SecPod: A Framework for Virtualization-based Security Systems

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Outline

1. Motivation
2. SecPod Design
3. Implementation
4. Evaluation
5. Related Work

Page Table Integrity

Kernel protection requires page table integrity

- Page tables decide address translation (from VA to PA)

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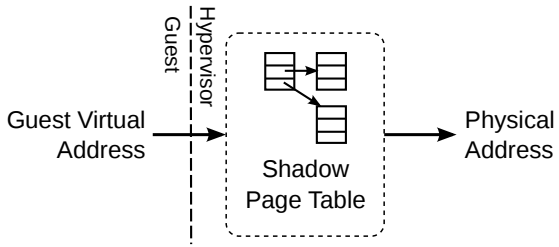
However, page tables are always writable in the kernel

- Kernel needs to frequently change memory mapping
- Kernel protection can be subverted by manipulating page tables

Virtualization-based Kernel Protection

- Security tools are isolated "out-of-the-box", but need to intercept key guest events
  - e.g., guest page table updates, control-register updates



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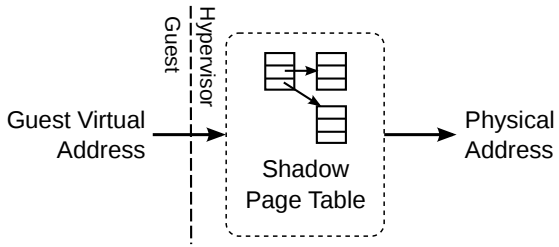

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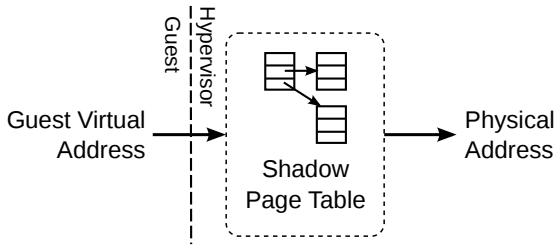

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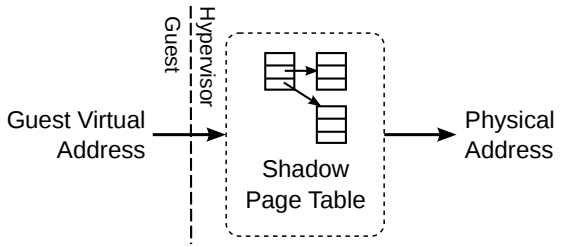
  - SPTs supersede GPTs for address translation



Virtualization Hardware Obsoletes Shadow Paging

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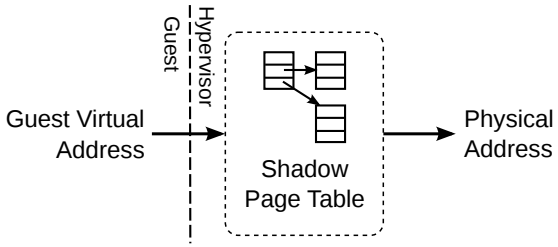
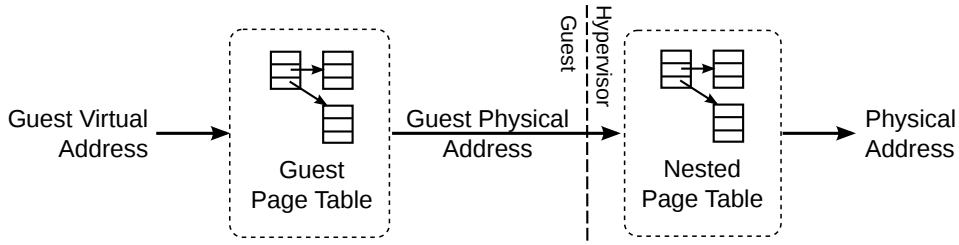
  - Both GPT and NPT are used by CPU for address translation





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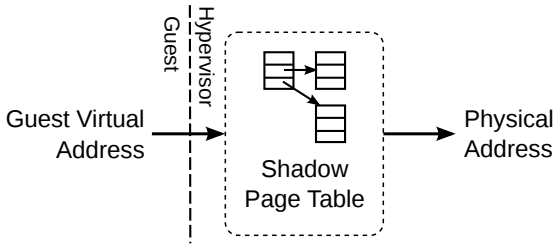

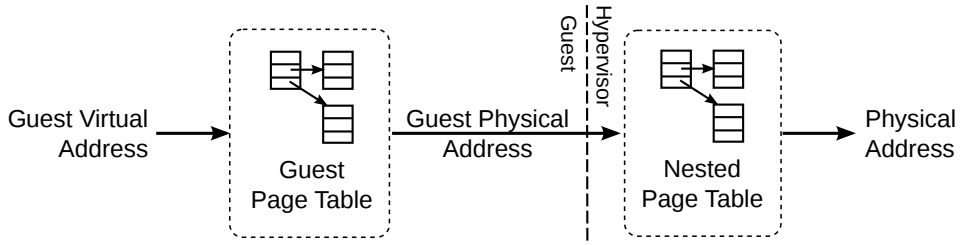

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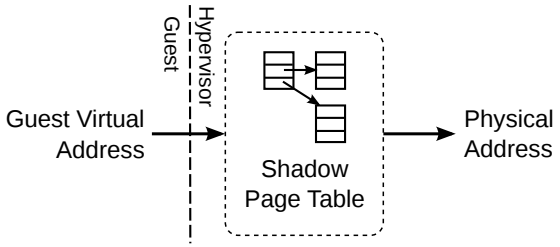
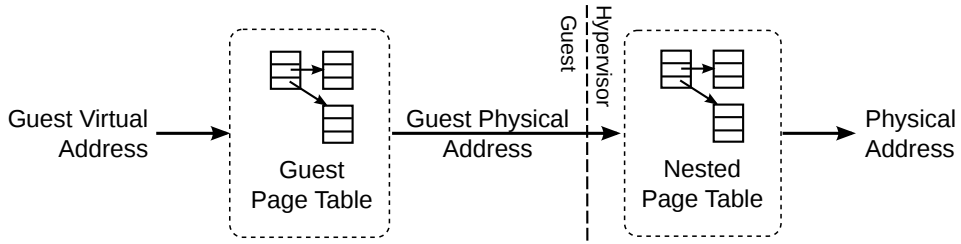
- Security tools cannot intercept guest memory updates with NPT
  - Guest is free to change its GPTs, without notifying hypervisor





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SecPod: A Framework for Virtualization-based Security Systems

Threat Model and Assumption

- Trustworthy hardware and trusted booting
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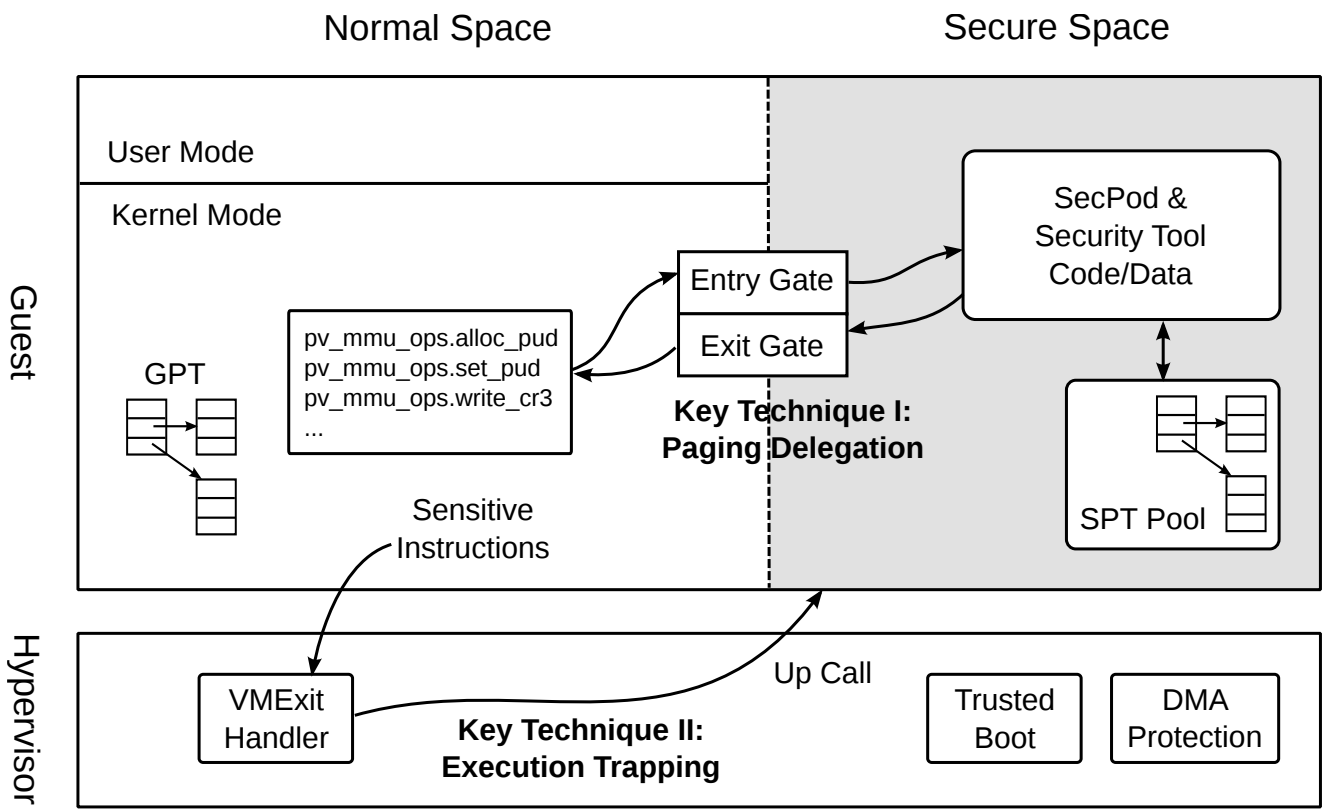
- Hypervisor is trusted
  - ▷ Formal verification [seL4, SOSP'09], integrity protection and monitoring [HyperSafe, S&P'10]
- Kernel is benign but contains vulnerabilities
  - ▷ Powerful attackers can change arbitrary memory of the kernel

SecPod Architecture



Key Technique I: Paging Delegation

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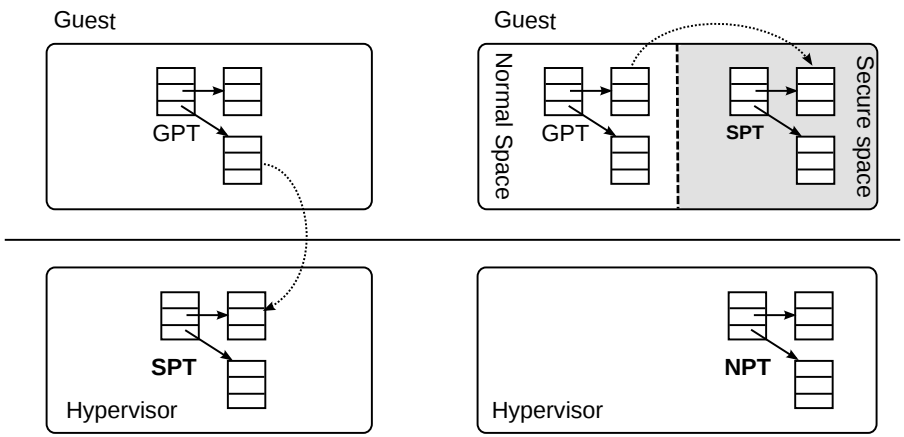

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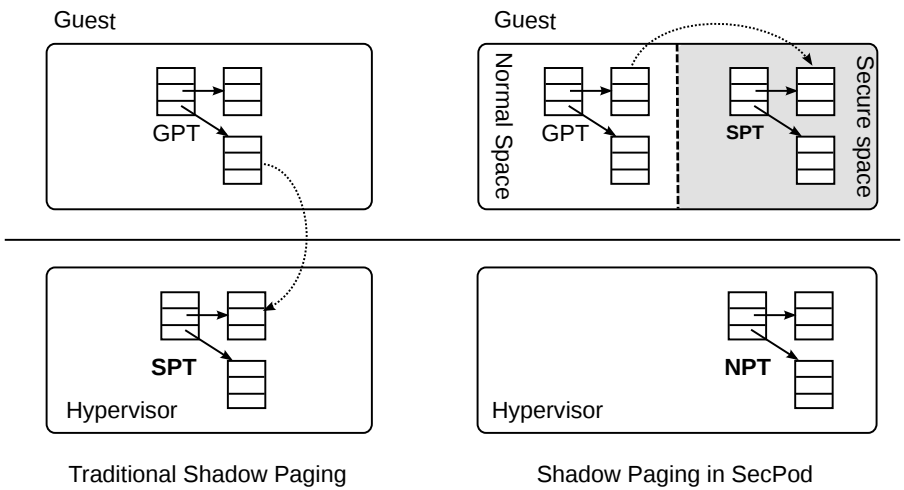

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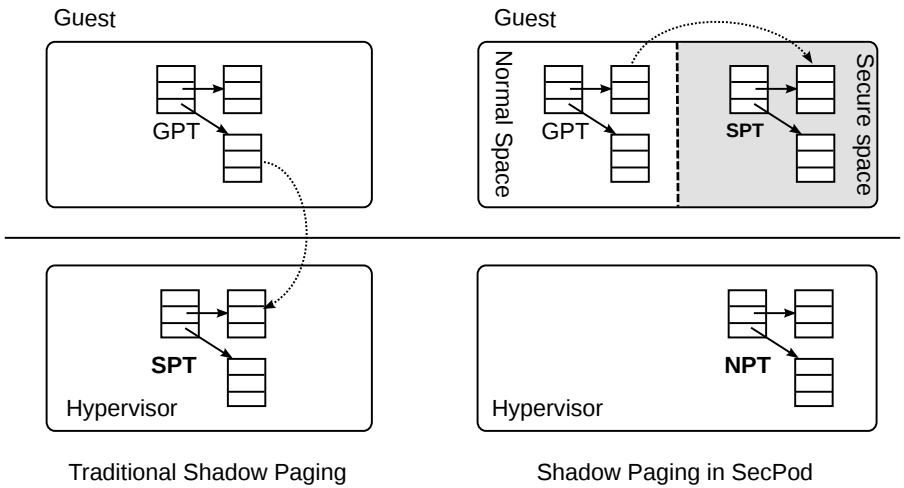
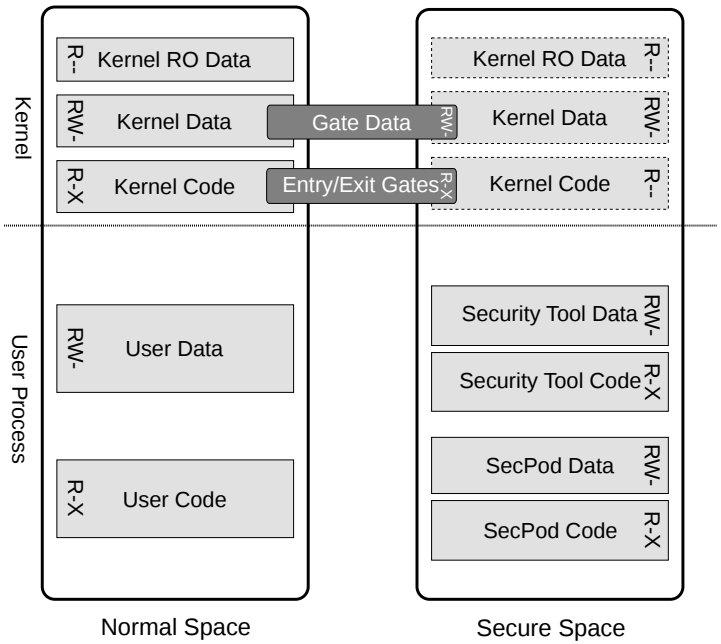
- SecPod forwards guest page table updates to secure space



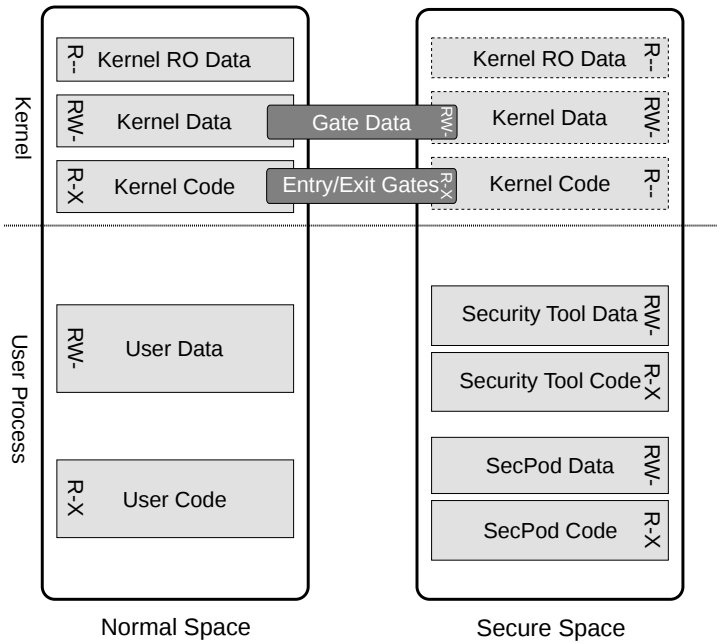
SecPod Address Space Layout

- Normal/secure spaces use page-table based isolation
  - Entry/exit gates are the only passage



SecPod Address Space Layout

- Normal/secure spaces use page-table based isolation
  - ▷ Entry/exit gates are the only passage
- Guest kernel is mapped in secure space
  - ▷ Security tools can access guest memory, but not execute it



Protecting Secure Space

Attacker might try to:

- Enter secure space without security checks
- Request malicious page table updates
  - e.g., to map secure memory in guest
- Misuse privileged instructions
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Our countermeasures:

- Secure and efficient context switch
- Page table update validation
- Execution trapping of privileged instructions

Secure and Efficient Context Switch

- Entry/exit gates are only passage between secure/normal spaces
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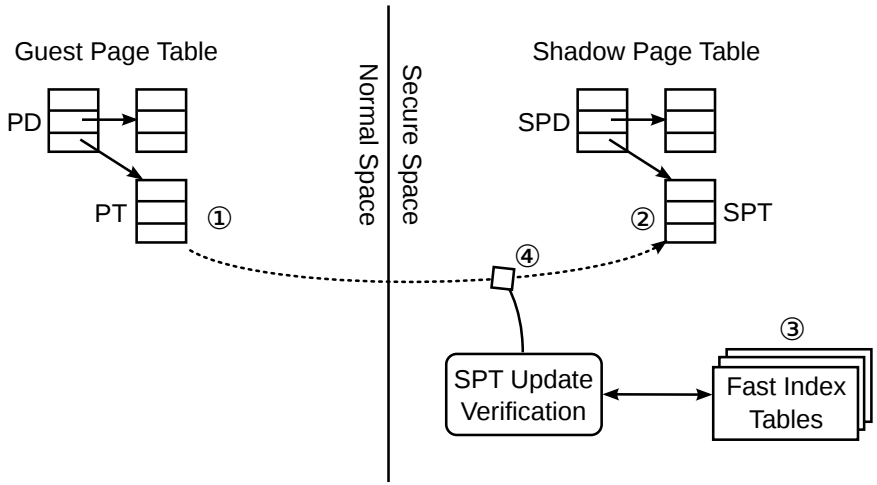
- Loading `CR3` is a privileged instruction trapped by SecPod
  - Performance overhead is high if each context switch is trapped
- Intel CR3 target list to the rescue:
  - Four page tables can be loaded without being trapped by CPU
  - There are many SPTs for the guest
    → use a fixed top-Level page table for all SPTs

Page Table Update Validation

- SecPod enforces basic kernel memory integrity for guest
  - No mapping is allowed to the secure space code/data
  - Enforce kernel W⊕X



Key Technique II: Execute Trapping

- SecPod traps malicious privileged instructions executed by guest
  - ▷ It can trap intended and unintended[2] privileged instructions
- Hypervisor notifies secure space trapped instructions via upcalls
  - ▷ Similar to signal delivery in the traditional OS

[2] X86 has variable-length instructions, unintended instructions can be "created" by jumping to the middle of an instruction.

Trapped Sensitive Instructions

Instruction	Semantics
`LGDT`	Load global descriptor table
`LLDT`	load local descriptor table
`LIDT`	load interrupt descriptor table
`LMSW`	load machine status word
`MOV to CR0`	write to `CR0`
`MOV to CR4`	write to `CR4`
`MOV to CR8`	write to `CR8`
`MOV to CR3`	load a new page table
`WRMSR`	write machine-specific registers

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- Paging delegation
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  - ▷ Leverage Linux paravirtualization interface: `pv_mmu_ops`
- Execution trapping implemented in the Hypervisor (KVM)
- Security tools:
  - ▷ Compiled as ELF libraries and loaded into secure space
  - ▷ Implemented an example tool to prevent unauthorized kernel code from execution (Patagonix [USENIX Sec '08], NICKLE [RAID '08])

Security Analysis

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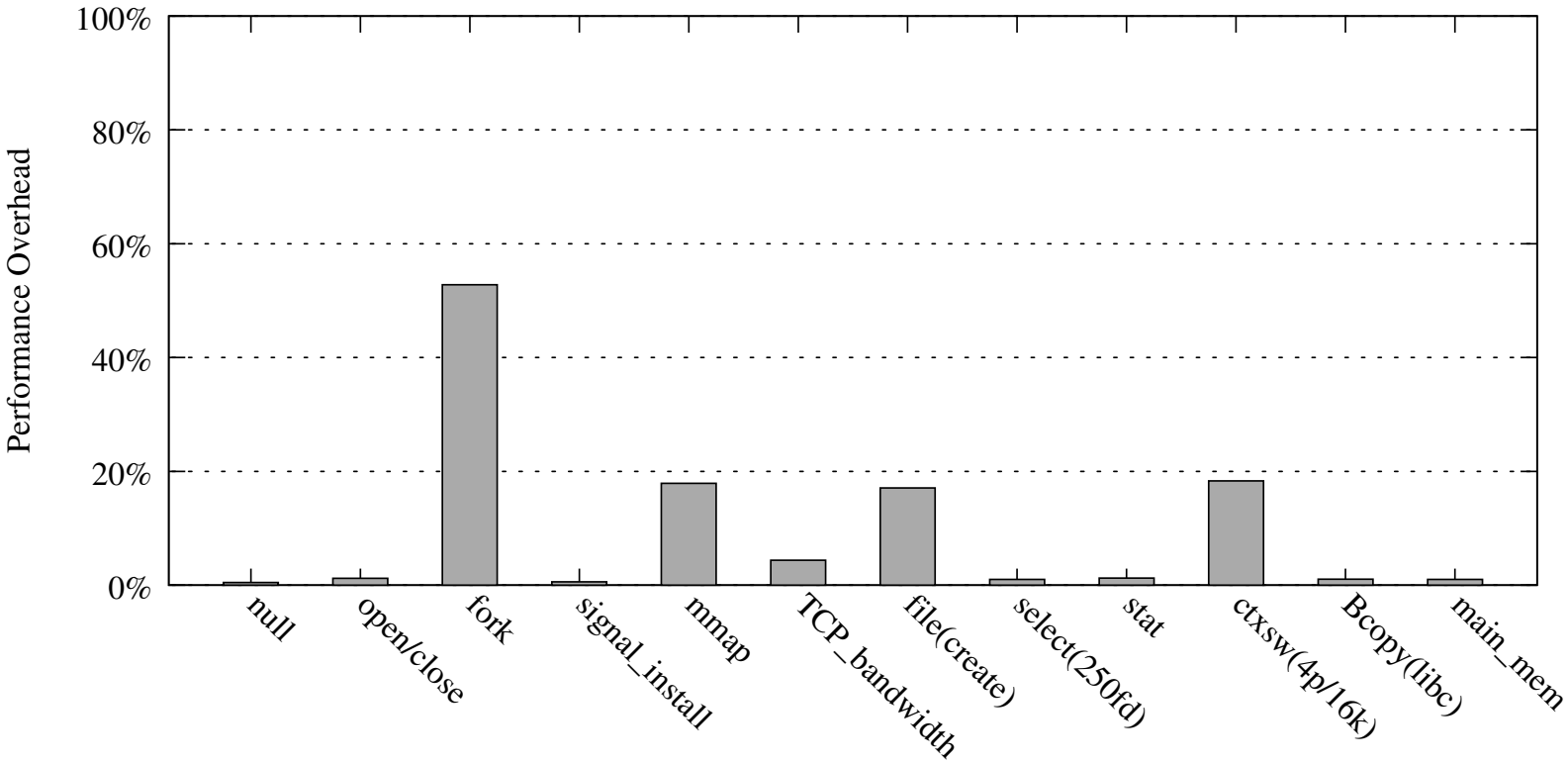
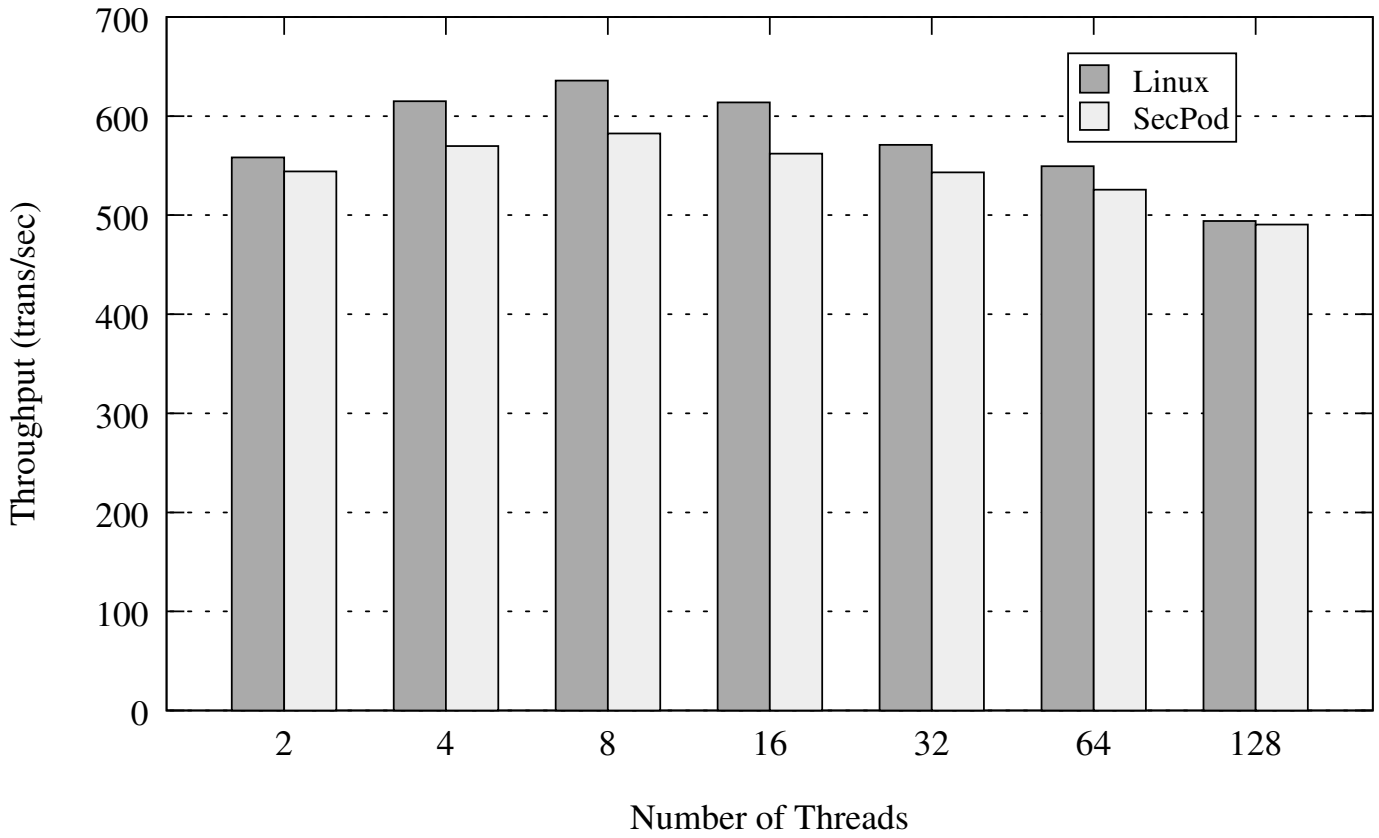
- Misuse privileged instructions
  - Privileged instructions by guest are trapped and verified

Performance Evaluation: LMBench



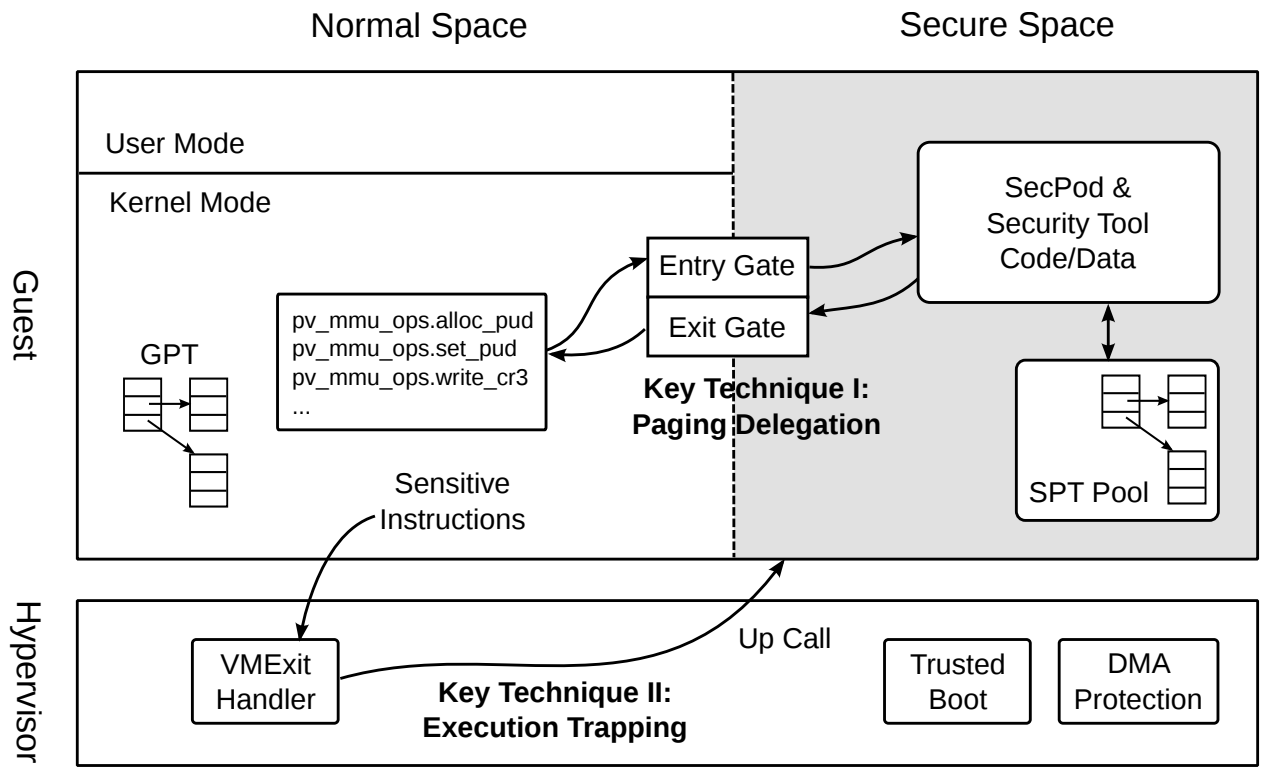
Performance Evaluation: SysBench OLTP



Related Work

- Virtualization-based security
  - Malware analysis: Ether[CCS'08]
  - Rootkit detection and prevention: PoKeR[EuroSys'09]
  - Virtual machine introspection: Virtuoso[S&P'11], SIM[CCS'09]
- Kernel/user application security
  - Exploit mitigation techniques: ASLR, DEP, CFI[CCS'07]
  - Kernel/hypervisor memory integrity: TZ-RKP[CCS'14], HyperSafe[S&P'10], Nested Kernel[ASPLOS'15]

Summary



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Thank you & Questions?