Using Hardware Features for Increased Debugging Transparency

Fengwei Zhang, Kevin Leach, Angelos Stavrou, Haining Wang, and Kun Sun. In S&P'15.

Presented by Fengwei Zhang

Overview

- Motivation
- Background: System Management Mode (SMM)
- System Architecture
- Evaluation: Transparency and Performance
- Conclusions and Future Directions

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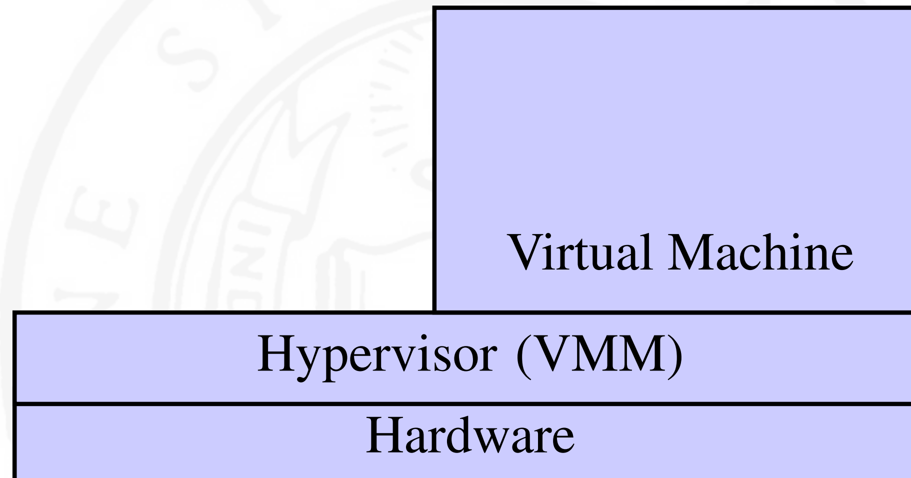
Motivation

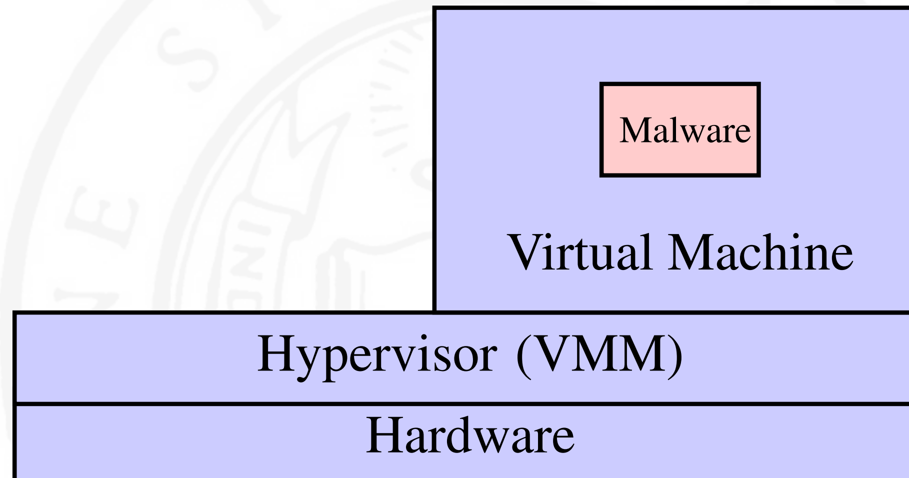
- Malware attacks statistics
  - Symantec blocked an average of 247,000 attacks per day [1]
  - McAfee (Intel Security) reported 8,000,000 new malware samples in the first quarter in 2014 [2]
  - Kaspersky reported malware threats have grown 34% with over 200,000 new threats per day last year [3]
- Computer systems have vulnerable applications that could be exploited by attackers.

Traditional Malware Analysis



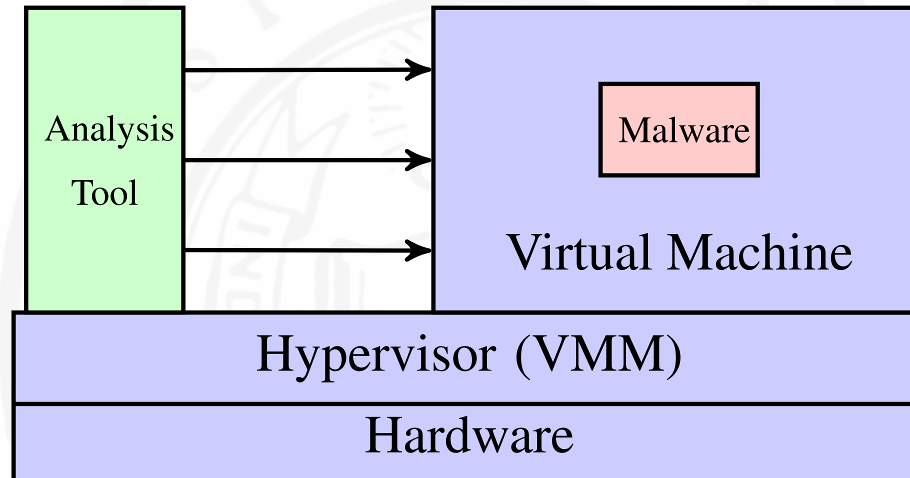
- Using virtualization technology to create an isolated execution environment for malware debugging

Traditional Malware Analysis



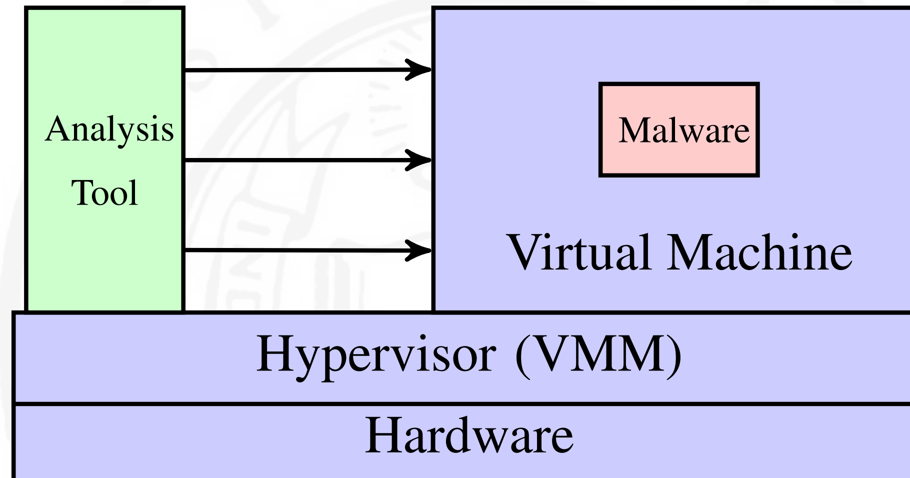
- Using virtualization technology to create an isolated execution environment for malware debugging
- Running malware inside a VM

Traditional Malware Analysis



- Using virtualization technology to create an isolated execution environment for malware debugging
- Running malware inside a VM
- Running analysis tools outside a VM

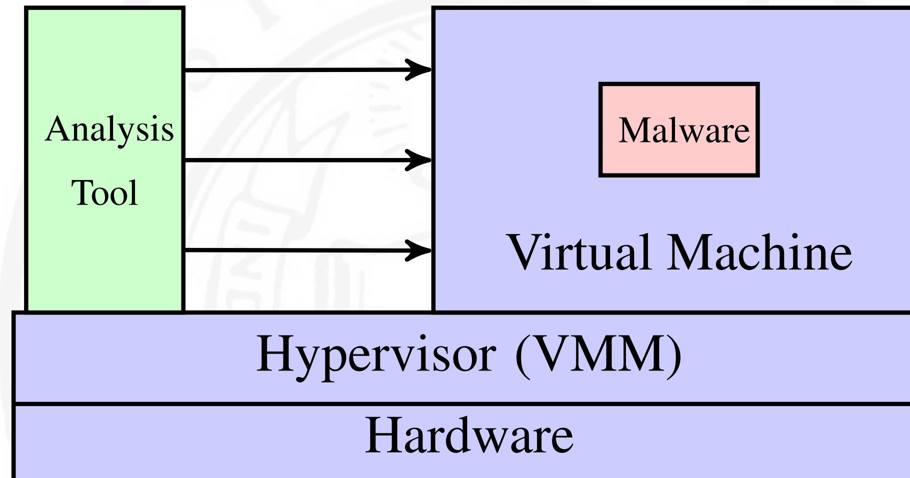
Traditional Malware Analysis



Limitations:

- Depending on hypervisors that have a large TCB (e.g., Xen has 500K SLOC and 245 vulnerabilities in NVD)
- Incapable of analyzing rootkits with the same or higher privilege level (e.g., hypervisor and firmware rootkits)
- Unable to analyze armored malware with anti-virtualization or anti-emulation techniques

Our Approach



We present a bare-metal debugging system called MalT that leverages System Management Mode for malware analysis

- Uses System Management Mode as a hardware isolated execution environment to run analysis tools and can debug hypervisors
- Moves analysis tools from hypervisor-layer to hardware-layer that achieves a high level of transparency

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Background: System Management Mode

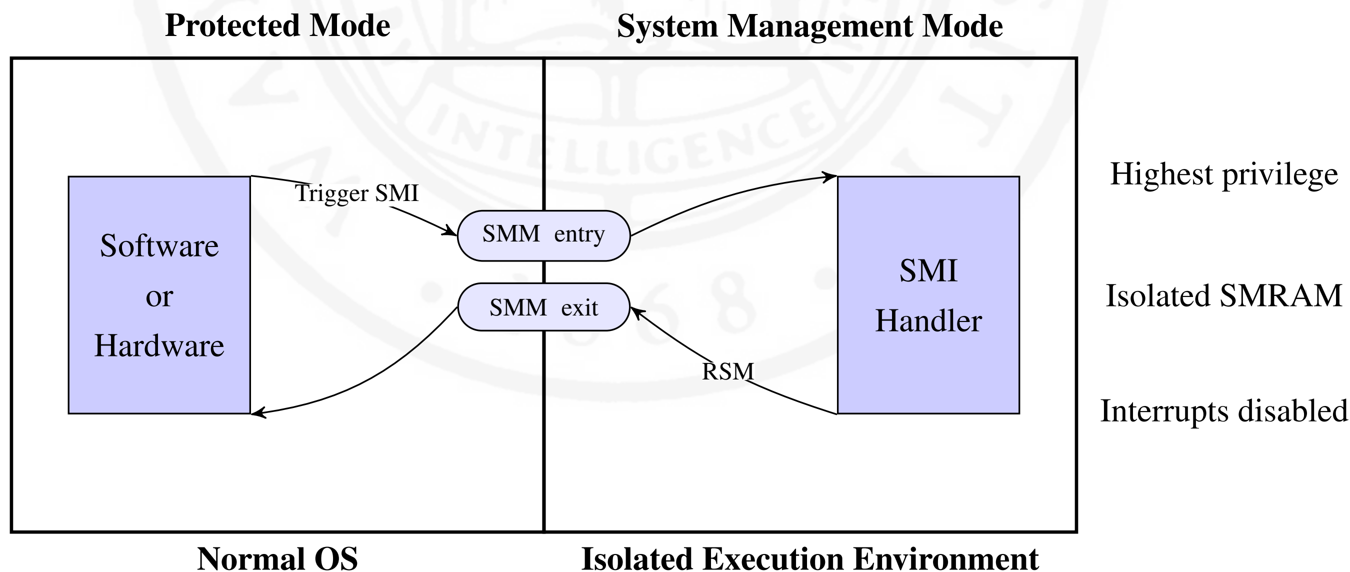
System Management Mode (SMM) is special CPU mode existing in x86 architecture, and it can be used as a hardware isolated execution environment.

- Originally designed for implementing system functions (e.g., power management)
- Isolated System Management RAM (SMRAM) that is inaccessible from OS
- Only way to enter SMM is to trigger a System Management Interrupt (SMI)
- Executing RSM instruction to resume OS (Protected Mode)

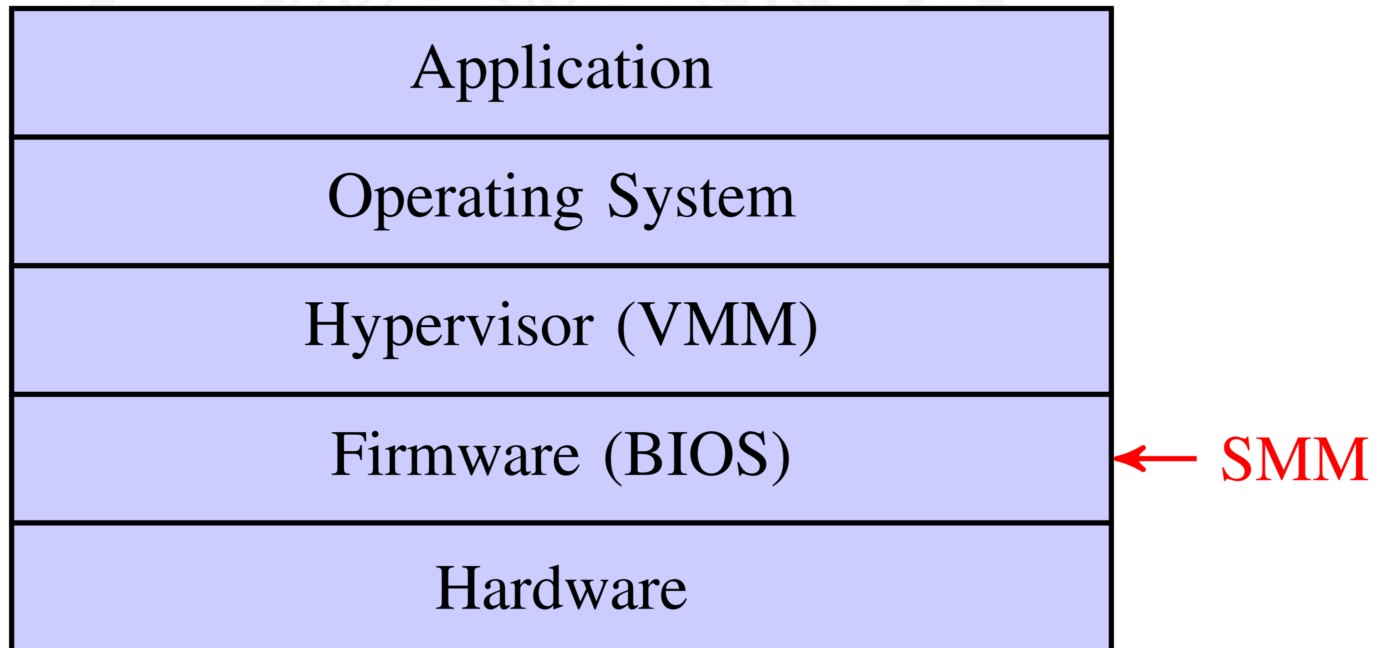
Background: System Management Mode

Approaches for Triggering a System Management Interrupt (SMI)

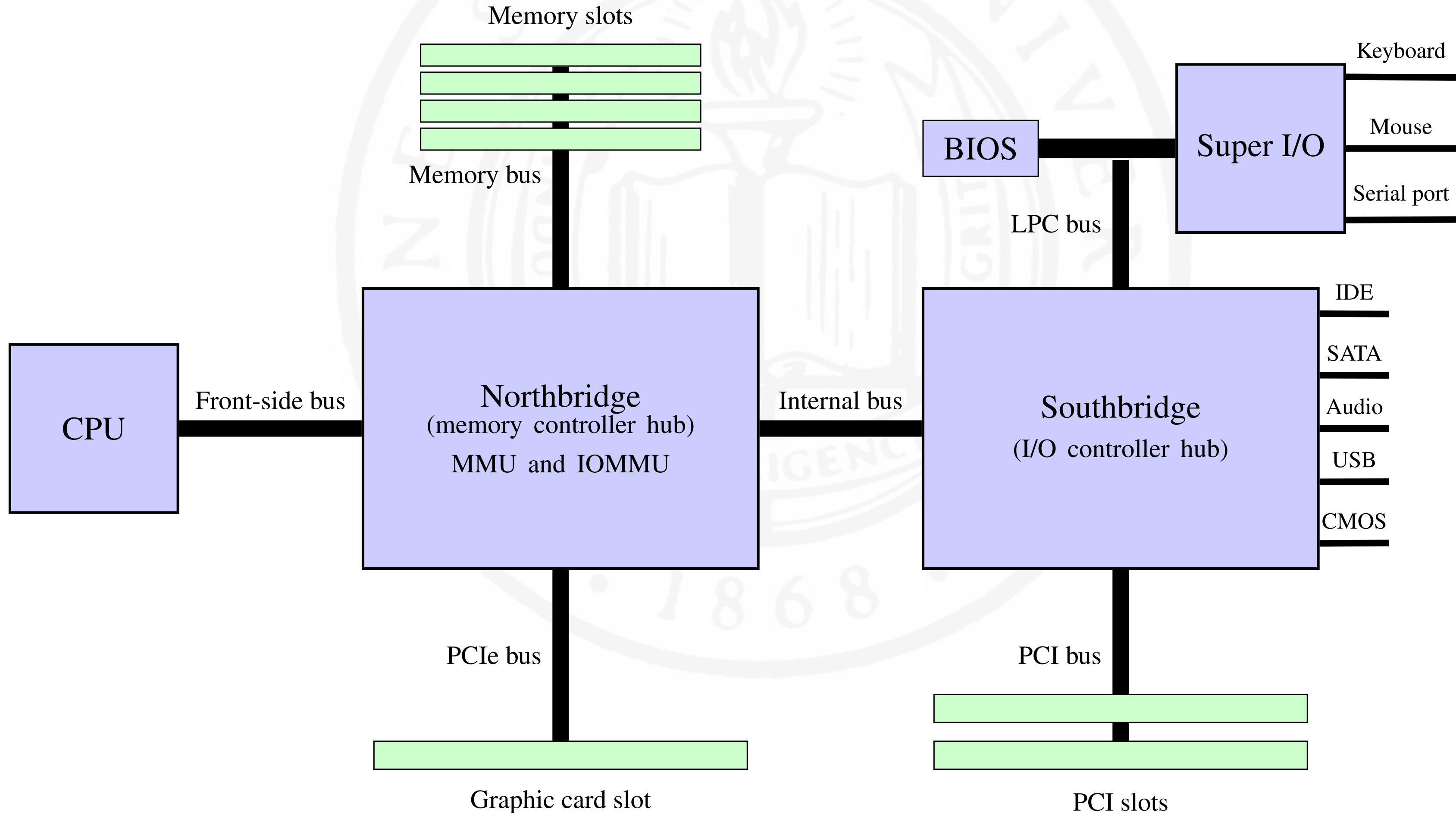
- Software-based: Write to an I/O port specified by Southbridge datasheet (e.g., 0x2B for Intel)
- Hardware-based: Network card, keyboard, hardware timers



Background: Software Layers



Background: Hardware Layout



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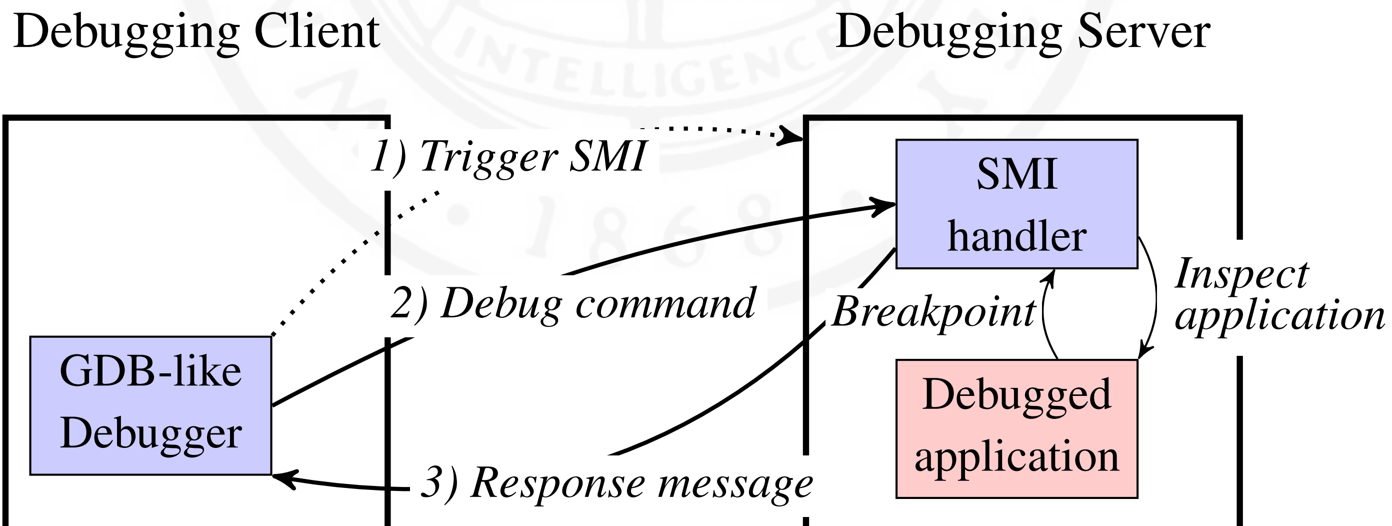
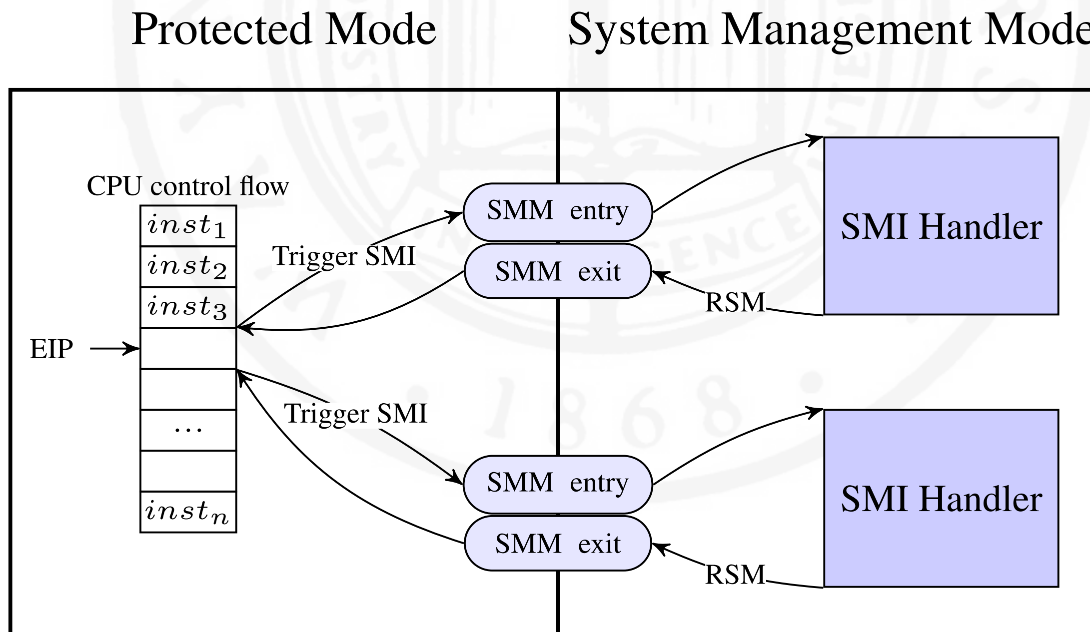
System Architecture

- Traditionally malware debugging uses virtualization or emulation
- MalT debugs malware on a bare-metal machine, and remains transparent in the presence of existing anti-debugging, anti-VM, and anti-emulation techniques.



Step-by-step Debugging in MalT

- Debugging program instruction-by-instruction
- Using performance counters to trigger an SMI for each instruction



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Evaluation: Transparency Analysis

- Two subjects: 1) running environment and 2) debugger itself
  - Running environments of a debugger
    - SMM v.s. virtualization/emulation
  - Side effects introduced by a debugger itself
    - CPU, cache, memory, I/O, BIOS, and timing
- Towards true transparency
  - MalT is not fully transparent (e.g., external timing attack) but increased
  - Draw attention to hardware-based approach for addressing debugging transparency

Evaluation: Performance Analysis

- Testbed Specification
  - Motherboard: ASUS M2V-MX SE
  - CPU: 2.2 GHz AMD LE-1250
  - Chipsets: AMD K8 Northbridge + VIA VT8237r Southbridge
  - BIOS: Coreboot + SeaBIOS

Table: SMM Switching and Resume (Time: μs)

Operations	Mean	STD	95% CI
SMM switching	3.29	0.08	[3.27,3.32]
SMM resume	4.58	0.10	[4.55,4.61]
Total	7.87		

Evaluation: Performance Analysis

Table: Stepping Overhead on Windows and Linux (Unit: Times of Slowdown)

Stepping Methods	Windows	Linux
	π	π
Far control transfer	2	2
Near return	30	26
Taken branch	565	192
Instruction	973	349

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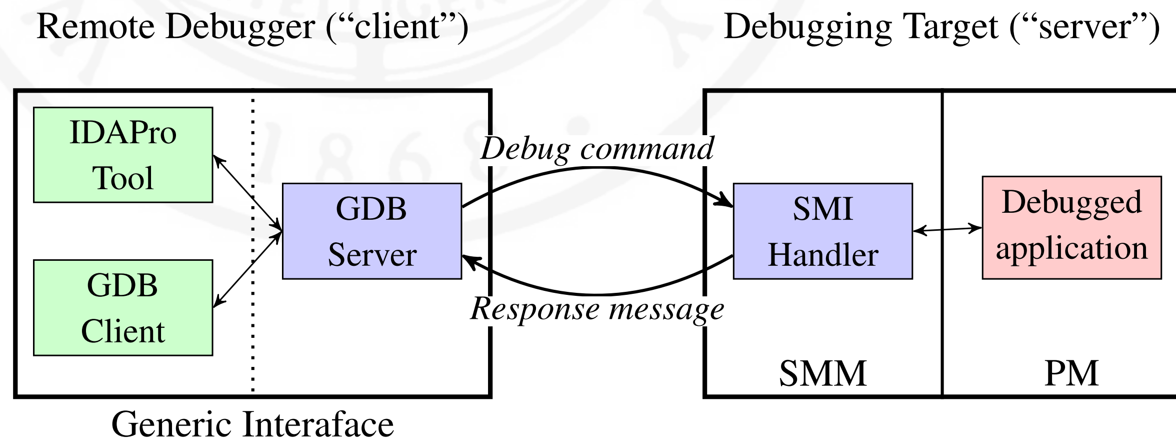
Conclusions and Future Work

- We developed MalT, a bare-matal debugging system that employs SMM to analyze malware
  - Hardware-assisted system; does not use virtualization or emulation technology
  - Providing a more transparent execution environment
  - Though testing existing anti-debugging, anti-VM, and anti-emulation techniques, MalT remains transparent
- Future work



References

[1] Symantec, "Internet Security Threat Report, Vol. 19 Main Report," http://www.symantec.com/content/en/us/enterprise/other_resources/b-istr_main_report_v19_21291018.en-us.pdf, 2014.

[2] McAfee, "Threats Report: First Quarter 2014," http://www.mcafee.com/us/resources/reports/rp-quarterly-threat-q1-2014-summary.pdf.

[3] Kaspersky Lab, "Kaspersky Security Bulletin 2013," http://media.kaspersky.com/pdf/KSB_2013_EN.pdf.

Paper Discussion

- Sai Tej Kancharla
- CSC 6991 – Advanced Security

- **Using Hardware Features for Increased Debugging Transparency**

- The research paper *Using Hardware Features for Increased Debugging Transparency Fengwei Zhang , Kevin Leach , Angelos Stavrou , Haining Wang , and Kun Sun* discusses about MalT which is a debugging framework that uses System Management Mode(SMM) to transparently and debug Armored Malware.
- MalT is executed on 2 machines: The target machine and the Debugging client machine. The basic process of MalT is that the Debugging machine sends an SMI trigger to make the target machine enter SMM mode and then we run the debugging code in the SMM. The response generated is sent to the debugging client for verification. The whole communication between the 2 machines is done by using GDB like protocol with serial messages.
- The advantage of Malt over other systems is that it does not rely on the Operating System but it relies on BIOS to analyze malware on bare metal. Also since Malt is run on SMM it has smaller Trust Computing Base (TCB) then other Hypervisor based systems. Also it is capable of debugging the Hypervisor rootkits and kernel mode drivers cause of unrestricted access in SMM.

Paper Discussion

- Zhenyu Ning,
- CSC 6991 – Advanced Computer System Security

- Using Hardware Features for Increased Debugging Transparency

- In this paper, a new usage of System Manage Mode is introduced to achieve transparently debugging and analyzing of malware. The MALT system, based on SMM and consisted by a debugging server and a debugging client, is deployed to insert breakpoints and handle step-by-step debugging. The debugging client communicates with the debugging server through serial port with a self-defined protocol to implement a GDB-like debugging experience. Also, MALT did a lot of jobs, such as dynamic flashing BIOS image, locking SMRAM, modifying timers and so on, to avoid itself from being detected by malware.
- In general, MALT can transparently debug malware armored with anti-debugging, anti-virtualization and anti-emulation techniques with low TCB, but as a new born, it also has some flaws. Firstly, when using MALT to debug, we can not use symbols and also we have to provide a target address but not a target line or instruction to add a breakpoint, which are not so friendly like other debug tools. Secondly, additional time has to be taken to reflash the BIOS image after every restart to keep transparent, I guess maybe this can be overcome by a mock hash value just like it has done to mock time.

Paper Discussion

- *Hitakshi Annayya*
- *CSC 6991 – Advanced Security*
- **Using Hardware Features for Increased Debugging Transparency**

- In this paper "Using Hardware Features for Increased Debugging Transparency" by Fengwei Zhang , Kevin Leach , Angelos Stavrou , Haining Wang , and Kun Sun states debugging the advanced malware attacks in virtual machines and emulators create artifacts and weak detection and to maintain a string defense. To have stealthy malware detection and analysis, authors present MALT, a debugging framework by leveraging System Management Mode (SMM), a CPU mode in the x86 architecture to transparently debug software on bare-metal and study armored software.
- The MALT workflow is to run malware on one physical target machine and employ SMM to communicate with the debugging client on another physical machine. While SMM executes, Protected Mode is essentially paused. The OS and hypervisor, therefore, are unaware of code executing in SMM. Because we run debugging code in SMM, we expose far fewer artifacts to the malware, enabling a more transparent execution environment for the debugging code than existing approaches.
- Compared to other debuggers such as BareBox, V2E, Anubis, Ether, VAMPiRE, SPIDER, IDAPRO
- Advantages of MALT:
  - Minimal footprint on target machines and more transparency execution environment for bare- metal debugging
  - MALT runs the debugging code in SMM without using a hypervisor. Thus, it has a smaller Trusted Code Base (TCB)
  - Designed a user-friendly interface for MALT to easily work with several popular debugging clients, such as IDAPro and GDB
  - Implemented various debugging functions, including breakpoints and step-by-step debugging.
  - MALT induces moderate but manageable overhead on Windows and Linux environments
  - Testing MALT against popular packers, antidebugging, anti-virtualization, and anti-emulation techniques, MALT remains transparent and undetected.
- Limitations of MALT:
  - Restoring a system to a clean state after each debugging session is critical to the safety of malware analysis on bare metal, MALT simply reboots the analysis machine and reimages the disk and BIOS by copying and reflashing.
  - In MALT, assuming that SMM is trusted.

Reminders

- Paper reviews
- Next class: Transparent Malware Analysis II
  - Android malware
  - Hitakshi Annayya will present the paper
  - Preparing the slides and sent them to the mailing-list before the class
  - 40 mins presentation + 40 mins discussion