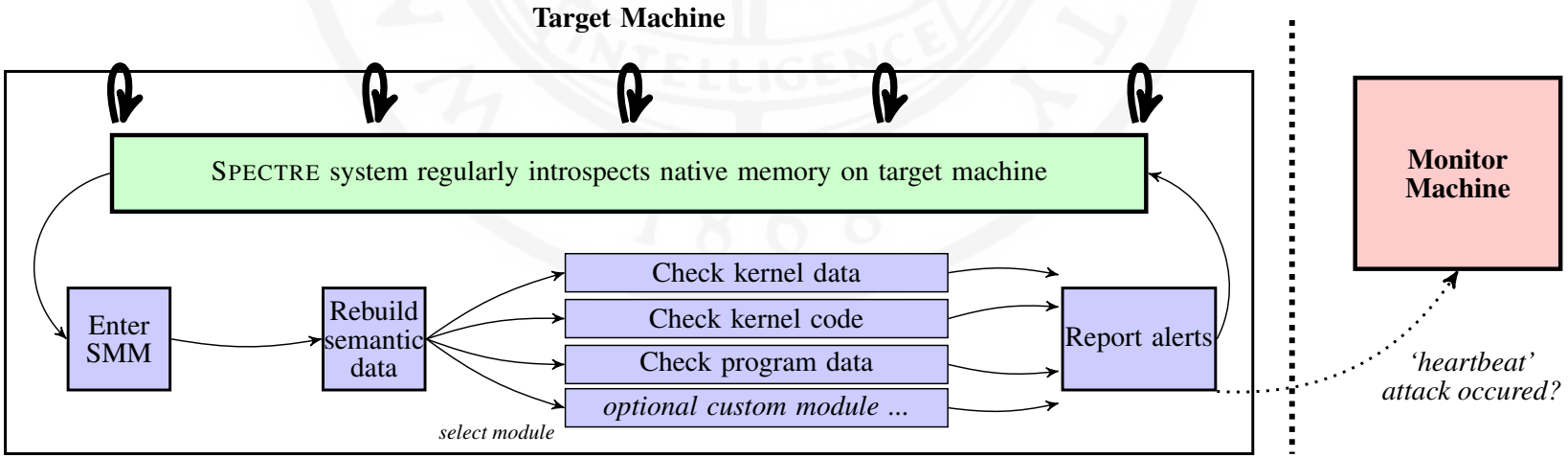
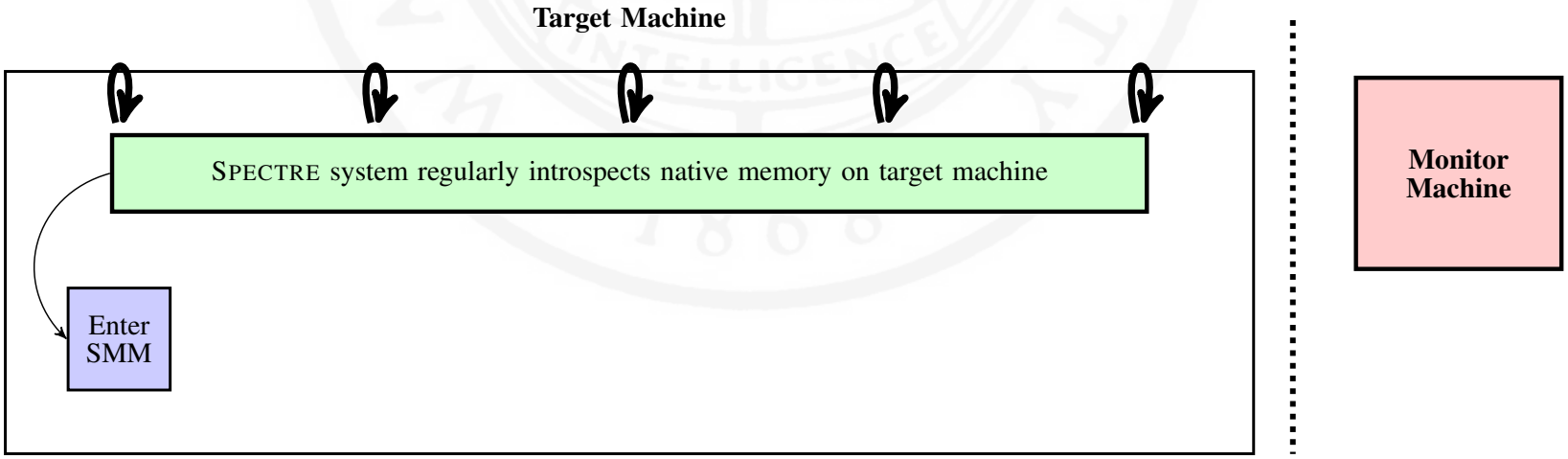
System Framework



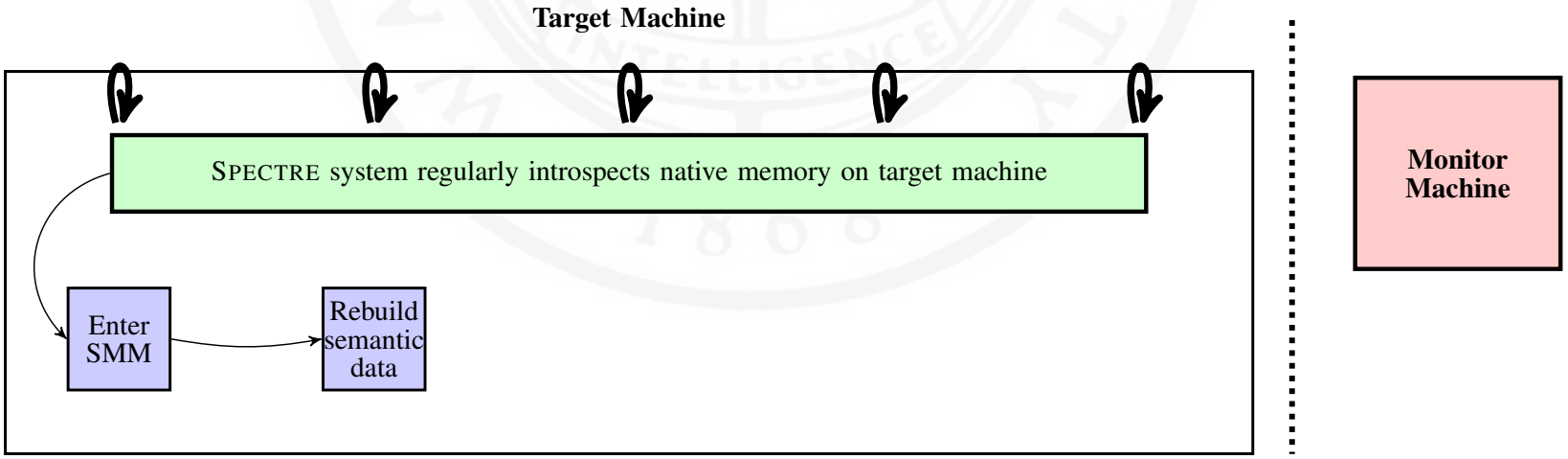
System Framework

- Step 1: Periodic triggering of SMM



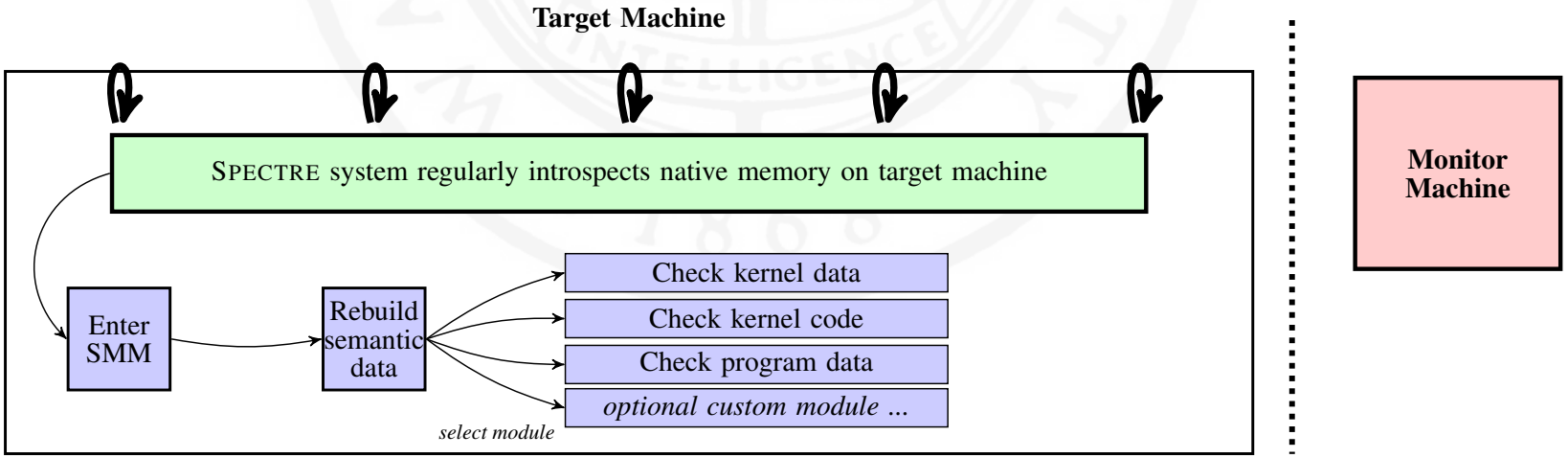
System Framework

- Step 1: Periodic triggering of SMM
- Step 2: Rebuilding semantic information



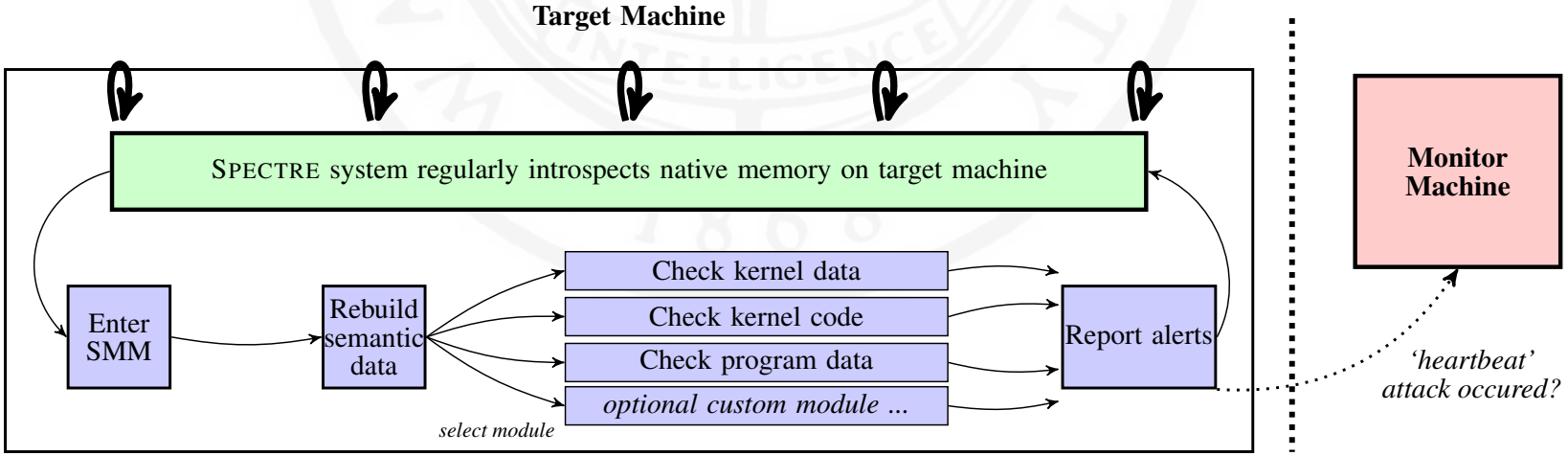
System Framework

- Step 1: Periodic triggering of SMM
- Step 2: Rebuilding semantic information
- Step 3: Running a detection module



System Framework

- Step 1: Periodic triggering of SMM
- Step 2: Rebuilding semantic information
- Step 3: Running a detection module
- Step 4: Communication with monitor server

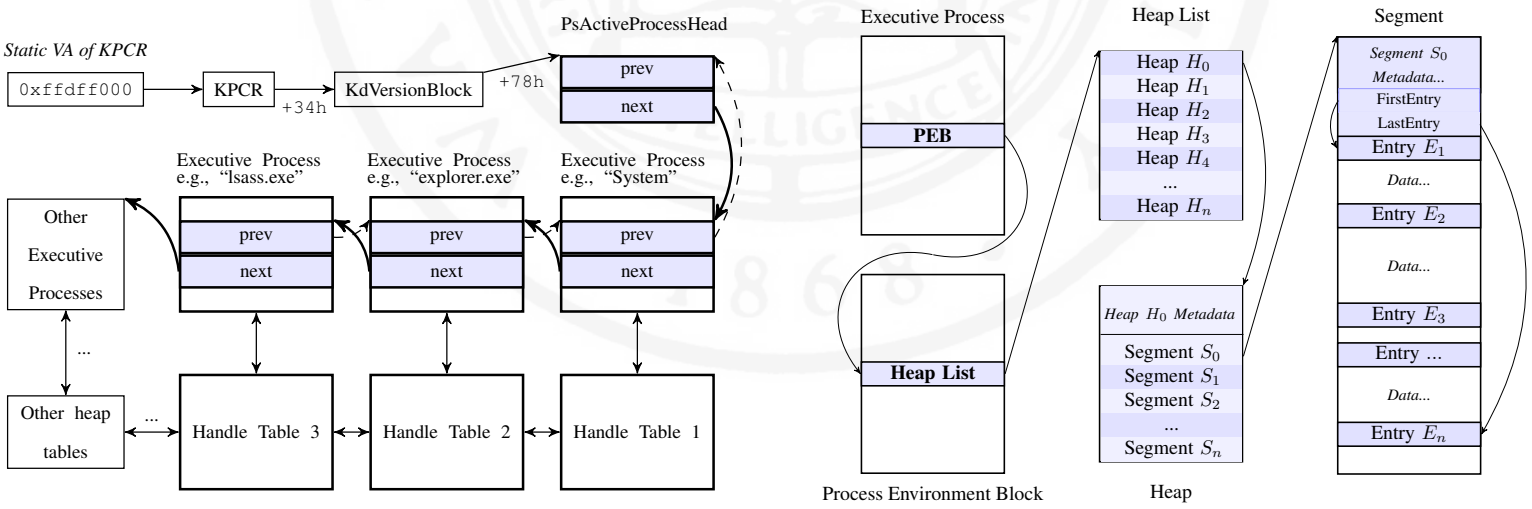


Step 1: Periodic Triggering of SMM

- Two ways to trigger an SMI
  - Software-based: write to an ACPI port specified by chipsets
  - Hardware-based: NIC card, keyboard, mouse, and hardware timer
- Hardware-based method is more reliable than software-based method, so we use a hardware timer at southbridge to periodically assert an SMI

Step 2: Rebuilding Semantic Information

- SMM only sees the raw memory, and does not know the semantics of the memory (e.g. OS data structures)
- Similar to the semantic gap problem in VMI systems
- We manually bridge the semantic gap in our prototype, automatically bridging (e.g., Virtuoso [6], VMST [4])



Semantic Gap Problem in VMI

- SoK: Introspections on Trust and the Semantic Gap. Bhushan Jain, Mirza Basim Baig, Dongli Zhang, Donald E. Porter, and Radu Sion. In S&P'14.

- SMM-based Systems, TrustZone-based Systems, SGX, other hardware isolated execution environments (HIEEs)

Step 3: Running a Detection Module

- We demonstrate the capability of our framework with three memory-based attacks:
  - Detecting heap spray attacks
  - Detecting heap overflow attacks
  - Detecting rootkits
- Other checking modules can be extended into Spectre with corresponding detection algorithm

Step 4: Communication with Monitor Machine

- The SMI handler alerts the monitor machine over a serial or Ethernet cable
- We port the NIC driver into SMI handler because we do want to trust any code in the OS
- 'Heartbeat' message can be used to detect denial of service attack
- Exit from SMM and resume OS states

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Prototype Specification

- Hardware
  - Motherboard: ASUS-M2V MX SE
  - CPU: 2.2GHz AMD Sempron LE-1250
  - RAM: 2GB Kingston DDR2
  - NICs: Integrated NIC and Intel e1000 Gigabit with PCI
- Software
  - BIOS: Coreboot+SeaBIOS
  - OSes: Linux (Cent OS 5.5) and Windows XP SP3

Memory Attacks Detection

- Run various memory attacks, and measure the detection time in the SMM
- Detection time = Time at SMM exit - Time at SMM enter

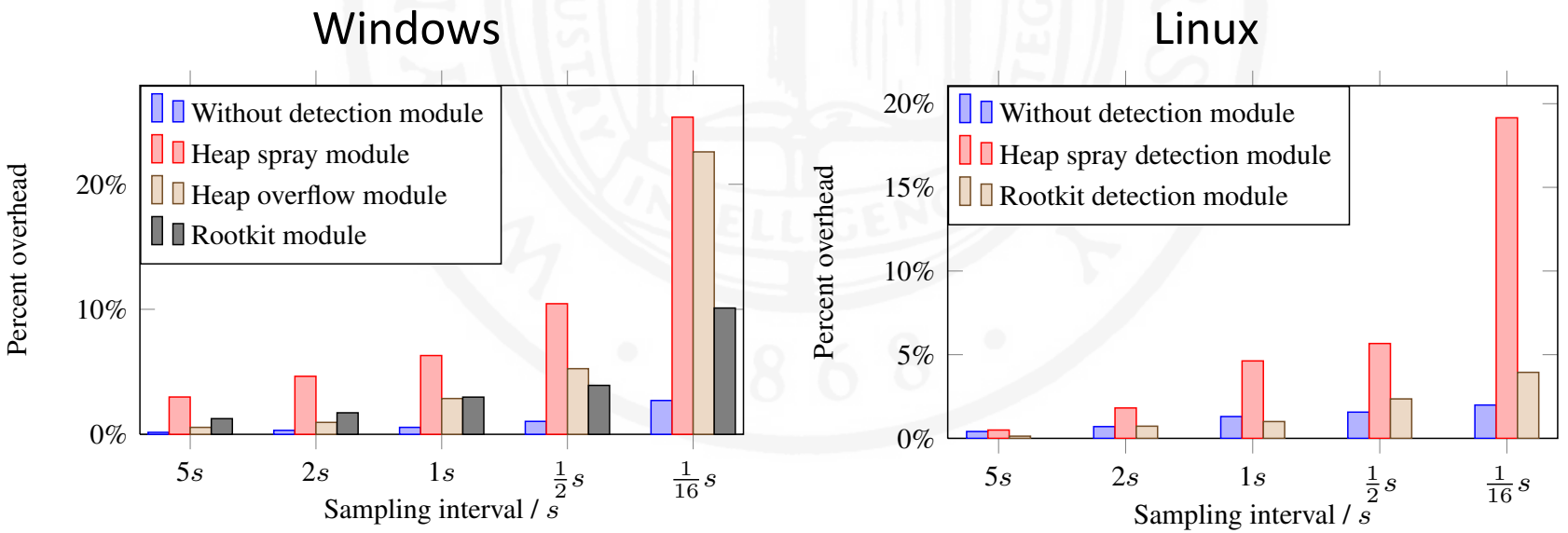
Modules	**Attacks**	**Time** (*ms*)
Heap Spary	Firefox CVE-2009-2478	31
	Internet Explorer CVE-2010-3971	28
	Adobe Acrobat CVE-2011-2462	26
	Adobe Flash Player CVE-2011-6069	29
Heap Overflow	XnView CVE-2012-0276	32
Rootkit	Fu rootkit	8

System Overhead

- Spectre is OS-agnostic, and can detect memory attacks on both Windows and Linux platforms.
- Benchmark: PassMark on Windows and UnixBench on Linux
- First, we run different detection modules, and record their benchmark scores
  - Without detection module
  - Heap spray detection module
  - Heap Overflow detection module
  - Rootkits detection module
- Second, we change the SMI triggering rate, and it ranges from 1/16 s to 5s

System Overhead

- X-coordinate: Sampling interval
- Y-coordinate: Percent overhead



Comparison with VMI Systems

- Smaller code base–Spectre only trust the BIOS, but VMI systems need to trust hypervisor
- More transparent–armored malware with anti-VM techniques cannot detect it
- Better Performance

Table: Runtime comparison of introspection programs between SPECTRE and Virtuoso

		Spectre (ms)	**Virtuoso** (*ms*)
Windows	`pslist`	6.6	450.2
	`lsmod`	7.6	698.1
Linux	`pslist`	4.3	6494.1
	`lsmod`	4.4	2437.0

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Conclusion

- We introduce a hardware-assisted framework that can examine code across all layers of a running system
- Spectre is OS-agnostic and fully transparent to higher level software
- We have implemented a prototype of our framework in both Linux and Windows, and demonstrates that our system can detect various memory attacks including heap spray, heap overflow and rootkits.

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